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Proceedings of The First World Landslide Forum

Tokyo
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Proceedings of

The First World Landslide Forum

18-21 November 2008
United Nations University, Tokyo, Japan

Parallel Session Volume

Global Promotion Committee of

The International Programme on Landslides (IPL)

International Strategy for Disaster Reduction
Global joint initiative by United Nations organizations, governmental organizations, non-governmental organizations, and individuals.

International Consortium on Landslides (ICL)

I symbolizes Cultural heritage at landslide risk.
C symbolizes a moving landslide mass.
L symbolizes Retaining wall to stabilize slopes.

Slight inclination of C symbolizes motion of landslide and the Consortium.

- ICL was established in January 2002 and legally registered as a non-profit scientific organization (No.1300-05-005237) in the Government of Kyoto Prefecture, Japan in August 2002.
- A full-color international quarterly journal “Landslides” was founded by ICL in April 2004. The impact factor of this journal is 0.986 for 2007.
- Approved as a scientific research organization (No.94307) eligible to apply and receive the Grants-in-Aid for Scientific Research by the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT) in March 2007.
- Approved as a NGO in operational relations with UNESCO by the 176 Session of Executive Board of UNESCO in April 2007.

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Cover photo: Landslides in the Beichuan county triggered by the 2008 Wenchuan earthquake, Sichuan, China (Courtesy by Yueping Yin, China Geological Survey)

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Preface

The First World Landslide Forum is organized by the International Consortium on Landslides (ICL) and ICL supporting organizations at the United Nations University, Tokyo Japan during 18-21 November 2008. It is the first global cross-cutting information and cooperation platform for all types of organizations and individuals involved in landslide risk reduction. This parallel session volume contains 169 papers accepted for oral presentation in the following seventeen parallel sessions and one dialogue of the World Landslide Forum.

Parallel Sessions

- A look from space
- Case Studies and National Experiences
- Catastrophic slides and avalanches
- Climate change and slope instability
- Landslides threatening heritage sites
- Economic and Social Impact of Landslides
- Education, Capacity Building and Public Awareness for Disaster Reduction
- Environmental Impact of Landslides
- Landslides in General
- Landslides and multi-hazards
- Mapping: Inventories, Susceptibility, Hazard and Risk
- Monitoring, prediction and early warning
- Policy and Institutional framework for Disaster Reduction
- Rainfall, debris flows and wildfires
- Risk Management Strategies in Urban Areas
- Engineering Measures for Landslide Disaster Mitigation
- Watershed and Forest Management for Risk Reduction
- Landslides in dam reservoirs

Dialogue: International Cooperation Initiatives

In addition to those papers, two planetary session papers: Special Report “Landslide hazards triggered by the 12 May 2008 Wenchuan earthquake, Sichuan, China” and a keynote lecture “Effects of global change on landslide risk” are included.

Other publications related to the First World Landslide Forum are:

- Plenary Session Volume. A full colour book “Landslides: Disaster Risk Reduction” published by Springer, Germany (editors: Kyoji Sassa and Paolo Canuti) containing ten keynote lectures, nine papers in the Plenary Open Forum “ Progress of IPL (International Programme on Landslides) Activities, and sixteen papers on objectives and major contents of parallel sessions by their conveners.
- Poster Session Volume. It contains papers presented to the poster sessions and the titles, abstracts and authors of posters.

- Web proceedings of the First World Landslide Forum. It contains 4-20 full color papers submitted to the Forum in the Web Proceedings. It includes papers by participants and non-participants. It will be uploaded after the Forum.

Acknowledgements

The First World Landslide Forum is an integral meeting of parallel sessions proposed and convened and edited by conveners as well as plenary sessions. I express my gratitude for all conveners and participants contributing their papers of the First World Landslide Forum.

It is acknowledged that the organization of this forum and the publication of this volume was financially supported by the Japanese Funds-in-Trust to the United Nations Secretariat of the International Strategy for Disaster Reduction (UN-ISDR), the Grant-in-Aid for Publication of Scientific Research Results of the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT), and the Commemorative Organization for the Japan World Exposition ('70).

Kyoji Sassa

Kyoji Sassa
President of the International Consortium on Landslides

Contents of this Volume

Papers for Parallel Sessions

Landslide Hazards Triggered by the 12 May 2008 Wenchuan Earthquake, Sichuan, China

Yueping Yin (China Geological Survey) · Fawu Wang (Kyoto University, Japan)· Ping Sun (China Geological Survey)

(This paper has been submitted to Landslides: the Journal of International Consortium on Landslides)

Abstract. The Wenchuan earthquake (Ms=8.0; Epicenter located at 31.0°N, 103.4°E), with a focal depth of 14.0 km was triggered by the reactivation of the Longmenshan tectonic belt in Wenchuan County, Sichuan Province, China on 12 May 2008. This earthquake directly caused more than 15,000 geo-hazards in the form of landslides, rockfalls and debris flows which resulted in about 20,000 deaths, a quarter in totals. It also caused more than 10,000 potential geo-hazard points, especially for rockfall, reflecting the great difference on high and steep slopes in mountainous areas affected by the earthquake. The seismic effects had obvious amplification effects on the mountain tops. Through analyzing the capacity of landslide lakes, the height of landslide dams, and the composition and structure of materials that blocked rivers comprehensively, 33 of the significant landslide lakes with the height of their respective landslide dams larger than 10 m were assessed. According to the evaluation result, the collapse risks of landslide dams are divided into four levels, i.e., extremely dangerous, highly dangerous, moderately dangerous, and low-level dangerous.

In the meizo-seismal area, the landslides caused by the earthquake have a general character of "cuspidal impact" without continuous flat sliding surfaces. The sliding surfaces can be classified into the following three types, i.e., concave shape, convex shape, and stair shape. It is observed in the field investigation that vertical-motion vibration had great effect on buildings and their resultant destruction and nearby landslides. The motion process of the landslides can be divided into three categories, i.e., shacked by the earthquake, collapsed by impacting, and rapid runout. During the rapid runout process, three effects were generated. 1) High speed air-blast effect. The landslide consisted of boulders, large stone blocks and debris with certain thickness, and the blast distance may reach 1-3 km; 2) Debris flow effect. The fragmented debris moved in fluid-like style, and when it was highly saturated with water, the landslide moved for a long distance; 3) Scraping and erosion effect. With the great percussive force, the rock mass in the lower part can be scraped and eroded, and through entrainment, formed new landslides and rockfalls. However, their thickness is limited, and the sliding surface is wavy.

In this paper, two landslides are used as examples. One is the Chengxi landslide in Beichuan County and the other is the Donghekou landslide in Qingchuan County. In each case, the rapid runout process and disaster forming mechanism of landslides induced by the earthquake were analyzed. The Chengxi landslide killed 1600 people and destroyed a lot of buildings. It may be one of the most catastrophic landslides in the world. The Donghekou landslide is a typical compound type of rapid and long runout landslide and debris flow. The rapid debris flows scoured the left bank of the Qingjiang River after it moved for 2.4 km, and subsequently formed a landslide dam. This landslide buried seven villages and killed more than 400 people.

Keywords. Wenchuan earthquake; landslide; landslide lake, rapid and long runout

1. Introduction

The "5.12" Wenchuan earthquake, Sichuan Province, China, occurred in the Longmenshan tectonic zone, which is located at the eastern edge of Qinghai-Tibet Plateau. By intensive compression between the Qinghai-Tibet Plateau and Sichuan Basin, the Longmenshan tectonic zone is in an active state and has generated many strong earthquakes. It is one of the steepest gradient zones among the global mountains. On a scale of 100 km, the height difference can be up to more than 5000 m, and mountains and canyons were formed in this zone where there are many tributary sources of Yangtze River.

Differing from other intensive seismic areas in China, the Wenchuan earthquake triggered lots of landslides, rockfalls, and contributed to the formation of debris flows. In the rainstorm time after the earthquake, many debris flows occurred in the Minjiang River watershed, and caused disastrous casualties and property loss. The preliminary estimation shows there are about 20,000 deaths directly caused by the geo-hazards related to the earthquake. In this paper, the distribution of the geo-hazards triggered by the earthquake is introduced first, and then the properties of landslides and landslide lakes are analyzed. Finally, the dynamic characteristics of typical rapid and long runout landslides are presented.

2. Distribution of landslide hazards triggered by the earthquake

The Longmenshan area is located in the turning part of the first and the second terrain bench of China. It is the zone where geo-hazards have frequently occurred. According to the geo-hazard investigation after the earthquake, there are a total of about 5,430 potential geo-hazard points in the 42 affected counties (cities) of Sichuan Province. The potential geo-hazards include 3,572 landslides, 600 rockfalls, 737 debris flows and 521 unstable slopes. After the earthquake, more than 800 landslide experts from the Ministry of Land and Resources (MLR) of China investigated the disaster areas systematically, and conducted the remote sensing analyses. The investigations indicate there are about 15,000 geo-hazard points. At the same time, 4,970 new potential geo-hazard points were determined, including 1,701 landslides, 1,844 rockfalls and 1,093 unstable slopes.

As an overview, the potential geo-hazard points increased by 237% because of the earthquake (Table 1), and the rockfall incidence increased by 617% which is more obvious than other geo-hazards. The unstable slopes, the debris flows and landslides increased by 480%, 152% and 123%, respectively. This reflects the great difference indicated by earthquake-induced effects on high and steep slopes in mountainous areas, where obvious amplification affects at the tops of mountains, result in numerous occurrences of rockfall. Noting the percentages of each geo-hazard before the earthquake, landslides is about 61%, and rockfalls, debris flows and unstable slopes are all 13%, respectively. However, among the geo-hazards after the earthquake, rockfall has 34%, and landslide, unstable slope and debris flows has 31%, 27% and 4%, respectively. Of all the potential geo-hazard points, the proportion of landslides is the highest, reaching 40%, while the proportion of rockfall is only 27% (Fig. 1).

Table 1 Potential geo-hazards in the counties of extremely severe hazards caused by earthquake

No.	Name of the county	Geo-hazard points	Points of Geo-hazard				
			Rockfall	landslide	Debris flow	Unstable slope	Total
1	Wenchuan	A	7	43	71	10	131
		B	150	71	78	43	342
		Total	157	114	149	53	473
2	Beichuan	A	21	211	23	0	255
		B	48	168	22	38	276
		Total	69	379	45	38	531
3	Mianzhu	A	35	47	17	7	106
		B	94	31	24	2	151
		Total	129	78	41	9	257
4	Shifang	A	21	57	13	11	102
		B	64	8	3	-6	69
		Total	85	65	16	5	171
5	Qingchuan	A	18	76	5	42	141
		B	177	211	6	443	837
		Total	195	287	11	485	978
6	Maoxian	A	8	91	16	0	115
		B	67	91	29	100	287
		Total	75	182	45	100	402
7	Anxian	A	2	25	2	6	35
		B	28	37	3	2	70
		Total	30	62	5	8	105
8	Dujiangyan	A	19	29	1	6	55
		B	195	92	45	44	376
		Total	214	121	46	50	431
9	Pingwu	A	12	60	5	3	80
		B	41	117	5	24	187
		Total	53	177	10	27	267
10	Pengzhou	A	A	70	0	71	149
		B	B	43	17	58	187
		Total	Total	113	17	129	336
Total		A	151	709	153	156	1169
		B	933	869	232	748	2782
		Total	1084	1578	385	904	3951

A: Existing points before the earthquake; B: New points caused by the earthquake.

Differing from other intensive earthquakes, the Wenchuan earthquake triggered many disastrous landslides, rockfalls, and debris flows that resulted in casualties. It is too difficult to get precise data in a short time, however, based on our field investigations, visiting, and other information, a list is provided in Table 2, on 23 landslides and rockfalls which caused more than 30 deaths at one site, organized by location. Among them, the Chengxi landslide located in the western part of old area of Beichuan County-town is the most severe one as it caused 1600 deaths, and destroyed half of the county-town. In the 20 km long national road from Yingxiu town to Wenchuan county town, which is the most important part of the national road from Chengdu City to Jiuzhaigou Resort, 340 landslides and rockfalls occurred and blocked the road until very recently. At the time of the earthquake occurrence, traffic density was at its yearly peak. According to the numbers of destroyed buses and cars, the deaths occurring on the road were estimated to be more than 1,000.

Fig.1 Ratio of potential geo-hazards in the counties of extremely severe hazards before/after earthquake

Beichuan County-town is the place suffering the most damage from this earthquake. It is located in a narrow valley terrace of the Jianjiang River, with an area less than 2.0 km^2. The Wenchuan earthquake fault cut through the old area and new area of the county-town from southwest to northeast, and the intensive thrust fault zone was formed in the town, resulting in damaged buildings that were located on the fault or in close proximity to the fault. Almost half of the old area of the county-town was destroyed by the Chengxi landslide located at the west side of the county-town (Fig. 2). The south side of the new area of the county-town was affected by the Jingjiashan rockfall, which consisted of huge blocky stones with maximum single block of hundreds of cubic meters. This rockfall destroyed several buildings and the main road passing the county-town, and caused disastrous casualties (Fig. 3).

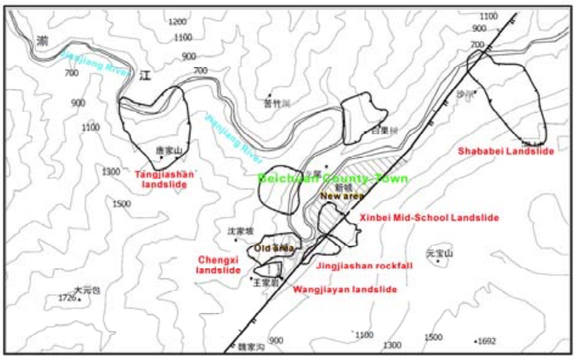


Fig.2 Map of earthquake-triggered landslides in the Beichuan

The landslide that occurred at the Xinzhong Junior High School of Beichuan County consisted of an old landslide mass and a hazardous rock mass. According to the investigation data from the No. 909 Team of Chinese Hydro-geology & Engineering Geology Prospecting Institute, this area belongs to the area of Luanshijiao landslide. The bedrock of this landslide is the thick limestone of upper Devonian System and lower Carbonic System, with a length of 560 m, a width of 200 m, an average thickness of 20 m, the maximum thickness of 40 m, a height difference of 300 m, and a volume of 2.4 million m^3. This landslide has the characteristics of rockfall and is mainly formed by huge blocky stones with maximum single block of 1,000 m^3. The rocks might have generated great impact force and caused a three-story building and adjacent buildings destroyed. About 500 people were killed in this landslide (Fig. 4). At the toe part of the landslide deposit, upheaval occurred at the ground surface along the main street, which was thought to be related to the thrust scarp resulting from movement on the earthquake fault.

Fig.3 Destroyed road and houses due to huge rock falls

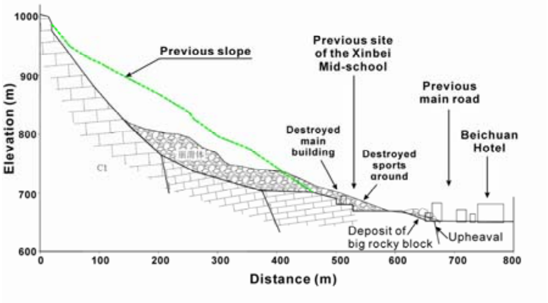
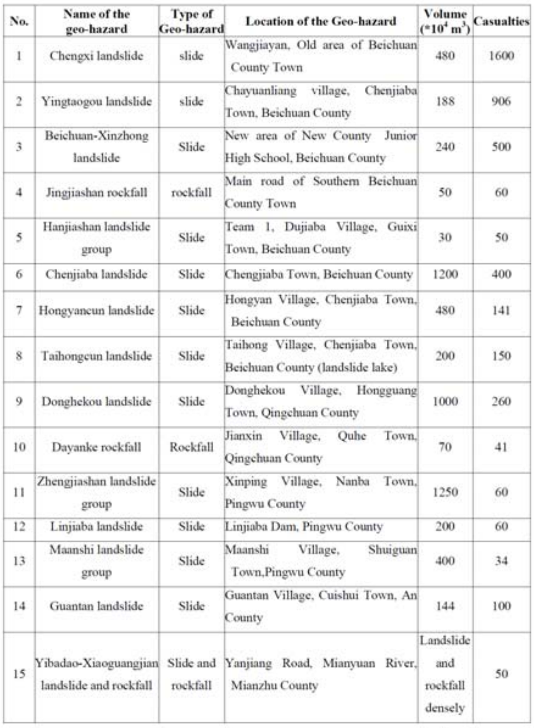


Fig.4 Section of the Xinzhong landslide on the Beichuan town (500 deaths)

3. Landslide lakes and their risk assessment

There are densely distributed water systems in the Longmenshan area, mainly including the Minjiang River, the Tuojiang River and the Jialingjiang River, which are all mountain streams with the maximum relative height difference of 5,000 m. A great number of landslides, rockfalls and debris flows were triggered by the Wenchuan earthquake, which seriously blocked the stream channels. From northeast to southwest, the following rivers are blocked: the Qingjiang River, the upper stream of the Fujiang River, the Tongkouhe River, the Jianjiang River, the Xiushui River, the Baishuihe River, the Mianyuanhe River, the Shitinghe River, the Minjiang River, and the Xihe River (Fig. 5).

Table 2 Fatalities (≥30 persons) due to earthquake-triggered landslides




No.	Name of the geo-hazard	Type of Geo-hazard	Location of the Geo-hazard	Volume ($*10^4$ m^3)	Casualties
1	Chengxi landslide	slide	Wangjiayan, Old area of Beichuan County Town	480	1600
2	Yingtaogou landslide	slide	Chayuanliang village, Chenjiaba Town, Beichuan County	188	906
3	Beichuan-Xinzhong landslide	Slide	New area of New County Junior High School, Beichuan County	240	500
4	Jingjiashan rockfall	rockfall	Main road of Southern Beichuan County Town	50	60
5	Hanjiashan landslide group	Slide	Team 1, Dujiaba Village, Guixi Town, Beichuan County	30	50
6	Chenjiaba landslide	Slide	Chengjiaba Town, Beichuan County	1200	400
7	Hongyancun landslide	Slide	Hongyan Village, Chenjiaba Town, Beichuan County	480	141
8	Taihongcun landslide	Slide	Taihong Village, Chenjiaba Town, Beichuan County (landslide lake)	200	150
9	Donghekou landslide	Slide	Donghekou Village, Hongguang Town, Qingchuan County	1000	260
10	Dayanke rockfall	Rockfall	Jianxin Village, Quhe Town, Qingchuan County	70	41
11	Zhengjiashan landslide group	Slide	Xinping Village, Nanba Town, Pingwu County	1250	60
12	Linjiaba landslide	Slide	Linjiaba Dam, Pingwu County	200	60
13	Maanshi landslide group	Slide	Maanshi Village, Shuiguan Town,Pingwu County	400	34
14	Guantan landslide	Slide	Guantan Village, Cuishui Town, An County	144	100
15	Yibadao-Xiaoguangjian landslide and rockfall	Slide and rockfall	Yanjiang Road, Mianyuan River, Mianzhu County	Landslide and rockfall densely distributed area.	50
16	Hongcun HPS landslide	Slide	Hongcun HPS, Shitingjiang River,Shifang County	100	150
17	Limingcun landslide	Slide	Liming Village, Zipingpu Town, Dujiangyan City (National Road 213)	20	120
18	Xiaolongtan rockfall	Rockfall	Yinchanggou Resort, Pengzou City	5.4	100
19	Dalongtan goukou rockfall	Rockfall	Yinchanggou Resort, Pengzou City	10	100
20	Xiejiadianzi landslide	Slide	Team 7, Jiufeng Village, Pengzou City	400	100
21	Liangaiping landslide	Slide	Tuanshan Village, Pengzou City	40	30
22	Taian-9-team landslide group	Rockfall	Zhoujiaping, Qingchengshan Town, Dujiangyan City	3 landslides with total volume of 1.2 million m^3	62
23	Yingxiu-Wenchuan Road landslide and rockfall	Slide and rockfall	Along the Tourist Road from Dujiangyan to Jiuzhaigou Resort	Landslide and rockfall densely distributed area.	1000
			Total		**6074**

The data were modified from Department of Land and Resources, Sichuan Province

The distribution of landslide lakes is closely related to proximity to the earthquake fault in the Longmenshan Mountain system. There are 22 landslide lakes distributed in the earthquake fault belt, which are 1/3 of the total number of landslide lakes. Notably, the Jianjiang River, the Mianyuanhe

River and the Shitinghe River landslide lakes are distributed along the central fault zone. It is obvious that the volume and sliding distance of landslides along the earthquake fault are larger and longer than others, and the earthquake fault zone becomes the area where landslide lakes were likely to be formed.

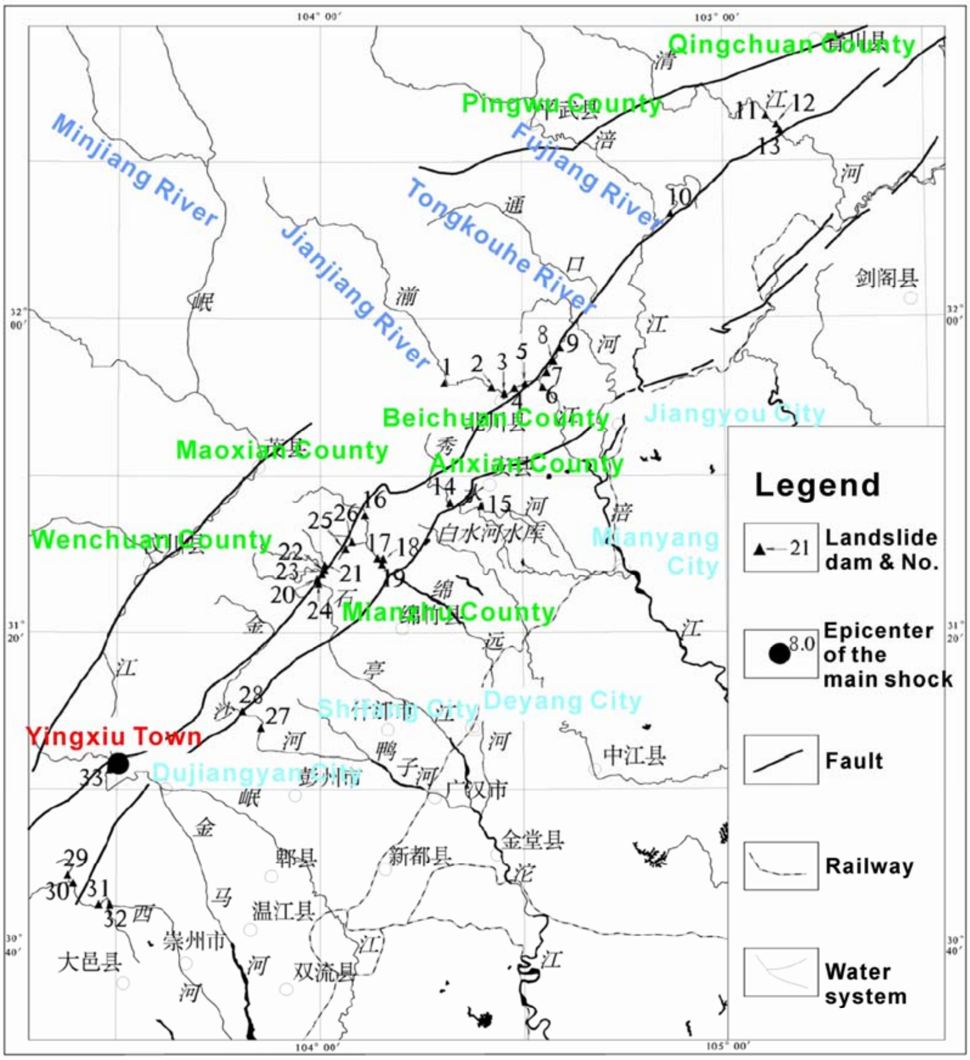


Fig.5 Distribution map of Landslide- dammed lakes (the Number is explained in the Table 4)

The biggest landslide lake is the Tangjiashan landslide lake which was formed by the Tangjiashan landslide which blocked the upper stream of the Jianjiang River, with a distance of 5 km from Beichuan County-town (Fig. 6). The Tangjiashan landslide consisted of medium-weathered and strong-weathered schist, slate and sandstone with a dip-structure. The height difference of toe and main scarp was 650 m, and the horizontal distance was about 1,250 m. This landslide has a length of 610 m, a width of 800 m, and a landslide dam height of 80 ~ 120 m, and a volume of 2 million m^3. Because of the impact onto the left bank, the debris with a thickness of 30~50 m was deposited at the north part of the landslide dam. It is the impact and returning runout area of the landslide. Below the elevation of 800 m, there are several small-scale synclines and folds distributed in the mountain. Therefore, the great number of layered folding rocks in the landslide mass may be formed by the original tectonic factor and then the strong sliding impact force. The maximum capacity of the landslide lake was $2.4*10^9$ m^3, with the backwater length of 20 km. At the beginning of June, the excavation measures were taken on this landslide dam with the horning depth of 20 m. After the highest water level of 743.10 m of Tangjiashan landslide lake which occurred at 1:30 on June 10, the water level had fallen back to 719.48 m at 20:00 on June 10, which was its height before the earthquake, and which is the safe design criterion.

According to the disaster characteristics of the landslide lakes formed by the Wenchuan earthquake, suggestions concerning risk assessment are proposed by considering the following three factors.

(1) Landslide dam height. The most important condition for landslide lake risk is the dam height at the head from the lower reaches of the dam to the object water level, which can indicate the impact force of dam failure. Because there is great difficulty in analyzing the latter factor, only the dam height is considered. Because many landslide dams were formed, and the water level difference in the stream even in dry season is more than 10 m, those landslide dams with the height less than 10m were simply considered safe.

(2)The capacity of landslide lake. This controls the pressure level of force on landslide dam. Even at a very high elevation, a landslide dam that does not generate enough reservoir capacity, likely cannot bring dam failure.

(3) The structure of the dam body. Different material compositions and construction characteristics will restrict the likelihood of dam failure. The dam body is mainly formed by soils that will break instantly after the overflow of a landslide lake. But the dam body made up of large stone blocks will be stable for a long time because of the reduction of pressure due to obvious seepage through the blocks.

Based on the above three factors, the risks of landslide dams are classified into four levels, as extremely dangerous, highly dangerous, the moderately dangerous and low-level dangerous.

According to the assessment grades of Table 3, the risks of 33 landslide lakes are evaluated (Table 4). The dam height of the Tangjiashan landslide lake is more than 100 m with a reservoir capacity of $2.4*10^9$ m^3, consisted of weathered slates and sandstone. As a result, it is ranked as extremely dangerous. Meanwhile, the 5 landslide lakes at the lower reaches of the Tangjiashan landslide lake with low danger and moderately danger are upgraded to the extremely dangerous grade by using the integral assessment method.

It is noted that not all the landslide lakes must be eliminated by taking mitigation measures, as some landslide lakes have tourism, economic, scientific, and even societal value.

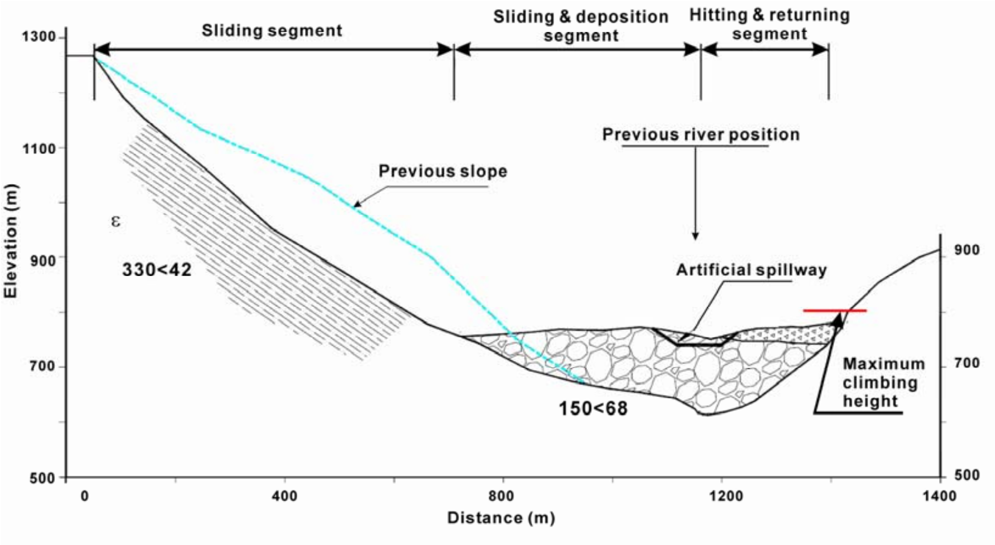
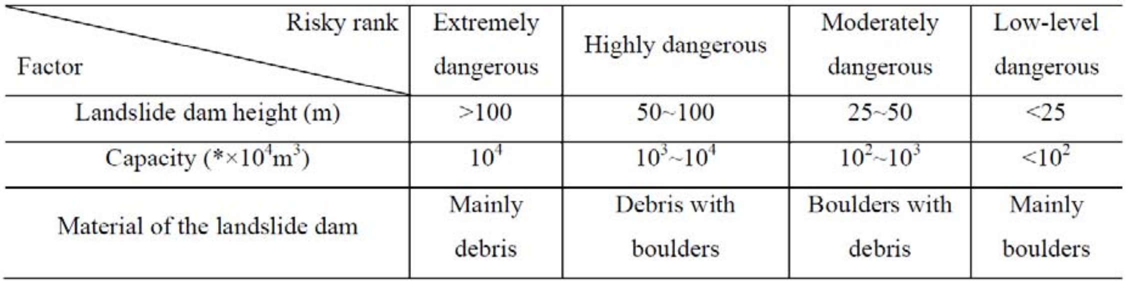


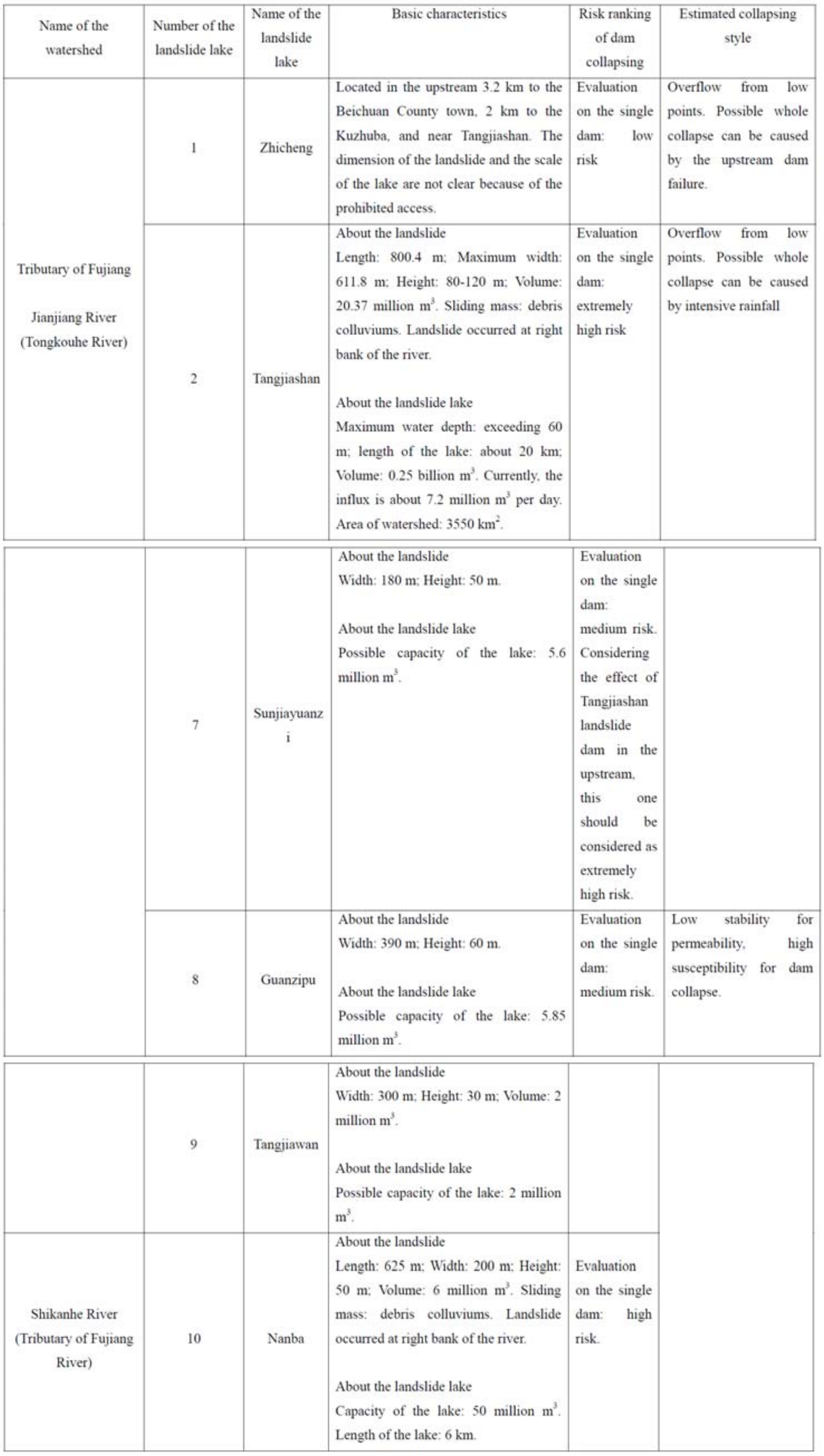
Fig.6 Section of the Tangjiashan landslide- dammed lake

Table3 Classification of risk assessment for failure of landslide lakes



Risky rank / Factor	Extremely dangerous	Highly dangerous	Moderately dangerous	Low-level dangerous
Landslide dam height (m)	>100	50~100	25~50	<25
Capacity ($*\times10^4m^3$)	10^4	10^3~10^4	10^2~10^3	<10^2
Material of the landslide dam	Mainly debris	Debris with boulders	Boulders with debris	Mainly boulders

Table 4 Assessment of the failure risk of landslide lakes



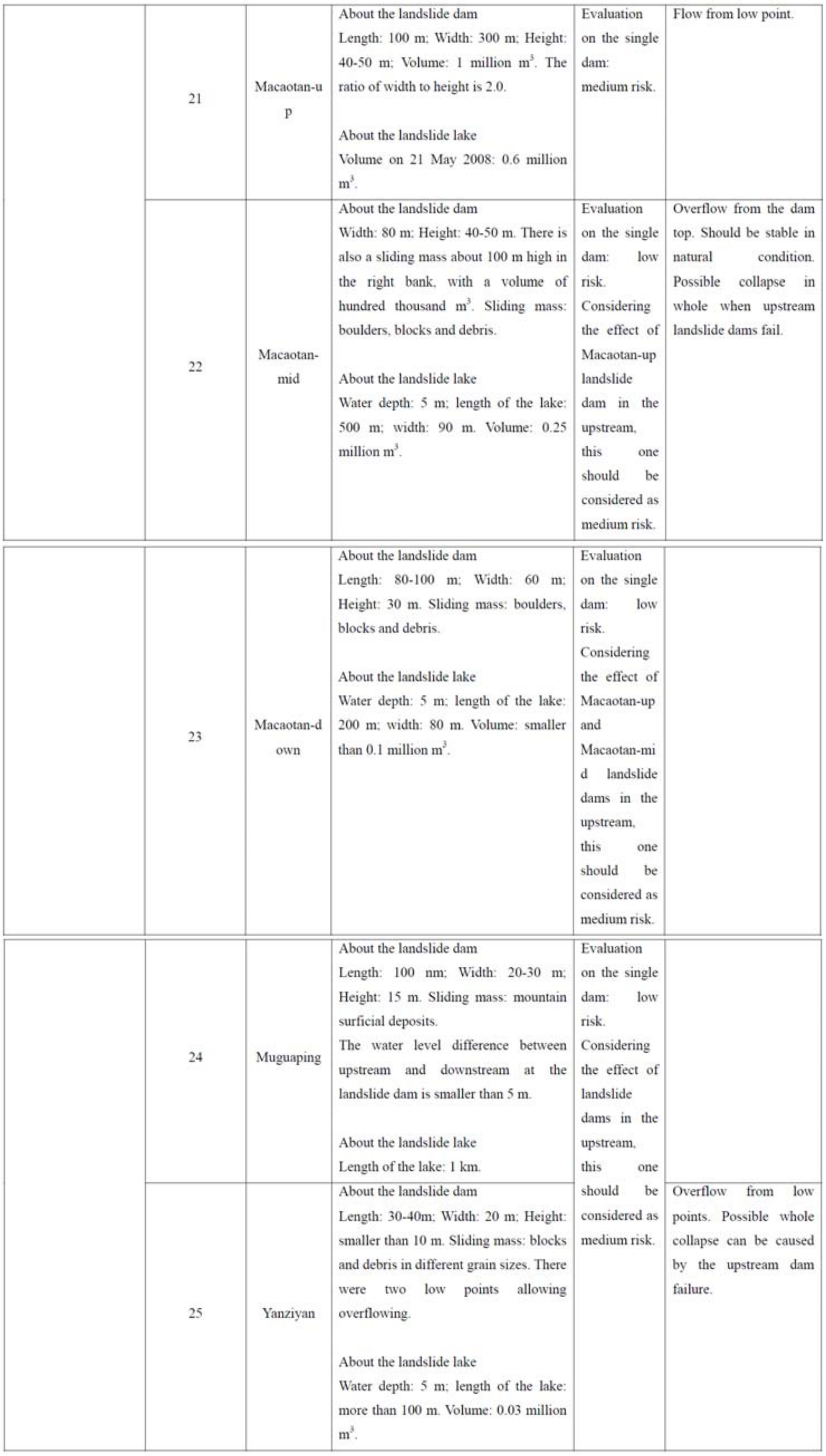
Name of the watershed	Number of the landslide lake	Name of the landslide lake	Basic characteristics	Risk ranking of dam collapsing	Estimated collapsing style
Tributary of Fujiang Jianjiang River (Tongkouhe River)	1	Zhicheng	Located in the upstream 3.2 km to the Beichuan County town, 2 km to the Kuzhuba, and near Tangjiashan. The dimension of the landslide and the scale of the lake are not clear because of the prohibited access.	Evaluation on the single dam: low risk	Overflow from low points. Possible whole collapse can be caused by the upstream dam failure.
	2	Tangjiashan	About the landslide Length: 800.4 m; Maximum width: 611.8 m; Height: 80-120 m; Volume: 20.37 million m^3. Sliding mass: debris colluviums. Landslide occurred at right bank of the river. About the landslide lake Maximum water depth: exceeding 60 m; length of the lake: about 20 km; Volume: 0.25 billion m^3. Currently, the influx is about 7.2 million m^3 per day. Area of watershed: 3550 km^2.	Evaluation on the single dam: extremely high risk	Overflow from low points. Possible whole collapse can be caused by intensive rainfall
	7	Sunjiayuanzi	About the landslide Width: 180 m; Height: 50 m. About the landslide lake Possible capacity of the lake: 5.6 million m^3.	Evaluation on the single dam: medium risk. Considering the effect of Tangjiashan landslide dam in the upstream, this one should be considered as extremely high risk.	
	8	Guanzipu	About the landslide Width: 390 m; Height: 60 m. About the landslide lake Possible capacity of the lake: 5.85 million m^3.	Evaluation on the single dam: medium risk.	Low stability for permeability, high susceptibility for dam collapse.
	9	Tangjiawan	About the landslide Width: 300 m; Height: 30 m; Volume: 2 million m^3. About the landslide lake Possible capacity of the lake: 2 million m^3.		
Shikanhe River (Tributary of Fujiang River)	10	Nanba	About the landslide Length: 625 m; Width: 200 m; Height: 50 m; Volume: 6 million m^3. Sliding mass: debris colluviums. Landslide occurred at right bank of the river. About the landslide lake Capacity of the lake: 50 million m^3. Length of the lake: 6 km.	Evaluation on the single dam: high risk.	

Qingjianghe River (Tributary of Jialingjiang River)	11	Shibangou	About the landslide Length: 450 m; Width: 800 m; Height: 60 m; Volume: 8.1 million m^3. Sliding mass: loose debris. Landslides occurred at both banks of the river. About the landslide lake Capacity of the lake: 20 million m^3. Length of the lake: 4 km.		
	12	Donghekou	About the landslide Length: 700 m; Width: 500 m; Height: 15-25 m; Volume: 10 million m^3. Sliding mass: loose debris. Landslides occurred at both banks of the river. About the landslide lake Capacity of the lake: 10 million m^3.	Evaluation on the single dam: medium risk. Considering the effect of landslide dams in the upstream, this one should be considered as high risk.	Dam collapse and overflowing. Collapse can be caused by upstream landslide dam failure.
	13	Hongshihe	About the landslide Length: 500 m; Width: 400 m; Height: 40 m; Volume: 1 million m^3. Sliding mass: loose debris. Landslides occurred at both banks of the river. About the landslide lake Capacity of the lake: 3 million m^3	Evaluation on the single dam: medium risk.	Low stability for permeability, high susceptibility for dam collapsing partially or in whole.
Chapinghe River (Tributary of Fujiang River)	14	Xiaojiaqiao	About the landslide Length: 250 m; Width: 200 m; Height: 80 m; Volume: 2 million m^3. Sliding mass: debris colluviums. Landslides occurred at both banks of the river. About the landslide lake Capacity of the lake: 20 million m^3. Length of the lake: 7 km.	Evaluation on the single dam: high risk.	Low stability for permeability, high susceptibility for dam collapse.
Kaijiang River (Tributary of Fujiang River)	15	Guantan	About the landslide Length: 120 m; Width: 200 m; Height: 60 m; Volume: 1.44 million m^3. Sliding mass: debris colluviums. Landslides occurred at left bank of the river. About the landslide lake	Evaluation on the single dam: high risk.	

			Capacity of the lake: 5 million m^3. Length of the lake: 2 km.		
Mianyuanhe River (Tuojiang River)	16	Hedongya	About the landslide Length: 700 m; Width: 120 m; Height: 35 m; Volume: 2 million m^3. About the landslide lake Capacity of the lake: 20 million m^3. Length of the lake: 400 m.	Evaluation on the single dam: medium risk.	
	17	Xiaogangjian-upstream	About the landslide Length: 172 m; Width: 120 m; Height: 72 m. Sliding mass: 60-70% of rock blocks. The ratio of width to height is 1.0. Permeability of the dam: 1 m^3/s. About the landslide lake Capacity of the lake: 11 million m^3.	Evaluation on the single dam: high risk.	

	18	Xiaogangjian-downstream	About the landslide Length: 150 m; Width: 150 m; Height: 30 m. Sliding mass: boulders. The ratio of width to height is 2.5. Permeability of the dam: 1 m^3/s. About the landslide lake Depth: 7 m; Length: 2 km; Capacity of the lake: 7 million m^3; Current volume: 1 million m^3.	Evaluation on the single dam: medium risk. Considering the effect of Xiaogangjian-upstream landslide dams in the upstream, this one should be considered as high risk.	Overflow from low points. Possible whole collapse can be caused by the failure of Tangjiashan dam in the upstream.

	19	Yibadao	About the landslide dam Length: 40 m; Width: 80-100 m; Height: 25 m. Sliding mass: boulders. The ratio of width to height is 2.0. About the landslide lake Maximum depth: 15 m; Length: 2 km; Capacity of the lake: 0.5 million m^3.	Evaluation on the single dam: low risk. Considering the effect of three landslide dams near Xiaogangjian in the upstream, this one should be considered as high risk.	Collapse step by step. Possible collapse in-whole can be caused by landslide dam failure in upstream.
Shitingjiang River (Tributary of Tuojiang River)	20	Ganhekou	About the landslide dam Height: 10 m. Sliding mass: boulders. Volume: 10 thousand m^3. About the landslide lake Capacity of the lake: 0.5 million m^3.	Evaluation on the single dam: low risk.	Overflow at dam top. No collapse.



	21	Macaotan-up	About the landslide dam Length: 100 m; Width: 300 m; Height: 40-50 m; Volume: 1 million m³. The ratio of width to height is 2.0. About the landslide lake Volume on 21 May 2008: 0.6 million m³.	Evaluation on the single dam: medium risk.	Flow from low point.
	22	Macaotan-mid	About the landslide dam Width: 80 m; Height: 40-50 m. There is also a sliding mass about 100 m high in the right bank, with a volume of hundred thousand m³. Sliding mass: boulders, blocks and debris. About the landslide lake Water depth: 5 m; length of the lake: 500 m; width: 90 m. Volume: 0.25 million m³.	Evaluation on the single dam: low risk. Considering the effect of Macaotan-up landslide dam in the upstream, this one should be considered as medium risk.	Overflow from the dam top. Should be stable in natural condition. Possible collapse in whole when upstream landslide dams fail.
	23	Macaotan-down	About the landslide dam Length: 80-100 m; Width: 60 m; Height: 30 m. Sliding mass: boulders, blocks and debris. About the landslide lake Water depth: 5 m; length of the lake: 200 m; width: 80 m. Volume: smaller than 0.1 million m³.	Evaluation on the single dam: low risk. Considering the effect of Macaotan-up and Macaotan-mid landslide dams in the upstream, this one should be considered as medium risk.	
	24	Muguaping	About the landslide dam Length: 100 nm; Width: 20-30 m; Height: 15 m. Sliding mass: mountain surficial deposits. The water level difference between upstream and downstream at the landslide dam is smaller than 5 m. About the landslide lake Length of the lake: 1 km.	Evaluation on the single dam: low risk. Considering the effect of landslide dams in the upstream, this one should be considered as medium risk.	
	25	Yanziyan	About the landslide dam Length: 30-40m; Width: 20 m; Height: smaller than 10 m. Sliding mass: blocks and debris in different grain sizes. There were two low points allowing overflowing. About the landslide lake Water depth: 5 m; length of the lake: more than 100 m. Volume: 0.03 million m³.		Overflow from low points. Possible whole collapse can be caused by the upstream dam failure.

	26	Hongsongcun-HPS station	About the landslide dam Length: 100 m; Width: 60 m; Height: 40-50 m; Volume: 0.4 million m^3. There was also a sliding mass about 100 m high in the left bank, with a volume of hundred thousand m^3. Sliding mass: boulders, blocks and debris. About the landslide lake Length of the lake: 2.2 km; Volume: 1-1.5 million m^3.		
Jin River (Tributary of Tuojiang River)	27	Fengmingqiao	About the landslide dam Length: 300 m; Width: 100 m; Height: 10 m. About the landslide lake Volume: 1.5 million m^3.	Evaluation on the single dam: low risk.	Overflow from low points.
	28	Xiejiadianzi	About the landslide dam Length: 250 m; Width: 70 m; Height: 10 m. About the landslide lake Length of the lake: 1 km; Current volume: 0.18 million m^3; Capacity: 1 million m^3.		Overflow from low points. Possible whole collapse can be caused by the upstream dam failure.
Wenjingjiang River (Tributary of Minjiang River) (Chongzhou County)	29	Zhugendingqiao-Jiguanshan Village	About the landslide dam Length: 500 m; Width: 68 m; Height: 90 m. Volume: 3 million m^3. About the landslide lake Capacity: 4.5 million m^3.	Evaluation on the single dam: medium risk.	Overflow from low points.
	30	Huoshiqiao	About the landslide dam Length: 500 m; Width: 40 m; Height: 120 m. Volume: 2.4 million m^3. About the landslide lake Capacity: 1.5 million m^3.		Overflow from low points. Possible whole collapse can be caused by the upstream dam failure.
	31	Haiziping	About the landslide dam Length: 500 m; Width: 50 m; Height: 50 m. Volume: 1.5 million m^3. About the landslide lake Capacity: 3 million m^3.		
	32	Liudinggou	About the landslide dam Length: 500 m; Width: 50 m; Height: 60 m. Volume: 1.5 million m^3. About the landslide lake Capacity: 3 million m^3.		
Wenjingjiang River (Tributary of Minjiang River) (Wenchuan County)	33	Yingxiuwan-Taipingyi HPS	About the landslide dam Length: 300 m; Width: 200 m; Height: 18 m. Volume: 1 million m^3. Sliding mass: blocky rocks. Dammed half of the river. About the landslide lake Capacity: 2 million m^3.		Overflow from low points.

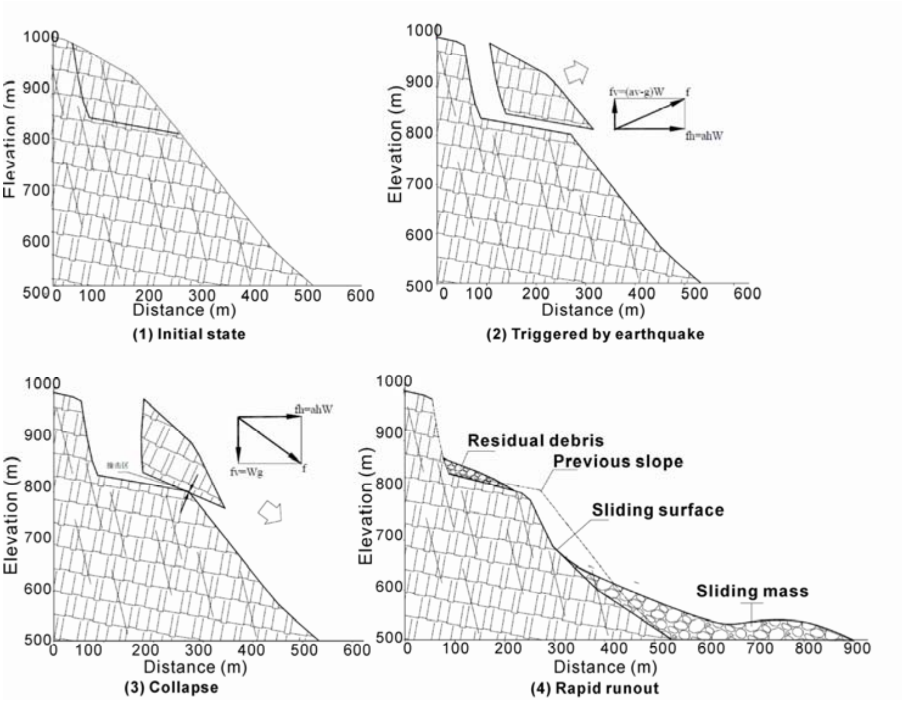
4. Analysis on the effect of earthquake force on landslides

The house destruction due to vertical earthquake acceleration has been studied by Qian (1983), and the vertical movement of some landslides has also been indicated by Collier & Elnashai (2001). Differing from other intensive earthquakes, the Wenchuan earthquake triggered landslides with a general character of "cuspidal impact" without continuous flat sliding surfaces, which can be divided into the following types (Fig. 7).

Fig.7 Typical sliding surface due to earthquake

(1) The transitional-type sliding surface. This kind of sliding surface is formed along the original sliding bed, and the long-distance debris flows will occur (if there is a high water content) or debris avalanches after the landslide slides from a high position.
(2) The convex-shaped sliding surface. This is generated under the action of vertical and horizontal earthquake accelerations. The rock mass on a high position will be dislodged and will create a forceful impact on the underlying bedrock and will finally become a high-speed debris avalanches (debris flows if there is a high water content) or a long runout landslide.
(3) The stair shaped sliding surface. The high rock mass is cut off by two discontinues surfaces, and one is the low-angle surface and the other is the steep surface. Under the action of vertical and horizontal accelerations, the rock mass will be dislodged and forcefully impacted on the edge of the plateau by the mechanism of dynamic friction. The obvious sliding layers can be found in the sliding mass of the Donghekou landslide of Qingchuan county, with a thickness of about 5~10 cm. The original orientation of sliding soil and rock layer is destroyed and new directional arrangements and layers are formed.

According to the three shape characters of sliding masses, the initial dynamic process of earthquake landslides in a meizo-seismal area can be divided into the following four stages (Fig. 8).



(1) Initial state
(2) Triggered by earthquake
(3) Collapse
(4) Rapid runout

Fig.8 Dynamic evolution of landslide due to earthquake

(1) The initial state slope. The height of the slope can be up to 200~300 m with the maximum height of 600 m such as is the case with the Donghekou landslide. The upper slope gradient can be up to and over 60~80°. Because of the relief joints, the structure of the mountain body is broken with most developed joints, and the large scale high-speed and long-distance landslides often are generated along the earthquake fault zones. The lithologic characteristics from Wenchuan County to Beichuan County and then to Qingchuan County, are mainly the rock strata of schist, phyllite, and sandstone of Cambrian to Silurian Systems, which can often generate landslides and rockfalls. In the area of Dujiangyan City and Wenchuan County, there are mainly granites with developed joints after long-term intensive extrusion, and this is also the area where landslides, rockfalls and debris flows can often be generated, along with the threat of the breakout of huge rocks. In the area of Mianzhu County, Shifang County and Pengzhou City, the carbonate rocks with huge thicknesses are often separated by large scale joints and fractures, which caused many large landslide dams and resultant landslide lakes due to landslides and rockfalls.

(2) Shaking from the earthquake. The seismic intensity of Wenchuan earthquake is up to XI degree (in Chinese Seismic Intensity system) and the recorded acceleration is more than 2g. Especially at the upper part of slopes, the acceleration can be evidently amplified. Based on the field survey, the vertical shaking effect on the buildings close to landslides is very obvious. Therefore the effect of vertical acceleration should be considered. That is to say, the earthquake force on the upper part of mountains has the character of parabolic curve, which is acted upon by the vertical and horizontal earthquake forces together, namely

$$f = \sqrt{f_h^2 + f_v^2}$$

Where f is the combined earthquake force with the obviously upward direction; f_h is the horizontal earthquake force and f_v is the vertical earthquake force.

It must be admitted that during the assessment of landslide stability and the mitigation projects, only the horizontal earthquake force has been considered and the vertical force is neglected until now. The necessary amendment of taking vertical acceleration into account should be implemented.

(3) Impact and break-up. After the upper mountain body is dislodged, it will fall rapidly and impact the convex bedrock or slope, and will form the smoothly orbicular convex or step (or terraced) slope ground. The earthquake force is mainly the horizontal inertia force, but the vertical force is mainly the gravity force, and the direction of the combined forces is downward. The dynamic friction will occur in the impact area, which can cause the original structure of sliding mass to be reformed.

(4) High-speed runout. The upper landslides or rockfalls will be disintegrated upon impact, and will generate the following three effects. First, they can generate the high-speed air blast effect. The landslide is formed by larger stone and soil blocks with certain thickness, and can run for 1~3 km. Second, they can make debris flows. The soils and blocks can slip a long distance in their streaming state, especially in a high water content condition. Third, a landslide can generate a scraping and eroding effect. Under the action of huge percussive force, the lower rock mass can be broken-up, and new landslides and rockfalls can then be generated with small thicknesses and a wavy sliding bed.

The Taihongcun landslide in Beichuan County has the obvious character of step or terraced sliding surface (Fig. 9), which is made of sandstone-shale and slate of Silurian System. The upper landslide body has a height of 70 m, a width of 100 m, a longitudinal length of 50 m and a volume of 0.35 million m^3. The upper sliding body impacted forcefully with the underlying bedrock, and induced the lower landslide. The height difference from step or terrace to channel bed is about 150 m, the width is 200 m, the longitudinal length is 150 m, the thickness of landslide deposit is about 50 m and the volume is about 1.5 million m^3, which formed a massive landslide dam generating the landslide lake. After being dislodged at a high position, the landslide impacted the thither highland, and formed an impact body of chipped soils and stones with a volume of 20,000 m^3, which overlaid the cornfield and showed characteristics of an air-blast effect.

Fig.9 Stair-shaped landslide at the Taihong Village, Beichuan (150 deaths)

5. Characteristics and hazards of rapid landslides triggered by the earthquake

Complex landslides triggered by strong earthquake is very common (Lin et al. 2003), but vertical movement in Wenchuan earthquake epicenter is dominant. Wenchuan earthquake triggered a great number of rapid and long runout landslides, thus generating momentous geo-hazards. The dynamics of landslides triggered by earthquakes are discussed above, and in this section, by analyzing the typical instances; the disaster process from triggering to forceful impact effects will be discussed. According to the records of earthquake acceleration observatories, the earthquake acceleration of Wolong is 0.9g, Zipingpu Dam is 2.0g, Jiangyou is 0.6~0.7g and Qingchuan is 0.4g. Therefore, in the meizo-seismal area especially the zone from Yingxiu Town to Beichuan County Town, the earthquake acceleration can be up to 2.5g, and at the upper part of the slope, the earthquake acceleration can be increased through amplification more than 1.5 times.

The landslide located in the west of old area of Beichuan County-town caused 1600 deaths and destroyed hundreds of buildings, which is the most severe landslide disaster triggered by the Wenchuan earthquake and is a very rare world-wide occurrence. This landslide is composed of sandstone-shale and schist of the Cambrian System and is a reverse-dip structure slope. In the superficial layer, there are deposits of ancient landslides and rockfalls, which are about 500 m far away from the central fracture. The height difference between the toe and main scarp is about 350 m, and the distance is some 200 m and the runout distance is 550 m. The sliding mass has a length of 400 m, a width of 400 m, a thickness of 30 m and a volume of about 4.8 million m^3. This landslide has the following three segments (Figs. 10 and 11).

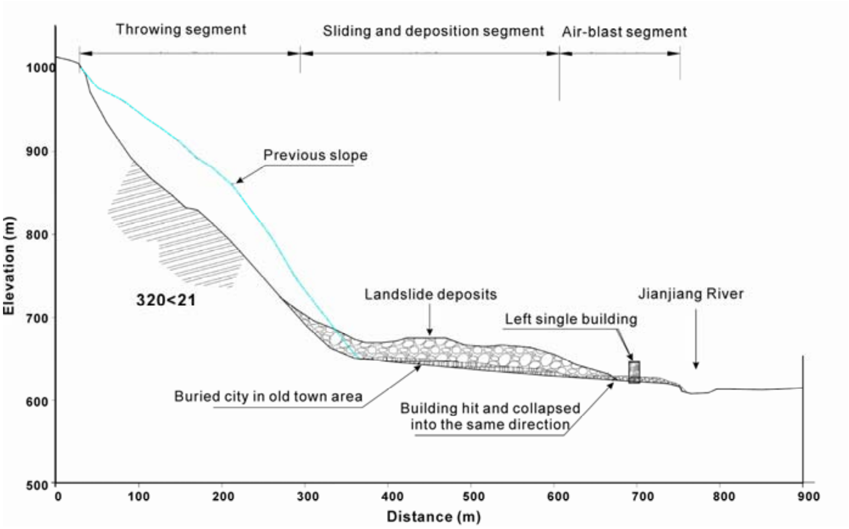


Fig.10 Section of the Chengxi landslide in the Beichuan town (1600 deaths)

(a) before sliding (b) after sliding

Fig.11 Old town and the Chengxi landslide on the Beichuan town

(1) The segment of high velocity dislodgement. The landslide burst out at an elevation of 800~1000 m by earthquake. The upper sliding mass has a length of about 200 m, a height difference of 200 m, a thickness of 20~30 m and a volume of 2 million m^3. The lower sliding mass was pushed by the impact of the upper sliding mass on

underlying bedrock, which has a volume of 2.8 m^3. The slope gradient of the sliding surface is about 45°, with an obvious convex shape.

(2) The sliding and deposition segment. Because of the air-blast effect, the landslide elongated to a length of about 400 m after runout. Then, it overlapped on the old area of the county-town and destroyed hundreds of buildings including 30 six-story buildings.

(3) The air-blast segment. At the toe of the sliding mass, there are broken buildings in a zone wider than 100 m, and at the two sides, the zone width was up to 50 m. Apparently different from the destroyed buildings in other locations, most of the broken buildings in Beichuan County appeared in a filament shape with a directional echelon, which shows the collapse of buildings were shaken by the earthquake and the strong action of air-blasts.

The Donghekou landslide-debris flow is a typical rapid and long runout compound landslide, with the height difference between the toe and main scarp of 700 m, a sliding distance of 2400 m and a volume of 10 million m^3 (Figs. 12 and 13). This landslide buried 7 villages and caused 400 deaths. It is composed of sandstone-shale and schist of the Cambrian System, with a distance from the central fault fracture of about 4 km.

Fig.12 RS image of the Donghekou landslide-debris flow, Qingchuan County

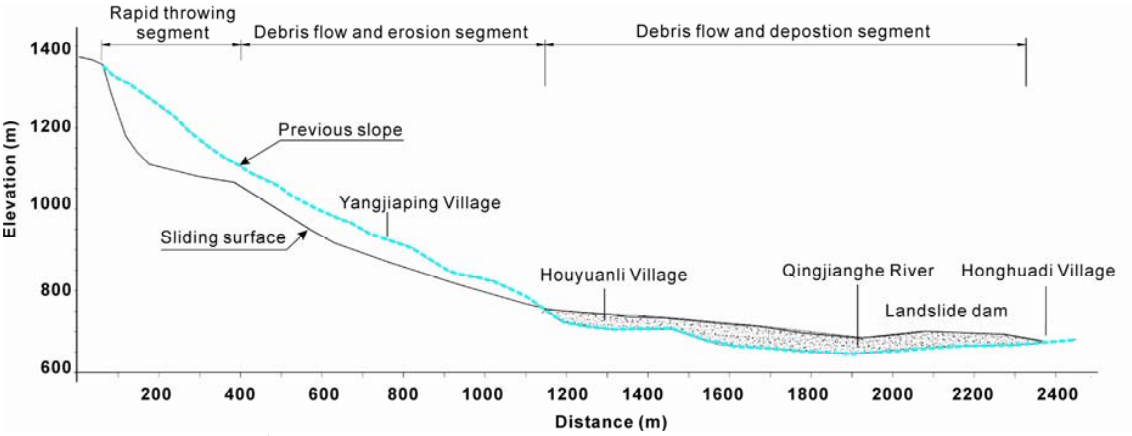


Fig.13 Section of the Donghekou landslide-debris flow (260 deaths)

The height difference of the upper sliding mass of the Donghekou landslide is 200 m, with a length of 150 m, a cross width of 200 m and a volume of 6 million m^3. At the elevation of 1050 m, the landslide burst out and dislodged the underlying bedrock, and then, the landslide became to a debris, with a length of 800 m, a cross width of 200 m, a thickness of 30 m and a volume of 4 million m^3. The rapid debris flow scoured the left bank of the Qingjiang River and generated a landslide dam consisting of loose debris and blocky stones, with a length of 700 m, a width of 500 m, and a height of 15~25 m.

The landslide lake overtopped on 17 June, with a flow of 20~30 m^3/s, the maximum flow less than 100 m^3/s and the peak flow of the lower stream channel of 500 m^3/s. Based on Table 3, its risk is evaluated as moderate risk.

6. Suggestions

Tremendous disasters have been triggered by "5.12" Wenchuan earthquakes, magnitude 8.0. The authors consider that the lessons from this seismic disaster must be analyzed and generalized seriously through the following three aspects.

(1) The theoretical research on engineering geology must be strengthened.

Prof. J.S. Lee, an outstanding Chinese scientist is a pioneer, who studied the earthquake geological problems of the Longmenshan area from the geological safety point of view. In the middle 1960s, with the planning and construction of numbers of important projects in the Longmenshan area, Prof. Siguang Li started the research into the engineering seismo-geological problems under the instructions of Premier Enlai Zhou. He announced that the tectonic activity is very intensive in this area, but some comparatively steady crustal blocks could be found for construction sites, which are known as "Safe Island". The investigation of this seismic disaster shows that the engineering sites selected according to the criteria of "Safe Island" were not fatally destroyed in this earthquake, which becomes a model of geomechanics serving important construction projects.

Since the execution of the western-China development strategy, the study of engineering geology encountered severe challenges. We knew just a little about the first geographic step, Qinghai-Tibet Plateau and its surrounding areas, of the three important geographic steps in China. However, in this step area, the social economy has been rapidly developed and the scale of engineering constructions has been expanded dramatically in the latest ten years, with the special requirement for engineering geology quite different from that in the plain area and in the middle-China area. The conventional engineering geological theory usually screens out the comparatively stable "Safe Island" in the areas with intensive tectonic activity. But in the actual cases, there are a few areas fit for construction sites in the Western-China. Meanwhile, during the layout of modern projects, it is obvious that the geological factor has been taken less into consideration than other factors, such as the societal factor and the economic factor, which results in the fact that there are no regulations to comply with for geological work and makes the geological work a passive "attendant" situation. Presently, the development of engineering geology has been lagging greatly behind that of engineering construction, which leads to decisions being made without enough engineering geological input, and as a result, the construction is not properly implemented.

The geoscience revolution brought by the rise of the theory of Plate Tectonics in 1970s has achieved quantities of theoretic ideas. But the engineering geology theoretical basis hasn't been deepened and strengthened yet, which creates the problem of lagging theory and resultant application. Plate Tectonics established a set of theoretical systems for explaining global dynamics, but there was still a big stride to be made on setting up the geological theory and method of safety evaluation on sites of major projects. Moreover, in recent years, there is a tendency towards theory being substituted by construction engineering, and it seems that all geological problems occurring in construction can be resolved through engineering techniques.

(2) The function of geology in seismo-geological disaster prevention must be improved.

In order to prevent seismic disasters, it is very necessary to intensify the research on the stability of mountain masses controlled by the first and second structural surfaces and the stability of the regional crust in western-China areas. Investigation, reconnaissance and evaluation should be deepened and intensified on the subjects of control and renovation. In the past more than ten years, the situation of productivity preempting the geology safety came into being during the construction of a great number of important projects and towns, and resulted in the neglect of mountain studies, through emphasis on the effects of rocks or soils. In the engineering geology field in China, the old generation geologists such as Prof. Dezhen Gu, Prof. Guochang Liu and Prof. Haitao Hu and so on, have emphasized the research on regional engineering geology. They paid more attention to the study of the stability of regional crustal and mountain masses, and solved the unique and extremely difficult geological problems using their original theories. However recently, many problems have occurred in China. First, engineering geology has been merged by other subjects and a talent crisis happened; second, although the site engineering geology has been intensified, the tactical engineering geology with the objective of the safety of regional geological environment has been weakened. This will induce momentous engineering construction problems; third, because of the lagging of theory, only a great number of foreign methods are used to solve the unique Chinese complex geological problems. The momentous engineering construction problems occur in China, foreign theories and methods cannot fully solve the problems properly. For example, the railway from Dali City to Ruili City built in the southwest of China will cross over the Nujiang River fault and Gaoligong Mountain, but how to evaluate the engineering geology stability of the mountains with high temperature, crustal stress and deep faults, and how to control and reform them are all new problems which cannot be solved even by using the existing foreign theories and methods. In the last ten years, the technical crafts and building structure were overemphasized, and resulted in weakening the importance of engineering geology and affect its vital value. The lack of administrative regulations and technical standards will not only induce great economic loss but also increases the human accidents and mistaken decisions.

In the view of earthquake disaster mitigation, the geological sciences are very useful. In the science of tectonic structure, the high mountains and valleys in northwest Sichuan have caused a reevaluation of the traditional view of the geological structure, and are recognized as the nappe structure caused by extruding of the Qinghai-Tibet Plateau to Sichuan crustal block. Soon after this earthquake, some there has been delays at the beginning of rescuing. People regarded the area of Wenchuan-Maoxian as the main disaster areas primarily because of the many ancient earthquakes that have occurred there. Without the foundation of geological theory, the mechanism of this earthquake area cannot be analyzed clearly. And without the clear mechanism, most phenomena cannot be explained. The Longmenshan tectonic belts include the Maoxian-Wenchuan fault, the central Qingchuan-Beichuan-Yingxiu fault, the Hanwang-Dujiangyan fault and the hidden or subsurface fault. It can be seen from the outlook of earthquake geology that the research on the central main fracture of this earthquake is not enough.

From the view of earthquake prediction, it is a comprehensively difficult problem of science and engineering, and many opinions are offered from the standpoints of mathematics, physics, geology, astronomy, biology and archaeology. In fact, the study of the geology developed a new style of its own as a result of studying the Xingtai earthquake, and has led to the formation of earthquake geology, opening the relative specialties and culture of many talents after the Xingtai earthquake happened in the 1960s. But in the nearly more than 20 years since, this science has not been developed well. The specialty basis of earthquake geology is geo-mechanics, and the study of active tectonic systems is its core. After the rise of the study of plate tectonics, most results had been achieved after the research on the earthquake geology of plates, especially the Japan ocean trench and the Chile ocean trench. For example, Prof. Kiyoo Mogi, Prof. Tsuneji Rikitake and other researchers studied the theoretical problems of “seismic gap” and “seismic migration” of the Japan island arc. The earthquakes in the Chinese Mainland often belong to the intraplate causative factor, which cannot be solved well by using foreign theories and methods. The geologists had done a great deal of work in geotectonic geology, lithospheric structure, crustal deformation and crustal stress, and some study and conclusions had been come into being. In 1975, after the Haicheng earthquake being predicted successfully, many researchers seemed to be optimistic. But after devoting a lifetime of effort, earthquake prediction is still regarded as a pessimistic science. Therefore we should treat the Wenchuan earthquake and the research on earthquake prediction as interesting but not very useful as, there is still a long way to go to predict earthquakes successfully.

(3) The geo-hazard hazard and risk control for development for watershed and town construction in mountain area must be strengthened.

This earthquake caused many rivers to generate landslide lakes, for example, there are more than 9 landslide lakes, including the Tangjiashan landslide lake that occurred in the Tongkouhe River in Beichuan County, and in Qingchuan, Pingwu, Mianzhu, Shifang and Dujiangyan, there are also many landslide lakes. The landslide lakes can do great harm to the step power stations in these areas. In fact, there are many historic disasters of landslide lakes bursting in the Longmenshan tectonic belt. For example, on August 25, 1933, the Diexi earthquake (Ms=7.5) occurred in Maoxian County and induced many rockfalls, landslides and debris flows, which jammed and blocked more than 10 tributaries of the Minjiang River and brought tremendous disaster. Presently, there are still many remaining landslide lakes triggered by the Diexi earthquake. The mountain collapse induced by the earthquake ruined the ancient Diexi town with a history of one thousand years in a moment, and resulted in 500 deaths. On 9 October 1933, the Diexi landslide lake burst and flooded into the Minjiang River, destroyed the farmhouses and farm fields of lower reaches and caused the deaths of 2500 people. On 1 June 1786, the magnitude 7.5 earthquake occurred in the south of Kangding, located in the southwest of the tectonic belt. This earthquake induced a landslide on the Caihong Bridge of the Daduhe River and generated a landslide lake. After 10 days of water accumulation, the landslide lake burst and the resulting flood level was more than 10 m, which was the biggest landslide lake in our country. The flooding submerged hundreds of thousands of people. Therefore we should not only summarize the river basin geo-hazards triggered by this earthquake, but also take history as a mirror and a future indicator. Besides the Longmenshan area, the geologic environmental safety of the Minjiang, the Daduhe, the Jinshajiang, the Yalongjiang, the Lancangjiang and the Nujiang Rivers all should have more attention paid to them, and the river basin assessment and risk management of geo-hazards should be done.

This earthquake is also closely related to the irrational engineering activities of mankind. Earthquake is a normal action of earth dynamic force, but the earthquake hazard mainly depends on the preventive and resistance ability of human beings. Taking the Beichuan County as an example, it can be seen that the scale of this county site was small in the 1990s, and the population was only distributed in the southwest of the county at that time. But later, it was enlarged rapidly and expanded onto the front edge of a slumping mass, crossing over the active fault zone. The landslide triggered by this earthquake destroyed almost half of old area of the county-town, and the new town area was almost destroyed by rockfalls and by active faults. In this site, the problem of how to ensure the safety of the geological environment in an extremely hazardous area was proposed to us, but the problem remains as to how to determine the extreme risks attributed to the basic geological theory. In the western-China areas where the geological structure is intensely active, the relief is very steep because of the deep down cutting of valleys. Therefore most towns can only be seated on the relatively gentle slopes. However on the contrary, due to the fact that these are areas of accumulated materials deposited by landslides and debris flows, or are in potential damage zones of active faults, they are very dangerous. Especially in recent years, with the quick expansion of the scale of town construction, the geo-hazard risk management of town construction in mountain areas must be developed with serious considerations as to avoid the reoccurrence of geo-hazards triggered by earthquakes such as the Wenchuan earthquake.

7. Conclusions

This paper presented studies of the earthquake geo-hazards triggered by the Wenchuan earthquake on a preliminary basis, and analyzed the geo-hazards and incipient faults in a systematic approach. It can be considered that the Wenchuan earthquake caused 15,000 incidences of geo-hazards in the form of landslides, rockfalls and debris flows and caused 20,000 deaths. There are about more than 10,000 potential geo-hazard points induced by the Wenchuan earthquake, especially for rockfalls, which reflects the great different effects of the earthquake on high and steep slopes in mountain areas with the obvious increase in impacts through amplification of effects on top of mountains. The authors assessed the break-out risk of landslide lakes, studied the dynamics of triggering factors of the earthquake and the sliding type, process and disaster mechanism. The “cuspidal impact” is a common characteristic of landslides developed in meizo-seismal areas. The landslides can be classified into the following three types, for example, the transitional type, the convex or rotational type and the step or terrace type. By taking the Chengxi landslide located at the west of Beichuan County and the Donghekou landslide in Qingchuan County as examples, the authors analyzed the rapid sliding process and the hazard mechanism of landslides triggered by the earthquake. The authors also considered that the lessons from this seismic disaster must be analyzed and summarized seriously, and the theoretical research on engineering geology must be intensified, the function of geology in seismo-geological disaster prevention must be improved and the geo-hazard risk control of development for river basins and town construction in mountain area must be strengthened.

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Effects of Global Change on Landslide Risk

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Abstract. Landslides represent a major threat to human life, property and constructed facilities, infrastructure and natural environment in most mountainous and hilly regions of the world. Statistics from the Centre for Research on the Epidemiology of Disasters (CRED) show that, on average, landslides are responsible for a small fraction of all fatalities from natural hazards worldwide. The socio-economic impact of landslides is, however, greatly underestimated because landslides are usually not separated from other natural hazard triggers, such as extreme precipitation, earthquakes or floods in natural catastrophe databases. This underestimation contributes to reducing the awareness and concern of both authorities and general public about landslide risk.

As a consequence of global change factors in many parts of the world, the pattern of risk associated with landslides is changing. Climate change, increased susceptibility of surface soil to instability, anthropogenic activities, growing urbanisation, and uncontrolled land-use change with increased vulnerability of population and infrastructure as a result, all contribute to the changing landslide risk in many parts of the world. It is therefore important to strengthen the ability to forecast landslide hazard and detect risk zones for all types of landslides such as debris and mud flows, rock falls, slides and avalanches. There is also a need for developing risk assessment and management tools and strategies for dealing with the risk associated with landslides at local, regional, and national scales and establishing the baseline for the landslide risk. In a rapidly changing world, these tools should be designed such that they could readily incorporate the effects of global change on the underlying parameters.

Developing countries are more severely affected by natural disasters than developed countries, especially in terms of lives lost. This underlines the importance of accounting for the vulnerability the exposed population and infrastructure in landslide risk assessment. Developing measures for risk mitigation at a local level is a key factor for dealing with the growing landslide risk in the coming years. The risk mitigation measures are not limited to physical measures, but include early warning systems and measures of organizational, political, legal and administrative manner. Mitigation also includes efforts to influence the lifestyle and behaviour of the exposed population in the societies at risk.

To develop optimal strategies for managing the landslide risk and dealing with the changes in the risk pattern, several research projects have been, or are being initiated. The aims of these projects are: (1) evaluate the changes in risk pattern caused by climate change, human activity and policy changes;

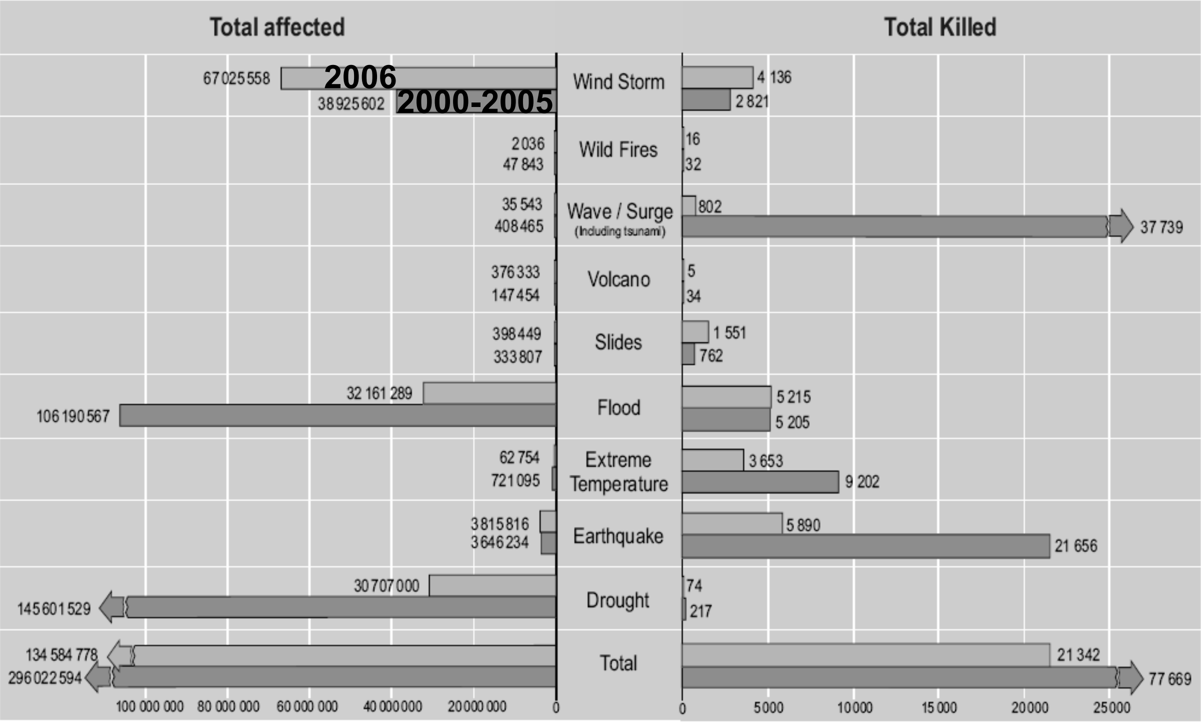

Fig. 1 Human impact by disaster types during 2000-2006 (from CRED-EM database).

(2) provide policy-makers, public administrators, researchers, scientists, educators and other stakeholders with improved methods for the assessment and quantification of landslide; and (3) provide guidelines for choosing the most appropriate risk management strategies.

Keywords. Landslide risk evaluation, hazard prediction, risk management, global change

1. Introduction

According to the Centre for Research on the Epidemiology of Disasters (CRED) 86% of all disaster-related deaths in the last decade were caused by natural hazards, with just 14% resulting from technological disasters such as transport or industrial accidents. Landslides do not seem to represent the major natural hazard causing fatalities, as indicated in Figures 1 and 2.

Nonetheless, landslides represent a major threat to man and the environment. In the period 1991-2005, a total of 12733 deaths from landslide are reported by CRED-EM. This represents approximately 2% of the total deaths caused by natural hazards in the period. These figures are, however, greatly underestimated because in the records, landslides are often not separated from other natural hazard triggers, such as extreme precipitation, earthquakes or floods.

In the CRED-EM database a disaster is defined as an event with more than 10 people reported killed or more than 100 people affected (displaced or evacuated). The reported numbers of occurrence of landslide disasters per country in the period 1974-2003 is shown on Figure 3. This figure

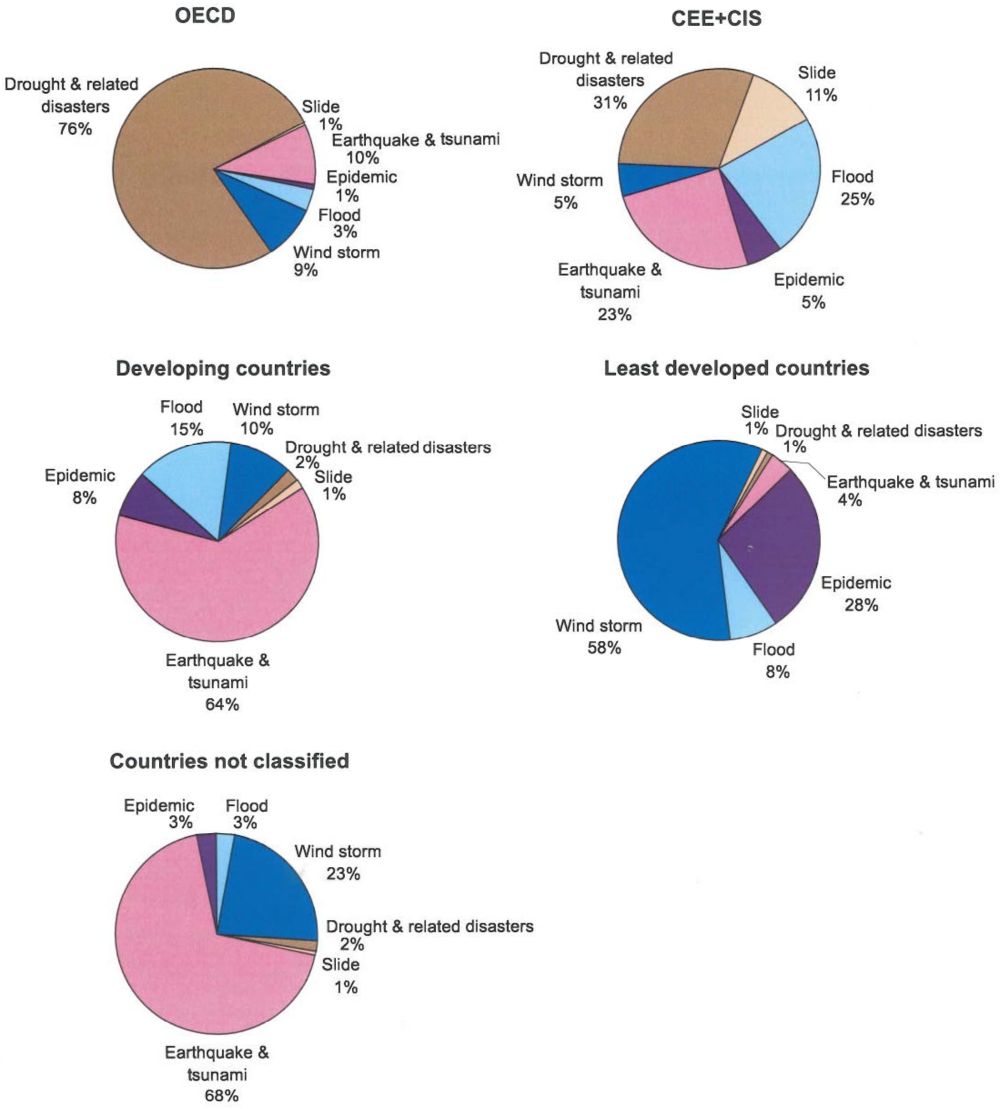

Fig. 2 Number of people killed sorted by type of disaster and level of development during 1991-2005 (from CRED-EM database).

suggests that the most exposed countries are located in eastern Asia, the Mediterranean region, and Central and South America. This global geographical distribution of fatal landslides is confirmed by the landslide fatality dataset of the University of Durham. Analysis of the global occurrence of fatal landslides recorded in this dataset by Petley (2008) showed that Asia and America respectively accounted for 76% and 14% of the fatalities caused by landslides in 2007.

As a consequence of environmental change and social developments such as an increase in exposure in many parts of the world, the consequent risk associated with landslides is changing, mostly increasing. In areas with high demographic density, protection works often cannot be built because of economic or environmental constraints, and it is not always possible to evacuate people because of societal reasons. In other regions, human activity totally changes the surface topography including the top soil cover. As a consequence, these areas might be more – or sometimes less – prone to landslides.

In any case, to develop an effective strategy for landslide risk management, one needs to forecast the occurrence of landslide and the risk associated with them. Climate change, increased susceptibility of surface soil to instability, anthropogenic activities, growing urbanization, uncontrolled land-use with increased vulnerability of population and infra-structure as a result, contribute to the change – and in most instances growth – of landslide risk. There is therefore a need for developing generic quantitative risk assessment and management tools and strategies for landslides at local, regional, continental and societal scales and establishing the baseline for the risk associated with landslides.

This paper provides a discussion on the effects of global change on landslide hazard and risk and outlines the challenges and strategies for adaptation to the ever-changing risk pattern.

2. Terminology

The terminology used in this paper is generally consistent with the recommendations of ISSMGE Glossary of Risk Assessment Terms (http://www.engmath.dal.ca/tc32/) and Glade et al. (2005). The important terms used in the context of this paper are:

Danger (Threat): Natural phenomenon that could lead to damage, described by geometry, mechanical and other characteristics. Description of a threat involves no forecasting.

Hazard: Probability that a particular danger (threat) occurs within a given period of time.

Risk: Measure of the probability and severity of an adverse effect to life, health, property, or the environment. Mathematically, risk is defined as Risk = Hazard × Potential

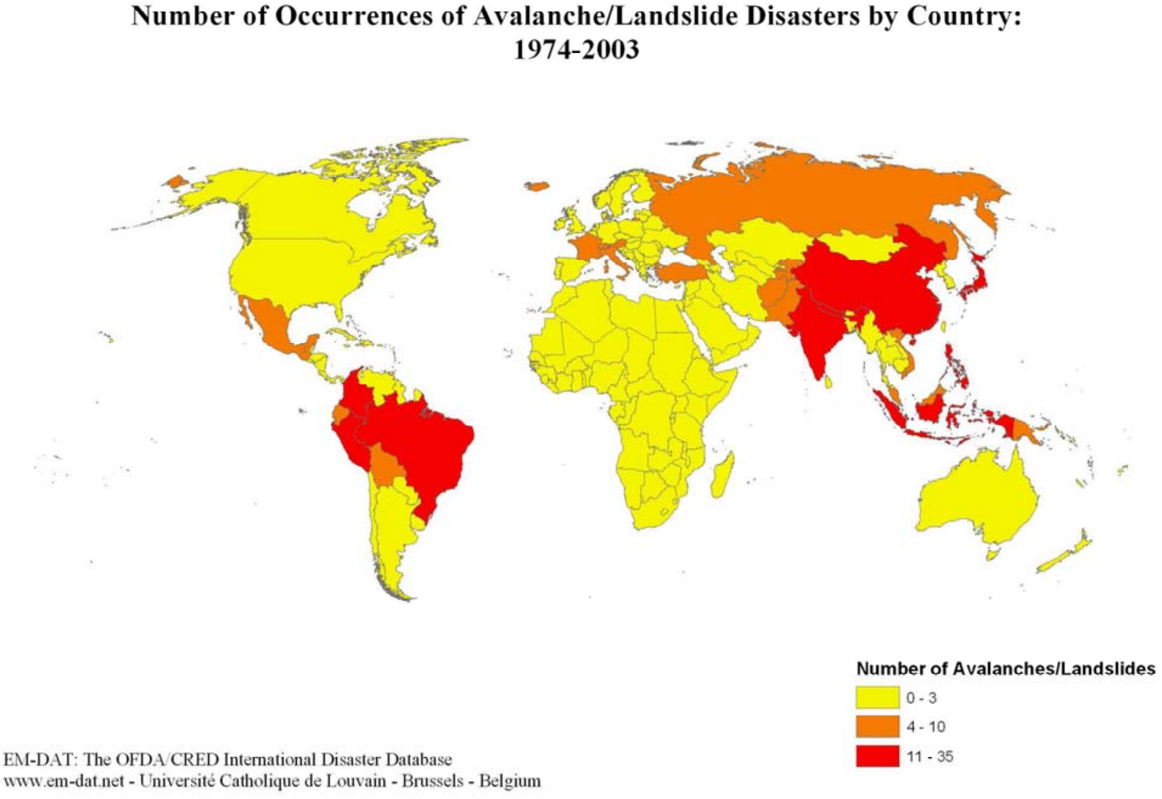

Fig. 3 Number of occurrence of landslides (from CRED-EM database).

worth of loss, also often written as Risk = Hazard × consequences, or Risk = Hazard × Elements at risk × Vulnerability.

Vulnerability: The degree of loss to a given element or set of elements within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).

The approach to vulnerability estimation is referred to as "technical" or "physical", as it addresses the effects of the physical interaction of a damaging agent and the environment. Vulnerability to natural hazards from the social science perspective has been defined by several authors. Blaikie et al. (1994), for instance, provided the following definition: "… the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural or man-made hazards". The main focus in this perspective is society. For this reason, such vulnerability is termed social vulnerability (e.g. Rashed and Weeks, 2003; Glade, 2003) or societal vulnerability (e.g. Lee and Jones 2004) in the natural hazards and risk literature. An important distinction between the social and technical perspectives on vulnerability is that technical physical vulnerability is scenario-specific, while social vulnerability is not (Fell 1994). Uzielli et al. (2008) provided a detailed discussion of the perspectives on vulnerability analysis.

Common to all these definitions is that the calculated risk does not reflect the coping capacity of a society, which is of outmost importance when dealing with the long-term consequences of landslides. In other words, a similarly calculated landslide risk may influence a prone society with missing coping strategies much more than societies that have adapted to this landslide risk.

"Global change" refers to the expected future changes in demography, infrastructure and environmental change, i.e. changes in the factors that affect the landslide hazard, elements at risk, and their vulnerabilities. Of course, climate change is one of the most important factors in causing the global change, but it has to be stressed that it is not the only one. Changes in vegetation or in geochemical patterns of the top soil influence the landslide occurrence strongly. Similarly, changing social patterns, e.g. driven by employment possibilities, might influence landslide occurrences. Large social groups might move out of a region, reducing the stress to the environment; or large groups might cluster in a new area over a short period of time, increasing the stress to the environment immensely (e.g. Favelas in Brazil).

3. Factors affecting the landslide risk

3.1 Landslide hazard

The assessment of landslide hazard requires an understanding of landslide triggering factors and run-out processes. Even though there has been a growing understanding of these processes in recent years, there is still need for more research. Existing models for qualitative and quantitative modelling of landslide hazard can be improved by use of statistical data, monitoring technologies and enhanced efforts on the study of the physical processes involved.

Triggers

The most important triggering factors for landslides are heavy precipitation, earthquakes and human activities. Water has a major role in triggering of landslides. Figure 4 shows the relative contribution of various landslide triggering events factor in Italy. These data suggest that, in Italy, heavy rainfall is the main trigger for mudflows, the deadliest and most destructive of all landslides.

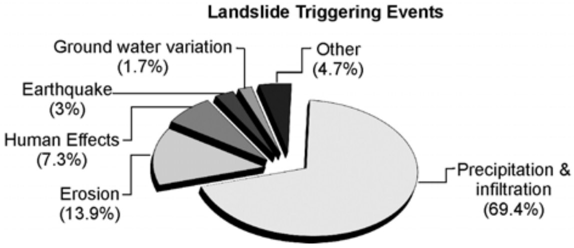

Fig. 4 Landslide triggers in Italy (Ref.: CNR-GNDCI AVI Database of areas affected by landslides and floods in Italy).

Criteria and thresholds for climatic conditions and weather-related phenomena that would trigger landslides are important aspects related to precipitation-induced landslides that are not yet fully developed. This includes extreme rainfall, snow melting and other climate-induced effects such as erosion and soil deterioration.

A strong earthquake is a very effective mechanism for triggering of landslides. The recent earthquakes in China in May 2008 and Pakistan in October 2005 have once again shown the devastating consequences of earthquake-induced landslides. The frequency and magnitude of earthquakes are obviously not functions of climatic effects or human activity. However, the consequences of earthquakes (and hence the associated risk) do vary in both spatial and temporal scales due to the dynamic components of exposure and vulnerability.

Anthropogenic factors also contribute considerably to the triggering of landslides. In many areas of the world these are the most important factors that lead to increased occurrence of landslide events. For example, in Norway, the main triggering mechanism of quick-clay slides has gradually shifted from meteorological factors to human activities during the past few decades.

Hazard maps

To determine where protective measures are necessary, landslide inventories and risk assessment maps over large areas are needed. The first landslide maps were prepared in the 1970s (i.e. Kienholz, 1978). Landslide hazard maps show the areas that are stable and the areas that may be affected by existing or future landslides, including areas that could be affected by the landslides run-out. The hazard maps should also provide information of the temporal probability of occurrence of landslides and their magnitudes (Varnes, 1984).

None of the early landslide hazard maps had the capability of predicting the temporal probability of occurrence. In recent years, this type of maps are referred to as "susceptibility maps", reflecting the fact that they provide no information about the frequency of occurrence of landslide events. The spatial probability (susceptibility) represents the failure potential of a terrain unit characterized by a set of parameters (slope angle, soil strength, etc.). The temporal landslide probability can be estimated by analyzing the temporal characteristics of triggering mechanisms and/or by doing a statistical analysis of previous landslide events.

In the literature, useful reviews of landslide hazard assessment and mapping may be found (i.e. Varnes, 1984; Soeters and Van Westen 1996; Cascini et al. 2005). Methods used for landslide hazard assessment include: (i) heuristic methods, where expert opinion is used to assess the hazard. These methods combine the mapping of the landslides and their geomorphologic setting as the main input factors for assessing the hazard; (ii) knowledge-based analysis or heuristic 'data mining', which is the science of computer modelling of a learning process; (iii) statistical or probabilistic approaches, based on the observed relationships between the each factor and the past distribution of landslides (multivariate analysis, logistic regression, Bayesian methods and neural networks); and (iv) deterministic methods applying classical slope stability principles such as infinite slope, limit equilibrium and finite element techniques and some with GIS-integration.

3.2 Vulnerability

As discussed earlier, there are two different perspectives for assessing vulnerability: those that have their roots in natural sciences and those that are based on the social science concepts. In the first perspective, the hazard event is the active agent while the human system is the passive agent in the vulnerability assessment. Thus, an element at risk has a different vulnerability to different hazardous event magnitudes. The natural science perspective of vulnerability dominates the engineering literature, where the emphasis is on the assessment of hazards and their impacts, while the role of human systems in mediating the consequences is often not considered. In natural science approaches, vulnerability is defined as the physical vulnerability of the elements at risk, and it is an important component of consequence evaluation.

Social science approaches of vulnerability refer to the human system. Attention is directed to the underlying structural factors that reduce the capacity of the human system to cope with a range of hazards, rather than the negative impacts following one specific hazard. There is no unique definition of vulnerability in social sciences. In the recent studies carried out by UNEP [United Nations Environment Program], ISDR [International Strategy for Disaster Reduction], UNDP [United Nations Development Programme], and the World Bank, vulnerability with respect to natural hazards is assessed on the basis of a series of socio-economic indicators (e.g., Gross Domestic Product [GDP] per inhabitant, Human Poverty Index [HPI], inflation rate, and population characteristics such as density, growth, age, life expectancy at birth, illiteracy rate. It is generally accepted that resilience and coping capacity are important factors in the societal vulnerability that are difficult to measure and quantify. The approach used when required (for lack of anything better) is to include them as a subset in the vulnerability assessment while acknowledging the fact that social vulnerability cannot easily be expressed in numbers.

Several well-documented studies have shown clearly that developing countries are more severely affected by natural disasters than developed countries, especially in terms of lives lost (UNDP 2004, ISDR 2004 and International Federation of Red Cross 2004). Table 1 shows the data compiled by IFRC (2001) for the decade 1991-2000. Of the total number of persons killed by natural disasters in this period, the highly developed countries accounted for only 5% of the casualties. The numbers given in Table 1 demonstrate the importance of considering societal vulnerability in landslide risk assessment. While the numbers of reported disasters in low and medium developed countries was three times higher than for highly developed countries, the corresponding number of fatalities was forty times higher. Due to the global change this discrepancy is believed to increase further unless major actions with regard to mitigation and social programs are put in action in a global scale.

Country	No. of disasters	No. of lives lost
Low and medium developed countries	1838	649 400
Highly developed countries	719	16 200

Table 1 Natural disasters in the period 1991- 2000 (after IFRC 2001)

The concepts of biophysical vulnerability and social vulnerability have also been used to distinguish between two quite different approaches to vulnerability. Biophysical approaches emphasize the physical outcomes. Biophysical vulnerability focuses on the sensitivity of the physical environment to shocks and stressors, and is often associated with traditional approaches to hazards. In other words, the most vulnerable are considered to be those living in the most precarious physical environments, or in environments that will undergo the most dramatic changes. Social vulnerability, in contrast, focuses on the social construction of vulnerability through issues of access and entitlements, political economy relationships, and social capital. Social vulnerability studies also focus on local livelihood strategies and the ways that people secure these in dynamic physical and socio-economic environments (O'Brien et al., 2006).

The vulnerability to landslides of the exposed elements has different components (Birkmann, 2006). It represents the systems or the community's physical (structural), economic, social and environmental susceptibility to damage. Some approaches exist for single elements (Leone et al. 1996; Faella and Nigro, 2003; Roberds 2005). For landslide risk zoning, it is necessary to develop specific vulnerability indicators for every element at risk, using the concept of probabilistic fragility functions and appropriate definition of relevant damage states (Pitilakis et al. 2006). Fragility functions and damage states for every element at risk, including sources of uncertainties related to the temporal probability and the probability of spatial impact therefore must be addressed. The fragility functions should consider most uncertainties (natural or aleatory, epistemic, site characterization, mathematical or model and others) quantified through probability distribution functions.

Similar to hazard, vulnerability is a dynamic factor with spatial and temporal variations. The perspectives with respect to vulnerability changes must therefore be reflected in the risk analyses.

3.3 Risk

In engineering and the physical sciences the term risk refers to a functional relationship between probabilities and consequences. In mathematical terms risk is often defined as the product of hazard, value of the element at risk (exposure) and their vulnerability. In this context risk is expressed quantitatively and the methods for doing so are referred to as QRA (Quantitative Risk Assessment). Landslide risk zonation and mapping could be done by implementing QRA using tools such as Geographical Information Systems (GIS).

In many countries, there is an extensive use of landslide susceptibility and hazard zoning, and to a lesser extent landslide risk zoning. Many of the zoning schemes are qualitative in nature. For appropriate landslide risk management, however, one needs to quantify the hazard by assigning an annual probability (frequency) to the potential landslide, and to quantify risk.

Despite significant improvements produced in automatic data capture, data analysis and treatment and computational advances, the landslide QRA is far from a routine activity. Key components such as magnitude (intensity)-frequency relationships and vulnerability of the exposed elements require significant research.

The most direct way of computing landslide risk is by quantifying each of the components of the hazard equation (Hungr et al., 2005). In terms of conditional probability, the landslide risk for properties may be determined as follows, accounting for all potentially affected elements at risk and all landslide types (Fell et al., 2005):

$$R(P)=\sum_{i=1}^{k}\left[P(L_i)\times P(T:L)\times P(S:T)\times V(D_i)\right]\times C$$

where

R(P): expected annual loss due to landsliding (i.e. €/yr)

$P(L_i)$: annual probability of occurrence of a landslide with a magnitude "i"

P(T:L): probability of a landslide with a magnitude "i" reaching the element at risk

P(S:T): temporal-spatial probability of exposure of the element at risk

$V(D_i)$: vulnerability of the exposed element in front of a landslide of magnitude "i"

C: value of the element

i=1,..k: landslide magnitudes

Practical application to zoning at a specific location or region is a challenge. Upscaling the above expression to a map requires the analysis of the spatial and temporal probabilities where specific groups of elements at risk in the map may be hit by mass movements of different magnitudes (Van Westen et al., 2005). These are then used to estimate the degree of loss.

The outcome of the QRA can serve as reference risk maps, using integrated GIS-based models. The analysis uncertainties, vulnerability, landslide susceptibility and frequency, may be ascertained in such studies. Such QRA systems have dual dimensions as they do not only treat technological development on landslide hazard (frequency) and harmonising quantification procedures, but also include the sociological aspects such as societal vulnerability, and the elements at risk. The landslide hazard and risk "hotspots" (where hazard and/or risk are highest) may be another outcome of the QRA analyses. These analyses should

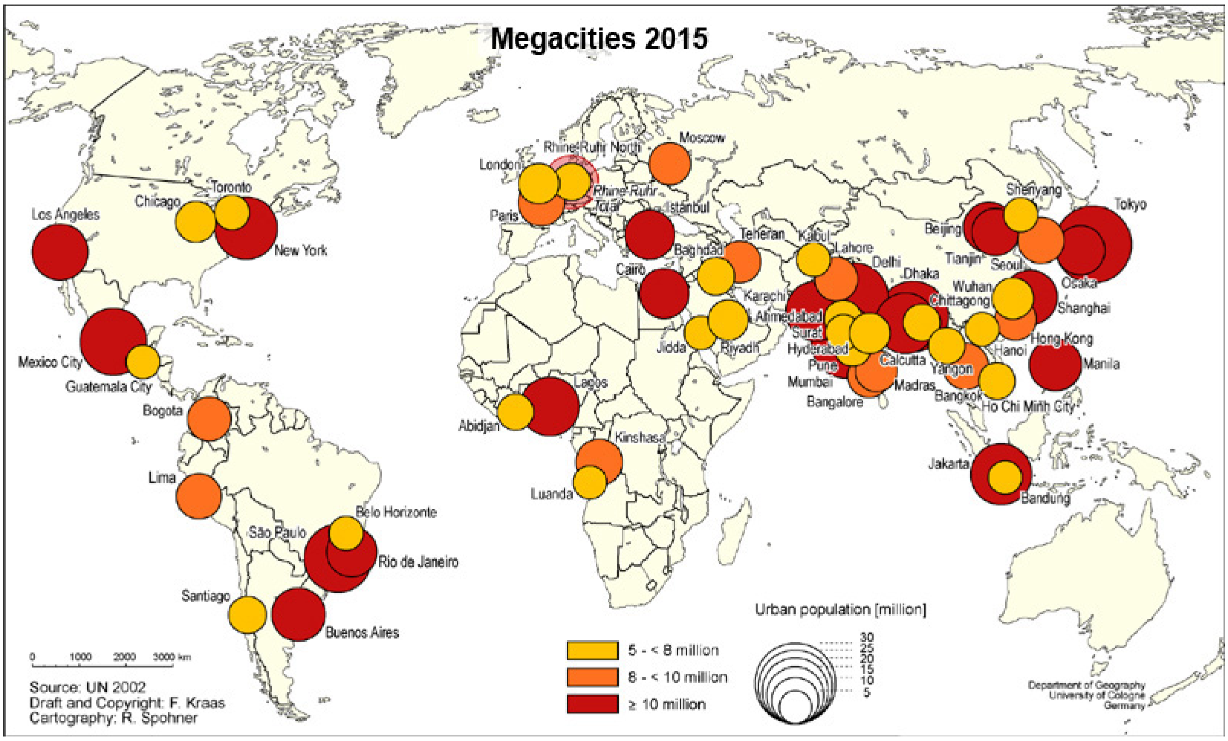

Fig. 5 Megacities worldwide in 2015 (Ref: Univ. of Cologne, Dept. of Geography).

preferably quantify the importance and effects of uncertainties on the results obtained.

The scaling of the landslide risk assessment is a key parameter. Assessing the risk at the local scale (individual slopes) is different from assessing the risk at a regional or a continental scale. To identify the landslide hazard and risk "hotspots" in a global scale, a simplified first-pass analysis method similar to the approach adopted by Nadim et al. (2006) in the Global Hotspots study for the ProVention Consortium can be used. In this study the scale of the analysis was a grid of roughly 1km × 1km pixels where landslide hazard was estimated by an appropriate combination of the triggering factors (mainly extreme precipitation, human activity and seismicity) and susceptibility factors (slope, lithology, soil moisture, vegetation cover, etc.). The intersection of the landslide hazard "hotspots" with population density and infrastructure density maps, and appropriate set of socio-economic indicators (GDP, Human Development Index, etc.) provides a first-pass estimate of landslide risk "hotspots". In their "Global Hotspots for Landslides" study Nadim et al. (2006) demonstrated through a statistical analysis of fatalities caused by landslides that the following parameters show a strong correlation with vulnerability to landslides: Human Development Index (HDI), deforestation and the percentage of "arable land". The last parameter indicates that rural population is more vulnerable to landslides than urban population. The global hotspot study for landslides will be updated in spring 2009.

4. Global change factors

4.1 Changes in demography

The pace of urbanization is increasing rapidly everywhere in the world. In 1950, 30% of the world’s population lived in cities. By the end of 2007, the urban population of the world

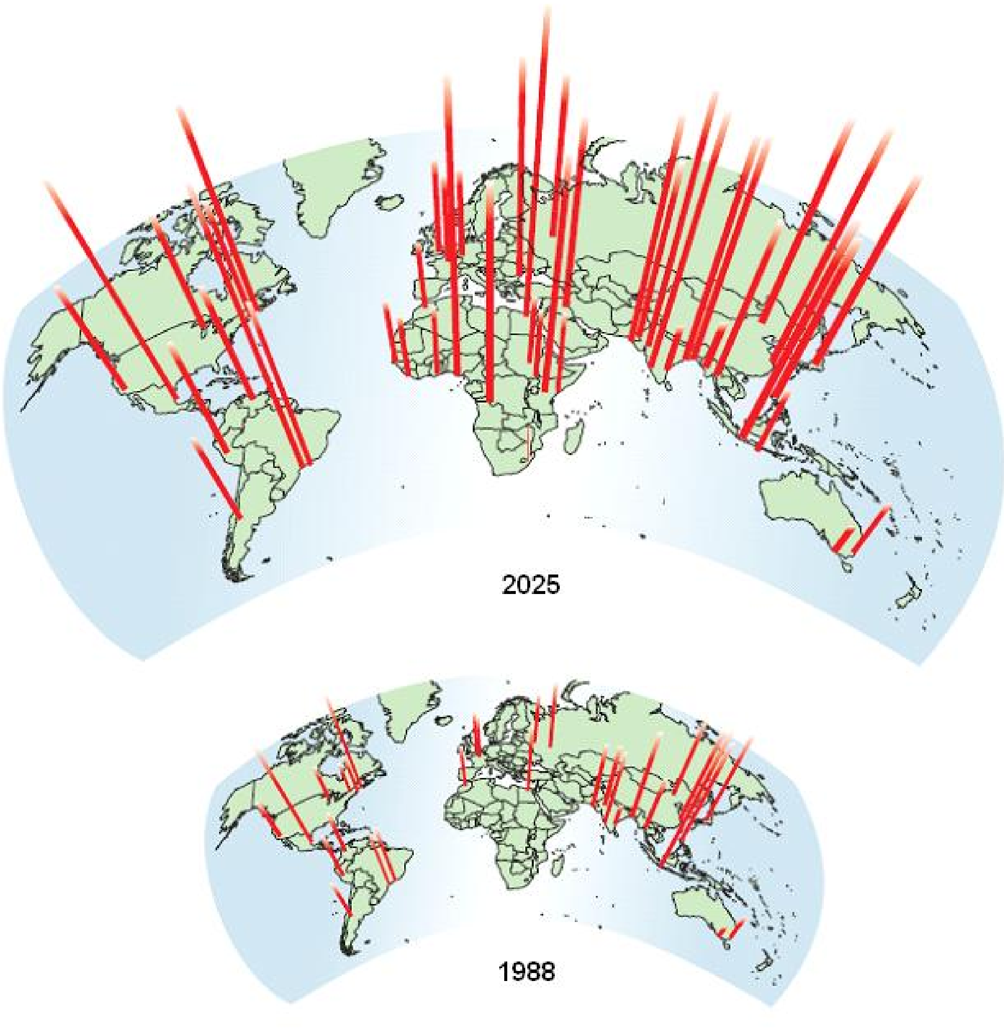

Fig. 6 Megacities and population growth, 1988- 2025.

had increased to more than 50%. The average population of the world's 100 largest cities has swelled from 700,000 in 1900 to 5 million in 1990. Such rapidly increasing urbanization, particularly in developing countries, creates both opportunities and challenges.

The total urban population of the world may reach 60% by 2030, and a good portion of the population will be living in megacities. In this paper, megacities refer to very large urban areas with several million inhabitants. A universally accepted definition of megacity does not exist. Different scientists and organizations use population thresholds of 5, 8 or 10 millions for designating an urban area a megacity.

It is estimated that by 2015 the world may contain as many as 60 megacities, together housing more than 600 million people. These megacities are where much of the worldwide process of urbanization is and will be taking place. The spatial distribution and growth of megacities are illustrated in Figures 5 and 6. Megacities are more than just large cities. Their scale creates new dynamics, new complexity and new simultaneity of events and processes – physical, social and economical. They host intense and complex interactions among demographic, social, political, economical and ecological processes. Today, cities are larger than ever before and growing in size at an unprecedented rate. As cities have grown, they have often expanded onto hazardous land. For various reasons, people are choosing or are forced to live in harm's way as the cities have grown without proper control.

4.2 Climate change scenarios

The number, frequency and intensity landslides are likely to change (mainly increase) in landslide-prone areas because of climate change. Although there is no general consensus on the relationship between the temperature variation and landslide activity, the role of heavy precipitation in triggering landslide activity is universally accepted. However, the effect of temperature variation resulting in a change of water content or even the ground fabric, for instance creation of fissures and cracks, in combination with precipitation may also have a dramatic effect on landslide susceptibility.

During the Little Ice Age, with increased rainfall combined with lowered temperatures, an increase in landslide activity was observed all over Europe. It is therefore important to assess the combined effect of precipitation and temperature variation. One ‘empirical’ observation for the French Alps is that wetter winters and drier summers are becoming more common, i.e. more-or-less the type climate typically experienced in Italy or the Spanish Pyrénées. The empirical observations do not allow quantitative statements about location or magnitude and frequency of future landslide events because of the diversity of landslide types, environmental predisposing factors (susceptibility) , and climate parameters in mountain areas (orography, vertical gradients, etc.).

The IPCC Fourth Assessment report draws the following conclusions about the future changes in precipitation patterns around the world (IPCC, 2007):

- Significantly increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia.
- The frequency of heavy precipitation events has increased over most land areas - consistent with warming and increases of atmospheric water vapour.
- Very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent.
- Likely those future tropical cyclones will become more intense, with larger peak wind speeds and heavier precipitation.

The causal relationship between climate and landslides is not simple, and is regarded by many researchers as problematic, especially in terms of spatial and temporal scales. Climate also influences the magnitude and frequency of landslides via the non-linear soil water system. One of main challenges in predicting the effects of climate change on landslide risk is downscaling of the climate change scenarios to spatial scales and formats that are relevant for landslide assessment by geoscientists.

Figure 7 shows the United Nations prognosis of the urban population of Europe and selected countries in Europe with high landslide risk (UN, 2008).

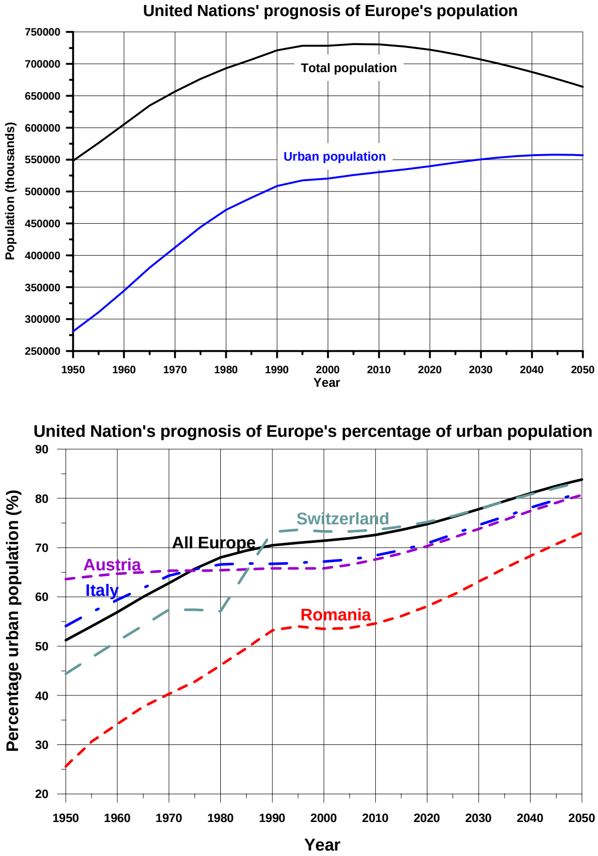

Fig. 7 United Nation’s prognosis of the urban population in Europe until the Year 2050.

4.3 Other factors affecting landslide risk

Besides the factors discussed above, other climate- and human-related factors are also important for the assessment of landslide risk, for instance:

- Changing land-use (meadows, pastures, abandoned lands, forests) which may have a strong influence on soil moisture availability. During the last century, forest expansion has changed remarkably the Alpine landscape. This has been related to the population migration from mountains to valleys and abandonment of traditional agricultural practices.
- Changes in vegetation species or vegetation cover (human-induced or climate-induced), which effects may be subdivided into the loss of precipitation by interception and the removal of soil moisture by transpiration.
- Changes in the vegetation root characteristics which may either enhance or reduce slope stability through time by modifying the soil characteristics (loading, strength parameters, hydrological parameters).
- Human activity like deforestation or timber harvesting, which may modify the hydrological regime of the slopes and/or increase sediment yield.
- Expansion of new developments and facilities (roads, train lines, buildings) which may change slope geometry or hydrology.
- Improvement of living standards, increased concentration of people, land use, infrastructure and goods in environmentally privileged but hazardous regions increases the level of risk, may escalate in the future, and need to be quantified.
- Advances in landslide science, in particular monitoring and remote sensing technologies, early warning systems, and basic understanding of landslide mechanisms, as well as more appropriate risk management strategies, are likely to reduce the risk to the exposed population and infrastructure.

4.4 Changes in landslide risk

The effect of global changes on the landslide risk is schematically illustrated in Figure 8.

In order to estimate the global evolution of landslide hazard and risk by the end of the century, the most realistic scenarios for climate change and human activity in the next 50 to 100 years must be established and the impact of global environmental change (climate, forest vegetation, land use etc.) and human activities on exposed slopes must be quantified.

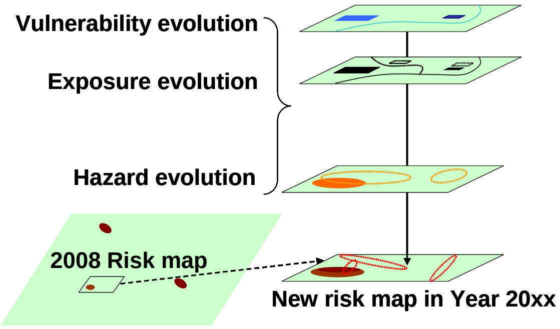

Fig. 8 Schematic strategy of landslide risk mapping incorporating global change.

Several experiments using downscaled climate change time series in hydrological and slope stability models have been proposed to quantify the impacts of climate change on landslide activity in the Italian and French Alps, in Southeast Spain, in Norway and in South England. Recent projects (European, national) related to climate change impact on landslide hazard and risk include:

- Project ClimChAlp, (Interreg IIIB "Alpine Space"): http://www.climchalp.org/
- GeoExtreme Project (Norway, conducted by ICG, Bjerknes Centre for Climate Research, Meteorological Institute, CICERO): http://www.geoextreme.no
- Project SIGMA: Surveillance des régimes cInématiques des Glissements de terrain lents et récurrents en relation avec les changements cliMAtiques (BRGM, France)
- Project TRAMM: Triggering Rapid Mass Movements, funded by the Competence Centre for Environmental Sustainability, Switzerland : http://www.cces.ethz.ch
- Project GACH2C (France, ACI FNS Aléas et Changement Global) (Ubaye et Trièves)
- ESPRC (British Council, UK) CLIFS: "Climate impact forecasting for slopes"
- Project Versinclim (Switzerland)
- European program 'TESLEC - The Temporal Stability and activity of Landslides in Europe with respect to Climatic change'. (Université d'Heidelberg)

The interdisciplinary research project GeoExtreme, referred to above, focuses on investigating the coupling between meteorological factors and landslides and avalanches, extrapolating this into the near future with a changing climate and estimating the socio-economic implications. The project is still ongoing, but detailed studies of slope stabilities in one of the selected study areas show a high sensitivity of slope stability in a changed precipitation regime (Jaedicke et al., 2008).

In addition to the projects listed above, local and regional studies have been done by several researchers, and major European projects are being planned for the coming years. Mainly because of the uncertainties in the down-scaled climate scenarios, the results of the studies done to date are ambiguous. Cepeda et al. (2008) did a time trend analysis of extreme precipitation events in Central America for the period 1961-2003. They found statistically non-significant time trends in the occurrence of landslide-triggering extreme events. Schmidt and Glade (2003) studied the potential landslide effects of climate change in two regions on the North Island of New Zealand. They concluded that both regions show a significant trend towards a decrease in landslide activity during the latter part of the 21st century.

5. Landslide risk management: What could be done?

5.1 Risk management

A proactive approach to risk management is instrumental in reducing significantly loss of lives and material damage associated natural hazards. The major natural disasters that have taken place over the last 5-10 years and received wide media attention, have clearly changed people’s mind in terms of acknowledging risk management as an alternative to emergency management.

One can observe a positive trend internationally where preventive measures are increasingly recognized, both on the government level and among international donors. There is, however, a great need for intensified efforts, because the risk associated with natural disasters clearly increases far more rapidly than the efforts made to reduce this risk.

It is the major task of risk assessment to identify and explore, preferably in quantitative terms, the types, intensities and likelihood of the (normally undesired) consequences related to an activity or event. In addition, these consequences are associated with special concerns that individuals, social groups, or different cultures may attribute to these risks. They also need to be assessed in terms of making a prudent judgement about the tolerability or acceptability of risks. Once that judgement is made, it is the task of risk management to prevent, reduce or alter these consequences by choosing appropriate actions (Renn, 2008).

The main objectives of landslide risk management are: (1) to propose mitigation and prevention measures, and produce harmonised toolbox of technically and economically appropriate (and innovative) prevention and mitigation measures based on experience and expert judgment; and (2) to develop a risk-communication and stakeholder-led participatory process for choosing prevention and mitigation measures that are most appropriate from the technical, economic, environmental and social perspectives.

While the economic damage from natural hazards is highest in the developed countries, the number of deaths caused by natural hazards is by far largest in the developing countries (see Table 1). Naturally, the means and resources for use in risk management are quite different for these two opposites in welfare dimensions. Successful risk management stories have been told from Hong Kong (Chan, 2008) and Norway (Karlsrud, 2008). However, these stories are typical for developed countries requiring large resources. The landslide risk programme in Hong Kong has an annual budget of over US$ 100 million. For developing countries, risk management implies somewhat different methods. Kjekstad (2007) suggested an approach based on three pillars for landslide risk management for developing countries. The three pillars are:

Pillar 1: Hazard and Risk Assessment

Hazard and risk assessment are the central pillar in the management of geohazards risk. Without knowledge and characteristics of hazard and risk, it would not be meaningful to plan and implement mitigation measures. The value of proper geohazards risk assessment is convincingly highlighted in a recent report authorized by the European Commission on socio-economic impacts of natural disasters in Europe. The work was a part of the thematic network GeoTechNet (Koehorst et al. 2006).

Pillar 2: Landslide mitigation measures

Mitigation means implementing activities that prevent or reduce the adverse effects of extreme natural events. In a broad prospective, mitigation includes structural and geotechnical measures, effective early warning systems, and political, legal and administrative measures. Mitigation also includes efforts to influence the lifestyle and behaviour of the exposed population in order to reduce the risk. The Indian Ocean tsunami of 2004, which killed at least 230,000 people, would have been a tragedy whatever the level of preparedness. However, even when disaster strikes on an unprecedented scale, there are many factors within human control, such as a knowledgeable population, an effective early warning system and constructions built with disasters in mind, which can help minimize the number of casualties.

Pillar 3: International cooperation and support

Most of the developing countries lack the resources, capacity and technical skills to proceed with geohazards risk reduction measures at a pace that is desired and needed. International cooperation and support are therefore highly desirable. Over the last decade, a number of countries have been supportive with technical resources and financial means to assist developing countries where the risk associated with natural hazards is high. The development agencies of the United States (USAID), Canada (CIDA), Japan (JICA), Germany (GTZ/BGR), Switzerland (CONSUDE and SDC), Sweden (SIDA), Norway (NORAD/Ministry of Foreign Affairs), UK (DIFID), the Netherlands (SNV), Austria (ADA), and Australia (AusAid), as well as many NGOs, support projects related to the mitigation of risk due to natural hazards in developing countries.

A key challenge with all projects from the donor countries is to ensure that they are need-based, sustainable and well anchored in the countries' own development plans. Another challenge is coordination, which often has proven to be difficult because the agencies generally have different policies and the implementation periods often do not overlap. A subject which is gaining more and more attention is the need to secure 100% ownership of the project in the country receiving assistance.

A milestone in international collaboration for natural disaster risk reduction was the approval of the "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters" (ISDR 2005). This document, which was approved by 165 UN countries during the World Conference on Disaster Reduction in Kobe, January 2005, clarifies international working modes, responsibilities and priority actions for the coming 10 years. The Hyogo Framework of Actions states three fundamental principles:

- Each nation has the primary responsibility for preventive measures to reduce disaster risk, and is expected to take concrete actions as outlined in the Action Plan.
- Governments in risk exposed countries shall regularly report progress achieved to the UN coordinating unit which is the ISDR Secretariat (International Strategy for Disaster Reduction) with headquarters in Geneva.
- International cooperation is called upon to assist countries that need help.

The Hyogo Framework of Action has clearly increased the awareness and importance of preventive measures. It will also contribute to a much better practice for the implementation of risk reduction projects for two reasons: a) governments will be in the driver's seat, which means that coordination is likely to be improved, and b) ISDR is given the responsibility for the follow-up of the plan will put pressure for action from countries that are most exposed.

Risk management integrates the recognition and assessment of risk with the development of appropriate strategies for its mitigation. Landslide risk management typically (but not solely) involves decisions at the local level, and a lack of information about landslide risk and how this risk is changing on account of climate, land-use and other factors, appears to be a major constraint to providing improved mitigation in many areas. Beyond risk communication and awareness, pro-active mitigation and prevention options can broadly be categorised as (1) structural slope-stabilization measures to reduce the frequency and severity of the hazard, (2) non-structural measures, such as land-use planning and early warning systems, to reduce the hazard consequences, and measures to pool and transfer the risks.

In the coming years the research efforts in the field of landslide risk management should focus on developing a harmonised toolbox of "tried-and-tested” as well as innovative pro-active mitigation measures based on experience and expert judgement. Such a toolbox will facilitate the selection of appropriate risk reducing strategies in view of the expected global changes (both climate change and societal change).

Figure 9 illustrates in a "bow-tie” diagram the two components of hazard and risk mitigation. Mitigation and reduction of hazard and risk can be done by reducing (1) the frequency (probability) of an adverse event/threat occurring and/or (2) the vulnerability and/or exposure of the elements at risk. To mitigate or eliminate the risk, one could focus on measures that stop or reduce the effects of triggering factors (left hand side of the bow tie) and/or on measures that minimise the consequences (right hand side). The branches that are marked with stop sign refer to actions or situations where the risk has been completely eliminated (stopped).

The selection of appropriate mitigation strategies should be based on a future-oriented quantitative probabilistic risk assessment, coupled with useful knowledge on the technical feasibility, as well as costs and benefits of risk-reduction measures. International policy processes rarely consider probabilistic information (i.e. uncertainties) on the risks, costs and benefits.

Experts acting alone cannot choose the "appropriate” set of mitigation and prevention measures in many risk contexts. The complexities and technical details of managing landslide risk can easily conceal that any strategy is embedded in a social/political system and entails value judgments about who bears the risks and benefits, and who decides. Policy makers and affected parties engaged in solving environmental risk problems are thus increasingly recognizing that traditional expert-based decision-making processes are insufficient, especially in controversial risk contexts (Renn et al. 1999). Often heavily shaped by scientific analysis and judgment (e.g., acceptable risk), traditional policy approaches are vulnerable to two major critiques. First, because they de-emphasise the consideration of affected interests in favour of "objective” analyses, they suffer from a lack of popular acceptance. Second, because they rely almost exclusively on systematic observation, they often slight the local and anecdotal knowledge of the people most familiar with the problem, and they risk producing outcomes that are incompetent, irrelevant or simply unworkable. Conflicting values and interests, as well as often conflicting and uncertain expert evidence, characterise many landslide risk decision processes. These characteristics become more complex with long time horizons and uncertain information on climate and other global changes.

Risk communication and stakeholder involvement has been widely acknowledged for supporting decisions on uncertain and controversial environmental risks, with the added bonus that participation enables the addition of local and anecdotal knowledge of the people most familiar with the problem (Covello, 1998). Precisely which citizens, authorities, NGOs, industry groups, etc., should be involved in which way, however, has been the subject of a tremendous amount of experimentation and theorising. The decision is ultimately made by political representatives, but stakeholder involvement, combined with good risk-communication strategies, can often bring new options to light and delineate the terrain for agreement.

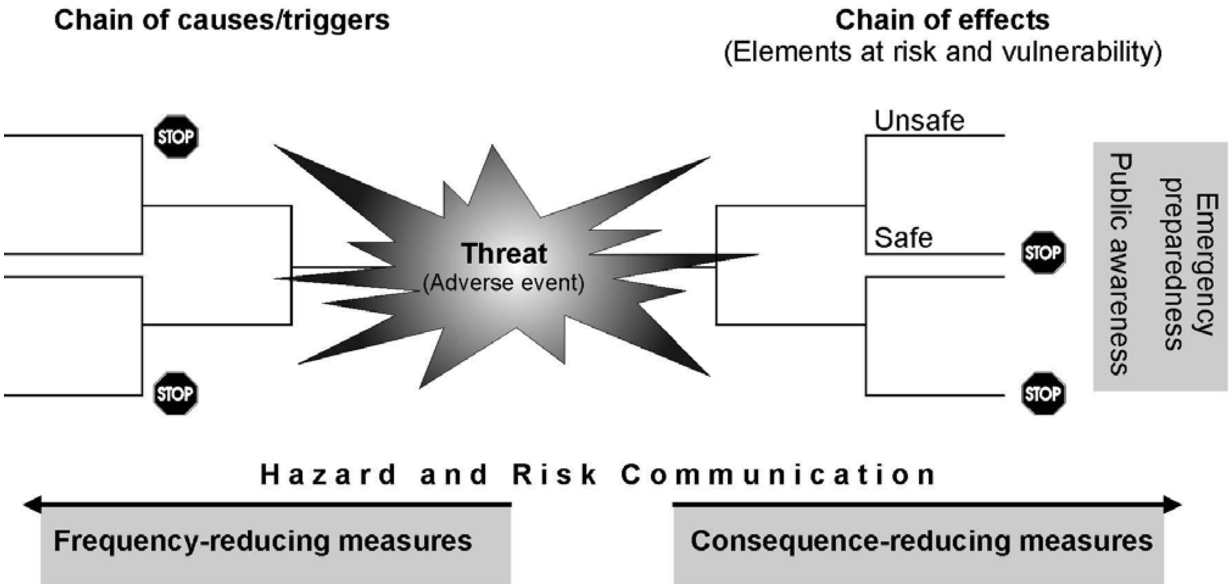

Fig. 9 Bow-tie diagram for risk assessment and mitigation.

There is therefore a need for developing and implementing an integrated and comprehensive approach to help guide decision-making. The methodologies developed should be tested in selected hazard and risk "hotspots”, in turn improving knowledge, methodologies and integration strategies for the management of landslide risk. The harmonised methodologies and technical developments, combined with the social, economic and environmental dimensions will play a significant role in the detection, prediction and forecasting of landslides and landslide risk posed to individuals, society and the environment.

A landslide is usually a localised event that affects tens to hundreds square metres of land. There is a need to link hazards and risks at the local scale, i.e. individual slopes and slides to the hazards and risks at the global scale. The smallest scale of interest refers to the local slope scale (less than 3 km^2) where most of research on the triggering factors is being done. The regional studies, typical for "hotspots" evaluations, form the intermediary scale: from 10 to 200 km^2, depending of the site. The largest scale is the "country" and global scales.

To develop the required methodologies, one must improve and adapt existing knowledge on landslide hazard and risk to link the slope-scale results to methodologies required for the assessment of landslide hazard and risk at regional and global scales. The knowledge on landslide hazard and risk is still under development. Even if basic mechanisms are well known, quantitative relationships between triggers and hazard are still not well enough established. For instance, as discussed earlier, the relationship between slope stability and rainfall, not only in magnitude but also in frequency of different ground instabilities, is not well established. Climate change, through the modulation in amplitude, frequency as well as duration of precipitation events, will dramatically influence ground stability.

There is a need for integrating the technology and social aspects to ensure that the risk assessment and management strategies are realistic and representative of the forces at play in an actual situation. Global changes, due to both climate and human activity, will provide insight in future risk patterns. The landslide risk assessment and management strategies should be implemented to forecast future risk.

5.2 Role of geoscientists

The main role of geoscientists in the context of the problems discussed in this paper is to (1) provide policy-makers, public administrators, researchers, scientists, educators and other stakeholders with improved frameworks and methodologies for the assessment and quantification of landslide risk; (2) evaluate the changes in risk pattern caused by climate change, human activity and policy changes; and (3) provide guidelines for choosing the most appropriate risk management strategies, including risk mitigation and prevention measures.

5.3 Improvements in landslide science

The ability to predict landslide occurrence is a fundamental prerequisite for effective risk mitigation. In fine-grained soils, the evaluation of a slope failure is relatively long (months, years), and the analysis of precursors (rainfalls and hydrological cycles) and geo-indicators (observed movements) is essential for successful prediction. In other cases (landslides in rock and in granular soils), the challenge is the very short time between initiation of failure and slope collapse (Picarelli 2000; Imre & Springman 2006).

Significant progress has been made on the understanding of triggers and processes of slope failure. In particular, a number of numerical codes have been developed to predict: a) the long-term preparatory factors of slope deformation and failure; b) the short-term conditions that can lead to a catastrophic failure; and c) the spatial and temporal distribution of landslides triggered by precipitation, and the landslide features affecting the risk. The stability of active layers in mountain permafrost within a global warming scenario has also been investigated numerically (Arenson et al. 2006).

Monitoring of instrumented sites and experiments on small to full-scale physical models have provided important data for the improvement of both understanding and the codes available. On the other hand, statistical methods have been developed to define thresholds to be used within early-warning systems (Picarelli et al. 2007). Numerical codes for the assessment of the size, run-out and velocity of landslides (Hungr 1995; Pastor et al. 2003) enable a rational evaluation of the hazard and the risk at the local individual slope scale, provided that the vulnerability of the elements at risk is known.

Scientists are today increasingly relying on global satellite data to produce landslide inventories and risk assessment maps over wide areas; remote sensing data from optical and radar sensors (Synthetic Aperture Radar, SAR) are applicable to landslide mapping due to multispectral and textural information, high repetition cycles and global coverage. The integration of SAR and optical images, along with SAR interferometric techniques, are currently used for characterising landslides. New techniques such as DInSAR and high resolution image processing are increasingly exploited for risk assessment studies. DInSAR is a powerful technique to measure from satellite centimetric displacements and has been successfully applied to detect subsidence and landslides, earthquakes or volcanic activity. Ground-based radar devices such as LISA (Linear SAR) are capable of assessing the deformation field of an unstable slope in the areas characterised by a high radar reflectivity.

Near surface geophysical methodologies (seismic, gravimetric, magnetic, electric and electromagnetic) are often applied to monitor hydrogeological phenomena. New electric and electromagnetic survey techniques have been applied to areas with complex geology (seismic, geothermal, volcanic and landslide areas, etc.).

5.4 Monitoring and early warning systems

In many landslide risk areas, it may be too costly to stabilise the potentially unstable slope(s). Mitigation work may be too intrusive in sites of cultural heritage, of outstanding beauty, or for other reasons. Early warning systems allow the adoption of strategies for the mitigation of landslide risk not involving the construction of expensive and environmentally damaging protective measures. On an operational basis, thematic layers (hazard/susceptibility maps, movements identification and monitoring) need to be coupled with "real time” continuous measurement and with observations on possible "triggering” events. The output thus can call for action at different levels, involving local, regional, national and even international authorities.

Methods for monitoring and early warning are typically based on: (1) short-term weather forecasts for shallow landslide predictions, (2) remote sensing detection and monitoring of slow-moving landslides, and (3) advanced air-borne and in situ techniques for site monitoring and early warning. These methods are verified with case studies and constantly updated as more information and data become available.

In particular, predictions of debris flows using an integrated model able to produce a warning regional map for landslides caused by meteorological events can be based on short-term weather forecasts. The output may in this case consist of threshold hazard maps. This warning map represents an innovative approach to present debris flow warning systems by integrating multidisciplinary knowledge such as meteorology, hydrology, geologic modelling, remote sensing and GIS.

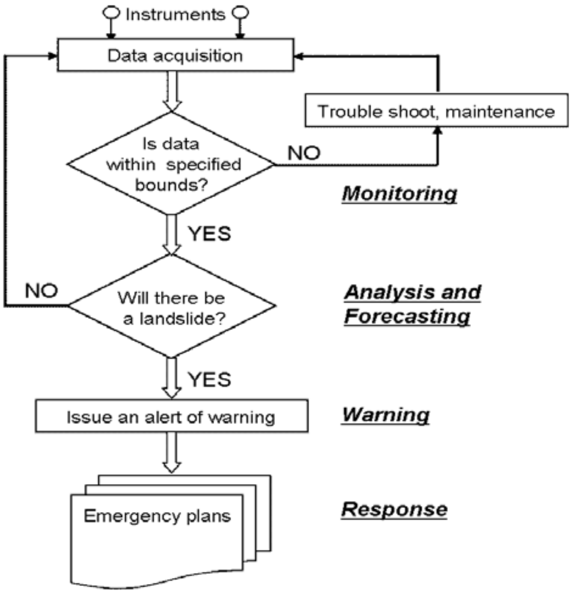

Fig. 10 Block-diagram of early warning system (DiBiaggio and Kjekstad, 2007).

One should aim for a common methodology for detection, rapid mapping, characterisation and monitoring of landslides at regional/catchment scale using advanced remote sensing techniques, as well as a common methodology for the rapid creation and updating of landslide inventories and hazard maps at regional/catchment scale. Three classes of techniques may be exploited and integrated: spaceborne radars, airborne and VHR spaceborne optical sensors, and airborne geophysics. The main expected outcome is the integration of these advanced remote sensing techniques within a QRA framework for a global integrated risk management process. The end-result may be user-oriented guidelines for incorporation of advanced remote sensing technologies within integrated risk management processes and best practices. The toolbox of remote sensing applications and early warning should be proposed as part of an integrated risk management process including procedures for data acquisition and updating, recommended processing methods, road maps for data integration in QRA and risk mitigation measures. A block diagram of a typical early warning system is shown in Fig. 10 (DiBiagio & Kjekstad 2007).

5.5 Landslide risk mitigation strategies

Mitigation means implementing activities that prevent or reduce the adverse effects of extreme natural events. In a broad prospective, mitigation includes structural and geotechnical measures, effective early warning systems, and political, legal and administrative measures. Mitigation also includes efforts to influence the lifestyle and behaviour of exposed population in order to reduce the risk. The mitigation and prevention of the risk posed by natural hazards have not attracted widespread and effective public during recent decades. If landslide risk reduction is to be successful in the future, geoscientists and engineers will find it necessary to develop new alternatives and innovative solutions that are appropriate for dealing with the changing circumstances which have been discussed in this paper.

This will involve refocusing attention on the little-explored interface between technical and natural sciences on one hand, and social and political sciences on the other. Such a stance will bring the different professions face to face with the problem of fostering risk reduction measures that have broad appeal to stakeholders as well as potential victims, researchers and risk management professionals.

A mitigation strategy would involve: (1) identification of possible disaster triggering scenarios, and the associated hazard level; (2) analysis of possible consequences for the different scenarios; (3) assessment of possible measures to reduce and/or eliminate the potential consequences of the danger; (4) recommendation of specific remedial measure and if relevant reconstruction and rehabilitation plans; and (5) transfer of knowledge and communication with authorities and society.

Any mitigation strategy needs to be adapted for different natural hazards and different parts of the world. Especially for developing countries, it is vital to establish and promote proper land-use planning and construction practices to regulate human activities that increase risk to landslides and to prevent settlement of communities in high-risk areas. Ensuring that people do not live in "high risk" zones should therefore be included in the decision process.

Conclusions

In the coming years further research is required for scientists, authorities and stakeholders to be able to quantify triggers, their mechanisms, conditions and thresholds, to model and quantify the landslide run-out, and to forecast landslide hazard and detect risk zones. Uncertainties should be quantified and taken into account in any realistic hazard and risk calculation. A framework for the quantitative assessment of the risk associated with landslides should be developed and procedures should be tested to ensure that the implementation of risk management is effective, with a toolbox for the selection of the most appropriate set of mitigation and prevention measures and proven process of risk communication.

If a proactive approach to management of landslide risk is adopted by the stakeholders and decision makers, then the following future trends in landslide hazard and risk should be expected:

- Frequency of landslide events in natural slopes (landslide hazard) will most likely increase because of the expected increase in extreme precipitation events.
- The economic consequences of landslides will probably increase because of the increase in hazard and increased value of the infrastructures at risk.
- The number of fatalities caused by landslides will most likely decrease because of increased urbanisation, reduced exposure of population at risk, advances in landslide monitoring and early warning systems, and implementation of appropriate risk management strategies.

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Papers for Parallel Sessions

Model of Slope Master Plan

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Abstract. Since 1993, Malaysia has experienced many landslides that have caused considerable numbers of death, destruction to properties and immense direct and indirect economic losses. The 1993 Highland Towers landslide incident near Kuala Lumpur is considered to be the landmark landslide that creates public awareness about the peril of landslides. In this incident, a tower block toppled over due to undermining of its foundation triggered by a landslide. No concrete actions were taken by the government or the private sector to address the landslide issues following the incident. In 2003, as a result of a massive rock slope failure that cut-off a toll highway that leads to Kuala Lumpur from the north for more than 6 months, the Malaysian Government decided to establish a branch within the Public Works Department of Malaysia to ensure that slopes in Malaysia are properly and systematically managed. The first major task assigned to the new branch is to produce a comprehensive National Slope Master Plan (NSMP) for the nation. The goal of the NSMP study is to provide a comprehensive and effective national policy, strategy and action plan for reducing loses from landslides nationwide. This paper highlights the key objectives, the scope, the methodology and some of the output of the NSMP study. The issues and problems faced by the study team to come up with a relevant Master Plan are also discussed.

Keywords. Slope master plan, policy, slope management, reducing losses from landslide

1. Introduction

Malaysia is not particularly mountainous country. In fact less than 25% of the land area lies 500 m above the mean sea level. Malaysia is also blessed with very few natural disasters. However, due to high rainfall, this country experiences rainfall related problems such as floods and landslides (including debris flow). In 1993, the Malaysian public was stunned by the collapse of an apartment block due to a landslide that undermined the building and killed 48 people. Subsequently there are numerous other disastrous landslides that killed and injured people and destroyed properties causing considerable pain and hardship to the public, especially, in the landslide prone areas.

There were a lot of media coverage and public outcry recently during any landslide occurrence even when the landslide is considered to be minor. The Slope Engineering Branch (Cawangan Kejuruteraan Cerun - CKC) of Public Works Department, Malaysia (JKR) considers major landslide due to the consequences of the landslide rather than the physical size of the landslide. A landslide that have any one of these criteria is considered to be major disaster:

1. Landslide that affect the economy, caused death and destruction to property
2. The road has to be closed for more than 24 hours
3. No alternative route to bypass the landslide area
4. Alternative route is more than an hour away by motorized vehicle
5. Caused road surface damage rendering it impassable to traffic by more than 24 hours.

Minor landslides are others that do fit the criteria for the major landslide mentioned above.

Construction on slopes in the cities has become a bane not only because of the concern about the safety of the residences up and down the slopes but also growing consciousness about the environment among the public in Malaysia especially in the cities.

After the Bukit Lanjan rockslide in 2003, Slope Engineering Branch was established in early 2004 within the Public Works Department of Malaysia. The rockslide caused a major toll expressway that lead to the capital, Kuala Lumpur, to be closed for more than 6 months. The incident also caused considerable losses to the expressway concessionaire and massive traffic congestion within Klang Valley area.

One of the major tasks assigned to CKC is to produce a National Slope Master Plan with the goal of providing detailed elements of a comprehensive and effective national policy, strategy and action plan for reducing loses from landslides. The NSMP has 10 components each having a major objective. The NSMP is loosely based on United States Geological Survey (USGS) Circular 1244 ((Spiker and Gori, 2003) and the work by the Committee on the Review of the National Landslide Hazards Mitigation Strategy Board of the United States National Research Council (2004). However, the NSMP is more comprehensive in terms of the topics covered, the scope of works and the output details.

This paper describes the methodology employed, the problems faced by the study team, the output and cost benefit analysis of the NSMP. The comprehensive nature of the master plan can be used as a model for other countries that aspire to produce a similar slope master plan.

2. The National Slope Master Plan

The NSMP study started in early 2005 by the preparation of the Terms of Reference (TOR) for the study. It was only in March 2006 before the study commenced in which 6 consultants were appointed. The preparation of the TOR was time consuming not only because the scope of the study is very wide but also because JKR wants to ensure that the output of the study would be specific and covers all the necessary aspects pertaining to excellent management of slope. Even at this stage, opinions of the local experts on slope were sought so that the slope management problems can be viewed from various angles. The study is expected to be completed in October 2008 with a total cost of approximately USD 1.8 million. Apart from the consultants, JKR has also appointed 2 internationally renowned technical advisors to review the NSMP during the course of the study.

Slope management can be presented as a cycle that is divided into 3 phases. The phases are:

1. Pre-landslide Phase (Prevention, mitigation and preparedness measures)
2. Landslide Impact Phase (Emergency relief measures), and

3. Post-landslide Phase (Loss assessment, Reconstruction and Rehabilitation measures)

These phases are interrelated and cannot be viewed in isolation. Figure 1 presents slope management as interrelated activities strengthening one activity in a phase would strengthen the other activities in the other phase provided that lessons are learnt from the activity and information disseminated to the relevant agency or people, which, would be acted upon.

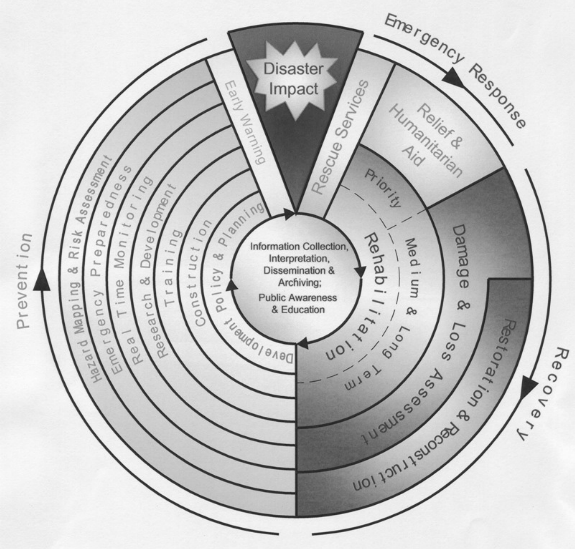

Fig. 1 Slope management cycle

3. Methodology of the National Slope Master Plan Study

The goal of the NSMP is to provide detailed elements of a comprehensive and effective national policy, strategy and action plan for reducing loses from landslides on slopes nationwide including activities at the national, state and local levels, in both the public and private sectors. The NSMP has 10 components that cover all the topics pertaining to slope management. The components are as follows:

1) Policy and Institutional Framework
2) Hazard Mapping and Assessments
3) Early Warning System and Real Time Monitoring
4) Loss Assessment
5) Information Collection, Interpretation, Dissemination and Archiving
6) Public Awareness and Education
7) Loss Reduction Measures
8) Training
9) Emergency Preparedness, Response and Recovery
10) Research and Development.

The NSMP will provide an assessment of the status, needs and associated costs for a national landslide hazards mitigation strategic program for first, second and third implementation phases.

Most of the landslides that caused considerable fatalities and damage to properties in Malaysia are due to human factors. The factors include, design errors, poor construction practice, lack of maintenance and inadequate public knowledge on slopes. In the NSMP study, special emphasis is placed on building capacity of the players involved. The first thing is identifying the needs and weaknesses of the existing slope management system. With these objectives in mind, part of the methodology implemented was focused on identifying these weaknesses. Technical committee involving stakeholders was formed to review the progress and proposals obtained by the study team. Questionnaires were sent to 64 federal agencies and 165 state and district agencies. Most of the technical committee members were from the federal and state government agencies, however, members from Non-Governmental Organizations (NGOs) and the private sector were also invited

The methodology of the NSMP study can be represented in a flow chart as shown in Figure 2. Since the directive to produce the NSMP is from the Malaysian Cabinet, when the study is complete it has to be presented to the Malaysian Cabinet for its endorsement. Presentations of proposals to the technical committee were carried out periodically starting from the interim report stage to the final draft stage of the NSMP. The major reports were sent to the committee before each discussion session. Comments and questions were compiled during the discussion sessions. The study team would deliberate on the comments and suggestions and revise the implementation plans accordingly. Before the draft NSMP was drawn up, it was presented to the committee for their final comments and suggestions.

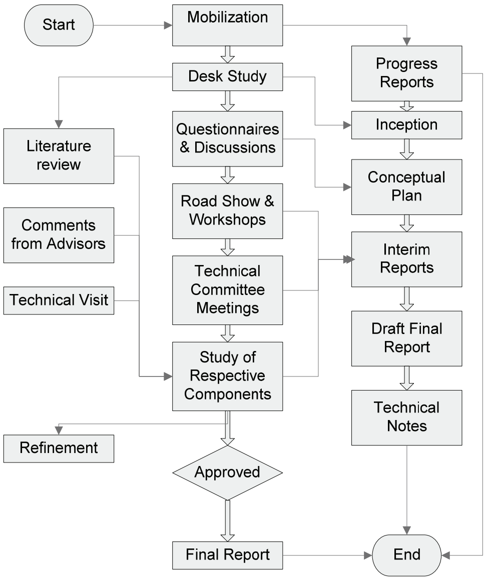

Fig 2 Flow chart of the methodology adopted by the NSMP study.

Technical visits were made to the Geotechnical Engineering Office of Hong Kong (GEO), United States Geological Survey (USGS), Japanese Ministry of Land, Infrastructure and Transport and Hazard Prevention Research Institute at Kyoto University to learn how these organizations manage slopes and some of the research on landslides that they were undertaking. These are some of the major organizations that are dedicated to slope and disaster management. The disaster management carried out by various countries such as

Korea, China, India and Russia, Australia and others was reviewed.

The NSMP study encountered a number of problems during the course of the study especially on the lack of database for landslides and the incurred cost of repairs. The reasons for these problems are poor record keeping, and even if the records are present; they are not in ‘palatable’ form which can be immediately utilized. The information are also scattered among the government agencies, universities, consultants and highway concessionaires. Some of the documents are secret either due to their sensitive nature or due to the trade secrets employed by some of the companies.

Other problems include the difficulty in getting feedbacks from stakeholders on questionnaires that were sent either because their lack of concern on the landslide issues or on the hand they themselves are not certain about their roles and responsibilities in matters pertaining to landslide

During the course of the study, integration and on assimilation problem were encountered between various components since all the components of the study are interrelated to one another. A project portal was established to provide information sharing and communication between various components.

4. Results of the National Slope Master Plan Study

The results of the NSMP study are divided into 6 sections which have the following headings:

1. Identification of the current situations
2. Strategic directions
3. Recommended strategies
4. Implementation plans
5. Key Performance Indicators (KPI)
6. Cost benefit analysis

The strategic direction includes the vision, mission, goal and strategic thrusts that are based on the main objective of each component. From each strategic direction, several strategies are developed for each component to effectively cater for the requirement of the strategic direction. Of the 10 strategic thrusts 38 strategies are recommended in the NSMP. With each strategy, implementation plans are formulated to response and accomplish the recommended strategies. There are 90 implementation plans generated from these strategies.

Each component will have a list of issues that need to be resolved. This is presented as the issues that have to be addressed by the NSMP study. Apart from the weaknesses and inadequacies, the necessary requirements are also generally identified from the methodology adopted. The identification of these problems is then analyzed to form the recommended strategies. The strategies are then translated into implementation plans. Some of the issues faced; the strategies to overcome the problems; and the implementation plans are presented. To monitor the progress of this implementation plans, KPI for the major plans are developed together with cost of implementation of the plan.

Whenever there is a landslide, usually government authority (or authorities) is to be blamed for allowing development to continue in high hazard area or for not maintaining the slope; questions are raised about the integrity of the personnel involved in approving the project in the first place, and why no monitoring of the construction works on hill slope being done by the authorities. Generally, there were lack of appreciation of the economic value and cost efficiencies of risk reduction compared to the cost of replacing lost assets due to landslides.

Landslide management was generally understood as post landslide relief such as providing shelter aiding recovery to victims. Until recently, at least, since the formation of CKC very little resources have been devoted to routine hazard identification or to support sustained risk management strategies especially in landslide prone areas.

Practices in developed countries, such as Hong Kong indicate that the overall responsibility of slope management is undeniably belongs to the government. However, its success also depends on participation from all the relevant parties in the government, the professionals and the public.

On matters pertaining to public awareness, Malaysia being a multiracial country with a diverse ethnicity of Malay, Chinese, Indian, and other indigenous groups; and many languages and cultures, a public awareness campaign and education will have to take these matters into consideration. Presently, very little public awareness programs are being carried out by the relevant authorities even in the landslide prone areas.

Landslides that kill and caused most damage to properties in Malaysia are generally due to design, construction errors or poor maintenance. The Total Economic Cost (TEC) due to landslides from 1973 to 2007 is estimated to be approximately USD 854 million. The approach to slope management has to be holistic starting from the planning to the maintenance stage. One of the endemic problems faced by many developing countries, including Malaysia, is poor planning and maintenance. Many projects were implemented without enough planning being done. Until recently, periodic maintenance of most constructed works, unless they may deem to endanger lives, was not implemented; facilities were only maintained after they broke down or when they started to falter.

Many public and private slopes are not properly designed - prescriptive design was the norm. Factors that may affect slope stability, such as geology and hydrogeology were sometimes ignored. These are some of the factors that increase the risk of landslides in developed areas. Because of this, a systematic approach in the design of engineered slopes has to be in place to prevent landslides from occurring especially in high risk areas.

The NSMP will be tabled to the Malaysian Cabinet for their endorsement, following which; it would then be implemented in phases.

Ten strategic thrusts have been identified in accordance with each component of the NSMP. This is summarized in Table 1.

From the strategic thrusts, several strategies are recommended for each component. Strategies for Public Awareness and Education are presented in Table 2. The recommended strategies will make it easier to generate concrete plans to achieve the aim of each strategic thrust. Implementation plans are divided into 3 phases: Phase 1 begins from 2008 to 2012; Phase 2 is from 2013 to 2017; and Phase 3 is from 2018 to 2022. If the NSMP were to be implemented in total and effectively, one of the key implementation plans is the setting up of a dedicated Slope Engineering Agency (SEA).

Other plan includes setting up of a network of public and private agencies, research institutions, specialists, NGOs and other stakeholders to augment SEA capabilities and to encourage best practices.

Table 1 Master Plan components and their strategic thrusts (after NSMP, 2008)

Component	Strategic Thrust
Policies & Institutional Framework	Develop effective policy and institutional frameworks for landslide risk reduction, mitigation and disaster preparedness.
Hazard Mapping and Assessments	Develop frameworks to establish an inventory of susceptible areas and different types of landslide hazard/risk mapping and assessment at a scale useful for planning and decision-making.
Early Warning and Real-Time Monitoring System	Provide advance monitoring and warning for slope hazards to help the relevant authorities in taking timely preventive measures and thereby, reduce the damage caused by landslides.
Loss Assessment	Develop a loss assessment framework for compilation, maintenance, and evaluation of data on the various types of losses resulting from landslides, to guide mitigation activities and track progress in reducing losses
Information Collection, Interpretation, Dissemination and Archiving	Design and develop a slope information management system (the "System") that exploits the current availability of information in the country and at the same time allows flexibility for it to evolve
Training	To develop training framework Establishment and coodination of national training framework through enhancement of slope engineering and slope management for capacity building of stakeholders involving in slope works
Public Awareness and Education	To provide needs-based awareness and education programs that encourage greater public participation to various target groups
Loss Reduction Measures	Implement systematic approach to identify factors and hazards related to slope failures and selection of appropriate loss reduction measures at local level throughout the country in order to reduce losses due to slope failure is the main strategic under the component of loss reduction measures.
Emergency Preparedness, Response and Recovery	Improve the country's ability to respond and recover from landslides nationwide through a structured systematic approach
Research and Development	Enhancement of Slope Engineering and Slope Management by Research and Development

In the loss reduction plan, development of detail framework for planning, design, construction and maintenance for slopes must be established to reduce landslides.

Setting up of data collection and dissemination system that can be access by the relevant agencies is one of the most important implementation plans that require integration and cooperation from various stakeholders.

Table 2 Strategies for Public Awareness and Education (after NSMP, 2008)

Strategic Thrust	Strategies
To provide needs-based awareness and education programs that encourage greater public participation to various target groups	▪ Strategy .1 :Build capacity of implementing agencies ▪ Strategy 2: Create programs based on user and needs requirements ▪ Strategy 3: Create a system of measuring program performance

Summary and Conclusions

The NSMP is the first comprehensive Master Plan for slopes in the world that proposes tangible Implementation Plans together with the cost required for each plan and the KPIs that will be able to gauge the success of the Implementation Plans. Cost Benefit Analysis is also carried out to ensure the viability of the implementation programs.

The success of the NSMP very much depends upon the political will of the Government, the setting up of the Slope Engineering Agency, the fund provided and collaboration among the stakeholders and cooperation from the public. This may be shaped by public opinion and by landslide events which may take place in the future. It is also important for relevant parties in the nation to understand that the NSMP must be dynamic and evolving to cater for the future changes in the climate, politics and the community. The implementation plans would be closely monitored based on the KPIs, and revision would be done after each implementation phase.

On the benefit of the hindsight, one component that should also be included is the environment. Although the subject is not completely ignored in this study simply because landslide and environment are interconnected, however, the topic is not explored in greater detail in the NSMP.

Acknowledgments

The authors wish to thank all the Technical Committee Members and the consultants who helped shape this NSMP. Our gratitude al

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Creation of Rainfall Soil Chart For Forecasting Landslide

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Abstract. Landslide is basically a continuous process caused by two prominent means of disturbance either geologically or accelerated that affects the geotechnical strata and the surface of the earth. The severity or impact on the soil strata depends significantly on the rainfall intensity, energy and magnitude of the rainfall erosiveness besides the degree or level of the soil erodibility. A combination of these two main factors namely rainfall erosivity and soil erodibility can be linked in order to create the rainfall - soil chart for landslide prediction. In mathematical terms, erosion is a function of the erosivity of the rain and the erodibility of the soil. By knowing the degree of rainfall erosivity and soil erodibility of an area, one can predict the potential risk of erosion induced landslide occurrence. This chart can be used as the deciding factor to confirm whether any landslide occurrences are totally due to the natural courses or man-made phenomenon.

Keywords: Rainfall erosivity, soil erodibility, landslide, chart.

1. Introduction

Unexpected situation like hazards can occur at any time without early warning and it can destroy any structure tremendously. With engineering technology nowadays, one should be able to take an immediate action to protect a structure and its surrounding besides minimizing the impact of the natural disaster such as slope failure, landslides and earthquakes that are closely related with rainfall erosivity and soil erodibility. The change of soil surface due to landslide can delays development planning, loss of properties, lives and cost millions of dollars to the government. Malaysia faces the problem of landslide primely due to its geographical location in the area of destruction which recorded an average annual rainfall exceeding 2,000mm. Based on the rainfall parameters measured on the past landslide tragedies namely rainfall amount, duration, intensity, energy and erosivity, the level of landslide risk in relation to rainfall erosivity categories such as low, moderate, high, very high and critical can be made known to the government authorities. As for soil erodibility, numerous indicators have been devised either based on soil properties determination in the laboratory or field study with regards to the response of the soil to rainfall. Soil properties parameters used to determine the landslide risk level with regards to soil erodibility consists of percentage of sand, silt and clay textural composition.

2. Methodology

The rainfall data analysis provide the basis of assessing the possible landslide risk due to rainfall impact and this can be established through three parameters such as monthly rainfall, erosion risk frequency and percentage of rainfall erosivity solely extracted from the daily rainfall data. The landslide risk is finally determined from the value of rainfall erosivity factor corresponding to the potential landslide risk such as critical, very high, high, moderate or low. The risk level will be shown on an annual calendar in different colour based on its landslide risk category for every month for each automatic rainfall station.

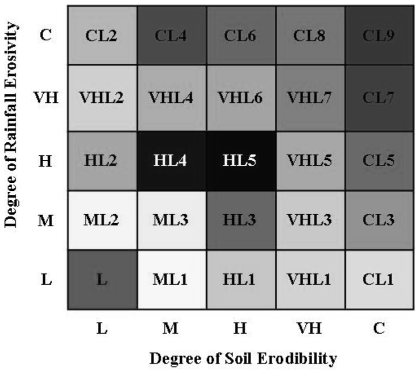
Besides rainfall factor, the degree of soil erodibility which can triggers landslide need to be known. The results obtained from sieve and hydrometer analysis provide the input in terms of percentage of sand, silt and clay that were then substituted into the erodibility index equation known as the ‘ROM_{EI}’ equation given in equation (1).

$$ROM_{EI} = \frac{\%\ Sand + \%\ Silt}{2\ (\%\ Clay)} \qquad \text{……..(1)}$$

The value was used as the ultimate indicator in determining the level of soil erodibility risk classified into Low, Moderate, High, Very High and Critical that can be implied to its susceptibility towards erosion induced landslide.

Conclusion

With regards to the landslide events and rainfall erosivity as well as soil erodibility relationship in Malaysia, the degree of landslide risk level are as shown in **Figure 1** and **Table 1**.



C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1
	L	M	H	VH	C

Colour Indicator	Landslide Risk Level
L	Low
ML1	Moderate Level 1
ML2	Moderate Level 2
ML3	Moderate Level 3
HL1	High Level 1
HL2	High Level 2
HL3	High Level 3
HL4	High Level 4
HL5	High Level 5
VHL1	Very High Level 1
VHL2	Very High Level 2
VHL3	Very High Level 3

Colour Indicator	Landslide Risk Level
VHL4	Very High Level 4
VHL5	Very High Level 5
VHL6	Very High Level 6
VHL7	Very High Level 7
CL1	Critical Level 1
CL2	Critical Level 2
CL3	Critical Level 3
CL4	Critical Level 4
CL5	Critical Level 5
CL6	Critical Level 6
CL7	Critical Level 7
CL8	Critical Level 8
CL9	Critical Level 9

Fig. 1 Rainfall Soil Chart with regards to rainfall erosivity, soil erodibility and degree of landslide risk

Table 1 Landslide tragedies with regards to landslide risk level using rainfall soil chart.

No.	Date	Location	Landslide Risk Level
1	11 Dec 1993	Highland Tower, Ulu Klang, Selangor	CL 3
2	28 Nov 1998	Bukit Awana, Paya Terubung, Penang	VHL 6
3	15 May 1999	Bukit Antarabangsa, Ulu Klang, Selangor	HL 5
4	20 Nov 2002	Taman Hillview, Ulu Klang, Selangor	CL 6
5	8 Jan 2006	Taman Pusing, Ipoh Perak	HL 4
6	15 Jan 2006	Taman Desa	ML 3
7	31 May 2006	Kampung Pasir, Ulu Klang, Selangor	HL 4
8	25 June 2006	Karambunai, Sabah	VHL 3
9	3 Oct 2006	Wangsamaju, Kuala Lumpur	CL 9
10	07 Nov 2006	Gunung Jerai, Kedah	CL 9
11	10 Nov 2006	Kampung Bukit Sungai Putih	CL 5
12	27 Feb 2007	Taman Pelangi, Rawang Selangor	CL 3
13	21 March 2007	Wilayah Persekutuan Putrajaya	VHL 1
14	02 June 2007	Duta Road, Kuala Lumpur	HL 4
15	8 June 2007	Setapak, Kuala Lumpur	CL 9
16	26 Sept 2007	Taman Melawati, Selangor	CL 9
17	23 Nov 2007	Kuala Kangsar - Taiping Road, Perak	CL 9

From all the landslide risk level for the respective 9 landslide locations using the rainfall soil chart, it can be seen from a typical example in **Figure 2** till **Figure 10** that either one of the risk level with regards to rainfall erosivity and soil erodibility are significantly noted to be high and above in causing landslide occurrence. Thus by knowing the risk level of rainfall erosivity and soil erodibility with regards to landslide risk, prediction on future landslide areas especially at sloping areas in the country can be made known. The rainfall soil chart not only can be used locally but also can be applied globally since rainfall erosivity and soil erodibility level can be determined.

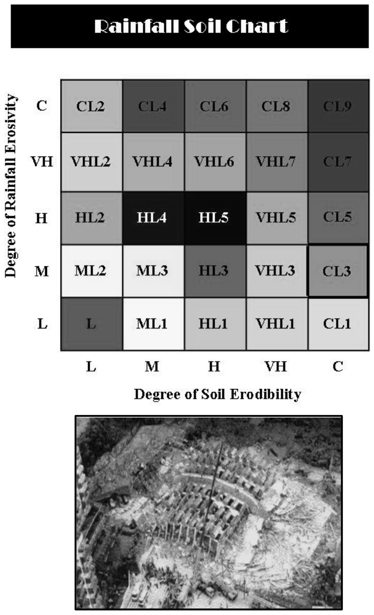


Fig. 2 Landslide incidence at Highland Tower, Ulu Klang, Selangor recorded landslide risk of CL3

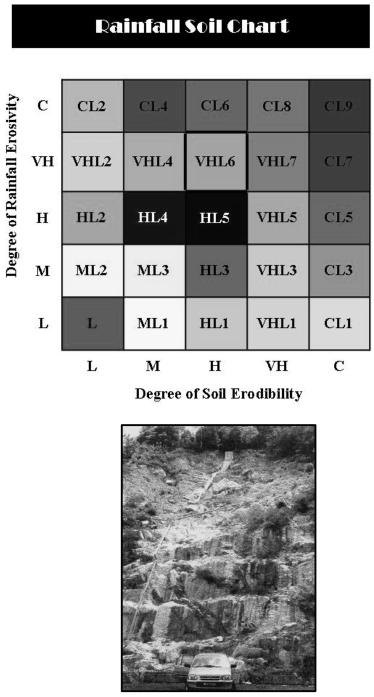
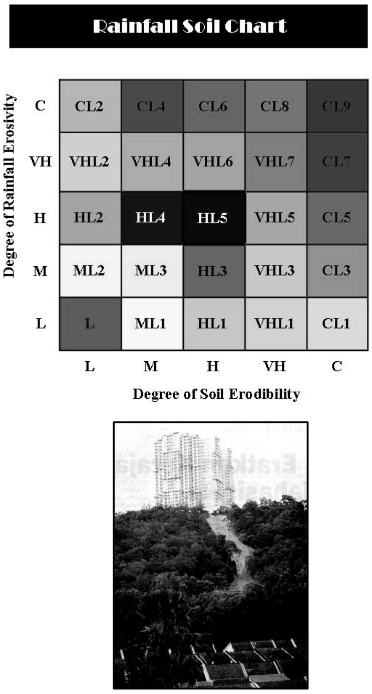
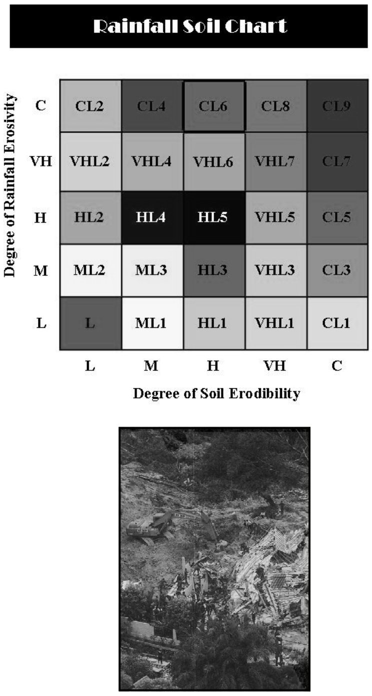


Fig. 3 Landslide incidence at Bukit Awana, Paya Terubung, Penang recorded landslide risk of VHL6



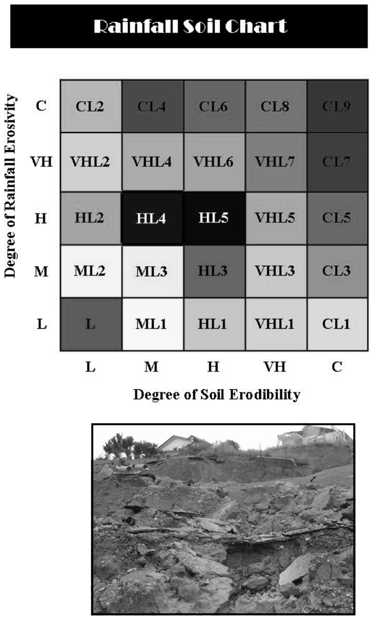
	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Fig. 4 Landslide incidence at Bukit Antarabangsa, Ulu Klang, Selangor recorded landslide risk of HL5



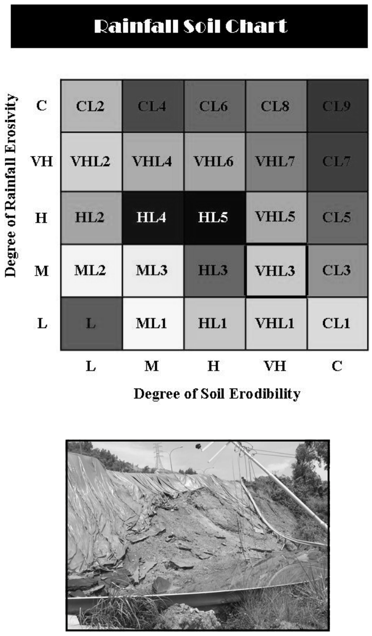
	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Fig. 5 Landslide incidence at Taman Hillview, Ulu Klang, Selangor recorded landslide risk of CL6



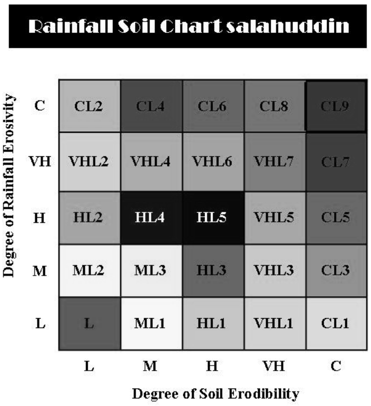
	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Fig. 6 Landslide incidence at Taman Pusing, Ipoh Perak recorded landslide risk of HL4



	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Fig. 7 Landslide incidence at Karambunai, Sabah recorded landslide risk of VHL3



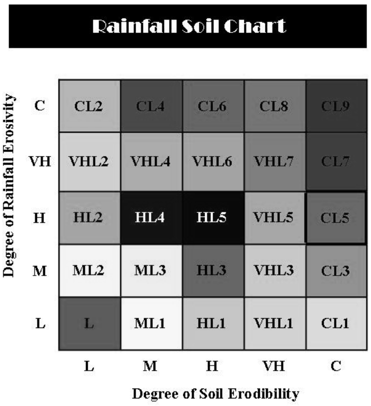
Rainfall Soil Chart salahuddin

Degree of Rainfall Erosivity

	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Degree of Soil Erodibility

Fig. 8 Landslide incidence at Wangsamaju, Kuala Lumpur recorded landslide risk of CL9



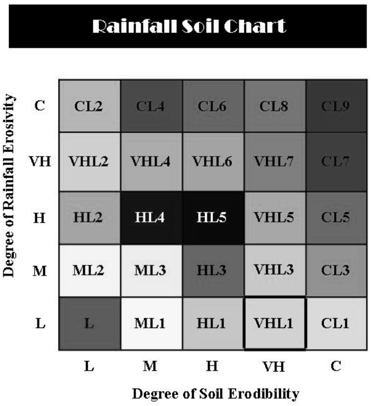
Rainfall Soil Chart

Degree of Rainfall Erosivity

	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Degree of Soil Erodibility

Fig. 9 Landslide incidence at Kampung Sungai Bukit Putih, Ulu Klang, Selangor recorded landslide risk of CL5



Rainfall Soil Chart

Degree of Rainfall Erosivity

	L	M	H	VH	C
C	CL2	CL4	CL6	CL8	CL9
VH	VHL2	VHL4	VHL6	VHL7	CL7
H	HL2	HL4	HL5	VHL5	CL5
M	ML2	ML3	HL3	VHL3	CL3
L	L	ML1	HL1	VHL1	CL1

Degree of Soil Erodibility

Fig. 10 Landslide incidence at Wilayah Persekutuan Putrajaya recorded landslide risk of VHL1

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The Importance of an Indexing Method for Holistic Landslide Disaster Management

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Abstract. This paper focuses and discuss how indexing could help pointing out gaps, vacuums, achievements of crosscutting aspects in a management cycle which may help understand landslide risk in a holistic manner stressing the importance of recovery of a community and sustainable development. Landslides have long been studied but they occur worldwide mainly in rugged mountains or hilly terrains due to various factor victimizing many people every year. Reasons beyond are a lack of political will and coordination in landslide risk management; and non-existence of landslide prevention culture and awareness.

The management to protect community people from landslides demands a broader vision of root causes of vulnerability; and triggering phenomena and different phases of landslides, not just disaster/hazard aspects. Scientists and researchers work very hard to understand the causes and effects of disaster phenomenon which is very important, in addition, scrutinizing the disaster in a holistic manner with community people calls for an urgent need, and this will only be achieved through coordination, policy change and involvement. A holistic policy guideline inclusive of community recovery must be formulated with the help an indexing system so that disaster managers are aware where they stand. The formulated policy guidelines should be a part and parcel of national development plans in order not to waste development gains.

Keywords: landslide indices, landslide culture, vulnerability, population explosion, coexistence, resilient communities

1. Introduction

Increasing trend of natural disaster events (Adikari et al, 2008) and population explosion (UN population, 2007) especially in developing nations has increased vulnerability to natural disasters including landslides. Disasters in general are viewed as a result of the complex interaction between potentially damaging physical events, where landslides are no exception, and the vulnerability of a society, its infrastructure, economy and environment, which are determined by human behavior (Birkmann and Wisner, 2006, thus anthropogenic or un-natural. Landslides directly affect people in remote localities such as in the case of St. Bernard Landslide in Leyte (Evans et al, 2007), and Payatas Garbage-slide in the Philippines, to mention a few. Would not the lives of the victims during these events have been saved if we had put a proper system in place? Where are the gaps and vacuums? Researches on landslides have made progresses on the physical aspects of landslides which are *sine qua non* for understanding the process to develop engineering methods to mitigate and prevent landslide disasters in the future (Sassa et al Eds., 2007). However, most of these researches have been either too academic or short lived and addressed few management and coping capacity issues indispensable for resilience and full recovery of a community. Large-scale landslides have significant humanitarian, social, political, and economic implications that undermine human security (UNDP, 2004). We strongly feel that disaster risk management cycle in case of landslide has an urgent need to be studied seriously to fill the vacuum. To reduce the number of fatalities ultimately to zero, through wide ranges of measures ranging from engineering to socio-anthropological, we would like to propose and discuss how indexing could help pointing out gaps, vacuum, achievements of crosscutting aspects in a management cycle which may help understand landslide risk management in a holistic manner stressing the importance of the recovery and sustainable development of a community. Besides, this school of thought aims to enable a method that could compare regions, countries and localities. Also a conceptualized disaster cycle in space-time continuum is introduced and explained.

2. Landslide disaster risk management

Disaster risk management cycle is used widely as a guideline to manage the disaster risk. Often disaster victims are forgotten in time and left alone even if they are not resilient; and this is where the disaster management cycle for landslide disaster seems to have its weaknesses. Reconstruction/rehabilitation is solely thought and practiced by the authorities on their own hypotheses. Caregivers will stop aid to a community, if they think that it is resilient despite the fact that it is still going hungry.

3. The concept of a community in landslide disaster management

Local communities are usually unaware of an impending disaster, be it a landslide, flood, tsunami or volcano, unless they have experienced the disaster or if there is a disaster culture, tradition, folk tale or modern method such as warning systems and awareness to educate communities about disasters.

Most landslide victims are from developing countries **(Fig. 1)**. Land-pressure leads small poor farmers to retreat further into steep mountains, which could result in fatal consequences at a time of landslide disaster. Disaster managers must play an active role so that communities become resilient after disasters.

4. Landslide indices

The following table shows an example of our proposed matrix of crosscutting aspects of landslide management cycle **(Table 1).** This table will help indexing landslide disaster by ranking each crosscutting factors corresponding to various management practices at different management stages allocating specific criteria. Utilizing this method we can come

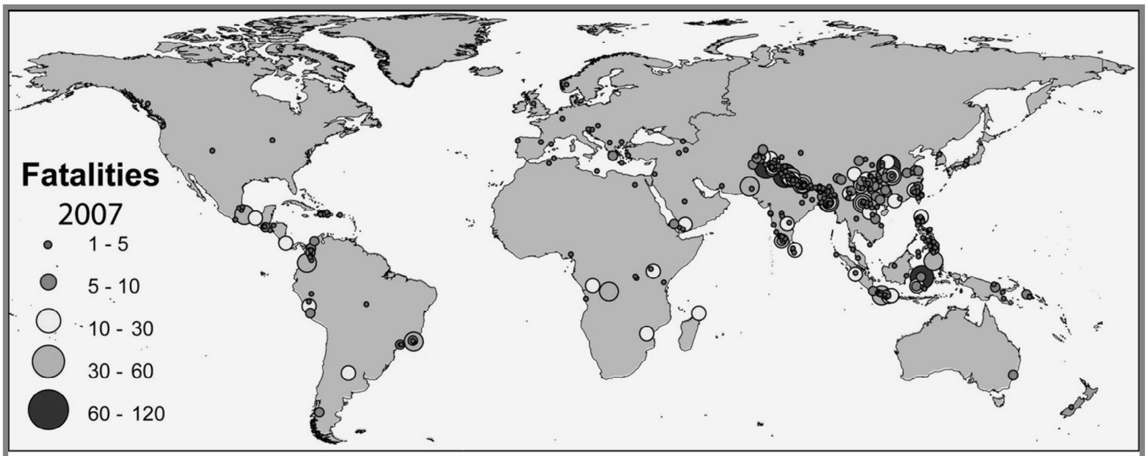

Fig. 1. Landslides fatalities in the world
SOURCE: http://daveslandslideblog.blogspot.com/2008/05/landslide-sizes-numbers-killed-around.html

up with specific numbers for each region (as shown in the example), country or locality. These specific numbers derived from the indexing system will indicate and delineate the progress, gaps and achievements connoting the strength and weakness of management which in turn will let realize where a country stands in term of landslide disaster management.

5. Disaster cycle in space-time continuum concept

The vacuum in the management process must be tackled with the help of indices otherwise the efforts of studies will not be utilized optimally especially in developing countries, and cooperation/coordination among different professionals, institutions, local communities and policymakers are *sine qua non*.

Success needs understanding in space-time continuum manner of different phases of disaster mentioned herein **(Fig. 2.)**. "***A: natural or peaceful phase"***; is the initial phase of the cycle of an expected landslide area which is still natural and stable; the risk of living in that place is minimal at this point in time. Population increases and human settlement start stressing the place, i.e. "***B: human stress or vulnerability increasing phase"***. When the stress gradually increases land-use changes, the hydro-geological regime change will simultaneously take place leading to many other changes in the natural system slowly but surely making it a fragile and landslide-prone area. The fragility is manifested by forest trees or underground water movement like springs help us to predict landslides, and thus this phase is termed as ***C: disaster***

Table 1. An example of the gaps and vacuums of distribution of important crosscutting aspects at various stages of a landslide disaster management cycle. Ranking system: ≥75% = 4, 50 ≥ 75% =3; 25 ≥ 50% =2, and ≥ 25% =1. This matrix is a useful tool for indexing disaster management helping record present status and improvement each year. It may also be advisable to further categorize the total into low, medium and high with a ranking system so that we know how each category is accounted for.

Management Cycle Crosscutting aspects	Response	Rehabilitation Reconstruction	Prevention Mitigation	Preparedness	Total
Governance Political will	4	3	2	1	10
Coping Capasity	1	1	1	1	4
Awareness Local knowledge, Culture	2	2	2	0	6
Financial Capasity	0	0	0	0	0
Institutional Development	4	2	1	1	8
Science, Technology and Knowledge	4	3	2	2	11
Legal setting	0	4	4	0	8
Total	15	15	12	5	

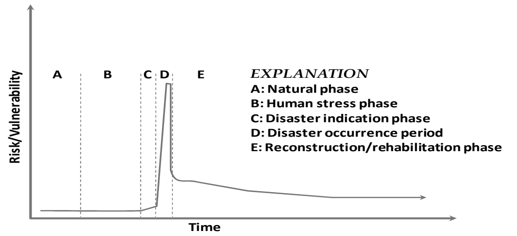

Fig. 2. A conceptual time line before, during and after a landslide disaster occurrence. A, B, C, D & E represent different phases which are important for the disaster management. See text for detailed explanation.

indication or risk increasing phase. "***D: disaster occurrence or emergency phase"***; is when a disaster takes place and finally ***E: rehabilitation/reconstruction phase***; during which everything is rehabilitated to regenerate the affected society back to the original or better state.

As stated in Table 1, ranking and indexing the crosscutting management aspects of landslide as measures of achievement and future targets is highly necessary. Generally speaking, at present allocation of funds are concentrated only around D and E phases shown in Fig. 2 without taking into consideration the multidimensional concept of vulnerability. Communication, coordination and cooperation among science, management and policy, raising awareness and partnership of locals, national, regional, international stakeholders for a common goal of protecting lives form the landslide disaster is indispensable.

6. *The Way forward*

(1) Cooperation among different stakeholders is a must to realize our goals of protecting people.
(2) The preparedness phase of the management cycle must be tackled in an unbiased manner taking community-based approach supported by income generation projects.
(3) Future studies should focus on pre-landslide indicator to develop early warning systems.
(4) A landslide project, like the RADIUS project of UNISDR for earthquakes, must be helpful to evaluate and categorize landslides and
(5) A system of indexing and systematic ranking of the crosscutting management issues at different phase is strongly recommended.

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Landslide Susceptibility Study of Batu Feringgi and Paya Terubong Areas of Penang Island Malaysia Using Soil Characterization

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Abstract. The predominantly hilly terrain of Penang Island combined with average maximum daily temperatures ranging between 27-35°C and rainfall as high as 325 cm per annum makes the overall area vulnerable to landslides. Over the recent past, construction industry has shown a rapid growth mainly due to increase in the number of tourists and other economic reasons. Consequently, the magnitude of disasters associated with landslides has also increased which is a cause of major concern for engineering geologists and geotechnical engineers. This paper attempts to characterize the largely granitic residual soils of two important areas of Penang Island, discussing the nature, structural features, mechanical behavior and field properties of soil samples extracted collectively from 12 locations in the area. Although there are other smaller geologic formations, Penang Island is divided into two major formations; namely, North Penang Pluton and South Penang Pluton. As a result, the two study areas were chosen so that they overlie different formations. The variation of index, strength and field properties of soils with depth is examined and important inferences are made. The correlation of compression index with liquid limit and initial void ratio is evaluated and found to be in agreement with the correlations found by other researchers. The paper concludes with some remarks about the degree of landslide susceptibility of both areas.

Keywords: Characterization, landslide, correlation, Malaysia

1. Introduction

The in situ behavior of soils is complex because it is heavily dependent upon numerous factors. To acquire appropriate understanding of soils, it is necessary to analyze them not only using a geotechnical engineering approach but also through other associated disciplines like geology, geomorphology, hydrogeology, climatology and other earth and atmosphere related sciences. However, it is known that the problems, even when tackled within the framework of geotechnical engineering, are both large and arduous. It is understood that geotechnical problems such as landslides which have significant socio-economic impacts can be addressed within a framework that accounts for behavioral features in natural soils. Research is actively taking place in many countries, each focusing on natural deposits of local importance, and a unified framework that can account for all important effects is still being developed (Soon and Phoon 2003). The development of this unified framework requires a significant joint effort from as many sources as possible. This paper attempts to summarize index, strength, compressibility and field properties of tropical residual soils of Penang and discusses important correlations and facts that emerged thereof.

2. Geography and Geology of Penang Island

Penang is the second smallest and one of the 13 states of Peninsular Malaysia (Fig. 1). It is situated in the northern region and constituted by two geographically different entities − an island (area: 293 km^2) called Penang Island and a portion of the mainland called Seberang Perai (area 738 km^2) − connected by a 13.5 km long Bridge. The island is located between latitudes 5° 8'N and 5° 35'N and longitudes 100° 8'E and 100° 32'E.

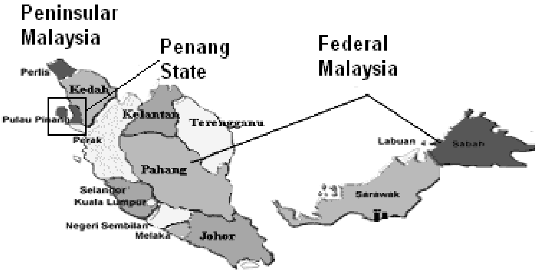


Fig. 1 Physical Map of Malaysia

The climate is tropical with the average mean daily temperature of about 27^o C and mean daily maximum and minimum temperature ranging between 31.4^o C and 23.5^o C, respectively. However, the individual extremes are 35.7^o C and 23.5^o C, respectively. The mean daily humidity varies between 60.9% and 96.8%. The average annual rainfall is about 267 cm and can be as high as 325 cm. The two rainy seasons are the south-west monsoons from April to October and the north-east monsoons from October to February. The terrain consists of costal plains, hills and mountains. The large forest cover and the population concentration on the eastern half of the island can be seen on the geological map as in Fig. 2.

There are three main geological formations in Penang and their distribution is as given in Fig. 2. Data obtained from different data points are so grouped that every data point in one group is located over different formation. Wherever necessary, the data collected from each group of sites is further divided into three subgroups each representing a distinct nature of soil (sandy, silty and clayey) found over that formation. The groups are as shown in Table 1.

The major portion of Penang Island is underlain by igneous rocks (Streckeisen 1967). The granites can be classified on the basis of proportions of alkali feldspar to total feldspars. On this basis granites of Penang Island are further divided into two main groups: the North Penang Pluton located north of latitude 5° 23’ and the South Penang Pluton. In the northern part of the island, the alkali feldspars that generally do not exhibit distinct cross-hatched twining are orthoclase to intermediate microcline in composition. In the southern region, they generally exhibit well-developed cross-hatched twining and are believed to be microcline. The North Penang Pluton has been divided into Feringgi Granite, Tanjung Bungah Granite and Muka Head micro granite. The South Penang Pluton has been divided into Batu Maung Granite and Sungai Ara Granite. For a detailed explanation of these granite sub-classes see Ong (1993). Table 2 gives the proposed classification of the weathering profile over metamorphic rocks (clastic metasediment) in Peninsular Malaysia (Komoo and Mogana 1988). The thickness of residual soil layer varies from place to place depending upon other factors (Bergman and McKnight 2000) responsible for weathering such as rainfall, temperature, chemicals present, compositions of parent rocks, (Refer to Table 3) etc. and the extent to which the weathering process has advanced.

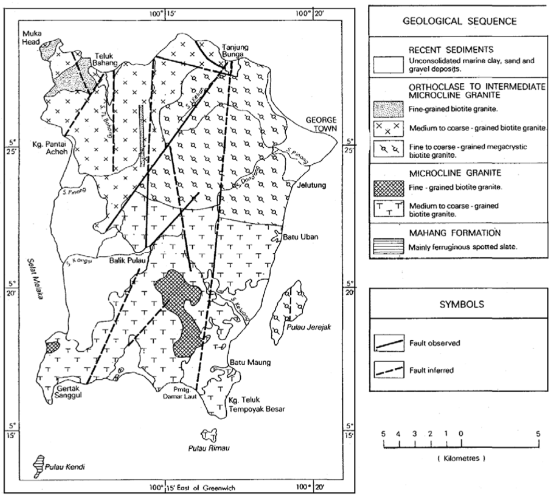


Fig. 2 Geological Map of Penang Island

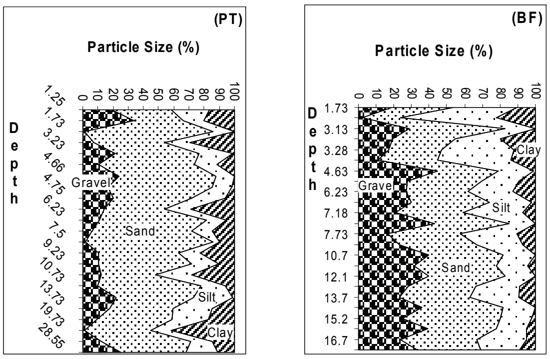


Fig. 3 Particle size Percentage distribution with depth

Table 1 Site groups representing each geological formation

Group Name	Code Used	Formation	Age
Paya Terubong	PT	Medium to coarse grained biotite granite with microcline	Early Permian to Late Carboniferous
Batu Ferringi	BF	Medium to coarse grained biotite granite with orthoclase to intermediate microcline	Early Jurassic

Table 2 Classification of Weathering Profile over Metamorphic Rock (Clastic Metasediment) in Peninsular Malaysia (Komoo and Mogana 1988)

Term	Zone	Description
Residual Soil	VI	All rock material is converted to soil. The mass structure and the material fabric (texture) are completely destroyed. The material is generally silty or clayey and shows homogenous color.
Completely Weathered	V	All material rock is decomposed to soil. Material partially preserved. The material is sandy and is friable if soaked in water or squeezed by hand.
Highly weathered	IV	The rock material is in the transitional stage to form soil. Material condition is either rock or soil. Material is completely discolored but the fabric is completely preserved. Mass structure partially present.
Moderately Weathered	III	The rock material shows partial discoloration. The mass structure and material structure is completely preserved. Discontinuity is commonly filled by iron-rich material. Material fragment or block corner can be chipped by hand.
Slightly Weathered	II	Discoloration along discontinuity and may be part of rock material texture are completely preserved. The material is generally weaker but fragment corners cannot be chipped by hand.
Fresh Rock	I	No visible sign of rock material weathering. Some discoloration on major discontinuity surfaces.

Table 3 Weathering agents and their description

Factors	Description
Climate	Refers to the effect on the surface by temperature and precipitation
Geologic	Refers to the parent material (bedrock or loose rock fragments) that provide the bulk of most soils
Geomorphic/ Topographic	Refers to the configuration of the surface and is manifested primarily by aspects of slope and drainage
Biotic	Consists of living plants and animals, as well as dead organic material incorporated into the soil
Chronological	Refers to the length of time over which the other four factors interact in the formation of the particular soil

3. Soil Classification and Its Properties

The profiles of bedrock depth for the two areas are as shown in Fig. 3. The mean and range values remain almost the same for both areas but the range is quite high as shown in Table 4. Nevertheless, the minimum and maximum values are quite in agreement with the ranges given in literature (Tan 2004).

The soil classification as indicated in Table 5 to 6 and Fig. 3 to 5 for their respective comparison soil parameters for the area of research. All the test results were conducted using BSI (1993).

The residual soils are generally found in unsaturated condition. The shear strength of unsaturated soils can be represented by the extended Mohr-Coulomb criterion (Fredlund and Rahardjo 1993).

$$\tau_{ff} = c' + (\sigma - \mu_a)\tan\phi' + (u_a - u_w)\tan\phi^b \qquad (1)$$

τ_{ff} = shear stress on the failure plane at failure; c' = effective cohesion; σ = normal stress; u_a = pore-air pressure; $(\sigma - u_a)$ = net normal stress; ϕ' = effective angle of shear resistance; u_w = pore-water pressure; $(u_a - u_w)$ = matrix suction; and ϕ^b = angle indicating the rate of increase in shear strength relative to matrix suction. As the soil approaches saturation, the pore pressure, u_w, approaches the pore pressure, u_a and equation (1) becomes:

$$\tau_{ff} = c' + (\sigma - \mu_w)\tan\phi' \qquad (2)$$

Table 4 Summary of Bedrock depth

Area	**Bed rock Depth (m)**		
	Range		**Mean**
PT	0.9	23.55	10.9
BF	1.5	24	10.2

Table 5 Summary of Dry density

Location	Dry Density		
	Min	Max	Mean
PT	1.13	1.93	1.60
BF	1.45	2.01	1.70

Table 6 Summary of Specific Gravity

Location	G of Soil Solids		
	Min	Max	Mean
PT	2.56	2.67	2.63
BF	2.65	2.76	2.71

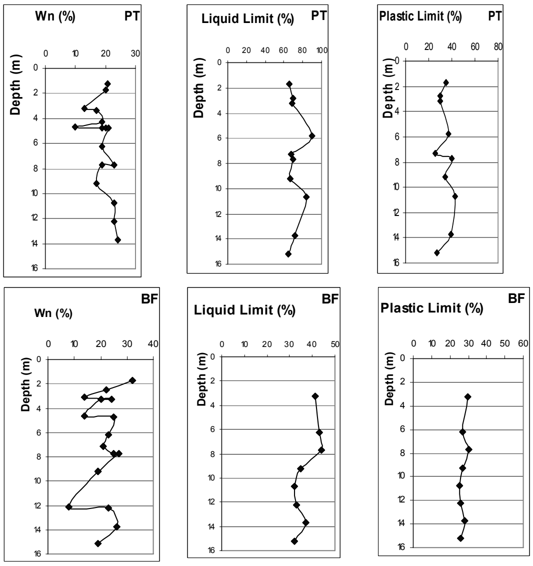
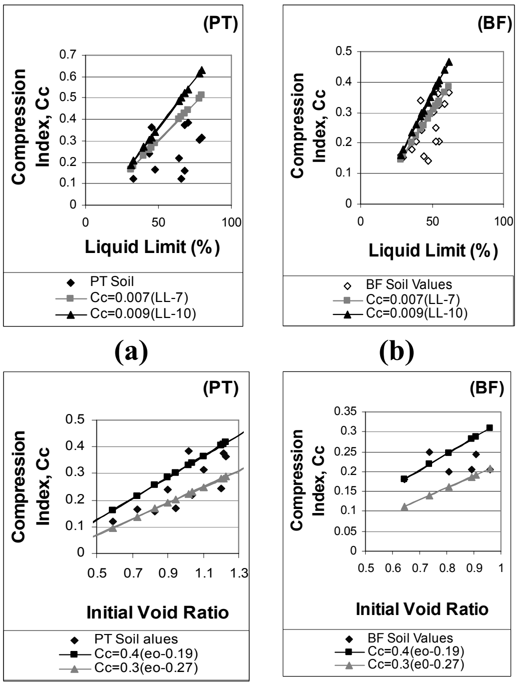


Fig. 4 Variation of Natural Moisture Content, Wn, LL and PL with Depth



(a) (b)

(c) (d)

Fig. 5 Correlation between Compression Index and Liquid Limit

Conclusions

After analyzing the data obtained collectively from 12 different points located on Batu Feringgi and Paya Terubong areas of Penang Island, the following conclusions and recommendations are made.

1. Through the plasticity charts (Fig. 5) it is shown that soil at Batu Ferringi area is more of a silty type whereas at Paya Terubong area it is a clayey type.
2. The effective cohesion shows a wide variation that may be attributed to its unsaturated condition, due to which the shear strength component due to matrix suction, gets included in the cohesion intercept.
3. The soil at the Paya Terubong area shows higher clay content and the clay layer is relatively deep, which makes it susceptible to deeper landslides.
4. The empirical relationships for coefficient of compression, C_c, as suggested by Azzous et al. (1976) are found to show strong correlation with granitic residual soils of Batu Feringgi and Paya Terubong areas.

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The San Juan de Grijalva Catastrophic Landslide, Chiapas, Mexico: Lessons Learnt

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Abstract. Following a period of intense precipitations, on November 4, 2007, a catastrophic landslide took place in San Juan de Grijalva, a community located on the edge of the Grijalva river, near the Peñitas dam, in the south-eastern province of Chiapas, Mexico. The landslide involved a volume of circa 50 Mm^3 that blocked the Grijalva river covering a run-out distance of 800 m length along the main channel, and including a meander zone between 200 and 280 width. Following the initial movement, a 50 m wave was produced causing considerable damages to several houses and a church. According to official information, the aftermath was 19 deaths and 6 people missing.

Above and beyond the direct and immediate effects of landsliding in the adjacent communities and landscape, further hazards associated to dam breaking were likely to occur as more than six weeks were needed to remove the huge volume of material filling the river. As a result of the presence of unstable hillslopes, and flooded areas, more than 3500 people were evacuated.

A discussion of the main processes of the Grijalva landslide, including geological, geomorphological and climatic settings, is presented in this paper, in addition to some reflections derived from the occurrence of this type of events in developing countries, and taking into account a hazard assessment perspective.

Keywords. Grijalva landslide, rainfall, vulnerability, disasters, Chiapas, México.

1. Background of Juan de Grijalva

The Juan de Grijalva town is located in Province of Chiapas, Mexico (fig. 1), in the northern edge of the Maspac geologic belt, between the Malpaso and Peñitas dams, in the transitional zone of the Mountainous System of Chiapas and the Tabasco plains. Climatic conditions are characterized by a humid tropical regimen with rainfall taking place all year long. Frequently, records show mean annual precipitation higher than 4000 mm, and mean temperatures ranging from 20 to 26^{o}C. This area belongs to the Peñitas reservoir in the hydrologic region Grijalva-Usumacinta within the Grijalva-Villahermosa River Basin (fig. 2).

Although there are no landslide records in historical time in this terrain, different ancient mass movements can be easily identified through geomorphological features.

The geological setting of Chiapas is quite complex, lithological variations occurred in time and space covering from the Paleozoic to the Holocene (COREMI, 1999). Sedimentary rocks are deposited and discordantly distributed on surface: limestones are mainly concentrated in the center, and northeast, whereas, interstratified Tertiary sandstones and lutites are located in the eastern sector. Volcanic rocks such as breccias, basalts and andesites outcrop in the North. Moreover, in the area parallel to the Pacific Coast, intrusive igneous rocks -particularly granites- are found on the surface as a result of tectonic activity. The most recent deposits dated from the Pliocene-Holocene) comprise limes, sands, clays and pyroclastic deposits derived from volcanic activity.

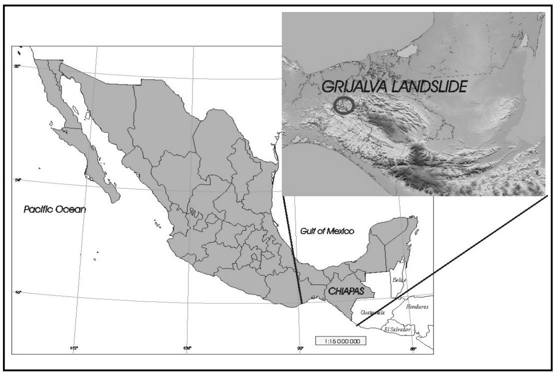

Fig. 1 Location of the area of interest

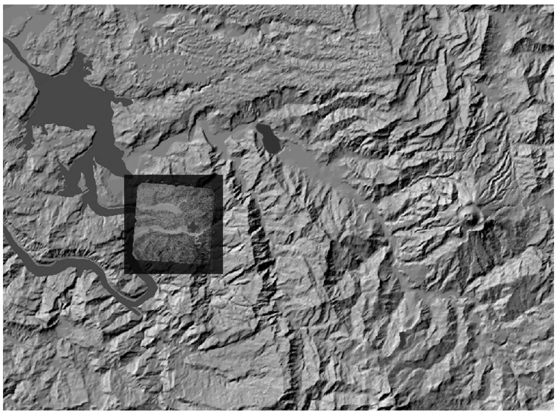

Fig. 2 Digital Elevation Model of the regional landscape

2. Antecedent rainfall

At the end of October and beginning of November, 2007, in the southeastern region of Mexico, a high precipitation event took place producing floods –mainly in Tabasco- and landslides. According to the National Meteorological System (SMN, 2007), this event resulted from the combination of the hydrometeorological conditions derived from the presence of two cold fronts (number 2 and 4). More than 1500 mm of rainfall associated to the first cold front were recorded during October, whereas linked to the second one, in just a nine days period, precipitation amounted approximately 1160 mm. The latter has been considered as the most intense rainfall events in the last 57 years.

2. The San Juan de Grijalva landslide

After some days of intense precipitation, on November 4th, 2007 at circa 20:32 hrs, a landslide took place on one of the slopes of the San Juan de Grijalva river, in the Ostuacán municipality, Chiapas, Mexico. Almost immediately after the movement, the river was blocked. Following the initial movement, a 50 m wave was produced causing upstream considerable damages to several houses and a church located in both, the right and left margins of the river. According to official information, the aftermath was 19 deaths and 6 people missing.

Fig. 3 Blocking of the river by the Grijalva landslide

Based on field observations and the stratigraphic and geological setting of the area, the San Juan Grijalva was a translational mass movement and the slide surface took place on a lutite layer (figs. 3 and 4). Lutite strata are dipping out of the slope towards the river and are indeed potential slide planes. According to landslide measurements taken in the field the movement had a length of 1200 m, 610 m width, and a depth of 70 m. Therefore, on a first stage, the total involved volume of material was estimated to be 51 millions of cubic meters. Subsequently, detailed topographyc survey carried out by the Federal Electricity Commission calculated a volume of 55 million cubic meters (Arvizu et al., 2008). From that amount, at least ten percent blocked the river giving rise to a natural dam which had a height of some dozens of meters above the water level.

The magnitude of the landslide was so earsplitting that the vibrations produced during its occurrence were registered in a seismic station located at a distance of 16 km on the flanks of Chichonal volcano. Such records indicated that the mass movement took place during approximately 80 seconds.

The main controlling factors of the San Juan Grijalva landslide were as follows (Domínguez-Morales, 2008):

a) Structural geology: faults and fractures
b) Water level changes and suction regimen in the rock layers
c) Mechanical properties of materials, expressly of lutites, which lowered resistance when saturated
d) Spatial distribution and stratigraphic character of the rock masses
e) Rock dipping
f) Local topography, although the slope gradient before the landslide was slightly higher than 10 degrees
g) Intense precipitation
h) River bank erosion
i) Deforestation

Fig. 4 Field evaluation of the landslide impact on the San Juan de Grijalva town (source: La Jornada, http://www.jornada.unam.mx/2007/11/07/)

The mass moved down slope exposing the sliding surface, on which triturated rock, large fragments and fractured rocky stacks could be observed (fig. 5).

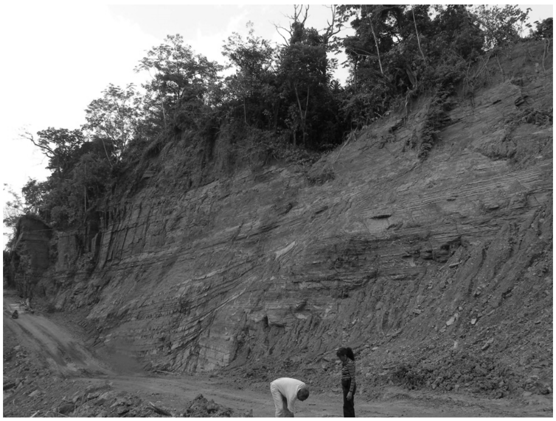

Fig. 5 Rock folding near the Grijalva landslide base at the right flank

Since part of the displaced material significantly blocked the river, it was necessary to restore the flow conditions by opening the canal and excavating a tunnel in an area far from the meander where the actual movement took place, and in order to drain the reservoir formed upstream (fig. 6).

3. Vulnerability, landslides and disasters

According to Alcántara-Ayala (2002), risk is determined by the relationships among hazards and vulnerability. While hazards results from the interactions of the natural dynamic of the Earths, vulnerability is unquestionably associated the complexity of societies (Blaikie et al., 1994; Cutter, 1996). As

Cannon (1993) pointed out, vulnerability ‘‘is a characteristic of individuals and groups of people who inhabit a given natural, social and economic space, within which they are differentiated according to their varying position in society into more or less vulnerable individuals and groups. It is a complex characteristics produced by a combination of factors derived especially (but not entirely) from class, gender, or ethnicity’. Therefore, and despite of the crucial need of understanding mass failure mechanisms, landslides disasters require a full comprehension of vulnerability.

Fig. 6 Authorities opened a canal to avoid subsequent floods and a larger disaster

The generation, systematization and application of hazards knowledge is not sufficient enough to understand risk, and hence to achieve disaster prevention. A multi, inter and transdisciplinary approach needs to be considered and a risk management strategy adopted.

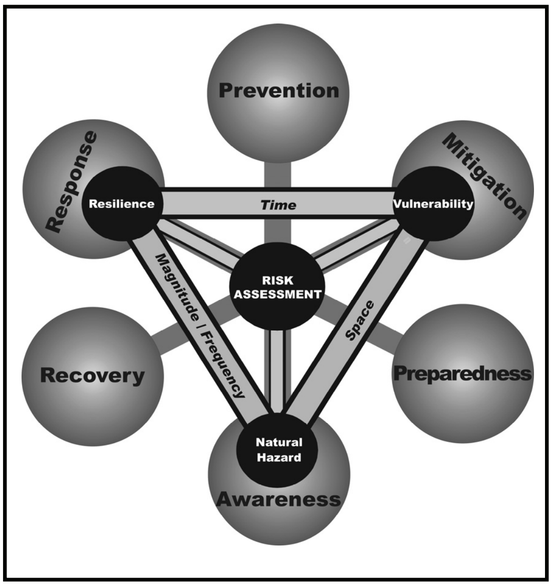

Fig. 7 Risk Management Model: the Atomium (Alcántara-Ayala, 2008)

Based on the fully understanding of the trilogy hazards-vulnerability-resilience, Alcántara-Ayala (2008), defined the Atomium (fig. 7), a risk management model that can be defined as the process comprising a set of strategies, programmes and projects to coordinate reduction and mitigation actions in order to prevent, confront and recover from disasters or devastating conditions.

If applied to landslides, such trilogy can be defined along these lines: a) hazards analysis and assessment (Keefer and Larsen, 2007) would involve the understanding of controlling factors, triggering mechanisms, typology, magnitude, spatial and temporal distribution, and such like; b) vulnerability would require a critical evaluation of the social, economical, political and cultural character of the exposed population group; and c) resilience would involve the evaluation of the capacity of that community to be organized, and adapted, by means of resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This situation is to a great extent determined by capacity of the social system to organizing itself aiming at increasing its capacity to learn from past disasters for better future protection and to improve risk reduction measures (ISDR).

4. San Juan Grijalva: vulnerability issues

It is quite clear that the impact of disasters depends not only on the magnitude of hazards, but on the degree of the vulnerability of the exposed communities to such hazards. In this sense, is not difficult to understand the disaster of San Juan Grijalva (Ostuacan-Chiapas). Chiapas is one of the poorest Provinces of Mexico, and within, the municipality of Ostuacan is characterized by very high levels of marginality. In the native zoque language, Ostuacan means cave of the tiger, however, local inhabitants have translated this meaning into cave of poverty and marginality since notwithstanding the richness of the surrounding fertile lands, they live isolated from other human settlements (fig. 8). The quality of living conditions can be regarded as a window to identify vulnerability and thus understand the impact of hazards, specifically of the landslide occurred in November 4, 2007. At least 25% of the population aged 15 years and more is analphabet, housing of 31% of the inhabitants lacks of drainage system, 37% have no electricity, 36% have no water supply, and 72% live under overcrowding conditions (Coespo).

Fig. 8 Aerial view of the town of San Juan Grijalva (extracted from Google Earth)

Quite clearly, in rural communities of developing countries such as Mexico, there is a lack of disaster prevention strategies, and specifically no interest on reducing vulnerability. In the case of the Grijalva landslide, attention was paid to the event, not entirely because of the number of human losses, but as a result of the disaster complexity. On one hand, the bordering province of Tabasco was dramatically flooded, and on the other, Malpaso and Peñitas dams were considerably affected.

Authorities face indeed a big challenge: communities need to be permanently evacuated and the housing strategy to be offered to them not only demand improved living conditions, but the recreation of their social and cultural setting, where they feel comfortable to re-build their own home. Risk management at local level must be reinforced (Lavell, 2002).

Conclusions

The catastrophic landslide of San Juan de Grijalva caused considerable damage as a result of the involved mass extent, which was able to block the flow of one of the most important and plentiful rivers of Mexico. Although accumulated rainfall played a significant role for soil saturation, the slide triggering mechanism remains unclear. Likewise, even though there is deforestation in the area, this factor can not be considered either as a critical responsible for mass failure.

The volume of this mass movement involved more than 55 million cubic meters of material, the largest landslide recorded in historical time. Consequences were very severe for the communities, and also for the national hydroelectric infrastructure. The lesson needs to be consciously learnt: reducing vulnerability of populations, especially in rural communities must be a priority, and disaster prevention strategies need to be identified, properly structured and wisely applied by considering a inter-multi-interdisciplinary risk management approach which comprises the comprehension of the interrelationships among hazards, vulnerability and resilience.

Acknowledgments

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Institutional Frame Work for Community Empowerment towards Landslide Mitigation and Risk Reduction in Indonesia

B. Andyani, D. Karnawati, S. Pramumijoyo (Gadjah Mada University, Indonesia)

Abstract

This paper describe the background of problems which require the establishment of institutional frame work for community empowerment with respect to disaster mitigation and risk reduction. Poor communication and coordination has been highlighted as the main constrain to develop community empowerment and provide effective community-based disaster mitigation and risk reduction. To minimize such problems, the established institutional frame work has to include multi stake holders with inter-discipline approach. Success story of the implementation of community-empowerment conducted under such inter-discipline approach also addressed together with the discussion to develop the necessary follow up plan.

Keywords: Institutional frame work, community empowerment, disaster risk reduction, inter-discipline approach.

1. Introduction.

The author's experiences as a volunteer in Aceh's tsunami and Yogyakarta earthquake May 2006 (Andayani B and Koentjoro in Karnawati et al, 2008) had taught some lessons which are necessary to be addressed in the National Plan for Disaster Risk Reduction. First, the needs to improve community resilience against any potential disaster (such as landslide) have not yet been institutionally addressed in the existing disaster management effort. Second, the invlovement of social scientist or social disciplines needs to be further elaborated in the disaster mitigation and risk reduction. In fact, people's psychological aspect had never been touched by disaster management system (Koentjoro, 2008). Therefore, some efforts to establish institutional frame work for disaster risk reduction with respect to community resilience are suggested in this paper. Such frame work should also highlight the importance of social consideration and approach.

2. Role and function of the institutional framework.

Admittedly, in Indonesia there have been a lot of institutions conducting some efforts for community empowerment with respect to disaster risk reduction. Yet, the effects and results of such efforts remain ineffective. Poor coordination and communication among stake holders and institutions dealing with the disaster risk reduction seem to be the main constrain in providing effective efforts of community-based disaster risk reduction. Accordingly, a frame work to facilitate coordination, communication and cooperation among stake holders need to be established at regional/ provincial level to minimize such constrain. This frame work also has an important function to campaign the disaster risk reduction program to be regularly included in the regional action plan, and may also to develop linkage of coordination and communication among regional (provincial) and national levels.

Obviously, this frame work needs to include various stake holders from private sectors, potential funding institutions, universities, professionals, non government organization, mass media, and the representative from the government institution in order to guarantee:

1. The effectiveness of community-based disaster risk reduction.
2. The best harmony of coordination and communication among government at provincial levels and between the provincial governments with the community.

However, obtaining strong commitment from each institutional member of this frame work and facing the financial constrain have been identified as the main challenge to maintain the sustainability of this frame work .

3. Implementation of community mpowerment

Quite intensive efforts to mitigate geological disasters such as landslides, earthquake, tsunami and volcanic eruption have been carried out in Indonesia. Most of the mitigation efforts cover the provision of hazard mapping, risk analysis, development of appropriate technology for landslide early warning and countermeasures. In fact, those are usulally provided mainly based on the technical approach. Yet, there is still minimum consideration on soicio-cultural aspect. Accordingly, most of the hazard map, analysis, early warning system and technology, as well as the countermeasure facilities cannot be effectively implemented and operated by the community, especially in the developing countries.

Therefore, it is suggested to establish more systematical approach and mechanism to include socio-cultural and economical consideration in the process of developing institutional frame work for disaster risk reduction. Indeed, research for social investigation and mapping needs to be formally established in parallel with the technical research for disaster mitigation and risk reduction.

4. Success story of the implementation of community based disaster risk reduction.

One success story in incorporating the

socio-cultural considerations in landslide mitigtion is the application of community-based landslide early warning system in Banjarnegara Regency, Central Java (Fatahani TF and Karnawati D, 2007). In early 2007, the Indonesian Ministry of Development for Disadvantage Region committed to improve the community resilience in landside prone area by providing a pilot program for community based landslide early warning system in one selected area in Banjarnegara, Central Java. This warning system was developed in coordination with the Local Government of Banjarnegara Regency and Gadjah Mada University. During the development process, community participation for landslide preparedness and the empowerement training for implementation of early warning system were intensively carried out. Stake holders consisting of schools, women organisation, village community, local red cross, local team of Search and Rescue, local police and NGO actively participated during the empowerment training and evacuation drill (Figure 1). After installment of this early warning system, on November 7, 2007, the early warning alarm was on that made the local community living in the vulnerable site immediately leave this site and moved to the safer area. Then about 4 hours later, the landslide occurred without any victim. In fact, this become very good lesson learned which can save about 40 families living in the vulnerable site. The success of this community based early warning system encouraged the local government to further develope similar system to be applied in sevarl other vulnerable sites in Banjarnegara Regency. This also stimulated the National Board for Disaster Management to develope further similar early warning in several different vulnerable Provinces in Indonesia.

5. Discussion and follow up plan.

The success of this community-based early warning system was due to an appropriate investigation on socio-cultural characteristics of the community. Therefore, in the next effort for landslide and seismic hazard mapping in Bantul Regency at Yogyakarta Province, similar investigation is also carried out in order to gurantee the effective implementation of the produced hazard map. From the investigation and mapping on social characteristics, it was identified that the main obstacles in the implementation of hazard mapping is the poor knowledge and understanding on geohazard phenomena (including landslide), which then results in serious public anxiety and poor community's capability for disaster preparedness. In such situation, the introduction of any hazard map to the community accordingly will create more anxiety and socio-economical problems related to the land ownership and worse development for economical investment. To avoid such problems, in parallel with technical efforts for hazard mapping, continues public education is carried out thorugh the establishment of a motivation team in village or district level. This team consist of elements form school teachers, woman organisation, youth organisation, difable group and supported by the key persons in the village. The main mission of this team is to continuesly disseminate practical information about the cause of landslide hazard, how to prevent and how to prepare or to anticipate. Such information can be disseminate informally through the community radio, informal community meeting, traditional attractions, and other informal popular media. Continues monitoring of activities and empowerment for the motivation team should be done under the responsibility of the local government and supported by the local university and/ or NGO.

Conclusion.

Learning from above case experiences, it is obvious that socio-cultural aspect should be appropriately considered to improve the community resilience with respect to disaster mitigation and risk reduction. The role of social and psychological disciplines is crucial to support the technical efforts in disaster mitigation. Cross-cutting coordination among research insitutions/ universities or technical departments (offices) as the source of information for disaster mitigation and the receiver organization/ institutions which are responsible for community preparedness is proposed by Karnawati et al (2005) as illustrated in Figure 2. The main goal of this institutional frame work for community empowerment is to develop cultural willingness and preparedness for disaster (including landslide) mitigation and risk reduction.

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Figure 1. a) representative for the local government and military institution, b) search and rescue team, c) universities, schools and NGO, d) village man power were integrated in the community empowerment activities (Karnawati and Burton, 2008).

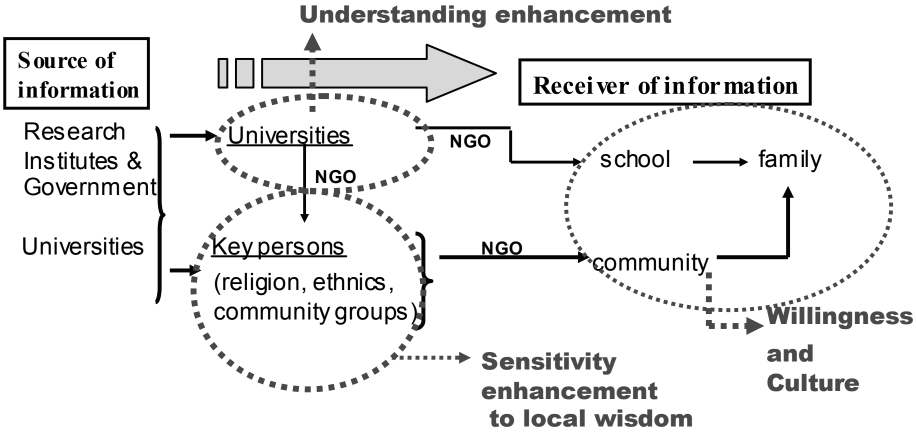

Figure 2. Components of the institutional frame work for community empowerment (Taken from Karnawati, et al. 2005, also presented in Session 7 by Karnawati et al)

A New Sustainable Landslide Risk Reduction Methodology for Communities in Lower Income Countries

Malcolm G Anderson (Bristol University, UK) • Elizabeth A Holcombe (Bristol University, UK)

Abstract

Unplanned housing developments in vulnerable communities on steep tropical and sub-tropical hillslopes in many developing countries pose major problems for the residents; for Governments, in terms of potential relocation costs; for engineers, in determining the precise nature of the hazard and risk; and for donor agencies, such as the World Bank, in establishing the form of disaster mitigation policies that should be promoted. Some of these communities have, in the past, had to be relocated, at costs of millions of dollars, because of major slides triggered by tropical storm rainfall. Even so, evidence shows that: (1) risk reduction is a marginal activity; (2) there has been minimal uptake of hazard maps and vulnerability assessments and (3) there is little on-the-ground delivery of construction for risk reduction.

This paper directly addresses these issues by presenting a new low-cost, community-based approach to landslide risk reduction in such a context. It is founded on the vision that there is often sufficient capacity within Governments to address such landslide issues without needing to incur significant additional costs by employing non-Government specialist staff. Such expenditure adds to debt and only sub optimally builds within-country capacity.

The approach we present develops a cross-ministry Government management team, implements a community-based approach to landslide risk assessment, develops low-cost interventions through the social intervention fund and builds capacity through community knowledge transfer. We report on the successful pilot undertaken in St Lucia, West Indies and on the uptake of the methodology by regional organisations and international donors within the Caribbean region. Importantly, the implementation of this new methodology to communities on the ground, testifies to the importance of within-Government capacity build as the optimal approach to minimising landslide risk to the most vulnerable communities in the developing world.

Key words: Landslide risk; mitigation; community; geotechnical; hydrology; drainage; low-cost.

Introduction

The Caribbean region is subject to rainfall events that act to trigger landslides on the steep slopes which characterise a significant percentage of the area of many islands states. Current climate change predictions point to the increased hurricane activity in the near future and suggest that the region is likely to see an increase in extreme rainfall events and hence an increase in landslides (Mann and Kerry, 2006). A second major element in the creating landslide hazard in the region is that in many areas there is a significant amount of unplanned housing (approximately 60% in St Lucia, for example) located on slopes that are at risk of landslides. It is this combination of triggering rainfall and unplanned housing on steep slopes that affects what are already the most vulnerable groups in society.

There have of course been a number of initiatives and programmes that have sought to map hazards in a spatial context (Caribbean Development Bank, 2004). The scale of the mapping in relation to the scale of the triggering mechanisms remains a critical issue as far as practical remediation is concerned. Such maps may identify communities within hazard prone areas, however, as this paper will demonstrate, we now need to look within those communities to examine and model the instability triggers that actually cause landslides in order that appropriate mitigation can be undertaken.

The scale at which such communities most frequently experience landslides is illustrated in Figure 1. As is the case here, processes such as highly localised soil water convergence can be very important landslide triggers – physical processes which are operating at scales orders of magnitude smaller than hazard mapping can be resolved to.

Figure 1. Example of a typical landslide in an unplanned community.

The effective decoupling of hazard mapping and dominant process controls through the issue of scale incompatibility is reinforced by, on the one hand, the recognition of hazard reduction as a key agenda; but on the other, by very limited on-the-ground delivery. Over the last three decades policy statements by all major agencies have included risk reduction as a pre-condition and an integrated aspect of sustainable development. However, Wamsler (2006) observes that when it comes to practical implementation of mitigation strategies in communities there has been comparatively less activity, even when money is available. The challenge that we address in this paper is two-fold. First, to develop a methodology for landslide risk reduction that tackles the issue at a scale appropriate to facilitate meaningful risk reduction. Second, to deliver on-the-ground landslide risk reduction measures for the most vulnerable communities.

Community Context

The occurrence of a landslide can seriously affect individual residents, cause disruption to essential services and involve a significant cost to the authorities in terms of engineering intervention. Issues of instability are often increased by virtue of the fact that metered water is supplied to the dense, unplanned housing areas, in the absence of any surface water drainage management. When housing density approaches 70% the effect is to nearly double the amount of surface water going onto the slope compared with just the annual rainfall.

The identification of appropriate landslide risk reduction measures can most appropriately begin with learning from communities as to the particular areas of greatest concern. The knowledge of all community members is vital in gaining an understanding of the highly localised slope processes leading to landslides. Community leaders can have a catalytic part to play in projects: conveying the vision to other residents, and helping in selecting workers for construction. In some cases an individual with particular skills and a grasp of the technical aspects of the project can act to raise awareness of slope management issues in their own and other communities.

Understandably, householders are concerned that they will benefit from the risk reduction measures and will need reassurance, for instance, that a drain built up-slope of their house will actually help them even if it is not on their property. The fact that such decisions, such as the design of the community drainage system, are not an imposed solution, but that the community has taken ownership of the process from the beginning, is important here. Engineers against Poverty (www) comment:

> *"Poor people are too often the subjects of development rather than active participants in the process. For improvements to be sustainable, poor people must become empowered through the development process."*

The community is thus a central focus of the MoSSaiC programme outlined in this paper.

Political Context

Major landslides can be expensive to Government in the context of re-housing and relocation costs. Whilst appropriate mitigation measures can be extremely cost-effective in both social and financial terms, a major issue that has to be tackled is the multi-disciplinary nature of slope stability problems. A key aspect of the MoSSaiC framework for landslide risk reduction is therefore the formation of a Management Team. This comprises local government agency 'experts' in the fields of civil engineering, social development and community outreach, emergency management, project management and finance, agriculture and water resources management, for example. This team acts as the bridge between regional and national initiatives for risk reduction, technical and field teams and the communities. Because of this role it is important for the Management Team to establish an understanding of the relational nature of the community – its key players, leaders and elected representatives; and the relationships with government ministers especially in terms of previous social intervention fund activities. Such understanding establishes appropriate consultative channels at the start of the intervention, and ensures that expectations are set correctly in terms of intervention outcomes and likely beneficiaries (Anderson and Holcombe, 2007a).

The MoSSaiC Framework for landslide risk reduction is shown in Figure 2. This places the scientific-basis for landslide mitigation (discussed in the next section) within the community and political contexts. It underpins effect delivery of mitigation measures on the ground.

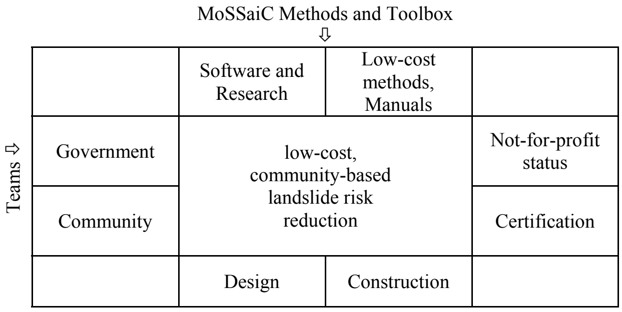

Figure 2. The MoSSaiC Framework for Landslide Risk Reduction

Landslide Risk Reduction

In the physical environment 'risk' comprises two components: the probability of a hazard occurring; and the consequence of the occurrence of that hazard – to people, property or the economy, for example). This is expressed by equation 1.

$$\text{Landslide Risk} = \text{Landslide Hazard Probability} \times \text{Consequence} \qquad (1)$$

(Australian Geomechanics Society, 2000)

Therefore, to reduce landslide risk in communities we must either reduce landslide hazard; or reduce the vulnerability of communities to landslides; or do both.

This paper is primarily concerned with reducing landslide hazard – the probability that a landslide will occur. However, the approach taken by MoSSaiC also has the effect of improving community and government awareness of landslide risk

Assessing the Hazard

It is important to understand the mechanisms that trigger the landslides and the scale at which they operate since this provides the scientific basis for mitigating landslide hazard. Landslide hazard results from a combination of preparatory factors relating to slope geometry, soil and geology, vegetation, surface-water and groundwater regimes; and triggering mechanisms such as rainfall and seismic events. Tropical regions are especially susceptible to landslides due to high intensity and high duration rainfall levels; the rapid rate of weathering and the deep soils that result (often on steep slopes). Rainfall has been identified as the main landslide trigger in the Tropics, and preliminary evidence suggests that climate change could result in increasingly intense precipitation events in regions such as the Caribbean. thus increasing the probability of landslides. However, even without climate change, anthropogenic activities are increasing landslide risk in some of the most vulnerable communities in the Caribbean. These activities include altering slope geometry with earthworks (cut and fill), and loading slopes with buildings and infrastructure. Associated with this are variations in the surface-water and groundwater regimes, and changes in vegetation. The pressure of development on both land and population is ensuring that the poorer, most vulnerable sections of society are living on the most 'marginal', landslide-prone hillsides. Such preparatory and anthropogenic factors discussed above are summarised in Table 1.

Table 1 Spatial Scales of Landslide Preparatory Factors and Triggering Mechanisms

landslide preparatory factors, triggering mechanisms and anthropogenic influences	spatial scales over which variation occurs				
	local / household		hillside		region
	$1\ \text{m}^2$	$10\ \text{m}^2$	$100\ \text{m}^2$	1000m^2	$100\ \text{km}^2$
triggering mechanisms					
• rainfall			▨	▨	▨
• seismic activity				▨	▨
preparatory factors					
• slope geometry		▨	▨	▨	
• soils and geology	▨	▨	▨	▨	▨
• slope hydrology	▨	▨	▨	▨	▨
• vegetation	▨	▨	▨	▨	▨
anthropogenic influences					
• ⇧ surface-water	▨	▨	▨		
• ⇧ groundwater level		▨	▨	▨	
• ⇧ slope angle (cut)		▨	▨	▨	
• ⇧ load (building)		▨	▨	▨	
• ⇩ vegetation	▨	▨	▨	▨	

It can be seen that many of these parameters operate over wide spatial scales. At one end of the scale this enables hillside-scale (100-1000 m^2) mapping techniques to identify zones of increased landslide hazard based on the overlay and indexing of topographic, soil/geology and vegetation maps. However, the *prediction* of landslide hazard in such a way as to inform a community-based landslide risk reduction strategy requires some parameters to be resolved at the household scale (1-10m^2). In particular, in densely populated communities it is vital to identify the effects of highly localised surface-water regimes, man-made structures and cut slopes. Finally, in such locations, the surface- and ground-water regimes will vary over short timescales in response rainfall events and the addition of household water to the slope.. These physical parameters need to be modelled in a fully dynamic way (i.e.

over time) to reveal the precise mechanisms which are determining the stability of the slope, and hence how the slope stability can be increased. The next sub-section describes how the CHASM software (Combined Hydrology And Stability Model) is configured for just such a purpose

Combined Hydrology And Stability Model (CHASM)

The CHASM software is a physically based combined soil hydrology and slope stability model that comprises fully integrated hydrology, surface cover (vegetation) and stability components. The model procedure adopted for the hydrological system is a forward explicit finite difference scheme in which the slope is divided into a series of rectangular columns, each subdivided into regular cells (Anderson, *et al* 2007b; Anderson *et al.*, 1996). The model simulates surface detention storage, infiltration, evaporation, and unsaturated and saturated flow regimes. Rainfall is allowed to infiltrate the top cells governed by the infiltration capacity. Unsaturated vertical flow through each column is computed using the Richards' equation (Richards, 1931), solved in explicit form. We have described certain of the main features of the model elsewhere (Anderson et al 1997; Bishop, 1955; Wilkinson, 2000), but it is appropriate to provide an outline description here.

Within the integrated model structure, the hydrology scheme represents slope plan curvature (convexity and concavity) by varying the column breadth. The effect of the 3-dimensional topography on water fluxes can thus be investigated (in a suitably approximate manner), and its impact on stability estimated. This approach requires identification of the zero flux boundaries at either side of the slope - the degree of convergence or divergence of which defines the downslope change in column breadth (Geotechnical Control Office, 1980). The generated pore pressure field is then used as input to standard 2-dimensional stability analyses where the slip surface is located within the mid-plane of the 3-dimensional structure. At each major time step of the simulation, the hydrology module is directly coupled to a limit equilibrium method for determining slope stability. The techniques used are Bishop's simplified circular method (Bishop, 1955) (equation 2) and Janbu's non-circular method (Janbu, 1954). These limit equilibrium methods are used to determine the shear strength along the failure surface, the mobilised shear strength, and the ratio between these two – the Factor of Safety (FOS) – providing a measure of the relative stability of the slope (Nash, 1987). In the model formulation outlined here, pore pressures, both negative and positive, are incorporated directly into the effective stress determination of the Mohr-Coulomb equation for soil shear strength.

MoSSaiC Model for Landslide Risk Reduction – Saint Lucia Pilot

On the ground, the MoSSaiC framework (as illustrated in Figure 2) incorporates: detailed scale landside risk assessment using the CHASM software; detailed topographic and community-based mapping; low cost methodologies for the management of surface water; and public awareness initiatives. These approaches are articulated and delivered using intensive community engagement and are guided by the MoSSaiC cross-ministry Management Team. The St Lucia MoSSaiC programme funded by Government 2005-07 facilitated the implementation of low-cost, community based risk reduction measures in five communities within the Castries Basin. It is useful here to briefly outline the core elements of that delivery plan.

Controlling surface water on slopes is a critical element in landslide risk reduction. Whilst effective drainage preventing excess pore pressures triggering slope instability is an obvious general requirement, hard engineering solutions can prove expensive. MoSSaiC has developed an inexpensive drainage solution that individual residents can afford consisting of a specialised plastic, held in place by a wire mesh. This 'STAR^{TM} drainage system' has been installed in the Skate Town Community in Castries as part of the project. Importantly, additional STAR^{TM} drains have subsequently been installed by community residents – see Figure 3 (Anderson & Holcombe, 2004).

MoSSaiC have developed three approaches to encourage individual home owners to be aware of these issues and to take steps to connect to newly provided drains. First, a 'show home' was selected by the community – an existing house within the community – and the necessary features of 'good drainage practice' installed with the involvement of members of the community. Second, a poster was designed which illustrated all the features of the show home as an example of 'good practice' for improving slope stability through better drainage. Finally, we participated in media coverage of the project, with particular emphasis on the STAR^{TM} drain design, since this is a low-cost intervention that individuals can implement themselves.

Figure 3. STAR^{TM} drainage system installed by residents in St Lucia

It is important to reflect on the true impact that such an approach may have. For these or other measures to have greatest impact, requires as full an understanding and consequential mobilisation of social capital as can be achieved. Social capital (defined by Putnam, 1995, as 'features of social life – networks, norms and trust – that enable participants to act together more effectively to pursue shared objectives') is unquestionably the focus in interventions of this type, since *de facto* they are community-based in concept, implementation, final delivery post-project maintenance and capacity-build.

Establishing a Regional Pilot Programme

The success of the St Lucia implementation and MoSSaiC methodology allowed the pilot to be extended elsewhere within the region (Anderson & Holcombe 2006a, 2006b). MoSSaiC was incorporated into the OECS Sub-regional programme 2005-6 Disaster response and Risk reduction programme. This allowed a pilot to be established in the Fond Cole Community, near Roseau, Dominica in 2006, whilst the 2006-2009 programme has facilitated commencement of a pilot in St Vincent and a further one in Bequia in the Grenadines in 2007.

The critical elements in these pilots is that, as well as delivering landslide risk reduction to specific communities, they are being used as a means of assessing the MoSSaiC methodology as far as team training and community communication are concerned. Government and Community structures, relationships and organisation differ somewhat from State to State in ways that require accommodation in a pilot programme of this type. The OECS programme provides an important vehicle for testing the implementation of the MoSSaiC methodology in differing environments. Importantly, the 2006 Dominica pilot project was reported on by the Dominica representative at the 2006 Annual MoSSaiC workshop in St Lucia. This is a significant element of regional-capacity build in that with Community members and contractors from the local community present and participating, they could profitably exchange implementation issues and identify common themes for further attention such as longer term drain maintenance.

Measuring the Benefits of the MoSSaiC Programme in St Lucia

Having secured acceptance of a 'preventative measures' policy, delivered an appropriate management structure, and implemented an 'on the ground' programme, the next test is that of evidence-based assessment. There are serious methodological problems here: the basic one being to know what would have happened in the absence of the intervention (Bird, 2004). Assessing the impact of such a project rests less on proving impacts than on showing improvement in practice (Mayoux and Mosedale, 2005; Hulme, 2000). However it is important to make an impact assessment of a programme of this type, given that a core objective is that of working closely with communities and delivering low-cost mitigation measures on the ground. The 2005-07 MoSSaiC programme in St Lucia provides an important opportunity to gauge project impact; key impacts included 496 person weeks of community employment, 93% of all funds spent on materials and community labour, slopes shown to be stable against 1:1~1:4 year storm and Hurricane Dean rainfall and media interest in the form of a 30 minute MoSSaiC documentary commissioned.

Political Uptake of MoSSaiC and ongoing Sustainability

A major positive impact of the programme as outlined has been the recognition by Government (Saint Lucia), political organisations (OECS) and donors (USAID) of its originality and success. The St Lucia pilot programme illustrates the importance of on-the-ground delivery and the critical role of the MoSSaiC management team. On the other hand it also illustrates the potential vulnerability of such a pilot to funding regimes and political changes which if not managed appropriately with the vision constantly reasserted can have detrimental and long lasting impact on the very communities one is seeking to assist. This is a real issue in terms of programme delivery, where community acceptance is key; the expectation of individual community making contributions to surface water management is one of changing behaviour in many cases which means a sustained and visible programme over years, not months. These outcomes are fragile and dependant for their continuance (sustainability) on a number of factors, including Ministerial continuity, capacity in Government agencies, programme visibility in the light of other initiatives, the potential difficulty for funders to prioritise a programme in a 'dynamic' political environment, and the relative priority of risk reduction approaches The St Lucia pilot has demonstrated the central importance of keeping close and sustained links with vulnerable communities before, during the main period of intervention and construction, and subsequently in terms of maintenance and public awareness. A clear, sustained, visible medium-term programme is required to fully achieve those goals.

Discussion

The challenge is to be able to demonstrate that low-cost, community-based, risk reduction programmes have real impact and in so doing seek to influence donor agency funding approaches. This paper adds additional weight to the need for donor agencies to increasingly recognise low-cost, high impact programmes for risk reduction. Additionally, a central outcome of the pilot programme is the need for that recognition to be based on a 5 year plus time horizon. This is needed in order to deliver sustainability within communities with regard to both the physical interventions (individual owners making provision for surface water management themselves) and behavioural changes that are needed (maintenance of drains within communities). A regional framework platform with that scope and timeline we believe can deliver a significant landslide risk reduction programme of sufficient originality and impact that global agencies would see merit in replicating it elsewhere in the world.

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Nomenclature

MoSSaiC	Management of Slope Stability in Communities
OECS	Organisation of Eastern Caribbean States
USAID	United States Agency for International Development

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Effective Land Use Planning Solutions for Landslide Risk Management in Urban Areas in Asia

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Abstract.
Landsides and other mass movements are becoming one of the most frequent natural geological phenomenon especially in the urban areas covered with mountainous terrain in many countries in Asia and the Pacific. It is not very clearly manifested by the number of loss of life but damages to property, lifelines and utilities are quite widespread and significant. This was seen in earthquake induced occurrences observed in Pakistan in 2005 October and also number of rain induced landslides reported recently in countries such as Nepal, Sri Lanka, India, Indonesia and Philippines. It also suggests that landslides can be one of the most significant outcomes of global climate change in future.

In many instances landslides occur without any prior warning and people do not understand well the nature of pre-event symptoms to take actions before the event occur. Hazard mapping can easily delineate the potential areas of high risk but very few countries have taken steps to implement national programs for hazard zonation mapping at any level. Therefore it is impossible to provide a lead-time to undertake precautionary measures in the potentially affected areas to prevent loss of life and property. This is the most important reason why landslides are becoming one of the most frequent of the natural calamities of geological nature.

Over the last decade, landslides have caused considerable socio-economic impacts in several Asia and Pacific region countries associated with mountain hill ranges including India, Indonesia, Philippines, Pakistan, Nepal, Sri Lanka, China, and Thailand etc. Their occurrence is due to intense rainfall occurrences or earthquake induced. Landslide vulnerability of communities is not uniform and there are large variations within Asia Pacific and largely associated with the socio-economic differences, political commitment, location of settlements, policies and practices.

Risk factors (physical, social and economic) that have not been addressed for a considerable time lead to landslide disaster events. Most of the landslides that have occurred in the past in Asia Pacific region had a mild impact on the urban areas, as their impact was concentrated towards the rural areas. However, recently reported events have proved the high vulnerability of the urban areas to landslides. Independent of the triggering mechanism, when landslides occur in the urban areas the human and economic damage is tremendous due to failure of many slopes simultaneously within a considerable area. It is resulted due to similarity in slope characteristics, land use practices, sub-surface formations etc and capable of affecting large population and heavily built infrastructure. In fact, the impact of the disaster event associated with such events is very closely related to the type of built environment (buildings and infrastructure) and other land use practices.

Escalation of events observed in the urban areas are accompanied by high level of inappropriate construction practices, uncontrolled development, reluctance of local planners and engineers for strict enforcement of land use controls and regulated practices in prone areas. This has created serious problems in landslide mitigation. Though the recent landslides that have affected the urban areas, have put some pressure for enforcement of the land use regulations by authorities, the better construction practices, appropriate policy guidelines for development of urban hill slopes as well as public awareness creation yet to feature in the agenda of urban local bodies. This paper summarizes some of the experiences of the Asian Disaster Preparedness Center (ADPC), Thailand in promoting the appropriate land use planning practices in urban areas prone to landslides in Asia in order to mitigate the landslide impacts.

1. Introduction

It is a fact that the incidents of landslides have increased within many countries in Asia during the last decade inflicting heavy property losses, economic impacts and many deaths. It is hard to believe the possibility of changes of engineering geological parameters of affected areas within a short time period and contributions of such changes in increase of landslide events. Therefore key likely factors for increase in landslide events can be attributed to change of the pattern of the natural triggering factors (such as increase in rainfall, increase in the number of earthquakes in hilly areas etc) as well as changes in the land use pattern in prone areas. Scientists are working on the climate change issues, possible attributes and it's obvious that there is a variation in climate related factors within Asia which is reflected in occurrence of frequent extreme hydro-meteorological events such as cyclone Sydr, Cyclone Nargis etc. There are hard evidences to provide proof for the possible increase in associated rainfall events, its intensity so on within even smaller catchments areas which can contribute to occurrences of landslide and other natural hazard events. Certain land uses can amplify the effect of such trigger mechanism and there is a direct correlation between geo-environmental factors and physical factors associated with land use which demands control in land use in order to bring about reduction of devastating impacts of landslides. The driving force in land use planning is the need for change, need for improved land management and execution of control of land use can consider as a parallel effort to adjust the land use to suit the changing circumstances. This paper tries to bring the possible relationship between the land use changes and its contribution for the increase in landslide events and discuss the measures that can be taken to regulate the land use in landslide prone areas in order to reduce number of future devastating events of landsides.

2. Relationship Between Landslides and Land Use

The way how a community uses land at a given time could be defined as "Land use" and usage of particular land parcel is categorized by the socio-economic description or functional dimension of the land. In most cases the usage of land is decided by the owner considering its suitability for a particular use, convenience of the user, as well as social, economic and environmental factors. On the other hand the vulnerability of people to natural hazards is determined by the relationship between the occurrences of destructive hazard events, the proximity of people to these occurrences, and the degree to which the people are prepared to cope with these hazardous events natural or manmade. This is common to natural occurrences of landslides too and failure or limitation of the human system to interact with the physical system depends on the degree of vulnerability. Careful development of hillside slopes can reduce economic and social losses due to slope failures and land use planning can ensure sustainable development within hill country areas. But the land in mountainous areas are being used for different purposes and the historical evidences and scientific research have shown that the planning of land allocation in developing countries in Asia for different activities/services is never decided upon the fact that the particular usage will sustain the physical condition, diversity and productivity of the respective land or not.

Certain land users can increase the possibility of landslide events. For example forest land in hilly urban areas can be given for establishment of new human settlements as a solution to land scarcity created due to urbanization and in developing the land, cutting and filling operations, removal of trees, etc., can negatively impact the stability of the entire area. In most cases no attempt is being made to study the area, from the point of previous occurrences of landslides in verifying the possibility of dormant landslides within the area or possibility of accumulation of debris of former slide so on prior to allocation for development for particular use. Therefore measures are needed to be taken in land use planning in hilly areas in order to see that such planning helps in restoration and maintenance of the physical condition of the land, preserve natural and cultural aspects, reduce threats to safety of population and neighborhood, and provide opportunities for environmentally friendly usage for residential, recreational or commercial purposes. Through such a systematic and interactive procedure carried out in land allocation is needed in order to create an enabling environment for sustainable development of land resources which meet people's needs and demands as well as preserve the safety and stability of the land.

2.Impact of Landslides and Mass Movements

2.1 Landslide Hazard and Other Mass Movements

Landsliding, erosion and subsidence are natural processes, which recur in certain geologic settings and certain environmental conditions in upper watersheds and hilly areas. It is an observed fact that the use of marginally suitable land for development in hilly areas has increased the potential for slope instability in recent times and allocation of land is a compelling need in most countries due to scarcity of suitable buildable land and affordability of population to purchase the land in safer areas. Many landslide damages that have occurred might have been prevented or avoided if accurate landslide hazard information had been made available to public and landslide mitigation measures in land development had been used.

2.2 Consequences

The most commonly cited cases of landslide losses are loss of manpower, loss of animals and property. Economic losses due to natural hazards include both direct and indirect costs. Schuster and Fleming (1986) define direct costs of damage as the costs of replacement, repair, or maintenance due to damage to property or facilities within the actual boundaries of a hazardous areas and the cost of cleanup. All other costs are considered to be indirect. Examples of indirect costs given by Schuster and Fleming (1986) include: reduced real estate values, loss of productivity of agricultural or forest lands, loss of revenues from properties devalued as a result of landslides, costs of measures to prevent or mitigate future landslide damage, adverse effects on water quality in streams, secondary physical effects, such as landslide caused flooding, for which the costs are both direct and indirect, loss of human productivity due to injury or death, costs of litigation, damage to places of cultural importance, loss of access, etc. In addition to economic losses, there are intangible costs such as personal stress, reduced quality of life, and the destruction of personal possessions having great sentimental value.

2.3 Approaches for Reduction of Landslide Impacts in Development Planning Mountain Areas

Land use planning and control plays a central role in natural resource management and reduction of impact of natural hazards. It is a tool for mediating with competing demands for land development and thereby facilitating the regulatory development within prone areas. Landslides unlike other natural hazards only can inflict damages within a comparatively smaller area and sustainable use of the given land depends on the measures undertaken to stabilize the area. The most effective and economical way to reduce the landslide losses is to locate developments on stable ground and or to undertake slope stabilization measures, mitigation measures as a component of development initiative. The assurance for stability of the slope comes with the commitment of the users to follow mitigation principles accompanied by engineering as well as non-engineering measures. Land use is one element of an overall or comprehensive planning process that has to be carried out in combination with other disciplines such as transportation engineering, housing, open space management for recreation purposes, community welfare and social services, natural resources and environmental management public safety, and economic development. All development within mountain areas need to follow an integrated planning approach by linking different above mentioned sectoral strategies with land use planning strategies. Therefore mountain area development can be viewed as an interdisciplinary issue where land use planning should play an integral part. Its content and method has to be adapted according to local conditions but by a group of people who can advise on various issued connected not only with land management and land use but also mitigation of impacts of landslides or maintaining the stability of slope while it’s being used for particular type of land use. For example it is necessary to design road traces not only considering its cost effectiveness by reducing the shortest distance between two locations but also the potential geo-environmental effects and landslide hazard potential. In most cases in such development planning Environment Impact Assessment is used as a tool for control or analyzing the environmental impact due to particular development. But there are instances of such road projects end up in utilizing considerable additional expenditure for landslide control and mitigation under repair and maintenance budgets even after getting through the EIA process.

3. Tools for Development Control

One of the most effective and economical ways to reduce the landslide losses is by land use planning to locate developments on stable ground and having introduce preparedness and mitigation initiatives as a component of development initiative. The potential landslide prone areas or land parcels that have a potential to destabilize due to particular type of land use can be dedicated to other low-intensity users or designated as open areas or as areas allocated for restricted development. In such areas development can be restricted or discouraged.

The basis for action for mitigation and preparedness measures or allocating land use for certain areas will be landslide hazard zonation map. Such maps can be prepared using complex methodologies using many parameters as well as simple hazard zonation based on a few parameters such as slope categories, geology, and rainfall intensities.

3.1 Relocation or Converting Existing Development

If in some areas where existing development is threatened by landslides such development can be diverted or relocated into a safe area. The recurring damages can be eliminated or reduced by evacuating the area or by converting the existing structures or facilities to alternative uses, which are less vulnerable to slope failures. In some instances especially where human settlements are threatened by landslides it will be difficult to relocate a complete settlement to another area as socio-economic factors may force the inhabitant communities in getting relocated into a new area. In such cases the minimum should be to have preparedness measures accompanied by good early warning system for early evacuation at established threshold limits of rainfall. Conversion of existing structures and facilities to uses that are less vulnerable may be undertaken by individual property owners or in the case of public properties by the government. The success of conversion depends on the value and importance of facilities, their potential for triggering or resisting slope failures or whether they can be retrofitted to resist failures. In cases of such conversion or retrofitting to have higher safety level the government can encourage the owner by providing incentives such as credit on soft terms, reduction of tax, etc.

3.2 Measures for Discouraging Development in Landslide-Prone Areas

The successful methods used in developing countries to discourage development are public awareness programs, disclosure of hazard to potential property purchasers, exclusion of public facilities (prohibit or limit the services of for example water, gas, electricity, etc.), display warning signs, tax credits and special concessions, new financing policies (restrictions imposed through secondary sources such as lending institutions), request for Insurance coverage for development initiatives (request for insurance certificates to be provided by the owner of the land), government acquisition of unsafe land and public awareness creation especially on issues such as legal liabilities.

3.2 Regulating Development

It is difficult to assume that whole development initiatives in landslide-prone areas can be discouraged indefinitely by non-regulatory methods discussed above. Therefore, the more practical way is to restrict particular development and allow for restricted development in areas with potential landslide hazards. In order to regulate development the governments can introduce zoning methodology for the hazardous areas depending on the hazard potential. Areas with high hazard can be allocated for passive usage such as reforestation, conservation (parts, playgrounds, etc.), livestock, agriculture that does not increase potential for instability. In addition, government, through employing competent professionals who can suggest designs incorporating measures to reduce the landslide risk.

3.2.1 Land-Use Zoning Reguations

The hazard zonation mapping of landslide areas provide information on high hazard-prone areas. Such information can be used in land use zoning of prone areas. It helps in restricting development for high hazardous zones and directing the areas in undertaking other appropriate development initiatives in corresponding zones with different degree of hazards. Zoning regulations control the locations and density of development on hillsides. For example areas with low hazard or no hazard can be allocated for housing and human settlement development. In high hazard prone areas development can be limited. Relevant limitations or regulations can include provisions that prohibit specific land users or operations that might cause slope failures to be located in high hazard prone areas. Such practices are development of human settlements, construction of roads and lifeline facilities, irrigation system, storage of hazardous waste, etc. A least danger is associated with land uses such as woodlands, parks, parking areas, non-irrigated agriculture, recreations, wildlife sanctuaries, forest areas, etc., and industrial uses such as temporary stores, storage yards, parking areas for portable or moving equipment, etc. Such land uses can be located in medium hazard areas or areas allocated for controlled development. Other controls such as subdivision regulations, special regulations for restricted areas, promotion of conservation practices and landslide reduction measures are also considered to be very effective tools in regulating development in high risk areas.

4. Role of Local Governments in Land Use Planning and Difficulties in Execution of Control in Development Within Landslide Areas

Local government is the lowest unit of administration which is authorized to issue building control permits and permits for other development initiatives. But at the local government level, hazard mitigation is often a controversial issue. One might argue that the land use control is a selfish way of controlling development and can be used as a weapon to take revenge from certain elements by political authorities. Also, since in many cases it is difficult to obtain hazard zonation maps the decisions will be based on very subjective recommendations by professionals and may lead to controversies. Technical staff and officials of local governments are usually subjected to pressure from political authorities to issue permits for development initiatives and without proper technical support they may have difficulties to maintain their stand regarding restrictions on land use and development. Local officials, as well as individual builders, property developers, contractors and other parties in the development. Local officials, as well as individual builders, property developers, contractors and other parties in the development process, are increasingly being found liable for actions, or failures to act. It is true that most of the landslide damages are related to agricultural or/and non-agricultural human activity such as the construction of roads, utilities, homes, etc., the best opportunities for reducing the impacts of landslide hazard events are found in land-use planning, land administration and enforcement of codes and ordinance. However when deaths, injuries and property damages result in natural hazards officials responsible for issue of permits cannot be liable to legal action due to difficulties connected with legal procedures.

4.1 Action to Support Implementation of Land-Use Planning in Landslide-Prone areas – Mandatory Provisions

Land-use planning will be successful only when there are institutions mandated to undertake implementation. In most cases those institutions which are responsible for land-use planning do not have the authority to implement such regulations and responsibility for enactment of such regulations is wasted with other authorities such as city corporations. In most cases urban development authorities are given the authority for planning (in case of Bangladesh Dhaka city development is under RAJUK and implementation is done by Dhaka City corporation). They are reluctant to impose such regulations due to anticipation of other connected issues such as resettlement, regulatory development in certain areas, payment of compensation, etc.

Institutional Arrangements for Landslide Service and Studies

The land-use planning is based on landslide hazard maps of appropriate scale and it should be carried out by a competent authority. As an example the government of Sri Lanka implements a National Landslide hazard mapuing program covering 8 landslide-prone districts. They have an institution dedicated to landslide studies and services under National Building Research Organization (NBRO). Nepal has established a Water Induced Disaster Prevention Center a few years ago to provide technical assistance on landslide-related issues to government and private sector institutions.

Base Maps for Maps and Land-Use Planning

In some cases even there are competent institutions who can handle the land-use planning aspects as well as landslide hazard mapping since there are no base maps available in convenient scale they cannot carry out any landslide mapping. This problem exists in many landslide-prone countries in Asia.

Guidelines for Local Government Institution

It is necessary to issue guidelines for land-use planning as well as to integrate risk-based approach for planning so that risk minimization measures are included in development plans.

5. Conclusions

The effectiveness of local landslide mitigation programs is generally dependent on the ability and d4termination of local government officials to apply the mitigation techniques available to them to limit and guide growth in hazard-prone areas. Land-use planning is one of the techniques that planners and land managers may use to reduce the impact of landslide hazards in the at-risk communities. The key to achieving landslide loss reduction is the identification and implementation of specific land-use planning solutions to discourage new development in high-hazard areas, and regulate existing development. It is necessary to have a general consensus in integrating such policies in a local or district-level development plan.

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Landslide Hazard Assessment, Vulnerability Estimation, and Risk Evaluation at the Basin Scale

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Abstract. For one area in central Italy, landslide hazard was ascertained, landslide vulnerability was estimated, and landslide risk was evaluated, for different scenarios. To ascertain landslide hazard, a specific probabilistic model was adopted to predict where landslides will likely occur, how frequently they will occur, and how large they will be in a given area and period. For the study area, a multi-temporal landslide inventory map was prepared through the interpretation of five sets of aerial photographs covering the period from 1941 to 1997, and field surveys in the period from 1997 to 2004. For each mapping unit: (i) the probability of spatial landslide occurrence was obtained through discriminant analysis of a large set of thematic and environmental variables; (ii) the probability of experiencing one or more landslides in different periods was determined adopting a Poisson probability distribution model for the temporal occurrence of landslides, and (iii) the probability of landslide size was obtained by analyzing the frequency-area statistics of known landslides. Assuming independence of the three computed probabilities, landslide hazard was determined as the joint probability of landslide size, of landslide temporal occurrence, and of landslide spatial occurrence. Landslide vulnerability curves established for the Umbria Region using information on landslide damage to buildings and roads caused by individual landslides based on slide type were adopted. Assuming independence of hazard and vulnerability, and exploiting (i) the multi-temporal landslide inventory map, (ii) the obtained landslide hazard assessment, and (iii) the available landslide vulnerability curves, landslide risk to the road network was evaluated for different scenarios. Results indicate that landslide risk can be determined quantitatively over large areas.

Keywords. Landslide, hazard, vulnerability, risk, model, Italy.

1. Introduction

The ultimate goal of many landslide studies is the determination of the risk posed by existing or future slope failures to either the population and/or the infrastructure. To achieve this goal, information on landslide hazard (Guzzetti et al. 1999, 2005, 2006a) and vulnerability (Galli and Guzzetti 2007) to landslides is required. Several different techniques have been proposed to evaluate landslide hazard, and the literature on the topic is extensive. Assessment of landslide hazard involves determining "where" landslides are expected (i.e. landslide susceptibility), "when" or how frequently they will occur, and how large or destructive the slope failures will be, i.e. the "magnitude" of the expected landslides (Guzzetti et al. 1999, 2005, 2006b).

Studies of the vulnerability to landslides, including methods to determine vulnerability and examples of damage assessments have been proposed by several authors (for a review see Galli and Guzzetti 2007). Investigators do not agree on methods and scales for determining landslide damage, and accepted standards for measuring landslide vulnerability are lacking. This is particularly the case where vulnerability has to be determined over large areas (Cardinali et al. 2002; Reichenbach et al. 2005). Lack of established methods to assess the damage and of reliable information on vulnerability, hampers our ability to properly determine landslide risk (Galli and Guzzetti 2007).

In this paper, we report the results of an attempt to ascertain landslide risk in the Collazzone area, central Umbria, Italy.

2. Study area

The Collazzone area extends for about 79 km^2 in central Umbria, with elevations ranging between 145 m and 634 m. The landscape is hilly, and lithology and bedding attitude control the morphology of the slopes. In this area sedimentary rocks are mantled by soils that range in thickness from a few decimeters to more than one meter. Precipitation is most abundant in the period from September to December; with a mean annual rainfall between 1921 and 2001 of 885 mm. Snow falls on the area on average every 2–3 years. Landslides are abundant in the area, and range in age, type, morphology and volume from very old, partly eroded, large and deep-seated slides to young, shallow slides and flows. Slope failures are triggered chiefly by meteorological events, including intense and prolonged rainfall and rapid snow melt. Although the area is seismically active, no information is available on earthquake induced slope failures in the area.

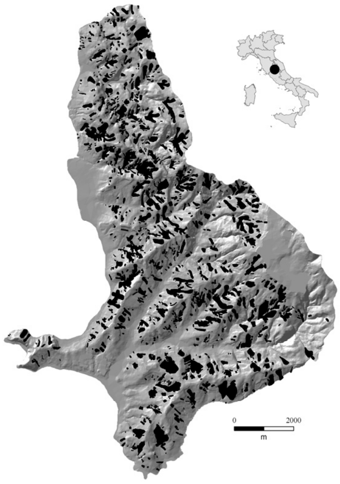

Fig. 1 Multi-temporal landslide inventory map for the Collazzone area

Landslide and thematic information is available for the

Collazzone area. A multi-temporal landslide inventory map, at 1:10,000 scale shows 2760 landslides in the study area (Fig. 1). The inventory was prepared through the systematic interpretation of five sets of aerial photographs covering the period from 1941 to 1997, supplemented by field surveys conducted in the period from January 1998 to December 2004 (Galli et al. 2008). A 10 m × 10 m digital representation of the topography (DEM) is available for the area, and was used to partition the study area into 894 slope units (Carrara et al. 1991), a terrain subdivision that has proven reliable to determine landslide susceptibility and hazard in Umbria (Carrara et al. 1991; Cardinali et al. 2002; Guzzetti et al. 2006a). Geological information, including lithology and bedding attitude, is available from a geological map at the 1:10,000 scale, prepared through field mapping aided by the interpretation of medium and large-scale aerial photographs. Information on land use types, including the presence of roads, was obtained from a land use map compiled in 1977 by the Umbria Regional Government, largely revised and updated by interpreting the most recent aerial photographs and by inspection of detailed topographic maps at 1:10,000 scale, and limited field checks.

3. Landslide hazard assessment

To determine landslide hazard in the Collazzone area, the probabilistic model proposed by Guzzetti et al. (2005) was used. The model predicts where landslides will occur, how frequently they will occur, and how large they will be in a given area.

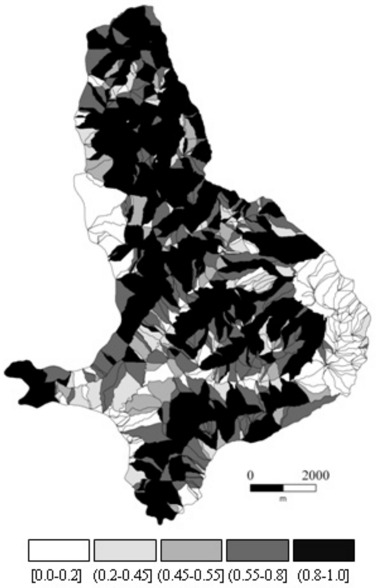

Fig. 2 Map showing spatial probability of landslide occurrence (landslide susceptibility) in five classes, obtained through discriminant analysis of 46 thematic variables. Square bracket indicates class limit is included, round bracket indicates class limit is not included

First, a probabilistic estimate of the spatial landslide occurrence (i.e., of landslide susceptibility) was ascertained. Landslide susceptibility was obtained through discriminant analysis of 46 thematic variables, including morphology, lithology, structure, land use, and the presence of large relict landslides. As the dependent variable for the multivariate analysis, the presence or absence of landslides in the 894 slope units was selected. The result of the susceptibility assessment is shown in Fig. 2. The obtained susceptibility zonation correctly classifies 83.0% of the slope units. The model performs better in classifying unstable areas (i.e., slope units that contain known landslides, 89.8%), and is poorer in the classification of stable areas (i.e., slope units that are free of recognized landslides, 67.6%).

Next, the temporal probability of slope failures was ascertained. To obtain this estimate, the number of landslides that occurred in the 64-year period from 1941 to 2004 in each slope unit was counted, and the average rate of landslide occurrence in the individual slope units was calculated. Knowing the mean recurrence interval of landslides in each slope unit (from 1941 to 2004), assuming the rate of slope failures will remain the same for the future, and adopting a Poisson probability model for the temporal occurrence of the events (Crovelli 2000; Coe et al. 2000; Guzzetti et al. 2005, 2006a), the probability of having one or more landslides in each slope unit was determined for different periods.

Next, the probability of landslide size (area), considered a proxy for landslide magnitude was determined. To determine the probability of landslide size, the truncated inverse Gamma probability distribution of Malamud et al. (2004) was applied to the landslides shown in the multi-temporal inventory in the period from 1941 to 2004. The obtained result can be used to predict the probability that an individual landslide in the Collazzone area exceeds a given size.

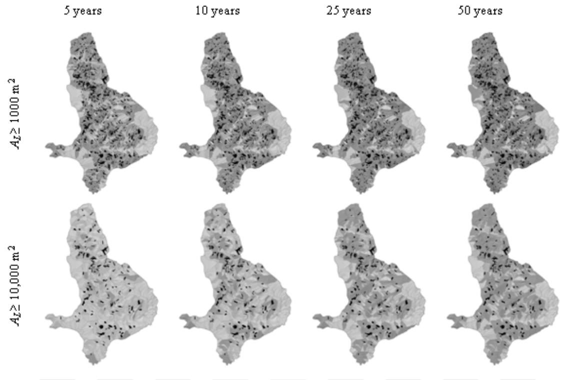

Fig. 3 Landslide hazard scenarios for four periods, from 5 to 50 years, and for two classes of landslide size, $A_L \geq 1000\ m^2$ and $A_L \geq 10{,}000\ m^2$. Shades of gray show landslide hazard, i.e., the joint probability of landslide size, of landslide temporal occurrence, and of landslide spatial occurrence. Black polygons denote landslides

Assuming independence of the three computed probabilities, the probability of landslide size, the probability of landslide temporal occurrence, and the probability of spatial occurrence were multiplied to obtain estimates of landslide hazard, i.e., the joint probability that a slope unit will be affected by future landslides that exceed a given size, in an established period. Fig. 3 shows examples of the landslide hazard assessment prepared for the Collazzone area. The figure portrays landslide hazard for four different periods (i.e., 5, 10, 25 and 50 years), and for landslides of two size classes, greater or equal than 1000 m^2 and greater or equal than 10,000 m^2.

4. Landslide vulnerability and risk evaluation

Information on the vulnerability to landslides is lacking almost everywhere in the World (Alexander 2000; Glade et al. 2005; Hungr et al. 2005), hampering our ability to evaluate risk. For the Umbria region, landslide vulnerability curves were established exploiting information on landslide damage to buildings and roads caused by individual landslides of the slide type in the 24-year period between 1982 and 2005 (Galli and Guzzetti 2007). Empirical observations revealed that, in Umbria, the proportion of direct damage caused to buildings and roads by slides and slide-earth flows depends on the area of the damaging landslide. As a first approximation, the direct damage caused by a slope failure increases with the area of the hazardous landslide. However, the proportion of the damage does not scale linearly with the area, complicating the assessment of landslide vulnerability. Minimum and maximum vulnerability curves were established for roads in Umbria and were used to map the expected vulnerability of the road network to landslides in the Collazzone area.

Assuming independence of hazard and vulnerability, and exploiting (i) the multi-temporal landslide inventory map, (ii) the obtained landslide hazard assessment and, (iii) the available landslide vulnerability curves, landslide risk to the road network was evaluated in the Collazzone area, for different scenarios.

5. Discussion and conclusions

For the Collazzone area, landslide hazard was ascertained, landslide vulnerability was estimated, and landslide risk was evaluated. Results of this exercise indicate that landslide risk can be determined quantitatively over large areas, provided a set of adequate forecasting models are adopted, and reliable landslide and thematic information is available.

The adopted models hold under assumptions that must be considered when using the hazard, vulnerability, and risk forecasts. For landslide hazard, assumptions include the following (Guzzetti et al. 2005): (i) landslides will occur in the future under similar circumstances and due to the same factors that triggered them in the past, (ii) landslide events are independent (uncorrelated) random events in time, (iii) the mean recurrence of slope failures will remain the same in the future as observed in the past, (iv) the statistics of landslide area do not change in time, (v) landslide area is a reasonable proxy for landslide magnitude, and (vi) the probability of landslide size, the probability of landslide occurrence for established periods, and the spatial probability of slope failures, are independent. For landslide vulnerability, relevant assumptions include the following (Galli and Guzzetti 2007): (i) no relationship exists between the amount of displacement, the type and extent of the damage, and the engineering characteristics of the affected elements, (ii) the time required for repairing the damage or to replace a lost (destroyed) road section, and the importance of the road to the population were considered heuristically, (iii) to rank damage to roads, indirect damage to the population and the economy was considered locally, (iv) only damage caused by landslides of the slide type – or prevalently of the slide type – were considered, and (v) the type and proportion of the damage caused by past landslides in Umbria was considered comparable to the expected damage caused by similar, future slope failures in the Collazzone area. Lastly, for the evaluation of landslide risk, the key assumption was made that landslide hazard and landslide vulnerability are independent (Alexander 2000; Galli and Guzzetti 2007). Most of the listed assumptions were adopted in the attempt to simplify the problem, and make it mathematically and geomorphologically tractable. Determining the validity of the adopted assumptions proves difficult (Guzzetti et al. 2005; Galli and Guzzetti 2007). The relevance and legitimacy of the assumptions may vary in different areas, and should always be tested using independent (i.e., external) information and geomorphological inference.

We conclude by pointing out that the main scope of a landslide risk assessment is to provide probabilistic expertise on future slope failures to planners, decision makers, civil defense authorities, insurance companies, land developers, and individual landowners. The proposed method and the associated models allowed to prepare a large number of different maps, depending on the adopted susceptibility model, the established period, the minimum size of the expected landslide, the available vulnerability estimates, and the adopted risk scenarios. How to combine such a large number of forecasts efficiently, producing cartographic, digital, or thematic products useful for the large range of interested users, remains an open problem that needs further investigation.

Acknowledgments

We dedicate this work to Mirco Galli, a friend and colleague who passed away suddenly on 29 November 2007. His contribution was instrumental to the outcome of this research.

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Landslide Geotechnical Monitoring for Mitigation Measures in Chosen Location inside the SOPO Landslide Counteraction Framework Project, the Carpathian Mountains, Poland

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Abstract. Practical application of different geotechnical monitoring methods for landslide mitigation measures inside the SOPO project is presented. Research was financed by loan from the European Investment Bank and from the public budget. Author of this paper had opportunity to investigate twenty-three landslides in chosen Carpathian locations. Study discusses practical aspects on landslide investigation methodology applied. Research integrated different methods such as diamond impregnated 132mm core drilling together with sampling, vane tests, laboratory tests (index, IL oedometer and direct shear tests), GPR profiling, GPS-RTK mapping, instrumentation, and slope stability analysis. Laboratory tests detected very high moisture and liquidity index, low cohesion and angle of shearing resistance. Monitoring starts from January 2006 and covered inclinometer ground movements, water level, pore pressure (piezometers, pneumatic and VW transducers) and precipitation measures (courtesy PAS). Control slope stability analysis using LEM and FEM analysis using SoilVision codes allowed relative factor of safety and landslide behavior prediction. Landslide mitigation measures included building of effective drainage systems, drilled piles or micropiles into bedrock, reinforced earth retaining walls, road reconstructions and monitoring. Research proved that used methods could deliver needed data for landslide characterization and mitigation measures, however it should always include methods and schedule chosen with respect to the landslide type and size.

Keywords. Landslides instrumentation, monitoring, counteraction, geotechnical laboratory and in-situ tests.

1. Project background

In Poland 95 % of landslides, in total number of 23000 is situated in the Carpathians that cover only 6% of state area. (Fig.1). In these mountains one landslide is situated on every one square kilometer and every five kilometers of public road. Prone to sliding activity is caused by high slope inclination, flysch type geological stratification consist of many permeable and impermeable layers covered by the weathering zones. Intensive precipitations together with floods, erosion in river valleys and snow melting in early spring periods were the main activating ground movement's factor. In poor Carpathian regions, due to not proper regional planning, landslides often made loses in private properties built from all live saved assets. It is complete lack of data how many of public roads in Poland were located in landslide areas. To lower risk Republic of Poland took a loan of over 50mln EUR from European Investment Bank. Loan was used mainly for landslide mapping, database creation, site investigation reports, recognition of counteraction possibilities and stabilization project preparation together with civil engineering stabilization works for public roads reconstructions.

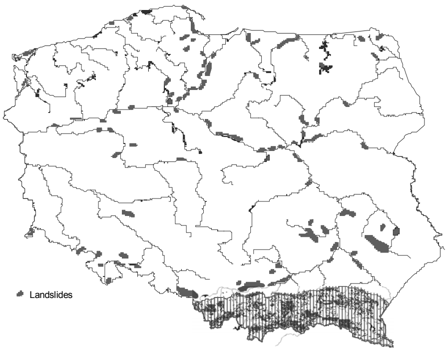

Fig. 1 Landslides in Poland

It was planned that project will be consist of two components "A" and "B". Component "A" included mainly landslides mapping, engineering geology site investigations and instrumentations. Component "B" had to included monitoring measurements of instrumented slopes and installation of new equipment. It was planned that both parts of the project have to start in the same time in 2005 but component B didn't started however there are some efforts to start this component from 2009. In presented project ground movement and groundwater conditions had been examined on the base on systematic inclinometer and pore pressure measurements during a period of over 2.5 years on 23 landslides without any finance support. Observed movements varied from few millimeters to even ten centimeters in over two year's and depends on the borehole. In some cases it already reached critical values and probably will be no longer possible to collect the data. Identification of landslides phenomena is usually not easy task and required careful and long enough usage of different investigation methods. Large-scale landslides in Carpathian Mountains were reactivated many times therefore are difficult to measure its actual behavior and activity.

2. Landslide characterization

Investigated landslides were formed inside deposits of Tertiary marine clastic sedimentation, mainly shale's and sandstones. When the Carpathian Mountains were buiding, during Alpine Orogenesis layers were folded, elevated and displaced to the north. Intensive erosion in river valleys and high groundwater level, during the Holocene era caused huge numbers of landslides in clayey sediments. Investigations using C^{14} method of organic sediments in colluviums near Szymbark indicated that landslides were formed in period of 8210 ± 150 years BP. They often represent ancient landslides many times reactivated in wet periods (Raczkowski & Mrozek 2002). Creep and geodynamic processes caused that colluviums represents heterogeneous mixture of soils and rocks. Saturated claystones and sandstones, sometimes are covered by weathering zones. Claystones in some parts had mechanical parameters characteristic for weak cohesive soils due to the geodynamic processes. Sandstones usually occurred as thin layers with different degree of digenesis. They represented more permeable strata inside clayey layers and allowed water infiltration and seepage rising due to many crack and joints. Landslide depth was changing from few to dozens of meters. Slopes inclinations were varied from 15^{o} to 35^{o}. Groundwater level was usually very shallow and varied 0.5m bellow the natural terrain level.

3. Failure mechanisms recognition

Development of slope instability on investigated slopes was mainly caused, besides geological factors, by geometry, changes by river erosion together with changes in groundwater regime caused by intensive precipitation. These processes increased the disturbing weight, decreased effective stresses and finally decreased shear strength in the slopes. The shear strength was stabilizing agent for slopes and the calculated factor of safety against instability, expressed the ratio of the shear strength to applied shear stress. The effective normal stresses in the material depended on the total stresses and the pore water pressure. Failure occurred when shear stress in material exceed the shear strength. In some cases, landslides were activated by external factors, as undercutting of its lower parts by the roads or by the additional loads – embankments. In landslide mechanism failure recognition special attention was paid to slope and layers inclination, together with ground movements and groundwater regimes interpretation using instrumentation (Fig. 2)

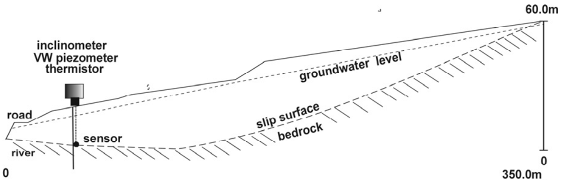

Fig. 2 Landslide instrumentation scheme

4. Site investigations

Site investigations included over 600m of core drillings and sampling, 20 km of Ground Penetration Radar (GPR), GPS-RTK profiling, vane tests and landslide instrumentation on 23 investigated landslides. Special attention was paid to drillings and samples quality. Boreholes were used for calibrations of 100MHz and 250 MHz RAMAC GPR profiles. Obtained results of GPR scanning had fairly good correlation with inclinometer measurements and allowed to detect slip surfaces, internal structure and faults (Fig.3) Boreholes, depth of 9-30 meters allowed geological profiles, cross-sections and gave samples for laboratory tests. It also helped in interpretation of over 20 km GPR RAMAC scanning which was found to be a useful method for prospecting of flysch sediments up to depth of 10-15m.

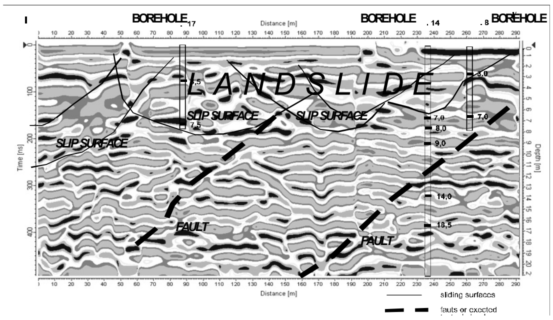

Fig. 3 GPR RAMAC profile, Wapienne landslide

5. Laboratory tests

Geotechnical laboratory tests included 130 sets of index tests (grain size, moisture content, liquid and plastic limits, unit weight, soil particles unit weight), 48 direct shear tests and 10 incrementally loaded (IL) odometer tests. Soils used for these tests represented silty loams, silty clays to claystones (rock). Soils inside the sliding surface usually had very high moisture content 20-36%, liquidity index up to 0.5, cohesion from 6.5 kPa, angle of shearing resistance 11^{0}. The highest values of moisture content and plasticity index were often observed in samples taken form the sliding surface depth, at it was observed at the Sekowa landslide (Fig.4).

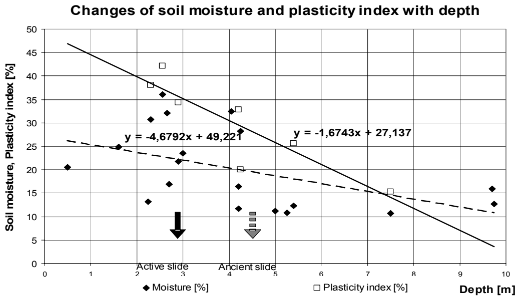

Fig. 4 Soil moisture and plasticity index with depth

6. Instrumentation

To evaluate landslide risk, preparation of engineering geology site investigation reports and monitoring of the ground deformation over 250m of 70mm inclinometer casings were placed in 24 monitoring points. Casings were installed in boreholes and equipped with special moving joints for settlement monitoring. Water level and pore pressure monitoring included 19 standpipe piezometers, 11 pneumatic piezometers and 2 vented wire automatic piezometers with temperature sensors installed inside boreholes. Monitoring measurements performed by the period of over 2.5 years were vitally important and necessary, however not included in the SOPO project and had to be financed by the author. Hopefully it was a chance to perform it because of other ongoing projects. Without monitoring data the possibility of landslide stabilization and effective landslide remedial works couldn't be planned, and very high costs of remedial works probably had to be approved.

7. Ground movement monitoring and mitigation measures

Inclinometers measurements had started in January 2006 and were continuously performed during 30 moths in 19 places (Fig.5). Inclinations of 70mm ABS casings were controlled in two surfaces A and B in steps of 0.5m. Systematic errors were eliminated by combination of two readings A (landslide direction) and C (rotated by 180°).

Fig. 5 Inclinometer monitoring

Subsequent surveys indicated changes in profile during the ground movement. Displacement profiles were useful for determining the magnitude, depth, direction, and rate of landslides ground movement on the landslides. Inclination measurements were converted to lateral deviations. Measured cumulative ground movements varied from several to 89 mm and depended on landslide activity and size. The largest movement was observed on the Bystrzyca, Lubatowa and Sekowa landslide (Fig. 6). The largest monthly movements of 12-20mm were noticed between May and June 2006 what correspond with a record high monthly precipitation of 230mm. It occurred after water pore pressure had reached 60-80 kPa on the slip surface (Fig.7, 8).

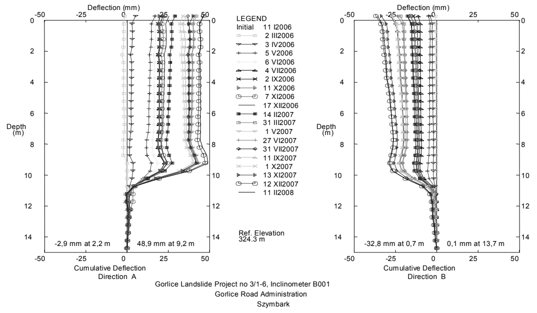

Fig. 6 Cumul. displacements, Bystrzyca landslide

8. Groundwater monitoring

Three types of piezometers were installed. They were standpipe piezometers, pore pressure pneumatic and vented wire transducers with automatic data acquisition. Monitoring measurements was performed together with inclinometer tests at more or less monthly intervals. Measurements of pore water pressure by pneumatic transducer were performed using nitrogen gas and two measuring methods with gas flow and. after gas shut of. Water table location and pore water pressure were measured in order to estimate effective stresses. Achieved results were compared with mean monthly precipitation measured in the investigated areas (PAS). The record monthly precipitation of 230 mm in Jun 2006 had response in high, 45 kPa pore water pressure at Sekowa landslide (Fig.7). Values of pore pressure had usually better correlation with displacements than with groundwater level depths (Fig.8)

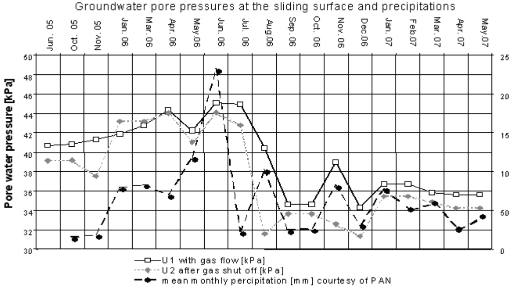

Fig. 7 Comparison of pore pressure and precipitation, Sekowa landslide

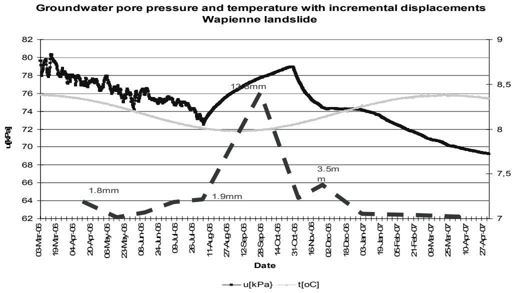

Fig. 8 Comparison of displacements, pore press. and temperature, Wapienne landslide

9. Slope stability analysis

Slope stability calculations were performed on two landslides chosen for remedial works. They included different methods of calculations with classical Bishop, Janbu and FEM analysis using SOILVISION codes. Exemplar results of stress analysis of Sekowa landslide using FEM and linear elastic model are presented on figure 9. These analyses included cumulative ground movements and pore pressure monitoring measurements for the sliding surface. Accounted final mesh indicated that the landslide is still very active and could damage a public road. Proposed counteraction was checked using classical methods, based on relative factor of safety (Fs). Values of Fs before stabilization were slightly above Fs =1.0. Bishop Method gave relative factor of safety equal 1.13 before counteraction and 1.58 after proposed stabilization works (Fig.10).

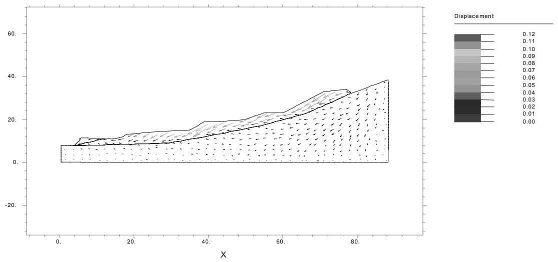

Fig. 9 Slope stability analysis by FEM method - calculated displacements

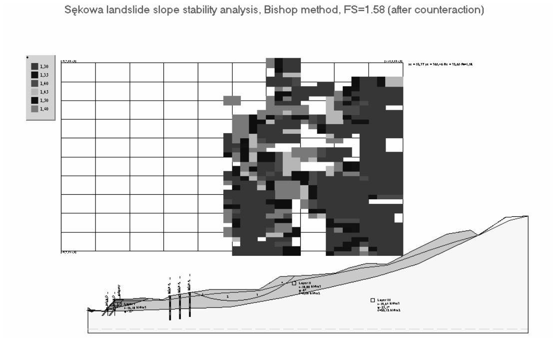

Fig. 10 Slope stability analysis by LEM, Bishop method with remedial works

10. Mitigation measures and prevention

Project included four remediation projects preparation together with the geotechnical site reports in very short period of time (with no finance for monitoring). For other landslides preliminary stabilization concepts had to be proposed. Remediation included construction of landslide effective drainage systems, rebuilding of the roads, stabilization by micropiles or piles and reinforced earth retaining walls on micropiles foundation. Slope stability analysis's detected that in Sekowa stabilization of landslide lower part crossed by the public road is possible. It was planned that before stabilization works, effective drainage systems should be built. Due to the lack of financing, counteraction works were stopped few times and drainage system was not built on time, however author of this paper order it. When shallow excavation for micropiles wall was formed above the road cumulated displacements increased and reached value of 72mm in 2 months time, that was 3 times more than during all 2006 year (Fig. 11). Hopefully after drainage system building and micropiles installation movements stopped, however some movements in B direction occurred. Monitoring measurements performed by the period of over 2 years detected that some landslides, due to its size and observed ground movements was found to be economically impossible for remediation and only partly counteraction and building effective drainage systems seems to be possible.

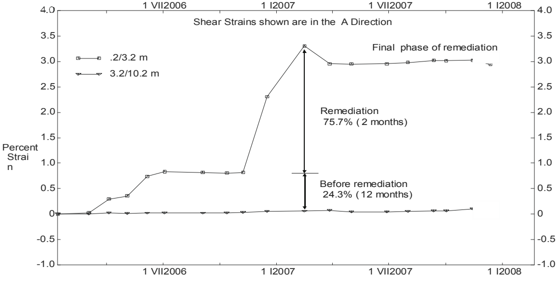

Fig. 11 Shear strains before, during and after remediation, Sekowa landslide

Conclusions

The results of research and the background of SOPO project were introduced. Summary of monitoring results conducted since January 2006 are presented on figure 12. It includes landslide depth, activity, groundwater level depth and pore pressure parameters. These results indicate that landslides to depth of 10m had usually the largest displacements, however sometimes probably only upper parts of paleolandslides were activated. They usually had very high pore pressure values at the sliding surface.

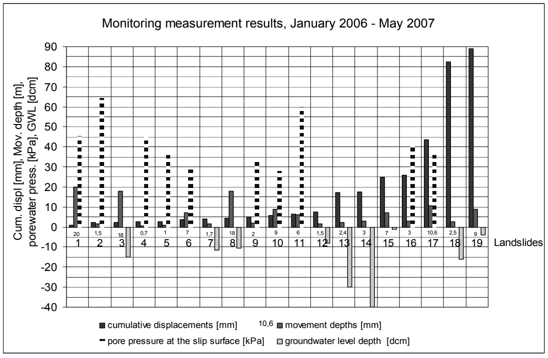

Fig. 12 Comparison of landslide monitoring results

Major findings of the investigation are:

1. Presented investigations allowed landslide complex characterizations and delivered new data for prediction of its behavior, stabilization possibilities and preparation of four landslides counteraction projects for landslide remediation.
2. Investigated landslides as soil-rock type deposits involved in creep processes were difficult for in-situ and laboratory tests therefore the main effort was connected with proper instrumentation, monitoring and data interpretation.
3. Monitoring measurements detected slip surfaces depth and groundwater parameters. Investigated flysch landslides varied in depth from 1.0m to 20.0m with movements from few to ninety millimeters. Movement activation was caused mainly by the intensive precipitation.
4. Research proved that site investigation together with laboratory tests and monitoring, could deliver many landslide data for remediation and should be performed before description of landslide counteraction possibilities by the enough long period of time.
5. Carpathian landslides are not easy task for stabilization in all of the scientific, technological and financial aspects therefore research methods should always be adequate to the landslide type and included monitoring measurements.

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Landslide Hazard in Changunarayan Hill of Nepal: Need of Geotechnical Investigation and Preventive Plan for the Protection of a World Cultural Heritage Site

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Abstract. Changunarayan Hill in Kathmandu Valley of Nepal is home to Nepal's oldest Hindu temple and one of the seven world cultural heritage monuments in the valley. Due to various human activities and natural changes, the hill slopes are at risk of failure, which may severely damage the temple, the peripheral structures, and the heritage area. Recent human intervention such as road cutting, sand mining, rise in number of unprotected slopes and unprotected river banks have largely contributed to the increasing risk of landslides in the hill. To prepare a comprehensive preventive plan against possible landslide damage to the structures of great historical value, it is urgently important to go for detailed investigation in the hill. This paper presents a brief background of the Changunarayan Hill, and puts forward a plan of geotechnical investigation for an integrated approach to protecting the heritage site from landslide threat during earthquakes and extensive rainfalls based primarily on the findings of a few times of preliminary surveys in the area.

Keywords. Changunarayan, Cultural heritage, Kathmandu valley, Landslide hazard

1. Introduction

The Changunarayan Hill, situated on the northeast corner of Kathmandu Valley, is an extended low-height hillock of Dolagiri Ridge measuring about 200 m from the nearest river level and about 1550 m above mean sea level (Figure 1). It lies on the left of one of the main rivers in Kathmandu Valley, Manohara River, and is home to one of the seven world cultural heritage monuments in the Kathmandu Valley. Due to increasing human intervention as well as changes in natural conditions such as geology, geomorphology, and groundwater hydrology of the hill, however, the world heritage site has been threatened by landslides and related slope failure problems. The risk of landslide damage, especially during a high-magnitude earthquake or concentrated heavy precipitations is very high, but no concerned authority in Nepal seems worried about the level of damage risk. One major problem behind no such initiatives towards protecting the cultural heritage sites from earthquake or landslide hazards in the part of government agencies may be lack of financial resources. The only fund that is being used in maintenance of the temple premises comes from the entrance fee paid by foreign visitors, which merely amounts to around a million rupees (equivalent to about 15 thousand US dollars) in one year making it almost impossible to go for planning any kind of technical investigation and preventive measures against the natural hazards. For a quick reference, the record of number of visitors to the temple premises shows that a total of 20,251 foreign nationals visited the temple in the year 2000-2001 while the number decreased to 19,188 in the year 2001-2002.Decreasing further in 2002-2003 and 2003-2004, the number came down to 12,831 and 6,634 respectively (source: Changunarayan Village Development Committee, 2004). This clearly indicates that the collected entrance fee is not even enough for the regular maintenance work.

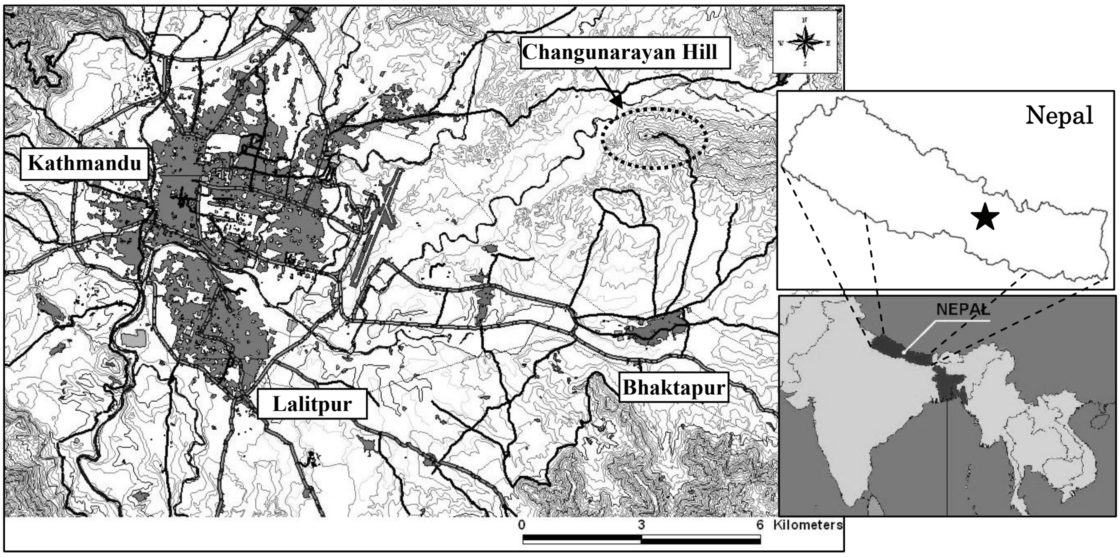


Fig. 1 Changunarayan Hill in Kathmandu Valley

There certainly are concerns of locals and committees associated with the temple management and maintenance including the Department of Archeology, the sole government authority to look after all affairs related to protecting the cultural heritage, about the ageing of the temple structures as well as landslide threat. However, lack of coordination among the government agencies, management caretakers, and the stakeholders has resulted in no concrete plan towards protecting the oldest standing historical monument of Nepal. It is therefore urgently necessary to go for detailed geotechnical investigation to reveal the facts of landslide hazard in the Changunarayan Hill and the level of damage risk to the temple structures and surround area, and to prepare a preventive plan before an 8-Richter Scale earthquake hits central Nepal within a decade or so or a heavy downpour initiates a massive landslide in the hill.

1.1 Changunarayan Temple

Changunarayan Temple atop Changunarayan Hill is situated at a distance of approximately 13 km northeast of Kathmandu center and about 5 km north of Bhaktapur core area (MoIC, 2000). The temple and its surrounding area were listed as world cultural heritage monument nearly three decades ago (in 1979), and the Government of Nepal has recognized the whole temple area as protected historical monument zone under the provision of the Ancient Monument Preservation Act 1956. With great historical, religious, and archeological value, the temple is highly artful in its construction (Figure 2). The temple complex also houses several exquisitely carved Nepalese stone art work of high cultural and historical value. Moreover, the temple courtyard houses half a dozen statues of Hindu God Vishnu including a 5th century 10-armed masterpiece. Based on a stone inscription dated 464 A.D. discovered inside the temple premises, it is considered that the Changunarayan Temple is the oldest pagoda architecture of Kathmandu Valley (Witzel, 2004). The erection of temple itself dates back to 325 A.D. After subsequent human settlements around the temple, the Lichhavi King Manadeva erected the inscribed stone pillar in 364 A.D., which still exists (MoIC, 2000) in the temple premises. The present outer structure of the temple, however, was rebuilt in 1702 A.D. following a destructive event of fire (DOA, 2004).

1.2 Changunarayan Hill

There are about 900 households in whole village of Changunarayan while 143 households are located atop the hill (source: Changunarayan Village Development Committee, 2004). This has obviously made the Changunarayan Hill undergo influence of human activities and land use, some of which may include significant reduction in vegetation cover, various agricultural activities leading to increased groundwater level, water pooling for various purposes, slope cutting, sand mining, soil excavating, construction work, etc. Moreover, the unprotected slopes and erosion-prone top layer soils have led to occasional slope failures. All this has aggravated the chances of landslide initiation anytime during heavy rainfalls or even a low-intensity earthquake. As shown in Figure 3 (southwest view), the average hill slope angle is very gentle, at a range of 10 to 15 degrees. However, local slope angles at various locations go as high as 30 to 40 degrees. It clearly indicates that the Changunarayan Hill has many undulations and flattened slopes, and these are the indications of previously occurred landslide blocks, which may be stagnant or stable at present. Such naturally stabilized landslides, with the passage of long time, may be reactivated by external factors such as heavy rain or earthquake in addition to the human disturbances. The geology of Changunarayan Hill consists of about 2000 m thick hard rock strata of Kulikhani Formation which is composed of greenish biotite schist with schistose quartzite, as shown in Figure 4. According to Shrestha (1998), this rock formation is relatively resistant to weathering and possesses quartz veins with some base metal mineralization. They also state that the rocks in this formation when weathered deeply are very much prone to landslides and slope failures. This also indicates that the chances of landslide initiation in the Changunarayan Hill are high.

2. Traces of Landslide Hazard and Expected Damage

The authors have had a total of three occasions in three consecutive years beginning 2003 to conduct field inspection of the hill upon being informed unofficially that the hill slopes in the Changunarayan area were being observed moving at different locations including numerous spots of minor surface-layer failures. The topographical inspection and the visual confirmation of ground subsidence including failure of top layer soil at many locations (Figure 5, 6) were evident that the hill consists of slow moving seasonal landslides.

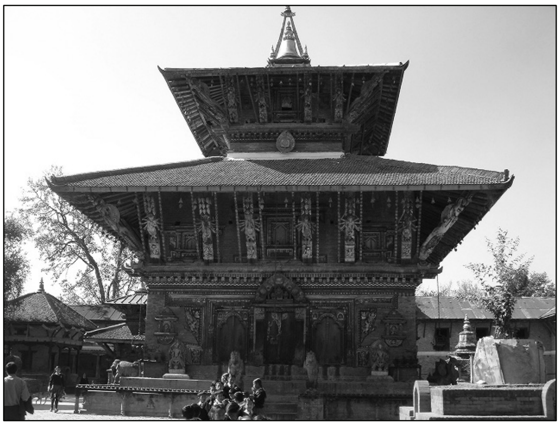


Fig. 2 The Changunarayan Temple (2004.11)

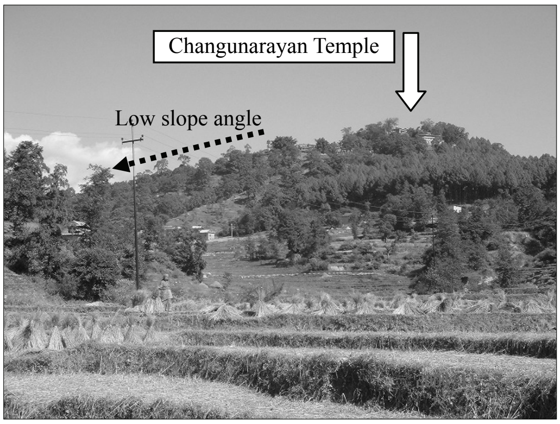
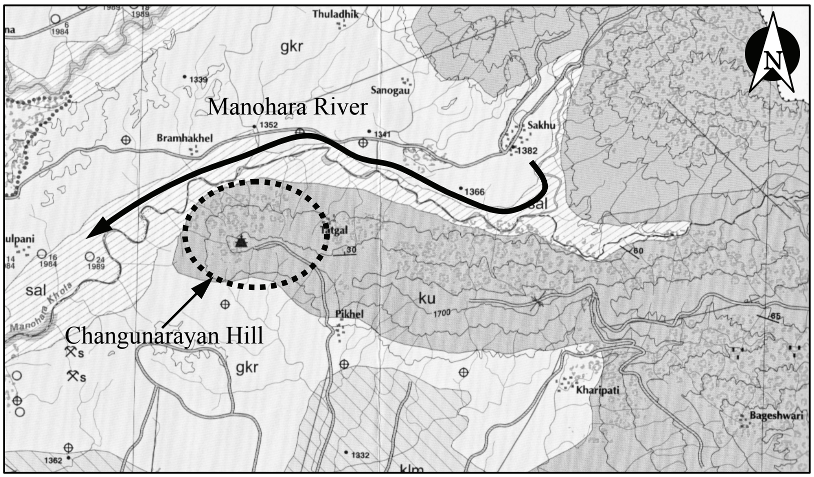


Fig 3 A southwest view Changunarayan Hill



Environmental Geological map of Kathmandu Valley (Shrestha, 1998)

Legend

klm	Kalimati formation
sgn	Sheopuri gneiss
Ku	Kulikhani formation
Sal	Recent alluvial soil
gkr	Gokarna formation

Fig 4 Geological map of Changunarayan Hill and surrounding area

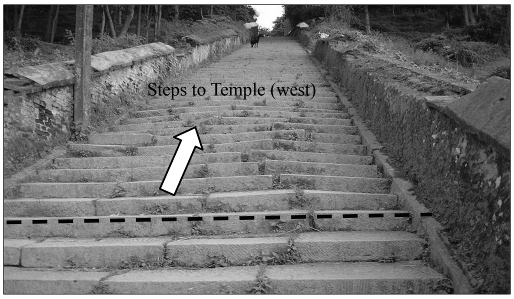


Fig 5 Bulged steps to the temple (November 2003)

The inspection team confirmed that there were enough traces of landslides in the Changunarayan Hill and collected a few top layer soil samples for laboratory tests. The test results further confirmed that the topographical features of the hill slopes and soil strength characteristics are very close to causing land-sliding and slope failure. Moreover, a few places of exposed sedimentary deposit were found to consist of weak layers of clayey silt, which might have played a role of slippery strata for the landslides. This confirms that the Changunarayan Hill is no less free of landslide hazard. The precipitation record of Kathmandu Valley indicates that the annual average value stands at about 2000 mm and as high as 100 to 200 mm of maximum hourly value. This means that there is enough rainfall potential to cause land sliding in the hills and mountains of Kathmandu Valley. Besides, the earthquake risk in Kathmandu within the next 10-20 years has been predicted to be one of the highest in the world.

Although no accurate prediction of earthquake-induced landslides and slope failures has been made yet, it is expected that a large number of natural and man-made slopes within the valley will collapse extensively. The Changunarayan Hill will be no exception. There is enough potential that the existing landslide blocks in the hill will move largely during the earthquake and cause damage to the temple premises.

In the worst situation, such damage may result in complete destruction of the Changunarayan Temple and the monuments in its surroundings.

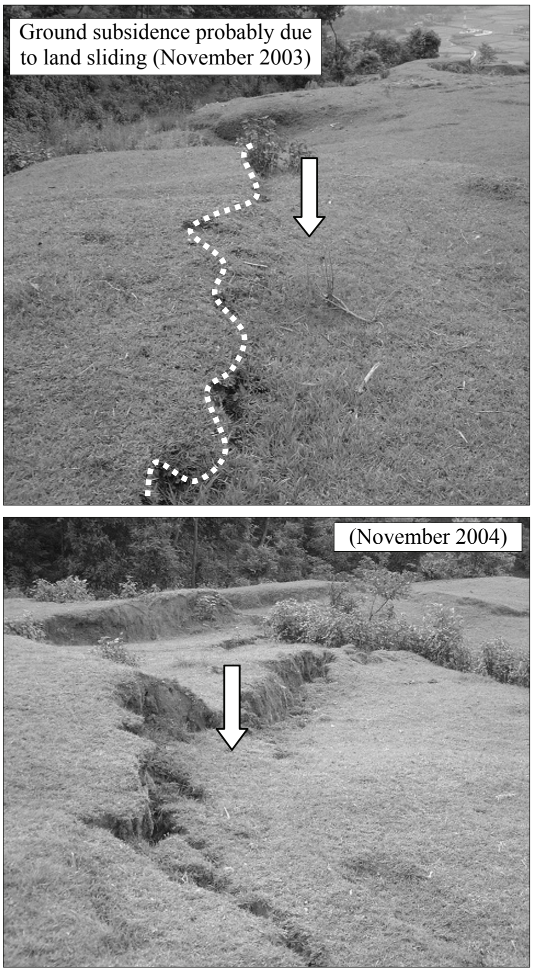


Fig 6: Photographic evidence of landslide initiations in Changunarayan hill slopes (November 2003)

3. Possible Causes

Apart from the natural causes, such as erosion, weathering of geological strata, ageing of structural material, etc., the human interventions such as land use activities, agricultural activities, road cutting and unprotected slopes, water storing ponds, sand mining, unprotected river banks, etc. seem to have significantly contributed to aggravation of chances of landslide occurrence in the Changunarayan Hill. As shown in Figure 7, the interpretations from aerial photo and topographic map reveal that the hill area consists of four major landslide blocks on north, west, and south sides. This probably is the major cause of landslide hazard in the hill slopes, and the minor slope failures and land subsidence on the north side (Figure 6) may be surface ruptures of these landslide movements.

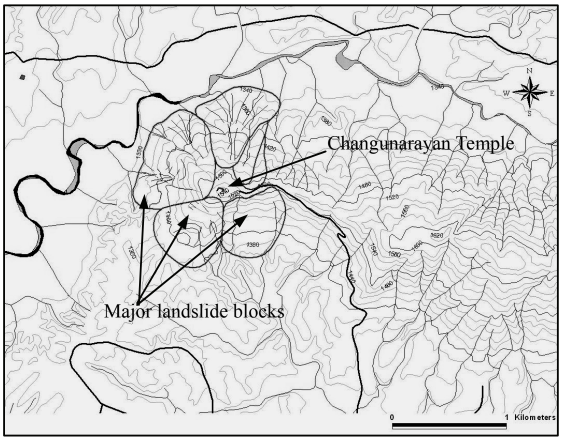


Fig 7 Major landslide blocks in Changunarayan Hill as identified in aerial photo and topographic map (1:25000)

4. Investigation for Preventive plan

a) Historical evidence survey: The historical evidences indicate that the Changunarayan Temple is the oldest religious monument in Kathmandu Valley. So, it is obvious that there are records of historical developments and changes. A study of these records and questionnaire survey over the local people and historians will reveal various facts about past landslides and related failures in the hill.

b) Community level participatory activities: Involvement of various level of people such as students, locals, historians and experts in questionnaire surveys, awareness raising forums, etc, and participation of school students in field visits, drawing competitions, essay writings, etc. are expected to raise the landslide awareness of every level of people. This will greatly help reduce the human activities contributing to landslide initiation.

c) Landslide mapping: Identifying existent landslides with the help of topographical map, aerial photographs, land-use pattern, and geological map will help locate major landslide blocks and areas of greater instability leading to preparation of hazard map.

d) Geotechnical investigation: Geotechnical investigation needs to mainly focus on borehole exploration, standard penetration test, displacement measurement of active landslide blocks, and laboratory tests on collected soil samples to estimate strength parameters and mineralogical composition.

e) Borehole investigation including N-value and undisturbed sample collection: Based on the identified landslide blocks and their scales, 3 to 4 typical borehole locations will have to be selected. The borehole investigation may help find out precisely the depth of sliding landslide blocks, and may also serve as locations to measure amount of displacement and groundwater level. The determination of N-value (i.e., number of blows in standard penetration test) may also be carried out for an estimation of landslide mass strength so that it helps plan preventive measures. Moreover, undisturbed sampling will help determine close-to-true strength parameters, which will be used in stability analysis of landslides and slopes.

f) Laboratory soil tests: The laboratory soil tests may mainly consist of strength measurement in ring shear apparatus and mineral identification by x-ray diffraction test. However, to characterize the soil type involved in landslides and slope failures as well as the stable mass, it may be necessary to conduct other basic tests intended for the evaluation of physical properties such field dry density, solid density, liquid and plastic limits, gain size distribution, coefficient of permeability, etc.

5. Summary and Conclusion

Preliminary surveys in Changunarayan Hill in Nepal indicate that there are tremendous chances of landslide initiation leading to significant damage to Changunarayan Temple and structures in its periphery. Especially, the next large earthquake and concentrated heavy rainfall may destabilize the hill slopes. Growing human intervention in the area is also largely contributing to small-scale slope failures and large-scale landslide initiation. Since 2003, the authors have found traces of slope movements and existence of four major active or relict landslide blocks in the hill. Therefore, it is of urgent need that geotechnical investigations be conducted in the area and an integrated plan for landslide prevention be made so that one of the highly valued cultural heritages in Nepal can be protected from potential destruction. Due to lack of budget, however, Nepal Government cannot put this work in priority for some years to come, so the authors appeal to the international society for possible technical and financial assistance to conduct geotechnical investigation in the Changunarayan Hill of Nepal.

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Characteristic Features of Landslides in the Vicinity of Major Road Network in Central Nepal

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Abstract. Due to lack of investigation and inadequate preventive efforts, the landslides and slope failures that occur along the arterial roadway routes in Nepal cause massive infrastructural damage and economic impact every year. Except for simple retaining structures and slope bioengineering practices, there are little efforts toward roadside slope management. Not only due to natural causes, human factors are equally responsible for land sliding along side the roads, and road building process itself is often considered to have induced many landslides in Nepal, mainly because road building proceeds in Nepal without proper planning for roadside cut slope protection. With an aim to understand typical features of landslides in the vicinity of roads in Nepal, this paper focuses on a high landslide density area of the major road connecting the capital city of Kathmandu and major business centers and populous areas on the southern plains, and discusses at first landslide occurrence scenario, area-specific features, and distribution pattern, and then addresses land sliding mechanism in terms of the relation between material shear behavior and mineralogical composition.

Keywords. Landslides, Nepal, shear strength, mineralogy

1. Introduction

Nepal, as indicated in Fig.1, occupies nearly one-third length of the Himalayan Arc where the mountain chains range from a low class erosion-prone hills of immature soft rocks on the south to high altitude steep rocky mountains on the north. Various geological investigations and field verifications have revealed that the percentage of landslides and related failures occurring in low to middle class mountain ranges including the valleys between these mountains is far higher than that occurring in any other parts of the country. Especially, the landslides and slope failures including debris flows that frequently damage the road infrastructure in Central Nepal draw significant attention of the nation in terms of the concern over economic loss and public suffering (Fig.2). The road network that suffers the most from landslides during rainy periods includes the most important first class national roads in Nepal that connect the country's capital area to the rest of business centers and densely populated areas in southern plains. Despite almost every year's of suffering from landslide-related damage along these roads often resulting in days to week long road closures, however, there are insignificant efforts in the part of government as well as concerned people and organization to study these landslides and their engineering properties to go for appropriate preventive techniques.

For proper management of a road network, it is all important to deal with landslide problems, and to deal with the landslide problems, it is essential to understand their geotechnical aspect. As a part of the efforts to understanding Nepal landslides, Yatabe et al. (2005) have investigated a large part of the arterial roads in Central Nepal, and have prepared a landslide distribution map along the road corridors, as shown in Fig.3. Based on their findings and results of laboratory investigation involving ring shear tests and mineralogy, this paper discusses the landslide characteristics from soil strength and mineralogical points of view.

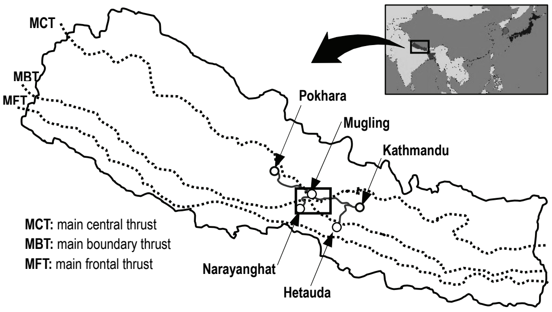

Fig. 1 Map of Nepal indicating the landslide-hit road network (Kathmandu-Pokhara-Narayanghat)

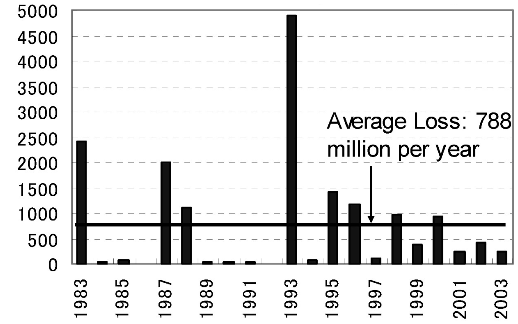

Fig. 2 Economic loss due to landslide and flood disasters in Nepal (1983-2003, DWIDP, 2003)

2. Landslides in Nepal and the study area

The present trend of prioritizing natural disasters in Nepal indicates that landslide events along the national trunk roads receive greater attention, mainly due to heavy economic losses and large number of people affected. Previous studies also indicate that there are many landslides and slope failures along two main national highways, namely Prithvi Highway and Tribhuvan Highway (LRA/DoLIDAR/Scott Wilson 2002) as most parts of these highways pass over geologically unstable slopes of the Lesser Himalaya. A study conducted by

Brabb, as mentioned in Bhattarai et al. (2002), revealed that the landslide density in Nepal ranges from 0.2 per linear kilometer on stable lands to 2.8 per kilometer on very susceptible areas exposed fully to human intervention. Likewise, Yagi and Nakamura (1995) upon analyzing landslides in an 85x75km area peripheral to Kathmandu valley mainly on the west in the Lesser Himalayan Zone revealed the effect of relief and rock types on the process of landslide occurrence. They calculated the mean landslide area ratio to be 6.61% of the total area mapped with a greater values over phyllitic and faulted quartzite zones and smaller values over granitic and quartzite zones.

Similarly, a landslide inventory study in the Lesser Himalayas conducted in a period between 1985 and 1990 by the Department of Mines and Geology of Nepal indicates that slopes ranging from 21 to 30 degrees and 31 to 40 degrees consist of greater number of landslides (Karmacharya et al. 1995). This study also revealed that there is domination of translational type of slides in central Nepal and that the highest number of landslide incidences has been found in geological formations consisting of schist and gneiss.

As such, the hazard mapping as a tool to deal with natural disasters in Nepal is yet to gain momentum although certain areas have been already mapped for landslide hazards. For example, Higaki et al. (2000) have mapped the landslides of Bhotekoshi area, and Dhital (2000) has discussed an overview of landslide hazard mapping in Nepal. Moreover, many other reports are available on different case studies of landslide hazard mapping in various mountain locations of Nepal. Little work is found, however, in the field of roadside landslides, which have been causing problems in greater scale for last several years and are a great challenge to Nepalese landslide professionals. Yatabe et al. (2005) have prepared a landslide map of main national highway corridors in Nepal, consisting Prithvi Highway (Kathmandu-Pokhara), Tribhuvan Highway (Kathmandu-Hetauda), and Narayanghat-Mugling Highway. They conclude that there is greater distribution of large-scale landslides in Prithvi Highway corridor section from Malekhu to Mugling and Narayanghat-Mugling Highway corridor section from Mugling to Jugedibazar (Fig.3).

With this background, this paper focuses on the most suffering sections of the national road network, as already mentioned elsewhere. As indicated in Fig. 1 and Fig. 2 (black rectangle over the map of Nepal), the study area consists of about 75 km of the road network to Kathmandu and is almost midway from Kathmandu to Pokhara. The geology of the study area consists mainly of phyllite, slate, and quartzite as the dominant rock types and closely passing Main Central Thrust (MCT) and Main Boundary Thrust (MBT), as also indicated in Fig.1, along with numerous local faults (Stöcklin & Bhattarai 1982). In the past 20 years or more, the landslide problem in this section of the road network has been so extensive that the road traffic had to be closed for a few days to as long as one to two weeks every year (during monsoon period), massive maintenance budget has been spent so far in repairing the damaged road sections, and that a huge amount of economic loss due to disrupted traffic as well as maintenance work has been incurred. All these repeated problems in this road network urgently demand an integrated scientific approach to study landslide mechanism and their mitigation in more geotechnical way.

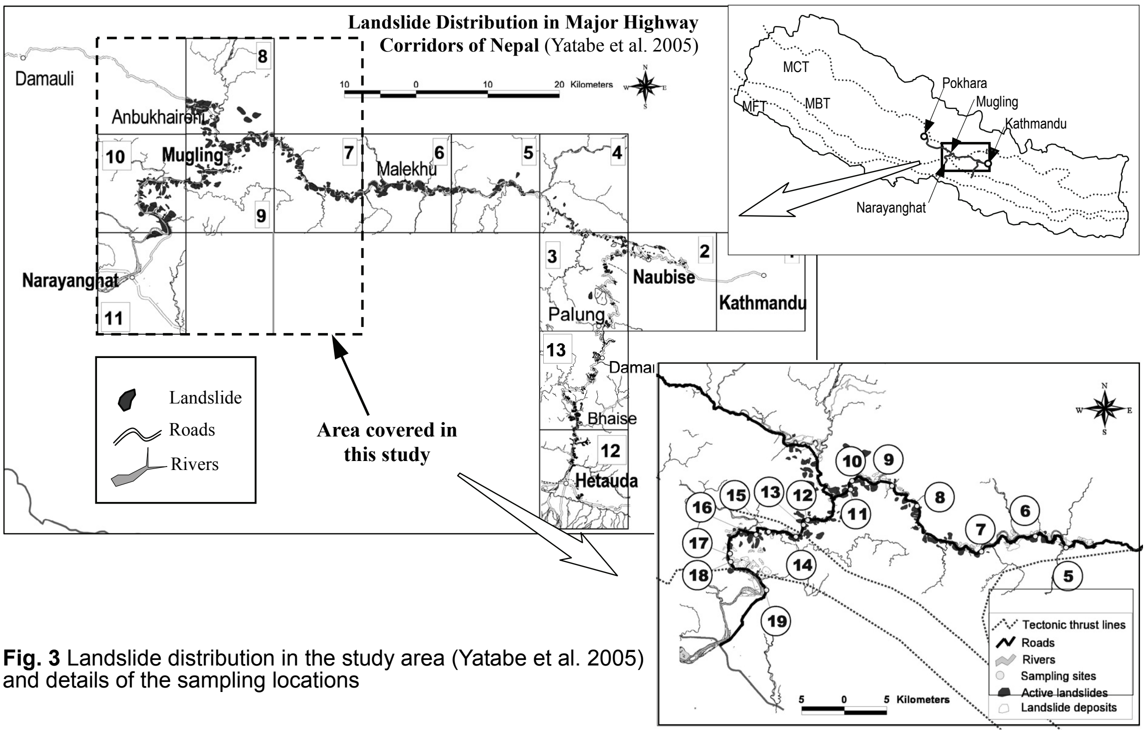

Fig. 3 Landslide distribution in the study area (Yatabe et al. 2005) and details of the sampling locations

3. Material and method

In the first part of the study, the landslide distribution pattern in the target area was analyzed from geological and geomorphological points of view, basically in terms of geological formation and average angle of existent landslide slopes. The method used for this includes identification of active landslide sites over the topo sheets, digitizing them over ArcGIS environment, calculating their individual areas and slope angles, and analyzing the obtained data. As stated previously, the study area lies in phyllite and slate dominant zones, so the analysis was done grouping the landslides in these two geological formations.

In the second part, laboratory investigation mainly focusing on shear strength and mineralogical influence was conducted on the samples collected from the landslide areas. About 16 soil samples were collected from location number 5 to 16 (Fig. 3). Due to limitations of sampling technique, however, the samples consist of both exposed clayey soils of the landslide mass and exposed slip layer soils. The collected samples were tested in laboratory for physical properties, drained strength parameters by ring shear machine, and mineralogy by X-ray diffractometer. All samples tested in the ring shear machine were sieved through 425μm mesh, and shearing was conducted over remolded, saturated, normally consolidated annular specimens of 8 cm inner dia, 12 cm outer dia, and 10-12 mm thickness. The average shear rate was set at 0.15 mm/min through the shear plane so as to let any developed pore-water pressures dissipate completely. In X-ray diffraction (XRD) tests, all samples were examined by powder method (for overall constituent minerals) as well as oriented aggregate method (for constituent clay minerals).

4. Results and discussion

Fig.4 presents a summary of geological and topographical distribution of landslides in terms of dominant rock type, landslide area, and average slope inclination based on the GIS analysis (Yatabe et al., 2005). The data indicates that the landslide slopes range between as gentle as 15 degrees to as steep as 50 degrees, and that the landslide area ranges from a few thousand square meters to as high as 0.65 square kilometers. From the figure the upper bound slope-area relation can be estimated to be (area = - 2.6*slope angle + 130) for slope range of 25 to 50 degrees.

The results of all laboratory tests including physical parameters, strength parameters, and mineralogical composition are summarized in Table 1. The ring shear tests results indicate that the peak angles of internal friction for the tested samples vary from 20 to 35 degrees and the residual angles of internal friction vary from 18 to 34 degrees (as also indicated in Fig. 5). Comparison of Fig. 4 and Fig. 5 reveals that the average slope angle is slightly greater than average angle of internal friction, which may infer that most landslides are in the state of movement. The angles of drained internal friction when plotted against the clay fractions of the samples show a trend of decreasing friction angles with increased clay fraction (Fig. 6). This trend is similar to the results presented by various previous researchers (such as Skempton, 1964; Borowicka, 1965; Binnie et al., 1967). However, the data can be seen scattered widely, which perhaps is due to dissimilar composition of constituent minerals. For example, one sample with high quartz content (sample no. 7-1) is seen to have high angles of internal friction despite having more than 20% clay fraction.

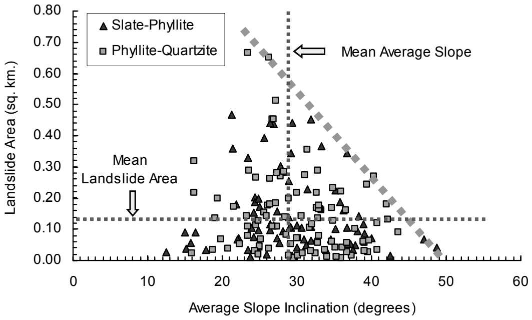

Fig.4 Relation between average slope angle and landslide area

Table 1: Summarized results of physical tests, ring shear tests, and X-ray diffraction tests

Sample No.	Solid density (g/cm³)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	ϕ_d (degree)	ϕ_r (degree)	Grain size distribution (%)			Peak intensity of main constituent minerals					Geology (rock type)
							< 2μm	2~75μm	75~425μm	Sm	Chlorite	Micas	Quartz	Feldspar	
5(2004.11)	2.74	34.10	20.69	13.41	22.04	21.00	21.00	59.70	19.30	-	300	3600	800	-	Chloritic phyllite, tuffaceous
6(2004.11)	2.78	-	-	-	25.77	25.32	18.00	70.50	11.50	-	250	2300	800	-	Slates, phyllites
7(2004.11)	2.72	21.70	18.26	3.44	24.00	23.06	12.00	80.20	7.80	-	950	1800	900	-	
7-1(2004.11)	2.68	19.42	15.61	3.81	35.69	33.87	21.50	58.20	20.30	-	150	220	1500	-	
7-2(2004.11)	2.81	34.50	14.76	19.74	26.05	25.32	6.50	76.60	16.90	-	450	1320	650	-	
8(2004.11)	2.83	27.90	14.14	13.76	22.39	20.96	24.00	69.40	6.60	-	2600	3350	200	-	Phyllite, phyllitic quartzite, conglomerate
10(2004.11)	2.73	29.60	16.81	12.79	26.88	26.63	27.00	62.70	10.30	-	500	1100	700	-	
11(2004.11)	2.73	24.57	14.55	10.02	31.15	30.34	8.50	39.10	52.40	-	200	750	800	-	
12(2004.11)	2.76	34.67	20.41	14.26	22.51	20.39	16.00	76.40	7.60	-	4045	1115	260	-	Phyllites, quartzite, dolomite
14(2004.11)	2.79	30.50	13.21	17.29	20.07	18.74	20.50	68.00	11.50		1620	870	720	130	Dolomite, dense stromatolitic
15-1(2004.11)	2.77	28.50	15.36	13.14	24.07	23.51	27.00	65.80	7.20	-	1000	1160	485	-	Slates, phyllites
15-2(2004.11)	2.76	33.25	14.33	18.92	26.44	23.51	21.80	67.60	10.60	-	1600	950	500	-	
15-I(2005.11)	2.79	38.30	18.67	19.63	23.63	22.58	21.00	67.20	11.80	○	555	340	370	590	
15-II(2005.11)	2.80	31.00	16.50	14.50	26.67	24.42	24.80	66.50	8.70	-	610	430	495	960	
15-III(2005.11)	2.76	32.15	19.62	12.53	24.96	23.83	16.00	69.70	14.30	◎	785	465	425	490	
16(2004.11)	2.86	25.50	12.72	12.78	28.91	27.91	13.00	75.90	11.10	-	1415	-	-	1135	

The XRD test results, on the other hand, show that the main constituent minerals of the tested soil samples are chlorite, micas, and quartz (minerals of minor presence are excluded). Since the presence of chlorites and micas in the tested samples is notably high, there may be significant influence of these two minerals on the shear characteristics of the collected soil samples. Assuming influence of other factors to be little, the peak intensities of chlorites and micas as obtained from the XRD charts are considered to inversely affect the frictional resistance of a sample. A quick and rough estimation of relative amount of constituent minerals can be made by comparing the peak intensities, especially when the degree of mineral decomposition is found negligible. Fig. 7 shows influence of the ratio of sum of peak intensities of chlorites and micas to that of quartz and feldspar on the internal friction angle. The trend is that the increased ratio results in reduced frictional resistance. This is because of lesser frictional resistance of chlorites and micas against any applied stress, especially in presence of water.

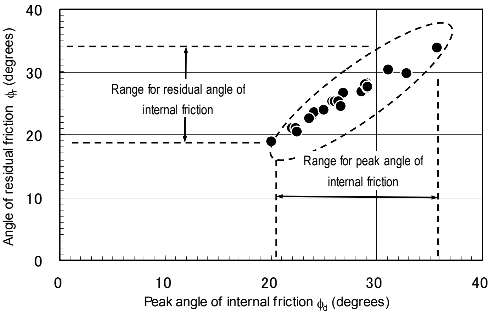

Fig.5 Range of peak and residual angles of internal friction for the collected samples

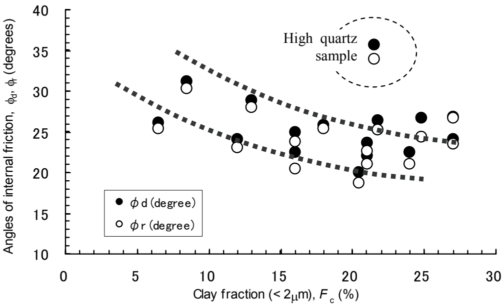

Fig.6 Variation in angles of internal friction with the amount of clay fraction (<2μm)

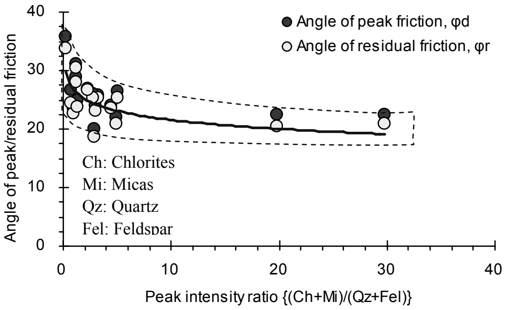

Fig.7 Variation of internal friction angle with peak intensity ratio of (chlorite+micas) to (quartz+feldspar)

5. Concluding remarks

A basic analysis of geology and geomorphology of landslides along a section of major roadway network in Central Nepal revealed that the landslide density is high in phyllitic and slate zones. It also revealed that the average angle of landslide slope in the study area is close to 30° while the mean landslide area is as big as 0.15 sq. km.

The laboratory investigation of the identified landslides revealed that the landslide soils have comparatively high angles of internal friction and possess high composition of chlorites and micas as main constituent mineral, especially in phyllitic zones. An analysis of influence of chlorite and mica content on the frictional resistance of collected samples indicated that the soil strength remarkably decreases with the increase in chlorite and mica composition. Particularly, the sheet-like mineral structure of micas with specific surface in the range of 65 to 100 m2/g gives them greater water absorption capacity, and illite (i.e. hydrous micas) particles tend to disaggregate considerably in water (Grim 1962) causing reduced particle-to-particle attraction leading to lesser frictional resistance.

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Large Slow-moving Rock Slides - Earth Flows: the Case Study of Ca’ Lita (Northern Apennines, Italy)

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Abstract. The Ca’ Lita landslide is a large and deep-seated mass movement located in the northern Apennines of Italy. It consists of a complex-composite landslide that affects Cretaceous to Eocene flysch rock masses and chaotic complexes. The landslide head zone resumed activity in 2002 and in 2004 the landslide was totally reactivated. More than 50 m retrogression of the scarp, and about 400 m advancement of the toe threatened villages and an important road connecting several key industrial facilities located in the upper watershed.

A national state of emergency was declared by the Authorities, following the evolution of 2004. A large plan of civil protection interventions was implemented, aimed at the management of risk and at the identification and realisation of structural mitigation.

The Ca’ Lita landslide is a noticeable case history both from the geomorphic and the risk management perspectives.

The relatively fast evolution undergone by the phenomenon from 2002 to date, and the remarkable advancement of the toe, point out that total and partial reactivations of dormant landslides can cause unexpected consequences in terms of involvement of new areas that, in practice, have no previous hazard rating assigned.

Also, the landslide is a test bed for coupled monitoring and mitigation actions that, in a relatively short time, have allowed passing from response, to mitigation and preparedness phases.

In this work, the management of the emergency is presented in the frame of monitoring, mitigation and modelling activities that are the result of the shared effort of public offices and research institutes.

Keywords. landslide risk; investigation; monitoring; numerical modelling; mitigation

1. Introduction

Reactivation of large prehistoric landslides affecting weak rock masses are a concern in many mountain valleys throughout the world. Weak rocks make up most of the northern Apennines of Italy, so that landslide events are most often due to partial or total reactivation of ancient landslide bodies created by complex deep seated rock slides – earth slides-flows (Rossi et al., 2007).

This paper deals with the reactivation of the Ca’ Lita landslide, that took place from 2002 to 2004, when the landslide mass was remobilized over an area of more than 1 km^2, with an advancement of the toe of more than 400 m (Borgatti et al., 2006). No person was injured or killed, but the magnitude of the event was such that a national road of strategic importance and socio-economic activities inside and in the vicinity of the landslide were endangered for months. This caused a national emergency status to be issued for the affected areas. Since 2004, more than 6 million Euros have been invested by regional Civil Protection Agency to finance response, preparedness and structural mitigation actions. This allowed for the collection of a large investigation and monitoring dataset, and for the design and construction of countermeasure works such as, principally, a large number of deep drainage wells and of pile-founded retention walls.

The aim of this paper is to summarize the investigation, monitoring and modelling activities carried out from 2004 in order to support the analysis of landslide triggering and evolution mechanisms and, ultimately, to identify and design proper countermeasure works.

2. Geographic, geologic and geomorphic setting

The Ca’ Lita landslide is located in Northern Apennines of Italy, within the Secchia River basin, at an altitude ranging from about 650 m to 250 m (Fig. 1). Administratively, it belongs to the Province of Reggio Emilia that, in turn, is part of Emilia-Romagna Region.

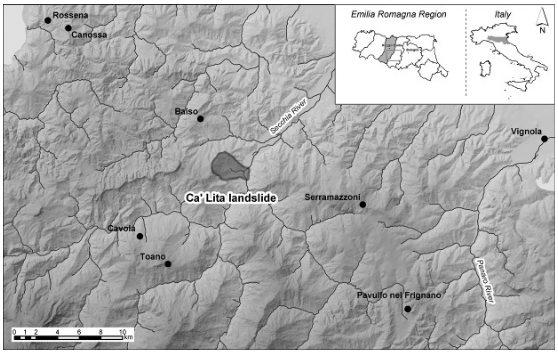

Fig. 1 Geographical location of the study site

The northern Apennines are characterized by a fold-and-thrust geometry that was produced after the collision of the Adria and European continental plates starting from the Oligocene. The outcropping rock masses are represented by arenitic flysch rock masses and mélanges, with an abundant or prevailing clayey component. In all the units, the degree of tectonisation is always intense and different sets of joints are detectable at any observation scale, with repetitions of tectonic phases and inversion of stress directions. Arenaceous flysch rock masses show also marked lithological and structural complexities that imply heterogeneity and anisotropy, both at a mesoscopic and macroscopic scale. The clayey materials described as mélanges are characterised by disarranged layers of competent rocks and clay shales, jointed up to sheared, which display a chaotic structure. In this case, the primitive condition of weak rock masses (Bieniawski, 1989) is often lost because of weathering processes, and the rock mass behaves more like a clayey soil aggregate.

On the whole, the Ca' Lita landslide can be described as a reactivated composite roto-translational rock slide - earth slide and flow (WP/WLI, 1993; Cruden and Varnes, 1996). As previously mentioned, the landslide resumed activity in 2002 and underwent a surge phase by March-April 2004, when the total reactivation occurred after 150 mm of cumulated precipitation in two months, and following a rapid snowmelt event (Borgatti et al., 2006). In particular, from a temporal sequence viewpoint, the 2004 event was characterised by multiple and retrogressive roto-translational slides in the upper part and multiple and advancing translational slides in the middle part. Advancing and widening earth flows and mud flows affected the mid and lower sectors of the landslide body. At that time, the failure affected an area 3 km long and up to 400 m wide, and caused the landslide toe to advance more than 400 m over a slope angle of about 10° at velocities up to 10 m/day. The toe of the landslide filled the local valley with a 30 m thick deposit and almost reached residential houses and the main valley bottom road (Fig. 2).

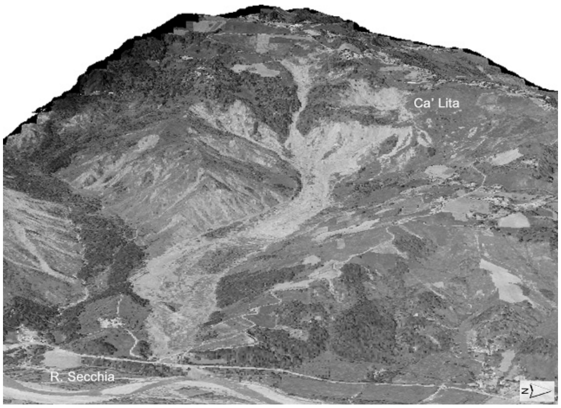

Fig. 2 Panoramic view of the landslide in 2004

On the basis of DEMs comparison, it has been estimated that this total reactivation mobilised twenty million cubic meters of mixed clays and boulders (Borgatti et al., 2006). This reactivation raised particular concern for the possible interruption of road connection to the upper Secchia River basin, eventually caused by further advancement of the landslide toe and also for the possible involvement of some hamlets as a consequence of retrogressive sliding in the crown area.

3. Emergency management

The phases and the actions undertaken to manage the landslide emergency linked to the total reactivation event of April 2004 are described hereafter.

Adopting the nomenclature of Kienholz (1994), it can be stated that the implementation of the emergency plan started with the response and the recovery phases.

During the response phase, excavators were working on 24 hours shifts to prevent the landslide to reach a few houses at the bottom of the slope and, especially, interrupt the provincial road, a primary asset for the economy of the upper watershed of River Secchia basin. Monitoring in the source area was essentially carried out with low-cost systems such as alignments of markers and simple wire extensometers laid across the main cracks in the crown.

In the recovery phase, which coincided with the onset of summer, the surface drainage network was re-established and extra extensometers were set up.

The prevention and mitigation phase started soon after, (beginning of August), with an investigation and monitoring campaign aimed at collecting relevant data for the design of structural mitigation measures. Detailed field survey, supported also by high definition DEMs produced in the meantime with airborne LiDAR allowed precise geomorphic mapping to be achieved (Corsini et al., 2007).

Ground monitoring systems, such as inclinometers and TDR cables, were also installed in different phases during 2004, 2005, 2006 and 2007.

On the basis of incoming monitoring data and field observations, structural mitigation of the Ca' Lita landslide was started. The basic scheme was the coupling, in key critical areas of the landslide, of deep-drainage systems consisting of alignments of several 150 cm diameter wells drilled as deep as 35 m, and deep-founded anchored pile walls. The construction of the first set of permanent structural consolidation works (Corsini et al., 2006) lasted from spring till autumn 2005; in the meantime, the monitoring systems was extended, with the aim to control both the evolution of the movements and the effectiveness of the structures.

A second and third set of consolidation works were built in 2006 and 2007, when the main scarp of the landslide was also significantly re-profiled.

In 2008, with reference to the general emergency framework, the situation is entering the preparedness phase, during which the slope and the structures are to be monitored and maintained on a long-term basis and further investigations and analysis are to be carried out in order to ameliorate the stability conditions, including also modelling of further possible interventions.

4. Monitoring, structural mitigation and modelling

A lot of reference data, both quantitative and qualitative, were collected regarding slope morphology, general soil and rock characteristics and tectonics. To build up a conceptual geotechnical model of the slope and to reconstruct the displacement fields, both at surface and at depth, the following data were used:

- multitemporal DEMs (photogrammetry in year 2004 and LiDAR surveys in years 2005 and 2006);
- geophysical investigations, boreholes;
- lab analysis on soils and geomechanical classifications of rock mass;
- inclinometers, TDR cables, extensometers and piezometers.

The location of instruments and of countermeasure works, as well as the summary of most relevant data is given in Fig. 3. The set of monitoring data is consistent with the general style of activity of the landslide (retrogressive rock slides in the upper slope and earth slides down slope), evident also from DEM comparison between the years 2005 and 2004 (Corsini et al., 2007).

Monitoring devices such as inclinometers and extensometers showed that during the summer 2004 the landslide continued to move at a rate in the order of mm-cm/day.

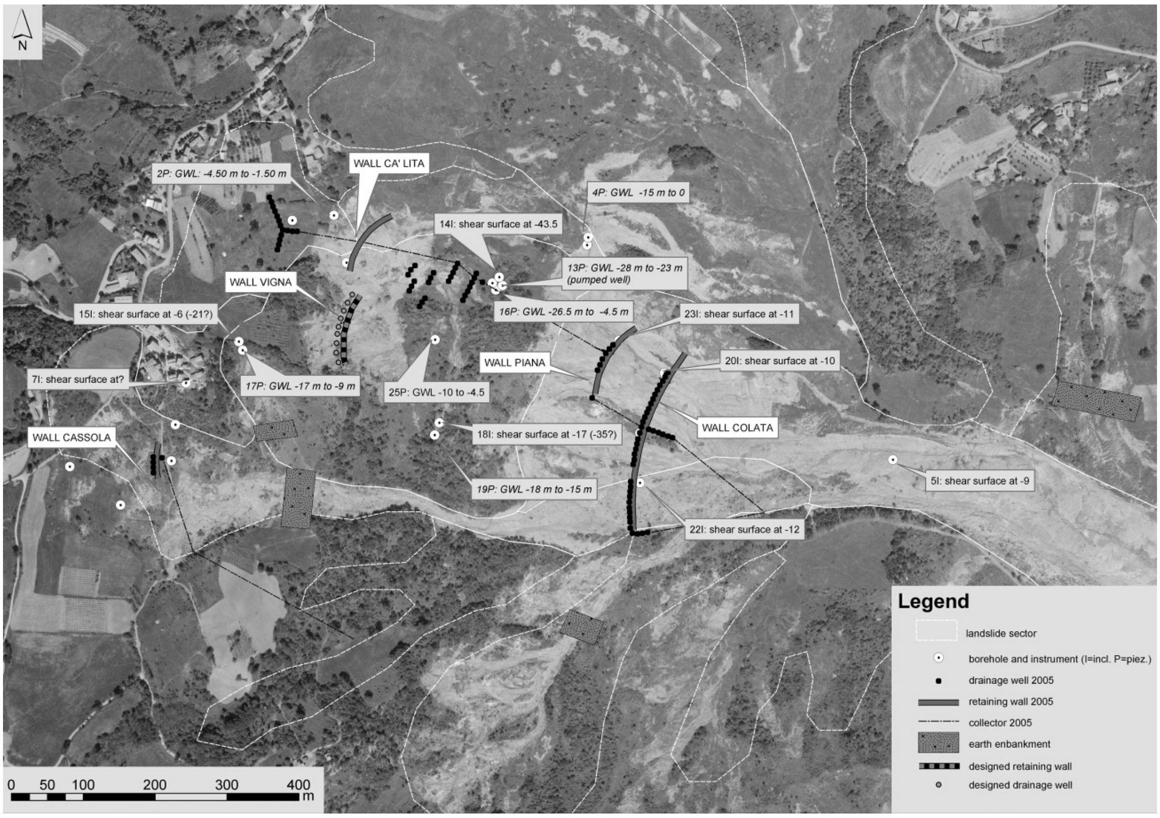

Fig. 3 Location of instruments and countermeasure works (walls and wells). Information on depth of movements and groundwater levels (modified from Borgatti et al., in press) is also given, with reference to the set of instruments that are presently installed

Afterwards, during autumn 2004 and winter 2004-05, movement took place especially in the source area at rates of decimetres up to meters per day, causing the retrogression of the main scarp and the cut-off and loss of inclinometers installed in the landslide body during the summer.

Before being cut-off, inclinometers and TDRs showed two main sliding surfaces in the head zone: one superficial, around 10-15 meters, the other around 43-49 meters. The first surface was due to debris and earth mobilisation, whereas the second was due to sliding of weak rock masses.

In summer 2005 new inclinometer cases were installed in the head zone, close to where inclinometers were cut off the previous winter. At the same time, open-pipe piezometers (fissured across the sliding surfaces and equipped with pressure transducers) were installed in the head zone and in the crown zone.

Despite the fact that quite significant retrogression of the main scarp occurred in January 2006, the inclinometer data collected during winter 2005-2006 (inclinometer 14I, see Fig. 3) indicated that the rock slide had slowed down to a rate of only a few mm/months, and did not have any significant acceleration phases. At the same time, no movements were recorded down slope in the earth flow area, that can actually be considered as inactive since 2006.

By summer 2007 the overall displacement recorded by the inclinometer located in the rock slide area (14I) reached about 7 cm along the 43 m deep sliding surface. To avoid loss of data, new inclinometers were installed and were equipped with two automated inclinometers put in place across the 43 m deep sliding surface.

Groundwater level recorded on a continuous basis since summer 2005 in different sectors of the slope showed that, while fluctuations in the order of 10 m can take place suddenly in the crown zone in response to rainfall, the groundwater in the rock slide has a much smoother plot, with peaks in the order of 5 m occurring with a delay from rainfall that can be of few days to weeks. In this area, piezometer data recorded at different depth, i.e. below and above sliding surface, seem to be related to two different types of aquifer. The upper one develops into the displaced rock mass and has a quicker response to rainfall and tends to reach about -10 m from surface (this level, however, is kept artificially to -28 m with drainage wells, see below). The lower one develops into the undisturbed flysch bedrock located below the sliding surface, and shows the characteristics of a semi-confined aquifer, with pressure heads that can cause level in the piezometers to rise as up as -5 m from ground on a seasonal basis (with no response to the effects of drainage wells).

From Spring 2005, permanent structural consolidation works have been carried out in distinct key areas of the landslide (Corsini et al., 2006). As mentioned above, a number of drainage wells (1200 cm diameter) have been drilled in the head zone and in other key areas. At places, they are complemented by sub-horizontal drains (up to 100 m long). Wells and drains are generally coupled with tied-back retaining walls founded on piles. Tied-back retaining walls act as retention structures, and as a large reaction plate for rock anchors, that transmits the anchor loads into the rock mass. In a few other areas earth dams have been built on specific earth and mud flow fronts.

The wells are drilled closely one another, and each well is connected to its neighbour with a basal sub-horizontal discharge pipe of 100 mm diameter. Most of these systems drain by means of gravity flow through this pipe; however, pumps have also been used temporarily in order to remove water from low-level collectors when the discharge pipe was not completed yet. The water drained by the wells and collected by the outlet drains is conveyed to the streams that border the landslide body by a pattern of diversion ditches and collectors.

All the reference data, and all the design characteristics of mitigation works, came to a use in 2007 for the numerical modelling of the landslide source area using FLAC2D (Itasca, 2002). The main objective of modelling was to reconstruct the landslide evolution at natural and engineered conditions, and to envisage further countermeasure works that would make the mitigation project more robust. In practice, modelling covered different slope stages, from the year 2005, which is to be considered as the natural, initial, state of the slope, to year 2007, when a big deal of mitigation works were completed.

More in detail, modelling was focused on:

- the state of the sliding process at different stages of landslide development, from natural to engineered with first set of countermeasures works;
- the potential behaviour of the slope under scenarios in which further countermeasure works are simulated.

Thanks to the numerical simulation, it was found out that, most probably, the best solution to further increase stability after drainage and sustain was assured by wells and tied-back walls, was to change the upper scarp profile by decreasing its inclination, and to build an additional retaining wall and drainage wells shield at its bottom. These works were actually designed and completed from summer 2007 to summer 2008. The re-profiling of the upper main scarp area involved a removal of material estimated in the order of 60,000 m^3.

Conclusions

In this paper, the evolution of Ca' Lita landslide from the reactivation of 2002 to the present engineered state has been summarised in the frame of risk management procedures. This national relevance case study has been studied and mitigated in the relatively short period of 4 years. A good knowledge base has been achieved in parallel to the construction of structural countermeasures. In this frame, monitoring and modelling have been reference points for decision making, either *a priori* or *a posteriori*. In a more general sense, the numerical modelling has allowed a better understanding, interpretation and integration of measured time series. Moreover, the results of modelling support also the optimal localization of new interventions and monitoring devices, indicating the most critical areas in the slope. Obviously, maintenance of engineering works and near-real time monitoring systems are to be continued over time to assure mitigation of future events and preparedness to possible slope evolution.

Acknowledgments

A large amount of data have been made available from Regione Emilia-Romagna, Servizio Tecnico dei Bacini degli Affluenti del Po, in the frame of a bilateral agreement. Special thanks to Gaetano Sartini, Giuseppe Caputo and Nicola De Simone for the precious support during field work and data elaboration.

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Landslides as Proxies of Climate Change: Evidence from Past Activity Records in the Dolomites (Italy)

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Abstract. This study concerns the relationships between climate changes and hillslope evolution during the Late Quaternary, with particular attention to landslide processes. The research has been carried out in test areas located in the Dolomites (Italy), following the basic idea that modifications in landslide frequency may be interpreted as changes in the hydrological conditions of the slopes, which are in turn controlled by climate. By analysing a large data set, consisting of 75 radiocarbon dates, obtained with reference to 24 landslides, temporal clustering of dated mass movements have been observed, that is a necessary condition to look for possible causes of past activity periods. By analysing the data set, four periods of enhanced landsliding have been outlined. These four periods have been compared with different Late Glacial and Holocene paleoclimatic records, in order to check the correspondence between temporal concentrations of landslide events and climatic events. Besides the intrinsic difficulties in the correlation among these records, which are mainly due to different spatial scales (local, regional and global), to dissimilar time-resolutions and dating constraints, remarkable evidence comes forward. The periods of enhanced slope instability in the Dolomites display a quite good correlation with cold and humid phases. At the same time, also periods of dry climate have a clear influence on landslide activity, resulting in gaps in the time series. The results suggest that landslide activity could have been climatically-driven and that, in particular, a positive moisture balance could have played a major role in conditioning slope instability at the hundred to thousand years time scale.

Keywords. Landslide activity, cimate change, Holocene, Dolomites, Italy

1. Introduction

Previous investigations have clearly shown that from the Late Glacial to the present, climate has influenced slope evolution, either directly or indirectly, and that slope processes may be considered geomorphological indicators of climate changes (Goudie, 1992). Temporal clustering of ancient landslide events has in fact been reported from different European regions such as Great Britain, Spain, Italy and Eastern Europe (see the review in Borgatti et al., 2001). Case studies from Africa (Thomas, 1999; Busche, 2001), from northern and southern America (Bovis and Jones, 1992; Trauth et al., 2000, 2003; Smith, 2001; Holm et al., 2004) and from Asia (Sidle et al., 2004) have also been recently published. Research has been focused on the correlation between slope movements, climatic changes and land-use in prehistoric and historic times and on precipitation regime and seismicity as triggering causes of temporal and spatial concentrations of landslide events.

The results presented here concern the study of the relationships between climate and slope evolution from the Lateglacial to the present. The research has been carried out in study sites located in the Dolomites (Alps, northern Italy), to assess to what extent slope instability processes can be considered geomorphological indicators of climatic changes

2. Study area

Cortina d'Ampezzo (46°32'14.58"N, 12° 8'20.12"E) and Corvara in Badia (46°33'3.94"N, 11°51'35.10"E) are located in the eastern Italian Alps in the Dolomites (Fig. 1). The mountain groups, that rise from 1400 m a.s.l. in the valley bottom up to 3000 m a.s.l., are made up of dolomite rocks, with, in most cases, marls or limestones alternating with clay shales outcropping in the slopes underlying the dolomite peaks.

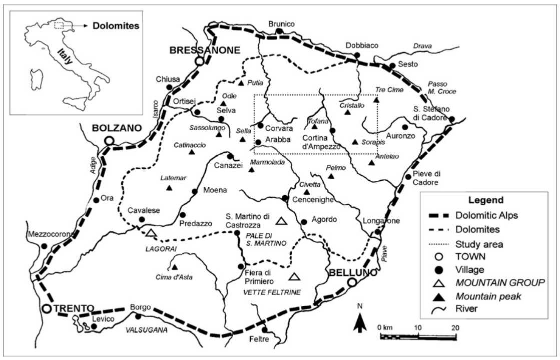

Fig. 1. Geographic setting of the Cortina d'Ampezzo and Alta Badia areas (Dolomites, Italy)

Active and inactive landslides are widespread: the dolomite cliffs are involved in lateral spreads, rock falls and topples, while rotational and translational slides and flows affect the slopes where clay-rich rocks outcrop. In some cases, landslide deposits can be more than 100 m thick and extend for several square kilometres. At present, the deepest sliding surfaces are dormant, while recurrent reactivations tend to be more superficial and are mainly due to intense and/or prolonged rainfall and snowmelt (Corsini et al., 2005). Specific investigations into the temporal occurrence of landslides have been carried out in the Dolomites since the 1990s (Panizza, 1990). A large data set has been presented in Soldati et al. (2004), where the geological and geomorphological setting are thoroughly described.

3. Landslides dating

In the study areas, the stratigraphy of landslide bodies has been reconstructed and many organic samples have been collected by means of coring, in natural or artificial scarps inside landslide accumulation zones. Direct or dating of landslides has been carried out using and radiocarbon analyses by conventional or AMS methods. Conventional radiocarbon ages have been calibrated using Calib (Stuiver et al., 2004) and the IntCal04 calibration data set (Reimer et al., 2004), with a 2 sigma error. Then, in order to analyse the temporal occurrence of landslide events, the distributions of probability for each dating have been summed, producing plots for the each site and for both together. In this procedure, besides the direct dating of landslide events, also the ages obtained from lake sediments have been considered; in fact, these ages have been recognized as a the sedimentary expression of abrupt mass wasting phenomena occurred in the Corvara catchment (Borgatti et al., 2007).

4. Landslide activity records in the Dolomites

Starting from the synthesis of the set of data presented in Soldati et al. (2004) and from eleven new datings, the sequence of enhanced slope instability has been further developed, by analysing the statistical distribution of calibrated radiocarbon ages.

The first outcome is the difference between the two data sets (Fig. 2). In the area of Cortina the ages are clearly older, with the oldest samples to be referred to more than 14 ka cal BP.

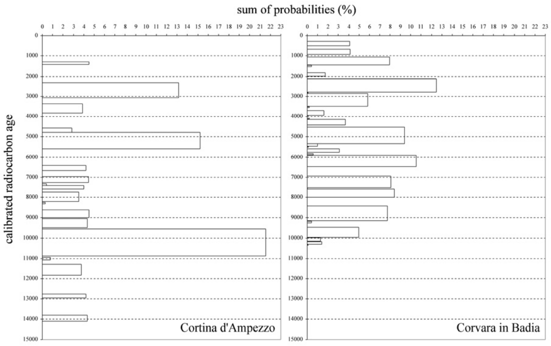

Fig. 2 Temporal distribution of dated slope instability events in Cortina and Corvara (modified from Borgatti and Soldati, accepted).

This difference can be related to the timing of deglaciation and of the subsequent reforestation at different altitudes (Cortina d'Ampezzo 1224 m a.s.l., Corvara 1568 m a.s.l.) and to the different morphological settings of the two sites, with respect to valley width and exposure. Indeed, no tree vegetation occurred in the Dolomites until 14.5 ka cal BP, that means also low chance to find organic matter buried by a mass movement before that time. Moreover, only few deep drillings or exposed sections reach the basal sliding surface and, therefore, many initial failures may be still not dated. On the other hand, the lack of very old landslides could have also a climatic significance, related with progressive and delayed permafrost melting processes at higher altitudes. In the area of Corvara the ages distribution shows a persistent landslide activity during the entire time span of the Holocene, whereas in Cortina the ages tend to be more scattered. This could be linked to the number of dated samples, i.e. 24 samples in Cortina, 49 in Corvara. Anyway, some clusters are recognisable in both records (around 5 ka cal BP and from 2 to 3 ka cal BP), while others are not analogous, such as the 11,000-9500 temporal cluster in Cortina, which is not so marked in Corvara. If the sum of probabilities is plotted for both study sites together (Fig. 3), the clustering around certain ages is more evident.

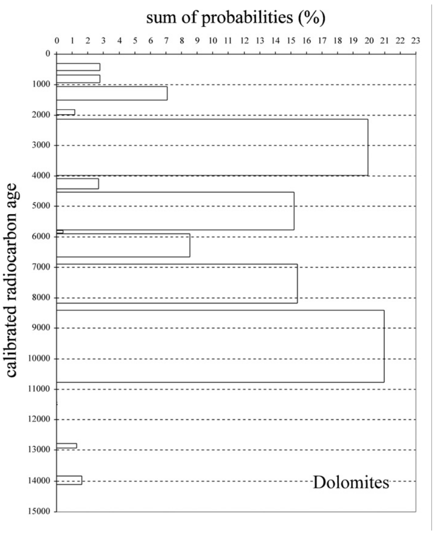

Fig. 3 Temporal distribution of dated slope instability events in the Dolomites (modified from Borgatti and Soldati, accepted)

By analysing the complete data set, four periods of enhanced landsliding can be outlined: I. from 10,700 to 8400 cal BP, between Younger Dryas and the Preboreal; II. from 8200 to 6900 cal BP, during the older Atlantic; III. from 5800 to 4500 cal BP, between Atlantic and Subboreal; IV. from 4000 to 2100 cal BP, between Subboreal and Subatlantic (Borgatti & Soldati, accepted).

5. Climate as a causal factor for landsliding at a broad temporal scale

Field observations of present-day activity and historical records show that first-time failures of large landslides follow a complex hydrological and mechanical behaviour (Corominas, 2001). In fact, first-time failures are the result of long-term evolutionary processes of the slope rather than the near-immediate response to a specific trigger. On the other hand, the influence of moisture balance is evident in the case of reactivations of dormant landslides, the acceleration of active movements and in the triggering of shallow slope failures. Therefore, considering the significance of rainfall regime and the resultant hydrologic response of the slopes in triggering mass movements (if it is possible to exclude the direct influence of seismicity and human activity) the periods of enhanced landsliding have been compared to different Late Glacial and Holocene paleoclimatic records, in order to verify the climatic control on the clustering of landslide events (Fig. 4).

The proxy records come from different realms, either continental or marine. Some of the records carry clear signals of cold and humid phases, whereas others are more related to warmer periods, primarily as a consequence of the nature of the proxy.

The landslide records from the Dolomites show the periods of enhanced landsliding documented in this study and periods of reduced landslide activity as described in Borgatti et al. (2007).

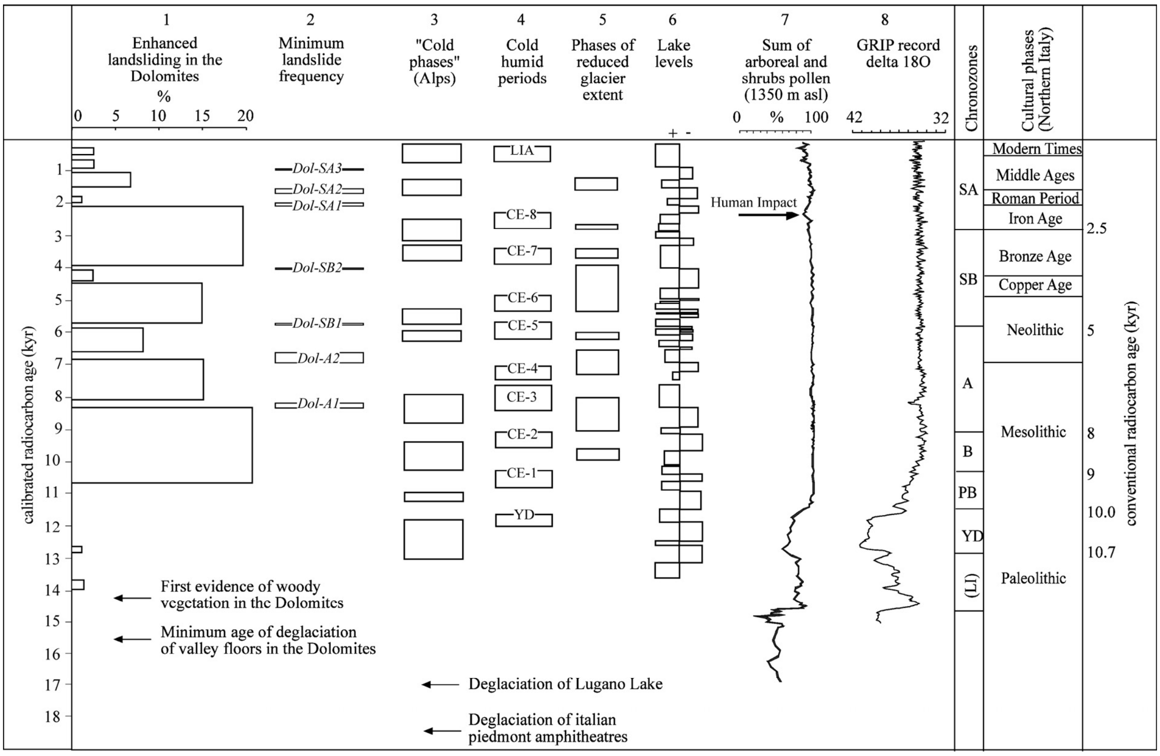

Fig. 4. Comparison of different Late Glacial and Holocene paleoclimatic record at different spatial scales (modified after Borgatti et al., 2007). 1. Enhanced slope instability events in the Dolomites (Borgatti and Soldati, accepted); 2. Phases of minimum landslide frequency in the Dolomites (Borgatti et al., 2007); 3. Cold and humid periods in the Alps and on the Swiss Plateau (Haas et al., 1998; Tinner and Amman, 2001; Tinner and Kalterieder, 2005); 4. Phases of reduced glacier extent, recorded by the retreats of the Unteraar and other Swiss glaciers (Hormes et al., 2001); 5. Mid-European lake levels (Magny, 1999) as palaeohydrological indicators; 6. Tree line in the mountain belt of the Alps: sum of arboreal and shrub pollen (local plants excluded from percentage calculation) from Pian di Gembro, Rhetian Alps, 1350 m a.s.l. (Pini, 2002; courtesy R. Pini). 7. Delta 18O in GRIP ice cores, central Greenland (Johnsen et al., 1997). Cultural periods in Northern Italy (Cardarelli, 1993). The age of deglaciation onset of Italian piedmont amphitheatres is from Monegato et al. (2005). LI: Lateglacial Interstadial, not a chronozone and therefore shown in brackets; YD: Younger Dryas; PB: Preboreal; B: Boreal; A: Atlantic; SB: Subboreal; SA: Subatlantic

Despite the intrinsic difficulties in correlating these records, that are mainly due to different spatial scales (from local to regional and global), dissimilar time-resolutions and therefore several dating constraints, some remarkable indications are apparent.

The periods of enhanced landsliding recognized in the Dolomites display quite a good correlation especially with the indicators of cold and humid climate, suggesting that these slope instability phases could have been climatically-driven.

In particular, this suggests that a positive moisture balance could have played a major role in conditioning landslide activity at the hundred to thousand years time scale.

At the same time, the phases of minimum landslide frequency identified from Borgatti et al. (2007) alternating with the enhanced landsliding periods fall within phases of reduced glacier extent, with warmer summers and/or reduced rainfall.

Mass wasting processes are primarily controlled by the geological and structural predisposing factors, which may differ from region to region, but this record shows that the apparent modulations are induced by centennial to millennial-scale climate changes. In addition, in formerly glaciated mountain belts, the long-term effects of the deglaciation and permafrost melting may result in effects that may be opposite to the contemporary climate tendencies, as in the case of the clustering around the onset of the Holocene. Finally, during the upper Holocene, the long-term tendency towards slope stability after the last deglaciation could then be counterbalanced by the effects of human activity, starting from 4 ka cal BP.

6. Conclusions

Landslides provide a record of climate variability at a range of temporal and spatial scales. Besides the intrinsic complexity of the landsliding phenomenon, many factors may produce changes in the frequency and magnitude of both first-time slope failures and reactivations. A variety of triggers may account for the first-time failures of large landslides, while reactivations of are mainly due to humid periods, extending for long periods.

In this study, the effects of different environmental changes (temperature fluctuations, rainfall regime, vegetation disappearance), seismicity and human impact have been taken into account. The results show that clusters of landslide events and regional and global paleoclimatic framework are linked. This suggests that, in particular contexts, landslides can be considered as geomorphological indicators of climatic changes.

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Numerical Modeling of the Triggering of a Loess Slide Considering Seismic and Hydrogeologic Factors

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Abstract. In April 2004, an earthflow mainly composed of loess occurred close to the village of Kainama in the Central Asian Republic of Kyrgyzstan after a combination of small-magnitude-earthquakes and heavy rain falls. Its high velocity and the long run-out zone caused the destruction of 12 houses and the death of 33 people. A field survey consisting of geophysical and seismological measurements was carried out in summer 2005 along the adjacent slope. We noticed several evidences of past (and probable future) slope failures threatening public buildings located at the foot of the slope.
In order to develop an efficient disaster management, a good understanding of the main causes of these mass movements, i.e. increased groundwater pressures and seismic shaking, is required. In this regard, we conducted 2D finite difference numerical tests based on the geometry and elastic properties of the layers defined by microseismic measurements and electrical tomography, strength properties derived from literature and geotechnical tests performed on sites presenting a similar loess cover.
The most probable set of strength parameters was obtained assuming that the slope was marginally stable in static and wet conditions prior to the earthquake. We then investigated cyclically induced pore pressures and their consequences in terms of factor of safety against liquefaction.
We found that, for a dry slope, moderate ground-motion amplifications develop below the crest; they are responsible for very small and localized displacements. On the other hand, for a partially saturated slope, partial liquefaction affecting the upper part of the slope produces a decrease of the soil shear strength leading to small permanent displacements spanning the entire slope. Hypotheses are elaborated to understand the discrepancy between modeled small displacements (millimeters) and observed catastrophic displacements (several meters).

Keywords. Landslide, liquefaction, numerical modelling.

1. Introduction

Landslides are a major concern of many mountainous areas frequently hit by moderate to strong earthquakes. In the Central Asian Republic of Kyrgyzstan for instance, the eastern rim of the Fergana Basin, located south and west of the country, is the region affected by the highest concentration of landslides. Since this region is densely inhabited, the mass movements cause regularly damage to settlements and are responsible for a yearly loss of more than 30 human lives.

In April 2004, an earthflow (220 000 m^2) mainly composed of loess occurred close to the village of Kainama (Fig. 1). It developed into a very rapid flow with a long run-out zone: the involved mass travelled over a distance of 1000 m on the southern flank, crossed the river and went up on the opposite flank over a distance of 250 m. Its high velocity and the long run-out zone caused the destruction of 12 houses, the death of 33 people and 64 families became homeless. This landslide was preceded by an increased seismic activity: on March 26, 2004 an earthquake of M = 4.7 occurred at 40 km SW of the Kainama site. Two other earthquakes were registered some 50 km NW of Kainama on April 8 (M = 4.2) and April 9, 2004 (M = 4.2). Besides, the rise of the groundwater level after spring rains and snow melting may also have played an important role in the triggering of this landslide.

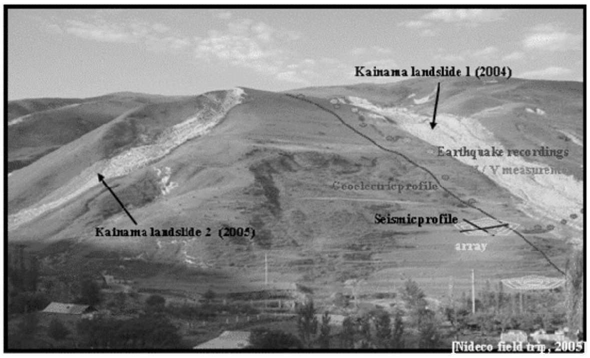

Fig. 1. Investigated slope in Kainama.

One of the major concerns in the Fergana Basin is therefore the development of risk management related to mass movements. To do so, a good understanding of the main causes of these mass movements, i.e. increased groundwater pressures and seismic shaking, is required. In this regard, we conducted 2D finite difference numerical tests based on the geometry and elastic properties of the layers defined by microseismic measurements and electrical tomography, strength properties derived from literature and geotechnical tests performed on sites presenting a similar loess cover. We focused on two possible triggering mechanisms: a seismic origin related to site effects and an activation resulting from complex phenomena involving both seismic shaking and groundwater flow.
In the first part of this paper, the model and its properties are briefly described. The second part of the work is focused on the numerical simulations of slope stability.

2. Creation of a 2D model of Kainama slope

We used the 2D finite difference code FLAC (Itasca, 2005) to generate a grid adapted to the desired shape (Fig. 2). Its layering and elastic properties were derived from field measurements while its strength parameters come from a literature review of other loess sites (Derbyshire, 2001).

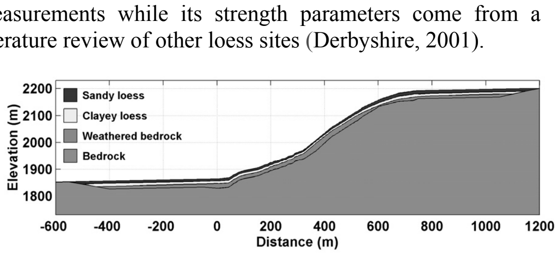

Fig.2. 2D cross-section of the Kainama slope.

As shown in Table 1 summarizing material properties, the loess layer was subdivided into two units according to their clay contents.

Table 1: Material properties of all layers constituting the Kainama slope.

	Dry density (kg/m^3)	S-wave velocity (m/s)	P-wave velocity (m/s)	Poisson's ratio	Coh. (kPa)	Friction angle (°)
Sandy loess	1500	180	400	0.37	45	32
Clayey loess	2000	400	900	0.38	45	28
Weath. bedrock	2100	600	1500	0.40	150	34
Bedrock	2300	1400	2500	0.27	200	35

In the lack of ground-motion recordings of the sequence of earthquakes that preceded the triggering of the landslide, numerical simulations were performed with a synthetic seismic signal applied along the base of the model. This signal is a plane elastic SV-wave propagated vertically towards the surface and polarized horizontally. We used a sum of two single Ricker wavelets with a maximum amplitude of 0.025 g, a total duration of 5 s (with approximately 0.4 s of strong motion) and a frequency band ranging approximately from 2 to 8 Hz.

3. Modelling of slope stability in dynamic conditions

From the field observations and measurements arise many questions regarding the origin of the Kainama failure. Focusing on two possible triggering mechanisms, a seismic origin related to site effects and an activation resulting from complex phenomena involving both seismic shaking and groundwater flow, we conducted dynamic slope stability analyses with FLAC software considering two different saturation scenarios. First, a reference scenario in which the slope is considered as dry. And, a more realistic scenario based on electrical tomography measurements, in which the slope is partially saturated with a perched groundwater table located between the base of clayey loess deposits and 2 m above the base of sandy loess deposits.

3.1 Reference scenario (dynamic and dry conditions)

In this scenario, all layers are assigned the classical Mohr-Coulomb failure criterion (linear elastic perfectly plastic). After the propagation of a 5 s long seismic signal inside the slope, additional timesteps are executed to allow detection of permanent deformations in the slope. Fig. 3a displays the total accumulated shear strains induced by seismic shaking: zones coloured in red indicate areas where intense irreversible deformations develop while blue zones stand for areas where at most elastic deformations are computed. From Fig. 3a, it can be seen that small and localised plastic shear strains develop in a non-flat zone below the crest: they are attributed to the presence of site effects. However, for a dry slope under such dynamic conditions, the movement of the slope is minimal (Fig. 3b), contrary to field observations.

3.2 The more 'realistic' scenario (dynamic and wet conditions)

The literature review of other loess sites revealed that sandy loess deposits comparable to those of Kainama slope may suffer irrecoverable volume contraction of the matrix of grains when subjected to seismic loading. The volume of the void space decreases mainly due to grain rearrangement. If the voids are filled with water, then the pressure of the water increases. This results in a decrease of effective stresses acting on the matrix of grains that may induce liquefaction.

To model this behaviour with FLAC software, we used Finn model based on the classical Mohr-Coulomb failure criterion incorporating the formula from Byrne (1991), which relates the decrease of the volume of the void space to cyclic shear strain amplitude. Considering the irreversible volume change, FLAC takes care of pore pressure build-up and decrease in effective stresses. The Finn model was applied to sandy loess deposits while the other layers were assigned the classical Mohr-Coulomb failure criterion.

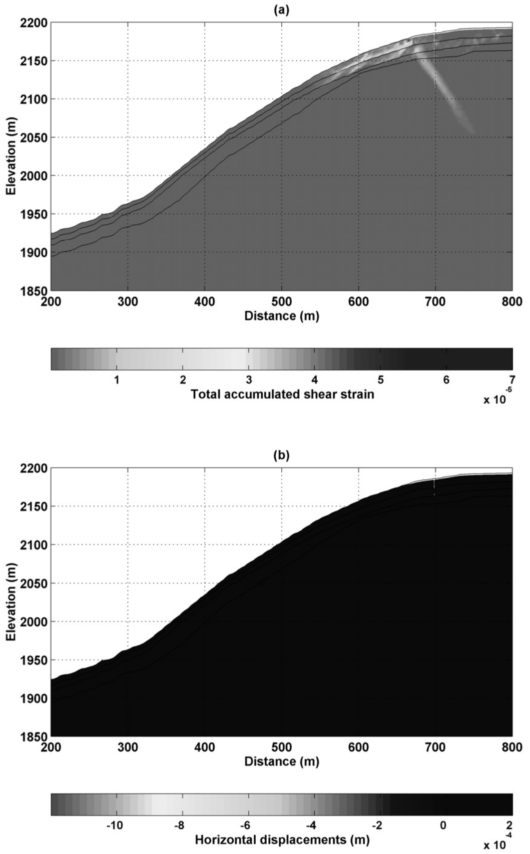

Fig. 3. Total accumulated shear strains (a) and permanent displacements (b) inside the dry slope at the end of the simulation.

When modelling slope stability in dynamic and wet conditions, we found that plastic shear strains resulting from the propagation of a 5 s long seismic signal are significantly larger than those computed in the dry slope (compare Fig. 3a and Fig. 4a). They induce small permanent displacements spanning the entire slope, although the largest displacements develop uphill where a partial liquefaction affects loess deposits (Fig. 4b). However, these computed displacements (millimetres) are still several orders of magnitude smaller than the observed displacements (several hundreds of meters).

Conclusions

This preliminary numerical analysis of Kainama landslide showed that, for a partially saturated slope, partial liquefaction affecting the upper part of the slope produces small permanent displacements spanning the entire slope. Hypotheses are currently elaborated to understand the discrepancy between modeled small displacements (millimeters) and observed catastrophic displacements (several meters).

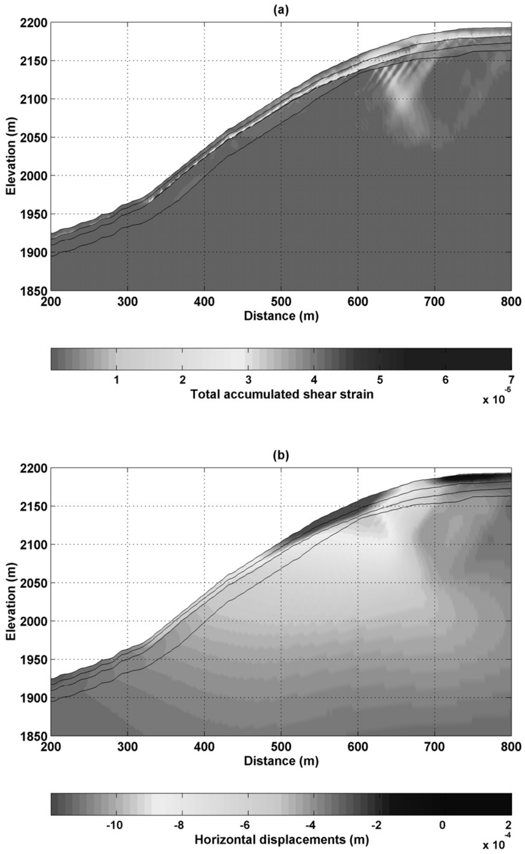

Fig. 4. Total accumulated shear strains (a) and permanent displacements (b) inside the wet slope at the end of the simulation.

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Full-scale Experiments on Shallow Landslides in Combination with Flexible Protection Barriers

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Abstract. Full-scale shallow landslide experiments are carried out on newly conceived test sites in Switzerland simulating the shallow landslides by releasing large amounts of material. Test barriers are set up at the end of the acceleration zone to study the acting impact and filling loads and the interaction between the filling material and flexible barriers. The material consists of a mixture of earth, gravel and silt saturated with water.

Keywords. Shallow landslides, protection systems, mitigation measures, full-scale testing

1. Introduction

Strong rainfall events saturate hillslopes and can trigger hazardous landslides. Meteorologists assume that extreme precipitation events are likely to increase in the future (Global Climate Change) elsewhere in the world. Protection authorities now believe that the number and severity of shallow landslides will increase, requiring suitable protection measures for roads and railway lines. Protection against shallow landslides is also required for existing buildings.

In contrast to flexible debris flow barriers (Volkwein et al. 2006, Wendeler et al. 2006), shallow landslide barriers are intended to be applied on unchannelized slopes. Fig. 1 shows the different application of barriers against rockfalls, debris flows and shallow landslides modeled with a specially developed Finite-Element software. There are various and fundamental differences between those two protection systems that are due to the differences in the processes and in the terrain configuration where they occur:

- different impact processes and load transfer (higher velocities, smaller volume, less drainage),
- different structural layout of protective structure (e.g. no gap at the bottom, multi-field barrier),
- other foundation and anchoring methods,
- different modeling of impact and load transformation processes.

The new application against open hill shallow landslides mainly enters a new terrain requiring the development of a new barrier type. This necessitates (1) to quantify the loads that a shallow landslide exerts on a flexible barrier and (2) to design the barriers to withstand these forces in open terrain. These questions are addressed using a combination of full-scale field tests, laboratory experiments and numerical modeling.

2. Preparation of full-scale experiments

Full-scale experiments are carried out on newly conceived test sites Veltheim and St-Léonard (Switzerland). Shallow landslides are simulated by releasing large volumes of material (up to 70 m^3). The 30° and 50° respectively steep slopes make the material reach velocities between 6 and 12 m/s. Test barriers are installed at the end of the acceleration zone i.e. after 40 m and 50 m, respectively. The material consists of a mixture of earth, gravel and silt saturated with water. During the experiments, energies superior to 5 MJ are dissipated in the barriers and a small berm in front of the barrier (an example experiment carried out at St- Léonard on 2008 May 30th is shown in Fig. 6).

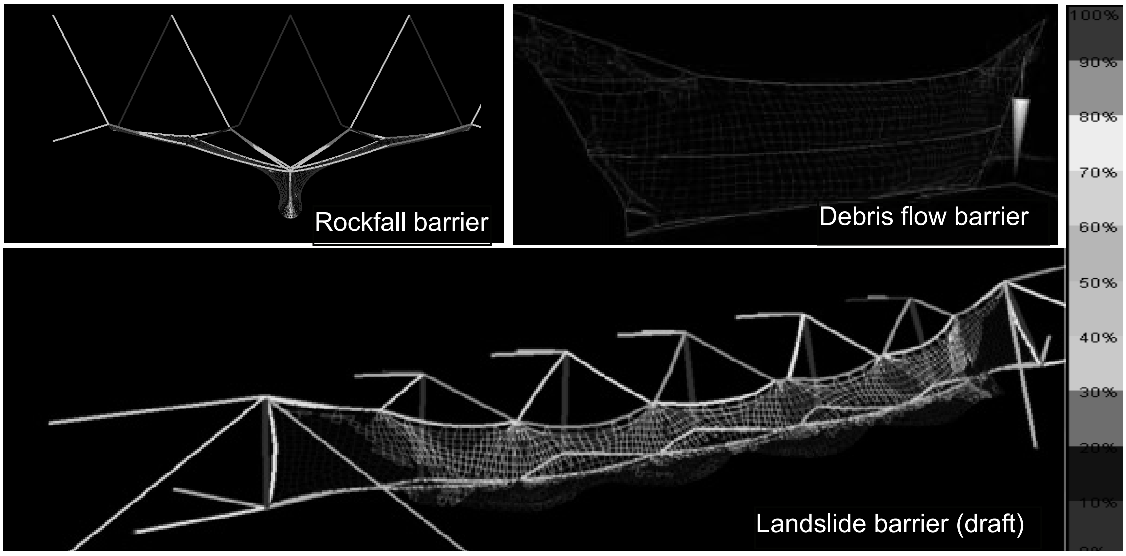

Fig. 1 Computational simulations of different flexible barrier types

It is the aim of the ongoing project to study different aspects regarding the protection barriers against shallow landslides:

- dimensioning and location of the barrier,
- type of the net (primary and secondary mesh geometries and sizes)
- number and type of brake elements optimizing the performance of the barrier.

Before the first experiment could be conducted following tasks had to be fulfilled:

(1) **Selection of the test site**. The test slope should have a typical inclination angle for shallow landslides i.e. 20° to 50° (Rickli 2005, Imura 2007). It should be either convex or flat to direct the material towards the net, and yet allow for some lateral spreading as is typical for shallow landslides. The site must have electricity and water supply, must be fairly remote to ensure safety, and finally it should be possible to perform 10 - 20 experiments. The properties of the surface (vegetation, roughness, erosivity) become important as far as they influence the dynamic of the flow.

(2) **How to construct a mass release system** (see Fig. 2). A reliable release system must be constructed in order to restrain up to 100 m^3 (200 tons) of landslide material. The opening mechanism must enable the free release of the mass and should be rapid enough to minimize the effects of the restrain and release conditions. The area near the release zone should be large and secure enough to allow for adequate preparation and homogenization of the material, e.g. digger, truck and other large machines. Even then, it is not clear that once the material is released, it will flow the required distance.

(3) **How to create a proper landslide material**. The portion of the single components within the mixture of earth, gravel and silt saturated with water must guarantee a flowing process similar to a natural shallow landslide. E.g. with certain slope properties a granular front can develop after release. Fig. 3 shows the preparation of the material and the fine and coarse material used for the tests.

(4) **How to remove mass from the barrier and test site**. When the material is in the barrier, it must be removed before the next experiment. Thus must be easy and safe (at the research site as well as in practice). Other critical situations might arise, such as when the flow mass does not reach the net and is deposited on the slope. Here too, a method must be found to clean the slope of material if required.

(5) **Measurement techniques.** The impact process is captured by several cameras from different perspectives, also high-speed video (recording rate set to 60fps). The forces in the bearer cables are measured using load cells at a sample rate of 1 kHz. Furthermore, one test site will be instrumented with basal shear and normal force plate, flow height sensors, basal pore pressure sensors and obstacle for measurement of impact pressure. The instrumentation for capturing dynamic features of the flow will provide complementary information to the material properties in order to understand the rheology of the simulated shallow landslides (Mc Ardell 2007).

Fig. 2 Release apparatus for artificial shallow landslides

Fig. 3 Used fine and coarse material and its preparation

3. Setup for test in St-Leonard on 17.06.2008

The material solid phase was composed of ~50 vol-% gravel (0/60 mm), ~40 vol-% soil (terre végétale), ~10 vol-% silt. The solid phase with density 2500 kg/m^3 was enriched with water until saturation was reached according to visual judgement. The posterior laboratory analysis revealed a mass percentage of water of 11 %. The landslide material was transported to and poured into the release reservoir by dumper. The total volume was 65m^3, calculated from the dimensions of the release mechanism (8m width and 2m filling height). The inner surface of the reservoir was previously covered with geotextile and plastic film to prevent drainage and to reduce friction with the bottom of the reservoir.

The barrier at the lower end of the 50° test slope was installed with an angle of 15° with the vertical on a horizontal berm (1.5 m distance between slope and barrier, see Fig. 4). The flexible barrier was 15 m long and 3 m high. The net consists of loosely connected flexible rings (Rocco®) with 300 mm diameter made of high-strength steel. The function of the so-called primary mesh is to distribute the impact and static loads to the supporting structure consisting of bearer cables, anchor cables and posts spanning the net over the three fields. Additional integrated energy absorbing elements reduce and soften the peak loads during impact. Four load cells in the upper and lower bearer cables measure the acting forces during the impact and filling process.

To prevent the fine material from penetrating the barrier a secondary mesh with 50 mm openings was attached on top of the ring net. Furthermore, two additional mesh segments leant on two embankments in order to prevent the material from leaving the barrier at both ends.

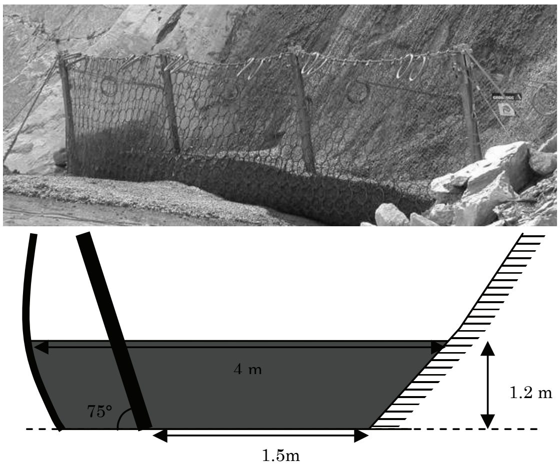

Fig. 4 Flexible barrier after sediment capture

3. Test results

Fig. 5 shows a sequence in time of the experiment. After the release the material flew out of the reservoir almost completely. Over the first 10 m the material movement was an homogenous flow. At a small terrace in the test slope some material was deviated forming a saltation layer and changing into simultaneous flowing and falling processes. The material reached the barrier after approximately 4.5 s signifying an average front velocity of ~11 m/s.

The barrier was filled almost evenly to a 1.2 m height over the whole barrier length. The impact mainly happened in the middle field over the total barrier height. The filling process was finished after ~10 s. A fraction of the fine material flew through the net and deposited right in front of the barrier (ca. 2 m^3).

The volume of the retained material has been determined to 55 m^3 calculated from dimensions of the filled barrier and (see Fig. 4). This means, about 10 m^3 of the material was lost through the barrier (as mentioned above), along the slope and in the reservoir.

The acting forces in the lower and upper support ropes were measured for 25 s at a sample rate of 1 kHz (see Fig. 6). The measured values represent relative forces, i.e. the loads originating from pre-stressing the barrier ropes during erection are not included and the offset of the load cells describes the situation right before the experiment.

The loads in the top bearer cable appeared pretty symmetrical. The maximum load was reached 3 s after the first impact. About 9 s later the level of the rope forces remained constant. The static load represent 90% of the maximal dynamic load. This rather small dynamic load peak due to the impact is explained through the berm in front of the net, which takes most of the impact load (first contact with falling material).

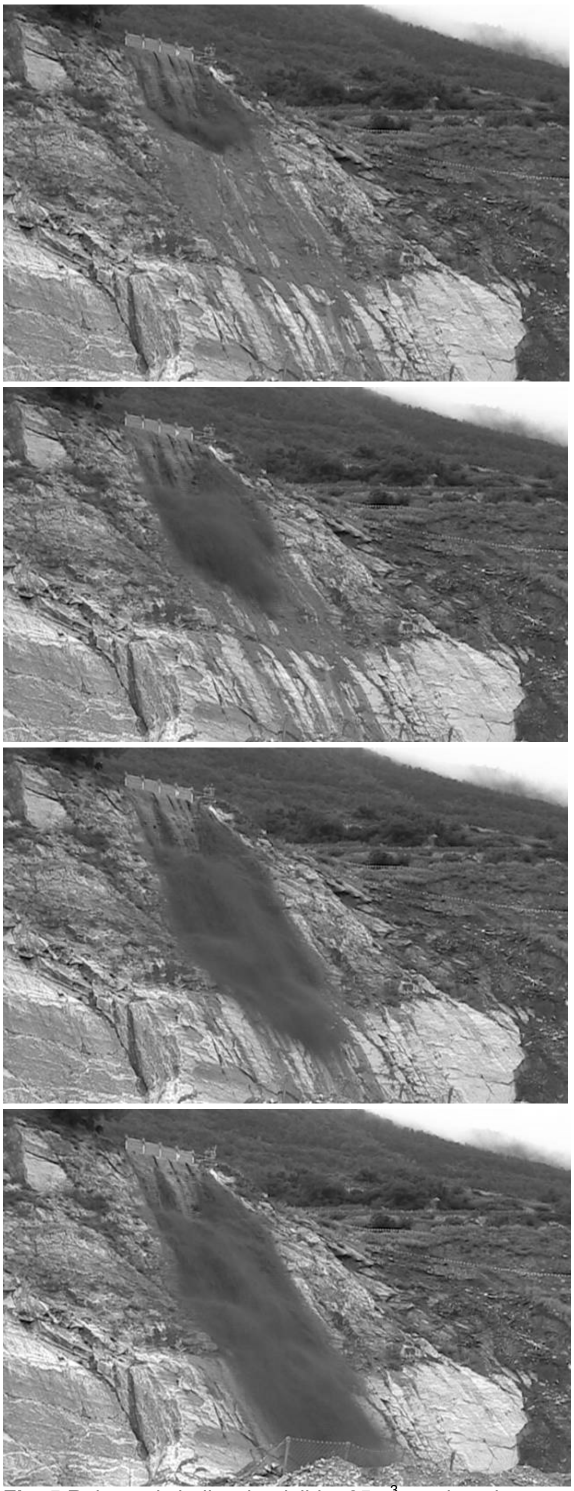

Fig. 5 Released shallow landslide: 65m^3 moving along a 50° steep rock bed surface (time = 2, 3, 4 5 s after release)

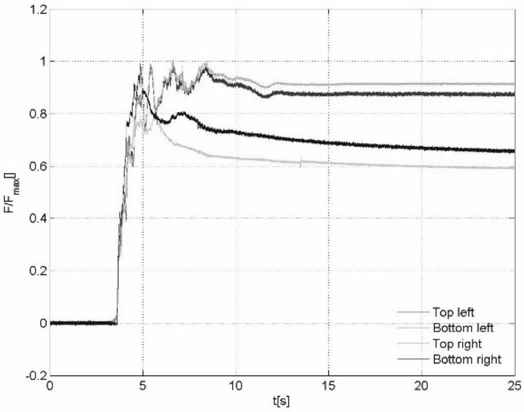

Fig. 6 Measured loads on support ropes of the impact barrier over the time

The loads in the lower support rope presented asymmetrically with higher values on the barrier's right side although the barrier has been filled symmetrically. The difference can be explained by unequal friction between the rope and the posts or ground. Another reason could be a stronger loss of material through the net on the left side. The maximum load has been measured 1.5 s after impact indicating that the top bearer cable is more affected by dynamic loading.

The loads in the lower support rope did not reach a constant or static value within the measurement time. The reduction still lasts after 20 s with a load level of ~60 % to the maximum load level. This indicates that processes such as drainage, consolidation (sedimentation) take place in the retained material reducing the loads acting on the barrier.

After the experiment the reservoir was cleaned with pressurized water jet making the installation ready for the next test. The material in the barrier was removed with a digger quickly after the event before consolidation could take place.

4. Conclusions

Two test sites for 1:1 field experiments of shallow landslides in combination with flexible protection barriers are in use and delivered the first results. The 30° and 50° inclination of the test slopes account for representative inclination in the occurrence of shallow landslides and enable the simulation of shallow landslides with a wide range of velocities. An efficient release system allows for events with volume up to 70m^3.

Different flexible barrier types distinguished by mesh type and size, energy absorbing elements and their location in the barrier system are tested. The loads during and after impact are quantified using force measurements within the barrier. The gathered information is essential to the further modeling and model calibration of flexible protection barriers.

The first results show that in the presence of a berm in front of the barrier reduces the maximum impact loads within the barrier.

Future instrumentation concentrated on the dynamic properties of the flow and filling processes will contribute to the development of integrated load and impact models for flexible protective systems.

Acknowledgments

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Modelling Rockfall Protection Fences

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Abstract. The paper reports an analytical formulation of a block impacting into a metallic net of a rockfall protection fence able to evaluate the net elongation and its braking time; furthermore, such formulation can determine when the barrier provides an essentially plastic response.

The analytical procedure has been calibrated through a comparison with the experimental results of full scale impact tests using several blocks of different size, following the instructions provided in the Guideline for European Technical approval of falling rock protection kits (ETAG 027).

The results presented in the paper refer to experiments carried out in a vertical-drop test site, which is a structure able to accelerate a concrete block to an established speed and to impact it, in free-fall motion, onto a sample of rockfall protection barrier. The barrier sample is made of three functional modules and is anchored orthogonally to a vertical slope. The handling of the testing block, made of concrete and in the shape of a polyhedron, is performed by a crane. In the impact test, the block trajectory is vertical and the block impacts into the centre of the middle functional module. No ground contacts occurs after the impact, ensuring that there is no energy loss but the air friction. Therefore, the kinetic energy is a function of the sole mass and height of fall of the block. As a result, this kind of test is particularly suitable for the purposes of model calibration.

The test site is also provided with high-definition video cameras for the direct measurement of both the net maximum elongation and the braking time in dynamic conditions. Such values, when evaluated analytically, show a remarkably good agreement with the experimental results.

The metallic net behaviour is assumed to be elastic and the event is described by a non homogeneous, second order differential equation with constant coefficients, determined by imposing the initial conditions.

The motion equation in the post impact phase is derived by integrating the differential equation: the net maximum elongation and the test block braking time is thus estimated**.**

Keywords. Rockfall protection fence, analytical modelling, full scale modelling.

1. Introduction

The use of flexible fences as a passive measure to protect roads and other infrastructures against rockfall is very rapidly growing.

A rockfall protection barrier is a metallic structure made of identical functional modules assembled in sequence for the required length. The functional modules are made of several components, each serving different functions. In particular, a module consists of an interception structure and a support structure, kept together and connected to the foundation through various elements.

The function of the interception structure, which is typically made of a metallic cable net (i.e. the principal net), is to bear the direct impact of the intercepted falling rocks and to transmit the relevant forces to the foundations. The principal net is kept in position by the supporting structures, usually made of steel posts, connected to the net either directly or by means of other metallic components, like ropes, cables, wires, junctions, clamps and energy dissipating devices.

Several manufacturers have developed different flexible rockfall protection barriers that are now commonly used. As a consequence of the ever increasing use of these structures, the development of reliable design methods is becoming a crucial issue, especially for the State and Federal Environmental Agencies.

In 1996, De Col and Cocco examined the behaviour of 100 rockfall protections barriers located within the municipal district of Trento: 70% had been installed on the sole basis of statistical or deterministic analysis of falling rock movements and only 15% had been suitably designed to arrest the falling blocks. The authors observed that the most frequently damaged components were the net, the ropes and the posts. They also pointed out that damages were frequently caused by the impact of small blocks (500 to 1000 N) with high velocities (50 to 80 m/s), producing the net perforation (*projectile effect*).

Owing to the complexity of the structure and of the impact characteristics, rockfall protection barriers are usually developed on the basis of results from full scale testing. In the last ten years, various testing standards have been developed with the purpose of comparing design methods and ensuring the barriers suitability and national guidelines for the certification of cable type barriers for public purposes have already been published, like the ETAG 027, "Guideline for European Technical approval of falling rock protection kits" (EOTA, 2008).

According to the ETAG 027, a rockfall protection kit is a special type of a construction system and consists of several components which are commercially distributed together, with a common CE marking, and assembled on site. The rockfall protection kit behaviour has to be assessed by full scale testing and is made by a minimum of 3 functional modules (i.e. at least 3 fields of principal net and 4 posts). In Figures 1 and 2 a schematic of a rockfall protection kit and relevant components, as defined in the ETAG 027, are shown.

The full scale tests have to be carried out using concrete blocks, whose volume and shape depend on the net nominal height, and the main geometrical and mechanical characteristics should be measured throughout the impact. A simplified scheme of the test site and procedure, as recommended in the ETAG 027, is given in Figure 3. The overall aim of the experiments is to assess the so-called *fitness for use* of the assembled kit.

The assessing method of a rockfall protection kit is usually based on the amount of kinetic energy of the impacting block the kit is able to stop in a full scale test. Two threshold levels of kinetic energy are defined in the EOTA Guideline: the maximum energy level (MEL) and the service energy level (SEL). The barrier, once tested, is classified and named after the energy level absorbed.

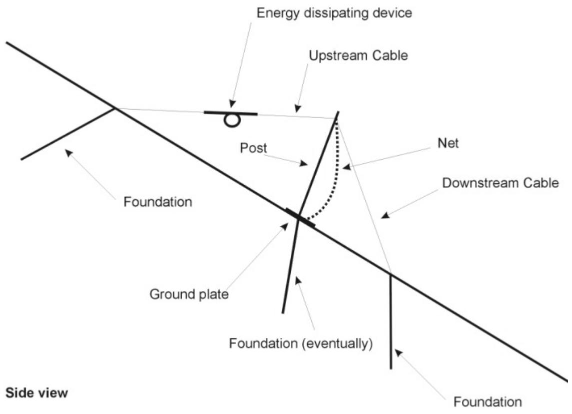

Fig. 1 Lateral view of a rockfall protection kit (after the ETAG 027).

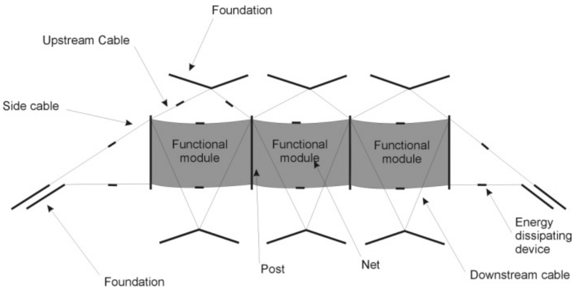

Fig. 2 Back view of a rockfall protection kit (after the ETAG 027).

In the paper, selected results from full scale tests carried out according to the European guidelines are briefly described and reported. A simple analytical model is then presented which is intended to capture the experimental events under a macroscopic point of view. The model scope is to provide a reasonable estimation of the block velocity, the block braking time and the barrier deformation, rather than to fully describe the impact of a block onto a rockfall protection barrier.

A reasonably good agreement between the in situ measurements and the model predictions was observed.

2. Full scale testing procedures for rockfall protection barriers

In response to the need of design methods for rockfall protection barriers, full scale impact tests have been carried out since the Seventies. Franzetti and Luraschi (1974) pioneered the approach, analyzing the behaviour of barrier samples subjected to the impact of natural blocks rolled down a slope. The experimental approach was more fully developed by Smith and Duffy (1990), who introduced video-cameras to record the event and accurately evaluate the damages undergone by the tested barriers. Further tests have been carried out by Duffy (1992, 1996) intended to verify the efficiency of a barrier to withstand successive impacts.

In the experiments carried out by Ballester et al. (1996), forces were also measured by means of dynamometers. The test site featured a rope-way which was used to guide the blocks to impact the net in a pre-established position. Through the use of a guided trolley, the block speed at impact could be controlled, ensuring repeatability of the experiments and thus enabling the comparison of results.

Peila et al. (1995, 2001) established a test site in which the blocks were thrown into the net through a trolley sliding on a cable. The experimental set up had a capacity of 70 kN and was able to guide the test block to impact into the net with velocities up to 34 m/s, providing a maximum kinetic energy level of 4,000 kJ. The tests were monitored by high resolution video-cameras for the direct measurements of the block speed. The maximum and final elongation of the net, the impact angle and the braking time were measured and dynamometers were also used to compute forces acting on the cables.

Similar tests were performed by Gottardi and Govoni (2008) in a test site suitably designed and established following the drafts of the EOTA guideline, during its process of approval, and the Swiss national standards. Several experiments were carried out on different barrier types, subjected to the impact of blocks with a great variety of energy levels. The test site is a vertical fall type: the block motion is parallel to the slope and impact into the barrier sample practically normal to it.

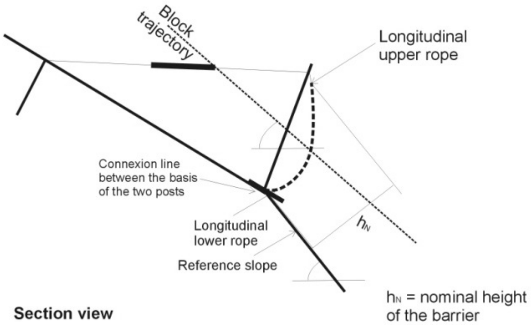

Fig. 3 Test site slope (after the ETAG 027).

3. Full scale modelling of rockfall protection barriers

The experimental data used in the paper for the purposes of the analytical model calibration, refer to full scale impact tests carried out at the Fonzaso (Belluno, Italy) test site (Gottardi and Govoni, 2008).

The Fonzaso test site was set up by suitably profiling a naturally subvertical slope. The test site features a crane hinged to the ground which enables a test block, made of concrete and in the shape of a polyhedron, to be lifted to the established height and then automatically released.

The rockfall protection sample, made of three functional modules (i.e. the falling rock protection kit), is connected to the ground plates which are in turn anchored to the slope. The interception structure consists of a principal net made of steel cables, joined into a square or ring mesh, underlying a finer hexagonal meshwork. Four steel posts, all provided with a hinge at the base, support the structures through longitudinal ropes. Upstream and side cables transfer the stresses to the foundations and hold the structure in position. Energy dissipating devices are placed all along the connecting ropes and steel cables. The anchorages are all provided with load cells recording the relevant tensile force during impact.

A laser sensor, located just above the barrier, is used to measure the speed of the block before the impact. Video-cameras, suitably located at the test site, record the barrier behaviour throughout the test.

A schematic layout of the experimental set up is illustrated in Figure 4 and relevant pictures are given in Figure 5.

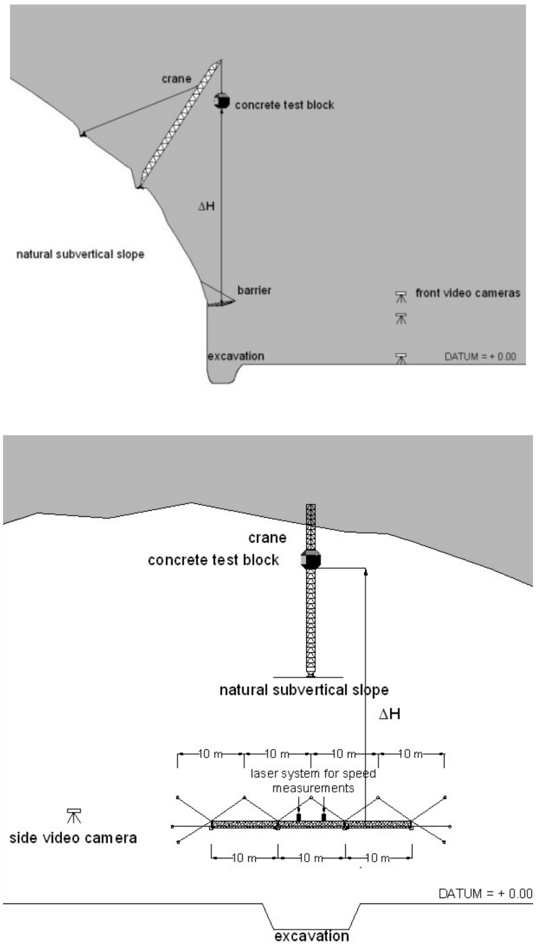

Fig. 4 Schematic side and front view of the Fonzaso (Italy) test site.

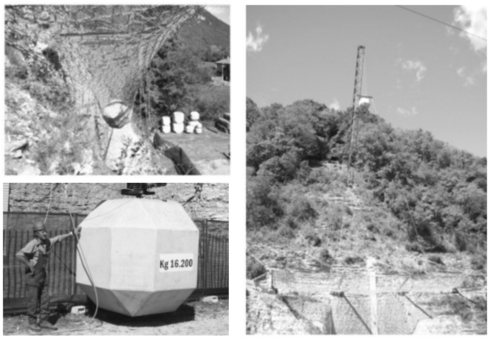

Fig. 5 Pictures of the Fonzaso (Italy) test site.

In the impact test the concrete block is released from the hoisting arm and, in free-fall motion, impacts the middle functional module of the barrier sample. Such a procedure ensures that no block-ground contact occurs at any stage of the test, therefore the energy loss is solely due to the negligible contribution of air friction. Therefore, the kinetic energy of the block at impact may be simply evaluated from the initial potential energy. As a result, the relevant data are the height of fall (ΔH) and the mass (m) of the concrete block. Such tests are thus easily replicable and particularly suitable for the purposes of model calibration.

Results here presented refer to full scale impact tests involving seven different models of rockfall protection barriers, belonging to five different energy level classes, according to the ETAG 027. The barriers are named CTR 05/07/B (Class 2, energy level 500 kJ), CTR 10/04/B (Class 3, energy level 1,000 kJ), CTR 20/04/B (Class 5, energy level 2,000 kJ), CTR 20/04/A (Class 5, energy level 2,000 kJ), CTR 30/04/A (Class 6, energy level 3,000 kJ), OM CTR 30/04/A (Class 6, energy level 3,000 kJ), OM CTR 50/07/A (Class 8, energy level greater than 4,500 kJ), where letter A identifies barriers with ring cable net and letter B barriers with square cable net.

A sample of each of these barriers was subjected to one launch performed at a value of kinetic energy greater than the corresponding energy level class (MEL test). A further launch at a lower energy level, greater than 1/3 of the energy level class (first launch of a SEL test), was also performed onto a new sample of the rockfall protection barriers CTR 05/07/B, CTR 10/04/B, CTR 20/04/A and OM CTR 30/04/A.

During the impact, the following quantities were measured: the speed of the concrete block, the maximum downhill displacement of the net in dynamic conditions (the kit maximum elongation), the time elapsed between the first contact between the block and the net and the maximum net elongation (the kit braking time) and the tensile forces acting at the anchorages. At the end of the test, the minimum distance between the lower and upper longitudinal ropes (the kit residual height), the travel of the energy dissipation devices and the net final elongation were also measured.

The data of interest for the purposes of the model calibration are: the block speed, v_{imp}, the braking time t_{s}, and the maximum elongation of the barrier D_{m}. Such data are summarized in Table 1 together with the relevant test details.

4. Analytical modelling of rockfall protection barriers

The main assumptions of the analytical model are as follows. At the initial time $t_0 = 0$, corresponding to the instant at which a block of mass m impacts into the barrier, the initial velocity v_0 is directed normally to the net which is placed at an angle α (varying between 0 and π/2) to the vertical direction.

According to the experiments at the Fonzaso test site (Gottardi and Govoni, 2008), here the model angle α is π/2 and the model initial velocity v_0 is vertical in direction (see Figure 4).

If the motion of the block, assumed as a lumped mass, is linear and only the elastic component of the deformation of the system is considered, the net elongation throughout the impact can be described by the equation

$$\ddot{s} = g\sin\alpha - \frac{k}{m}s \qquad (1)$$

where the constant parameter $k > 0$ is the net elastic coefficient. Expression (1) is a non-homogeneous, second-order linear differential equation with constant coefficients (i.e. an harmonic motion equation).

Substituting $\frac{k}{m} = \omega^2$, the solution of the differential equation (1) can be written as follows

$$\tilde{s}(t) = c_1 \cos\omega t + c_2 \sin\omega t + \frac{g}{\omega^2}\sin\alpha \ .$$

For the given initial conditions, the constant c_1 and c_2 assume the following values

$$c_1 = -\frac{g}{\omega^2}\sin\alpha,$$

$$c_2 = \frac{v_0}{\omega}$$

The equation which describes the block motion after the impact then becomes

$$s(t) = \frac{g\sin\alpha}{\omega^2}(1-\cos\omega t) + \frac{v_0}{\omega}\sin\omega t$$

and the block velocity can be then expressed by the equation

$$\dot{s}(t) = \frac{g\sin\alpha}{\omega}\sin\omega t + v_0\cos\omega t$$

whose zero is

$$t_c = \frac{1}{\omega} arctg\left(-\frac{\omega v_0}{g\sin\alpha}\right) \qquad (2)$$

corresponding to the maximum elongation of the net:

$$s_m = s(t_c) = \frac{g\sin\alpha + \sqrt{(g\sin\alpha)^2 + \omega^2 v_0^2}}{\omega^2} \ . \qquad (3)$$

If the block is modeled as a point of mass *m*, then it becomes apparent that the net response to the impact (i.e. *k*) is independent from the block size. One way to account for such a crucial feature, is to introduce a positive constant μ such as

$$k = \mu A \qquad (4)$$

In equation (4), *A* is the area of the contact surface between the block and the net. Given the difficulties in providing a value for *A*, it is convenient to express the coefficient *k* as a linear function of the block mass *m*

$$k = \eta m^{\frac{2}{3}} \qquad (5)$$

where η is a positive constant, hereinafter referred to as net constant. If the block is modeled as homogenous and sphere-shaped, equations (4) and (5) are equivalent and the net constant η is a function of the block density.

5. On the deformation mechanism of rockfall protection barriers

In a full scale test on a rockfall protection kit, the interception structure, which bears the direct impact of the test block, undergoes large elasto-plastic deformations and transfers the impact forces to the support structures and to the connection components, typically cables and ropes anchored to the ground, usually provided with elements able to dissipate the kinetic energy through the development of permanent deformations (i.e. energy dissipating devices). The travel of such elements, together with the deformation of the interception structure, determine the downhill displacement of the principal net with respect to the initial position (i.e. the net elongation).

The net elongation depends also on the boundary conditions (i.e. the net restraints), which determine the way the interception structure is allowed to move relatively to the supporting and connecting components. Boundary conditions may vary with the energy level class of the barrier. Since the experiments presented here involved samples of barriers of different energy classes, different deformation mechanisms were observed.

Therefore, if the analytical model is applied to estimate the maximum elongation of a rockfall protection barrier in a full scale test, the net elastic coefficient *k* should be treated as an equivalent coefficient depending on the stiffness of the assembled system, which in turn depends on its components (cable nets, ropes, cables, energy dissipating devices), and on the boundary conditions. Values for *k* are listed in Table 1.

6. Analytical model calibration

In Table 1 selected data obtained from the full scale test on rockfall protection barriers (Gottardi and Govoni, 2008) are presented together with the outcome of the analytical model predictions.

Test n°. Barrier name	***m*** [kg]	***v_{imp}*** [m/s]	***D_m*** [m]	***t_s*** [sec]	***v_m*** [m/s]	***k*** [kgf/m]	***t_c*** [sec]	η
1.CTR 30/04/A	9540	25.72	5.20	0.36	14.4	263614	0.310	586
2.CTR 20/04/A	6760	25.78	4.65	0.32	14.5	230224	0.280	644
3.CTR 20/04/A	2285	25.48	4.20	0.26	16.1	92283	0.260	532
4.CTR 20/04/B	6855	25.62	4.30	0.32	13.4	269534	0.260	747
5.CTR 10/04/B	3320	25.74	3.50	0.22	15.9	194289	0.210	873
6.CTR 10/04/B	1085	25.42	2.80	0.19	14.7	97029	0.170	919
7.CTR 05/07/B	1610	25.44	2.95	0.17	17.3	130442	0.179	950
8.CTR 05/07/B	540	25.49	2.40	0.15	16.0	65221	0.146	984
9.CTR 50/07/A	16200	25.45	5.60	0.39	14.4	391349	0.330	611
10.OM CTR 30/04/A	9560	25.61	5.35	0.30	17.8	254122	0.306	565
11.OM CTR 30/04/A	3430	25.80	3.90	0.22	17.7	167363	0.230	736

v_{imp}: measured impact velocity;
D_m: measured maximum elongation of the barrier;
t_s: measured braking time;
v_m: average velocity evaluated in the braking phase;
t_c : computed time;
k: computed net elastic coefficient corresponding to the experimental D_m;
η: dimensional constant, see equation (5).

Tab. 1 Comparison between experimental and analytical results.

Data of test n° 5 refer to an experiment in which a block of mass *m* = 3,320 kg impacted in free fall motion into a sample of barrier CTR 10/04/B with measured velocity v_0 = 25.74 m/s. The maximum elongation of the barrier, as measured after the impact, was D_m = 3.5 m and the braking time, as evaluated by the video-camera frames, was t_s = 0.22 s. The analytical model, with α = π/2 and *k* = 194,285 kgf/m, a value corresponding to D_m, gives a prediction of braking time t_c = 0.21 s, in good agreement with the measured braking time t_s.

From equation (5) a net constant η = 872.77 may be calculated and used to estimate the maximum elongation and braking time of any sphere-shaped block impacting with constant μ into the same type of rockfall protection kit. The test block shape, a polyedron with flattened corner, as suggested in the ETAG 027, can be in fact reasonably approximated by a spherical block (Figure 6).

With η = 872.77 and m = 1085 kg, equations (2) and (3) give a prediction of 2.87 m for the maximum barrier elongation and a braking time t_c = 0.175 sec. Such values are consistent with the corresponding experimental data measured in test n° 6 (i.e. D_m = 2.80 m and t_s = 0.19 s).

In order to assess the ability of the analytical model to capture the main features of the full scale tests, all 11 experiments have been modeled. A good agreement between experimental data and model results, independently of block dimension and barrier type, can be observed in Table 1, where the values of the net constants k and η are also reported. Notice that such parameters tend to be greater for the lower energy level barriers, which were designed with more restrictive boundary conditions (see Section 5).

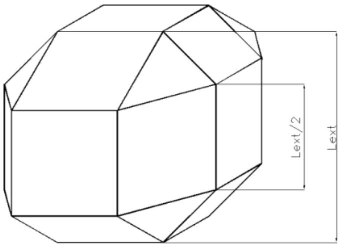

Fig. 6 Schematic of a test block (after the ETAG 027).

7. Shortcomings of the energy level approach to assess the capacity of a rockfall protection barrier

In the available published testing standards (e.g. ETAG 027, Swiss guidelines for the approval of rock protection kits), an approach entirely based on the energy level is used to classify and assess rockfall protection barriers from full scale testing.

Experimental data have shown that the tensile forces mobilised at the anchorages increase as the maximum elongation of the barrier increases (Gottardi and Govoni, 2008). As a consequence, one might suggest that a procedure to assess the efficiency of a rockfall barrier based on its maximum elongation could be also adopted as an appropriate criterion, and a rockfall protection barrier deemed efficient with respect to all the impacts that produce a maximum elongation less than critical.

The simple analytical model presented here can be suitably applied to explain the advantages of such an alternative approach.

With reference to the rockfall protection barrier 10/04/B already examined, let us consider the following two cases:

1) A sphere-shaped block of mass m = 24,990 kg impacting into the barrier with speed v_0 = 25.74 m/s: the analytical model would predict a maximum elongation D_m = 5 m.

2) A block of mass m = 3,320 kg impacting into the barrier with the same speed v_0 = 25.74 m/s. The shape of the block is non-spherical and its contact surface is 1/3 of a spherical block with the same mass (i.e. k = 194,289/3 kg/m): the analytical model would now predict a maximum elongation D_m = 6.28 m.

If the critical maximum elongation is taken for instance 5 m, the block would damage the barrier in case 2, producing a greater net displacement, whilst it would not cause any damage in case 1, despite having a 8 times higher kinetic energy!

According to the model, parameters other than the energy level (like the area of the contact surface) can be vital for the assessment of the response of a rockfall protection barrier and therefore care should be taken in the use of the energy level criterion, since a barrier which has proved to be able to suitably stop a block of a given kinetic energy, might not be able to stop any block of the same energy level.

8. An alternative method for assessing the efficiency of a rockfall protection barrier

A simple method for estimating the mass of blocks which a barrier can stop is here suggested, according to the maximum elongation criterion. From equation (3) it is easy to deduce

$$\omega^2 = \frac{2s_m g \sin\alpha + v_0^2}{s_m^2}$$

which, combined with equation (5), gives

$$m = \left(\frac{\eta s_m^2}{2s_m g \sin\alpha + v_0^2} \right)^3 \tag{6}$$

where m is the mass of the sphere-shaped block and η is the net constant. If the maximum velocity $v_{\max}$ and the critical elongation s_c are known, since form equation (6)

$$m_c = \left(\frac{\eta s_c^2}{2s_c g \sin\alpha + v_{\max}^2} \right)^3 , \tag{7}$$

it is easy to show that any sphere-shaped block of mass $m < m_c$ with impact velocity $v_0 < v_{\max}$ produces a barrier elongation D_m less than critical.

In other words, the net is able to absorb the kinetic energy of any spherical block having a mass smaller than m_c. Such value may be thus named critical mass m_c.

To account for non-spherical shapes, equation (7) can be modified in the following way

$$m_c = \left(\frac{i}{100} \frac{\eta s_c^2}{2s_c g \sin\alpha + v_{\max}^2} \right)^3 \tag{8}$$

where i (0 < i < 100) is a safety factor: the net is considered able to stop a block of $m < m_c$, even if the contact surface is the i % of a spherical block with the same mass.

With reference to the rockfall protection barrier 10/04/B (η = 872.77), let us assume s_c = 5 m, v_0 = 30 m/s and i = 66%. Equation (8) gives m_c = 3,095. The net can be then considered able to stop blocks of mass m not greater than 3095 kg and contact surface equal to 2/3 of an equivalent spherical block with the same mass.

Concluding remarks

The design of protection methods against falling rocks first involves the evaluation the possible paths of detachable blocks. Such analysis includes geomechanical surveys and site investigations necessary to an appropriate rockfall modelling, which enables to predict trajectories, velocities and kinetic energies assumed by the blocks during their fall.

Within the area interested by the installation of passive measures to protect roads and other infrastructures, the correct position of a structure able to catch the falling blocks is often evaluated by selecting the location corresponding to the minimum kinetic energy of the blocks (Giani, 1992; 1997; Giani et al., 2004). The block kinetic energy is thus the most relevant parameter for the design of a rockfall protection structure.

However, a design procedure entirely based on the energy level criterion can be not fully adequate in certain circumstances, since parameters other than the kinetic energy, such as the area of the contact surface between the block and the interception net, may be crucial for the barrier deformation. It is therefore important, when using the energetic approach, to take into consideration also the shape, size and mass of the block having the prescribed energy level.

The shortcomings of the energetic approach becomes crucial if the rockfall protection barrier is installed with the aim of protecting areas against debris flows or snow avalanches. Such circumstances are not considered in the ETAG 027, yet the barrier are widely used with such purposes.

According to the prediction of the model presented herein, for a given energy level, the greater the contact surface the smaller the maximum net elongation. Although such simplified model cannot be applied to suitably describe debris flows or snow avalanches, it can be observed that the maximum elongation undergone by a barrier subjected to the impact of debris or snow should be reasonably less than that of a rock block. Being equal the energy level, it is in fact realistic to expect that the area of the contact surface between the rock and the net is much smaller.

Acknowledgments

The authors would like to thank Mr. Diego Dalla Rosa and the Consorzio Triveneto Rocciatori of Fonzaso (Belluno, Italy) for the use of the experimental data presented in the paper.

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Rockfalls in the Cliff of Pitigliano (Central Italy): Integrated Techniques for Landslide Hazard Assessment

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Abstract. Pitigliano (Southern Tuscany, Italy) is an interesting case-history for the analysis of interactions between geotechnical features, man-induced factors and geological hazards. The landscape of the town, in fact, is the consequence of a continuous geomorphological evolution and slope instability phenomena, such as rockfalls, toppling and associated debris slides, which destroyed buildings and reduced the extension of the urban area. Even if this situation is very frequent in Central Italy and some other towns are affected by the same problems, Pitigliano provides an additional element of interest, represented by the presence of an extensive network of chambers and passages excavated probably starting from Medieval times. The survey of these tunnels constituted the first step of an extensive engineering geology survey of the cliff, carried out in order to obtain a complete set of information about the rock mass.

This paper summarizes the methods and techniques used in this study and the results: the survey of tunnels and chambers (that led to the identification of about one hundred different underground paths) has been realized with speleological techniques; a laser scanning survey allowed the reconstruction of the digital elevation model of the cliff and the integration of structural data in impervious areas; characterization and classifications of the rock mass have been performed through traditional methods; for the localization of the most critical sectors of the cliff kinematical analyses have been carried out; finally, an innovative wireless monitoring system of some critical cracks has been implemented.

The results of these different analyses represent an interesting case history and a complete data set for the realization of consolidation works that are being carried out.

Keywords. Stability analyses, Rockfalls, Laser scanner, Landslide monitoring.

1. Introduction

Pitigliano is placed on a flat slab, bounded by steep cliffs, and it represented an ideal location for defense purposes (Fig. 1): Pleistocene tuffs with variable geotechnical features outcrop in the area, and the town slab is composed by a 25 meters thick plateau of the strongest material (Fig. 2) (Varekamp, 1980; Conticelli et al., 1987; Vezzoli et al., 1987).

The village has very ancient origins (Etruscan and pre-Etruscan), and nowadays it shows the complex result of the superimposition of architectural stiles and influence, with a prevalence of medieval and renaissance features.

Throughout the ages, geomorphological evolution tackled the human settlements: in fact, the tuff plateau is deeply affected by physical degradation and erosion processes and this, coupled with the presence of joint systems, led the slopes to be prone to landslides, thus threatening the buildings and the heritage conservation.

Fig. 1 Panoramic view of Pitigliano (photo by R. Fanti)

The ancient inhabitants (in the Middle Ages, but perhaps also during the Etruscan times) worsened the situation, realizing a system of chambers and corridors beneath the buildings: this underground network consists mainly of tunnels ranging in length from a few meters to over a hundred meters, with a rectangular cross-section one-two meters wide. They were excavated for several reasons: firstly as quarries for the extraction of construction material for the buildings of Pitigliano, secondarily for accessing the volcanic ash beneath the tuff for use as cement, and finally to develop cellars for the production and storage of wine.

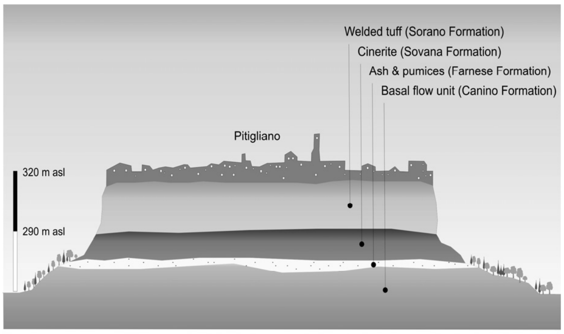

Fig. 2 Geological sketch of the town

The underground system (never completely surveyed in the past) is an important structural element and causes a general weakening of the rock mass (Fig. 3), so the knowledge of the extension and layout of the tunnel network is very important for the overall stability assessment.

Furthermore, considering that the remedial measures already in place and those to be carried out require the installation of nails and anchors in the rock mass (Focardi et al., 2003), knowledge of the tunnel network layout, especially in proximity of the rock face, can reduce the risk of undesired interaction between the network and the execution of the works (Canuti et al., 2008).

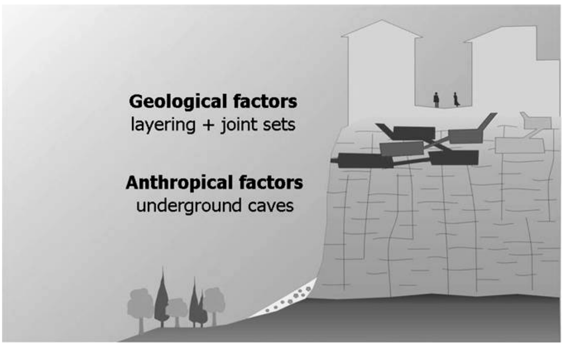

Fig. 3 Schematic cross section of the cliff: slope instability factors

As consequence, the underground survey and its integration with the data deriving from a terrestrial laser scanning represented the main objective of the study, coupled with an engineering geology survey of the rock mass and with the test of an innovative monitoring approach.

2. Terrestrial laser scanning survey

The terrestrial laser scanning has been aimed to realize a very detailed digital model of the cliff and to obtain some additional data for the engineering geology survey. The work has been realized through a Long Range and High Accuracy 3D Terrestrial Laser Scanner system (LMS-Z420i – Riegl LIS) composed by a high performance long-range 3D laser scanner, associated operating and processing software RiSCAN PRO, and a calibrated and definitely orientated high-resolution digital camera.

The investigation has been carried out both of the southern and of northern portion of the cliff of Pitigliano. The first step has been the definition of the different field-of-views in order to obtain an homogeneous cover of the scanning scene and the designation of the scan techniques to guarantee an uniform acquisition resolution. To acquire the complete scanning of the cliff of Pitigliano seven point-of-views have been selected.

In Fig. 4 the mosaic of the all point-cloud data taken from the seven different point-of-views is presented. It should be noted that the obtained results can be used as a milestone in the documentation of the cliff morphology and of its evolution: historical documents demonstrate the high ‘activity’ of the external limit of the town and, through the elaboration of the laser scanning data, a series of very detailed maps (accuracy 25 cm) of the present cliff is now available (Fig. 5).

These maps have been realized coupling a contour lines representation of the cliff with the laser scanner images; in order to maintain the correct geometry of the data, this work has been carried out dividing the cliff in 8 sectors, clockwise from the SE limit. From the laser scanner data we obtained also a series of maps of the exposure of the different sectors of the cliff and a map of the overhanging sectors. All these products required the development of some specific software codes, given that commercial software doesn’t provide with this kind of elaboration.

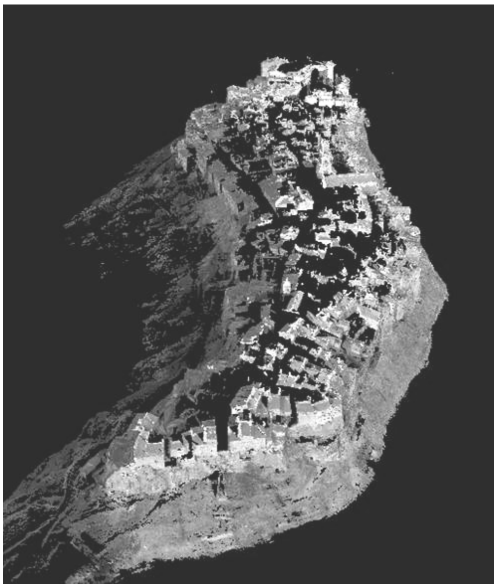

Fig. 4 Laser scanning point cloud representation of the Pitigliano cliff

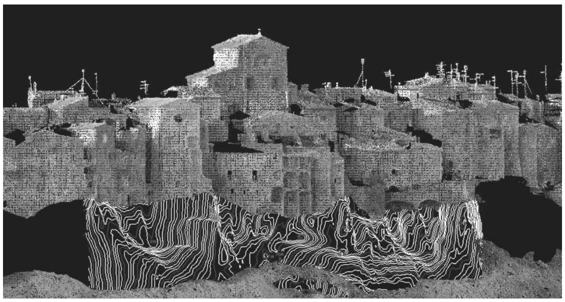

Fig. 5 The contour line model of the cliff (particular of the southern side)

3. Rock mass analyses

Considering the importance of a deep knowledge of geotechnical parameters of rock masses, an extensive engineering geology survey was planned permitting the achievement of a complete series of geotechnical data.

This task has been realized following the international standards in this field (guidelines and recommendations of ISRM, International Society for Rock Mechanics): a complete series of document and data has been obtained through this activity and they led to a rock mass classification, according to Bieniawsky (1989), Barton et al. (1974) and Palmstrom (1996) systems.

Fig. 6 shows the synthesis of the structural data collected on the cliff: the set labeled JN2 is under represented, because most of the scanlines were in the same direction. These data have been used for the stability analyses, carried out through traditional methods, even if with some original adaptation in order to evaluate the overhanging sectors.

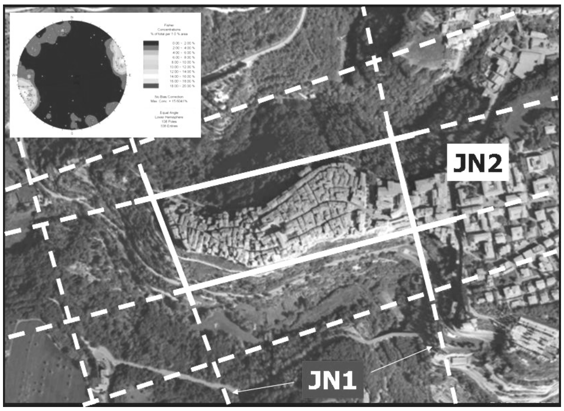

Fig. 6 Aerial view of the area and stereoplot of the structural data collected on the cliff

The results of this activity are a series of maps: in the different sectors of the cliff for each mechanism a stability relative index has been calculated. A synthesis of these information is a map of the cliff that represents the most critical mechanism in each sector (Fig. 7).

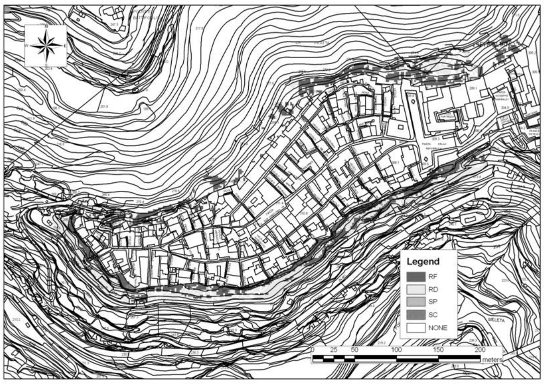

Fig. 7 Map of the most critical mechanisms around the cliff (RF, flexural toppling; RD, direct toppling; SP, planar sliding; SC, wedge sliding)

4. Underground survey

An important topic of the study has been represented by the survey of underground network.

The mapping of the cavities has been carried out assigning them a spatial location and geometric parameters (length, width, height, inclination angle). The spatial location of the cavities has been detected by using a GPS, Global Position System, while to collect the information concerning the geometric parameters of the chambers speleological techniques have been used.

The investigation allowed to the measurement of 93 chambers (Fig. 8). The results can be viewed in GIS environment where the location of the entrance of each tunnel corresponds to a point or by means of a specific speleological software.

The knowledge of the geometry of this network is important, especially during the project of engineering works such as rock bolts and anchors (Canuti et al., 2008).

Fig. 8 Location map of the surveyed chambers (white spots)

In order to maximize the comprehension of geometric relationships between the cliff and the underground chambers, the data of the survey and the results of laser scanning have been combined, obtaining a sort of 3D model.

In addition, the underground survey allowed to observe the rock mass from an inside point of view, thus obtaining some additional data. However, given that the caves have been excavated along the main joint direction (Fig. 9), the underground data are very similar to the data collected on the cliff.

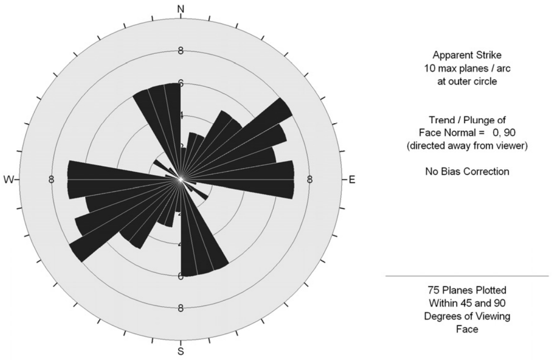

Fig. 9 Rose diagram of 75 direction data of underground chambers: the comparison with the structural data (see Fig. 6) testifies that the caves have been excavated according the main joint

5. Monitoring system

The installation of a rockfall monitoring system in Pitigliano presents some peculiar aspects: a) it is necessary to plan a 24h/24 real time system, because the possible phenomena can evolve in a very short time, and it is not compatible with a traditional monitoring system (manual deformometer); b) there is a strong constraint linked to the high landscape value that prevents from the adoption of traditional systems for the data acquisition (it is not suggestible a net of wires and cables, used to connect the instruments to the data logger, winding the cliff); b) even if the previous condition can be solved through special wires and multiple data loggers that would increase dramatically the cost of the system, and furthermore the number of the monitoring points implies serious problems for the maintenance.

These constraints led to the planning of a monitoring system based on: some deformometers with automatic data collection; radio systems for the transmission of deformometric data; a local gateway that receive the data from the radios, forwarding the information by GPRS to a remote server; an easy-to-use website showing the data 24h/24.

The system was installed in August, 2007 and, after a test period, it is considered operative since the end of September. The data are available on a web site and also a wap access has been realized, assuring the connection from mobile phones.

For the moment, two of the most critical situation are being monitored with four deformometers and two radios (Fig. 10). Each monitored crack is equipped with to deformometers in order to assure the detection of displacements in any directions: as regards to the results, in the last 12 months, no relevant movements have been recorded (Canuti et al., 2008).

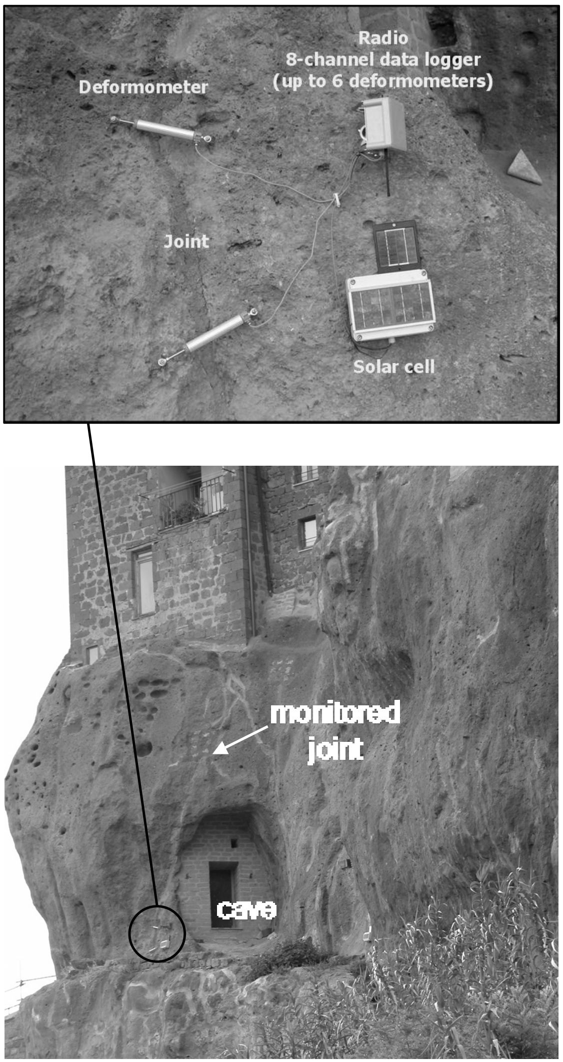

Fig. 10 Part of the monitoring system: the radios are in communication with a gateway, equipped for GPRS data transmission and located at the foot of the cliff

6. Conclusions

Pitigliano is a simple case history, but its interest is represented by the integration of different techniques and by the fact that its geological situation is common in several towns in Central Italy, so this study can be used as a guideline in similar situations.

It should be also noted that the installed monitoring system represents both an important step towards a better surveillance of the instability phenomena affecting the cliff of Pitigliano, and a very interesting innovative technical solution. In fact, the system is very simple and it guarantees a strong reliability and no-maintenance is required, so representing an interesting prototype for similar situations.

Acknowledgements

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Effects of Landslides on Machu Picchu Cultural Heritage

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Abstract. Scope of the present work is to provide a possible interpretation from geological and geomorphological point of view of the deformations patterns which exists upon the archaeological structures and buildings, underlying the link between natural geomorphologic process and anthropogenic ones (e.g. local subsidence, underground caves, structural deficit or deformation patterns due past seismic activities). The main input to such interpretation came from the census activities realized during the last three field of survey (2003-2004 and 2005), of the entire structural conditions of the citadel. The study has been performed by the development of a specific and detailed vulnerability and damage data sheet for archaeological exposed elements. All the data has been analyzed trough processing techniques (vectorial intersection and spatial analysis). Damage and vulnerability analysis has been correlated by exposed element positions versus potential landslides map. The main purpose of this work is to provide basic data and geological and geomorphologic evidence to support the above theory. A damage/vulnerability map has been carried out through the synoptical reading of a multi layer project implemented on a GIS platform; providing various building typologies (exposure), their tensional and deformation paths (vulnerability) and the morphological view of the area.

Keywords. Landslide risk, Vulnerability, Cultural Heritage, Machu Picchu

1. General setting of the archaeological site of Machu Picchu

The monumental complex of Machu Picchu (Lat. 13° 09'South, Long. 72° 31'West), designated by Unesco as World Heritage Site in 1983, was discovered on 24 July 1911 by Hiram Bingham, an American historian and professor of archaeology at Yale University.

Although the citadel is only 80 kilometres far from Cuzco in line of air, the whole site was never found during the Spanish conquest; the detail is important to understand the particular shape and geographical asperity of the area.

The archaeological site is indeed located on the crest of two mountains, 2430 m.a.s.l., with the Urubamba river at its foot in a very inaccessible zone of Andean forest (fig.1). All the theories provided so far are based on studies and archaeological discoveries but there are no historical sources which provide information as to what happened in the "Lost City".

Actually, the site is affected by geological risk due to frequent landslide phenomena that threaten security and tourist exploitation. In the last years, the landslide scientific community has promoted a multi disciplinary joint programme for the monitoring and control of superficial deformation, with remote sensing techniques and field survey analysis to define the typology and magnitude of potential landslides. During the last geological field surveys it was possible to reconstruct in detail the geological model of the area.

Fig. 1 General view of the archaeological site of Machu Picchu citadel (photo by D. Spizzichino)

2. Geological setting

The area is characterized by granitoid bodies that had been emplaced in the axial zones of the main rift system that are now exposed at the highest altitudes, together with country rocks (Precambrian and Lower Paleozoic metamorphics) originally constituting the rift 'roots'. The Machu Picchu batholith is one of these Permo -Triassic granitoid bodies. The bedrock of the Inca citadel of Machu Picchu is mainly composed by granite and subordinately granodiorite.

This is mainly located in the lower part of the slopes (magmatic layering at the top). Superficially, the granite is jointed in blocks with variable dimensions, promoted by local structural setting. The dimension of single blocks is variable from 10^{-1} to about 3x10 m^3. Soil cover, widely outcropping in the area, is mainly composed by individual blocks and subordinately by coarse materials originated by chemical and physical weathering of minerals.

Part of the slopes exhibit debris accumulation as result of landslide activity. Grain size distributions of landslide accumulation are closely related to movement types and evolution. Talus and talus cones are composed by fine and coarse sediments, depending from local relief energy. Alluvial deposits outcrop along the Urubamba River and its tributaries.

They are composed by etherometric and polygenic sediments, that may be in lateral contact with the talus deposits. Anthropic fill and andenes, on top of Citadel, reflect the work of Inca activities in the area (fig. 2).

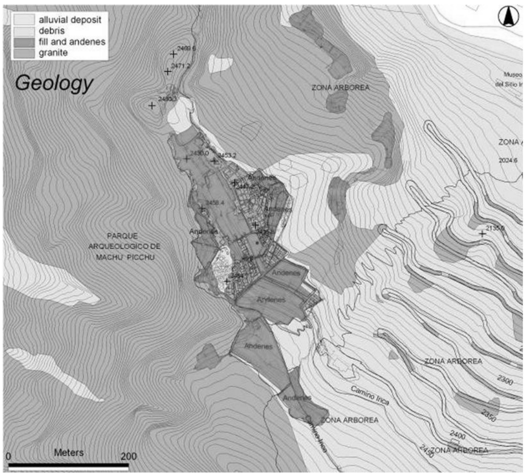

Fig. 2 Sketch of local geological map of the Inca citadel of Machu Picchu (by Canuti et alii, 2005)

3. Geomorphological setting

The general morphological features of the area are mainly determined by the regional tectonic uplift and structural setting. As consequence, kinematic conditions for landslide type and evolution are closely depending on the above factors. Several slope instability phenomena have been identified and classified according to mechanism, material involved and state of activity. They are mainly related to the following: rock falls, debris flows, rock slides and debris slides. The area of the citadel has been interpreted as affected by a deep mass movement (Sassa et al. 2001, 2002) that, if confirmed by the present day monitoring systems, it could be referred to a deep-seated gravitational slope deformation (DSGSD), probably of the type of the compound bi-planar sagging (CB) described by Hutchinson (1988).

A main trench with NW-SE trend, related to a graben-like structure, is located within the archaeological area and supports this hypothesis. Other trenches are elongated in the dip direction of the slope. Rock slides and rock falls may produce blocks with dimension variable from 10^{-1} to 10^2 m^3. Debris produced by rock slides and rock falls, as well as from weathering processes is periodically mobilized as debris slides and debris flow. Debris slides and debris flows are characterized by an undifferentiated structure varying from chaotic blocks immersed on coarse sand matrix. The grain size distribution is mainly depending on the distance from the source areas and slope angle. Finally, it is interesting to notice, on the NE side, the presence of a large debris accumulation, just below the citadel, presently being eroded by all around dormant slides. The accumulation it is probably the result of an old geomorphological phenomena now stabilized, still not clear in its original feature. Anyway, the mass movements occurred certainly before the Inca settlement since some of their terraces ("*andenes*"), are founded over this accumulation area.

4. Exposure, Vulnerability and Damage of Cultural Heritage

The concept of value during exposure and damage analysis cannot be merely applied to Cultural Heritage (CH) due to their singularity, peculiarity and un-repeatability. In addition, the assessment of the damage severity based on money refund for restoration can be difficult to estimate due to the impossibility, in most of cases, to reproduce the original features of the damaged element. Vulnerability as usually defined as the degree of loss on an element or group of elements at risk, resulting from the occurrence of a natural hazard (landslide) of a given intensity (Varnes et al., 1984).

Usually the vulnerability is expressed in a scale from 0 (no loss) to 1 (total loss) and is a function of the landslide intensity and of the typology of the element at risk $V=V(I;E)$. In practical terms the vulnerability is expressed by the link between the intensity of the landslide and its possible consequences.

Formally, the vulnerability may be expressed in terms of conditioned probability (Einstein, 1988):

$V = P\ (damage|event)$;

namely by the probability that the element at risk is prone to a certain degree of damage under the occurrence of a landslide of a given intensity. In the same time the vulnerability should consider also an assessment of the damage severity.

5. Methodological analysis for vulnerability assessment

The vulnerability assessment of an exposed element may be performed through the analysis of damage of an element with same structural characteristics affected by a given landslide type with the same intensity. The methodological process should consider the following steps:

1. definition of the localisation of the element at risk; historical and/or direct analysis of damage of the element at risk, in correlation with different landslide typologies with different intensity;
2. intensity/damage analysis of classes of elements at risk characterised by the same building/structural typology;
3. implementation of a vulnerability function depending on each class of exposed elements with respect to minimum/maximum expected landslide intensity.

6. Methodology for the analysis of static-structural conditions of the site

For each typology of element at risk a value of damage has been defined, after the stage of inventory and filling of a field survey catalogue (fig. 3). The field catalogue for the survey of the static-structural conditions of CH exposed at landslide risk has been derived from similar experiences carried out for the assessment of seismic vulnerability/degree of damage. In particular, the following parameters have been adopted:

- geometric properties of the CH in terms of height and wall thickness, in order to correlate these data with e.g. the impact force of fast slope movements;
- presence of restoration works, useful to understand past damage and, as well, the present capability to resist to a landslide with a given intensity;
- presence or absence of coverage is a fundamental parameter to understand the impact of weathering on structures;
- presence of cracks in order to reconstruct damage derived from the interaction between structure and soil;
- analysis of active strain processes (i.e. sinking, swelling, tilting) and degradation (i.e. humidity, decreasing of resisting sections) sub-divided into vertical and horizontal elements;
- classification following the main building typologies and their static-structural characteristics.

Fig. 3 Examples of cracks collected in the archaeological structures and buildings (photos by D. Spizzichino)

7. Conclusion

All the damage and vulnerability data collected for the citadel has been spatialised by GIS techniques and linked by geomorphological dynamics and processes acting on the area (fig. 4). A preliminary good correlation between retrogressive phenomena on the N- East portion of the citadel and deformation patterns along the archaeological builds has been performed by mapping a first damage catalogue evidencing tension cracks, patterns, caves and superficial deformations.

All the collected data and their interpretations should be helpful for the future development of the research activities in order to promote a landslide hazard and risk assessment, a stability model along a schematic profile (fig. 5) and design of low impact mitigation measures for the entire archaeological site.

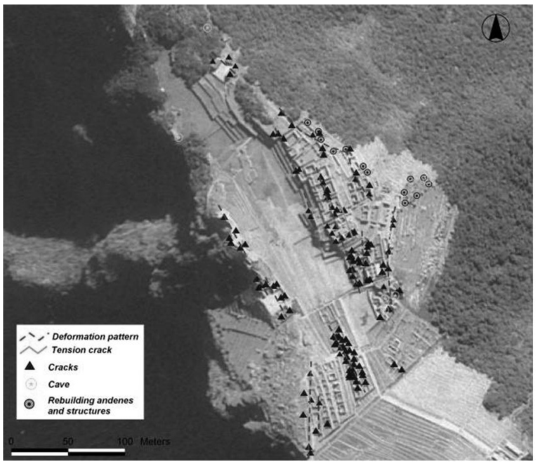

Fig. 4 Deformation patterns, tension crack, rebuilding *andenes* and structures and cave existing on the Citadel

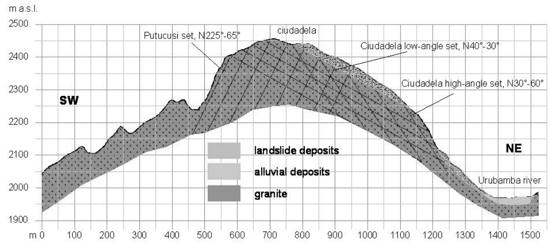

Fig. 5 Schematic profile for the implementation of stability model

Acknowledgments

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Living with Landslide: The Ancona Case History and Early Warning System

Geol. Stefano Cardellini, Geom. Paolo Osimani - Ancona Municipality Monitoring Centre – Italy

On 13th December 1982 Ancona city, an historical and capitol region of Le Marche - Italy, located on the East coast of the Adriatic sea, was involved in a large and deep landslide. (Figure 1)

Fig. 1 Italy and Ancona city

An intense landslide interested the northern area of the city, the "Montagnolo" hill started to slide towards the sea.
The event involved, during the movement, about 180 millions of cubic meters of ground. (Figure 2)

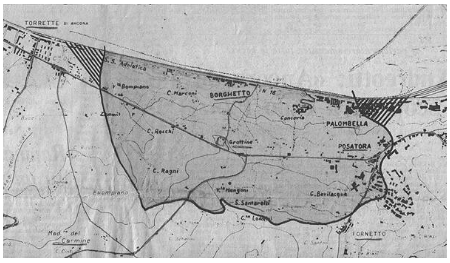

Fig. 2 First field map made the days after the event

It damaged structures and infrastructures and some important public and strategic buildings, among them the Faculty of Medicine building, the Oncological Hospital, the Geriatric Hospital and the Tambroni retirement home. All the older people and the patients were moved to the nearest Hospitals for the first aid.
The National Railway MI-LE (Adriatica) and regional Highway Flaminia slid down 10 metres towards the sea. The movements started from the lower border of the landslide and came up the slope. At the end of the event the movements surveyed were: on the base 8 metres in horizontal maximum and 3 meters on height, while on the top 5 meters in horizontal and 2,5 meters downwards.
On the 13th of December morning, after a night of uninterrupted movements and noises due to the opening fractures of buildings, the Residential Districts named "Posatora" and "Borghetto", were evacuated. (Figure 3)
The landslide damaged private houses and infrastructures and about 3000 people were evacuated. 1.562 people were moved to hotels and other residences by Municipality and they remained in that situation for a long time.

Fig. 3 The National Railway MI-LE (Adriatica) and regional Highway Flaminia

Gas and water supplies were interrupted too and the city remained for some days without the necessary services.

The more significant damages can be resumed as following:

- 220 hectares extension (affecting 11% urban area of Ancona)
- 3661 people evacuated (1071 families)
- 1562 people moved to hotels and other residences by Municipality
- 280 buildings destroyed or damaged (a total of 865 residences)
- Faculty of Medicine building, Oncological Hospital, Geriatric Hospital, Tambroni retirement home, were irreparably damaged
- 31 farms damaged
- 101 SME
- 3 industries
- 42 shops
- 500 people lost their jobs
- National Railway MI-LE (Adriatica) and regional Highway Flaminia blocked
- Gas and water supplies interrupted
- Luckily, no people died during the event!

The dynamic of the Landslide of Ancona can be explained in two steps:

1. A gravity settlement happened at great deep probably induced by some dislocations activated during the 1972 earthquake, then re-activated by the intense rain infiltration (some days before the event it rained for almost 6 days without any interruption).
2. After the first step we had an activation of superficial and medium landslides. These started to move after about 10 minutes, with consequent damages to buildings and infrastructures. (this second step continued for some hours)

The superficial geomorphology of the Ancona landslide is influenced by many and complex movements. The colluvial soils, in some places of the landside, where their thickness is about 10meters, have flown down as a mudslide. This dynamics was helped by the high rate of saturation .

Taking into account all the researches and investigations during the last 25 years spent in the site and in laboratory, we can conclude that the Great Landslide of Ancona city is an Deep-seated landslide (complex, composite according to Cruden & Varnes 1996) reactivated after a long period of precipitation; new fractures were opened by a long period of earthquakes 10y before (6 months duration). (Figure 4)

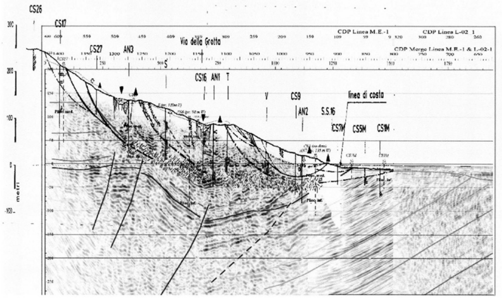

Fig. 4 Geomorphological and seismic section

The landslide involves clay and silty clay layers (Pliocene-Pleistocene), fractured with different OCR parameter, alternated with thin sand levels.

Overlapped sliding zones are active (maximum depth: 100-120 m, maximum depth 1982 event is 75 m bgl).

Across all the body of the landslide, in horizontal direction, parallel to the coast, there are two natural trenches that cross the slope. These trenches are upstream of old landslides slid down and now they are filled with heterogenic and plastic soils. These soils involves clay and silty clay, mud and thin sand level with some fragments of calcarenitic layers.

These trenches together with a complex structural system of fracture and discontinuity, influenced the system of underground water.

All the geological and geotechnical analyses of the landslide mechanisms aimed at the consolidation preliminary design in the 2000; but this plan concluded that a consolidation was impossible, both due to very large expenses and to a very strong environmental impact, which would have totally changed the site appearance with a severe socio-economical impact.

Ancona Administration decided then to live with the landslide reducing nevertheless the risk for the people living there.

During the last years, some partial interventions of the total preliminary design, for the consolidation stroke, have been made. Two drainages systems were done, one deep based on trenches and wells, and a more superficial one with canals. Reinforced bulkheads were built and in some part of the area reforestations were made.

Ancona Administration decided to continue the drainages systems both superficial and deep.

In 2002 the Regione Marche, (one of the main administrative units in Italy) made a law for the people that also today live in the landslide, to give Ancona Administration the responsibility of creating an Early Warning System and an Emergency Plan for people. The whole project has the aim both to issue to the population a certification to live safely in their homes and to check the landslide moving.

The projected Early Warning System consists in an integrated and continuous control at a superficial and deep level of the whole area.

The first phase of the monitoring system, concerning the control of the surface, has been working for some months. Within some months the Geotechnical in Place Continuous monitoring system (II phase) will be activated . (Figure 5)

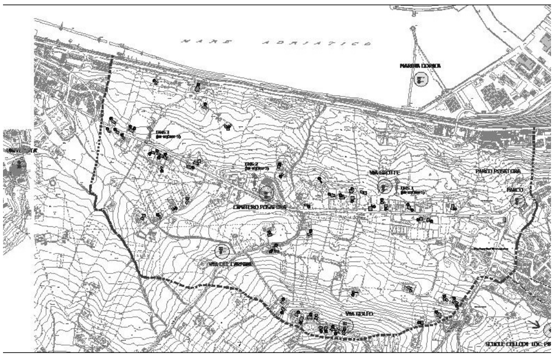

Fig. 5 Early Warning System

Surface monitoring

The surface monitoring system is based on:

- 7 Automatic Robotic Stations (of high precision)
- 230 reflector points (installed partly on the 64 inhabited houses and on the structures and infrastructures)
- 26 geodetic GPS (Global Position System – at single frequency L1 (installed on the 64 inhabited houses)
- 8 geodetic GPS at dual frequency L1+L2 (reference)
- 7 high precision clinometric sensors for the stability control of the main stations of the I and II level of the net (automatic geodetic boxes).

The combination of the different instruments: GPS, Automatic Robotic Stations and the clinometric sensors allows us to monitor in the three coordinates (3D, X, Y, Z) a great number of points previously identified, to keep them under supervision with different measuring technical and from different control positions. The adoption of the geodetic GPS at dual frequency assure an high quality of the GPS measures, and a greater versatility at all the system. This monitoring system is studied to try to determine every surface movement both in the area and in the inhabited houses and to produce some alarms managed by a Control Centre H24 placed in the Town Hall, where a staff of technicians have to estimate the alarms. Only whenever the situation requires the Coordinator starts the Civil Protection Plain.

The measuring cycle is set up on 30 minutes, but in emergency or after a long rainy period, the system can operate on every points of the dual frequency GPS net also in Real Time RTK, and with the 7 Automatic Robotic Stations. (Figure 6)

Fig. 6 Automatic Geodetic box in Marina Dorica

The surface monitoring is based on GPS system in 3 different active levels, on 7 Automatic Robotic Stations and a later control with 7 high precision clinometric sensors for the stability control of the main stations of the I and II level of the net:

A - GPS system:

1. Main Network (I level active at the moment) formed by n°3 main stations outside of the landslide area with n°3 geodetic GPS at dual frequency L1+L2 (reference) placed on two steady buildings, and a third one placed on a Geodetic box at Marina Dorica founded with a reinforced concrete pole (18 m).
2. Secondary Network (II level active at the moment), formed by n°5 main stations inside of the landslide area with n°5 geodetic GPS at dual frequency L1+L2 (reference) placed on one building and on n°4 Geodetic boxes founded with reiforced concrete poles (12-18 m).

All these geodetic GPS (n°3+n°5) form a high precision net working in the Early-warning system, on different control levels, to assure the GPS net (at single frequency L1), installed on 26 inhabited houses, a strong network; so that after an alarm it can work in real time RTK.

3. Third Network (III level active at the moment) formed by n°26 geodetic GPS at single frequency L1 installed on 26 inhabited houses inside of the landslide area.

B - Automatic Robotic Stations

The Automatic Robotic Stations (n°7 of high precision) are placed in the I and II level networks, in the same places of the geodetic GPS at dual frequency L1+L2, except for the "Collodi school" building. They control (angles and distances) of 230 reflector spots placed on the inhabited buildings left and on the consolidation structures built inside the landslide.

Geotechnical monitoring (DMS)

Now a in place Geotechnical Monitoring System DMS (patents and trade mark CSG-Italy) is under construction. It is maden by n°3 boreholes (100 metres) and, into them, will be installed n°3 Modular Dynamic System columns.

Each column is formed by n°85 Biaxial Inclinometric modules (range +/-20°, resolution 0,01°), n° 2 Piezometric Sensors (range 100 psi, resolution 0,01 m), n°85 Temperature Sensors (range 0-70°C, resolution 0,1°C) for a total active length of 85 metres with instruments, while the first ten metres and the last five ones are without any instruments.

DMS can be preassembled and installed in site forming an instrumented column, like a spiral cord, connecting the required number of modules, each containing one or more geotechnical-geophysical sensors and the electronic boards for data collection and transmission.

The modules are linked by special 2D/3D flexible joints that allow strong, continuous adaptability to bends and twists of the borehole, whilst maintaining rigorously the orientation with respect to a reference system defined during installation.

DMS Early warning management.(Figure 7)

The data from the DMS instrumentation column are sent through RS485 protocol to the control unit, which compares them with threshold values (set by the user) and storages them in a circular buffer.

In case of movements larger than threshold values, the control unit sends a warning SMS/direct call to the staff on duty of the monitoring centre.

The same is the case of rapid change of water-table levels. Warning levels are counted from 1 to 4, in a growing order of danger.

In the monitoring centre, the control software GeoMaster takes care of downloading the data stored in the control unit memory buffer.

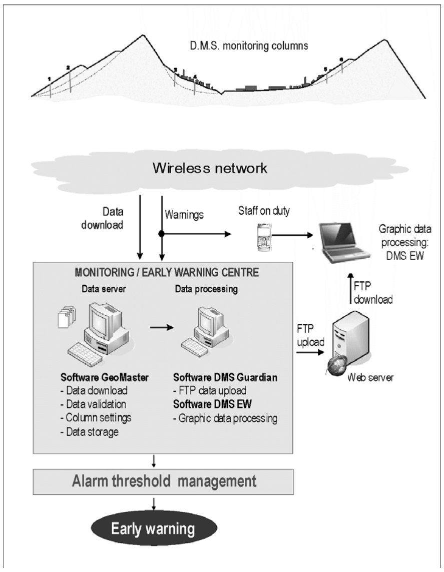

Fig. 7 DMS Early Warning system

The DMS Early Warning is the software that visualizes the subsurface data at the monitoring centre and wherever an Internet connection is possible. The software in a compact check panel allows the contextual control of displacement (E-W, N-S, Module diagrams, on Polar and Azimuthal plots) as well as the variations of the level of the water table and temperature; time history of each multiparametric module, and displacement-velocity are also displayed at selected intervals.

Transmission System

The transmitted data coming from the different sensors, are collected according to the two following procedures:

a. I and II Level Net: data transmission in real time through a WiFi Standard HyperLan to the Town Monitoring Centre. The system is based on a main radio line (spot to spot) between the Automatic Robotic Stations and the Ancona Municipality Monitoring Centre. Data transmission in real time works through some free frequencies radio links of 5,4 GHz (HyperLan). It realizes a strong transmission and a low environmental impact thanks to their noise controls system.
b. III Level Net: data transmission through periodic GSM in "dialing" with a data acquisition every 6 hours.

First data and conclusion

After some months of observation and studying of the data of the surface monitoring system, apart from any ordinary variations connected to the days and seasons, some little movements have been located inside the landslide.

Some geodetic GPS at single frequency L1 installed on 26 inhabited houses inside the landslide area (third network) have collected movements of 0,5-1,5 cm towards north (in valley direction) (Figure 8).

The interested area is where the landslide has the maximum depth (100 – 120 m) and where lots of plastic soils into the two trenches are found.

But the movements examined don't worry because they happen in a restricted area and during seasons changes (summer-winter) when the clay soils loose their humidity and reduce their volume.

These data have permitted to verify the monitoring system sensibility also for what concerns the smallest movements in the colluvial soils.

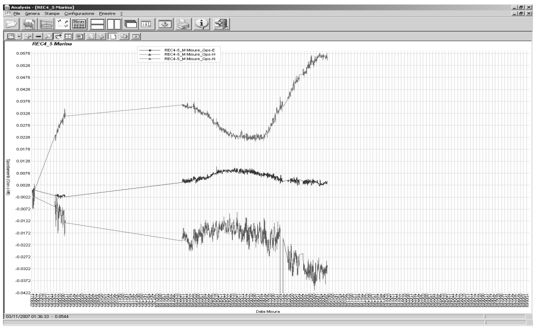

Fig. 8 GPS Time history of a movement

In this way, the Ancona administration has chosen to "LIVE WITH THE LANDSLIDE": this new concept implies that the safety of the population is achieved through a high-quality and comprehensive early-warning system. This in contrast with the more static concept of standard engineering remediation works, which are clearly impracticable so far, in our case.

This project is the result of the best conjunction between human resources and a more reliable technology in the Early Warning monitoring field, put in use for a best safety and peacefulness for the people living on the Ancona landslide.

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Ground-based InSAR Monitoring of An Active Volcano and Related Landslides

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Stromboli volcano (Italy) is characterized by a typical “Strombolian activity” which consists of very low energy explosions, every 10-15 minutes. In December 2002 an eruption caused a landslide on the NW slope of the volcano (Sciara del Fuoco slope, SdF) and produced a tsunami. Concerns over the possibility of further slope collapses of the SdF led to the set up of a permanent monitoring system of ground deformations.

The ground-based radar interferometer (GB-InSAR) system installed on the Stromboli Island (Fig. 1) was designed by the Joint Research Centre of the European Commission (Rudolf & Tarchi, 1999; Antonello et al., 2004); it is continuously active since 20 February 2003 (Antonello et al., 2003; Casagli et al., 2003 Casagli et a., 2004; Antonello et al., 2007) and produces, on average, 120 images per day of the area under investigation (NW flank of crater and the upper part of the SdF), characterized by a resolution of about 2m × 2m, with an accuracy of the measurement of less than 1 mm. Interferograms (obtained using pairs of averaged sequential images) contain the displacement vector along the line-of-sight (LoS) in the time interval between two acquisitions. Negative values of displacement indicate a movement toward the sensor (shortening along the LoS). On the crater area this direction of movement correspond to the inflation of the volcanic cone while, on the SdF, this is usually related to a local bulging or to the downslope sliding of the volcano-clastic material accumulated on the SdF slope. Conversely, a positive value of displacement identifies a movement backward with respect to the sensor (lengthening along the LoS) that on the crater area could be related to the deflation of the volcanic cone.

In January 2007, the GB-InSAR showed a progressive acceleration of deformation on the NE crater. The recorded velocity progressed from 0.04 mm/h to 0.7 mm/h toward the radar that suggest an inflation of the upper sector of the volcanic system. The increase in the deformation rate successively involves the portion the SdF (15 February 2007) in which the velocity increased from 0.02 mm/h to 0.25 mm/h, toward the sensor.

These events are related to the new eruption occurred at the end of February 2007. The effusive phase (from 27 February to 12 April) started with an explosion to the lower part of the crater (causing a landslide on the portion of the crater flank) and with the opening of the effusive vent at 600 m a.s.l. Velocities in the first hours of the eruption were so high that exceeded the capability of the GB-InSAR device.

After few hours from the effusion onset, the interferograms returned partly coherent and showed a complex deformation pattern characterized by:

1. a complete decorrelation on the crater flank due to the explosion and to morphological changes related to the crater collapse;
2. concentric interferometric fringes related to the bulging before the vent opening at 600 m a.s.l.;
3. parallel interferometric fringes related to landslide movements on the SdF.

During the entire effusive phase, velocity values, on the SdF slope, constantly decreased from 30 mm/h to 0.2 mm/h toward the sensor, with the only exception of two limited periods related to the opening of a new vent (8- 9 March) and to a major explosion (15 March).

In particular since 8 March the velocity recorded on the SdF increased again with movements toward the sensor. The interferogram highlighted a very high deformation rate (more than 300 mm/h, Fig. 2), which again exceeds the capability of the correct phase unwrapping. The arrangement of the interferometric fringes is related to the bulging due to the opening of a new vent, occurred at 14.30 UT of 9 March. Following the method proposed by Fukuzono (1985) and Voight (1988) it has been possible to predict in advance of one day the opening of the 9 March vent.

After 12 April, the eruption is to be considered concluded and the velocity recorded by GB-InSAR progressively decreased down to the values characteristic of the normal activity of the Stromboli volcano.

The GB-InSAR monitoring allowed us to highlight different deformation patterns, related to the eruption and to the associated landslides, suggesting different triggering mechanisms of the deformation process. Furthermore the GB-InSAR system has recorded changes in the deformation patterns, both on the crater area and on the SdF sector, in advance with respect to the onset of each one of the relevant events.

The absolute values of velocity recorded are plotted in Fig. 3: the light red line represents movements toward the sensor (negative radar displacements), while the dark blue line represents movement backward with respect to the sensor (positive radar displacements). In Fig. 3 the three different phases, above mentioned, are shown. The pre-effusive phase (from 10 January to 27 February) is represented by the first (light) shaded area, characterized by very low, progressively increasing, deformation rates; the effusive phase (from 27 February to 12 April) by the second (dark) shaded area, characterized by very high velocities of deformation and the post-effusive phase (from 12 April) by the last area in which the deformation rates decreased down to the pre-crisis values.

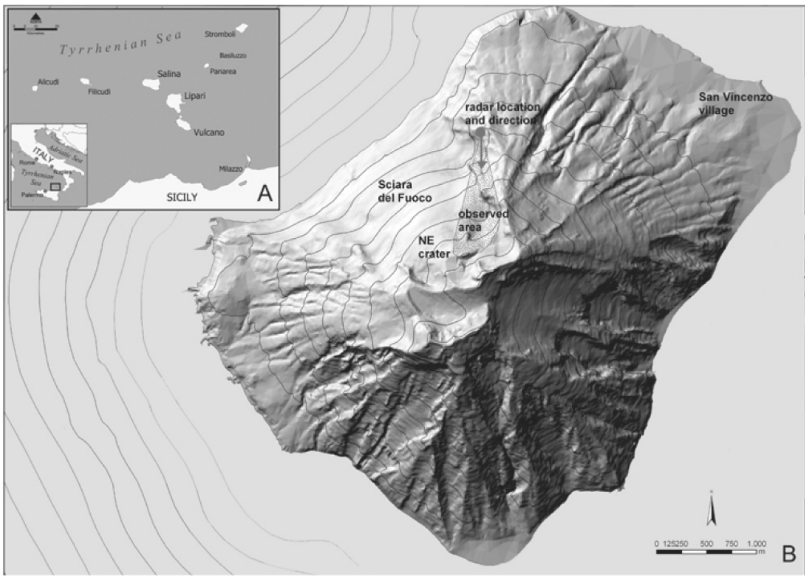

Fig. 1 Location map of the Stromboli volcano. A, Geographical location of the Stromboli volcano, the northernmost island in the Aeolian archipelago. B, Shaded relief image of the Stromboli volcano projected on a DTM showing the steep NW flank of the island, called Sciara del Fuoco. The dashed portion indicates the observed area. The radar location and direction are shown with the point and arrow.

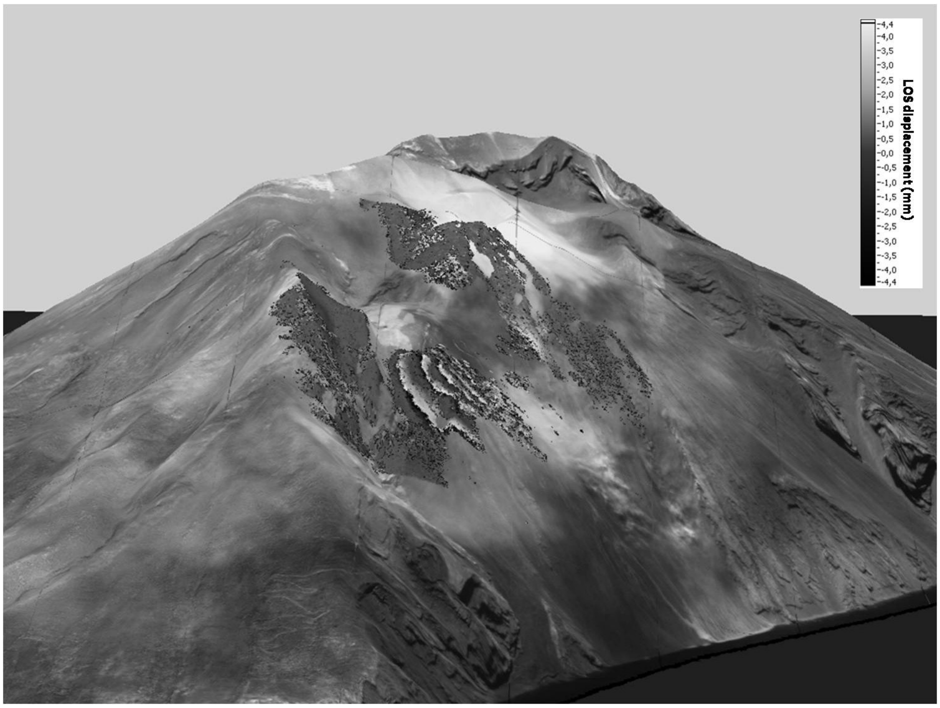

Fig. 2 3D model of the Stromboli Island (Sciara del Fuoco slope and NE crater) with an interferogram obtained from the GB-InSAR. The position of the radar is shown with the white symbol. The interferogram spans a time interval of 11 minutes (from 11.17 UT and 11.28 UT of 9 March 2007) showing a velocity greater than 300 mm/h.

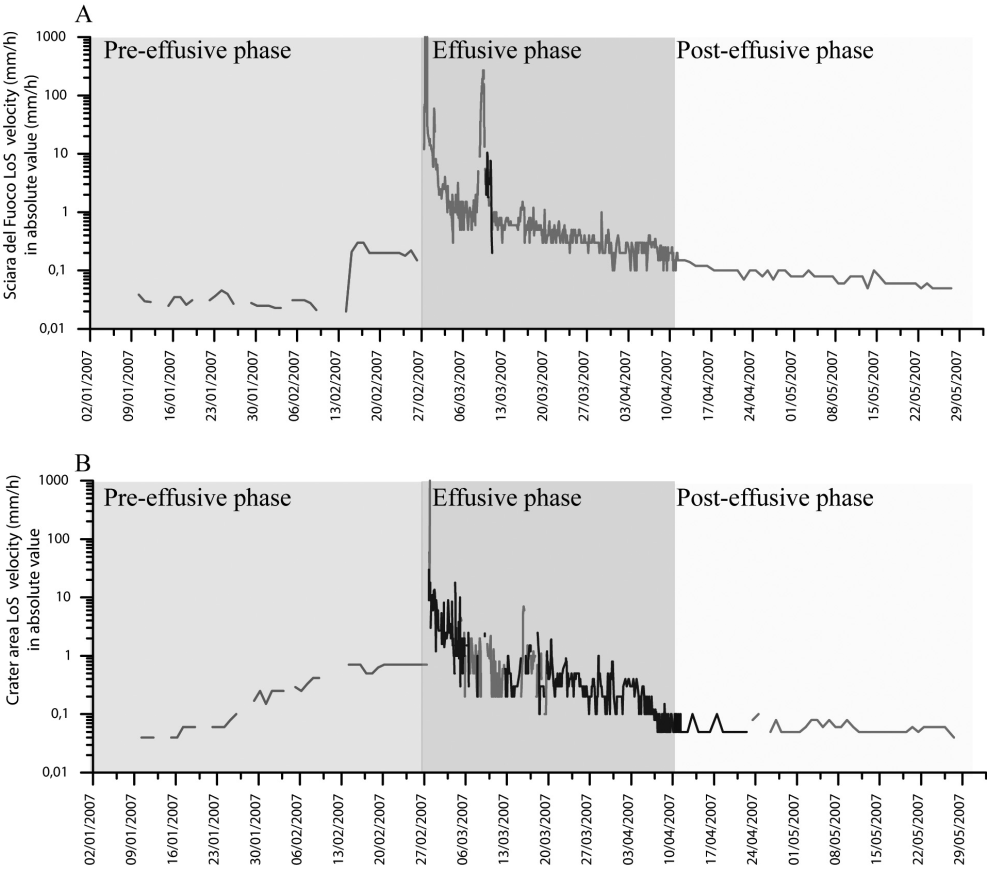

Fig. 3 GB-InSAR velocity plot during the 2007 Stromboli eruption measured on the Sciara del Fuoco (A) and on the crater (B). LoS velocity is in logarithmic scale to emphasize the low displacement rate in the first period of the pre-effusion phase and in the post-effusion phase. The lighter line represents a displacement toward the SAR sensor (negative radar displacement); the dark line represents the deformation backward with respect to the SAR sensor (positive radar displacement).

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Case Study on Local Landslide Risk Management During Crisis by Means of Remote Sensing Data

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Abstract. A case study of rapid landslide mapping in Southern Italy is here presented. A complex landslide affected the small village of Cavallerizzo di Cerzeto on March 7th 2005 causing several damages and the evacuation of the inhabitants. Civil protection authorities were immediately activated for the emergency and risk management. As an integration of *in situ* monitoring and field surveys, remote sensing data were used due to their quick availability and capability for rapid landslide motion survey. Very high resolution optical images and data from radar satellites were processed and analyzed; they were integrated with information from field survey and ancillary data. The analysis of the area affected by land movements was performed in 5 working days; this represents a good response for civil protection activities and demonstrates that remote sensing data are a valuable during emergency planning and risk management.

Keywords. Emergency, landslides mapping, civil protection, remote sensing.

1. Introduction

When a landslide emergency occurs, it is critical to map the landslide rapidly in order to produce the emergency plan and mitigation strategies as quickly as possible. Remote sensing can play a great role in emergency management. Optical images are the main sources for change detection before and after the event. InSAR technique can provide additional in-formation related to the mass movements. Combining both optical images and InSAR outputs together, it is possible to define the spatial extension and temporal evolution of landslides for the emergency management strategy.

Following landslide movements in Cavallerizzo di Cerzeto (Italy), the Italian National Civil Protection Department (DPC) asked the Department of Earth Sciences, University of Firenze, to monitor the area using remote sensing data from both optical very high resolution (VHR) satellites and radar sensors by means of InSAR technique. Indeed, it is considered that new generation VHR images could provide a powerful tool for civil protection activities in risk assessment, emergencies and disaster management, since they are readily available due to the possibility of programming data acquisition: those images represent a valuable tool for change detection before and after an event and thus give quickly evidence of the phenomenon for emergency planning and risk management (Casagli et al., 2005; Voigt et al., 2007). Spaceborne SAR interferometry (InSAR) has demonstrated in recent years its capabilities in providing precise measurements of ground displacements induced by slope instabilities. In the case of slow movements (up to few cm/year) affecting built-up areas multi-interferogram approaches, such as the Permanent Scatterers (PS), are able to retrieve the spatial distribution of displacements and their evolution along the monitored period: the PS technique, developed and patented by Telerilevamento Europa (Colesanti et al., 2003; Ferretti et al., 1999, 2001), has verified its capability in landslide motion survey (Colesanti et al., 2003; Farina et al., 2006).

2. Case study of national landslide risk: Cavallerizzo di Cerzeto, Italy

The small village of Cavallerizzo di Cerzeto, located in Cosenza Province, Calabria region, Italy, was affected and damaged by a catastrophic landslide event on 7th of March 2005 triggered by prolonged rainfalls and snowfall. According to Cruden & Varnes (1996) the Cavallerizzo landslide could be described as a complex debris slide–earth flow; it evolved along the San Nicola stream (Figure 1). In total, thirty buildings were severely damaged or destroyed by the landslide, and the main road connecting Cavallerizzo with the villages of Cerzeto and Mongrassano was disrupted (Figure 2). About 310 inhabitants had to be evacuated to nearby villages.

The study area is located along the western edge of the Crati graben (Lanzafame & Tortorici, 1981), a tectonic depression bounded by a N-S striking normal seismogenic fault system, active since the Late Pliocene. From a geomorphological point of view the area is characterized by widespread slope movements: there are several slides, complex slide-flows and sectors affected by severe erosion and by superficial slope movements. Evidences of recent activation in the slides can be generally recognized (Iovine et al. 2006).

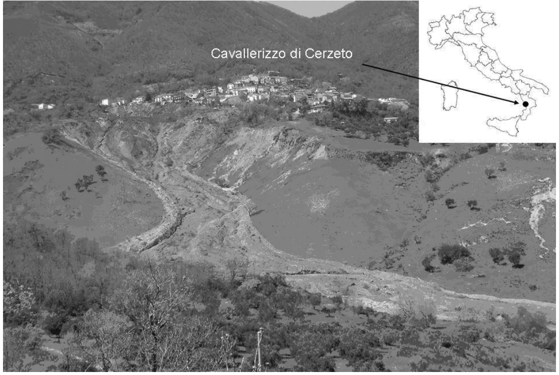

Fig. 1 Mud flow along the San Nicola stream just below Cavallerizzo di Cerzeto.

The Italian National Civil Protection Department (DPC) was immediately activated after the landslide and the

Department of Earth Sciences, University of Firenze, Competence Centre of DPC for hydrogeological risk, was asked to monitor the area using remote sensing data from both radar processing and optical very high resolution satellites images in order to obtain a rapid mapping of the event, damage assessment and residual risk analysis.

Fig. 2 The main road disrupted by the landslide.

3. Data processing and interpretation

Optical images have been taken from very high resolution Quickbird and Ikonos satellites: these kind of images have a spatial resolution from 4 meters up to 70 centimeters with spectral range from visible to near infrared; they have deeply showed their capability in environmental monitoring and emergency planning (Hervas et al. 2003; Chadwick et al., 2005; Davis & Wang, 2002). For this purpose a good Quickbird archive image was acquired (dated 3rd January 2003) while a new acquisition from the Ikonos satellite was programmed and resulted in a very good, clear image on 16th March 2005. These images were orthorectified and processed in order to produce the best color composites for visual interpretation: radiometric enhancement, such as linear and decorrelation stretching, was applied while principal components and band ratios analysis was performed; they were also rendered on a digital elevation model giving the 3D perspective views. Red-green-blu color combinations of bands were used as the most effective way for geomorphological mapping.

These data were photo-interpreted and change detection was carried out in order to identify the spatial extension of the landslide and main damages occurred: individual landslides and unstable areas around were recognized and mapped (Figure 3).

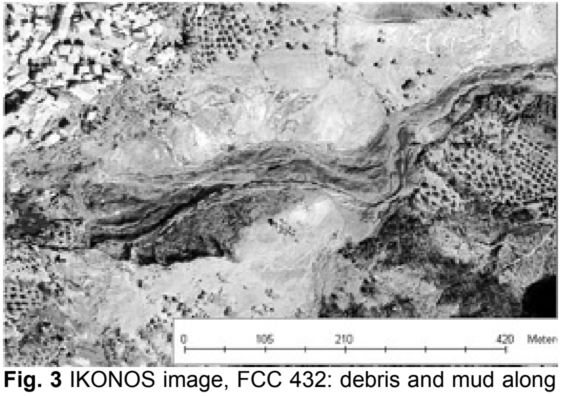

Fig. 3 IKONOS image, FCC 432: debris and mud along the S.Nicola stream (orange dotted line).

Spatial filtering was also applied, by means of sharpen and directional filter (N30E), in order to retrieve textural items related to lineaments and structural setting of the area.

Integration with information from PS analysis was then performed, using an ascending and descending radar images data sets collected by radar satellites from the European Space Agency (ESA). ERS1/2 satellites images over the nine year period 1992-2001 and 3 years (2003-2005) of Envisat images have been processed; the Standard Permanent Scatterers Analysis (Ferretti et al., 2005) was applied to 82 images in descending orbit and 21 in ascending orbit .

Ancillary data were collected such as coloured orthophotos (related to year 2003), thematic maps on geology, geomorphology, tectonics and topography; in particular a Digital Elevation Model (DEM) was available at a resolution cell of 20 meters and local landslides inventory maps from the Hydrogeological Asset Plan (*Piano di assetto Idrogeologico PAI*). These information, mostly given by the civil protection authorithies, were integrated in to the G.I.S. environment with those coming from remote sensing data processing in order to perform a consistent radar-interpretation, according to Farina et al. (2008), and photo-interpretation (Figure 4).

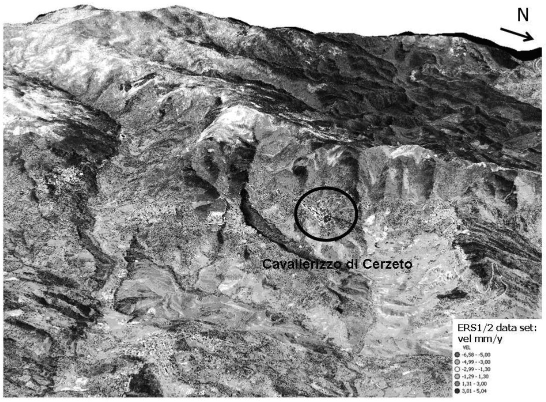

Fig. 4 3D view of Cavallerizzo di Cerzeto and surrounded area. IKONOS image rendered on DEM and PS from ERS1/2 dataset.

The interpretation of Permanent Scatterers provided information on the deformation rate and gave evidence of older unstable areas, as well as those affected by recent movements. The PS derived from images acquired in descending orbits gave information on movements in the direction towards the satellite, while those from ascending orbits gave information in the direction away from the satellite; by combining the two displacements and considering the component along the slope, the movement was estimated as 1 cm per year.

Several landslides, already defined in the *PAI* were updated regarding geometry, state of activity or both by means of photo-interpretation and radar-interpretation; at least four new landslides were identified (Figure 5).

The analyses of the area affected by land movements was performed in 5 working days, due to the quick availability and processing of optical and radar remote sensing data integrated with ancillary data.

Afterwards a field survey was carried out in order to validate and refine the results obtained from remote sensing data and to define the interpretation keys. Validation of PS was carried out by comparison with points gatherd using a GPS. Furthermore it was possible to verify the amounts of damages in the building and infrastructure: they have been compared with the results obtained from the change detection performed on optical satellite images.

Fig. 5 Detail of the landslides interpreted around the village of Cavallerizzo.

All the data, information and results were reported to the Italian Civil Protection Department in charge of risk management: they decided to permanently evacuate the village and relocate people to a new site.

Conclusions

A re-activation of a landslide in March 2005 caused severe damage to the Cavallerizzo di Cerzeto village, southern Italy. A Permanent Scatterers analysis of the previous 10 years, combined with the photo-interpretation of very high resolution satellite optical images (from Ikonos and Quickbird optical satellites) acquired on demand, provided information on the deformation rates and gave evidence of older unstable areas, as well as those affected by recent movements. These data, confirming the extension and the critical conditions of the area, showed that the slope could not be stabilized at reasonable cost for the community and helped the autorithies to decide for the re-location of the village.The analysis was performed according to the needs of civil protection autorithies for risk management.

The results demonstrate that a combined approach based on the use of multi-interferometric techniques and photo-interpretation represents a valuable tool for landslide rapid mapping and that, using this approach, it is possible to define the spatial extension and temporal evolution of landslides for the emergency management strategy. In fact, applications of remote sensing techniques to landslide detection and identification have been already outlined (Mantovani et al. 1996, Singhroy et al. 1998, Metternicht et al. 2005).

Anyhow, the field survey represented a crucial step for the validation of the remote sensing data and the consolidation of the whole analysis.

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Landslide-risk Reduction Strategies and Practices in the Philippines

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Abstract: The Philippines has been identified as one of the landslide hotspots in the world (Kjekstad, 2007). The frequency has dramatically increased during the last few decades due to rapid development, increasing demand for space and changing climate patterns. The two major landslide disasters in 2006 in Southern Leyte and Albay provinces placed the Philippines as the world's top climate victim in that year with more than 2,000 casualties and billions of pesos property damage. In the Philippines, compared with other geohazards the level of disaster-risk reduction lags behind for landslides. A shift in strategy from virtually responding only to disasters to improvement and institutionalization of disaster preparedness plans was a breakthrough in 2003. A comprehensive Geohazards Mapping Program was officially launched by the national government through the collaboration of various government agencies. A huge chunk of the national budget was infused into the Program while additional support was obtained from international funding agencies. As a result, 1:50,000 scale maps have been prepared for the entire country but still lack the accompanying booklet containing the methodology. Empowerment of the local community is the strength of the recent READY project through the establishment of community-based warning systems in critical areas, public awareness campaign, and initiatives to mainstream landslide-hazard assessment. As a proven formula in other countries that have attained significant success in reducing landslide risk, the National Disaster Coordinating Council (NDCC) has yet to tap the academe and the private sector as partners in landslide-risk reduction efforts in order to accelerate work and elevate the level of landslide hazard and risk assessment.

Keywords. Landslide- risk reduction strategies, national program on landslides, landslide susceptibility maps, Philippines

Introduction

Confluence of geologic, geographic and climatic factors makes the Philippines prone to natural disasters, particularly from landslides. Many communities in landslide-prone areas continue to grow. In 2006, recent major landslide events in Southern Leyte and Albay provinces in 2006 claimed more than 2,000 lives and caused billions of pesos of property damage.

This paper outlines the development of landslide risk reduction efforts and strategies in the Philippines as part of institutional building. Risk-reduction practices and challenges to improve/enhance the current system are discussed.

Landslide-risk Reduction Strategies

National government programs

In 2003, the national government strengthened its disaster-mitigation program through the launching of the National Geohazards Mapping Program. The umbrella organization of the Program is the NDCC, which is chaired by the Secretary of National Defense and executed mainly by member agencies including the Mines and Geosciences Bureau (MGB), Philippine Institute of Volcanology and Seismology (PHIVOLCS) and the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). As part of the campaign, landslide susceptibility maps for the entire Philippines have been produced mainly for a scale of 1:50,000 for the entire Philippines (MGB, 2004), using slope as primary criterion. MGB and PHIVOLCS, both members of the (NDCC), agreed to split the responsibility on landslide hazard mapping and assessment on the basis of trigger mechanism, i.e. MGB and PHIVOLCS for rainfall-induced and earthquake-induced landslides, respectively.

The NDCC has recently launched a multi-agency project called Hazards Mapping for Effective Community-Based Disaster Risk Mitigation or the READY Project (NDCC, 2008). The project is being implemented by the Office of Civil Defence (OCD) in cooperation with NDCC member agencies including MGB, the National Mapping and Resource Information Authority (NAMRIA), PAGASA and PHIVOLCS. It is aimed at addressing the problem of disaster-risk management at the local level. The project has been implemented in 27 selected and high risk Philippine provinces. The project has three components: 1) multi-hazard and risk assessment, 2) community-based disaster risk mitigation using community-based early warning system (CBEWS) and information campaign, and 3) mainstreaming disaster risk reduction plan into the local development.

Formulated in 2000 in the aftermath of the Cherry Hills landslide, the Engineering Geological and Geohazard Assessment (EGGA) has been instituted and became one of the requirements for government and private developers prior to developing a site. It is also an additional requirement for larger development projects which require Environmental Impact Assessment (EIA), if deemed necessary.

The academe

At least two universities have been independently conducting researches on landslides since the Cherry Hills landslide in 1999. These include the University of the Philippines (UP) and the Mapua Institute of Technology (MIT). The Cherry Hills landslide gained much publicity due the significant number of casualties (58) and its closeness to Metro Manila, the capital of the Philippines.

In 1999, the UP created a Geohazard Advisory Committee consisting of faculty scientists and engineers to address the landslide problems in its campuses all over the country. Later, some of the members of this committee continued to collaborate and expanded their researches. The group's activities include research and publication, giving lectures to other universities, providing advice to companies and communities, and in organizing training, workshop and conferences on landslides. Support from other countries such as Japan and Norway has recently started pour in through research collaboration.

Starting on June 2008, a Department of Science and Technology (DOST)-funded program will be implemented by the University of the Philippines as a collaborative research program of its units. The Program is aimed at developing low-cost sensors to monitor parameters in the field traditionally measured by commercially available but high-cost instruments (Marciano et al., 2008). The sensors are being designed to include features capable for real-time measurements, efficient connectivity, durability for deployment in steep and inaccessible terrains and more importantly, these will be cheap and affordable suitable for developing countries like the Philippines.

The MIT also shifted its gear by establishing a graduate program in engineering geology in cooperation with a foreign university. Equipment have been procured both for instructional and service.

Private sector and NGOs

Ateneo de Manila's Manila Observatory has also conducted separate studies on landslides supporting collaboration with non-government organizations (NGOs). Other NGOs have their own projects and initiatives in landslide-risk reduction such as training communities on geohazards and providing assistance in rehabilitating affected areas. Private companies, whose infrastructures are affected or threatened by landslides and slope failures, either conduct their own in-house studies and mitigation measures or sub-contract other companies specialized in slope stabilization and ground improvement, often times involving consultants from the academe.

Practices and Challenges

Hazard maps and risk assessment

The two national mapping programs of the government have been producing mainly 1:50000 landslide susceptibility maps. These maps indicate the potential initiation sites for landslides but lack the time component which is present in landslide hazard maps. Confusion on how to interpret the existing landslide susceptibility maps and their acceptability have been major concerns for communities, land-use planners and other stakeholders because the map identifies large tracts of land as unsafe as the frequency and magnitude of landslide occurrence have yet to be incorporated in the assessment.

Landslide inventories in the Philippines are produced mostly by ground checks, and are very much likely to be incomplete especially for single, regional landsliding events. Topographic maps are only useful for identifying landslides which occurred before the mapping date (usually 1940s to 1950s) and which are larger than the map resolution. Limited capability and/or resources to conduct aerial surveys and limited access to satellite-based data make it difficult to efficiently produce landslide inventories, particularly for recent events.

Since most of the maps are 1:50000, these cannot be directly used at the village level. Mapping with greater detail at the local level is still needed in the formulation and implementation of contingency plans.

Rain gauges have become the popular community-based monitoring instrument for the national program. These instruments, mostly manually operated, are intended to provide rough estimates of when landslides will occur or when evacuation is necessary. Rainfall threshold values have been established for lahar initiation in Mayon volcano (Rodolfo and Arguden, 1991) and Pinatubo volcano (Arboleda and Martinez, 1996; Tuñgol and Regalado 1996), and for landslides in Leyte and Surigao (Garcia, 2006). However, since the relation between rainfall and landslide occurrence is empirically-determined and site-specific, threshold values established for an area could not be applied to other areas.

Slope monitoring and engineering mitigation measures

Despite the high frequency of landslides in the Philippines, slope protection is limited while instrumental monitoring of critical slopes is almost non-existent (Zarco et al., 2007). In the few cases where distressed slopes are monitored, this is usually done visually due to high cost and the risk of pilferage of slope monitoring devices. Practically, slope monitoring can only be afforded by wealthy communities. In recent years, problematic slopes are most frequently stabilized by combining structural and bioengineering methods. However, improvement or installation of subsurface drainage is not frequently done despite water being a major destabilizing factor in most slopes.

Prior to the February 17, 2006 Guinsaugon disaster, landslides were limited mostly to relatively smaller and shallower slope failures of mainly soil materials. The Guinsaugon landslide challenged local scientists and engineers to better understand the mechanisms underlying slope failures in rock (Figure 1). It also highlighted the limited number of local experts in area of rock mechanics. Majority of the limited studies on the stability of rock slopes undertaken in the Philippines before February 17, 2006 were done as part of consultancy-based projects rather than being research driven. Furthermore, the volumes of data derived from these site-specific studies have yet to be systematically integrated into a form that is readily useful to geo-scientists and engineers.

Minimal institutional linkage between the government agencies, academe and other sectors

As the lead agency, the NDCC has been successful in bringing together government agencies to work on geohazard problems of the country. However, the Council did not recognize the need to involve the academe and private sectors. Turfing, proprietary data generated by private companies resulted to decentralization and limited access to relevant data. Delfin (2006) has pointed out that government agencies should make sure that critical data, as part of public domain, are accessible through their websites. Limited access to relevant data also resulted to difficulty in smooth and timely execution of disaster response and rehabilitation, limited peer review of methods and outputs, and uncoordinated efforts and conflicting statements/ positions.

Limited institutional capabilities and capacities

Very few geoscientists, who have the basic skills in geohazard mapping are involved in landslide-risk reduction. In the Philippines, only four universities offer geology courses resulting to very few graduates per year. Most geology graduates are immediately hired abroad due to attractive compensation. Locally, the uncompetitive compensation of a government geohazard specialist compared with those in the mining industry (due to the recent mining boom) makes government service much less attractive. Being traditionally a mining promotion and regulatory agency, MGB has yet to strengthen its capabilities as a geohazard research agency otherwise create a separate/sub-agency that will focus on geohazards only, similar to the USGS model as suggested by Delfin (2006). Furthermore, in spite the high number of civil engineers in the country they are not actively involved in the geohazard-risk reduction program. To maximize the existing manpower of the country, there is a need to further develop and enhance expertise in landslides by providing training, undergraduate and graduate scholarships, and by supporting research and publication.

Conclusions

Although landslide risk-reduction efforts has started to develop only recently in the Philippines, there is a need to improve the current practices and strategies. First generation landslide susceptibility maps were generated but these have yet to be peer reviewed and communicated properly to stakeholders. Construction of hazard maps that are larger scale than the current 1:50,000 maps and are more useful to communities should include time element. Hazard assessment which incorporates frequency, probabilities and takes into account the transport mechanism of landslides is desired. Institutionalization of partnership between the government agencies and the academe and the private sector in the national landslide-risk reduction program is paramount. Likewise, the Commission on Higher Education and the academe should intensify its campaign in recruiting students to consider career in geohazards by opening new programs and courses in more universities throughout the country.

Development of A Ubiquitous-based Monitoring System for Debris Flows on Natural Terrain in Korea

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Abstract. As one of damage mitigation technologies of landslides on natural terrain, this study developed a real-time monitoring system for debris flows. The developed monitoring sensors are a debris flow detection sensor, a slope displacement measurement sensor, and a water content measurement sensor. Because the monitoring system should be installed in the mountainous areas, it was designed with an independent power supply system and ubiquitous wireless communication network. Each sensor was connected to a RF logger which was developed for wireless communication with the master logger in this study. The transmitted measurement data to the master logger are sent to a remote monitoring center by the CDMA communication method in real time. It is possible to measure rainfall data of the site with a rain gauge attached to the master logger.

Based on the developed system, this study constructed a pilot monitoring system for debris flows at a site in the northeastern part of South Korea. The system is composed of one master logger, three sets of debris flow detection sensors, two sets of slope displacement sensors, four sets of water content sensors, one geophone, and one web camera. The pilot system is the first trial to construct a real-time monitoring system for debris flows on natural terrain in Korea, although there have been many repetitive debris flows. Based on this study, it is expected to develop more effective monitoring systems for debris flows in the near future.

Keywords. Real-time monitoring system, debris flows, mountainous areas, independent power supply system, ubiquitous wireless communication

1. Introduction

According to a statistical data issued by NEMA in 2006, there have been average annual human deaths as many as 47.2 people induced by landslides in Korea since 1976. It is 22.3 percents of total human deaths by all kinds of natural hazards occurred in Korea (Park et al., 2006). The percentage of human deaths by landslides to that of all natural hazards in 2006 reaches up to 36%. Based on these data, landslides are severe natural hazards in Korea, especially during the summer season. Therefore, there are increasing societal needs to reduce landslide hazards and damages in the community.

The major type of landslides on natural terrain in Korea is a debris flow which is triggered by a heavy rainfall during the summer season. Once landslides occur as a circular failure or a translational slide at the starting position, they are changed into debris flows with mixture of boulders, soil, and water toward down-slope (Kim et al., 2000). Because the movement velocity of debris flow is so fast reaching up to 30 m/sec (Dikau et al., 1996), it is important to detect landslides and debris flows at early stage of the occurrence. Moreover, landslides and debris flows usually occur on unspecified and very broad natural slopes. Therefore, we should approach to the detection and monitoring of debris flows on natural terrain with different concept from that of man-made slopes and creep type landslides.

In order to establish systematic damage mitigation technologies of landslides on natural terrain, this study developed a real-time monitoring system for debris flows. The monitoring system measures water contents and slope displacement near the upper slopes, and fast movement of debris flows along a natural terrain as well as rainfall of a site. Because the monitoring system should be installed in mountainous areas, it was designed with an independent power supply system and ubiquitous wireless communication network for observation of debris flows at a remote place from the site.

In this study, the monitoring system for debris flows was installed at a pilot site in the northeastern part of South Korea. Although there have been huge damages induced by debris flows, it is the first trial to construct a real-time monitoring system for debris flows on natural terrain in Korea. Therefore, it is expected to develop more effective monitoring systems for debris flows based on the results of this study.

2. Setting up of the Monitoring System on a Pilot Site

2.1 Composition of the monitoring sensors

The monitoring sensors are composed of a wire-type debris detection sensor, a slope displacement sensor with a tilt-meter, a water content measurement sensor, and a rain gauge. The wire-type debris detection sensor measures movement and velocity of debris along a valley. The slope displacement sensor detects slope failure on natural terrain. Since there are some differences of water contents dependent on soil property, vegetation as well as rainfall intensity, it is important to monitor the water contents using a water content measurement sensor. The rain gauge is designed to be attached to a master logger for the measurement of rainfall in a site.

The debris flow detection sensor is to detect movement of debris flow and to measure velocity of debris flow along a valley. The sensor should detect the debris flows rapidly and transmit the data without a delay time. Therefore, it should alarm occurrence of debris flow immediately with simple operating system. In order to satisfy these demands, this study developed a wire-type sensor for debris flow detection. When debris and water move down along a valley, the wire sensor installed across the valley would be cut by the force of debris flow. There is an electric signal induced by cutting of the wire sensor, which it is possible to recognize a debris flow. The electric signal is transmitted to the master logger via the RF logger connected to the wire sensor. This study developed another communication system considered with emergency due to rapid velocity of debris flows. In order to alarm the occurrence of debris flows immediately to the residents near the valley and a disaster response organization of government, this study designed to transmit a SMS message of a mobile phone using the CDMA modem. This communication method can reduce a delay time between detection of debris flows from a sensor and final alarm.

In general, debris flows are triggered by rapid saturation of soil due to infiltration of intense rainfall on natural terrain (Jakob and Hungr, 2005). They are initiated as a circular failure or a translational slide at the starting position, and then, changed into a flow type of debris along the slope and valley. Because the thickness of soil layer is not so thick in Korea, most of the landslides occur in shallow depths between the boundary of bedrocks and soil layer (Chae et al., 2004). Considered with the failure type on natural terrain in Korea, this study designed a slope displacement measurement sensor built-in a tiltmeter. The sensors are installed at several slopes with high potentials of failure in the mid or the upper part of a valley. The sensors measure minute displacement of slopes and transmit the measured data to the master logger via the RF loggers connected to the sensors.

This study also developed a water content measurement sensor to monitor the water contents and infiltration rate in the subsurface. The sensor can also be installed in different depths to measure difference of infiltration rate along the vertical depths at a position. The water contents measured from different geologic areas could offer important information for the relationship among rainfall intensity, water contents, and slope failure.

Since the monitoring area for debris flow is usually very broad on natural terrain, it takes much time and expense to connect all the sensors to a data logger using cables. It would also be a problem on stable management of the total monitoring system induced by cutting the cables or troubles of the logger. Therefore, this study developed a small RF logger that is capable of wireless communication with the master logger within a short range. The RF logger is attached to each monitoring sensor. It is possible to improve the efficiency of data communication, installation feasibility, and management conveniences using the RF logger system. This study designed a low power consuming circuit of the RF logger in order to be operated for a long time in the mountain areas. The logger is operated for one and a half year using a lithium battery without a supply of electric power. It can accept various types of sensors measuring an electric current and a voltage based on multi-function of measurement. Small size of the logger also offers easiness of installation in the field.

The master logger developed in this study saves the transmitted data from each sensor through the RF logger and sends them to a monitoring center in a remote area by TCP/IP communication using a CDMA modem. Based on the widely established IT network system in Korea, it is possible to communicate the data over the country using the ICP/IP network. The communication method also has fast incipient response in the system. The master logger has dual power supply system using a battery and a solar power. Several functions were installed in a firmware such as changes of system operating modes and emergency reporting function. It can accept various types of sensors based on multi-function of measurement. Figure 1 shows the basic concept of wireless network communication of the monitoring system in this study.

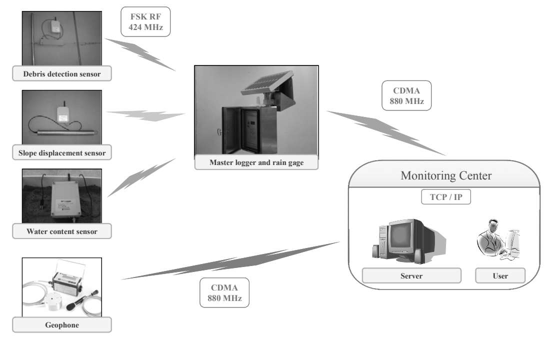


Fig. 1 Basic concept of the wireless network based monitoring system

2.2 Construction of a monitoring system in a pilot site

This study constructed a pilot monitoring system for debris flows at a valley on natural terrain in Korea. The pilot site is located at Deoksan village, Inje county, Gangwon province. There were big debris flows due to heavy rainfall in 2006 and 2007. The site is composed of the Precambrian gneisses with thick colluvium as much as 4m. There also are many boulders as large as 60cm x 50cm due to highly weathered rock masses. Since the site has high potential to debris flow in the future, this study selected the area as a pilot monitoring site.

This study installed twelve monitoring equipments at the site. The equipments are one master logger, three sets of debris flow detection sensors, two sets of slope displacement sensors, four sets of water content sensors, one geophone, and one web camera. Each sensor is connected to a RF logger which transmits the measured data to the master logger with FSK (Frequency Shift Keying) communication method.

The sensors were distributed on both slopes of the valley (Fig. 2). This study installed the water content sensors with different depths at a position such as 50cm and 80cm under the ground surface (Fig. 3).

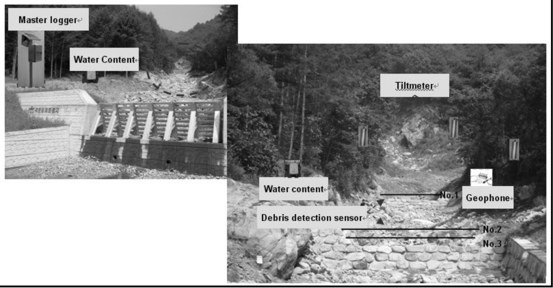
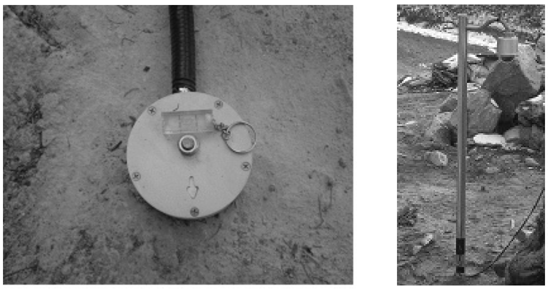


Fig. 2 A schematic view showing installation positions of the sensors

Fig. 3 The water content sensor and the slope displacement measurement sensor at one position

In case of the debris flow detection sensors, they have dual communication methods using the RF logger and the CDMA modem for immediate data transmission and alarm of a debris flow without a delay time. The geophone measures ground vibration induced by a debris flow at the upper slope of valley (Fig. 4 a). The web camera transmits a real-time movie of the site to the monitoring center at KIGAM by TCP/IP communication method (Fig. 4 b).



(a) (b)

Fig. 4 (a) The geophone for measurement of ground vibration, (b) The web camera installed at the site

3. Monitoring Results of Each Sensors

Construction of the pilot monitoring system was completed at January 10th, 2008. In case of rain gauge, it shows changes of rainfall amount induced by snow and rainfall (Fig. 5). The data will be used to analyze a relationship between rainfall and occurrence of debris flows with continuous measurement at the site.

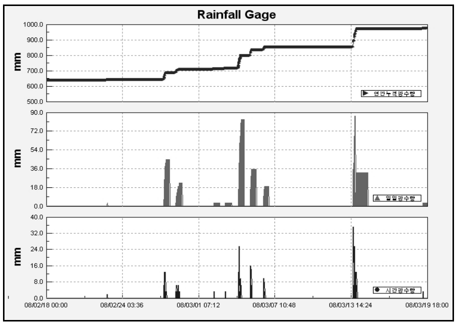


Fig. 5 Results of rainfall measurement using the rain gauge

The debris flow detection sensors show stable states without detection of any debris flow (Fig. 6). The "0" value means stable state and "1" value is a wire cut by a debris flow. When the wire is cut by a debris flow, an alarm message is displayed on a mobile phone and a warning light is operated (Fig. 7).

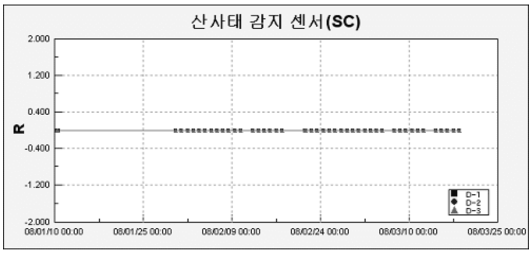


Fig. 6 Measurement results using the debris flow detection sensors

메시지

<토석류감지경보>

02/21 10:33:58

CH1:경보 CH2:정상 CH3:정상

한병언

01030657620

08. 02. 21 10:34

Fig. 7 An alarm message of a wire cut on the mobile phone

In order to monitor sliding of a slope, the slope displacement measurement sensors were installed in the subsurface at both slopes of the valley. The sensors detect minute slope displacement induced by melting of the ground in the spring season (Fig. 8).

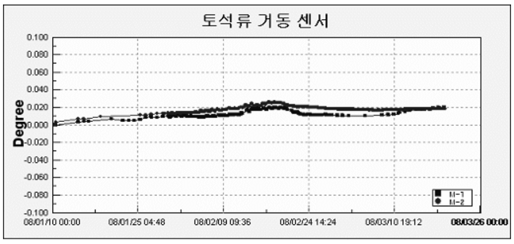


Fig. 8 Measurement results of slope displacement of the site

The water content sensors were installed at 50cm depths in the subsurface. Among them, C-2 and C-3 were installed at 50cm and 80cm depths at one position to observe the difference of infiltration rate dependent on different depths.

According to the monitoring results, each sensor shows different volumetric water contents influenced by geologic conditions and vegetation on the surface. The water contents have increased slightly due to melting of snow since early March. The abrupt increase of water contents of C-3 was caused by infiltration of snow during replacement of an abnormal sensor. In case of C-4, the abrupt increase of water contents was due to fast absorption of melted snow at the position (Fig. 9).

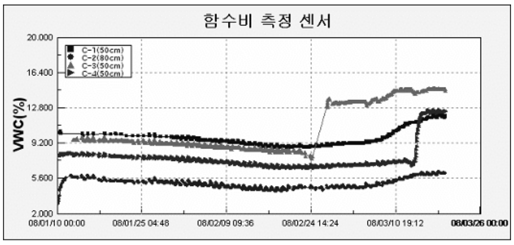
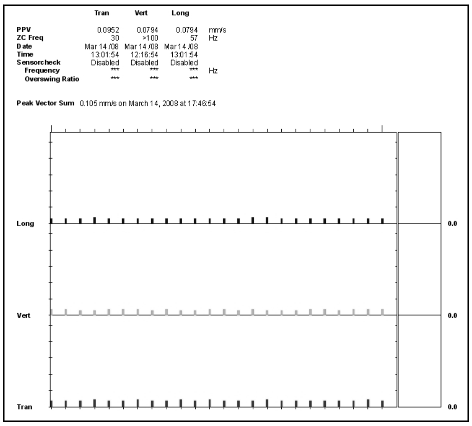


Fig. 9 Measurement results of the water contents of the site

The geophone shows no signal of ground vibration after installation at the site (Fig. 10). Fig. 11 shows an image captured from the real-time movie of the site recorded by the web camera.



	Tran	Vert	Long	
PPV	0.0952	0.0794	0.0794	mm/s
ZC Freq	30	>100	57	Hz
Date	Mar 14 /08	Mar 14 /08	Mar 14 /08	
Time	13:01:54	12:16:54	13:01:54	
Sensorcheck	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.105 mm/s on March 14, 2008 at 17:46:54

Fig. 10 Measurement data of the geophone

Fig. 11 A captured image of the site from the real-time movie recorded by the web camera

Conclusions

This study developed monitoring sensors and loggers for debris flow on natural terrain. The monitoring sensors are a debris flow detection sensor, a slope displacement measurement sensor, a water content measurement sensor. The sensors are connected to a RF logger for wireless communication with the master logger. The transmitted measurement data to the master logger are sent to a remote monitoring center by the CDMA communication method in real time. Because the monitoring system should be installed in mountainous areas, it was designed with an independent power supply system which can be durable up to one and a half year.

Based on the developed monitoring sensors and loggers, this study installed a pilot monitoring system for debris flows at a site in the northeastern part of South Korea. The system is composed of one master logger, three sets of debris flow detection sensors, two sets of slope displacement sensors, four sets of water content sensors, one geophone, and one web camera. Although there have been huge damages induced by debris flows, it is the first trial to construct a real-time monitoring system for debris flows on natural terrain in Korea. Therefore, it is expected to develop more effective monitoring systems for debris flows based on the results of this study.

Acknowledgments

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Slope Safety System and Landslide Risk Management in Hong Kong

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Abstract. The Geotechnical Engineering Office was established in 1977 by the Hong Kong Government to regulate geotechnical engineering and slope safety, in the aftermath of several serious landslides with multiple fatalities in the 1970s. Over the last 30 years, the GEO has developed a comprehensive and holistic slope safety management regime to combat landslide disasters and reduce landslide risk to the community.

Under the comprehensive Slope Safety System, the Government has been taking a proactive approach to reduce the landslide risk through exercising geotechnical control of new works, systematically rectifying substandard man-made slopes under the Landslip Preventive Measures Programme (LPMP), managing natural terrain landslide risk, maintaining Government man-made slopes, setting safety standards for slope engineering practice, promoting public awareness and response in slope safety through public education, and providing landslide emergency services.

Through the implementation of the Slope Safety System, the overall landslide risk from man-made slopes will be substantially reduced by the end of 2010 to less than 25% of the 1977 level. To continue the efforts to manage the landslide risks in Hong Kong, a Landslip Prevention and Mitigation Programme (LPMitP) has been launched in order to deal with the remaining landslide risks.

This paper presents an overview of the Slope Safety System, the framework for continuous improvement in technical standards to enhance slope engineering practice, and legislation improvements in mitigating landslide hazards and risk reduction in Hong Kong. Some recent novel applications of digital technology to natural terrain risk management in the GEO and the newly launched LPMitP will be introduced.

Keywords. Slope safety, landslide risk management, technical standards, legislative improvements, digital technologies

1. Introduction

Hong Kong, which is situated at the south-eastern tip of the mainland of China, has a total land area of about 1,100 km^2, covering Hong Kong Island, Kowloon, the New Territories and Islands. The terrain of Hong Kong is mountainous, with natural hillsides covering most of the land area: about 65% of the total land area has a gradient greater than 15^o, and 30% has a gradient of more than 30^o. Almost 50% of the available land area has high to extreme geotechnical limitations to its development potential. Hong Kong is sub-tropical, with an annual rainfall averaging about 2,200 mm. Rainfall intensities can be high, with 50 mm per hour and 250 mm in 24 hours being not uncommon.

Since the 1940s, the population has increased progressively to about 7 million in 2007. Extensive development had taken place, resulting in the formation of thousands of cut and fill slopes prior to 1977 with inadequate geotechnical engineering input. These sub-standard man-made slopes and natural hillsides are susceptible to landsliding during heavy rainfall. The scale of the landslide problem is reflected by a death toll of over 470 people since 1948. On average, some 300 landslides are reported every year. The acute landslide problem in Hong Kong is the result of dense urban development on steep hilly terrain, the legacy of a large number of substandard man-made slopes mostly formed before the 1970s and high seasonal rainfall.

2. Establishment of the Geotechnical Engineering Office

In the aftermath of the serious landslides at Po Shan Road and in the Sau Mau Ping areas, which claimed many lives in the 1970s, the Government established the Geotechnical Control Office (GCO) in 1977 (renamed the Geotechnical Engineering Office (GEO) in 1991, currently part of the Civil Engineering and Development Department of the Hong Kong SAR). The GCO was set up as a central body to regulate geotechnical engineering and slope safety in Hong Kong, with the mandate to develop a slope safety system to combat landslide hazards and reduce landslide risk to the community. In the past 30 years, the GEO has developed and implemented a comprehensive Slope Safety System which incorporates the application of the fundamental risk management strategies at the policy administration level to combat landslide hazards. The goals are to reduce landslide risk to the community through a policy of priority and partnership, and to address public attitude and tolerability of landslide risk to avoid unrealistic expectations. The Slope Safety System also adds value to the society through averting potential fatalities and improving the built environment.

Fig. 1 Landslide at Po Shan Road in 1972 (67 fatalities)

3. Hong Kong Slope Safety System

The Hong Kong Slope Safety System aims at reducing the landslide risk through the implementation of these four principal duties (Malone 1998):

- Policing through geotechnical control of new works, slope maintenance audits, clearance of vulnerable squatters threatened by hillslopes and safety-screening of private slopes
- Works projects: retrofitting of substandard Government man-made slopes, natural terrain landslide mitigation and boulder stabilization works
- Research and setting geotechnical standards
- Public education and information through slope maintenance campaigns, risk awareness programmes, landslip warning and emergency services

Development of the Slope Safety System since 1977 has resulted in significant improvements in many aspects to facilitate landslide risk management. The comprehensive Government's Slope Catalogue of about 57,000 sizeable man-made slopes, retaining walls and disturbed terrain features provides the necessary information for the systematic selection of substandard slopes for retrofitting under the LPMP, in a risk-based priority order (Wong 1998). The importance of promoting public awareness and response in slope safety and enhancing the appearance of engineered slopes is recognised, and these are now key components of the Slope Safety System. The Slope Safety System is reviewed regularly and benchmarked internationally through a Slope Safety Technical Review Board.

In the past 30 years, a number of improvements have been made to the Slope Safety System through technological advancement and institutional reforms.

4. Setting Geotechnical Standards

Before the 1970s, slopes were mainly formed by empirical means. There was little geotechnical engineering input in slope works and guidance on good engineering practice was lacking. In 1979, the GEO published the first Geotechnical Manual for Slopes. This Manual provides guidance for the standards of practice on a comprehensive scope of slope engineering including geology, ground investigation and laboratory testing, design and construction of slopes, instrumentation and maintenance.

Since then, the GEO has published a series of technical guidance documents, known as Geoguides, to supplement or update certain sections of the Geotechnical Manual for Slopes. Up to March 2008, seven Geoguides have been produced. These documents present standards of good practice for geotechnical engineering. The GEO also produced a series of publications that document the state-of-the-art methods in selected geotechnical engineering and geological subject areas. The latest publication title is Engineering Geological Practice in Hong Kong, which provides a useful reference for the geotechnical practitioners on the applications of principles of engineering geology to civil engineering works. In addition, findings of technical reviews and technological advancements are regularly promulgated by the GEO via Geospecs, Geological Memoirs, GEO Reports and GEO Technical Guidance Notes, which are available for viewing or downloading from the CEDD website (http://www.cedd.gov.hk).

5. Systematic Landslide Investigation Programme

The systematic landslide investigation (LI) initiative was introduced by the GEO in 1997 following the 1994 Kwun Lung Lau fatal landslide (Wong & Ho 1997). Under the LI programme, all reported landslide are screened systematically to identify cases that warrant follow-up inspections and detailed investigations (Ho & Lau 2008).

This programme has played a key role in advancing the state of knowledge on the slope performance and better understanding of causes and mechanism of slope failures (Chan & Ho 2001). The lessons and insights from landslide studies have provided major contributions in enhancing the reliability and robustness of engineered slopes and the continual improvement of the Slope Safety System.

6. Enhancement of Administrative and Regulatory Framework

Since 1977, the GEO has set up a comprehensive geotechnical control system to audit the adequacy of the design and construction of all geotechnical works including slope works, site formation, earth retaining structures, deep excavations and tunnels by private sector, public authorities and government departments. After the 1994 fatal landslide at Kwun Lung Lau, the Government set up an inter-departmental Standing Committee on Slope Safety (SCOSS), with high ranked representatives from the Government departments concerned, to endorse legislative proposals on slope safety for enactment.

Over the years, many legislative amendments and improvements to administrative instructions have been made to enhance the slope safety management for the private and public sectors respectively.

6.1 Legislative Amendments for Private Developments

The GEO was vested with the responsibility of checking the geotechnical aspects of private submissions under the ambit of the Buildings Ordinance (BO) (Chapter 123, Laws of Hong Kong) and its subsidiary Regulations. Since 1977, a number of legislative improvements have been made to these Ordinance and Regulations to incorporate the appropriate geotechnical requirements to safeguard public safety (Chan 1997). Examples of these include the special restrictions and geotechnical controls on the building works at the Mid-levels area and karstic marble area in the Northwest New Territories, requirement for submission of site formation plan for approval by the Buildings Authority, imposition of qualified supervision in respect of site formation works to be provided by geotechnical engineer.

Throughout these years, bills to enhance statutory geotechnical control on private developments have gained support from the industry as well as legislators. The latest initiative approved by the Legislative Council in 2004 was the setting up of a list of Registered Geotechnical Engineers (RGE) under the BO. It is now statutory requirement that only qualified geotechnical engineers are responsible for the geotechnical aspects of private building works, hence ensuring quality of geotechnical input.

6.2 Geotechnical Control on Public Works

The mandate for the geotechnical control of public works is derived from an administrative instruction first issued by the Policy Branch in 1978. Under the instruction, any Government departments responsible for public works projects are required to submit designs of their proposed permanent geotechnical works to the GEO for checking where this is warranted in the interest of public safety.

New or amended technical circulars are issued from time to time to strengthen or facilitate the geotechnical control of public works by the GEO. The more recent ones include the approval procedures for the use of permanent prestressed ground anchors and reinforced fill structures and slopes, and the requirements of obtaining GEO Checking Certificate for slopes and retaining walls.

6.3 Improvements in LPMP

In the last 30 years, significant improvements have been made on the output and robustness of the LPM works through the use of improved technology and innovative products together with enhanced project management techniques (Tang et al. 2007) in order to meet the changing needs of the general public. Its scope has been progressively expanded over the years to cover greening of slopes as part of the LPM works to significantly improve the built environment.

7. Natural Terrain Landslide Risk Management

Although the main focus of the Hong Kong Slope Safety System has been placed on landslide risk from man-made slopes, the risk from natural hillsides is on the rise in recent years due to increasing new developments in close proximity to natural hillsides coupled with progressive deterioration of the hillside condition. The susceptible terrain is prone to rain-induced landslide (Fig. 2). The current strategy is to keep the natural terrain landslide risk to a level that is as low as reasonably achievable. Study and mitigation of natural terrain hazards affecting existing developments are carried out following the 'react-to-known-hazards' principle.

Fig. 2 Natural terrain landslides affecting buildings

Undue cumulative increase in the risk to new developments is controlled through avoiding of development in hazardous areas as far as possible, and study and mitigation of hazards as part of new developments where required.

The GEO has been carrying out systematic research and studies on natural terrain landslide inventory since the early 1990s. Up to 2007, an inventory of 2,700 natural hillside catchments with a known history of failures affecting existing developments and major transport corridors have been established using aerial photograph interpretation.

Details of the latest development in natural terrain landslide risk management are given in Wong & Ho (2006).

8. Application of Digital Technology to Natural Terrain Landslide Risk Management

Notable advances have been made by the GEO in the application of digital technology and information technology to enhance the capability and efficiency of geotechnical work (Wong 2004). These include digital photogrammetry, Geographic Information System (GIS), Interferometric Synthetic Aperture Radar (InSAR), Light Detection and Ranging (LiDAR).

Digital photogrammetry, with improved efficiency, resolution and analytical capability over the conventional techniques, has notable applications in slope engineering work, which include stereo visualization and aerial photograph interpretation (API), compilation of digital terrain model (DTM) for 3-D GIS and virtual reality applications, and conversion of conventional aerial photographs into ortho-rectified images. Advanced GIS functionality has also been employed by the GEO for GIS-based geotechnical analyses (e.g. landslide susceptibility analyses, rainfall-landslide correlations, etc.), GIS modelling of landslide debris runout and QRA of natural terrain landslides. The GEO has also pioneered the technical development of a mobile field mapping system, which is integrated with a Global Positioning System (GPS) for detecting the spatial position on site (Ng et al. 2004).

9. Remote Sensing Technology

Remote-sensing technologies, which include LiDAR and InSAR, have been identified as being strategic to slope engineering practice. The GEO has been using a land-based LiDAR for topographic surveys where access is difficult or dangerous (e.g. fresh landslide scars). In addition, it can also be used for construction of high-resolution DTM, movement monitoring and change detection, and rock slope mapping and rock joint survey by judicious interpretation of the point clouds (possibly in conjunction with digital photogrammetry and image analysis techniques).

A pilot survey using multi-return airborne LiDAR was conducted by the GEO in December 2006. The results were promising and the high resolution data allows clear definition of ground features for terrain evaluation and interpretation of landslide morphology (Ng & Wong 2007).

InSAR can measure ground displacement with millimeters-level accuracy under favourable conditions. The GEO has completed a trial application of InSAR for detection of slope movement. This has identified the current limitation for such application (Wong 2004). Further development of ground-based and airborne InSAR is ongoing.

10. QRA for Landslide Risk Management

The GEO was among the first in the world to apply QRA techniques to manage landslide risk as well as to measure the performance of the Hong Kong Slope Safety System. In the past decade, QRA has been applied to global and site-specific landslide studies in Hong Kong. Global QRA was used to assess the risk due to contribution of different components to the total landslide risk. This provides a useful and valuable reference for landslide risk management, in particular, in the consideration of resources allocation and policy.

On the other hand, site-specific QRA aims at assessing landslide risk at a given site. It has been applied to problems that may not be directly amenable to conventional slope stability analysis or where a failure is liable to result in serious consequences. It is also used to develop cost-effective mitigation strategy for landslide and boulder fall hazards from natural hillsides at specific sites.

11. Strategic Planning of the GEO

The efforts for continuous technical development and improved standards for landslide risk management are driven by the change culture instilled in the GEO. The Steering Committee on Continuous Improvement (SCCI) which was set up in 1995 to steer and manage the change and continuous improvement programme. Since 1997, Strategic Plans on Slope Safety with 6 Strategic Goals have been formulated.

For each goal, strategies are developed and initiatives are formulated for implementation by the Goal Owners and the Strategy Teams. Success criteria and milestones are set for each Goal and the achievements are monitored by the SCCI.

12. Landslip Prevention and Mitigation Programme

With the completion of the current phase of the LPM Programme by 2010, all the high-risk substandard man-made slopes affecting buildings and major roads will have been retrofitted, thereby substantially reducing the overall landslide risk to 25% of the 1977 level. In order to contain the landslide risk within a low level, continuing efforts will be focused on retrofitting the remaining substandard man-made slopes with moderate risk and slopes that were treated over 20 years ago with less robust technology, and the vulnerable natural hillside catchments with known hazards and close to buildings and important transport corridors on a risk-based priority ranking system. A new Landslip Prevention and Mitigation Programme (LPMitP) has been launched by the Government in late 2007 to dovetail with the LPM Programme. The strategy of LPMitP is to prevent the increase in landslide risk due to slope degradation and urban development, and discharge Government's due diligence in dealing with known landslide hazards. An 'Asset Management' approach will be adopted by the GEO to deal with man-made slopes. Moderate-risk slopes that are at a more advanced state of deterioration will be selected for prompt follow-up action, on a rolling basis, as opposed to the 'Total Retrofit' approach currently adopted. Expanded efforts will be made under the LPMitP to systematically combat the natural terrain landslide risk pursuant to the 'react-to-known-hazard' approach.

Conclusions

The Slope Safety System of Hong Kong has evolved to its present state in the past 30 years. Hong Kong is now renowned for its comprehensive Slope Safety System in the region. Over the years, the GEO has made significant improvements on the development of the slope safety standards and a comprehensive geotechnical control system through legislative amendments. The keys to success attribute to the sustained commitment of the Government to combat the landslide risk, the dedication of the geotechnical professions within and outside the GEO, the continuous improvement culture in the organization and the support of the community at large on slope safety initiatives. Despite the achievements made to-date with regard to landslide risk reduction, there is no room for complacency for Government and the community. It is important that all stakeholders always maintain vigilant about the landslide risk and play their parts in a diligent manner in order to sustain the highest standards of slope safety in Hong Kong.

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Debris Flows in Urban Hong Kong – An Example of Risk Management

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Abstract. A large number of slopes and retaining walls have been constructed in Hong Kong to form flat land from the hilly terrain, to accommodate its large population and associated activities. Landslides at these slopes and walls have resulted in fast movement of debris that endangers the inhabitants. Since 1977, attention to slope safety by Hong Kong government has developed into a rational holistic slope safety management system with interwoven fronts and lines of action. This paper examines this effort from the angle of resource optimisation. The earliest effort in managing landslide risk included provision of resources for checking new geotechnical works to contain increase in risk, progressive retrofitting a large number of existing slopes that are found to be substandard, and provision of services that facilitates the work of the geotechnical profession. A tradition of responding to challenges through alertness to new challenges, determination to attack problems from the root, and presence of a core of capable staff for technical advancement has also been important to effective risk management. Examples of issues that have been so dealt with include landslides in squatter areas, learning from serious landslides, slope maintenance, development of the tool of quantitative risk assessment, and management of natural terrain landslide hazards. These are described in the paper.

1. Introduction

Hong Kong is hilly (Figure 1). Apart from reclamation from the sea, earthworks on the hillsides provide much of the space needed for its population of nearly seven million. Many slopes have been formed as a result over a period of some 160 years. More are added to the inventory continuously. At present, there are 57,000 sizeable slopes on record.

Fig. 1 Hilly Terrain of Hong Kong (around 1865)

Given this background, landslides affecting the community have been common in the history of Hong Kong. One notable example is the failure of a series of three retaining walls above Po Hing Fong on Hong Kong Island in 1925 (Chan, 1996). Seven three-storey buildings collapsed under the impact of the debris resulting in heavy casualties.

The rapid growth of population after the war created heavy pressure on housing development. Earthworks for land formation proceeded hurriedly, and mostly based on rules of thumb. Supervision and enforcement of specifications was not always to a desirable standard. This left slopes that could be unsafe especially during heavy rain. Fatal landslides became more frequent. For example, a rainstorm in June 1966 left 64 people dead (Chen, 1969). Then came June 1972. A road embankment in a new public house development liquefied and engulfed a temporary housing area (HKG, 1972a). Seventy-one died. A few hours later, a temporary excavation at the Mid-levels district of Hong Kong yielded, bringing down the natural hillside above it. The debris toppled a 13-storey building and killed 67 (HKG, 1972b). Government improved control on earthworks for building development and started studying stability of slopes in some landslide-prone areas of the territory.

In 1976, another road embankment in the same housing development of the 1972 failure again liquefied, killing 18 (HKG, 1977 and GEO. 1999). The state of social development of Hong Kong was such that focussed effort had to be started to prevent similar disasters. Government introduced institutional changes including the formation of the Geotechnical Engineering Office (called the Geotechnical Control Office then). In the some thirty years since then, the slope safety effort has evolved into a comprehensive system, with many lines and fronts tightly interwoven for maximum cost-effectiveness. This has been discussed in detail elsewhere, e.g. Malone (1998) and Chan (2000). The present paper does not repeat this effort. Instead, it aims at giving a quick discussion from the angle of organising resources to meet challenges.

2. Geotechnical Control

The first concern of Government after the fatal landslides of the 1970’s was that the state of design and construction of earthwork was unsatisfactory. This had left a legacy of problems that needed to be attended to but it was equally important to stop the scale of the problem from growing. Hong Kong had for a long time had a Buildings Ordinance (Hong Kong Law, Chapter 123) that controls the standard of building developments. This was extended to cover earthworks. For public projects, administrative arrangement was sufficient to subject earthworks designs to checking and related control (Chan & Chan, 1998).

3. Retrofitting Slopes

The immediate effort to address the problem of unsatisfactory slopes in existence then was on tall embankments and fill slopes, especially those that threatened public housing, hospitals and schools. The programme was extended to other types of slopes later, but only after an exercise to record existing sizeable man-made slopes. The resulting catalogue provides information on the size of the problem and basic information for ranking urgency of action. Recognising that such a ranking would be approximate, the system required that action on existing slopes proceeded in stages, so that slopes could receive the priority and extent of attention that each deserved. By 2000, the risk imposed by the old slopes on the whole community had been reduced by about half by the retrofitting programme. By 2010, the remaining risk is to be further reduced by half.

4. Supporting Services

It was also recognized early that geotechnical effort could be more effective if invested upstream of the design process, and if information needed for good design practice is made readily available. This led to the Geotechnical Area Study Programme, preparation of guidance documents and a comprehensive slope information management system. The Geotechnical Area Study Programme (GCO, 1989) studied air photographs and other information available to classify the whole territory into parcels of various degrees of geotechnical difficulties in land formation. Arrangements were made for land planning documents and plans for new public works projects to be commented on from the geotechnical angle.

The first Geotechnical Manual for Slopes was published in 1979, which was expanded and upgraded in 1984. This was followed by a series of geotechnical guidelines and publications that present good standards of practice on a wide range of geotechnical aspects. In addition, the GEO collected ground investigation and related reports for reference of the practitioners. It also started remapping the geology of Hong Kong in much more detail than previously attempted, to provide information to the geological practitioners in a series of memoirs and maps at 1:20,000 scale. Since 1990, the GEO also publishes internal reports with high potential interest to practitioners in a series called GEO Reports. A list of publications by the GEO can be found on the slope safety website of Hong Kong Government.

5. A Responsive Organisation

Through this rational process, the basic elements of the slope safety system were mostly in place by about 1982. By then, the GEO had also developed a tradition that would enable it to meet new challenges. This includes alertness to new problems, a determination to attack problems from the root, and nurturing a culture of technical excellence in its staff to support technical development and sourcing. The aim is to develop or adopt the right technology for use, and to transfer it to the practitioners. This tradition is critical to the richness and effectiveness of the present slope safety system as could be seen from the following examples.

6. Landslides in Squatter Areas

There was steady illegal immigration to Hong Kong before the 1980's. Many of the illegal immigrants found accommodation in squatters on wide stretches of steep hillside. In two heavy rainstorms in 1982, landslides at these squatter areas led to 24 deaths (Figure 2). A study of the nature of the problem quickly showed that it would be ineffective to carry out works on man-made slopes that put squatters to undue risk. A more direct solution would be to rehouse squatters subjected to landslide hazard. This started the Non-Development Clearance programme that effectively kept down further landslide casualties in squatter areas (Cheung & Shiu, 2002).

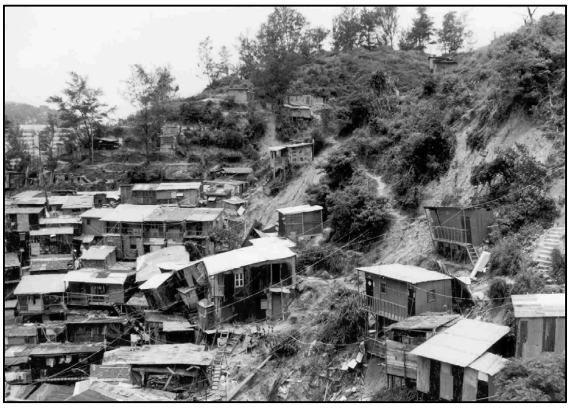

Fig. 2 Landslides at Squatter Areas

7. Landslide Investigation

Starting from 1982, the GEO documents landslides systematically. This includes general factual records of all landslides reported to the GEO and detailed investigation of selected landslides. Since 1983, the general factual records have been published annually (e.g. Lam, 2000). These have found useful applications in many occasions and are particularly important for the application of quantitative risk assessment (QRA) methodology to slope safety in the mid-1990's (e.g. Wong et al, 1997). The detailed investigations have revealed many new aspects of slope safety and slope engineering in Hong Kong and led to important improvements in practice (Chan & Ho, 2001).

8. New Catalogue and Slope Maintenance

Out of an investigation of a landslide at Baguio Villas on Hong Kong Island (Chan et al, 1996), two problems stood out. Drainage systems and other slope engineering components, unless regularly maintained, could fast become ineffective. The catalogue of existing slopes prepared in 1977 focused on slopes at or in the vicinity of urban areas. In the fifteen years since, urbanisation and population areas had spread. The potential consequence of failure of many slopes had become much more serious than before. To this, GEO started a programme to recatalogue all slopes in Hong Kong to serve as the basis of a more comprehensive slope safety management system (Lam et al, 1998). A state-of-the-art Geographical Information System was developed to facilitate processing and application of the information collected (Mak et al, 2001). The slope information is open to the public: this enhances transparency and facilitates participation of citizens in slope safety. A system was also developed to prioritize action based on the information collected (Wong, 1998).

GEO took a series of action to ensure that slopes are maintained. Guidelines on standard of good practice were published (GEO, 2003). A layman's version was prepared to benefit participation of non-engineering personnel and the public. The importance of maintenance was made known through television announcements, meetings with insurers and property managers, and public lectures (Massey et al, 2001). Principles on who to maintain slopes were agreed among Government departments that facilitate the identification of a maintenance party for every slope on the catalogue, and the results are made accessible to all. Lo et al (1998) discusses the effectiveness of slope maintenance in slope safety management.

9. Quantitative Risk Assessment

The fatal landslides of 1992 and the years after created heavy public pressure to speed up improvement of the state of slope safety in Hong Kong. The pressure stiffened with further fatal landslides in the following years. Additional resources were allocated. However, from discussions with people outside the engineering profession, there was gradual realization that the public may be asking for the impossible – zero landslide risk to life. While additional resources are welcome, the GEO is aware of the need for applying them wisely and rationally. It started experimenting with QRA methodologies in 1992 and gradually gained maturity (e.g. Ho et al, 2000). It is now a regular tool in setting strategies and priority of action (Ho & Wong, 2001), and in assisting people to see slope safety objectives in context (Yim et al, 1998).

10. Natural Terrain Landslide Hazards

For over one decade after its formation, the GEO focussed on man-made slopes. There were occasional records of landslides on natural terrain affecting country roads, but these were not posing too much hazards. In 1990, a natural terrain landslide occurred on Castle Peak at western New Territories (King, 2001) (Figure 3). The resulting debris measured some 20,000 cubic metres and the landslide was very large by Hong Kong standard. Although no one was hurt, it went through a planned housing platform abandoned for other reasons. The lesson was not lost that with the intensity of building and engineering development in Hong Kong, natural terrain hazards would have to be attended to soon. A series of actions was started to understand the nature and scale of the problem. This includes compilation of an inventory of natural terrain landslides from the aerial photographs (King 1999), studying of landslides (King, 2001 and Wong et al., 1998), reviewing documentary records of past landslides, and reviewing technical literature on the subject. When a natural terrain landslide in 1999 caused one death in an unplanned squatter development (FMSW JV, 2000), GEO was prepared for follow-up actions at the site. It was also ready to develop guidelines on good practice (Ng et al, 2002, ERM, 1998, Lo, 2000 and Wong, 2001) and natural terrain landslide risk management strategies for consideration of the policy makers (Wong, 2003). Work is ongoing in this area and GEO is confident that with the knowledge it has amassed, natural terrain landslide risks in Hong Kong could be effectively and meaningfully managed.

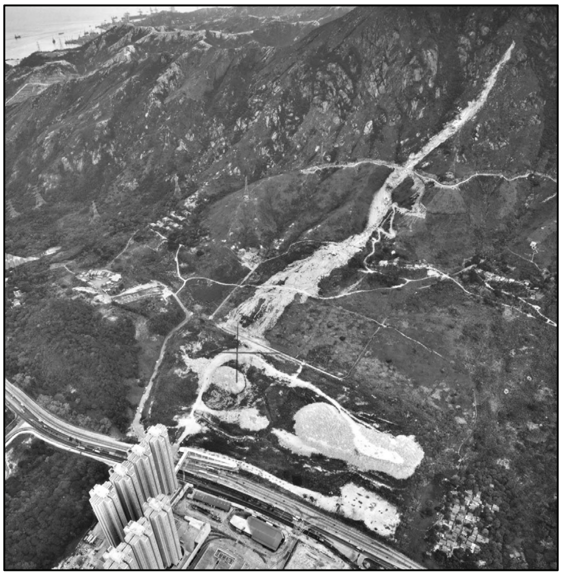

Fig. 3 The 1990 Tsing Shan Debris Flow

11. Acknowledgment

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An Experience of Agricultural Practices to Ensure Sustainable Livelihoods and Landslide Risk Reduction: Case Study from Honduras and Central America

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1. Background

In Meso America the predominant agro-ecological system is the "maize-bean" of the semi-humid deciduous woodlands that stretch from Michoacán in Mexico to Guanacaste in Costa Rica. This millenarian system inherited from the pre-Columbian civilizations of the region coupled with extensive cattle ranching defines a landscape where the destruction of the forests and degradation of the hillsides is only too visible. These land use systems are still the basis of the economy of 35 million people. 75 to 80% of the regions land is hilly or mountainous and while valley bottom land is concentrated in a few owners for export agriculture the small farmer has been driven to scraping a living off the hillsides. It is no coincidence that this is where the poverty of the region is concentrated. With current levels of population and limited access to land, the families that depend on it are caught in an ever downward cycle of impoverishment with extensive and ongoing deforestation and declining soil fertility[1]. This crisis of traditional rural society has been a source of ongoing violence in the region, with extensive out migration to the cities and the USA, and Guatemala and El Salvador competing for being the most violent societies in the world.

This region is subject to an unstable weather regime of six months rain and six months drought, but this varies from year to year. Although the traditional crops are adapted to that reality an important aspect of the summer rains is the "canicula" or short dry period in July/August that also varies widely each year. When this period extends to over four weeks the maize crop suffers. On the other hand, towards the end of the rainy season, the region is subject to hurricanes and depressions that result in heavy rains in very short periods of time. This increase in the severity and frequency of hurricanes[2] is occurring at the same time that the watersheds of the region are entering a state of accelerating degradation, the implications of which can be seen in Guatemala during tropical storm STAN in October 2005.

Climate change threatens to make this rainfall cycle even more unstable and local farmers are already very aware that something is amiss as they can no longer forecast weather patterns and hence when to plant. Studies in the region suggest that 80% of environmental damage, landslides to begin with, occur during extreme rain events. Before they occurred every 40 years,[3] now they are occurring every 8 to 10 years. Their increasing impact in Central America has led CEPAL to develop an instrument for measuring this impact on national economies that is now the international instrument of choice[4].

Figure 1. Map of the region

The department of Lempira, an area of 2,177km^2 with a population of 120,000, is one of the poorest and most isolated regions of Honduras, located in hilly terrain close to the border with El Salvador. In 1990, when the Lempira Sur project began, 85 percent of the people lived below the poverty line, malnutrition was chronic and 80% practiced subsistence agriculture. Infrastructure was restricted to a few unpaved roads, closed for days during the rainy season, and educational and health services were limited (65% illiteracy levels). The soil was poor, yields were low, and erosion and drought were common due to the prevailing slash-and-burn farming and extensive cattle ranching systems. This is the sub-humid tropical semi-deciduous forest of the Pacific located at an elevation of 140 to 2200 meters above sea level and 95% hillside. The average annual rainfall amounts to 800 to 1400 mms, rainfall can be erratic and very heavy in short periods. There is a distinct dry season of six months and regular drought spells can occur even during the rainy season. The soils are stony entisols (Lithic Ustorthents) and although

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[1] 65% of soils in Central America have already suffered degradation according to FAOSTAT.

[2] See fourth WGII report of the IPCC.

[3] Historical study carried out in Honduras for the author by a journalist reviewing the archives of the national press.

[4] See CEPAL website and their studies of the impact of the Tsunami in south Asia and the impact of STAN in Guatemala (2005)

influenced by volcanic ashes from past eruptions in neighbouring Salvador their fertility is naturally low.

In 1988, which was an El Niño year, the region was hit by drought and a large scale food relief program had to be mounted. The drought and subsequent emergency relief program was seen as a wake up call by the government and with FAO assistance a field survey was carried out to identify what was needed to change this situation. At the same time, the Dutch government was identified as a donor, and at the request of the Honduran Government the Lempira Sur project was agreed upon with the donor. Its main goal was to ensure food security by changing the predominant land use systems in a region of 120,000 people in rapidly degrading tropical hillsides where population pressure had undermined the viability of traditional systems.

2. The challenge, changing existing land use practices

Slash and burn agriculture, which predominated in Lempira until the nineties, provides two to three harvests with a minimum of inputs, the fertility coming from the ash left after burning the original biomass. With a growing population and less land, slash and burn was depleting the soils and heavy rain on exposed soils was doing the rest. By the end of the 80s productivity had dropped to 10.5 to 15 quintals per hectare for maize and 3 to 4.2 quintals per hectare for beans. Families were no longer able to feed themselves, even if they had land, and migration to coffee plantations, to the cities or to the USA became the norm. For over five years before the project various attempts had been made to introduce a change in land use practices in Lempira, but with little success. Where change had been adopted its' success had been due to the financial incentives offered to farmers to build physical infrastructure for soil erosion control, but these practices had been abandoned as soon as the incentives ended. In a process of participatory analysis of the problems faced and their prioritization, the lack of water and the need to promote practices that saved on labour were identified as important issues, but not soil degradation! The project had soil improvement as an objective and the target population did not recognise this as an issue!

In a small hamlet called Quesungual several farmers were growing maize with trees and bushes. They were still burning, but it was controlled burning and even more importantly they were looking after the trees, pruning them for firewood and opening the plots to more sunlight for the planting of maize and beans. This served their interests in conserving the trees for building and firewood. After a series of discussions an agreement was reached to experiment with various changes and/or additions recommended by the Lempira Sur project, the major one being to abandon burning and incorporate mulch. All changes proposed had to be tested and validated by the farmers themselves under normal conditions. The farmers led the process and soon a new set of practices began to take root; it is from here that has evolved what is now known as the Quesungual agro-forestry system[5].

With the goal of ensuring sustainability, the project took the decision from the beginning to eliminate all external financial incentives: payments for adoption of new practices and all subsidies on inputs (especially fertilizer) were removed, even food assistance was ended. An extension system was set up and all professional personnel were trained in livelihoods and participatory methodologies. Leading farmers were identified with the communities and those interested were sent for training in what is now known as "Farmer to Farmer" extension[6]. The project focused on building from existing farmer experiments and adding the technical knowledge of its' staff. The changes were always made on the field by the farmers who drove the process, the aim was to change a system and not a specific practice. There is now field data available on 15 years of continuous production of maize in the same plots with this system and yields continue to rise.

The focus on maximising water retention enabled the major food crops, maize in particular, to resist intermittent dry periods. Leading farmers were able to double yields while the average increase was 50% after three years, all this with reduced external inputs! Despite the good results, many farmers were sceptical. The big breakthrough came in 1997 when an El Niño-associated drought hit the area. The crops on the farms using the new method withstood the drought and experienced only 20% loss as compared to an average of 80% loss on the plots using the old maize farming techniques. In 1998 adoption was widespread and the capacity of the new system to resist the floods of hurricane MITCH put Lempira on the national map.

The Quesungual agro-forestry system is based on planting annual crops (maize, sorghum, beans) under an indigenous slash and mulch management system. The crops are planted in fields interspersed with naturally regenerating native trees (over 40 identified species) grown for building, furniture making, firewood and fruit, and there is an intensive management of mulch and biomass. Planting is done by hand: beans and sorghum are broadcasted and maize is planted with a digging stick. The trees are pruned just before the rainy season; the scale of pruning depends on the species and intended use. This system has shown itself to be most attractive to small holders of hillside land between 0.5 and 4 hectares and there is zero burning, no tillage, spot fertilization, hand sowing as well as selective pruning of native trees and mulching. Contouring is practised with live barriers that include various plants of use to the farmer (pineapples, bamboo, etc.)[7]. This allows for

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[5] For further information on the system it is recommended to search for the Word Quesungual via any search engine.

[6] See the new book by Holt-Gimenez, titled "Campesino a Campesina" published in 2008 by SIMAS Nicaragua.

[7] For details of the system see the publication "El Sistema Agroforestal Quesungual" by Liliana Fernandez and Edgardo Navarro published by FAO Honduras in 2005.

the natural regeneration of the soil. The mulch and more extensive root coverage increase soil coherence and stability, reduce erosion and increase water retention capacities. Mulch, trees and bushes greatly reduce the impact of heavy rain drops and the soil structure begins to recover, and so the landscape enters a virtuous cycle. By 2006 CIAT had figures of 59,475 hectares under zero burning, permanent soil coverage and managed native tree re-growth. 70% of that area lies within a range of 200-800 metres above sea level and 38% of total slope was greater than 50%.

3. Measurements, problems and achievements

FAO and CIAT have generated physical data on water retention rates, soil erosion levels, changes in crop yields and production costs. The World Bank has measured the impact of the project on the forest cover; it is the only region of Honduras where the forest cover is expanding. The abuse of chemicals, fertilizers, herbicides etc. has been significantly reduced, the fauna and flora is recovering and above all the population has entered a process of economic growth. The physical changes involved have been extensively monitored, first by FAO and subsequently by FAO and CIAT:

- ***Impact on yield:*** at the beginning of taking measurements (1992), yields were an average of 27 quintals per hectare for maize and 5.7 quintals per hectare for beans. By the year 2001 they reached 60 quintals per hectare for maize and 17 for beans.

- ***Effect on soil erosion:*** measurements in Lempira show a loss of soil of 223 tons per hectare under any hillside land use system that leaves the soil bare at the beginning of the rainy season. Under a mature agro-forestry system such as Quesungual the erosion rates are 14 tons per hectare, a little below the figure for a dry pacific forest. With grazing cattle this erosion figure rises to 23 tons per hectare.

- ***Humidity levels:*** again there has been a marked difference over time: at the beginning of the project, humidity levels of the soil at the end of the dry season were 8% and seven years later of continuous agro-forestry it was measured at 28%, a critical difference for farmers in a dry year.

- ***Economic impact:*** in a good year, the rate of return on maize in a traditional plot is 1.1. On the other hand it is 1.6 with Quesungual agro-forestry system, the saving on labour days is more than 20% and labour productivity raised by 40%. In times of rains and drought, levels of loss are much lower and hence so is risk and vulnerability.

These figures confirm that it is not the degree of slope that is the determining factor for soil erosion but the extent of soil cover. In the Quesungual agro-forestry system the soil is covered by stover from previous harvests and by the leaves, twigs and small branches from the pruning of the trees and bushes just prior to the rainy season. The various roots of the trees and bushes as well as of the crop under cultivation play an important role in capturing the rain drops and cushioning them before allowing them to be absorbed by more porous soils associated with the system. The more compact the soils are, the lower is the organic material and the greater is the rainwater runoff.

4. Impact of recent extreme events

The first extreme event that brought awareness to a wider audience as to the benefits and positive impact of sustainable hillside agro-forestry was hurricane MITCH. Hurricane Mitch, which left much of Honduras and northern Nicaragua in ruins, struck in October 1998. It was not the 180-mile-an-hour winds of this exceptional "category five" hurricane that did the damage. As Mitch slowed from category five to a mere "tropical storm", most people assumed the danger was past, and that the ex-hurricane would blow itself out harmlessly over the Caribbean. Instead of following its predicted course, the storm, which was blocked by a cold front from advancing northwards, dawdled for days over Honduras, dumping the huge volume of water it had picked up from the Caribbean over the mountainous spine of Central America.

In less than a week, much of Honduras experienced the equivalent of half a year’s rainfall. Only slowly did it dawn on the country’s authorities that a major tragedy was about to occur. But although the storm itself appeared to be a freak, once-in-a-century occurrence, the consequences were all too predictable, thousands died and hundreds of thousands were made homeless. Mitch passed almost directly over the Department of Lempira but the impact was minimal. In part this was the result of relatively lower rainfall (only 500 mms). Although roads were damaged it was impressive to see that there were only very few non road landslides and those which occurred were always associated with traditional slash and burn plots. This reflected the fact that the adoption of the Quesungual agro-forestry system had been widespread due to its success during drought. Now the system evidenced its role in a situation of excess rain.

Participatory research, led by Eric Holt-Giménez, was undertaken following Hurricane Mitch with smallholders practicing agro-forestry in Nicaragua. The aim was to assess the effectiveness of more than a decade of sustainable land management (SLM) practices based on agro-forestry following an unprecedented level of rainfall. The sustainability of SLM farms and conventional farms was measured by their relative differences in resistance to disturbances and the conclusion of the study was:

“Plots where sustainable land management practices were implemented consistently had more topsoil, less erosion, more vegetation and lower economic losses than conventional plots. They lost less arable land and had lower incidence of landslides, and rill and gully erosion. Vegetation resulted in lower storm impact and better regenerative processes. However, limitations to SLM were identified suggesting a threshold beyond which current SLM methodology proves ineffective." Quesungual in Lempira has shown itself to be an even more effective system than those studied by Eric Holt.

The second extreme event was that of tropical storm STAN in 2005. Again it was not the winds that did the damage but the intense rainfall over a short period. STAN did not dump 2000 mms of water as MITCH, it was only 400 to 500 mms, but the damage was severe and the result was dramatic: watersheds collapsed, landslides were innumerable, 1500 people were killed (most of them due to landslides), over 22,000 houses were destroyed or damaged, over 500,000 people faced hunger due to food shortages as they lost all or part of their harvest, the economic damage to Guatemala was huge. The underlying reason for the large number of landslides is the geomorphology of the watersheds. However, this natural vulnerability was greatly enhanced by the predominance of hillside clear cutting for agriculture and road building.

When the tropical storm STAN hit the region, the rainfall in Lempira was the same as in the Pacific region of Guatemala (400 to 500 mms), but the impact was totally different: in Lempira nothing happened except for a few landslides on the roads and this region had an excellent harvest. Unfortunately no studies have been carried out after STAN comparing land use systems and landslides as they were done in Nicaragua after MITCH.

5. **Final reflexions**

The Lempira Sur project evidences that agro-forestry systems, designed to respond to the food insecurity of the rural poor, can also increase soil stability and greatly reduce the incidence of landslides even during extreme weather events. Interestingly, the reduction has been the result of changes in land use strategies that did not have landslide control as priority. This experience shows that ensuring both sustainable livelihoods and slope stability is possible and of relevance to many tropical regions of the world.

The other lesson is that slope stability comes from maximising soil coverage based on a strategy of water management. It is not forest coverage per se as has been pointed out in various studies. It is a system that maximises soil coverage from organic materials, facilitates deep root penetration, eases the impact of heavy rains and ensures maximum water absorption. Such systems greatly reduce run off and increase soil humidity. Extreme events do most of the damage to watersheds, above all through landslides. The Quesungual agro-forestry system has shown to be able to resist landslides with rainfalls of 400 mms in 24 hours which the current deforested hillsides of meso America cannot. With climate change, heavy rains are expected to occur with increasing frequency (every 4 to 5 years in Central America). Experience in Honduras suggests that degree of slope is not one of the determining factors in resilience to landslides. Other elements such as presence of deep rooted trees, depth of soil, underlying geomorphology, intensity of rainfall during the extreme event play an equally important if not more important role than degree of slope. Extreme events that change landscapes used to occur once in a lifetime. With global warming they are now becoming more frequent and building resilience to them has its limits. The 1500 millimetres of rain that fell in two days in Nicaragua during MITCH is yet another dimension.

Experience in Honduras and other Central American countries have demonstrated that small hillside farmers are not more resistant to change than any other social group. However, they will only adopt new land use strategies that conserve soil and reduce landslide incidence if they can see that the changes will actually benefit them, will increase their food security, will reduce their vulnerability, risks and costs as well as increase their productivity. For that to take place the most efficient mechanisms are farmer to farmer transfer of knowledge and experience.

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Landslides Induced by the 2008 Wenchuan earthquake, Sichuan in China

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Abstract. 2008 Sichuan earthquake with a magnitude of Mw 7.9 induced thousands of landslides along the fault surface rupture with a maximum vertical separation of 6 m. Landslides were concentrated on the hanging wall of the earthquake fault, which appeared along the Longmenshan fault zone that runs NE-SW near the boundary between the Sichuan basin and the steep mountains on its west. The surface ruptures we observed were along the Yinghsiuwa-Beichuan fault and their total length was 180 km. Landslides distributed in an area with 300 km length with a maximum width of 25 km in the middle along the Longmenshan fault zone. Distribution area of landslide was wider near the middle of the earthquake fault and narrower toward both the ends of the earthquake fault

The most prevailing landslides were of carbonate rocks. The distribution area of landslides was wider around the middle of the surface rupture trace. The landslides varied from very small rock fall to a huge one. Largest landslide in history occurred in the middle of the affected area. It was 1.3 km wide and 5 km long with an area of 7 million m2 and its volume may be 1 billion m3 from the images of the satellite ALOS. This landslide was preceded by gravitational deformation, which is represented by a ridge-top depression. More than 30 landslide dams were made; dams consisting of large carbonate rubbles apparently stable and dams consisting of weathered marlstone or phyllite less stable.

Keywords. Landslide, earthquake, Sichuan

1. Introduction

The Sichuan earthquake occurred at 2:28 pm on 12 May 2008 at local time (6:23 at UTC) near the western edge of the Sichuan Basin in China. This earthquake with a magnitude of Mw7.9 occurred in the depth of 19 km at 30.986°N, 103.364°E (USGS, 2008). It induced numerous landslides, causing the worst mountain disaster in the 20th and 21st centuries and killing more than 69,000. The landslides induced by this earthquake made more than 30 landslide dams, which threatened the downstream and upstream areas. We here report the landslide distribution, their relation to the fault rupture, and their characteristics.

2. Methods

We used satellite images taken by ALOS of JAXA after the earthquake to interpret the distribution of landslides in the affected areas. The satellite images by ALOS we used were AVNIR II with a resolution of 10 m and PRISM with a resolution of 2.5 m. We also used satellite images of before and after the earthquake provided by Google Earth: The former was mostly by the SPOT of France and the latter was mostly the images by FORMOSAT II of Taiwan with resolutions of 2 m or 8 m. In addition, we made a field investigation for 2 weeks.

3. Geomorphic and geologic setting

The affected area was mountainous areas with elevations from 1000 m to 4500 m on the west of the Sichuan Basin. Ridges and valleys are generally trending NE parallel to the trends of the geologic structures, while large rivers, such as the Minjiang River, and the Fujiang River are flowing from the north to the south, crossing these trends. This mountainous area is located between the eastern end of the Tibetan Plateau and the Sichuan Basin on its east. The NE-trending Longmenshan fault zone runs along the boundary between the mountains and the Sichuan basin (He and Tsukuda, 2003), of which Yinghsiuwan-Beichuan fault is inferred to be the main fault that generated the 2008 earthquake (Fig. 1, Xu, 2008). The basement rocks of the mountainous areas range from Precambrian to Cretaceous in age. They are basaltic rocks, granite, phyllite, dolostone, limestone, alternating beds of sandstone and shale, etc. (Geologic map of China).

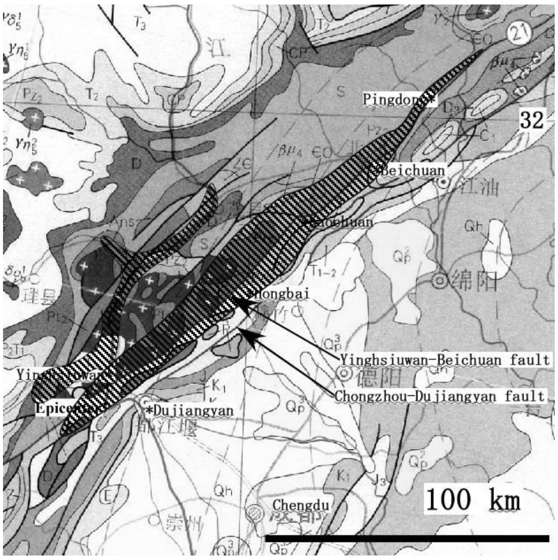

Fig. 1 Areas of dense distribution of landslides (hatched areas).

3. Distribution of landslides

Landslide distribution areas were mainly of two types: One was the area along the fault that generated this earthquake, and another was along the steep slopes along the Minjian River. Landslides around the fault were distributed in an area with 300 km length with a maximum width of 25 km in the middle along the Longmenshan fault zone (Fig. 1). Distribution area of landslide was wider near the middle of the earthquake fault and narrower toward both the ends of the earthquake fault.

In the northeastern area, particularly near Pingdong, landslides were concentrated on the hanging wall within 1 km from the rupture trace (Fig. 2). Outside of this zone of dense landslides was an area with ridge-top failures. In contrast to the hanging wall, much fewer landslides occurred on the footwall. The bedrock on both the sides are apparently the same weathered phyllite dipping NW.

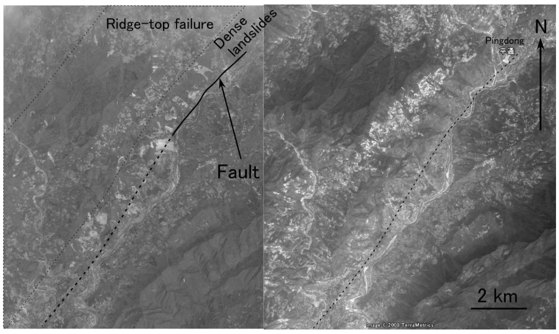

Fig. 2 Landslides concentrated on the hanging wall of the fault rupture trace near Pingdong. Left: ALOS PRISM image taken at 18 May, 2008 by JAXA. Right: SPOT image taken in 2008 before the earthquake provided by the Google

4. Largest landslide (31°38'15.52"N, 104° 6'2.84"E)

A very large landslide was detected on the images of the satellite ALOS on 4 June (Fig. 3). It occurred in deep mountains 2 km to the northwest of the inferred trace of the surface fault rupture between Beichuan and Honbai. We observed it by satellite images, so geological condition is not known. It was 1.3 km wide and 5 km long. Its area was 7 million m^2 and its volume may be 1 billion m^3. Comparison between the ALOS images and SPOT images before this earthquake clearly indicates that the top of the landslide was a ridge-top depression. This indicates that this landslide was preceded by gravitational deformation beforehand. The lower part of the future slide was a rather smooth and convex slope. This suggests that buckling or bulging of beds had occurred like the case of Chiufenershan slide at 1999 Chichi earthquake (Wang et al., 2003).

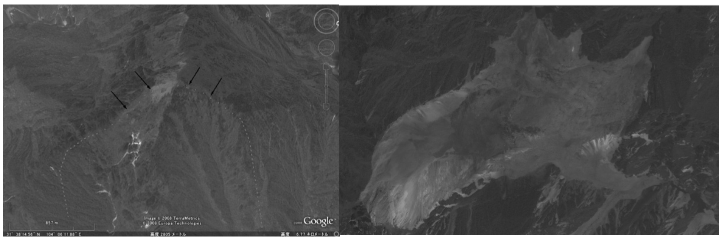

Fig. 3 Largest landslide by this earthquake. Left: Oblique view of the SPOT image taken in 2008 before the earthquake provided by the Google earth. Arrows: ridge-top depression long the upper margin of the landslide by this earthquake. Right: ALOS PRISM image taken on 4

5. Second largest landslide(31°32'56.73"N, 104° 9'6.62"E)

Second largest landslide occurred 4 km to the southeast of the inferred trace of the fault surface rupture between Beichuan and Honbai (Fig. 4). It was inaccessible and we observed it only on ALOS images. It was 4 km long and 1 km wide. The moving material went down along a valley, where the deposits reached higher elevations at the outer sides of the valley bents, indicating that the movement was a flow. This landslide occurred on a west-facing slope with a smooth surface and without gullies, suggesting that the underlying beds were permeable. This slope had no gravitational deformation features but it was undercut, which were observed with satellite images. This area is probably underlain by Triassic carbonate rocks, so underground dissolution could have developed before the slide.

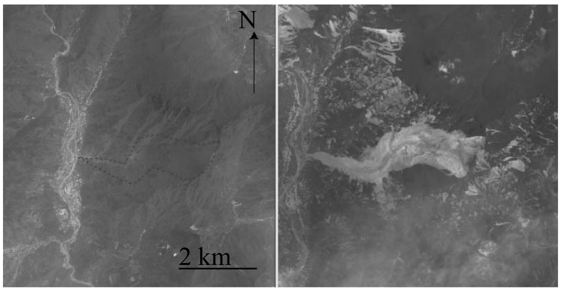

Fig. 4 The second largest landslide in an ALOS image (right) and an image before the slide by Google Earth (left). The slope before the slide was undercut..

Acknowledgments

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Landslide Incidence in the Limpopo Province, South Africa

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ABSTRACT: Landslides are a serious geohazard in the Limpopo Province of South Africa, as many densely populated rural communities live in close proximity to areas of steep relief, which are susceptible to slope instability. The region has experienced both historical and recent land sliding. This paper presents the findings of landslide inventorisation activities conducted in the province over the past year, and also explores a case study, i.e. a distinctive ancient landslide which formed Lake Fundudzi. This study has facilitated the production of the first landslide inventory map for the Limpopo Province. The map will display landslide occurrence and distribution throughout the province, and has the potential to mitigate development problems and promote a safer living environment, thus impacting positively on the local communities.

Keywords: discontinuities, Lake Fundudzi, landslide, Limpopo Province, rainfall.

1. INTRODUCTION

The Limpopo Province is the northern-most province in South Africa and borders Mozambique, Zimbabwe and Botswana (Fig. 1). The Council for Geoscience (CGS) National Geohazard programme identified the Limpopo Province for landslide inventorisation, as landslides are a major geohazard in the province and rural communities are becoming increasingly vulnerable.

Many countries around the world have realized the enormous impacts of these geohazards and have developed programmes for landslide inventory and susceptibility mapping. A Landslide Susceptibility map for Southern Africa was compiled in 1985 by Paige-Green, based on climate, geology, geomorphology and past landslides associated with roads and railways. The map was later revised, in 2004, by Paige-Green and Croukamp. The CGS has undertaken to map each province in more detail. This project is the second of its kind, following a similar project in the KwaZulu-Natal Province.

This paper presents the findings of the investigations conducted in the province over the past year, and assesses the ancient landslide case study of Lake Fundudzi. The primary objectives of this study were the following: 1) to add to the current body of knowledge of catastrophic landslides in South Africa; 2) to produce a landslide inventory map for the province; and 3) to infer the probable cause and failure mechanism of the Fundudzi landslide, based on the available data.

Landslides have a negative impact on human as well as natural environments and on socio-economic development. Therefore the “identification of landslide hazard areas is important for site selection and development planning of housing and infrastructure facilities within the landslide prone area” (Iwao *et al.,* 2002). This study has facilitated the production of the first landslide inventory map for the Limpopo Province, displaying landslide occurrence and distribution throughout the province and has the potential to mitigate development problems and promote safer living environments.

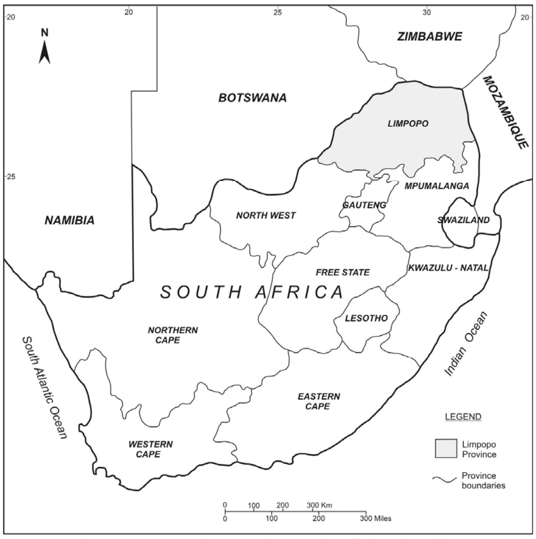

Fig. 1: Limpopo Province and South Africa locality map.

The inventory process for this project has now been completed and forms the basis of this paper. A distinctive landslide lake, examined during the inventory process, is also presented here as a case study. The published literature on Lake Fundudzi is limited. However, from available information it was inferred that the process of slope toe erosion by the Mutale River (van der Waal, 1997) and the presence of major structural discontinuities (faults and joints) were important controlling factors for tension crack initiation at the crest of the slope and the consequent mass-wasting event.

2. PHYSIOGRAPHY

The geology of the Limpopo Province varies from Palaeo-Archaean mafic, ultramafic and felsic extrusives to Mesozoic sedimentary rocks and flood basalts (1:1000 000 scale RSA Geological Map series, 1984). The topography varies from relatively flat areas to mountainous terrain. Limpopo is an area of mixed grassland and trees, generally known as bushveld. Three distinct mountain ranges were the focus of this project; these being clearly identifiable from the slope class map (Fig. 3). These ranges are the (i) south-eastern Drakensberg and Strydpoortberg mountains, which consist predominantly of Archaean granite and gneiss; (ii) the northern Soutpansberg and Blouberg mountains, which are highly block-faulted rocks, consisting of a volcano-sedimentary sequence of mainly basaltic lavas and quartzites, tilted to the north-northwest at an average of 20º. Lastly, (iii) the western Waterberg mountain range, which consists predominantly of sandstone with minor basic lavas at the base of the Waterberg Group (Brink, 1981; Barker *et al.,* 2006). The province has an extensive network of roads, creating a large number of road cuttings. Many cuts are poorly designed, resulting in numerous slope instabilities. The climatic conditions of the study area are characterised by summer rainfall, with an average annual precipitation of 620 mm. The northern and eastern areas are subtropical, with hot and humid summers (SA Weather Service, 2008). Mist is frequent in the mountain regions, and winters are mild and mostly frost free.

3. METHODOLOGY

The methodology implemented consisted of a desk study, encompassing a literature review; stereoscopic examination and interpretation of panchromatic aerial photo pairs and digitally enhanced aerial images. The colour 3D space imagery of Google Earth 2008 were also reviewed. Questionnaires were created and sent out to communities in the province, responses indicated areas that had been affected by recent landslides.

The desk study was followed by intensive field work in the region in order to investigate suspected landslide areas identified during the desk study. Field work included ground as well as aerial inspections using a light fixed-wing aircraft. All the acquired information was used to compile the preliminary provincial landslide inventory map, using ArcGIS software (Fig. 3).

A geomechanical survey was also conducted on the host rock walls of the Lake Fundudzi landslide and included a discontinuity survey as well as Point Load and Schmidt hammer tests, following ISRM suggested methods (1981) and ASTM standards (2000).

4. RESULTS

4.1 Landslide inventory and susceptibility mapping

The inventorisation process identified over 700 recent and ancient landslide events. These events were classified according to the abbreviated landslide classification scheme of Cruden and Varnes (1996), and are summarised in Table 1. Five types of movement were identified, namely: falls, topples, slides, flows and undifferentiated landslides.

These events vary in size, with the majority being rockfalls. Most of the landslides in Limpopo Province are a result of one or more factors, i.e. steep slopes, discontinuities, high rainfall, weathering and/or human intervention. These conditions increase shear stresses and decrease the shear strength of the materials.

Many slope instability events tend to occur along road cuttings in the province: poorly constructed mitigation measures have done little to prevent these events (Fig. 2). Eye-witness accounts obtained from locals during field investigations in the province, indicate that the majority of recent landslide events had occurred in February 2000 after particularly heavy and intensive rainfall. The Limpopo Province experienced its worst floods in living memory in February 2000 owing to cyclone Eline. As a result, flooding and rainfall induced landslides on man made as well as natural slopes caused loss of life (101), damage to houses, infrastructure ($166 million) and livestock losses (Limpopo Provincial Disaster Management Unit, 2000).

Table 1: Summary of landslides in the Limpopo Province.

Type of movement	Number of landslides
Fall	570
Topple	4
Slide	53
Flow	60
Undifferentiated	24

Fig. 2: Rock fall along a national road between Mokopane and Lephalale.

The first landslide inventory map of the Limpopo Province has been compiled (Fig. 3). The location and distribution of events were mainly located in the steeper mountainous areas of the province; these being areas where slope angle is greater than 12 degrees. These landslides fall within areas defined by Paige-Green (1985) as areas where “instability may occur”.

4.2 Case Study: Lake Fundudzi landslide lake

The Lake Fundudzi landslide is a large translational rock slide or rock avalanche situated in the Mutale River valley of the Soutpansberg mountains. The Lake Fundudzi landslide occurred tens of thousands of years ago and blocked the course of the eastward flowing Mutale River (Trevor, 1926; Janisch 1931; van der Waal, 1997). According to Costa and Schuster (1988) Lake Fundudzi is classified as a type 2 landslide dam in terms of material deposits on the valley floor. The slide occurred in the northward dipping quartzite of the Fundudzi Formation of the Soutpansberg Group.

The crest of the landslide scarp is approximately 450 m in length, 220 m above the lake, and has a slope failure plane surface area of approximately 17 ha (Fig. 4).

The calculated volume of rock that slid down the failure surface is estimated at 10 to 15 Mm^3, while rock blocks travelled a distance of up to 700 m across the valley floor.

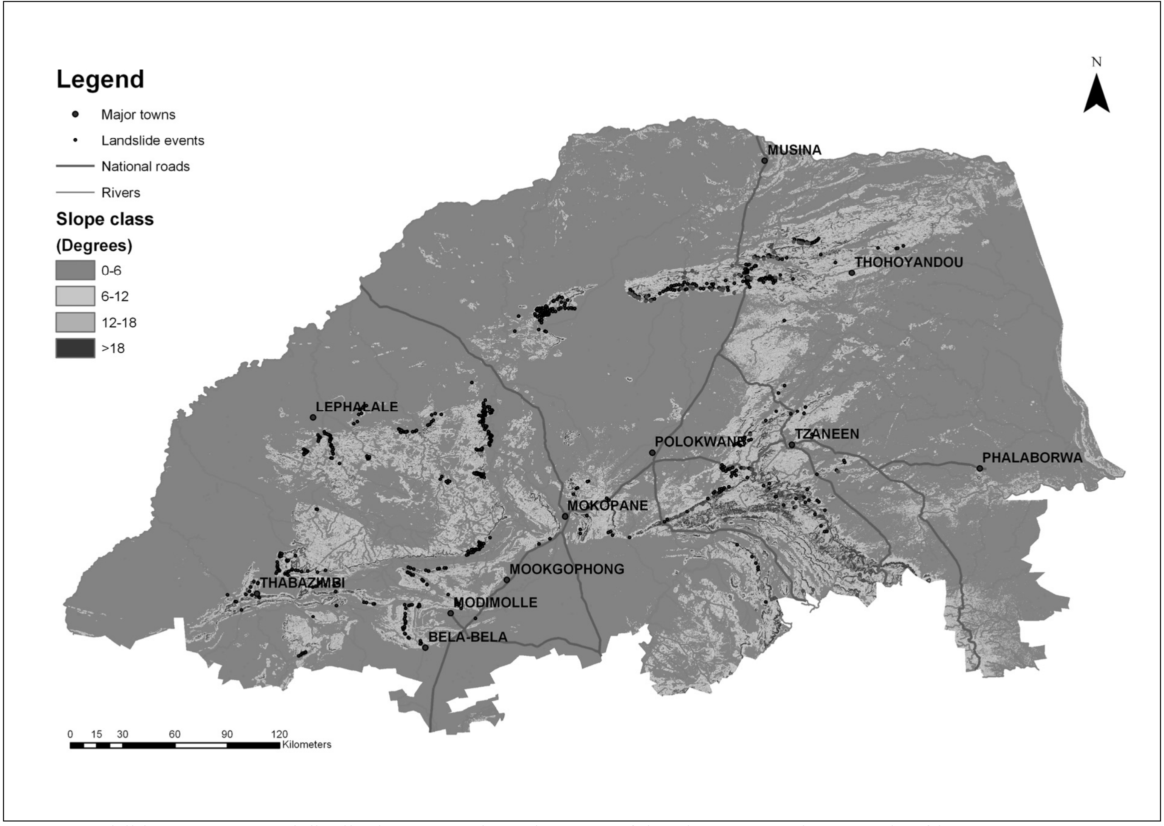

Fig. 3: Landslide occurrence and distribution over a slope class map of the Limpopo Province, South Africa.

The largest blocks have a diameter between 7 to 10 m. The failure slope dips approximately 60º to the south into the valley, while bedding planes dip an average of 20º to the north (Janisch, 1931).

Barker (1979) mapped two NW-SE and SW-NE intersecting faults which form the failure lines of each flanking buttress. Several minor rock slides and falls are still active and noticeable on the failure side of each buttress, and were also noted by Janisch (1931). Tension cracks were also observed at the crest of the failure slope.

The results for Point load tests on the Fundudzi Formation quartzite reveal UCS ranges between 26 MPa and 118 MPa, which classify as moderately strong to strong according to ISRM (1981). Schmidt hammer results reveal that the approximate uniaxial compressive strength is 60 MPa, which classifies as strong, according to Miller (1965). The rock is well jointed and the discontinuity survey identified three major joint sets. The sets have been numbered as J1 to J3 and are orientated SW-NE, WNW-ESE and N-S; respectively. The main failure surface of the Fundudzi landslide best correlates with J2.

5. DISCUSSION

The landslide inventory for the Limpopo Province has identified hundreds of landslide events, these have mainly occurred in the steeper mountainous terrain, often as a result of sustained heavy rainfall. Some of these events, especially those of February 2000, have resulted in loss of life and damage to the natural and human environment. The project has the potential to assist the Department of Works, Disaster Management and Roads and Transport in Limpopo Province with mitigation measures, given that slope instabilities are evident along many national, provincial and district roads.

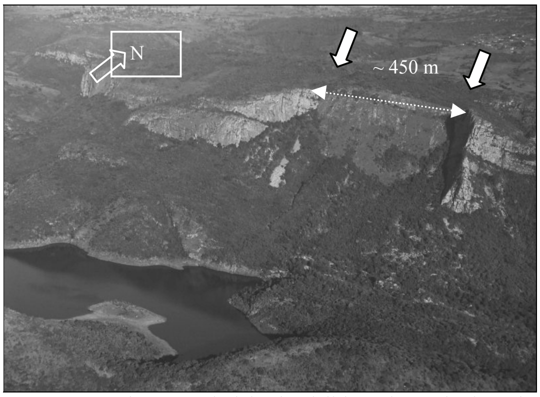

Fig. 4: Lake Fundudzi landslide situated in the Soutpansberg mountains

With regard to the Lake Fundudzi landslide, pre-existing conditions such as the joints, fractures and faults made the rock mass vulnerable to instability. The stream erosion by the Mutale River led to oversteepening of the slope (this in agreement with van der Waal, 1997), thus reducing its overall stability, and accelerating tension crack formation at the crest of the slope resulting in the failure. The Soutpansberg Mountains also experience high rainfall and as rainfall-induced slides are common in the province, this was also a probable trigger to failure. Available historical records of seismic data indicate a low level of seismic activity for the region, but may also have acted as an additional trigger at the time.

6. CONCLUSION

The study has facilitated the production of a first landslide inventory map for the Limpopo Province. The study has also shown that the rainfall-induced landslides of February 2000 had a major negative impact on rural communities. It is concluded that future landslides, initiated by extreme rainfall events, will continue to take a high toll if further research, proper management and mitigation measures are not implemented. The Inventory map will facilitate the compilation of the first landslide susceptibility map for the province, which is still to be produced. This map has the potential to mitigate development problems and promote safer living environments.

Proper design of cuttings and slope protection methods should be followed when constructing roads and railways, as most existing failures seen along roadways are caused by improper slope design.

7. ACKNOWLEDGMENTS

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The Importance of Shallow Landsliding for the Spatial Distribution and Ecology of Kauri*

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Abstract. In this paper the use of topographical attributes for the analysis of the spatial distribution and ecological cycle of kauri (*Agathis australis*), a canopy emergent conifer tree from northern New Zealand, is studied. Several primary and secondary topographical attributes are derived from a Digital Elevation Model (DEM) for a study area in the Waitakere Ranges. The contribution of these variables in explaining presence or absence of mature kauri is assessed with logistic regression and Receiver Operating Characteristic (ROC) plots. A topographically based landslide hazard index, calculated by combining a steady state hydrologic model with the infinite slope stability equation, appears to be very useful in explaining the occurrence and ecological dynamics of kauri. It is shown that the combination of topographical -, soil physical - and hydrological parameters in the calculation of this single landslide hazard index, performs better in explaining presence of mature kauri than using topographical attributes calculated from the DEM alone. Moreover, this study demonstrates the possibilities of using terrain attributes for representing geomorphic processes and disturbance mechanisms, often indispensable in explaining a species' ecological cycle. The results of this analysis support the 'temporal stand replacement model', involving disturbance as a dominant ecological process in forest regeneration, as an interpretation of the community dynamics of kauri. Furthermore a threshold maturity stage, in which trees become able to stabilize landslide prone sites and postpone a possible disturbance, together with great longevity are seen as major factors making kauri a 'landscape engineer'.

Keywords. vegetation pattern; DEM; shallow landslides; logistic regression; stand replacement model; Agathis australis (kauri); Waitakere Ranges; New Zealand

1. Introduction

In this study, the use of topographical attributes for the analysis of the spatial pattern and ecological cycle of kauri (*Agathis australis*) (Gardner 1981) is evaluated. We try to interpret statistically the presence or absence of mature kauri in association with properties derived from elevation data. Furthermore we explore the possibilities of using terrain attributes for representing environmental conditions, relevant geomorphic processes and disturbance regimes.

Kauri is a conifer of the Araucariaceae family and endemic to New Zealand. Evergreen rainforests dominated by kauri occur in the north of the North Island and the current natural southern limit is approximately latitude 38° S (Ecroyd 1982). Kauri trees form an emergent layer (35 m) above a mixed angiosperm canopy (10-20 m) and may, although numerically inferior, contribute much to forest structure and function (Ogden and Stewart 1995; Enright 2001). Conifers usually account for c. 40 % of the stand basal area but represent 50-60 % of above-ground biomass given the combination of large diameter and emergent habit (Enright 2001). Kauri changes its form markedly from juvenile stage to the mature tree: it undergoes a dramatic change from the conical, monopodial pole tree (known as a 'ricker') to the mature lollipop shape (Ogden and Stewart 1995). Dense stands of often even-aged kauri trees form a mosaic pattern in the landscape. Kauri trees can grow to an immense size and age estimates of over 1000 years have been made. Logging operations in the late 19th and 20th centuries all but wiped out the once extensive stands of mature kauri. Fortunately, many trees are now preserved in forest reserves and kauri is no longer commercially felled.

Several authors have tried to explain the population dynamics within kauri dominated forests in relation to local environmental conditions, disturbance and competitive interactions (Ahmed and Ogden 1987; Jessop 1992; Enright and Ogden 1995; Burns and Leathwick 1996; Enright et al. 1999). A commonly accepted interpretation of the community dynamics of kauri forests is the 'temporal stand replacement' (or 'lozenge') model, described by Ogden (1985) and Ogden and Stewart (1995). They attribute the preferred occurrence of kauri on ridge tops to more frequent disturbance by windfall and soil slipping, allowing the light-demanding kauri seedlings to establish. The model identifies multiple stages in the kauri-angiosperm ecosystem (Fig. 1; based on Fig. 5.6 in Ogden and Stewart (1995)):

A. A seedling recruitment phase immediately after a disturbance event. A dense cohort of kauri can establish favoured by light conditions.
B. A self-thinning phase in which tree density declines but total biomass remains the same. Possible gaps are filled by lateral growth of surrounding individuals rather than by recruitment from the seedling pool.
C. A cohort senescence phase in which biomass declines but gaps can be filled by recruitment from a second but less dense cohort of kauri. The second cohort is less dense because of the more competitive environment.
D. The tree density decreases further and only a limited number of large trees remain because opportunities for recruitment decline until a new major disturbance event starts the cycle again.
E. Large-scale exogenous disturbances can cause a return to the initial cohort stage.

Thus stand regeneration is episodic and dependent upon large scale forest disturbance by cyclonic storms or fire (Ogden 1985). Due to the great longevity of the species, commonly 600 years and sometimes > 1000 years, there is a high probability of this occurring during the life of any cohort (Ogden et al. 1995). The model was tested for validity with field plot data, not restricted to kauri dominated systems but for forests containing Araucariaceae in the western pacific in general (Enright et al. 1999). Coexistence of the araucarian element with angiosperm forest species was shown to be dependent upon disturbance events, which give the conifers a temporary competitive advantage over the co-occurring angiosperm tree species. Great longevity relative to most of the angiosperms, and occasional gap phase recruitment, facilitates their long-term persistence in stands through long periods without catastrophic disturbance (Enright et al. 1999). In addition, when kauri becomes able to locally postpone disturbance (by root reinforcement), it again exploits its capability to outlive other species.

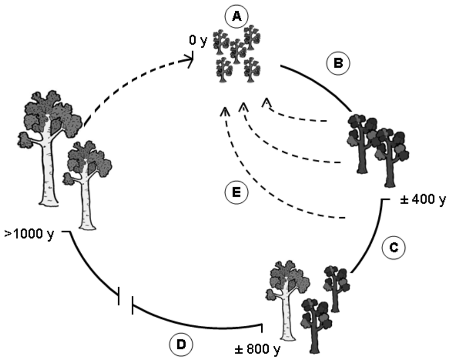

Fig. 1 Schematic representation of temporal stand replacement model. For explanation of stages A-E refer to the text.

A review of interactions between geomorphic processes and vegetation patterns as well as an overview of digital terrain analysis for ecological applications is given in Claessens et al. (2006).

2. Study Area

The Waitakere Ranges are located immediately west of Auckland, New Zealand (174.8°E, 36.9°S, Fig. 2). Altitude ranges from sea level to 474 m. The area has a warm and humid subtropical climate with a mean annual rainfall ranging from about 1400 mm near the Tasman coast up to 2030 mm at the higher altitudes. More information about the ecology and soils of the study area can be found in Claessens et al. (2006).

3. Methodology and Results

The methods used in this study (DEM analysis and topographical attributes, LAPSUS-LS model for calculating relative hazard for shallow landsliding (Claessens et al. 2007), presence-absence analysis, logistic regression, ROC and AUC for model performance) are described in more detail in Claessens et al. (2006).

Explanatory topographical variables derived from the DEM and used in the presence-absence analysis are: slope, aspect, altitude, contributing area, curvature, topographic wetness index and critical rainfall (*Qcr*, which is a relative hazard for shallow landsliding). The spatial distribution of *Qcr* is calculated with the LAPSUS-LS model (Claessens et al., 2006). Aspect and *Qcr* were both included as continuous and categorical variables. Aspect values were divided in 9 classes. Being relative measures of landslide susceptibility rather than physically interpretable absolute numbers, the *Qcr* values were divided in six classes: 1) Unconditionally unstable 2) Very high landslide hazard: $0.0 < Qcr < 0.05$ m day^{-1} 3) High landslide hazard: $0.05 < Qcr < 0.1$ m day^{-1} 4) Moderate landslide hazard: $0.1 < Qcr < 0.2$ m day^{-1} 5) Low landslide hazard: 0.2 m day^{-1} $< Qcr$ 6) Unconditionally stable.

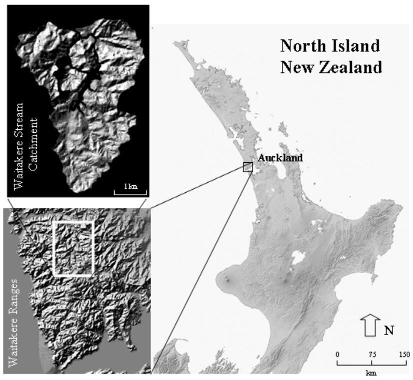

Fig. 2 Location of Waitakere Ranges and study area catchment. A mask (in black) is applied to exclude formerly logged and disturbed areas from the analysis.

To investigate the possible contribution of the landslide hazard index to the explanation of presence-absence of mature kauri, two logistic regressions were carried out, one without and one with critical rainfall as an explanatory variable (Tables 1 and 2). For fitting the logistic regression model, a random 50% sample of the data set was used. A forward stepwise regression was chosen to select the relevant variables explaining occurrence of kauri. This procedure only includes variables with a significant contribution in the model. Possible collinear independent variables are unlikely to be retained. For categorical explanatory variables, one class is used as a reference. Aspect classes were evaluated relative to class 2 (north), critical rainfall classes relative to class 6 (unconditionally stable). AUC values for model fit are 0.737 and 0.750 respectively.

Model validation was done by applying the logistic regression equation obtained with the calibration data set to the remaining 50% of the data and testing the probabilities against the occurrence of kauri with the ROC statistic. The AUC value is 0.769.

For the model without inclusion of landslide hazard, according to the standardized regression coefficients, the occurrence of kauri seems most correlated with slope and topographic wetness index (Table 1). After inclusion of landslide hazard, moderate to very high landslide hazards are highly correlated with the presence of mature kauri (Table 2). In both cases, west and south-west aspect positions seem to be preferred above north-west and east (with aspect class north as reference). Elevation (DEM) and profile curvature show relatively low correlation with the position of mature kauri. The AUC value of the ROC curve for the regression model including landslide hazard is higher, though not significantly, than the value obtained without landslide hazard as explanatory variable. Both AUC values are between 0.7 and 0.9 and indicate reasonable discrimination ability (Swets 1988). The AUC value for the ROC curve obtained by testing probabilities, calculated with the calibration regression equation, for the validation data set is higher than the value for the calibration data set itself and indicates good model performance. Probabilities of mature kauri occurrence are calculated with the regression coefficients of the model with inclusion of landslide hazard (Table 2) and are visualized against the kauri inventory dataset (Fig. 3).

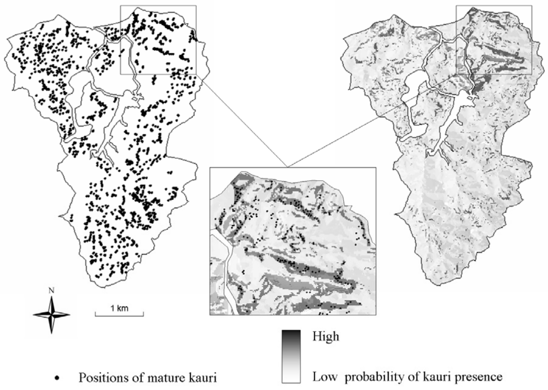

Fig. 3 Kauri inventory map for the study area and probabilities of occurrence. The inset shows a detail of an overlay of the two maps.

4. Discussion and Conclusion

Topographical attributes alone cannot fully explain all ecologically important processes that influence the spatial distribution of kauri trees or vegetation patterns in general. At least, as this study illustrates, they seem representative of an important part of the environmental conditions and/or processes that constitute a vegetation domain. Besides natural environmental conditions, human impact (both recent and historical), can have a huge impact on the distribution of vegetation types (Burrows 1990; Tappeiner et al. 1998). Unfortunately, spatially referenced data on tree harvesting, land use history or human disturbance are often lacking or hard to obtain.

The use of logistic regression for this analysis was not primarily intended to predict presence or absence of kauri but to point to the possible benefits of topographical analysis in explaining a species' ecological cycle. The statistical method used was intended to be explanatory and chosen to formulate and test hypotheses linking presence of kauri with spatially distributed topographical attributes. To select the relevant variables explaining occurrence of kauri, a forward stepwise logistic regression method was chosen. Although stepwise techniques have some disadvantages when used for theory testing, they are considered useful for exploratory purposes (see discussion in Menard (2001) p.63).

In Waipoua Kauri Forest, Burns and Leathwick (1996) found the vegetation pattern to be largely determined by topographical variation in soil fertility and moisture and altitudinally linked temperature and precipitation gradients. However, for this study area, relative elevation seems merely unimportant for the occurrence of mature kauri trees. In contradiction to the results of Jessop (1992), who found kauri preferentially on positions with north, north-east aspect, in this study area mature kauri trees seem to occur more on west, south-west facing slopes. For New Zealand in general, north-east facing slopes receive more solar radiation than south-west facing ones and this effect is more strongly pronounced for steeper slopes (Segal et al. 1985). Thus, the strong relationship between the spatial distribution of (mature) kauri and a high quantity of solar radiation found by Jessop (1992) is not confirmed in our study area.

The use of a topographically based landslide hazard index performs well in explaining the occurrence and ecological dynamics of kauri. The logistic regression models designed show that the combination of topographical -, soil physical - and hydrological parameters in the calculation of one landslide hazard index, has advantages over using solely topographical information calculated from the DEM. Less single explanatory variables are needed and a better model performance, reflected by a slightly higher AUC value, is obtained when including the landslide hazard as independent variable. More important, this study demonstrates the possibilities of using terrain attributes for representing geomorphic processes, often important in explaining a species' ecological cycle.

The results of this analysis support the temporal stand replacement model (Ogden 1985; Ogden and Stewart 1995) as an interpretation of the community dynamics of kauri and additionally point to landsliding as a relevant disturbance mechanism. Mature kauri trees tend to occur preferentially on sites with a moderate to high landslide hazard. Even unconditionally unstable parts (which would fail according to their terrain properties, even without triggering by rainfall), seem to host mature kauri trees. It must be stressed that the landslide hazard is a relative index, calculated from topographical, geotechnical and hydrological terrain intrinsic parameters. The very apparent influence of vegetation, and especially mature kauri trees with dense and strong rooting systems, on 'real' landslide hazard is deliberately not taken into account for the calculation of the index. In this way, the occurrence of mature kauri on landslide prone sites can be explained as representing an equilibrium stage with the tree supporting the unstable landscape position in the last phase of the ecological cycle, i.e. before a disturbance (landslide or windthrow) event takes place and the cycle starts again. At a certain maturity stage, when the rooting system and tree weight add relevant root reinforcement and vegetation surcharge to the soil cohesion, a threshold phase can be recognized, in which kauri starts to enhance the effect of its great longevity relative to other species by stabilizing its position and postponing disturbance by landsliding. In this way, a return to the initial cohort stage by exogenous disturbance (Fig. 1, phase E) is avoided or at least postponed and kauri fully exploits its ability to outlive other species. A field observation that additionally supports this idea is that especially dead or damaged mature kauri trees seem to be subject to landsliding or windthrow.

Although not primarily intended for prediction of presence of kauri, the method used could be adopted to delineate favorable sites or areas for possible kauri forest regeneration (Fig. 3) and could accordingly be used for nature conservation planning in areas similar to the study area.

Table 1 Forward stepwise logistic regression results excluding landslide hazard as an independent variable.

Variable	β	S.E.	b*	exp(β)
altitude	0.002*	0.001	0.011	1.002
prcurv	0.063*	0.013	0.009	1.065
slope1	0.093*	0.004	0.068	1.097
twi	0.089*	0.013	0.027	1.093
asp2				
flat	-15.779	1686.436	-0.102	0.000
north-east	-0.227	0.163	-0.006	0.797
east	-0.830*	0.218	-0.018	0.436
south-east	-0.108	0.183	-0.002	0.898
south	0.177	0.157	0.004	1.194
south-west	0.754*	0.132	0.018	2.124
west	0.812*	0.127	0.021	2.252
north-west	0.315*	0.134	0.009	1.370
constant	-7.676	0.252		0.000

* : Significant at 0.05 level.

Table 2 Forward stepwise logistic regression results including landslide hazard as an independent variable.

Variable	β	S.E.	b*	exp(β)
crrain2				
uncond. unstable	2.670*	0.219	0.018	14.443
very high hazard	2.095*	0.139	0.033	8.125
high hazard	2.282*	0.116	0.039	9.798
moderate hazard	2.315*	0.096	0.050	10.121
low hazard	0.559*	0.195	0.011	1.748
asp2				
flat	-15.867	1694.646	-0.134	0.000
north-east	-0.247	0.163	-0.008	0.782
east	-0.818*	0.218	-0.023	0.441
south-east	-0.164	0.184	-0.004	0.849
south	0.152	0.158	0.004	1.164
south-west	0.718*	0.133	0.022	2.050
west	0.821*	0.128	0.027	2.274
north-west	0.341*	0.134	0.013	1.407
altitude	0.002*	0.001	0.016	1.002
constant	-6.011	0.180		0.002

* : Significant at 0.05 level.

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A Civil Protection Operative Tool for Emergency Management of Landslide

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Abstract. During the last years, after strong precipitations recorded in the northern part of Basilicata Region, many landslide occurred in this area involving building trade and infrastructures. The Regional Department of Infrastructure and Civil Protection for the complexity of the phenomena decided that evacuation decrees were issued for a few of families. After that, IMAA-CNR has been involved for studying the phenomena by means of new geophysical techniques. In short times and with low costs, active investigations (dipole-dipole, geoelectrical tomographies) were carried out and data processing has been performed using innovative techniques for data inversion.

In this work we present the results regarding the application of unconventional geoelectrical techniques in the study of a high hydrogeologic hazard area located in the Lucano Apennine (southern Italy).

The results represent a valid cognitive support to choose the most appropriate technical solution for strengthening of the slopes and an example of best practice for the cooperation between the research activity (IMAA-CNR) and field emergency (Regional Civil Protection).

Keywords. Earth-flow, slide surface, electrical resistivity tomography.

Introduction

Basilicata region has been one of the southern Italian regions more involved in heavy meteorological conditions. Many snowy events occurred in the region in a range between 0.30 – 1.00 m (www.sinanet.apat.it, 2005).

The intense precipitations increased the saturation degree and the pore pressures of the terrains. The snow blanket made heavy the slope and it changed the equilibrium of the strengths involved in the stability of a slope. The discussed climatic conditions deteriorated the physical and mechanic characteristics of the terrains outcropping in the region. As consequences of all these alterations, the reactivation of many dormant landslides, which affected the lucanian slopes in the past, occurred. The main typologies of reactivation have been earth-flow, translational or rotational slides.

The new slides involved buildings and infrastructures constructed on the slopes. The risk for people and assets needed the intervention of the end users involved in the risk management and, in particular, the inspection of Regional Department of Infrastructure and Civil Protection (RDICP). In many involved areas and for many families evacuation decrees have been issued in order to allow the damage valuation. The complexity of the phenomena demanded a multidisciplinary approach based on the integration of all the data (direct and indirect) acquired in the area. An important contribution has been provided by the geophysical data and, in particular, by the 2D electrical resistivity tomographies (ERTs) that have been carried out in the areas some days after the event.

The use of 2D ERT method for investigating landslides is now well tested. Many examples of the ERT application are reported in literature. In many cases the results of its application allowed to reconstruct the geometry of landslide body, to outline the sliding surface and to locate areas characterized by high water content (Demoulin et al., 2003; Bichler et al., 2004; Perrone et al., 2004; Lapenna et al., 2005; Meric et al., 2005; Godio et al., 2006).

By using the Mobile Laboratory for chemical-physical and geophysical measurements of the Institute of Methodologies for Environmental Analysis (IMAA) of CNR, some ERTs have been performed in the more damaged areas of the Basilicata region. In particular, Picerno landslide, located at the western side of Potenza town, Southern Italy, has been investigated.

The area have been preliminary studied and the landslide bodies have been mapped by the technical staff of the RDICP. A geological and geomorphological map were used to locate the geophysical measurements.

For the site the obtained results allowed to help the decisions of RDICP. In particular , the information coming from the ERTs have been much useful in the phases of the valuation damage and the slope stabilization planning.

Location and geology

The investigated areas is located in Basilicata Region, along the axial zone of the southern Apennines chain. The latter is mainly composed of sedimentary cover of platform and deep water environments, scraped off from the former Mesozoic Ligurian ocean, from the western passive margin of the Adriatic plate and from the Neogene-Pleistocene foredeep deposits of the active margin. From west to east, the main Mesozoic domains are as follows: (1) the internal oceanic to transitional Liguride-Sicilide basinal domains (internal nappes), (2) the Apennine carbonate platform, (3) the Lagonegro-Molise basins, and (4) the Apulian carbonate platform (Scrocca et al., 2005).

The northern part of the Basilicata Region is characterised by Mount Vulture Volcano, located along the external thrust belt of the chain. It is a complex strato-volcano whose pyroclastic products are the results of both explosive and effusive activity occurred from the middle Pleistocene to the upper Pleistocene (Serri et al., 2001).

Picerno area is characterized by Sicilide Units, in particular by Corleto Perticara Formation. From a litological point of view Corleto Perticara Fm. is represented by alternating calcarenites, calcirudites and marly limestones.

According to Pescatore (1988), the terrains attributed to the Sicilide Units (Argille Varicolori, Corleto Perticara and Tufiti di Tusa) could represent the Upper Cretaceous-Neogene portion of the Lagonegro Basin Unit that deposited in the axial part of the basin.

In particular, the landslide area is characterized by a moderate slope angle of 13-16% with an elevation ranges between 970m and 1078m.

The landslide can be described as a trans-rotational earthflow slide of ancient genesis. Actually the landslide is stopped, even if local reactivations in the accumulation zone are present.

The landslide is approximately 700m long, about 140 to 230m wide. The landslide occurred on March 2006 in

Picerno area involving building trade and infrastructures (Fig.1).

Fig. 1 Map of Picerno landslide and damaged areas after meteorological events of March 2006.

The main objectives of RDICP were the safety of the families who live in this area and the way to follow the evolution of the event. The geoelectrical tomography allowed us to define the geometry of the body landslide and to individuate eventually new slide surface. The RDICP used this information to compile an evacuation plane that permitted to move only the families close to the slope surface.

2D Electrical Resistivity Tomography

The electrical resistivity tomography (ERT) is a geoelectrical method widely applied to obtain 2D and 3D high-resolution images of the resistivity subsurface patterns in areas of complex geology (Griffiths and Baker 1993). During the field survey, ERT can be carried out by using different electrode configurations (dipole-dipole, Wenner, etc.) placed at the surface to send the electric currents into the ground and to measure the generated voltage signals. Technically, during an electrical resistivity measurement, the electric current is injected into the ground via two electrodes and the potential drop is measured between two other electrodes in line with current electrodes. In surveying, several traverses are made with various value of *n*. The values of the apparent resistivity for each traverse along a horizontal axis are assigned at a defined depth and position.

In a second step, it is necessary to transform the apparent resistivity values obtained during the field survey into real resistivities of the subsoil. Same processes will need for depth values.

In this work, the algorithm proposed by Loke and Barker (1996) for the automatic 2D inversion of apparent resistivity data was used. The inversion routine is based on the smoothness constrained least-squares inversion (Sasaki, 1992) implemented by a quasi-Newton optimisation technique. The subsurface is divided in rectangular blocks, whose number corresponds to the number of measurement points. The optimisation method adjusts the 2D resistivity model trying to reduce iteratively the difference between the calculated and measured apparent resistivity values. The root-mean-squared (RMS) error gives a measure of this difference.

Analysis of the results

The knowledge of local geology associated with the high spatial resolution of the measumements give us an interpretative tool to explain the ERTs obtained for the case study of this work.

An ERTs along a profile has been carried out with direction ortogonal to the axis of the Picerno landslide by using a multielectrode system with 32 electrodes and the dipole-dipole array (Fig.2).

Fig.2 Multielectrode system for electrical resistivity tomography used on Picerno landslide

The profile (length 300 m) has been carried out by using an electrode spacing of 10 m, reaching an investigation depth of about 45-50 m. The tomography was topographically corrected. The ERT shown a first resistivity layer (30 – 35 m of thickness, $20 < \rho < 40\ \Omega$ m) which covered a more conductivity material ($0 < \rho < 20\ \Omega$ m). The contrast between conductive and resistive layers could be associated with slide surface. The higher conductive nucleus ($\rho < 10\ \Omega$ m) located after the source area of the landslide, at a distance ranging from 160 to 240 m from the profile origin, could be associated with an area characterized by high water content (Fig.3).

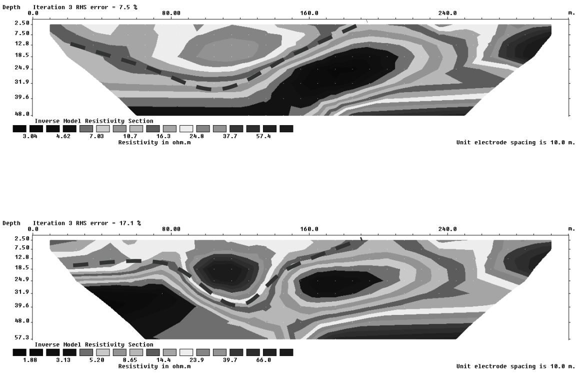

Fig. 3 2D Electrical resistivity tomographies on Picerno landslide using different electrode configurations (dipole-dipole on the top, Wenner-Schlumberger on the bottom). The contrast between conductive and resistive layers could be associated with slide surface (dotted line).

The higher shallow spatial resolution of the ERT allows a better geometrical definition of the resistivity layers, which is associated with slide material. Moreover, the conductive nucleus appears more visible. Taking into account that an increase of the water content could cause an increase of the pore pressures then a weakening of the slope, the presence of this high conductive nucleus could be represent one of the causes of the movement.

Conclusions

A new approach has been applied for investigating some landslides of recent genesis in Basilicata region. In particular a geophysical technique has been used to study a landslide bodies, which occurred in Basilicata region after the meteorological events of the 2006 year.

Geological and geomorphological data have been used to define the superficial characteristics of the investigated areas. Subsequently, electrical resistivity tomography method has been applied to obtain information about the deep characteristics of the landslide bodies.

The high resolution of the 2D ERTs allowed to locate the possible sliding surfaces of the landslide body. They also highlighted areas characterized by high water content; the increase of the saturation degree and pore pressures in these areas could have caused a weakening of the slopes.

The information obtained by the application of indirect surveys appeared to be particularly useful for the end users involved in the risks management. In particular, taking into account the cycle of landslides emergency, the obtained data could give a valid contribution during the post-event phase which mainly regards the damage valuation. Indeed, only a corrected assessment of the damage and a precise geometric reconstruction of the landslide body, can direct the intervention actions of the end users.

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The Distribution and Risk Assessment of Landslide Lakes in Wenchuan Earthquake Area

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Abstract. Landslides and rock avalanches resulting from the earthquake produced 256 landslide lakes. The authors traveled to the disaster zone to examine some of the debris dams. And the inspection of satellite images and aerial photos was also carried out. The results revealed that the earthquake-induced landslide lakes are primarily distributed along the fault rupture. The relationship between the number of landslide lakes and their distance to the fault rupture are consistent with the logarithm attenuation principle with a negative correlation coefficient of 0.9699.

The risk of landslide lakes was evaluated as those exhibiting extremely high risk, high risk, medium risk and low risk according to field observations of material composition, dam structure, dam height, maximum water storage capacity, and size of the population potentially affected. The 32 dangerous landslide lakes included 11 already overflowing lakes, one lake with extremely high risk (Tangjiashan Lake), 7 lakes with high risk, 5 lakes with medium risk and 8 lakes with low risk. Those dams that were not already overflowing were graded.

Keywords. Wenchuan, earthquake, Landslide Lake, flood outburst

1. Introduction

The Wenchuan Earthquake with its epicenter at Yingxiu Town, Wenchuan County (30.40°N, 103.47°E), was measured at M_s8.0 according to the China Earthquake Administration (CEA) ,and occurred at 14:28 on 12 May 2008 in the Sichuan Province of China. The earthquake brought overwhelming destruction to 8 provinces and cities, including Sichuan, Gansu, Shanxi, Chongqing, Yunnan, Shaanxi, Guizhou and Hubei. The heavily affected area was along the Central and Frontal faults of the Longmenshan fault system in the west of Sichuan, about 300-km-long and included Wenchuan, Beichuan, Dujiangyan, Pengzhou, Shifang, Mianzhu, An County, Jiangyou, Qingchuan, Pingwu, Lixian, Maoxian in Sichuan Province, Wen County in Gashu Province, and Ningqiang in Shanxi Province. The quake severely destroyed houses, roads, water and electricity projects, and communication establishments.

The main shock was very strong. Near the epicenter, intensities ranged up to XI and reverse slip could be seen along the surface rupture. The strong and intensive main and aftershocks shook the mountains, causing a great deal of rock falls, landslides, debris flows and other secondary mountain disasters. The large size of some of the landslides, collapses and debris flows caused damming of rivers, forming landslide lakes. According to preliminary investigations, 256 dammed lakes formed in total, including 32 lakes presenting a significant risk. The Tangjiashan Lake in Beichuan County was the most dangerous one, potentially impacting 1.3 million people downstream in Mianyang. As the rain season began, the water levels behind the many landslide dams rose, increasing the risk of uncontrolled outburst and greatly threatening the lives and property of more than 130 million people downstream. The earthquake lakes also brought tremendous threat to rescue and reconstruction work in the quake-hit areas. It was therefore critical and urgent to assess, monitor, and develop mitigation plans for the dammed lakes. In this paper, the distribution and risk analysis of dammed lakes are discussed.

2. The Distribution of the Landslide Lakes

The ground motion from the Wenchuan earthquake destabilized mountain slopes, generating landslides, debris flows, and rock avalanches. Where these slope failures were large they blocked rivers in the narrow valleys below. Lakes rapidly formed behind the debris dams as increasing amounts of runoff accumulated due to the start of the rain season. Inspection of remote sensing imagery, combined with field investigations, revealed that there were 256 landslide lakes in the earthquake-affected region (see Figure 1). Significant risk was posed by 32 of the earthquake lakes, particularly those in Beichuan, Qingchuan, Anxian, Shifang, Mianzhu, Pengzhou, Congzhou and Pingwu. The largest landslide dam produced Tangjiashan Lake, 3.2km upstream from Beichuan City, with a debris mass of 2.04×10^7m^3 , a maximum storage capacity of 3.15×10^8m^3, and a submerged area over 23-km-long. As can be seen in Figure two, the landslide lakes are heavily distributed along the fault zone. Both the number and scale of the earthquake-generated lakes are immense.

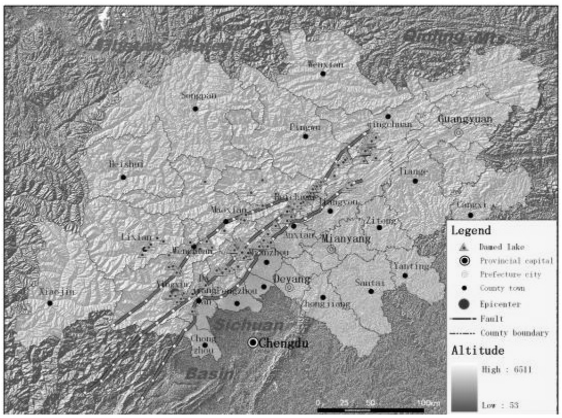

Fig.1 Distribution of landslide-dammed lakes caused by Wenchuan Earthquake

2.1 Distribution along the Longmenshan Fault System

The landslide lakes caused by the Wenchuan earthquake are mainly distributed along the Longmenshan fault system.

Most dams are clustered within 10km of the three strands of the Longmenshan fault system. There are 176 landslide lakes distributed within 10km of the main Central fault, also called the Beichuan-Yingxiu fault accounting for 68.5% of the total. The numbers of earthquake lakes along the Frontal and Back faults are 45 and 34, accounting for 17.5% and 13.2% respectively (see Fig. 1). These data indicate a strong correlation between the location of the surface trace of the main fault and the earthquake-generated landslides.

2.2 Pattern of the Landslide Dams along Rivers

Another feature of the landslide lakes as observed from the Wenchuan earthquake is that they are distributed in clusters along rivers like a string of beads. Within 30km of Tongkou River in Beichuan county are 9 strings of landslide lakes, and within 10km of the Mianyuan River are 4 strings, with a density of 0.4 lakes/km. There are seven within 8km of the Shiting River, with a density of 0.88 lakes/km; four within 7.5km of the Anzi River, with a density of 0.53 lakes/km; three within 5km of the Qing River, with a density of 0.6 lakes/km; and eight within 14km of the Jian River, a part of which is shown in Figure 2, with a density of 0.57 lakes/km. The Tangjiashan Lake, located on the upper reaches of the Tongkou River (tributary to the Fujiang River) is the largest one of the earthquake created lakes. Between the Tangjiashan Lake and the lower reaches of the Tongkou River near Beichuan County Town, landslide lakes occur every two kilometers on average. If the Tangjiashan landslide dam collapses, it is likely that the lakes downstream will collapse in a chain reaction due to the flood waters. The damage caused by this and other rivers' outburst chain reactions would be enormous; this problem must be addressed.

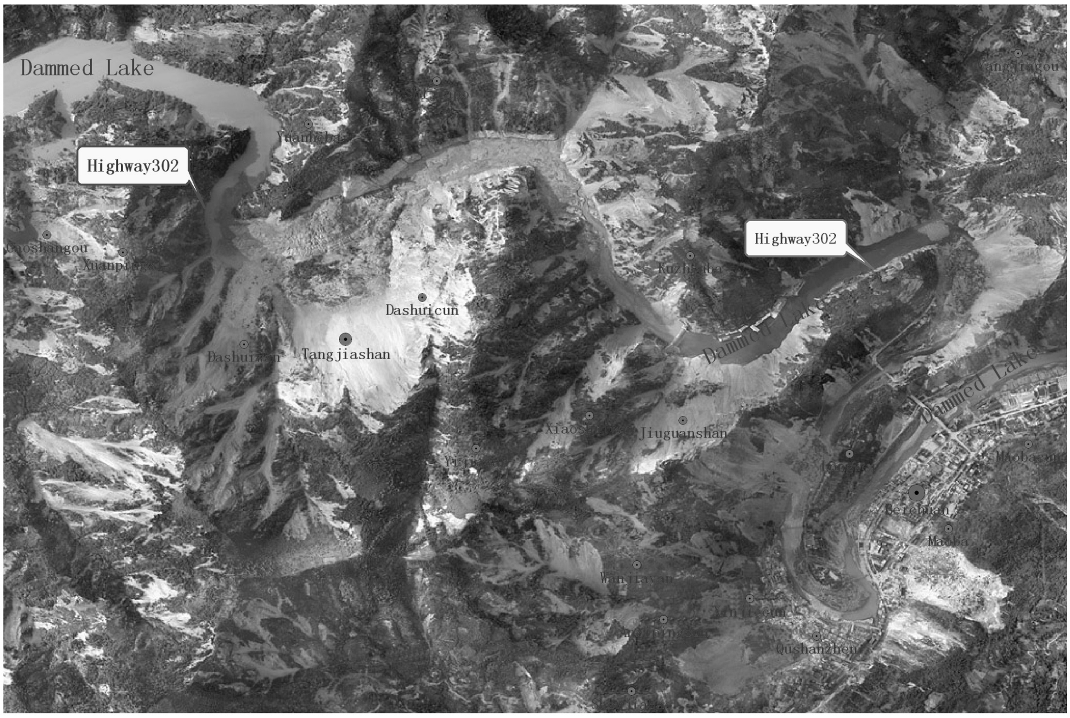

Fig. 2 The cluster of landslide lakes along the major River valley from Beichuan County to Tangjiashan
From left to right are Tangjiashan, Kuzhu and New – Street Village Dams (Image from the Chinese Mapping Bureau)

Table 1 Risk classification of landslide-dammed lakes

Grade / Index	Extreme high risk	High risk	Medium risk	Low risk
Dam height (m)	>100	50-100	25-50	<25
Water storage capacity ($\times 10^4 m^3$)	10^4	10^3-10^4	10^2-10^3	$<10^2$
Compositionof dam materials	Soil	Soil with some boulders	Boulders with some soil	Boulders

Remark: Two of the above three conditions need to be met to be considered highest risk.

Table 2 The risk and parameters of key landslide-dammed lakes

Location	County (City)	Drainage basin	Dam height (m)	Water storage capacity ($\times 10^4 m^3$)	Width to height ratio	Composition of dam	Risk category
Tangjiashan	Beichuan	Jianjiang River (Tongkouhe)	82-124	30200	9.8	Boulders with some soil	Extremely high risk
Downstream of Kuzhuba	Beichuan	Jianjiang River (Tongkouhe)	60	200	3.3	Boulders	Medium
Xinjiecun	Beichuan	Jianjiang River (Tongkouhe)	20	200	10.0	Soil	Medium
Baiguocun	Beichuan	Jianjiang River (Tongkouhe)	10	80	20.0	Boulders with some soil	Low
Yanyangtan	Beichuan	Jianjiang River (Tongkouhe)	50	560	3.6	Soil with some boulders	High
Sunjiayuanzi	Beichuan	Jianjiang River (Tongkouhe)	20	400	7.5	Boulders with some soil	Medium
Guanzipu	Beichuan	Jianjiang River (Tongkouhe)	60	585	6.5	Boulders with some soil	High
Tangjiawan	Beichuan	Fuxinghe---branch of Jianjiang river	40	1520	13.3	Small boulders with soil	High
Nanba	Pingwu	Shikan River	25	686	23.2	Small boulders	High
Xiaojiaqiao	An	Chaping River	64	2000	4.3	Small boulders	High
Upstream of Xiaogangjian	Mianzhu	Mianyuan River	62	1100	2.0	Boulders with some soil	High
Downstream of Xiaogangjian	Mianzhu	Mianyuan River	30	700	5.0	Boulder s	Medium
Yibadao	Mianzhu	Mianyuan River	25	50	4.0	Large boulders	Low
Ganhekou	Shifang	Shitingjiang River	10	50		Boulders with some soil	Low
Upstream of Macaotan	Shifang	Shitingjiang River	40	200	4.0	Boulders with some soil	Low
Middle of Macaotan	Shifang	Shitingjiang River	40	250	2.3	Boulders with some soil	Medium
Downstream of Macaotan	Shifang	Shitingjiang River	30	100	3.3	Boulders with some soil	Low
Muguaping	Shifang	Shitingjiang River	15	50	6.7	Boulders with some soil	Low
Yanziyan	Shifang	Shitingjiang River	10	10	4.0	Boulders with some soil	Low
Hongcun Power Station	Shifang	Shitingjiang River	40	150	2.0	Boulders with some soil	Low
Laoyingyan	An	Jushui River	130	1010		Small boulders	High

3. Rapid Assessment of the Risk from Breaching of a Landslide Dam

Confronted with numerous landslide-dammed lakes, it is critical to perform a rapid analysis of the hazard and risk for each lake's potential breach in order to focus the response to the most important situations. Unfortunately, this job is not only critical, it is difficult. The damaged, destroyed and unstable roads; the traffic delays; the unstable hillsides; and the frequent aftershocks all made it difficult to get to the landslides for analysis of the feature and landforms. The challenge of rapidly determining the types of materials at depth in the landslide dams adds to the difficulty of analyzing the lakes' risk.

The materials we used to make a rapid assessment of the risk caused by the landslide-dammed lakes were remote sensing imagery; basic information from field investigations; the length, width, height and composition of the dam determined from comprehensive analysis; and the backwater length of the dammed lakes. Based on statistics, we, by selecting the dam height, structure and the lake capacity as the main indices, established the method of assessing the risk of a single dammed lake (see Table 1), and categorized its risk into four types, namely extremely high, high, medium and low danger. After excluding the 11 already-overtopped dams behind which the water level were already reduced naturally, we came to the conclusion that the Tangjiashan Lake was extremely dangerous; seven lakes demonstrated a high level of danger, the Yanyang Beach, Guanzipu, Tangjia Bay, Nan Dam, Xiaojiaqiao, and Xiaogangjianshang; five lakes presented a medium danger, the Kuzhuba, Nee-Street Village, Sunjia Courtyard, Xiaogangjianxia, and the middle of Manger Beach; eight lakes were low in danger, the Baiguo Village, Yibadao, Gan River mouth, above Manger Beach, below Manger Beach, Muguaping, electrical station in Hong Village, and Swallow Rock (Table 2).

We further analyzed the high- and extremely high-risk dams by considering their width to height ratio and it's the dam's probably mode of failure. The dams with highest risk of breaching, in descending order, were: Tangjiashan, Laoyingyan, Nanba, Xiaogangjianzhong, Xiaojiaqiao, Tangjiawan, Guzipu and Yanyangtan.

4. Conclusion

5.12 The M_s8.0 Wenchuan earthquake was a macro-linear earthquake, with rupture along the Longmenshan Central and Frontal faults. The rupture was approximately 300-km-long and with primarily reverse and some dextral strike-slip motion. There were many aftershocks of small- and moderate-magnitude and some with long duration.

Due to the strong motion resulting from the earthquake, many landslides occurred over a large area; blocking rivers and forming as many as 265 landslide-dammed lakes. The lakes were mainly distributed in a belt along the rupture zone and in clusters along the river valleys. Most of the landslide-dammed lakes were the result of rock-type landslides. There were 3 large lakes that stored more than 108m^3 of water. Under the emergency circumstances, the dam height, composition and storage capacity was preliminarily used as an index of the dam's risk of collapse. Four risk levels were assigned, with1 with an extremely high danger risk, 7 with a high danger, 5 with a medium danger and 8 of low danger.

Acknowledgements

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Role of Monsoon Rainfall for Landsliding in Nepal

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Abstract. In the Himalaya, people live in widely spread settlements and suffer more from landslides than from any other type of natural disaster. The intense summer monsoons are the main factor in triggering landslides. Landslides in the Himalaya are scale-dependent, from massive extent of whole mountain ranges (gravity tectonics) through failure of single peaks to very minor slope failures. Considering rainfall as a main factor triggering landslides in Nepal, relationships between landslide occurrence and rainfall characteristics are described in this paper. Rainfall threshold established by Dahal and Hasegawa (2008) were used to prepare a protp-type landslide early warning system. Taking reference of the intensity-duration threshold and normalized rainfall intensity threshold, two proto-type models of early warning systems (RIEWS and N-RIEWS) are also proposed in this paper.

Keywords. Nepal, rainfall-triggered landslide, monsoon, early warning

1. Background

The Himalayan mountain chain measures 2400 km in length and is one of the tectonically most active mountain ranges on the earth. The annual economic loss due to landslide damages alone in this region is estimated to exceed one billion US dollars, including hundreds of human fatalities. Studies indicate that the loss due to landslides and related problems in the Himalayan region alone constitutes about 30 percent of the world's total landslide-related damage value (Li, 1990). Processes and characteristics that contribute to landslides in Nepal can be arranged in four categories: (i) geological causes (weak, weathered, sheared materials, and contrast in permeability of materials); (ii) morphological causes (fluvial, erosion of slope toe, tectonic uplift, erosion of marginal sides; (iii) physical causes (intense rainfall, prolong or exceptional precipitation, earthquake, and snowmelt); and (iv) human causes (deforestation, irrigation, mining, road construction, artificial vibration, water leakage, land use changes).

For Nepal, intense rainfall is a main trigger of landslides because Nepal suffers from tremendous landslide disaster problems every year, and a great number of people are affected by large- and small-scale landslides throughout the country, especially during monsoon periods. In this context, this paper highlights monsoon rainfall and their implications in the Nepal Himalaya. Similarly, this paper will also discuss a proto-type landslide early warning system for Nepal.

2. Monsoon and landsides

Geomorphology, geology, and climate play the most important role in preparatory process of landslide initiation in any region. With 83% low to high mountainous area, Nepal covers approximately one third of the Himalayan mountain ranges in the central Himalaya.

The climate of Nepal is extremely varied and it ranges from seasonably humid subtropics to semiarid alpine, but in a more global sense, the climate of Nepal is tropical monsoon, except for parts of the northern area, which lie in the rain shadow of the Himalaya and have a cold semi-desert climate. It is often said that wet monsoon over the Himalaya is responsible for almost 90% of South Asian water resources.

Orographic effect of mountains is the main cause of extreme rainfall in Nepal during monsoon. The prevailing winds (moisture laden vapor) from the Arabian Sea and the Bay of Bengal get intercepted to mountains. As the air hits higher land, the air is forced to rise. When air rises above the dew point, it can no longer hold all its water, which starts to condense. This results in high rainfall across the southern flanks of the Himalayan range (windward face) and low rainfall along behind Himalaya (leeward face). The orographic effect of the Mahabharat Range is also significant in whole Nepal and windward face of the range usually suffers much rainfall in monsoon. The orographic effect of the Fore Himalaya is responsible for extreme monsoon rainfall in Midland. The topographic profile of eastern, central and western Nepal clearly suggests these phenomena (Fig 1). Moreover, in southern part of central Nepal, the topography is relatively lower than other parts of country (Fig 2) but abruptly rise in north as Dhaulagiri, Annapurna and Manaslu ranges. As a result, Pokhara area generally gets much rainfall than other parts of Nepal because of strong orographic effect of Annapurna and Dhaulagiri ranges (Fig 2b). As a result, central Nepal always has high values of both mean annual rainfall and extreme 24 hours rainfall (Fig 3).

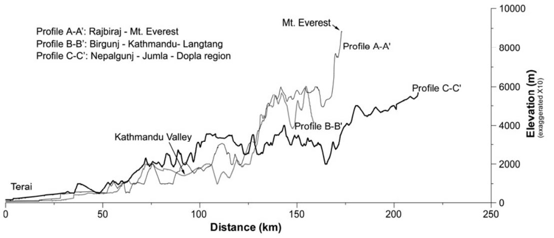

Fig 1. Topographic profile of eastern, central and western Nepal. The location of profile lines are given in Fig 2a. Usually, eastern and central Nepal has highly elevated monsoon barrier within 100 km distance from Indo-Nepal boarder to north whereas western Nepal has elevated mountain range at 200 km distance from boarder.

When spatial distributions of landslides were evaluated from record of more than 650 landslides, it was found that more landslides events were concentrated in central Nepal (area between Pokhara and Kathmandu (Fig. 3).

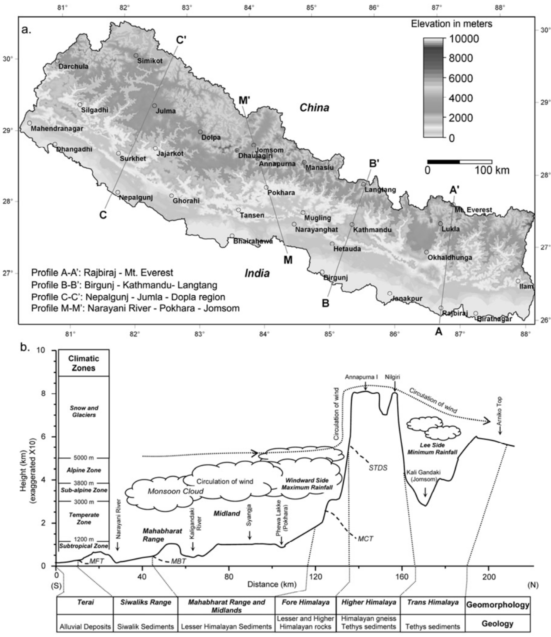

Fig 2. a. Relief map of Nepal, a lower altitude area is situated in the area between west of Kathmandu and Pokhara. The topographical profile of line AA', BB' and CC' already given in Fig 6. b. Topographical profile (through line MM' in Fig 7a) of Nepal Himalaya with illustration of climatic zones, main geology and geomorphology. Because of strong orographic effects of abruptly elevated mountains of North, central Nepal gets torrential monsoon rainfall

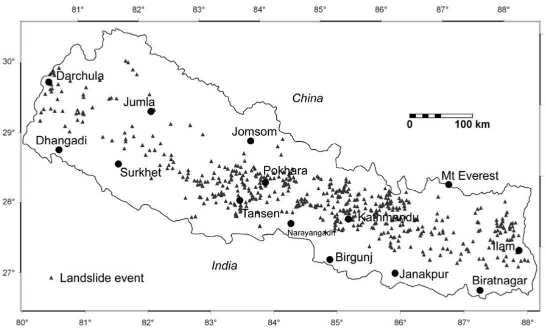

Fig 3. Landslide distribution in Nepal. This map was prepared using more than 650 landslide events.

The small-scale rainfall-triggered landslides in Nepal are generally shallow (about 0.5 to 2.5 m thick) and are triggered by changes in physical properties of slope materials during rainfall. Relatively large-scale and deep-seated landslides, on the other hand, are affected by long-term variation in rainfall. Annual monsoon rainfall in Nepal ranges from as low as 160 mm in the northwestern region to as high as 5,500 mm in some isolated areas of central Nepal (Fig. However, mean annual rainfall of 1,500–2,500 mm predominates over most of the country (Fig. 4). More than 80% of the total annual precipitation occurs during the summer four months (June–September). Likewise, the distribution of daily precipitation during the rainy season is also uneven. Sometimes, 10% of the total annual precipitation can occur in a single day and 50% of the total annual precipitation is often recorded within 10 days of the monsoon period. Such an uneven rainfall pattern is thought to play an important role in triggering landslides in Nepal.

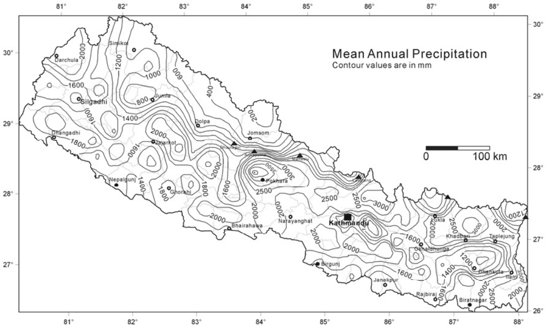

Fig 4. Mean annual rainfall in Nepal

When monsoon rainfall and landslide relationship was taken into consideration, it was noticed that a considerable number of landslides were triggered in the Himalaya by continuous rainfall of 3 to 90 days. It has been noticed that continuous rainfall of few days (5 days or 7 days or 10 days) are usually responsible for landsliding in the Nepal Himalaya. Fig. 5 shows some examples of rainfall and landslide occurrence time during monsoon period in eastern Nepal. It clearly demonstrates the relationship of progressive monsoon rainfall and frequency of landsliding. Monsoon rains usually fall with interruptions of 2–3 days and are generally characterized by low intensity and long duration. Thus, there is a strong role of antecedent rainfall in triggering landslides. Dahal and Hasegawa (2008) suggested that a moderate correlation exists between the antecedent rainfalls of 3 to 10 days and the daily rainfall at failure in the Nepal Himalaya.

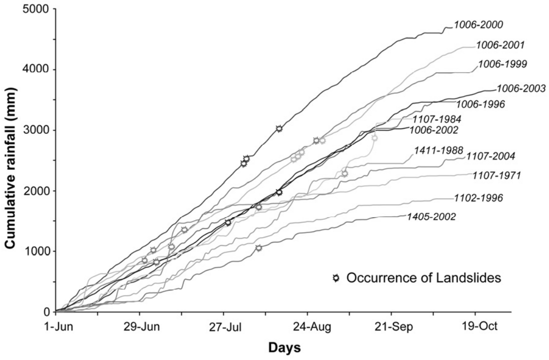

Fig 5. Illustration of cumulative rainfall and occurrence of landslides in eastern Nepal. Each curve is labeled with the station index number and year. Cumulative rainfall of station 1006, situated at about 60 km north east of Kathmandu, has a linear relationship with monsoon days.

3. Rainfall thresholds of landsliding

Until 2007, for the Himalaya, no generalized studies exist for landslide and debris-flow initiating rainfall thresholds although these mountains have tremendous landslide problems compared to other parts of the world. In early 2008, considering rainfall as a main factor triggering landslides in

Nepal, Dahal and Hasegawa (2008) established relationships between landslide occurrence and rainfall characteristics in the form of empirical equations. These empirical relationships of rainfall with landslide occurrence described a threshold rainfall necessary for triggering landslides in Nepal. The method employed by Dahal and Hasegawa (2008) in establishing the rainfall thresholds is similar to that by other researchers (e.g., Caine, 1980; Larsen and Simon, 1993; Aleotti, 2004; Guzzetti et al. 2007) for such estimations in different parts of the world.

Dahal and Hasegawa (2008) described rainfall threshold for Nepal in two different approach: intensity-duration threshold and normalized rainfall intensity threshold. They defined intensity-duration threshold as:

$$I = 73.90D^{-0.79} \quad \text{…………………………………….. (1)}$$

Where I is hourly rainfall intensity in millimeters (mm/hr) and D is duration in hours. According to this threshold relation, for rainfall events of shorter duration, such as below 10 hours, a rainfall intensity of 12.0 mm/hr is necessary to trigger landslides, while an average precipitation of less than 2 mm/hr appears sufficient to cause landsliding if continued for more than 100 hours. Similarly, if 24-hour rainfall exceeds 144 mm, there is always risk of landslides in Nepal.

Dahal and Hasegawa (2008) also analyzed the landslides and the corresponding rainfalls respect to the mean annual precipitation (MAP). The ratio between the critical rainfall of the event and the mean annual precipitation of the site is defined as normalized critical rainfall (NCR), and it is expressed in percentage. By normalizing rainfall intensity with NCR, Dahal and Hasegawa (2008) expressed following threshold for landslides in Nepal:

$$NI = 1.10D^{-0.59} \quad \text{…………………………………….. (2)}$$

Where NI is normalized rainfall intensity (hr^{-1}) and D is duration in hours. The threshold relation indicates that for rainfall events of 1-day, a normalized rainfall intensity of 0.17 hr^{-1} (i.e. 17% of MAP) is required to trigger landslides, while a normalized rainfall intensity of less than 0.07 hr^{-1} (7% of MAP) appears sufficient to cause landslides if continued for more than 100 hours.

4. Proto-type landslide early warning systems

Nepal still does not have any concept of early warning and every year more than 300 people died by natural hazards. In Nepal, rainfall threshold and warning system usually haves some limitations with rainfall data. Any of the rainfall thresholds described by Dahal and Hasegawa (2008) can be utilize for development of warning thresholds for early warning systems.

Conventionally, when rainfall intensity-duration is considered as basic parameters of rainfall threshold for landslide interpretation, whole monsoon rainfall can be plot in the form of temporal pattern of rainfall intensity vs. rainfall duration curve (Aleotti, 2004) as shown in Fig 6. The threshold line (TL) in Fig 6 represents Eq (1). The curve can be plot from daily rainfall data of monsoon period. When temporal rainfall intensity (TRI) is used, some none rainfall days also can be considered and as a result, curve shows negative trend of rainfall advancement (Fig 6a). Similarly, time of early warning usually appears when TRI curve trends to move near to the threshold line. Thus, for the consideration of early warning time, a warning threshold line (WTL) needs to be defined in Fig 6. Similarly, when critical time for evacuation is already fixed, warning threshold curve (WTC) can be prepared. Likewise, when TRI curve meet WTL or WTC, early warning information should be imposed in the area. In Fig 6a, five cases of TRI curves are illustrated to describe various patterns of rainfall and hypothetical landslide scenario. Fig 6b represents the condition described in Fig 6a in the real data. Fig 6b well illustrates the possible early warning for rainfall and landslide incidence and this is the one short of verification of model described in Fig 6a. Likewise, when normalized rainfall intensity is considered for early warning, similar model can be developed with consideration of Eq. (2). For ease of usage, the rainfall intensity-duration model and the normalized rainfall intensity-duration model are named a RIEWS (rainfall intensity based early warning system) and N-RIEWS (normalized rainfall intensity based early warning system).

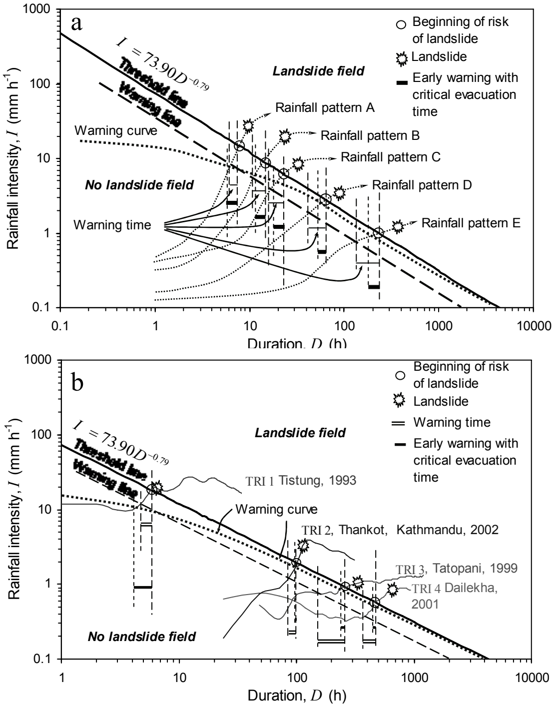

Fig 6. a. Early warning model for rainfall-induced landslides in Nepal based on rainfall intensity-duration data (RIEWS model), b. Implementation of RIEWS model for previous rainfall and landslide data

Early warning model described here show less time for evacuation in the case of short duration and high intensity rainfall, whereas for long duration rainfall, warning time is enough and when warning information disseminate to the people, people will aware to possible landslide risk. In the meantime, they will be mentally ready to tackle with possible disaster of coming hours or days and will avoid the consequences. On the basis of coarse hydro-meteorological data of developing country like Nepal, this simple and rather easy model of early warning will certainly help to reduce fatalities from landslides.

There are few automatic stations in Nepal which record hourly rainfall. Similarly, NASA and the Japan Aerospace Exploration Agency (JAXA) have started a joint mission named as Tropical Rainfall Measuring Mission (TRMM) to monitor tropical rainfall including monsoon of south Asia. A new series of quasi-global, near-real-time, TRMM-based precipitation estimates is now available to the research community. TRMM for the first time is providing accurate estimates of the rainfall over the strong-monsoon areas. TMPA (TRMM-based Multi-satellite Precipitation Analysis) precipitation data are available in both real-time and post-real-time versions, which are useful to assess the location and timing of rainfall-triggered landslide by monitoring landslide-prone areas while receiving heavy rainfall (Hong et al. 2006). Thus, for the high intensity rainfall condition of short duration (rainfall patterns A and B in Fig 6), it is strongly recommended to use hourly data of few rainfall gauging station and data from remote sensing satellite such as TRMM. Without such information, early warning of landsliding related to short duration high intensity rainfall is not possible.

A suitable flow chart of implementation of RIEWS or N-RIEWS model is shown in Fig 6. This proposed proto-type early warning system is purely an interdisciplinary work and it need combine efforts of engineering geologist, geotechnical engineer, meteorologist, remote sensing expert and disaster management expert. Flow chart clearly shows that preparation of temporal rainfall intensity curve is a very important stage for implementation of early warning models proposed in this paper. It means data of every day rainfall should be available to early warning team.

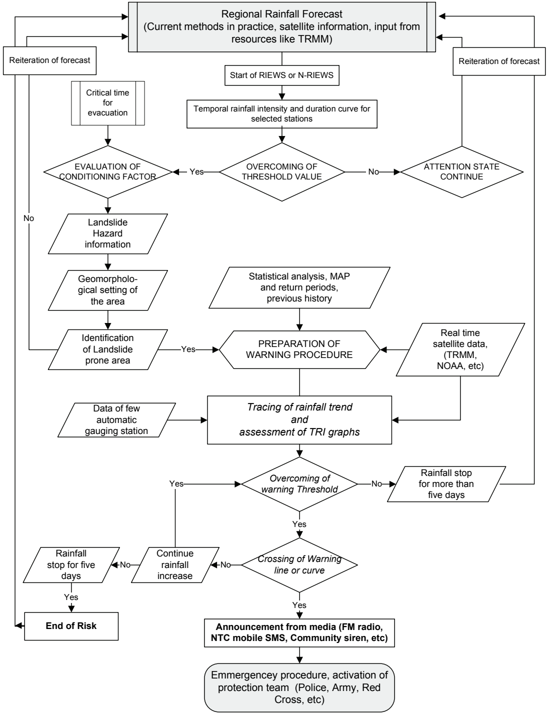

Fig 13. Operating procedure of RIEWS and N-RIEWS proto-type landslide early warning models

Available geological information along with 3D terrain views available in free internet resources, such as Google Earth, will certainly assist to geomorphologist for evaluating geomorphological settings of the area of risk. Meantime, communication media like FM stations, Nepal Telecom SMS service in mobile phone as well as community based siren system can be the best suitable method to spread warning to the people at risk. There are nearly 102 FM radio stations in operation in the different part of Nepal and they can play very effective role for information dissemination. Once awaiting disaster is known, civil security services can be also mobilized into the area of high risk and thereby people will get enough support for evacuation and sustenance.

5. Concluding remarks

An analysis of the 55-year record of landslides and rainfall events in the Himalaya has suggested that many landslides occurred under the influence of a wide range of rainfall durations (5 hours to 90 days). Monsoon rains usually fall with interruptions and are generally characterized by low intensity and long duration. As a result, landslides are usually initiated only after few days of first monsoon rainfall and role of antecedent rainfall for landsliding in Nepal is bona fide. Orographic effect of Himalayan range is responsible for extreme rainfall in central and eastern Nepal. As a result, central Nepal usually faced many landslides related disaster than western Nepal.

Early warning of rainfall-induced landslides is a very urgent work of Nepal and but still there are many limitations in the rainfall data and resources. On the basis of available resources, this paper attempts to establish proto-type model of early warning systems: RIEWS and N-RIWES. The models are based on recent findings about rainfall threshold of the Nepal Himalaya (Dahal and Hasegawa, 2008). The empirical thresholds described in this paper are a fundamental element of the implemented real-time warning systems. However, when using them, we must take into account several major restrictions.

Acknowledgements

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Landslide Detection Methods, Inventory Analysis and Susceptibility Mapping Applied to the Tien Shan, Kyrgyz Republic

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Abstract. This paper presents results of the last five years of landslide detection and landslide susceptibility mapping in the Central and Southern Tien Shan. Landslide inventories have been compiled for areas of major interest in the Kyrgyz Republic. For those areas, landslides were first mapped manually using KFA satellite images and aerial photographs. Recently, a landslide detection method has been developed in order to map landslides automatically. This method is based on a neural network scheme applied to detect particular slope failure features from remote sensing data. Multi-spectral and/or panchromatic ASTER and SPOT images as well as digital elevation models (DEMs) are used as inputs. This automatic method is designed to map medium-size mass movements (10^5-10^7 m^3). This approach supplements the manual mapping of large slope failures and helps to complete the inventory of mass movements and related landslide susceptibility/hazard maps for large areas within the Tien Shan. Size-frequency analyses have been applied to the two existing regional landslide inventories. These size-frequency analyses revealed the incompleteness of the respective inventories (in the low-size domain) as well as regional and local differences due to natural and anthropogenic influences. To be able to perform reliable susceptibility and size-frequency analyses, the completed inventories need to be verified. At present, we perform local verification by manual mapping and control, but automatic verification methods are being developed. They will also allow us to determine the level of uncertainties. Ongoing research is focused on the propagation of uncertainties throughout the chain of processing.

Keywords. Loess, rockslides, detection, susceptibility, size-frequency, Tien Shan

1. Introduction

In the frame of the EU FP6 NATASHA project, a new inventory of landslides of the Tien Shan is being compiled for the Kyrgyz Republic. After completion of the project, the work is supposed to be extended to other Central Asian mountain regions in the Tajikistan, Uzbekistan, Kazakhstan and Western China.

This paper presents results of landslide detection and landslide susceptibility mapping in the Central and Southern Tien Shan. First, landslide inventories have been compiled for areas of major interest in the Kyrgyz Republic: the Suusamyr region affected by a Ms=7.3 earthquake in 1992 (Havenith et al., 2006a); the Mailuu-Suu valley, nuclear waste storage and former mining area (Havenith et al., 2006b); the Gulcha area (Danneels et al., in press), affected by several loess-landslide disasters in 2002 and 2005. For the first two areas, landslides were mapped using KFA satellite images and aerial photographs. Recently, an automatic landslide detection method has been developed in order to map the loess-landslides in the third region of Gulcha. The first part of this paper is focused on the automated method of landslide detection in the Gulcha area, whereas the second part is focused on size-frequency and susceptibility analyses in the regions of Suusamyr and Mailuu-Suu.

2. Landslide detection method

The following approach with three main steps has been adopted. The first step consists of a pixel-based classification using an Artificial Neural Network (ANN) with the spectral information of the remote sensing images as input features. Once the model has been trained, it is used for application to the entire study area. For each pixel (independently of the neighbouring pixels) a likelihood value is obtained (the pixel is likely to be part of a landslide).

Next, the output likelihood map is segmented in order to create connected sets of pixels representing the detected landslides. The segmentation is conducted using the double threshold technique, also known as hysteresis threshold (Soille 1999), which results in a cleaner segmentation and is less sensitive to the chosen threshold values.

In the third step, spurious detected landslides are filtered out by stepwise elimination based on several object-oriented decision rules, including shape and geomorphologic properties. A first decision rule is defined by the slope value: the median slope value (derived from the DEM) inside the object must be larger than 10 degrees. A second geomorphologic condition is based on the slope direction. As mass movements are always sliding in the direction of steepest slope, the object orientation should be similar to the slope direction inside the object. Furthermore, according to the type of landslide, shape properties can also be defined. In the case of earthflows, objects must be elongated.

3. Application to Gulcha loess flows

The Gulcha area is located in Southern Kyrgyzstan, in the transitional zone between the Fergana Basin in the north and the Alai Range in the south (see Fig. 1). Two types of landslides can be differentiated: elongated earthflows consisting only of loess and earthslides, which involve both loess and the underlying bedrock. Two different satellite images were available for 2004: a 15 m resolution multispectral ASTER image (15 May 2004) and a 5 m resolution panchromatic SPOT image (20 August 2004). These images were taken after the activation of several landslides connected to the 2004 earthquakes; they show numerous “fresh” landslides.

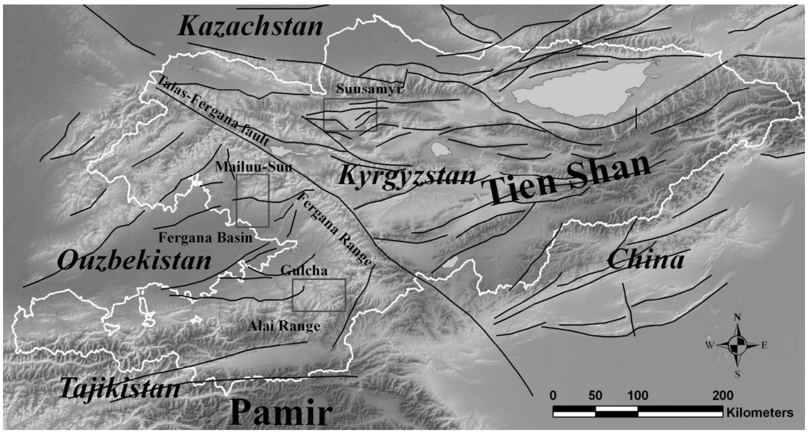

Fig. 1 Shaded relief map of the Kyrgyz republic and Tien Shan range. Study areas (Suusamyr, Mailuu-Suu and Gulcha) are indicated by rectangles. Tectonic faults are indicated by black lines.

The stereoscopic bands of the ASTER image were used to create a DEM, which served to orthorectify all images and to derive the geomorphologic parameters (slope and slope direction). The study area used for the classification covers a surface of 18 km by 9 km. Thirteen earthflows of varying size were manually delineated on this study area. A training area of 1 km by 2 km containing 3 medium-sized earthflows has been defined. The whole process of landslide detection was performed using Matlab.

Results and discussion of landslide detection

In order to evaluate the beneficial contribution of the panchromatic band, two cases are compared: first, only the 3 first bands of the ASTER image are used as input units. In order to combine these images with the SPOT image, we decided to subsample the multispectral image to the spatial resolution of the panchromatic image. In the second case, four images (3 subsampled ASTER bands + 1 SPOT band) are used as input features for the ANN classification. The decision rules selected for the object classification are based on the elongation, slope and slope-direction values.

Validation of the intermediate results (after segmentation) and final results (after object-based classification) is done by comparison with the manually defined landslides. Table 1 summarizes the results for both cases. Based on the ASTER images, 11 of the 13 delineated landslides were detected. One small earthflow was already missing after the segmentation process; this mass movement is too small and thus not taken into account during the segmentation process. Another landslide has been rejected during the object decision rules due to its complex geometry. By adding the high resolution panchromatic band as input feature, all delineated landslides could be retrieved with the automatic detection method (except for the complex geometry earthflow). However, the number of erroneously detected landslides is also highly increased. It should be noted that some of these erroneously detected landslides could actually be real small mass movements. Verification on terrain is needed to check this.

These results show that major earthflows can be correctly detected, extracted and (partly) reconfigured, demonstrating the potential application of the method. Further research will be conducted by applying the method to other regions with the same type of landslides. Moreover, we intend to adapt the method to the detection of other landslide types such as rockslides and rotational landslides. The input parameters for these types of movements will differ; the incorporation of textural parameters, which provide information about the roughness of the surface, will be more useful.

Table 1 Validation of results compared to 13 manually delineated landslides (Interm. = after segmentation; Final = after object-based classification)

		ASTER	ASTER + SPOT
Number of correctly detected landslides	Interm.	12	13
	Final	11	12
Number of erroneously detected landslides	Interm.	99	271
	Final	12	54

4. Size-frequency and susceptibility analyses

Landslide susceptibility (LS) mapping has been completed for two regions of different sizes: the Suusamyr region with an area of roughly 9000 km^2 and the central Mailuu-Suu valley with an area of about 70 km^2. In the Suusamyr region, 446 mass movements with volumes larger than 2000 m^2 have been mapped – some are related to the Ms=7.3 Suusamyr earthquake of 1992. For the Mailuu-Suu area, landslides larger than 1000 m^2 have been recorded at different times: 78 landslides in 1962, 117 landslides in 1977 and 220 landslides in 2003. A new inventory is being compiled – first results show that at least 30 new or reactivated slope failures occurred between 2003 and 2007 over an area of 70 km^2.

The results of the size-frequency analysis are presented in Fig. 2. According to the method of Malamud et al. (2004), the size–frequency relationship of these data sets was analyzed in terms of the frequency density function (f) of landslide areas (AL):

$$f(AL) = \delta NL / \delta AL$$

where δNL is the number of landslides with areas between AL and $AL + \delta AL$.

This function follows a power-law, with decreasing frequency density for larger areas. This trend breaks down for small areas and shows a so-called roll-over (with decreasing frequency density for very small landslide areas). Such roll-overs are often explained as incompleteness of the data set. Malamud et al. (2004), however, consider their landslide inventories as complete well below the roll-over, and hence regard the latter as "real", but do not explain its origin. From Fig. 2 it can be seen that the roll-over occurs for smaller landslide areas in the case of the Mailuu-Suu landslide data sets compared with the Suusamyr landslide-rockslide data set. For the latter, the maximum frequency density is computed for an area of about 7,500 m^2 whereas it is about 2,500 m^2 for the Mailuu-Suu landslide data set. Malamud et al. (2004) noticed that all their analyzed landslide data sets reveal a maximum probability density for 400 to 500 m^2. Our data sets appear to be incomplete for landslides smaller than ~10,000 m^2 in the case of the Mailuu-Suu data sets and smaller than ~100,000 m^2 in the case of the Suusamyr data set. Power-law trends were fitted to the data larger than these areas. For the Mailuu-Suu landslides of 1962 and 1977, the exponents are 2.23 and 2.43, similar to values found by Stark and Hovius (2001) and Malamud et al. (2004) for various types of landside distributions. The power-law exponents for the 2003 Mailuu-Suu and Suusamyr records are 1.9 and 1.94, respectively, significantly lower than values obtained for landslide inventories analyzed by the cited researchers. These trends are, however, consistent for records of large landslides, which can be considered complete and reliable. In the case of the Suusamyr records, no particular reason was found to explain the low exponent. The particular power-law behavior of the 2003 Mailuu-Suu landslide distribution could be explained by the formation of large landslides by coalescing smaller landslides (or growth of smaller landslides) so that the number of smaller landslides has been reduced with time.

The outcomes of the LS analysis were analyzed with regard to 10 (out of 20) different combinations of the following factors: slope (S), curvature (C), aspect (A), geology (G), distance to faults (F), and Principal Components x,y,z of the VNIR spectral bands of ASTER images (PCxyz).

The LS maps (in terms of scarp density corresponding to five different combinations, S-A, S-A-C, G-S-A-C, F-G-S-A-C and PC12-S-A-C (Fig. 3) show that increasing combination complexity allows us to distinguish more clearly high-susceptibility from low susceptibility zones. Combinations with more than four factors detect highest susceptibilities mainly within existing scarp areas (see Figs. 3c,e). Medium to large susceptibilities can also be found in other areas, showing that there is significant potential to develop new landslides. A large instability potential was found in a zone west of the Mailuu-Suu region. This zone is now recognized as landslide Bedresai mapped only recently, after completion of our analysis (see arrow in Fig. 3c). Within the landslide polygon (white) map-scaled landslide density values (using PC12-S-A-C combination) are higher than outside the area of slope instability. This landslide probably occurred in 1993 (but it is difficult to detect it on remote imagery). From this it can be inferred that the method does not predict this landslide occurrence but detects it as existing instability (in addition to other slope failures included in the conditional analysis). Such a "blind detection" confirms the reliability of the method. Its ability to predict future slope failure locations can only be proved by comparing it with future landslide occurrences.

Conclusions

During the last 5 years, a series of landslide inventories have been compiled for regions within the Tien Shan, Kyrgyz Republic. Until now, most data were collected by manual mapping. Since the Tien Shan is a large mountain range presenting high mass movement hazards (partly related to high seismic hazards), manual mapping using field and remote sensing data needs to be supported by automatic detection methods.

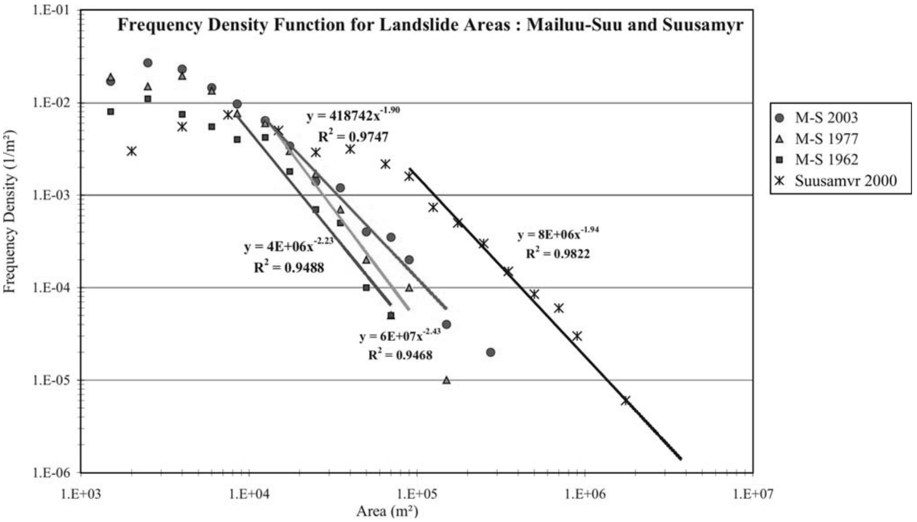

Fig. 2 Frequency-density function for landslide areas in the Mailuu-Suu Valley in 1962 (78 events), 1977 (117 events) and 2003 (220 events) compared with the frequency-density distribution of landslides and rockslides in the Suusamyr region (446 events). Havenith et al. (2006b)

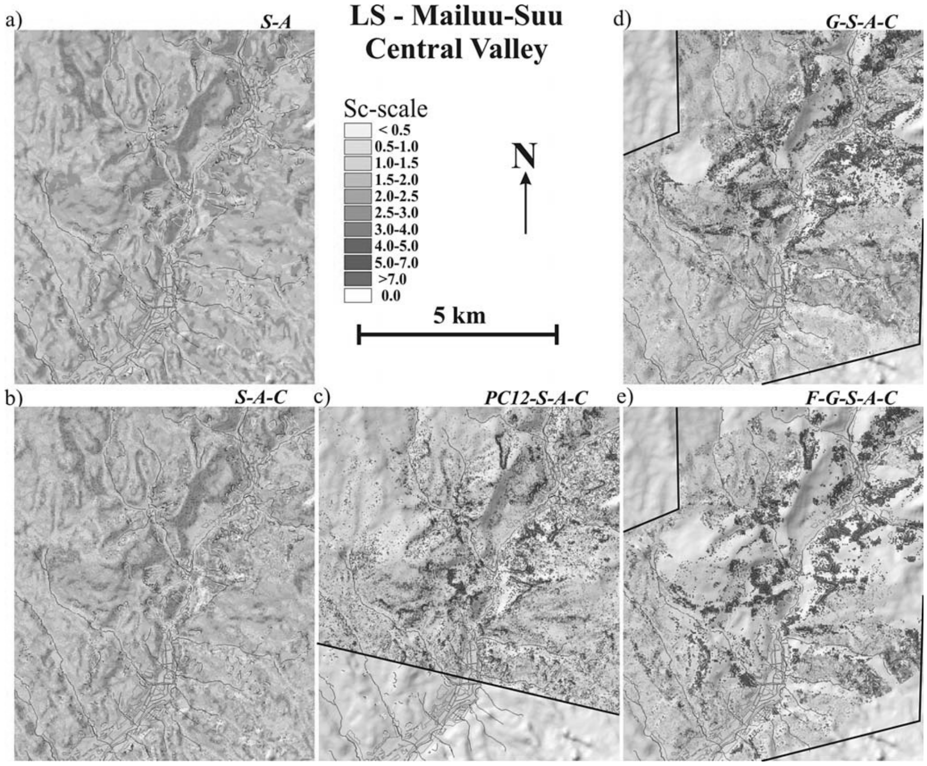

Fig. 3 Comparison between five different LS maps of the Mailuu-Suu Valley in terms of map-scaled scarp densities (see Sc-scale), overlay of scarps (thin, *black*), landslide bodies (thin, *white*), rivers (*grey*) and town (*grey*). Abbreviations used in the map titles are explained in the text. Limits of investigated map extents are marked by *black lines*.

These methods are being developed using neural networks and are limited by the quality of the inputs. Certainly, also the type of processing needs to be improved. Here, we presented the pixel-based approach followed by object-related elimination rules; now, we are developing a technique based on the segmentation of the image. Verification methods are also under study, because the quality of the landslide inventory directly affects the reliability of the derived landslide susceptibility maps. Here, we outlined two methods to compute such maps: a statistical and a process-based approach. Both present advantages and disadvantages and are best to be used in combination. For the landslide susceptibility mapping, such as for the landslide detection, we aim at developing a method able to differentiate between landslide types. Further, we hope that soon we will be able to produce transnational landslide inventories and susceptibility maps in collaboration with experts from the neighbouring Kazakhstan, Uzbekistan, Tajikistan and China.

Acknowledgments

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Geomorphology and Landslide Potential of the Bamiyan Valley (Afghanistan)

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Abstract. The present work reports geomorphological and geotechnical investigations carried out in the UNESCO site of the Bamiyan valley (Central Afghanistan) in 2007 in order to reconstruct active deformation processes and geomorphological hazards affecting Cultural Heritage. The site is known worldwide for two standing giant statues of Buddha destroyed by Taliban in March 2001.
The geomorphological field survey has reconstructed the main active geomorphological processes along the cliff area mainly related to superficial waters (e.g. erosion, infiltration along joints, accumulation of mud/debris) and slope deformations (e.g. toppling, rock falls, rock slides, jointing). The geomorphological survey has been integrated with geotechnical, structural and kinematic analyses concentrated in 17 distinct sections of the cliff where geological processes were more prominent. This to detect and investigate potential failure modes of the jointed rock masses forming the Bamyian cliff. The kinematic analysis produced different results for the various slope failure modes analysed according to local structural and geomorphological characteristics of the cliff. A geomorphological map reporting the main processes surveyed in the area has been produced.

Keywords. Geomorphology, Slope instability, structural analysis, landslide kinematics, Bamiyan

1. Geological setting

The Bamiyan valley (Fig. 1) is an intramountainous basin, subsequently filled with debris material originating from the surrounding mountain ranges (Lang, 1971; Reineke, 2006). The Neogene near-horizontally bedded sediments can be distinguished into four strata. Starting with the Eocene Dokani Formation (>80m sandy carbonate and anhydrite) and the Zohak Formation (>1000m red conglomerate), the so called Buddha Formation is deposited in the Oligocene and built up by >70m yellow-brown pelite, sandstone, conglomerate and some volcanic material. The top is composed by the Miocene Ghulgola Formation (>200m sandstone, clay and lacustrine carbonate) and the Pliocene Khwaja-Ghar Formation (ca. 200m travertine, sandstone and conglomerate. The Qal'acah Formation is almost contemporary to the Buddha Formation and reflects a detritic facies on the slope of a volcano (Lang, 1972).

At north and south of the fault lines of the tectonic graben, red clayey soils formed by metamorphic contact can be found. Along these fault lines, volcanic activity can be recognized. This may have modified (fritted) the surrounding sediments and changed their colour into red.

From the late Pliocene to the end of Pleistocene (Reineke, 2006) the Neogene sediments have been incised by fluvio-glacial erosion. Alternating warm and cold periods lead to changing conditions between accumulation and erosion, so that different Quaternary terraces developed.

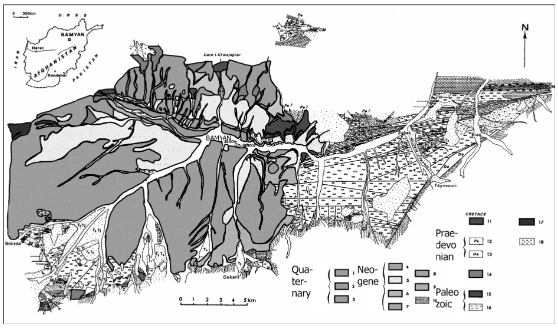


Fig. 1 Geological map of Bamiyan (Lang, 1971; redrawn from Reineke, 2006)

The cliff and niches have been excavated into the so called Buddha Formation and are composed by alternance of conglomerate and siltstone (yellow at the bottom and red in the middle of the cliff) with some pelite, sandstone and volcanic material. The conglomerate is the predominant material in the cliff and presents a moderate cohesion The differentiated grain size distribution (from conglomerate to clay) is clearly demonstrating a not selective depositional environment, with high energy (flood plain). The siltstone exhibits an apparent moderate cohesion under dry conditions whereas, when saturated, the material tends to disaggregate completely. This is due, as demonstrated by mineralogical and petrographical analyses (Margottini, 2004), by the absence of cement in the matrix. All lithotypes forming the slope are variably jointed.

2. Geomorphological analysis

Bamiyan is located at 2,540m elevation on the N edge of the 600-km-long EW valley along the Herat fault, at the confluence of three different rivers. The flood valley is mainly formed by fluvial (alluvial and alluvial fans) and slope sediments (landslide and slope deposits). Its evolution is related with various factors such as lithological characteristics, tectonic activity, palaeoclimatic events, river and slope evolution in the cliff. The cliff where the Buddha statues are located presents a general E-W orientation an average slope inclination of ca. 85° and a total length of approx. 1,350m. The cliff can be divided into two distinct sectors: the western side, where the West Giant Buddha statue is located, shows a N65°E orientation with a length of approx. 820 m, whereas the eastern portion, where the East Giant Buddha is placed, exhibits a N95°E orientation and a length of ca. 525 m. The two segments are separated by a large alluvial cone generated by two distinct torrents flowing into the Bamiyan river, still very active, that have diverted the river flow towards SSE. The change of orientation from EW to NNE-SSW occurs in correspondence of the torrent located at E. This configuration is likely due to tectonic activity regarding the Herat fault system and local faults oriented NE-SW.

The reconstruction of the geomorphological activity in the Bamiyan valley was developed with detailed field surveys integrated with a kinematic analysis on 18 distinct sectors of the cliff in order to define active and potential landslide types. In general terms, in the area the following active processes have been recognized:

- Water infiltration from the upper part of the cliff;
- Gully erosion in the upper catchment area and along the slope face;
- Accumulation of debris sediments at the toe;
- Mud flows;
- Toppling and rock-falls involving some isolated blocks;
- Rock-sliding along pre-existing joints;
- Active deformation processes with progressive opening of joints in the external part of the cliff.

Fig. 2 Debris accumulation (left) and gully erosion on the slope face of the Bamiyan cliff

Some processes, e.g. rock-falls and stress development along joints are affecting the niches of Buddha statues, accelerated also by the explosion of March 2001 that destroyed the statues. The Eastern Giant Buddha niche exhibits, at present, the most critical stability conditions. Recently, this area has been partly stabilized with urgent mitigation works. In the Western Giant Buddha site major effects were the collapse of the statue and the consequent instability of the back side of the niche.

Landslide deposits are diffusely outcropping along the slope toe, generated by rock falls and toppling of large conglomerate and siltstone blocks with modest run-out also evidenced by their typical sharp-edged shape. Block volumes vary from $<1m^3$ to $>10m^3$. Planar sliding deposits are diffusely outcropping at the base of the cliff and somewhat immersed and/or partially covered by the debris.

The top of the cliff, as well as the outer walls, are largely affected by diffuse and intense erosion of conglomerate and siltstone, especially in the western side of the cliff. This produces gully erosion that is the typical landform that outcrops in the slope face and in the upper parts of the Buddha cliff.

The concentration of gullies is very high in the very small basins located on the top of the cliff area, especially along the steep slopes of those tributaries creeks that form active debris cone when flowing into the Bamiyan valley.

The easily erodible soils with a weak structure like those forming the Bamiyan cliff, the absence of vegetation as well as climatic conditions of the area are prominent factors in accelerating this type of phenomenon in the catchments located on the back of the cliff, with a typical retrogressive activity.

Recent and past landslide activity and soil erosion are the consequence of climate fluctuations that occurred in Central Asia from Late Pleistocene up to present (Esper et al., 2002; Kamp et al., 2004; Bush, 2005).

Considering the main geomorphological features briefly described above and the long-term evolution of the cliff vs. climate and tectonic activity, three main stages have been recognized (Delmonaco & Margottini, 2007) and briefly described.

Stage 1: At the end of the last maximum glacial (13,5 ky BP) the rock slope experienced development of vertical cracks and deep rock sliding phenomena due to the deepening of the valley. This resulted in straining of rocks and development of parallel cracks and joints with E-W orientation. The intersection of this system with the one linked to the tectonic stress, oriented at S (dip direction) generated deep rock sliding phenomena affecting conglomerate and siltstone layers at the base of the cliff. Old landslides, mostly in inactive or quiescent state of activity, occurred before the human exploitation of the slope as demonstrated by stable caves excavated in the landslide body. Nevertheless the presence of two caves with evidence of displacement reveals the occurrence of rock slides at least after the 5-6th century AD.

Stage 2: The sea level rise after the cold peak terminated in the Early Holocene promoted large deposition of debris and alluvial sediments. The reduction of the potential energy in the slope and a consequent decrease of stress conditions concentrated at the slope toe changed landslide kinematics in the Bamiyan cliff from deep landslides to toppling-sliding failure mode that are affecting the middle-high sectors of the slope.

Stage 3: The so-called Little Ice Age (15th -19th centuries AD), with more humid conditions than present, have promoted an increase of erosion and debris production from the upper catchments especially in the western sector of the cliff. In the middle of the slope, where the two segments of the cliff with different orientations converge, the most active areas of debris production outcrops, evidenced by the coalescent debris cones that have diverted the flowing of the Bamiyan river through SSE. At present, arid climate conditions with low annual rainfall amount and concentrated precipitation promote deep erosion of loose sediments (e.g. gullies), mud flows along the channels and water infiltration inside the slope materials causing decrease of cohesion along the joints and acceleration of toppling/falling processes.

3. Landslide kinematic analysis

Structural setting analysis and potential instability failure modes of the slope-forming rocks has been undertaken in June 2007 in order to provide a preliminary sketch on potential morphological evolution of the cliff.

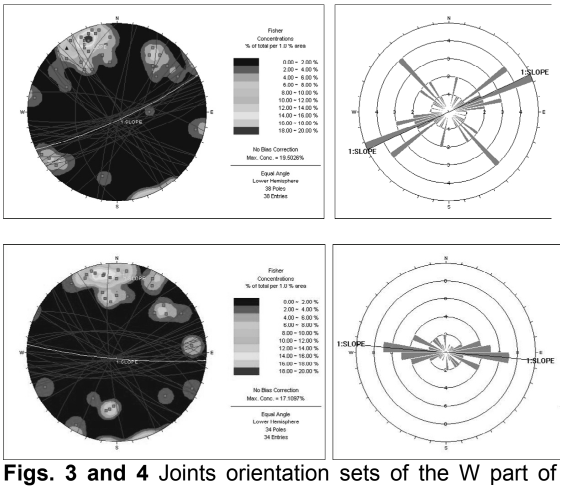
The angle for most of the rock face is approximately 80°-88°. The outcropping soft rocks present prominent discontinuity sets whose origin, especially the joint system parallel to the slope face, can be associated to the geomorphological evolution of the valley as well as to tectonic setting (Ambraseys and Bilham, 2003).

This situation has caused apparent slope instability phenomena, somewhat aggravated by the explosions during the destruction of the Buddhist statues in 2001 around the niches areas. A total of 17 structural stations were selected by visual inspections in the areas of the cliff where historical structures (e.g. Buddha niches, external and underground caves) display prominent or potential instability conditions (Table 1).

Table 1 List of structural stations with orientation and global localisation

SITE ID	Dip Dir. (°)	Dip (°)	Location
Station 1	141	86	N34°49'44,1" E067°49'02.2"
Station 2	141	86	N34°49'47,3" E067°49'07.6"
Station 3	158	82	N34°49'47,4" E067°49'09.1"
Station 4	155	82	N34°49'47,5" E067°49'10.7"
Station 5	164	81	N34°49'47,7" E067°49'11.0"
Station 6	162	80	N34°49'49,1" E067°49'14.3"
Station 7	162	85	N34°49'51,0" E067°49'17.6"
Station 8	153	88	N34°49'51,4" E067°49'21.7"
Station 9	153	85	N34°49'51,8" E067°49'23.5"
Station 10	157	84	N34°49'54,8" E067°49'29.8"
Station 11	189	88	N34°49'54,5" E067°49'31.9"
Station 12	178	85	N34°49'54,1" E067°49'33.3"
Station 13	185	83	N34°49'53,3" E067°49'38.5"
Station 14	167	86	N34°49'52,9" E067°49'40.3"
Station 15	164	85	N34°49'53,3" E067°49'42.2"
Station 16	192	82	N34°49'53,2" E067°49'46.2"
Station 17	198	88	N34°49'52,9" E067°49'47.9"

The main joint orientation data in each observation point was represented with the Schmidt equal angle stereonet and rose diagrams. For the selected stations, kinematic analyses have been implemented to estimate the potential failure modes (toppling, plane and wedge sliding), that may develop along the slope. This was divided into two main sectors: W sector, where the Western Giant Buddha is located (stations 1-10) and the eastern side that includes the area of the Eastern Giant Buddha (stations 11-17). The two sectors displays different orientations, respectively 155/85° and 185/82°, due to tectonic effects (Figs. 3 and 4).



Figs. 3 and 4 Joints orientation sets of the W part of Bamiyan cliff (stations 1-10, above) and of the E part of Bamiyan cliff (stations 11-17, below) represented through stereonet (left) and rose diagram (right)

The toppling analysis has provided the following results (Fig. 5) considering a value of $\phi'=30°$ along the joints in siltstone materials, as the weaker lithotypes where higher stress condition can develop.

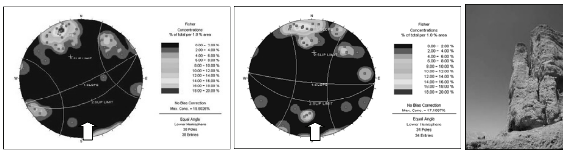


Fig. 5 Results of kinematic analysis for toppling for W side (left) and E side of the cliff (middle); the arrows show the region where toppling is possible (between slip limit and lower stereonet border). Toppling evolution in the cliff (right)

In general, the toppling potential seems to be higher in the W part of the cliff, especially in potential remobilized volumes. In the E side a potential toppling failure mode exhibits minor potential volumes involved due to a higher density of fractures in the jointed mass that presents, as well, a higher number of joint sets.

The stereographic analysis for planar failure is shown in the Fig. 6.

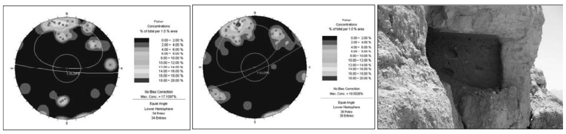


Fig. 6 Results of kinematic analysis for planar sliding for W side (left) and E side of the cliff (middle); the arrows show the region where planar sliding is possible (inside the slip limit area and the upper friction cone line). Planar rock-slide involving an ancient cavity (right)

Planar sliding is highly potential in both sides of the cliff, also as a secondary movement connected with toppling failure, that, factually, determines the sliding of vertical blocks previously deformed following a typical toppling evolution. This occurs especially when the "pivot" of the block is located inside a siltstone layer where the major stress is concentrated. In that case the evolution of failure is that typical of a sliding, sometimes with the development of circular-shaped rupture surface in cohesive materials (Mohr-Coulomb behavior of weak siltstone).

Kinematic analysis for wedge failure is shown in Fig. 7.

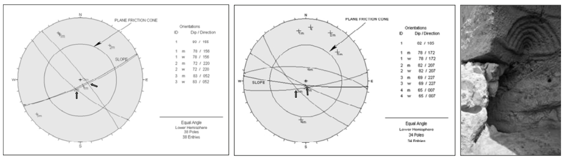


Fig. 7 Results of kinematic analysis for wedge failure for W side (left) and E side of the cliff (middle); the arrows show the intersections of planes that may cause sliding inside the potential area (crescent shaped region between slope limit and lower friction cone). Potential wedge sliding along the cliff (right)

Major planes have been selected with the Terzaghi weighted mean statistical technique.

In the W side, wedge failure is possible in rock blocks delimitated by joints 1-2 (oriented respectively158°/76° and 220°/72°) and 1-3 (158°/76° and 052°/83°). In the E side wedge failure can be promoted by joints 1-2 (172°/78° and 207°/82° oriented) and joints 1-3 (172°/78° and 227°/69°). It can be affirmed that in the W portion, since the most important system is the discontinuity oriented parallel to the slope, this kind of failure mode is very difficult to occur, since this system primarily produces rock falls and toppling phenomena. As a matter of fact, no special evidence of wedge potential, although theoretically possible, has been surveyed in this area. On the contrary, the E side has shown wide sectors of the slope where wedge failure has been detected, especially in the lower parts of the slope where siltstone is prevalent, although this kind of failure mode can mobilize small volume of rocks due high frequency of discontinuities.

According to the main geomorphic processes reconstructed in the Bamiyan cliff, a geomorphological map has been produced (Fig. 8).

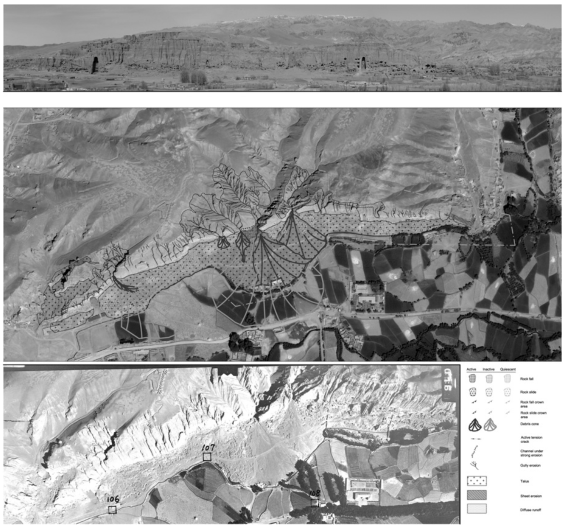


Fig. 7 View of the Bamiyan valley (upper) and geomorphological map of the cliff where the giant statues of Buddha are located. The distance between the niches is 790m. The lower aerial photo is the first image of the Bamiyan valley (late ’60)

The geomorphological investigation carried out in Bamiyan on the cliff where the giant statues of Buddha are located has evidenced that several active processes are affecting the area. Intense erosion is mainly affecting the upper part of the cliff and the slope face whereas landslide processes are involving different sectors of the slope. According to kinematic analysis undertaken in the structural stations detected along the cliff of Bamiyan, the slope may experienced, as in the past, toppling, planar sliding and wedge failure, although with distinct perspectives.

Planar sliding is the most diffuse failure potential both sides of the cliff, although most of the movements have occurred in the past. This failure type can be considered as the secondary movement type after toppling evolution of unstable blocks, especially when the failure surface is located inside siltstone layers. Toppling of rock blocks is equally diffuse and may be considered the most hazardous landslide type for all the cliff, even if in the W side it can be expected a higher magnitude of events with respect to the E part of the cliff. Wedge sliding is potentially developing in both parts of the cliff. Nevertheless, the structural conditions suggest that this type of movement is more probable in the eastern sector, characterised by high potential frequency and low magnitude of events, as also surveyed during the field mission of June 2007.

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Climate Change and Slope Stability Forecasting in the UK - An Overview of Research Needs

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Abstract. The relationship between climate and pore pressure regimes in slopes is complex and currently not fully understood. Key processes include interactions between vegetation and climate (i.e. type of vegetation and growth patterns), and between the vegetation and soil (i.e. moisture removal leading to soil desiccation and cracking, and formation of zones of increased permeability). Because of the complexity of the system it is not currently possible to model these processes reliably so that long-term slope stability variations can be predicted, appropriate solutions can be designed and efficient slope management can take place. However, good information is now available for climate risk management; uncertainty is therefore not a reason for inaction and climate risks should be embedded into mainstream decision-making. The probabilistic forecasts that are to be delivered as part of the UKCIP08 programme (delivery in late 2008) are a key development enabling further integration of climate and slope stability models. To make full use of this potential for integration it is required to further develop the slope modelling capacity.

Keywords. Climate change, landslide forecasting, slope stability modelling

1. Introduction

It is now widely accepted that climate change is occurring. The headline messages from current climate forecasts for the UK (UKCIP02) include wetter winters, warmer and drier summers, and changes in the nature of precipitation (Table 1; Hulme et al., 2002). Current relatively extreme events are likely to become the norm in the future. Temperature and, in particular, precipitation form significant drivers determining the stability of slopes. For example, the winter of 2000/1 was the wettest on record in some parts of the UK and rainfall caused more than 100 slope failures in natural and constructed slopes in Southern England alone. Heavy rainfall was also to blame for extensive slope failure affecting infrastructure in Scotland in 2001 and 2004 (Fig. 1; Winter et al., 2007; Dixon et al., 2008; Glendinning et al., 2008).

Despite observed slope response to extreme precipitation events, it has not yet been possible to achieve a clear picture of the overall effect of climate change on the stability of slopes using model studies. For slopes where stability is controlled by pore water pressure, the direct and indirect consequences of climate change will be important. One of the driving mechanisms in the UK for further work on long-term slope stability has been the realization that climate change may significantly affect the performance of constructed slopes, in particular those related to infrastructure. Failure mechanisms may change; some sites may become higher risk areas and increased seasonality may have serviceability consequences (Figs. 2 and 3).

Table 1. A selection of headline messages from UKCIP02 (Hulme et al., 2002; Dixon et al., 2007).

Higher temperatures, with regional and seasonal variation
By the 2020s: annual warming of between 0.5°C and 1.5°C by the 2050s: annual warming of between 0.5°C and 3.0°C greater summer warming in SE than the NW of the UK greater warming in summer/autumn than in winter/spring very high summer temperatures occur more frequently
Changing patterns of precipitation
wetter winters, up to 15% (2020s) and up to 25% (2050s)
drier summers, up to 20% (2020s) and up to 40% (2050s)
heavy winter downpours twice as frequently by the 2080s
significant decreases in snowfall
Changes in other variables
the number of winter storms could increase from five (the 1961-90 average) to eight by the 2080s
soil moisture in summer and autumn to reduce significantly across the UK, with the largest reductions - between 20% and 50% by the 2080s - in the south and east.

Triggering of slope deformation may generate form responses that significantly alter future threshold transgressions. Whether, in certain cases, a meta-stable dynamic system needs to be applied can be assessed by comparing the modelled responses to climate change using variable levels of sensitivity in this kind of system, with outcomes predicted on the basis of steady state assumptions of trigger and form response. The importance of including these more complex responses has already been illustrated by studies such as those of van Beek (2002), and many publications reporting on the research outcomes from large European funded programmes investigating the links between climate change and slope stability (including EPOCH: Temporal occurrence and forecasting of landslides in the European Community – see Geomorphology, issue 15; its follow-up TESLEC: The temporal stability and activity of landslides in Europe with respect to climatic change – see Geomorphology, issue 30, and RESPONSE: responding to the risks of climate change on the coast (e.g., McInnes, 2006). On the basis of observations that broadly the average annual moisture availability will decrease (following increases in temperature, evapotranspiration and decreases in average annual precipitation), it can be concluded that it is likely that there will be a reduction in landslide risk over time (see, for example, Dixon and Brook (2007)). However, other factors including increased seasonality, the effects of vegetation, shrinkage cracks, material availability, and pore pressure variations may yet prove to provide significant influences changing these trends. Thus, significant uncertainties remain and this compromises the reliability of the scenarios describing the slope failure conditions. At present, correspondence of the model outcomes with some future observation of slope failure may be based on coincidence rather than process model relevance. Because of the complexities, it is not yet possible to quantify the effects of climate change on long-term slope stability. In order to improve forecasting capabilities there is a need to concentrate on research filling in the gaps. For example, efficient asset management of infrastructure earthwork slopes relies on reliable assessments of long-term slope behaviour to formulate appropriate design solutions and efficient maintenance strategies (Dixon et al., 2008).

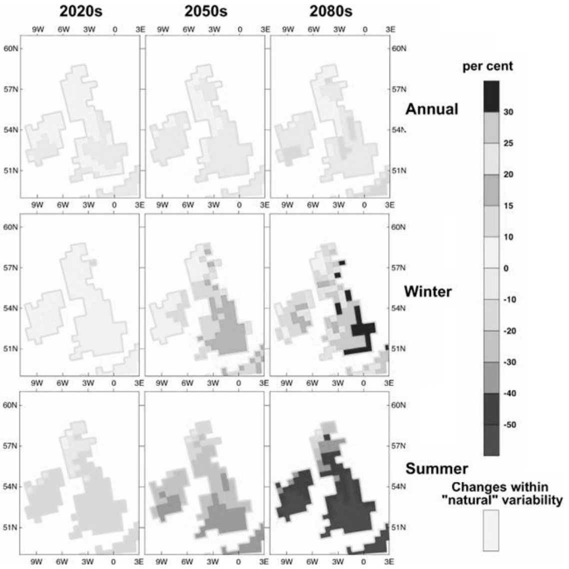

Fig. 1. UKCIP02 'High Emissions' model outcomes for precipitation changes in three time slices – the 2020s, 2050s and 2080s (modified from Hulme et al., 2002). Regional and seasonal differences are clearly visible.

Many observations on the generics of slope instability are derived from the study of natural slopes. Despite obvious differences between natural and constructed slopes, there is significant scope for knowledge transfer from natural slope investigations to earthworks stability research.

2. Research needs to improve forecasting capability of slope stability variations driven by climate change.

Significant deterioration of slopes (in term of both serviceability and ultimate limit states) is plausible. Drier summers are likely to lead to more and more frequent summer settlement. Wetter winters are likely to lead to more and more frequent winter failures. Higher evapotranspiration is likely to lead to a reduction in infiltration and more intense rainfall is likely to lead to less infiltration and more run off. The consequence of these observations is that failure mechanisms may change. Different sites (more permeable ones?) may become higher risk areas. Increased seasonality may have swell/shrink consequences. There are likely to be more frequent washout events, and issues of flooding, scour and erosion are more probable. In addition, the importance of cracking – high permeability and low strength – at end of summer conditions is an issue that needs careful consideration. To fully understand the conditions at a site it is therefore important to address all key risk assessment factors.

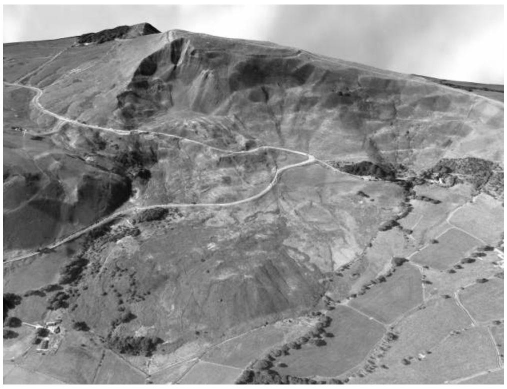

Fig. 2. Digital elevation model of the Mam Tor landslide in central UK. Long-term instability forced closure of the road (see Dixon and Brook, 2007; Walstra et al.; 2007).

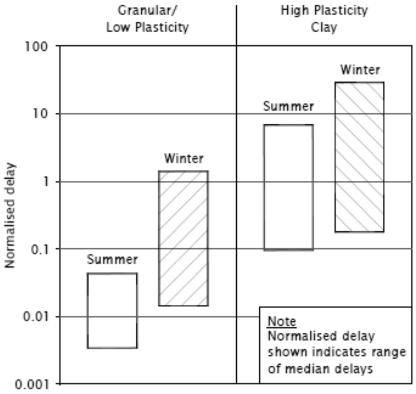

Fig. 3. An illustration of the importance of plasticity on the performance of railway earthworks (O'Brien, 2007).

Whether these scenarios are likely to occur requires further research. Due to the episodic nature of slope stability events and a lack of understanding of parameters and processes to which these events respond, current levels of uncertainty are so great that forecasts are still effectively meaningless. There is therefore an urgent need for further research to achieve a better understanding of the pathways to failure that both natural and constructed slopes are subjected to. In the following sections some key areas are highlighted.

2.1 Soil parameters

Spatial and temporal (including strain dependency) characterization of soil properties is required in some detail to provide a basis for the establishment of slope models capable of useful integration with climate change forecast models. Plasticity is generally well addressed, but characterisation of shear strength requires further work. Issues of variability and uncertainty for many geological strata and derived fills remain and there is a need to upgrade strategies for obtaining input parameters and their calibration/validation. This requires sites and long-term data sets. The opportunities offered by probabilistic approaches in geotechnical analysis, in particular, could be very useful for better incorporation of probabilistic outputs of UKCIP08 climate change models.

2.2 Characteristic properties

It is important to determining site scale deviations from general characterizations to capture local deviations from regional trends. This includes a closer look at deviations from the general stress field to identify locally overstressed zones, "hidden defects" such as previous failures and granular pockets, variations in compaction and permeability contrasts, effects of drainage, etc. Characterisation of permeability, in particular near the surface, and the links with infiltration, soil moisture deficits and pore pressure variations in the slopes are key to understanding slopes (see Smethurst et al 2008 in these proceedings). Historical datasets need to be collated to answer some of these questions, but, probably more importantly, considerable research is needed to test hypotheses in the field.

2.3 The effect of vegetation

The effect of vegetation is generally poorly addressed in site investigation and project development. This research would benefit from more accurate measurements (and extrapolation) of vegetation related pore pressures regimes, and would lead to more complex "real" scenarios of long term slope development that should include the effects of cracking (a process that is likely to be much more prevalent in the future). More work is also needed to fully understand the effects of vegetation removal on stability, in terms of soil type, permeability and type of vegetation. In terms of soil-vegetation interaction the BIONICS test bed site should provide important additional data, however additional test bed sites (especially for high plasticity clays) are required (see Glendinning et al., 2008 in these proceedings).

2.4 Key critical climate scenarios and the integration into a systems model.

Model building needs to incorporate the observed seasonal and short term behaviour of pore water pressures in slopes to create non-steady state systems which can then be simulated with sequences of possible future climate scenarios relevant to the long-term responses of slope systems. Once a better, formalised, set of scenarios of climate-vegetation-slope interactions has been developed, it is required to develop flexible models based on UKCIP08 probabilistic outputs of climate change. In turn, this could then lead to the development of solutions for the optimum design and management of slopes. The probabilistic forecasts delivered as part of UKCIP08 are promising, but it is questionable whether the geotechnical community is ready to implement this data on a large scale into the modelling of long-term slope stability.

2.5 Long-term monitoring - an example from Northern Ireland

Elevated as well as pore-pressure cycling are both responsible for decreases in soil strength and the stability of slopes (Potts et al., 1997). Recent studies in Northern Ireland have been directed towards investigating the effects of rainfall events on the long term stability of cuttings on both railway and road infrastructure. Cuttings in glacial till have been investigated by Queen's University Belfast in detail and long-term monitoring of near surface pore pressure changes have been recorded and correlated with rainfall events (Hughes et al., 2001; Clarke et al., 2005).

Climate change in Northern Ireland is characterised by greater inter-annual variation in precipitation and evapotranspiration, with minimal overall annual variation. This inter-annual variation has caused more extremes in weather, and more prolonged dry and wet periods.

The current and future increase in frequency of extreme events will have detrimental effects on the long term stability of slopes. If the magnitude and frequency of both climate events and pore pressure responses increase, there will be a subsequent increase in the number of progressive slope failures. Pore pressure response to rainfall is a function of initial soil moisture conditions, rainfall intensity, time, slope permeability and slope depth. The relative importance of these parameters is being evaluated at 3 sites including a site of a major road cut through a glacial till deposit (drumlin) at Loughbrickland, Northern Ireland (Fig. 4).

Fig. 4. Loughbrickland, NI, site photograph (10-2004).

Installing piezometers that will survive for very long periods (e.g. 10 to 20 years) and monitoring pore pressures over the full range of conditions (i.e. prolonged wet winter to dry hot summer) is crucial in assessing the long-term stability of slopes. The monitoring data from these pore pressure observations can be used to assess the stability and serviceability of earthworks and prioritise these for remediation. The experimental programme at Loughbrickland Drumlin is providing preliminary insights into the factors influencing the groundwater flow system and the interaction between climate and pore pressure dynamics.

Antecedent rainfall is one of the crucial factors in determining the initial soil moisture conditions and subsequently the pore water response to rainfall. Figure 5 shows the pore pressure responses to rainfall events, clearly indicating the significant time lag that increases with depth.

The occurrence of pronounced groundwater peaks rapidly following precipitation events is greatly dependent upon the initial groundwater conditions. The 1m unsaturated zone between the phreatic surface and ground surface remains at a high level of partial saturation, and therefore only requires low levels of rainfall to cause significant pore pressure responses. For example, the near surface layer with a water content of approximately 25% and a porosity of 35% only has 10% volume available to reach saturation. An infiltration of 100 mm will therefore lead to a tenfold increase in pressure head.

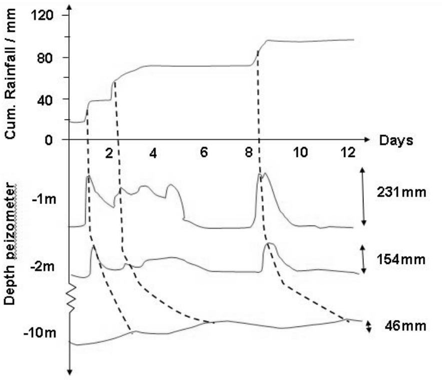

Fig. 5. Pore pressure responses to rainfall in the Loughbrickland Drumlin.

3. Conclusions – the role of networking and effective communication

Good, solid, 'old-fashioned' models have worked well thus far. If forecasts indicate change in slope stability, the underpinning science must be robust enough to convince slope managers that they need to change their management strategies. Many research groups are working on aspects of the problem, but poor communication between groups involved in research, consultancy and the stakeholders thus far has limited the potential benefits of cross-fertilisation. CLIFFS (CLimate Impact Forecasting For Slopes) is a UK-wide network based at Loughborough University providing a forum for all groups involved in this multi-disciplinary field. The network is funded by the UK Engineering and Physical Sciences Research Council (EPSRC) and information on the network and downloads of the contributions to the various workshops can be obtained from the website at cliffs.lboro.ac.uk. Since its inception in 2006 CLIFFS has seen its membership grow to some 140 people, more than half of whom participated in the CLIFFS symposium in February 2008.

The workshops allowed the sharing of expertise and ideas and have been used, among others, to formulate research questions, to keep stakeholders informed, obtain guidance from them on priorities and address specific issues raised by the end user community. Interaction between the network members has identified key areas for further addressed in this paper. At present these areas still suffer from a significant degree of uncertainty and further work is needed to reduce this. Even though it is important to be able to live with uncertainty, too much of it obfuscates the decision-making process.

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The 3 June 2007 Landslide in the Valley of Geysers, Kamchatka

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Abstract. The largest geological catastrophe of the year 2007 on the territory of Russian Federation occurred in the Valley of Geysers on the 3rd of June on Kamchatka. The spur (791 m height) collapse in the basin of one of the Geysernaya feeders resulted in the 20 million m3 rocks slide, the mudflow into the Shumnaya River valley and the dam and the dammed lake in the lower part of the river formation. Several large geysers were destroyed or flooded. We observed the alteration of the surface thermal regime in the Geysernaya hydrothermal system, small landslides along the lake banks resulted in thermal zones and hot springs migration. The paper discusses some results on the catastrophe consequences: possible reasons, current processes during and after the landslide.

Keywords. Valley of Geysers, landslide, dam, mudflows, lake, equi-plane, thermal anomalies.

Main events

The Kamchatka geysers are located in the 4 km long canyon-shape valley of the Geysernaya River that drains the east border of the Uzon-Geysernaya volcano-tectonic depression. Numerous streams form riverheads of the Geysernaya river till the confluence of Mutny and Prozrachny brooks into a single bed and come slightly into the surface of Kihpinych volcano edifice. But the river forms narrow canyons right in the confluence zone and traps the volcanic plateau 50-70 m deep. The depth and width of the valley increase gradually and within the Tsentral'noye geyser field they are 700 m and 3 km respectively (Fig.1).

Fig.1 Kikhpinych Volcano (at the left side of photo), canyon-shape the Valley of Geysers (in the center), and the Landslide (on the right) – arena of events mutually connected and pressed in time in the beginning of June, 2007.

The left part of the valley is broader. It is formed by steeps of Gornoye plateau (its brow is 800-900 m altitude) in the beginning, but then degrades smoothly to the bed. The Verhne-Geysernoye thermal field zone gives evidence to this degradation. This slope is characterized by intense soil slips. The latest landslide (before 2007) likely occurred in 1986, in the fall time.

The spur (791 m height) collapse that occurred in the basin of the Vodopadny stream (the left feeder of the Geysernaya River) resulted in the large landslide 3 June 2007 (Fig.2).

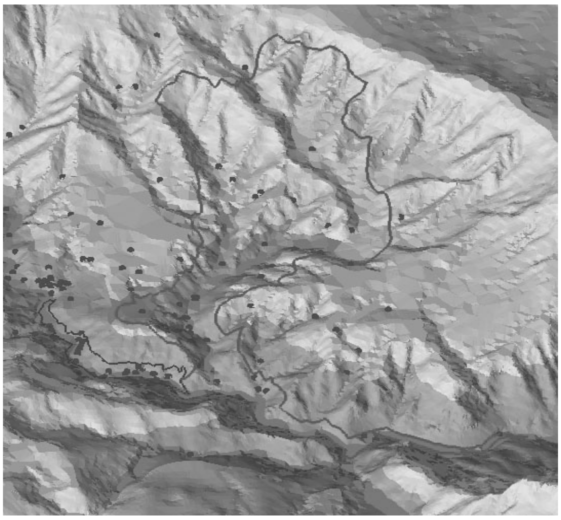

Fig.2 Head water of Vodopadny stream - a zone of formation of a landslide and accompanying events (3d - model) center of zone is allocated the body-2 (allochthon). Blue points - hot springs and geysers. A red line - a contour of the area captured by a landslide. The “equi-plane” crest is seen in the center.

Its deposits blocked the Geysernaya River and resulted in formation of the dammed lake. The lake has been flooded 4 days later and on 7 June the water started to overflow through the dam. After 4 hours the river made a new bed in the dam and the water level lowered on 9 m and the maximum lake depth comprised 20 m (on echolocation date). Several large geysers were destroyed, several others occurred in the flood zone; small landslides went down the bluff shores of the lake, new short-life thermal springs were formed.

The landslide was formed in the result of two collapses(Fig.3). First, the spur (791 m height) in the form of so-called equi-plane (Geological dictionary, 1973) (body 1) collapsed and formed main landslide deposits down the valley. Then, the adjoining southwest spurs (body 2) went down to the free from the main spur area (Fig.4).

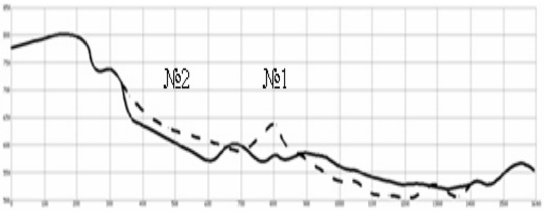

Fig.3 Vodopadny stream valley longitudinal profile. The dotted line means the surface before the landslide, the firm line means the surface after the landslide (profile along the axis of movement).

Fig.4 Perspective view on formation zone of the landslide in a combination with 3d-model. The body-2 (allochton), which is the second part of a landslide, is allocated in the center of this zone.

Table 1 gives the results of photogrammetric processing of aerial photographs on 23 August 1993 and 12 June 2007 for the territory suffered by the landslide.

Table 1. Quantitative characteristics of the 3 June 2007 landslide

Type of deposites	Volume (m^3) or area (m^2)
body 1 volume (equi-plane)	12,240000 m^3
body 2 volume (allochthon)	4,760000 m^3
Deposit volume Dike volume Underwater part of the dike Total volume of mudflows	20,750000 m^3 4,160000 m^3 **760000 m^3 305000 m^3
Area of deposits	~1,000000 m^2
Area of Lake surface on 2007 July, 7	76000 m^2

Discussion

On the geological map (Fig.5) we can see that the Vodopadny brook head formed in ancient lake deposits. Leonov (2008) shows that the interdigitation of solid rocks and less solid rocks, altered under hydrothermal conditions. Permeable and impermeable layers interlay. All these factors along with the strata inclination in the valley and the fractures favour the landslide formation.

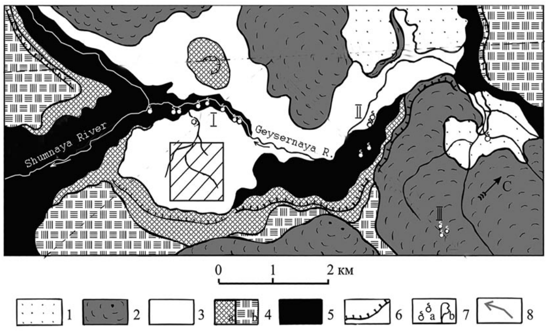

Fig.5 Schematic geological map of Geysernaya river basin. 1 - lake deposits (age of 9-12 thousand years); 2 - dacitic, rhyolitic lavas; 3 - lake deposits (age of 20-35 thousand years); 4 - lavas of an onboard complex (a), pumices, ignimbrites, age of 39-40 thousand years (b); 5 – precaldera deposits; 6 - erosive ledges; 7 - thermoanomalies. The basic thermal fields: I - Geysernoe, II - Verkhne-Geysernoe steam jets, III - Kikhpinychskoe. A rectangular - area of a landslide 2007. (Leonov 2008)

Events shows there are numerous factors that favoured the Geyzer valley landslide formation. But the valley suffered the landslide even earlier in the beginning of Holocene. It occurred on the eastern slope of Krugloe plateau and dammed the Sestryomka river resulting in a lake formation with the diameter equal to the lake formed in the Geyzernaya river in 2007. If analyze the present situation in Geysers valley, we may conclude that the severest landslides are formed here in the low part of the Geysernaya and Sestryonka rivers. This is the place where the rivers' valleys are the deepest and have the steepest slopes.

Various factors may have caused the landslide in Geysers valley (Varns 1981, Zolotaryev 1983). According to the previous data on geology and hydrogeology of the region, we can distinguish the following major factors:

1) Geological position – allocation near the caldera edge. The caldera has enclosed and attached to its edge lacustrine deposits occur with a tip to the Geysernaya river valley.
2) Hydrothermal unload peculiarities – the thermal fluids are located to the east from the upwelling zone. A lateral flow of thermal spring goes from NE to SW toward the Geysernaya river.
3) The peculiarities of rock sections suffered the landslide are the permeable and impermeable layers.
4) The slope morphology – steep slopes caused by brook washing.
5) The rock alteration caused by hydrothermal activity.
6) Tectonic structures.

Precursors*

Neither precursors nor triggers were recorded prior to the event since there have been no recent observations carried out in the Valley. The only report was from a reserve ranger Zlotnikov V.A., which smelled hydrogen sulfide a day prior to the event when he was going down the valley of Vodopadniy stream in the landslide zone.

The diagram of relative 3D tidal deformation shows the time of the landslide that occurred in intra-month maximum (Fig.6). The 1st body plane of rapture goes through the fissure tracing the volcano-tectonic fault in submeridional direction. Aerial photos revealed this fault in 1973.

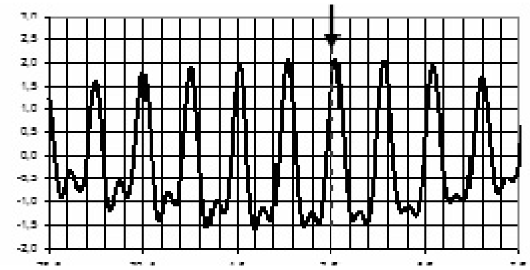

Fig.6 The diagram of relative 3D tidal deformation shows the time of the landslide that occurred in intra-month maximum.

Thermal anomalies

The collapse in zone of the spur break off (791 m height) was accompanied by a large steam plume. The flow contained portions of heat rocks, they kept teaming long after they had stopped moving. The heat rocks were penetrated in the zone of the landslide formation. Now this zone shows the formation of a new thermal anomaly. The thermal anomaly is projrcted on the cliff plane of the body-1.

The rock redeposition caused by the landslide generated heat sufficient for keeping high temperature (to 60°C) in Vodopadny stream as long as one month after the event. A half-year later the water temprature decreased to 7,8°C.

Some peculiarities of the landslide

The collapsed rocks that form the landslide body are represented chiefly by Upper-Pleistocene lake sediments and loosely cemented tuff. The flow may be classified as a large-block, though scientists have not measured the fractal size. The large blocks are several meters in lateral dimension. The recent flow obstructed the way due to the water-bearing filling material of the flow. The eyewitnesses reported the flow had passed about 2 km for 2-2.5 minutes, but such data are questionable. The data probably concern just the visible upper part of the Vodopadny stream watershed that is no longer that 1 km.

In spite of the doublet character of the landslide the single collapse amphitheater was formed in the area of its origin. The body 2 formed more than 0.22 km^2 allochthon. At least in side and front parts, the landslide moved along the snow cover, involving snow into the flow. Natural obstructions significantly influenced the landslide dynamics and its deposits profile. Extrusive formation "Triumphalnye vorota" blocked the flow on the Geysernaya River and significantly increased the dam height. The Vodopadny stream surface water discharge was not yet finished. We demonstrate possible to the summer 2008 lakes distribution area on the flow deposits (Fig.7). The total water volume may comprise 400000 m^3. The greatest from this lakes can include 250000 m^3.

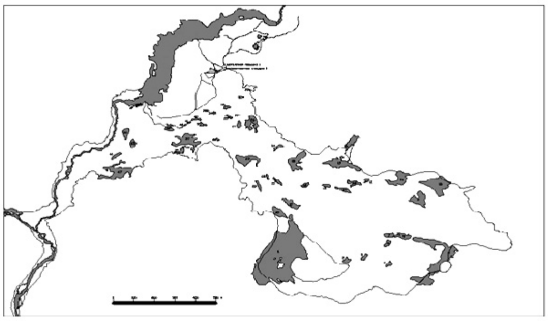

Fig.7 Predicted lakes area (marked by gray) by the time of the 2008 spring snow melting maximum.

Geysernaya River carried out fragmental material into Shumnaya River. This material deposited in the lake and increased the volume of alluvial deposits, manifested in the form of the mobile spit. On 12 July its volume comprised 5000 m3, on 10 September 2007 comprised 8000 m3. Most material was carried out during cyclones and in spring, during snow melting. The time of the lake filling up is 70 - 100 years.

Fortunately, in spite of the fact that on 3 June 2007 in the Valley of Geysers were tourists and employees of Kronotsky Reserve this grandiose natural event has done without human victims. Even the economic damage was minimal (Fig.8)!

Fig.8 The front of a landslip has approached closely to "Visit-center" of Kronotsky Reserve, having destroyed only of the electro-generator building.

Conclusions

The largest geological catastrophe of the year 2007 on the territory of the Russian Federation occurred in the Valley of Geysers on 3 June on Kamchatka. The spur (791 m height) collapse that occurred in the basin of one of the Geysernaya feeders, resulted in the 20 million m3 rocks slide, and produced the mudflow into the Shumnaya River valley and the dammed lake in the lower part of the river formation. Several large geysers were destroyed or flooded. We observed the alteration of the surface thermal regime in the Geysernaya hydrothermal system, small landslides along the lake banks resulted in thermal zones and hot springs migration. The paper discusses some results on the catastrophe consequences, possible reasons, current processes during and after the landslide.

Such landslides or even larger ones are typical for this region and explained by the caldera side, deeply opened by erosion. They are caused by: volcano-tectonic effects; lacustrine sediments thickness, depositing at an angle to the Geysernaya River valley, thermal waters circulation and so on. Today Geysernaya hydrothermal system is adapting to the altered hydrogeological conditions.

Notes:

*Regional net of the Kamchatka Branch of the GS RAS contains data on the earthquake practically concur with the landslide: 2007.06.03 01:23:34,5; with the epicenter 54.829º N, 164.051ºE, at a depth 40.1 km.Ks=6.7 (oral report of D.V. Droznin)

** On data of echo-sounding survey of T.K. Pinegina

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Catastrophic Landslides – Quantifying the Link to Landscape Evolution

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Abstract.
Rock avalanches are considered a high magnitude, relatively low frequency event in the high mountains. Rock avalanches are triggered by a number of forcing factors, rainfall, seismic acceleration, and more debatably, through the longer term the action of glacial de-buttressing, and also long term creep (sackungen). They are an extremely efficient way of linking hillslopes to rivers and relieving the landscape of tectonic derived stress. It is becoming clear that rock avalanches are responsible for large proportions of mountain erosion and have significant effects on other landscape formational processes. During emplacement rock avalanches thoroughly fragment to leave a deposit composed of predominantly sand and gravel grades, material that should be readily transported by most major mountain river systems. A complication at this stage is added by the common formation of landslide dams by rock-avalanche debris, delaying for a period of several days to millennia the dispersal of this fragmented debris. The timing of the failure of such dams results in an interruption to the evolution of the mountain landscape and valley-fill over varied spatial and temporal scales, and a geomorphic imprint that may extend into the geological record and affect landscape evolution at regional scales. The geomorphic signature of this interruption and the subsequent dispersal of rock-avalanche debris is a key issue for both hillslope and river processes with as yet un-quantified feedbacks and links to ongoing tectonics.

Keywords. Landslide, physical modelling, cellular modelling, hillslope coupling

1. Introduction

In tectonically active mountain belts catastrophic landslides are an extremely efficient mechanism of delivering large quantities of sediment to river networks. Onsite impacts of the delivery of material can range from near immediate dispersal of the input, a long-lasting point sediment source, to a full blockage as a landslide dam of uncertain persistence that can be measured in days to millennia. Much research has focussed on these immediate aspects of the coupling between landslides and the drainage network for hazard and risk (Dunning et al. 2006, 2007). More recently researchers have tried to integrate state-of-the-art fluvial geomorphology and hillslope science over a diverse range of temporal and spatial scales (for example Korup, 2005, Hewitt 2006). The key limitation for such studies is usually the timescales of interest when considering the impacts such landslide-river coupling has on the landscape. Traditionally the techniques of choice either substitute space for time and attempt to link a sequence of ‘process snapshots’ to provide a reasoned and coherent model of landscape response; or, use highly dynamic landscapes where the geomorphic lag-time is measured in years to decades. A good example of the first method is the ‘Disturbance regime landscape’ model of Hewitt (2006) that focuses on rock-avalanche deposits. Rock avalanches are a high magnitude, low frequency catastrophic landslide that are particularly effective at blocking rivers due to the mechanism of emplacement and volume of debris (Fig 1). During emplacement rock avalanche debris is fragmented into a fractal mixture of gravel and sand (Dunning 2006), so although initially forming an efficient dam with important upstream and downstream geomorphic consequences, upon breaching much of the deposit is removed through subsequent river action. It is often the geomorphic response of the landscape that persists rather than the original in-situ landslide debris. These geomorphic responses are in themselves often transitory, and often linked to multiple blockages along a river profile, hence the delimitation of a series of broad stages of landscape response in the model of Hewitt (2006).

Fig. 1 Chronic supply of debris altering a landscape for an as yet unknown period of time, the 2005 Hattian Bala rock avalanche deposit.

Utilising the rapid geomorphic and tectonic rates in New Zealand has enabled Korup (2004, 2005, 2006) to assess the impact of either pulsed (Fig. 2) or chronic (Fig. 1) supplies of landslide debris to river networks. On a short timescale (years to decades) landslide-debris coupled with valley floors has resulted in alterations to river long profiles; forced avulsions, catastrophic aggradation and degradation as a series of sediment pulses, and perhaps most importantly has shown that these processes exceed background trends by an order of magnitude.

Based on the studies briefly outlined above, the immediate question that arises is: ‘If landscapes and fluvial systems in tectonically active terrain are frequently perturbed by large landslides can they ever achieve ‘steady state’?’ Where steady state is a temporally invariant topography, a balance between uplift and erosion. Within this, bedrock or the more commonly observed mixed bedrock-alluvial rivers must transport all of the sediment being supplied from upstream, and also incise its bed at a rate equal to the tectonic uplift (Whipple and Tucker, 2002). With the large number of known events, both chronic and pulsed that exceed 'background rates of delivery', and their interpreted return periods it can be seen that the inputs can have fundamental effects on regional scales in the short term of years to decades and may persist geomorphically for millennia. It is within this framework that equipment has been commissioned to investigate the spatial and temporal impact of chronic and pulsed hillslope-river coupled debris as it is dispersed through the landscape.

Fig. 2 Pulsed supply of debris being fed into a river able to sluice the toe and disperse the material downstream, Edwards River, New Zealand.

2. Proposed methodology

To gain insight into the geomorphic response to landslide debris dispersion two methods are being utilised, microscale hydraulic modelling (herein termed MSM) and numeric cellular modelling, both to be backed with field studies for prototyping and verification.

2.1 Microscale hydraulic modelling (MSM)

Physical modelling has developed alongside mathematical approaches to understand the complex relationships between the production and transport of sediment under the influence of water. Physical models have the benefit of allowing the formation and destruction of fluvial features as a continuous process usually impossible to constrain using field investigation alone.

Hydraulic modelling is suitable to investigate a range of problems and takes a number of forms dependent upon the similarity to the prototype system required, be it a specific prototype or a generic class of geomorphic feature. The choice of modelling technique is a balance between model specificity and the scale of interest, both spatially and temporally (Peakall et al. 1996). The models offering the best replication of natural systems are 1:1 models, often used for fluvial bedforms, however, this is clearly unsuitable for the scales of interest in this study and it is more usual to compromise specificity and distort scaling. This study utilises microscale modelling, or analogue modelling, the least representative of the prototype but retaining many important geomorphic similarities that can be used to test large-scale dynamics of complex, slowly evolving geomorphic settings, or rapid systems where time needs to be compressed, things currently difficult to achieve by other means (Schumm et al. 1987, Peakall et al. 1996). Famous analogues for this approach include Stanley Schumm who '…once refused to let his daughters eat a bowl of chocolate pudding for two days, because, as it desiccated, fractures that resembled lunar features were forming on its surface' (Schumm et al. 1987, p. 1). MSM reproduces significant aspects of the form of the fluvial system, in this case the morphologic characteristics using the ideas of 'similarity of process' (Hooke, 1968, in Schumm, 1987). The real problems lie in trying to upscale these models and delimit rates of evolution, as well as the variability of natural system variability and inputs.

With these issues in mind, MSM is a useful methodology and has produced successes that directly relate to this work, notably, studies of river aggradation, (Davies et al. 2003), fanhead trenching due to landslide debris inputs (Davies and Korup, 2007), and the incision of bedrock rivers in response to bedload supply (Finnegan et al. 2007).

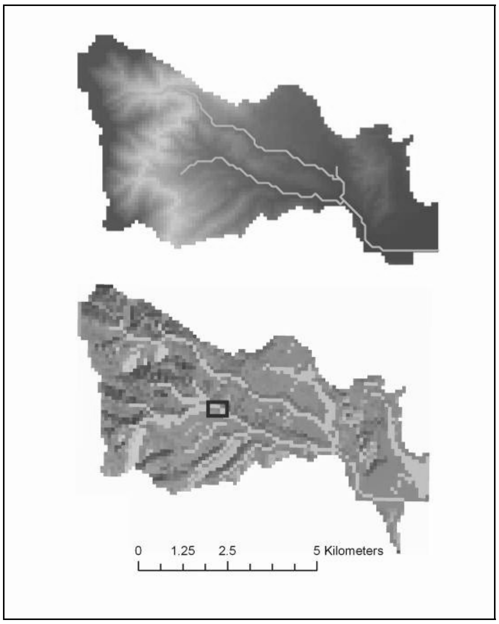

Fig. 3 (Upper) Shaded DEM of Ram Creek catchment with only the rivers draining the upland area of interest marked (Lower) Example output of CAESAR model showing the routing of a severe rainfall/flood event through the catchment, note the backwater effect due to the presence of the remnant landslide dam (square). The DEM has been rotated 180° for model convention.

The MSM modelling equipment in use has been constructed by Lincoln University, with scientific input from Canterbury University, New Zealand. The model is a 5 m x 2 m system in three modules designed so that differential subsidence / uplift can be included within model runs. Water is supplied at up to 3 l/min and sediment up to 200 g/min. What makes the model different from many is the inclusion of an overhead rainfall simulator capable of 20-60 mm/hr rates usually used for channel initiation studies. This allows the driving of hillslope-river coupling using forcing factors other than river incision and hillslope steepening / hillslope lengthening. It also has the benefit of allowing comparison of the effects of landslide blockages and landslide sediment supply on the processes above and below input sites. In the case of a conventional model of a landslide dam, no drivers of change are active below the dam site once the pumped water is stopped by the dam debris. DEMs are derived using a combination of laser scanning and white light photogrammetric techniques.

Numerous scaling issues are present in this combination of model types but morphologic similarity still holds across the model as a fully functional landsystem in own right and as an analogue to the natural system. Fine silica sand is used for the alluvial component and can form the entirety of the model or be used with a bedrock substitute, a mixture of cement, fine sand, fly ash and a flow additive (Finnegan et al. 2007) or fine sand / kaolinite mixture (Schumm et al. 1987). These bedrock substitutes can be eroded using the supply of sand as tools and has proven success in fluvial modelling.

2.2 Numerical modelling

A numerical modelling approach has been chosen as complimentory method to investigate the impact of landslide derived sediment on hillslope and fluvial systems. The code of choice, CAESAR (see Van De Wiel et al. 2007) has considerable success in simulating the reach and catchment scale alluvial dynamics within a landscape evolution model. CAESAR is a cellular automaton model that follows a set ofrules designed to represent fluvial and hillslope processes. These rules are necessarily simplifications but when iterated allow complex non-linear geomorphic behaviour and feedbacks similar to natural systems (Fig. 3). The replication of channel incision, bed armouring, lateral migration, terrace formation, and vertical stratigraphy development are the most important model outputs for this study. The ability of the model to simulate both meandering and braided behaviour is key, in many instances the input of catastrophic landslide debris triggers the change from one to the other as the sediment disperses. The models simplicity requires few inputs, useful when hydraulic model inputs are often exceptionally difficult to quantify for the systems of interest. Required are a DEM, grain sizes for the grid, and vegetation parameters. The topography drives fluvial and hillslope processes to alter the landscape by erosion and deposition. The forcing factor can be rainfall data (actual or calculated) for a drainage basin mode, or discharge and sediment fluxes for a reach mode. In addition CAESAR can model the point source input of a defined sediment of interest, the equivalent of adding coloured sand to the physical model. This feature allows the tracing of the fate of landslide debris imputed (chronically or pulsed) into the system, be it initially coupled to the fluvial network or not and so constrain the dispersion and impact of the debris to river planform and the landscape.

3. Selected prototypes

The methods outlined above, in combination with field study allow for investigation of the role landslide debris plays in altering river geomorphology, and through this, potentially alter the response of landscape to the driving tectonic when compared to catchments without landslide inputs. Initially prototypes of both chronic and pulsed sediment supply in a region of high geomorphic activity are being investigated to allow the maximum chance for model verification. One example prototype of a rock avalanche dam deposit is outlined here.

3.1 Ram Creek, New Zealand

The Ram Creek rock avalanche was triggered by the 1968 Inangahua Earthquake (M 7.2) and involved around 4.4 x 10^6 m^3 (Nash, 2003) of granitic bedrock. The material dammed the small tributary ~ 6 km upstream of the major Buller River. The drainage basin above the dam site was comparatively small and the resultant landslide dammed lake took 13 years to overtop after a period of stable inflow / seepage outflow. When overtopping took place, it was catastrophic and the resulting breach released 1 x10^6 m^3 of water and a similar amount of debris. Field investigation of the remnant landslide debris not mobilised during the outburst supports the interpretation of a rock avalanche type mass movement, the interior of the mass is highly fragmented (D_{50} as measured by Nash (2003) is 70 mm). It is estimated from regression equations that the flood wave peaked at around 1000 m^3s^{-1} in Ram Creek, resulting in the equivalent to an annual flood in the gauged Buller River downstream (4335 m^3s^{-1}). Debris was deposited over a length of ~5.5 km below the dam site though most of the debris stalled immediately downstream of the breach (Fig. 4).

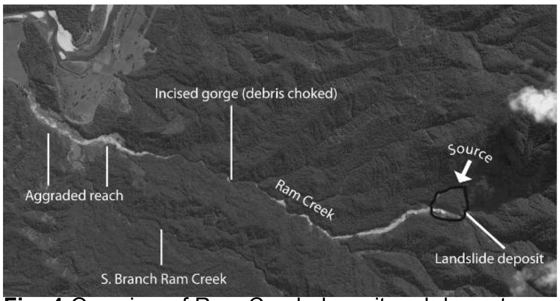

Fig. 4 Overview of Ram Creek deposit and downstream dispersal of debris since 1981 breach. Field of view is ~ 6km. Background image © DigitalGlobe courtesy of GoogleEarth Pro.

The original dispersion of this chronic supply of over 1 x 10^6 m^6 of material to the fluvial system is an interesting model prototype as it is estimated that a 2m depth of debris was deposited over 250,000 m^2 of land during several pulses of flood flow (Ben, 1990, in Nash, 2003). The future fate of this amount of sediment in a small (13 km^2) mountain catchment is a problem ideally scaled to the methods presented. The upsteam section of Ram Creek is an incised gorge (Fig. 5) typical of the west coast of New Zealand than opens out downstream into the Buller River (Fig. 4). Of interest is the reaction of Ram Creek to the immediate armouring of the gorge base and the subsequent alteration to incision and the downstream sedimentation and planform as the channel opens out, currently showing large scale aggradation. An additional factor suited to the physical modelling is that Ram Creek crosses the Lyell Fault below the dam site, interpreted to have been reactivated during the 1968 earthquake with downthrow to the west (Yeats, 2000).

3. Conclusions

Two methodologies have been presented to investigate the role that coupled hillslope-river landslide debris may have on the geomorphology of mountainous systems. The main problems encountered are validation and upscaling, essentially a model is being used to validate a model with great difficulty in testing prototype response due to the timescales involved. The methods rely on gross simplification of natural systems, but both retain similarity of geomorphic response and have proven success individually.

Fig. 5 View of the lower gorge section of Ram Creek with the landslide outburst flood sediment.

An initial set of models does not use CAESAR to test prototype DEMs against MSM modelling, it is applicable to treat the MSM model as a very controlled landsystem in its own right and use DEMs and rainfall / discharges derived directly from the model to test geomorphic response. This calibration of the numerical model against the physical model allows assessment of variation of MSM behaviour against actual DEM response in the CAESAR model and is the first step to upscaling results from both methods and allowing comparison against conceptual models of landscape response to landslide interruptions.

Acknowledgments
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Rock Slope Failures in the Italian Apennines: from Retrodiction to Prediction

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Abstract. This paper focuses on the possibility to carry out specific, predictive studies on the landslide hazard conditions in the Apennine chain starting from field evidences of past large-sized gravity-driven phenomena. Such evidences can in fact allow to frame also small events within longer evolutionary processes and, at the same time, become the key factor to calibrate the dynamic analysis addressed to the reconstruction of catastrophic landslide hazard scenarios. In this frame, we hereby present the case history of the Gran Sasso massif (Central Apennines, Italy), starting from the description of the rock-fall event which occurred on 22 August 2006, when a limestone block, with an estimated volume of about 30,000m^3, fell from the sub-vertical NE wall. Despite the small rock volume involved in the landslide, the rock fall deposits covered an area of about 35,000m^2, a giant and abrasive dust cloud was generated and determined destructive effects over an area of about 110,000m^2 at the base of the slope. Based on this evidence and on the presence of other larger unstable rock pillars, some hazard scenarios were reconstructed by means of dynamic analyses supported and calibrated by taking into account the presence in the valley bottom of some remnants of past huge landslides. As a result, it was possible to hypothesize for large rock volumes the evolution of huge rockfalls into dry granular flows able to cover long distances, due to the geomorphic control such as the presence of narrow valleys at the toe of the NE slope.

Keywords: catastrophic rockfall, landslide hazard scenario, central Apennines.

1. Introduction

The Apennines are a quite young mountain chain that formed during the Neogene-Early Pleistocene time interval and experienced several phases of tectonic uplift, that were accompanied by normal faulting. Particularly significant is the last doming-like uplift phase, which started at the time-boundary between the Early and the Middle Pleistocene (Dramis, 1992). As a consequence of the "dynamic" frame which characterized the Quaternary morpho-structural evolution, many DSGSD processes and massive rock slope failures occurred along mountain ridges. As a matter of fact many geomorphic evidence of large palaeo-landslides and DSGSDs have been widely recognized in the central sector of the Apennine belt (Gentili and Pambianchi, 1994; Galadini, 2006). In particular, the strict relationships existing between tectonic uplift, DSGSDs and large landslide events are being studied within the Central Apennines, with particular focus on the influence of the inherited structural pattern on the mechanisms of either massive rock slope failures or DSGSD processes (Bianchi Fasani et al., 2004; Di Luzio et al., 2004a; Di Luzio et al., 2004b; Esposito et al., 2007; Scarascia Mugnozza et al., 2006a). Also the sedimentological features and the elongation of the main rock-avalanche deposits as well as their effects on the environment (such as valley floor damming) were matter of specific studies (Scarascia Mugnozza et al., 2006b).

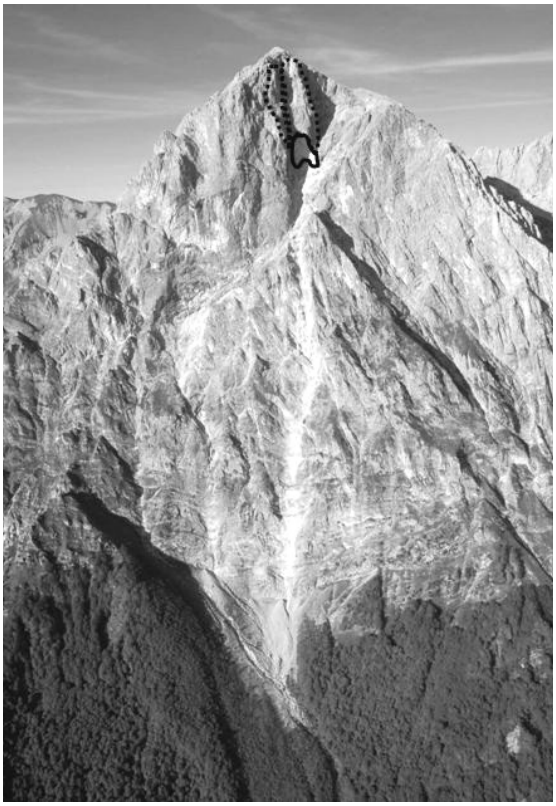

Fig. 1 Frontal view of the Gran Sasso NE slope; the continuous line encloses the detachment area of the 22 August 2006 event, the dashed lines enclose the unstable rock pillars.

Even if most of the large landslides identified and studied in the central Apennines can be regarded as paleo-landslides in the present morpho-structural and morpho-climatic conditions, the overall fabric inherited by the superimposition of tectonics and gravity forces could represent a potential factor for localized catastrophic failures, especially in the most elevated and/or steep slopes. In this view, a particularly significant case-history is represented by the Gran Sasso Massif (the highest peak of the Apennines), made of Triassic and Jurassic massive limestone and dolomite resting over relatively smooth valley slopes incised in bedded marly-limestone and sandy-marlstone. The geomorphologic pattern strictly reflects the structural setting of the area: it is featured by numerous thrust sheets, superimposed one each other during the Pliocene compressive tectonic phases: the resulting morphologic pattern of the north-eastern slope is featured by a sub-vertical "wall" (Fig. 1). Extensive historic and prehistoric rock-fall and debris-flow deposits have accumulated at the base of the wall, where some villages and important lifelines are located.

In this paper are presented results on hazard prediction relative to possible further massive rock-fall events along the NE slope of the Gran Sasso cliff.

2. The Gran Sasso event

Specific studies on this mountain area started a couple of years ago, when a rock-fall event occurred along the NE slope (22 August, 2006): a limestone block, with an estimated volume of about 30,000m^3, fell from the nearby Corno Grande peak, the highest peak of the Italian Apennines. Despite the small rock volume involved, the rock-fall deposits covered an area of about 35,000m^2, a giant and abrasive dust cloud was generated by the atmospheric pressure waves (air blast) induced by the rock-fall impact and determined destructive effects over an area of about 110,000m^2 at the base of the slope. Moreover the dust cloud covered a distance of about 3km, thus reaching the village of Casale San Nicola and the A24 motorway that was temporarily closed for security reasons (Bianchi Fasani et al., 2008) (Fig. 2).

Fig. 2 Photographic sequence of the rock fall event, showing the spreading of the dust cloud.

In the frame of this study, it was possible to preliminarily define the overall geomorphic, geomechanical and, finally, slope stability conditions along the whole NE wall of the Gran Sasso. For this purpose, data derived from direct surveys in the accessible areas were coupled to data inferred by remote techniques (such as laser telemetry), performed through devices easy to transport on steep and unstable tracks. As a result, other blocks within the rock mass prone to detachment have been recognized. Even if most of the so identified blocks have dimensions quite comparable with those of the hereby presented rock fall, it was possible to observe also some huge rock "pillars", with volumes ranging between 10^{5}m^3 and 10^{6}m^3, in potentially unstable conditions (Fig. 1). Furthermore, field surveys pointed out the presence of even large-sized (tens of cubic meters) limestone blocks ascribable to rock-avalanche deposits also in some areas downslope of Casale San Nicola village and the motorway, thus testifying the occurrence of past massive and catastrophic rock slope failures.

Based on this evidence, it is possible to hypothesize risk scenarios for both the motorway and the village. Even if the gravity-induced landscape evolution under the present boundary conditions seems to be characterized by frequent, small-sized rock fall events, the potential occurrence of massive rock slope failures involving the "pillars" under specific conditions, could evolve in a dry granular flow. As a matter of fact, the presence of deeply incised gullies at the base of the wall can represent the geomorphic "constraints" able to convey the highly fragmented debris, thus allowing a long run-out.

In order to depict the above mentioned scenarios, numerical simulations were carried out by means of DAN-3D code (McDougall and Hungr, 2005), which allowed the assessment of the run-out of potential rock avalanches. The numerical analyses were conducted by taking into account 3 possible scenarios, related to the assessed volumes of the above mentioned 3 main unstable "pillars". The presence of relict landslide deposits, which show sedimentological features ascribable to rock avalanche-type deposition mechanisms, even at distances up to some kilometers from the base of the "wall" (Fig. 3), represented an important calibration to evaluate the feasibility of the final results.

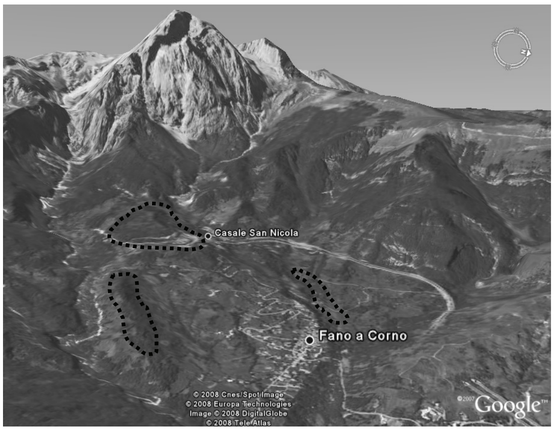

Fig. 3 Virtual 3D view of the Gran Sasso NE wall (from Google Earth); the dashed black lines enclose the remnants of the palaeo-landslide deposits.

The analyses were carried out by taking into account two different scenarios: the first one with a rockfall volume of 6.3 x 10^{5}m^3 and the second one with a volume of 1.1 x 10^{6}m^3; a Voellmy rheology was then considered for the mobilized debris. In both cases it is possible to observe long run-outs (as long as 4km), mainly due to the channeling of the debris into the valleys at the base of the slope: these results show a good fitting with the field evidence of palaeo-landslide deposits which were useful for calibration of the model outputs.

3. Conclusions

The results of the performed analyses, highlight the potential for large volume rockfalls (10^5-10^6 m^3) to evolve in mobile rock avalanches due to the geomorphic constraint represented by the narrow and deeply incised channels of San Nicola valley located at the base of the wall. Such calibrated results allow to predict the hazard conditions for some elements at risk (i.e. the village of Casale San Nicola and the motorway A24).

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Development of Landslide Monitoring and Early Warning System in Indonesia

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Abstract. Landslide is one of most major disasters in Indonesia due to the susceptibility of the region and socio-economical conditions of the country. Since 2007, a community-based early warning system has been introduced in a pilot area at Banjarnegara Regency, Indonesia. Simple extensometers and automatic rain gauge have been installed for landslide monitoring and prediction with the participation of local community. Furthermore the Asian Joint Research Project for Early Warning of Landslides led by International Consortium on Landslides (ICL), in collaboration with Gadjah Mada University (GMU) Indonesia, Disaster Prevention Research Institute of Kyoto University (DPRI/KU) and Asian Institute of Technology (AIT) Thailand have conducted a preliminary investigation and established a real-time monitoring and early warning system. The system consists of a fieldserver as its core component, which collects data from network camera, two long span extensometers, rain gauge and water pressure sensor. The early warning system allows data to be stored locally on the monitor at the site and also sends the data to a web server in AIT for graphs to be published on the internet. There is a necessity for the implementation of this real time landslide monitoring system for contribution towards local community early warning.

Keywords. Early warning system, landslide prediction, real-time monitoring, rural community.

1. Background of Landslide Early Warning in Indonesia

As the dynamic volcanic-archipelagoes, more than 60 % of Indonesian region are covered by the mountainous and hilly areas of weathered volcanic rocks, which are intersected by faults and rock joints. These geological conditions give rise to the high landslide susceptibility of the region. Moreover, the high rain precipitation which can exceed 2000 mm to 3000 mm per year, frequent earthquake vibrations as well as the extensive landuse changing and deforestation cause the occurrence of landslides frequently increase recently. Since the last 7 years, more than 36 landslide disasters occurred and result in 1226 people died or missing. Urgently, some efforts should be done to avoid or reduce the risk of landslides. Unfortunately, most landslide susceptible areas have very fertile soils and very good quality and quantity of water. This makes the susceptible areas are densely populated, and it create serious inducement to slope instability. Despite an effort to establish slope protection zone, which is restricted for any development and settlement, the relocation program is not easy to be carried out due to socio-economical constrains. Therefore, landslide monitoring, prediction and early warning system are urgently required to guarantee the safety of community living in such area.

2. Geological Condition of the Study Area

A pilot area for landslide monitoring, prediction and early warning program has been established in Banjarnegara Regency, Central Java Province. It is clarified that not only the rain intensity but also the morphology and geological conditions of study area significantly control the occurrence of landslides. The unstable zone in the study area is situated at lower slope of mountains with the slope inclination of 20^o to 60^o. The moving materials consist of colluvial deposits of silty clay overlying the inclined impermeable layer of clay, which is situated at the lower part of the andesitic breccias mountain. The clay layers are inclined at the same direction of the slope (i.e. 85^o) and this becomes the sliding failure for the above colluvial soils. The moving zone is saturated at most of the rainy season due to the lower position of the zone comparing to the surrounding mountainous slopes. The existence of impermeable clay layer underneath the colluvial soils creates the saturation condition within colluvial soil gradually increased and maintained during the rainy season, until then the rise of pore water pressure within this soil induces the movement. Therefore, monitoring of the pore water pressure (groundwater table) in response to the rain infiltration should be the main concern in establishing early warning for the slope movement.

3. Community-based Early Warning System

At the beginning of year 2007, Gadjah Mada University has developed low-cost equipment for landslide monitoring and early warning, where the rural community can easily operate and maintain the equipment based on their capability. As the initiation of quantitative investigation, two types of simple extensometers and automatic rain gauge were installed at a pilot area in Banjarnegara. The first type of extensometer is a handmade manual reading extensometer. Another type is the automatic extensometer, where the relative movement between two points is mechanically enlarged by 5 times and recorded on a paper continually. The installation of automatic extensometer is shown in Fig.1. Both types of extensometers are connected to the siren system in order to directly warn the local community for taking necessary actions in dealing with landslide disaster.

At the same time a simple modified rain gauge has been developed with hourly rainfall intensity recorded on a paper continually. The warning criteria are determined based on topographical, geological and hydrological conditions. During the installment, five local operators have been trained on how to install and operate this equipment (Fathani & Karnawati, 2007). On November 7th, 2008, a manual extensometer warned the community just four hours before the landslide occurrence, therefore the community has enough time to evacuate when the landslide destroys 400 m of district road and 10 houses. Due to a very active movement recorded by these extensometers, recently around 40 houses at the landslide susceptibility area have been relocated to a more stable area provided by local government. Fig.2 shows early warning system and evacuation scheme for local community under the supervision of head of village in coordination with disaster prevention team, Search and Rescue, Red Cross, health center, and other local authorities.

Fig. 1 Automatic extensometer installed at the upper part of houses at a dangerous zone.

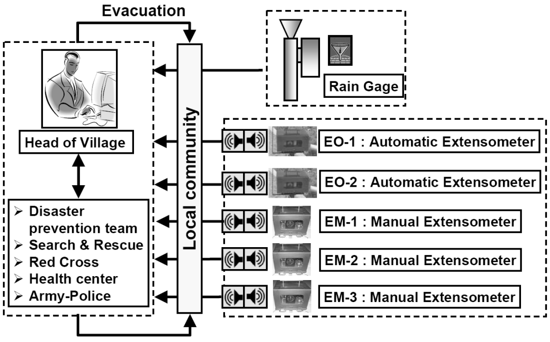

Fig. 2 Evacuation procedure for local community based on early warning from simple monitoring equipment.

4. Real-time Monitoring and Early Warning System

In line with the installation of simple monitoring equipment, on September 2007, the Asian Joint Research Project for Early Warning of Landslides led by ICL and in cooperation with Gadjah Mada University and Asian Institute of Technology has developed and deployed an early warning system for landslides in Banjarnegara Regency. A fieldserver as a sensing device was used to collect data from several sensors and display the results of monitoring in a web page. This system consists of a network camera, two long span extensometers placed above and below the data collection point in order to check ground displacement, and a rain gauge to constantly check the antecedent as well as current rainfall which affect land movement. Moreover, a water pressure gauge was placed at a depth of 2.5 m to measure the underground water level fluctuation. The data from the sensors and the images from the camera are collected and stored in a database in an embedded Linux system.

The real-time monitoring equipment consists of outdoor unit and indoor unit. Outdoor unit mounted on a fixed center pole consists of fieldserver, two extensometers, rain gauge, network camera and water pressure sensor (Fig.3). The extensometer placed at two positions connected by a pulley and a super invar wire which can measure both extension (+) and compression (–). Indoor unit has two crucial components i.e. processing unit and GPRS modem (Fig.4). The system applies an algorithm based on local observations by landslides experts to provide warning messages at several levels. The warning levels are determined depending on the data collected from two long-span extensometers and the rain gauge. A graphical interface is also provided at the local site for community to observe the movement and the warning level. The data and images collected at the site are also sent to a server at Asian Institute of Technology (AIT) in Thailand, where it is possible to make it publicly accessible through the internet. The system collects data every 5 minutes and sends the collected data to AIT server every 1 hour.

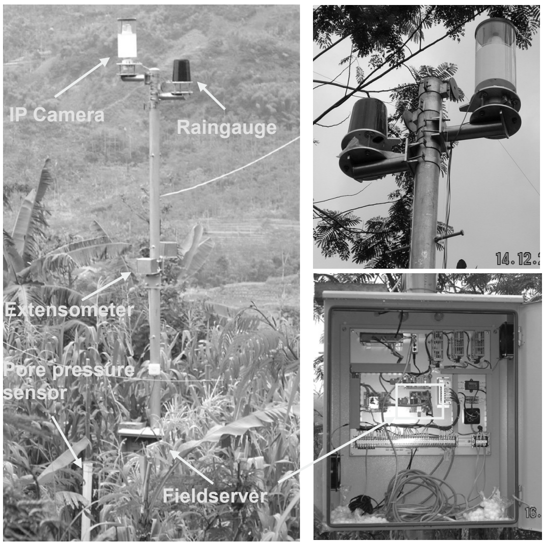

Fig. 3 Outdoor unit of real-time monitoring equipment

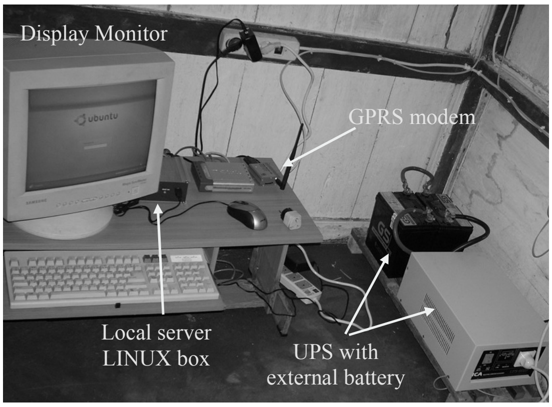

Fig. 4 Indoor unit of the real-time monitoring equipment placed inside a volunteer's house.

Fig.5 shows the aerial photo and topography map of the landslide area plotted by Balloon Photogrammetry System. This system combines the balloon aerial photography and digital photogrammetry for low-altitude aerial mapping. The balloon carries out a digital camera up to 400 m above the ground level and takes aerial photographs in appropriate viewing angle. The digital photogrammetry processes the photo-restitution to produce 3D model from the multi-view aerial photograph (Rokhmana, 2007).

The position of long-span extensometers poles (P1 to P6), rain gauge, pore water pressure gauge and indoor unit are shown in Fig.5. The installation of three extensometer poles (P1 to P3) was conducted on December 15th, 2007. The installation process had faced some problems since the slide occurring also on day of the system set up. As shown in Fig.6, starting from December 23rd, 2007, the extensometer has been saturated (up to 660 to 920 mm of displacement), therefore it cannot measure the movement when the landslide occurred on December 30th, 2007, which destroyed the center pole (P2), buried the lowest pole (P3) and also attacked several existing houses, farm land and district road (Fig.7).

Fig.5 Aerial photo, topography map and position of real-time monitoring equipment. Landslide fatalities are shown on the right.

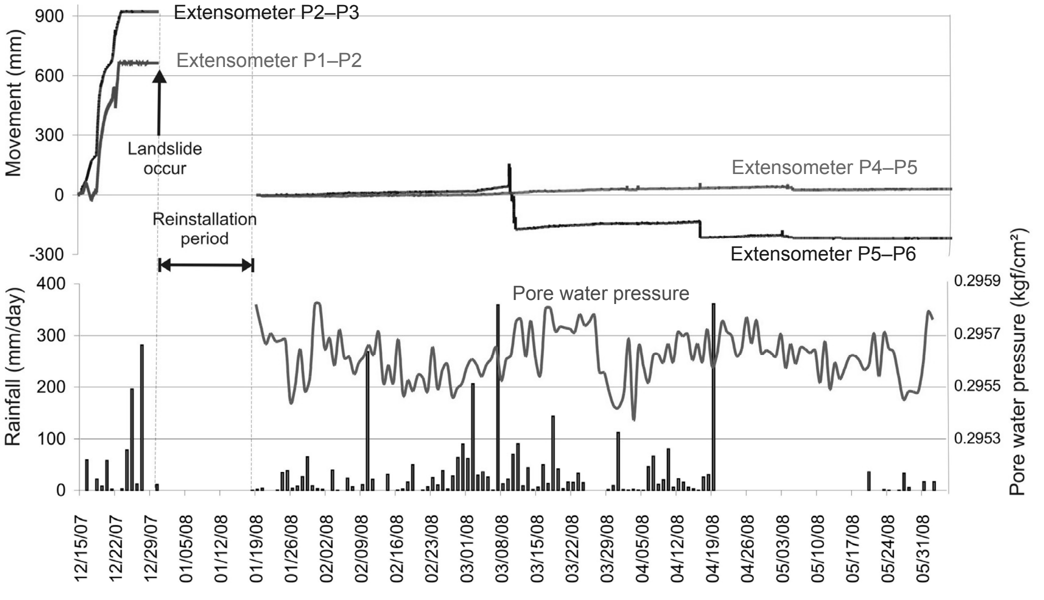

Fig.6 The results of measurement by two extensometers, rain gauge and pore water pressure sensor.

Fig. 7 Center pole (P2) was destroyed by landslide movement on December 30th 2007.

On January 19th, 2008, the monitoring system has been reinstalled at a new location about 150 m below the previous destroyed place (Fig.5). Three new poles (P4 to P6) were erected with two long-span extensometers, rain gauge and network camera mounted on the fixed center pole (P5). Pore water pressure sensor is placed inside a well near P5, whereas the indoor unit located in a house belongs to a volunteer resident near P4. The result of measurement of two extensometers, daily rainfall and pore water pressure fluctuation are shown in Fig.6. The accumulated movement of extensometer starting from January 19th until May 31st 2008 reaches of about 30 and 220 for Extensometer P4–P5 and P5–P6, respectively. Meanwhile the maximum rate of rainfall could reach 200 – 360 mm/day. It can be seen that the extensometer movements on March 7th and April 13th, 2008 were strongly related to the rainfall occurrence.

Discussion

Some lesson learned can be derived from this program that this real time landslide monitoring system can be a model for implementation at landslide prone rural community worldwide. Likewise, the early warning system of landslide should be based on the involvement of community participation. Therefore, both technical skill and communication skill are the main requirements to achieve the success of early warning system program. The system should include some technical aspect such as the geological surveys and site selection, development of equipment design which is simple (low cost) but effective, determination of early warning levels, installment and operation/maintenance at the field site, as well as include the social aspect such as social mapping and evaluation, public consultation and dissemination of program, community empowerment (including the technical training and evacuation drill) for landslide hazard preparedness and operational system of the early warning. Moreover, the communication with all stake-holders such as local, regional and national authorities, local leaders, local youth communities, and local non government organization should be established and maintained. The role of scientist or researcher is more like to be the motivator and facilitator, instead of the instructor or manager of program.

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Exploitation of Historical Satellite SAR Archives for Mapping and Monitoring Landslides at Regional and Local Scale

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Abstract. Permanent Scatterer SAR Interferometry (PSInSAR™) is today one of the most advanced technologies for surface deformation monitoring capable of overcoming most of the limitations of conventional differential radar interferometry. It exploits long temporal series of satellite radar data, acquired over the same area of interest at different times, to identify “natural radar targets” (i.e. the so-called Permanent Scatterers or PS) where very precise displacement information can be retrieved. This approach has been developed by Politecnico di Milano (POLIMI) in the late nineties. Since then, the processing of thousands of SAR scenes acquired by ERS-1/2, ENVISAT and RADARSAT has demonstrated how multi-temporal SAR data-sets can be successfully exploited for surface deformation monitoring, integrating successfully continuous GPS and optical leveling data and allowing the analysis of large areas of interest. Examples of application of this technology at regional and local scale will be presented in this paper.

Keywords: SAR, Permanent Scatterers, landslide inventory, monitoring

1. Introduction

Thanks to the availability of satellite data archives covering more than one decade, Permanent Scatterer SAR Interferometry (PSInSAR™) represents nowadays one of the most powerful techniques capable of retrieving surface displacements (Colesanti et al., 2003; Dixon et al., 2006; Ferretti et al., 2000; Ferretti et al., 2001, Hilley et al., 2004). Mapping landslide distribution at regional scale is traditionally based on geomorphological analysis, both from aerial-photo interpretation and field surveys. Nevertheless, where displacement rate is very low (millimeters to centimeters per year), assessing the activity of a landslide is generally difficult or even impossible without the help of long-term displacement data. This is for example the case of Deep-seated Gravitational Slope Deformations (DGSD), characterized by large areal extent and surface displacements ranging from few millimeters to tens of millimeters per year. Thanks to its capability to detect small displacements over long periods and large areas, PSInSAR™ analysis can be considered complementary to conventional geological and geomorphological studies in performing landslides inventories at regional scale.

During the last years several Italian Regions were studied with Permanent Scatterer SAR Interferometry (PSInSAR™) in order to detect and monitor slope instability phenomena. One of the last application of the PSInSAR™ technique was carried out at the end of 2007 on the whole Valle d’Aosta Region (NW Italy) area. Aim of the study was supporting the landslide inventory performed within the framework of the Italian Landslide Inventory (IFFI) Project, partly funded by APAT (Italian Agency for Environmental Protection and Technical Services). The study covered a time span of about ten years, from mid 1992 to early 2001. As many unstable areas of the region were reactivated by the intense meteorological event affecting northwestern Italy on October 2000, the surface displacement data provided by traditional monitoring networks installed since early 2001 could be compared with the displacement measured by PSInSAR™, before the event. This helped in better understanding the effects of reactivation on the behavior of the major landslides identified in the study area. An example will be discussed in this paper, after presenting the results obtained at regional scale.

2. PSInSAR™ technique application at regional scale: the Valle d’Aosta Region (NW Italy) example.

More than 400 SAR scenes acquired by ERS-1 and ERS-2 satellites were processed, covering the period May 1992 to January 2001. About 370000 PS in both ascending (**Figure 1**) and descending (**Figure 2**) geometries were identified within an areal extent of about 3200 km^2.

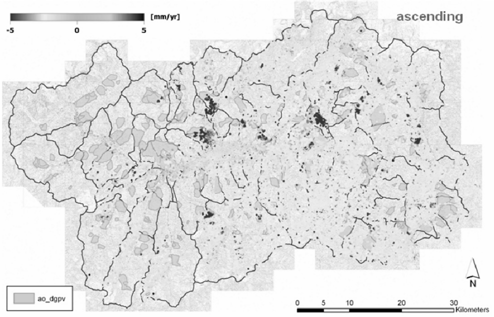

Fig. 1 PS distribution and velocity map (ascending geometry) over the Valle d’Aosta Region (NW Italy). Base map: DGSD perimeters from IFFI Project (Italian Landslide Inventory)

Displacements are measured along the “line of sight”

(LOS) of the radar beam. The availability of PS data in both ascending and descending geometries enhances the coverage of the study area and enables the estimation of vertical and E-W horizontal displacement fields in the areas covered by both ascending and descending data. An example is provided in **Figure 3**.

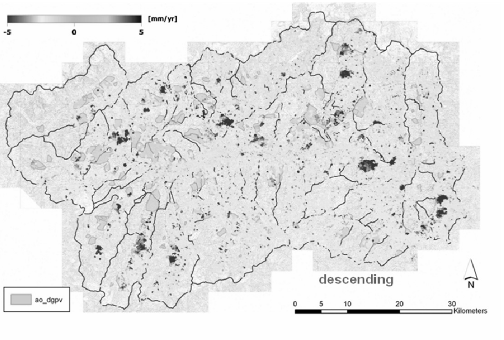

Fig. 2 PS distribution and velocity map (descending geometry) over the Valle d'Aosta Region (NW Italy). Base map: DGSD perimeters from IFFI Project (Italian Landslide Inventory)

The results of the PSInSAR™ analysis were compared with the ones of the Italian Landslide Inventory, also known as IFFI Project, promoted by the Italian Government and aimed at:

- identifying and mapping landslides over the whole Italian territory, based on standardized criteria;
- building up a National Landslide Geographic Information System;
- providing a tool for hazard and risk assessment and land use planning.

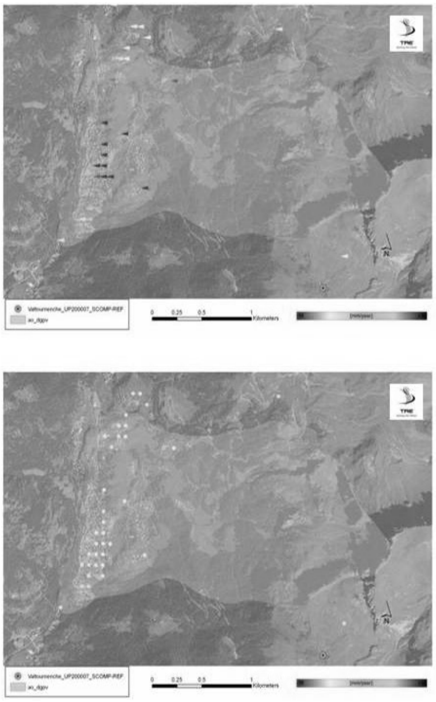

Fig. 3 E-W horizontal (upper) and vertical (lower) yearly average displacement rate for a selected case history obtained by combining ascending and descending LOS (Line of Sight) PS displacements

The IFFI Project was coordinated by the Geological Survey of Italy - Land Protection and Georesources Department (ISPRA, formerly APAT), which developed the guidelines, verified the data conformity, and built up a national geo-database and a WebGIS. Since 2005 the results of the IFFI Project have been available on the Internet.

The integration of the outcomes of the conventional geological-geomorphological studies with the results of the PSInSAR™ analysis is presently in progress and will definitely improve the results of the landslide inventory, in terms of landslide areal extent evaluation, unmapped phenomena detection and activity assessment of the identified phenomena.

3. PSInSAR™ technique application at local scale: the Bosmatto (Valle d'Aosta Region - NW Italy) landslide.

On October 2000 an intense meteorological event affected a wide area of northwestern Italy causing widespread landslide and flood events (**Figure 4**). During the night of October 15th a succession of debris flows poured down Letze torrent, devastating the area of Bosmatto village situated on the alluvial fan at the confluence with Lys torrent, in the municipality of Gressoney St. Jean (Aosta).

The debris flows, whose accumulated deposits were

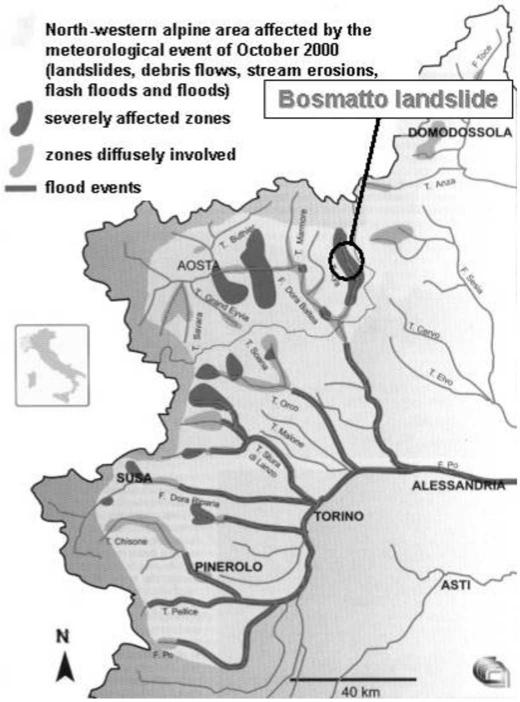

Fig. 4 Area affected by the consequences of the October 2000 meteorological event and location of the Bosmatto landslide (Tropeano & Turconi, 2001)

estimated in a volume of about 150.000-180.000 m^3, spread over an area of 135.000 m^2, destroying some buildings and cutting the main road. Moreover, evidences of the reactivation of an ancient instability phenomenon, located on the left side of Letze torrent about 1 km upstream the alluvial fan, were detected during the first on site surveys (**Figure 5**). Displacements of about 4 metres in one week were measured. After the reactivation of the landslides field investigations and studies were carried out in order to assess the residual risk for buildings and infrastructures and design an early monitoring system to control the evolution of the landslide. The monitoring system includes a GPS network; two measurements per year have been regularly carried out since the second half of 2002.

Fig. 5 View of the Bosmatto landslide area (dashed line), reactivated during the October 2000 meteorological event (Valle d'Aosta, NW Italy)

In this case, the results of the PSInSAR™ analysis provided displacement data regarding the landslide before the October 2000 reactivation. Due to the orientation of the unstable slope, only LOS displacements in descending geometry are available. GPS measurement record a point's position in x, y and z coordinates; in order to be comparable to the displacements provided by PSInSAR™ analysis, GPS data must be projected along satellite LOS. Moreover the position of a selected PS doesn't necessarily correspond to a GPS station. Nevertheless, each displacement time series provided by GPS was compared with the one relevant to the closest available PS. Finally, the gap between the PS and the GPS displacement history was neglected, as no displacement measurements were available during the considered time span.

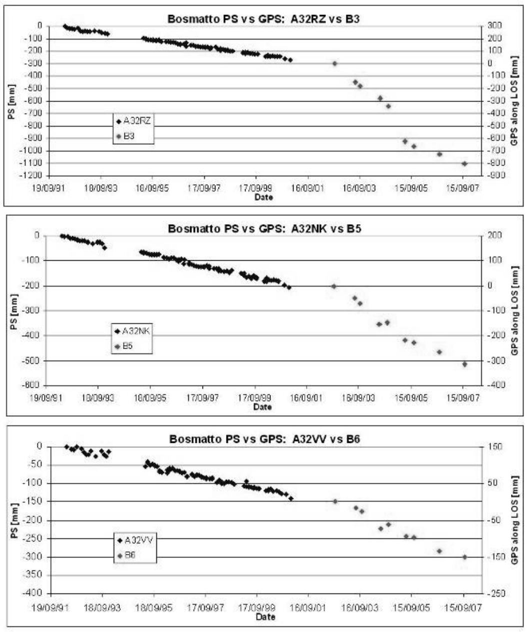

Fig. 6 Bosmatto landslide: three examples of GPS data (after 2001) projected along satellite LOS compared with corresponding PS time series (before 2001)

The comparison between PS time series and GPS measurements projected along LOS shows that the landslide was active before October 2000, but, after the reactivation, the average yearly displacement rate of the landslide is higher than before (at least 2x, locally higher), even if slowly decreasing through time. Three examples are provided in **Figure 6**.

6. Conclusions

The results achieved so far and, in particular, the activities carried out in agreement with the Italian Civil Protection authorities, confirm that the traditional geological-geomorphological and the innovative PSInSAR™ approches are indeed complementary tools for accurate landslide mapping. In particular, the assessment of the degree of activity based on multi-year historical datasets can be invaluable. The availability of surface displacement time series for all the radar benchmarks identified makes it also possible to change the scale of the analysis from regional to local, allowing an in depth study of the evolution of single instability phenomena, supporting the design of traditional monitoring networks, and even verifying the efficiency of remedial works. Furthermore PSInSAR™ can provide valuable information on the behavior of an area under study before the installation of any terrestrial measurement system, provided data archives are available.

The Italian Ministry of the Environment has recently awarded a contract for the processing of more then 12,000 SAR scenes acquired over Italy aimed at creating the first database of interferometric information on a national level for mapping unstable areas. This is somewhat an evidence of the fact that, in less than ten years from its development, this technology has become a standard monitoring tool.

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The new National Landslide Database and Landslide Hazard Assessment of Great Britain

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Abstract. The British Geological Survey (BGS) is the national geological agency for Great Britain. Part of the organisations remit is to provide government and citizens with information on the spatio-temporal occurrence of natural hazards. Since 2000 BGS has developed a series of National Geohazard Assessments, central to which is the new National Landslide Database (NLDB), which contains data on landslides across England, Scotland and Wales. The NLDB began with a series of inherited databases, which between them held around 9000 entries. Even though many of these entries have been removed (through a validation process), the NLDB now holds over 14,000 entries and expands every year. Importantly, BGS is moving towards digital data collection methods which will feed automatically into the National landslide database, providing the most up to date information and images to the users at minimal cost to the tax payer. A project has also been started to map all coastal landslides as well as producing a coastal slope stability assessment using remote sensing. It is hoped this will provide useful information on the nature and extent of coastal landslides and the hazards that these pose to infrastructure.
The database is used, alongside other information, to inform a series of National Geohazard Assessments. These GIS based assessments provide information on the susceptibility of the UK landmass to landslide activity. The information is used by government planners, insurance companies and utility operators. The dataset is also made available to citizens through a number of internet based 'resellers'. In 2006/07 1.4 million citizens accessed the information and used the results to support decisions about the purchase or modification to residential or commercial property.

Keywords: Landslide, Database, National Hazard Assessment

1. Starting Point: The first National Assessment of Landslides

Britain, as a whole, does not experience extreme climatic or tectonic events nor have the mountainous regions associated with large scale, destructive landslides. Despite this, landslides are common in Britain and several major landslides have occurred, usually with little warning. Examples of these have caused structural damage (Holbeck Hall Landslide, Scarborough; Lee 1999), interrupting transportation routes (Glen Ogle, Scotland; Winter et al. 2006) and resulting in fatalities (Whitehaven, Cumbria; Jenkins and Hobbs 2007).

Prior to a national assessment of landslides being undertaken, the subdued topography and degraded nature of many ancient failures meant that landsliding was not considered to be widespread or problematic in Great Britain. However, costly disruptions to projects in the 1960's such as the Sevenoaks Road By-pass (Skempton and Weeks 1976) and the Waltons Wood motor way embankment (Early and Skempton 1974) by reactivations of previously unknown landslides led to the realisation that research needed to be done to determine the significance and extent of the problem. The first national focussed assessment of landsliding was undertaken for the Government Department of the Environment (DoE) in the mid 1980s. It produced a database of landslides and a review by Jones and Lee (1994). This initial assessment was undertaken as a desk study, collating information from maps, journals, technical reports and books as well as university research and theses. The final number of landslides recorded was 8835, a figure far greater than the initial estimate of 1000 landslides (Jones and Lee 1994). . However, this initial study had several problems similar to those associated with other databases produced through a desk study approach (Jones 1998). These included a bias of information toward areas of concentrated and conspicuous landslide activity, which reflect detailed studies such as those covering the South Wales Coalfield (Conway et al. 1980), Southeast England (Hutchinson 1969), and the Jurassic escarpment (Chandler 1970). Other problems related to gaps in the available data, for instance information on the type and cause of landsliding was very limited, and many database fields remained unpopulated. During the study no distinction was made between small landslides and more extensive areas of landsliding; this lead to a lack of comparability and an overestimation of the overall landslide hazard. This lack of attribution and basic characterization (as opposed to the detailed classification that was adopted) severely limited the analytical potential of the database. A further fundamental flaw of the database (but not of the data itself) was that it used a non-proprietary software system (as might be expected of the time) that quickly became incompatible with newer computer systems.

This National Database, which contains information on over 35 landslide attributes, has been incorporated into the British Geological Survey National Landslide Database (NLDB). However, in building a new database, BGS is attempting to deal with a number of the issues encountered by the previous system.

2. New BGS Database

The new BGS National Landslide Database, running since 2002, currently documents over 14,000 landslides across Great Britain (Fig. 1). The primary source of information is the National Digital Geological Map (DiGMap) at 1:10 000 (DigMap10) and 1:50 000 scale (DiGMap50). Other data is collected through media reports, site investigations, journal articles and new direct mapping in the field. Data is stored within fully relational ORACLE database which can be accessed through a typographical (Microsoft Access) or geographical (ArcGIS) interface. The database stores up to 70 different types of spatial, temporal, physical and environmental data plus details of socio-economic impacts. Information is stored in 30 fully-relational data tables. To ensure compliance with the regulations that govern national archive databases in the UK, each data table is linked to a history table that records details of every change made to the database. Thus, all information within the database can be fully audited and details, including time, date, personnel, and landslide information of every change can be recorded and traced. This also means that in the event of a catastrophic information error, the database can be recreated to any point in the past. In common with other digital national datasets, the system is also backed up every 24 hours in three separate geographical locations to guard against physical damage to the system.

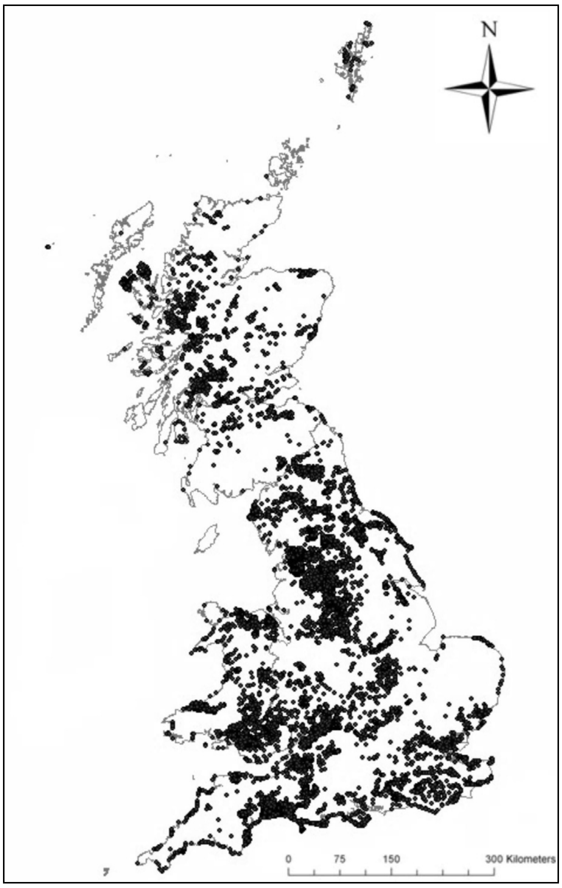

Fig. 1 Distribution of recorded landslides held by BGS. OS topography © Crown Copyright. All rights reserved. 100017897 / 2008

The landslide database forms part of the BGS Geodatabase, and as such is compatible with other data dictionaries used in the BGS. For instance, the database uses BGS standard dictionaries for lithological and stratigraphical nomenclature. Similarly, nationally and internationally recognised dictionaries are used for other data tables, such as location, damage type and land use. Wherever possible, details of each landslide are recorded using terminology from the World Landslide Inventory (IAEG Commission on Landslides 1990). An example of this is given in Table 1.

3. Data Collection

The database undergoes continual revision and update. New data collection is ongoing and is carried out by a wide number of geological survey staff. Geologists are provided with a pro–forma which is taken into the field to collect data regarding any landslides mapped. Each landslide characteristic is entered as a shortened attribute code, related to dictionaries definitions. In reality these pro-formas are shortened versions as geologists may be unable to collect information on all of the attributes due to time constraints. With the advent of the new digital geological field mapping equipment, MIDAS (Mobile Integrated Data Acquisition System), landslide database pro-formas are being loaded onto ruggedized pc's to be used in the field.

Table 1 Sample Dictionary for 'Landslide Style' from the BGS National Landslide Database

Style	Description
Composite	A composite landslide exhibits at least two movements simultaneously in different parts of the displacing mass.
Complex	A complex slide involves one of the five main types of movement followed by two or more of the other main types of movement.
Successive	Repeated shallow rotational slips each of limited extent down slope but considerable extent across it, forming cross slope steps or terraces.
Cluster	Cluster or group of small landslides on a section of slope with similar characteristics.
Single	A single event failure with no additional movements of the same type.
Multiple	A series of movements of the same type e.g. a series of slices failing in multiple rotational style.

4. National Hazard Assessment using the Database

In addition to its value as a scientific tool, the development of a landslide inventory, in the form of the National Landslide Database, was an important first step in the production of a national landslide hazard assessment. To assess the hazard posed by landslides it is necessary not only to be aware of their distribution, but to also understand the causative factors and their spatial distribution. The spatial modelling of landslide causative factors has been made possible through the use of Geographic Information Systems (GIS). The increase in processing and storage capabilities of GIS has made it possible to manipulate, analyse and model the causative factors of landsliding to create a landslide susceptibility model for the whole of Great Britain. The current GIS assessment of landslide hazard for the British Mainland, developed by the BGS, is called GeoSure. The

GeoSure methodology was developed using elements of both a deterministic and heuristic approach. The heuristic approach uses expert judgement to assess and classify the hazard, and determine the likely causative factors of landsliding (Soeters and Van Westen, 1996). The deterministic approach within GeoSure assesses the presence of the causative factors, giving each one a rating according to their relative importance in causing slope instability.

Research into the causative factors of landsliding in GB identified lithology, slope angle, hydrogeology, climate and the presence of discontinuities to be the most important. After several iterations, three key factors were used - slope, geology and bedrock discontinuities. It was possible to digitally capture most of these causative factors, although some were already available as corporate datasets. Digital geological polygons were assigned a score defining the potential of that material to fail. The score was based upon an additive algorithm that took into account the material strength, permeability and known susceptibility to instability of different lithologies, together with slope angle. The geological data was based upon geotechnical data, literature reviews and experience of geologists.

Discontinuities were assessed as an important causative factor, often reflecting the strength of a material, its susceptibility to failure and its ability to allow water to penetrate a rock mass. Detailed information about rock discontinuities was not consistently available for the majority of rock types in Britain. Therefore categories were defined in line with those used in the British Standard 5930: Field Description of Rocks and Soils (British Standards Institute 1990) and by Bieniawski (1989). Slope angle is one of the major controlling factors in landslides, and for this methodology, the slope was derived directly from the NEXTMap digital terrain model of Britain. The NEXTMap dataset was generated from an airborne survey and has a 5m resolution. This resolution was considered too detailed and too memory intensive for nationwide use, so it was resampled to 25 m for use in GeoSure. The method is flexible enough to allow alteration (nationally or locally) of the algorithm in the future and include other factors such as the presence and nature of superficial deposits.

Once all the contributing factors were identified they were easily combined using a multi-criterion technique. The multi-criterion approach applied a series of rules against the available data to provide a hazard ‘score’ for each location in Britain. A high score does not necessarily mean that the hazard has happened in the past or will do so in the future but that the conditions mean there is a potential for future landsliding. A simplified GeoSure layer for landslide hazards in Great Britain is shown in Fig. 2.

Inevitably when dealing with large datasets on a national scale there are issues. Although computing power is increasing rapidly, there are still limits to what can be achieved. Further problems arose from the introduction of fuzzy error, which is magnified as processing continues. By using grids to do the multi-criterion analysis, fuzzy errors were reduced and the processing speed increased. The grids were converted to a polygon file for distribution and use. These polygons maintained the pixilated form inherited from the grid which may appear unattractive, but does act to enforce the resolution of the data. The blocky appearance ensures that the user is made aware of the accuracy of the data as soon as they zoom beyond the 1:50,000 working scale of the model (Wildman and Forster 2005).

Validation of the dataset revealed problems in the slope model associated with false slopes created by tree stands and man made embankments. The tree issue was solved using data derived from Landsat data which were used to identify vegetation cover at a national scale using 2D scatter plot analysis to create training classes. These training classes were then used for GIS Parallelepiped classification to detect trees. Parallelpiped classification uses a standard deviation threshold taken from the mean pixel value of each training class. Once all of the trees were identified it was possible to remove them from the NEXTMap model.

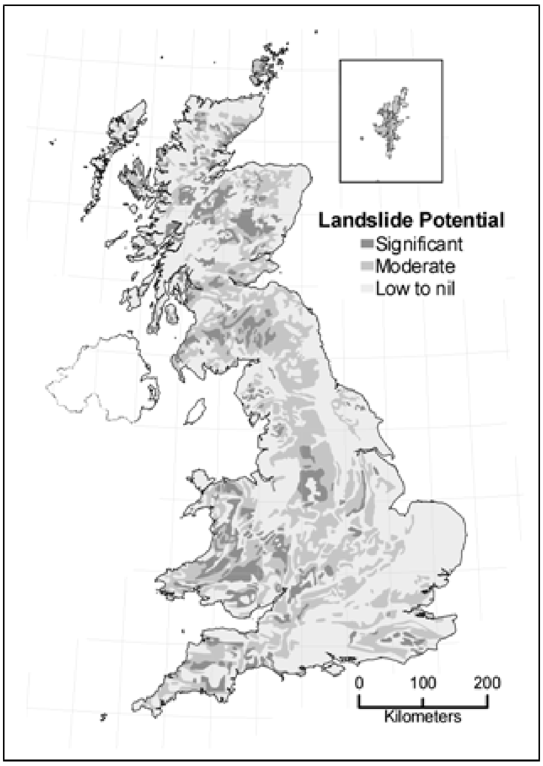

Fig. 2 Generalised GeoSure layer for Landslide hazard assessment. OS topography © Crown Copyright. All rights reserved. 100017897 / 2008

5. Discussion

The new national landslide database has been developed in light of a lack of knowledge of the distribution and nature of landslides Great Britain. The new database incorporates information from several sources including a previous national assessment, and has been designed to be ‘future-proof’ to new technological developments. The database contains far more information than previous national assessments and is used as the basis for detailed assessments of landslide risk in limited geographical regions.

The database represents a number of achievements including:

- Collation and validation of landslide records from the 1994 Department of the Environment Database

- Collation and validation of landslide records from other BGS databases including the South Wales Coalfield Database, Calderdale Database, Leeds Database, Bradford Database, London Database.
- Cataloguing and characterization of BGS landslides mapped post 1994 (6000 records).
- Migration of landslide records to a fully relational database, compliant with international standards for national archive and compatible with all other BGS National Geoscience Datasets.
- Development of Database and GIS interfaces for input and interpretation.

The database is currently being used to develop regional models of landslide behaviour for the UK and has proven to be invaluable in designing a targeted data collection programme of landslide mapping and characterization. There is a long term commitment to survey more landslides, collect information from third party sources and increase the level of detail held in each database record. For instance, detailed work is underway to produce a National Landslide Hazard Assessment of the Coast. Here problems associated with the sample spacing of the DTM plus the influence of geological structures and multiple lithologies can lead to inaccuracies in GeoSure at the coast. Results will be used to define Coastal Stability Units which may better characterise the potential for, and location of, instability around the coast of Great Britain.

The database also underpins the development of a national hazard assessment of the entire country, with information on the spatial distribution of different types of landslide used as an important input to the GIS algorithm. However, this assessment is based primarily upon the spatial distribution of lithologies and slope gradient. Thus the assessment does not rely upon evaluating the significance of a history of past occurrences. The method does not require a complete, uniform dataset to carry out the assessment. The resulting GIS model provides a reasonable assessment of landslide susceptibility across the country that is ‘informed’ by the landslide database rather than controlled by it. The Landslide Database is an important resource because it can display the location of thousands of known landslides. However, due to the very nature of inventories the information available is limited to where data has been recorded. Most end-users wish to access a model that shows the potential for landsliding at a specific location, not necessarily in an area where information is contained within the Landslide Database. It was therefore essential to produce a nationwide model of landslide potential (GeoSure). This model is typically accessed through automatically generated reports and in 2007/08 over 1 000 000 UK citizens accessed the dataset.

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Effective Forest Management to Reduce Landslide Risk in Reihoku Area in Shikoku: A Social Perspective

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Abstract. Japan has been suffered from various natural disasters such as floods, landslides, typhoons, volcanic eruptions and earthquakes. We have developed structural and non-structural measures to prevent and mitigate each disaster. Recently, global warming and abnormal weather affect the scale and type of disasters. Because the climate change has been a hot issue, the Meteorological Agency analyzed climate data from 1900 and issued as climate risk map. It says, the number of precipitation more than 100mm/hour is increasing, but average annual precipitation is decreasing [1]. As another trend, average annual standard deviation tends to be wide. It means, if it rains, the precipitation is very high in high precipitation years, on the contrary, the shortage of water may cause drought in the low precipitation year [2]. Therefore, occurrence of localized torrential rain is increasing, and the local areas will suffer enormous damage. Therefore, big scale local floods and droughts will be occurred. In addition to the climate change, social and natural changes cause different types and scales of damage. Aging issue is one of them. Estimated population of more than 65-year-old in Japan is 24,310,000 and the ratio in total population is 19.0 % on Sep. 15, 2003. It is about one fifth of total population [3]. It is estimated that the ratio of more than 65-year-old is increasing continuously and reach to 26.0 % (32,770,000) in total population in 2015, it is about one fourth of the total population. Especially, the ratio of old people in mountainous areas is higher than that of old people in cities. Since old people are vulnerable to disasters, the number of old victims are increasing. Deforestation and depopulation are also issues to expand the damages of mountain disasters. Forestry plays an important part to let the various forest function work effectively, however, the environment of forestry is not preferable recently. The forest production activity is declining because of the decreasing number of forest workers and aging. Therefore, now the forest management is important in points of mitigating mountain disasters to live safely, networking to help old people living well, and producing goods using forest resources to gain income. Comprehensive analysis is needed for sustainable forest management. It is also important to study policies of related governments and opinions of the local people. The research field is Reihoku area in Kochi prefecture, because the area has large forest and high rate of old population. This research focuses on the networking and sharing information mainly among ministries, local governments and local residents to prevent and mitigate mountain disasters.

Keywords. environmental changes, mountain disasters, forest management, networking

1. Background of Reihoku area

Reihoku area is located in the north of Kochi and in the center of Shikoku island as Fig. 1 shows. It is in upper Yoshino river basin. The area is about 757 km2 and shares 10.6% of total area of Kochi. There are three towns (Otoyo, Motoyama, Tosa) and one village (Okawa).

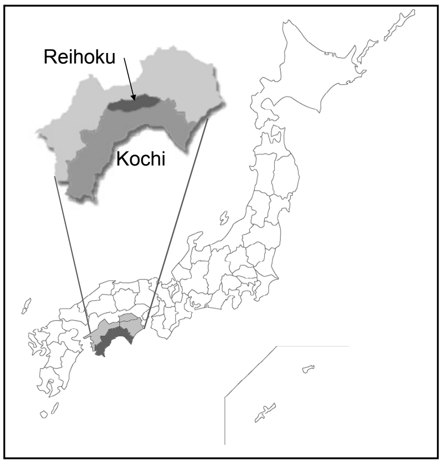


Fig. 1 Location of Kochi prefecture and Reihoku area

It is mountainous with steep mountains of 200 to 1,700 m high in the north. The forest rate of Kochi is 84 %, which is the highest forest rate in Japan. It is much higher than the total forest rate of Japan, which is 67 % [4], and the forest rate of Reihoku is still higher. Forest shares 87.9% of Reihoku, agricultural land shares 1.7% and residential area shares only 0.5%, therefore it is a typical mountain village [5].

The total population has been decreasing from 34,801 in 1965 to 15,270 in 2000 and the ratio of more than 65-year-old has been increasing from 11.6% in 1965 to 38.7% in 2000. It is estimated that the population decreases to 12,623 and the ratio of more than 65-year-old increases to 44.7% in 2015. As the demographic change in Fig.2 shows, almost half of the total population will be more than 65-year-old in 2015 as the dotted line shows.

In addition to the aging and decreasing population, importing cheap lumber has accelerated weakening the forest industry. Import liberalization of lumber had been promoted gradually since about 1955 and completed in 1964. As a result, the import volume of lumber had increased sharply from about 1955 to 1975. Though the key industry in Reihoku area, which forest ratio is 87.9%, is agriculture and forestry, the number of workers in primary sector of industry decreased from 8,308 to 1,913, and the ratio in total population decreased by half for 30 years from 1970 to 2000 (Table.1). Because of the declining agriculture and forest industry, people have no other choice but to find other jobs in the area or to move out of the area to find jobs. This causes the forest untreated and forest road unused. Therefore the owners and foresters have more difficulties to enter untreated forest for thinning, cutting and carrying lumber.

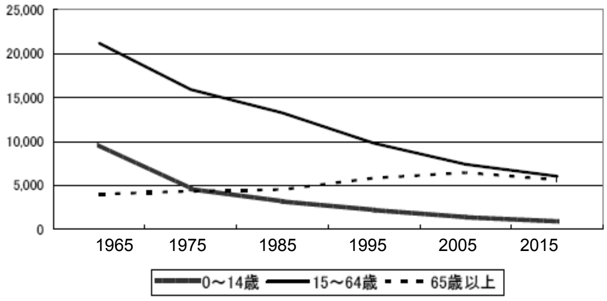


Fig. 2 Demographic change in Reihoku area
http://www.reihoku-k.jp/gaiyou/huruken1-2.pdf

Table.1 Changing number of workers in Primary Sector of Industry in Reihoku Area

	workers	ratio
1970	8,308	51%
1980	4,224	33%
1990	2,567	26%
2000	1,913	24%

http://www.reihoku-k.jp/gaiyou/huruken1-2.pdf

2. Changing Forest Environment and Impact on Mountain Disasters

The changing human environment, such as aging and decreasing population, and declining forest industry has been creating a vicious circle in Reihoku area, as Fig. 3 shows.

This human environment affects forest environment. A vicious circle has also been created in forest environment. Since the forest is not treated and managed, the forest function, such as preventing mountain disasters, recharging water source, mitigating disasters caused by weather phenomena and securing the biodiversity, is declining. Then the number of mountain disaster increases and the scale becomes bigger than before.

In addition to this forest environment and recent climate change, the scale and frequency of mountain disasters change and it becomes more difficult to predict the scale and the frequency.

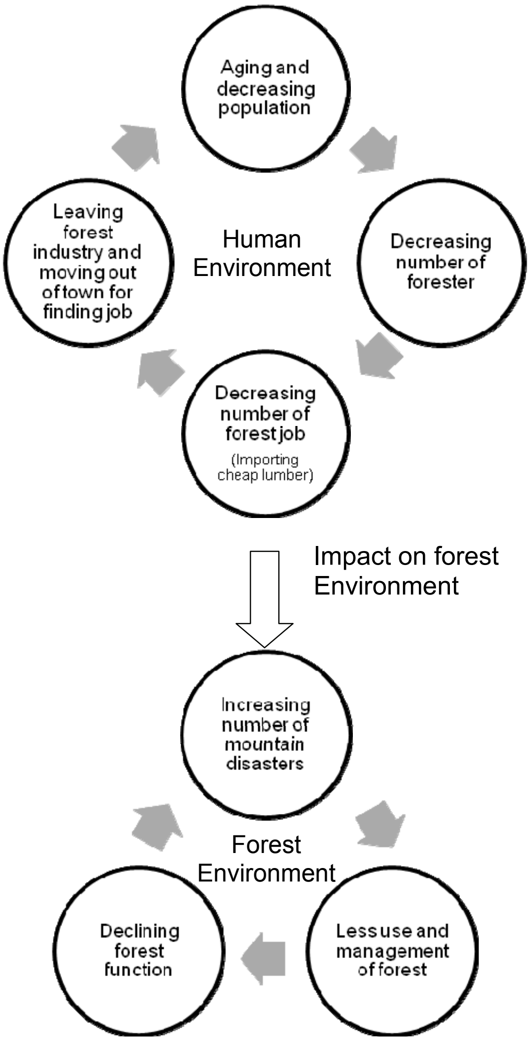


Fig. 3 Changing Human Environment and Its Impact on Forest Environment

3. Improving Network and Sharing Information

Changing human environment is needed to improve this situation. Improving existing network and making new network is one of the effective ways for improving the human environment. In addition, change in the thinking way by involved people is also needed. Legal action is one of factors to affect networking and improving awareness.

The Devolution of Power Law enacted in 2000 made it possible to create special taxes for specific purposes for local prefectures. As a result, prefectures are able to put the levy into practice as a tax which a local government may implement for a particular purpose [6]. Because of the revision of Local Tax Law, prefectures could have more authority to take measures to meet each local situation. The forest environment tax is one of them. Kochi is the first prefecture which introduced forest environment tax. The purpose is forest conservation by the participation of the prefectural inhabitants [7]. The tax revenue is used for preventing the depression of forest function which is preventing mountain disasters including water source recharge, mitigating disasters caused by weather phenomena and securing the biodiversity under the permission of local residents since they receive the forest benefit [8]. The tax is spent for forest maintenance project such as thinning and for public relations activities [8]. 500 yen has been charged on each individual and corporation every year from 2003, and after five years, the taxation term is evaluated [9]. The prefecture did not choose the special taxes for specific purposes but earmarked tax with the overassessment tax system to impose 500 yen on prefectural taxes of individual and cooperate, and the purpose of the uses are cleared by fund reserving [8]. 500 yen has been charged on each individual and corporation every year from 2003, and after five years, the taxation term is evaluated [9]. The first phase is five years started in 2003 fiscal year. The annual revenue from the tax was 140,000,000 yen in 2004 fiscal year. There are two projects to use this tax. One of them is “the project for promoting forest management by the people’s participation” and the other is “the project for forest environment urgent conservation”. The former mentioned project aims to educate the local residents how the forest is important, to enlighten forest owners, and to manage model forests. The later mentioned project aims to make mixed forest by thinning [10].

As another project promoted by Kochi prefecture is “Collaborative Forest Restoration with Environmentally Progressive Companies”. Kyoto Protocol went into force on February 16, 2005, and Japan held up a promise to reduce 6% of greenhouse gas between 2008 and 2012 based on the amount of greenhouse gas in 1990 as 100%. Japan focuses attention on the forest as the source of absorbing CO^2. As a result, establishing emissions trading system has been discussed in Japan. Since Kochi prefecture expects Japan establishes emissions trading system, “Collaborative Forest Restoration with Environmentally Progressive Companies” was started from 2005 fiscal year to promote forest restoration and interchange among Kochi prefecture, cities, towns, villages, forestry cooperatives and companies [11].

The Forest Environment Law promotes to educate the local residents how the forest is important, to enlighten forest owners, and to manage model forests. This is effective to networking among Kochi prefecture and local residents. “Collaborative Forest Restoration with Environmentally Progressive Companies” is effective to networking among Kochi prefecture, cities, towns, villages, forestry cooperatives and companies.

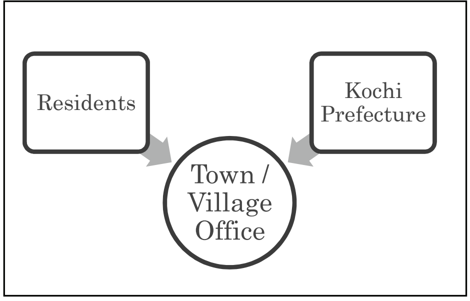
Thus the local residents and companies are encouraged to be involved in the projects for forest management. As a result, networking among Kochi prefecture, local residents and companies becomes stronger. Then, the role of towns and a village in Reihoku area becomes more important to be a strong bridge between the local and the prefecture. In addition, since the towns and village office make actual local plans of forest management and forest disaster prevention, they have more opportunity to tell local residents how to prevent and mitigate mountain disasters . These kinds of information are necessary to be shared by every person related to this area as the basic information to know and to understand more about their forest situation. Sharing information contribute to the stronger networking and improvement of individual awareness.

In this research, it is discussed if there is any other way to improve existing way of forest planning especially for mountain disaster prevention by investigating how the local disaster history is collected, used and shared for forest management planning.

4. Recording and Sharing Information of Mountain Disasters

When a disaster occur, information is gathered to the town and village offices and the offices decide how to deal with the disaster and tell related organization and make reports to Kochi prefecture as Fig. 4 shows.

Input of information



Output of information

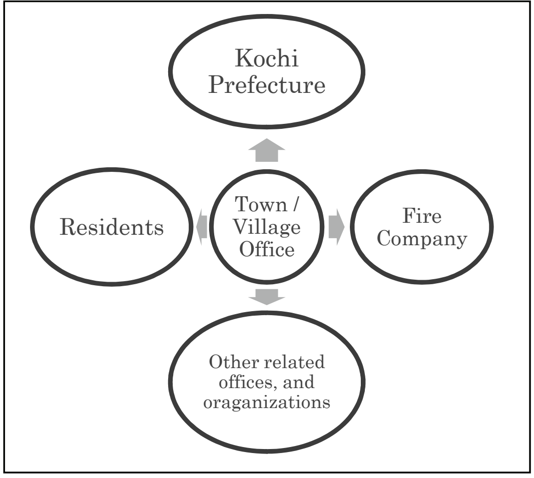


Fig. 4 Flow of mountain disaster information

Since the actual plan for mountain disaster prevention is made by each town and village, hearing was implemented to the people in charge of planning mountain disasters in three town offices and a village office. The result was similar. Each mountain disaster is recorded in detail on papers, and the paper-based records are copied and sent to the related organizations and Kochi prefectural office.

Two points for recording information have possibilities to be improved, one is digitizing and the other is standardizing:

1. Though each office recognizes the necessity of digitizing and analyzing past data, no office digitized the records in each office. The reports of mountain disasters from these offices are not digitized and standardized in the prefectural office also. The copy is sent to the related ministries, and it is digitized there. Though the reports are digitized, officers in town offices, village office and Kochi prefectural office did not recognized.
2. The reports are categorized in two based on the types of disasters, and sent to different organizations. For example, mountain fire is reported to the organizations and departments which are related to the Ministry of Agriculture, Forestry and Fisheries. Landslides, debris flow, slope failure and collapse were reported to the organizations and departments which are related to the Ministry of Land, Infrastructure and Transport. As a result, there is no system to share all mountain disaster information among the ministries and departments of Kochi prefecture.

Conclusions

Digitizing and standardizing the record of mountain disasters is effective for analyzing the situation comprehensively and the information is fundamental to make better plan for mountain disasters prevention and mitigation in forest management. Sectionalism among ministries and the government-initiated system used to be more effective for forest and disaster prevention planning, but the changing social background promotes the decentralization of power. Therefore local governments and residents need to recognize the recent environment more and to be involved to make forest management plan. In addition, because of the aging and decreasing population in Reihoku area, it is impossible to continue the same system for disaster prevention and rehabilitation as before. For example, since members of fire companies, who actually mitigate and rehabilitate disasters, are also aging and the number of member is decreasing. The digitizing and standardizing the record of mountain disasters is also helpful for limited number of human resource to recognize and make forest plan effectively. Since major disasters were recorded, digitized and standardized in Ministries, local offices are able to refer the way of data management for minor disasters. Because the information is supposed to be shared and referred by all related individuals and organizations, basic data should be simplified with same format. More survey and hearing are needed for utilizing the existing data and collecting data for the future.

Acknowledgments

The hearing was implemented with the cooperation of Reihoku NPO. The increasing number of NPOs and their activities are also noteworthy, since NPOs support local activities. Local residents and governments rely on their support more than before. Therefore they also need to know the same information. Sharing information makes the network stronger and more effective.

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Natural Dams, Temporary Lakes, and Outburst Floods in Western Canada

Marten Geertsema (British Columbia Forest Service, Canada) and John Clague (Centre for Natural Hazard Research, Canada)

Abstract Lakes impounded by dams of glacier ice and earth material (moraines, landslides, and alluvial fans) are common in British Columbia. Occasionally lakes drain catastrophically due to dam overtopping or failure. Some glacie- dammed lakes fill and drain annually or more often because hydrostatic forces and plastic flow allow subglacial conduits to open and close. Glacier dammed lakes tend to go through general cycles of growth and decay, with flood volumes diminishing over time as glaciers thin and retreat. Earth dams, especially moraine dams, may also breach and drain catastrophically. Once these dams fail, the lakes they impounded do not fill again. Although most outburst floods occur in remote areas, occasionally infrastructure and communities may be at risk.

Key words. Landslide dam, moraine dam, glacier dam, ice jam, beaver dam, outburst flood

1. Introduction

Lakes are formed by a variety of natural dams in western Canada. The dams may be composed of snow and ice, soil, rock, or organic materials. The dams may last for minutes or persist for millennia. Occasionally lakes drain catastrophically due to dam overtopping or failure.

2. Snow and ice dams

Ice jams and snow avalanches form short-lived natural dams in western Canada. Ice jams are dams formed by the accumulation of floating ice. They are particularly common in late winter on north-flowing rivers where the upstream areas melt before the lower reaches of the rivers. Examples are the Mackenzie and Liard rivers where ice jams raise water levels annually. Ice jams cause physical damage by scouring and by flooding. Ice jams are generally associated with spring thaw, but may occur at a variety of times during the winter (Brooks et al., 2001). They may persist for more than one month as in Prince George in the winter of 2007-2008 (Fig. 1). There an ice jam which grew to more than 34 km in length persisted for two months.

Snow avalanches may temporarily impound streams. The dams are typically short-lived, but may cause outburst floods and debris flows (Butler, 1989). In 1998 a snow avalanche dammed a mountain stream near Tete Jaune Cache, British Columbia. The outburst flood from the dam break caused a debris flow which closed a major highway.

Glacier dams may persist for decades, even centuries. Some glacier-dammed lakes fill and drain annually or more often because hydrostatic forces and plastic flow allow subglacial conduits to open and close. The dams may take on several forms (Fig. 2). Alsek River in northwestern British Columbia has been dammed by glaciers in the past, with the most recent damming by Lowell Glacier about 1850 (Clague and Evans, 2000). Today Tweedsmuir Glacier is perilously close to damming Alsek River after surging more than 1200 m since 2006 (Fig. 3; Chris Larsen: http://fairweather.gps.alaska.edu/chris/). At the time of writing (June 23, 2007) the glacier terminous was within 100 m of the valley wall (Doug Makkonen, personal communication). Glacier-dammed lakes may to go through general cycles of growth and decay, with flood volumes diminishing over time as glacier dams thin and retreat (Geertsema and Clague, 2005). Both Salmon and Tulsequah glaciers dam lakes that display such cycles (Figs. 4, 5, 6).

Fig. 1. Ice jam on Nechako River, British Columbia. Photo City of Prince George.

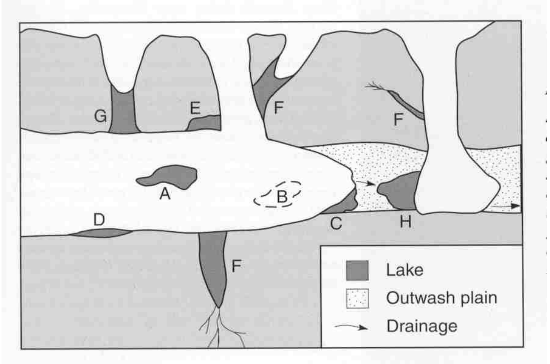

Fig. 2. Schematic diagram showing locations of different types of glacier-dammed lakes. A, supraglacial; B subglacial; C, proglacial; D, embayment in slope at glacier margin; E, area of coalescence between two glaciers; F, tributary valley adjacent to a trunk or tributary glacier; G, same as F except glaciers dam both ends of lake; H, main valley adjacent to a tributary glacier. Light toned area is land, white area is ice (after Clague and Evans, 1994).

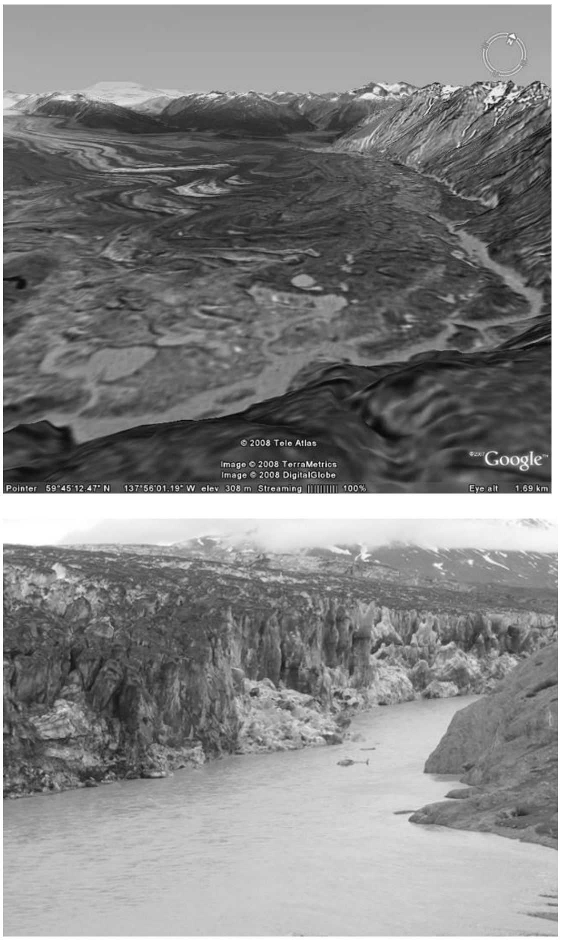

Fig. 3. Top: Surging Tweedsmuir Glacier threatens to dam Alsek River in northwest British Columbia. Google Earth Image. Bottom: Snout of Tweedsmuir Glacier at Alsek River, July 2008. Photo by Chris Pollard.

Fig. 4. Lake No Lake, after draining in 2001. Note icebergs strewn over the lake floor. Tulsequah Glacier in background. The lake drains under the glacier one to two times annually.

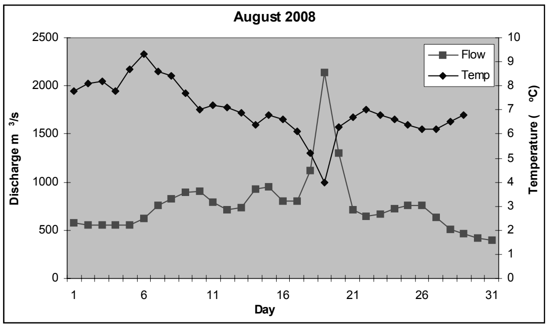

Fig. 5. Lake No Lake drainage event in 2008. Note the rapid rise and fall of the hydrograph and the drop in water temperature during the jökulhlaup.

Fig. 6. Jökulhlaup from Summit Lake. Note antidunes (standing waves), indicative of extreme discharge.

3. Soil and rock dams

Moraines, landslides, and alluvial fans can impound lakes in western Canada. Moraine dams form as glaciers retreat from their maximum positions. Moraine and landslide dam failures can result in catastrophic outburst flooding (Clague and Evans, 1994). Once these dams fail, the lakes they impounded do not fill again.

Landslide dams involving soil are especially common in northwest Alberta and northeast British Columbia (Cruden et al., 1993, 1997; Geertsema et al., 2006). Here deep-seated landslides in clayey glaciolacustrine sediments and till commonly impound streams (Fig. 7). On large rivers the dams rarely persist for more than a few hours, but on smaller streams dams may persist for decades.

A landslide in glacial sediments dammed Chilcotin River for one day (Fig. 8). The dip and spike in the hydrographs of the Chilcotin and Fraser rivers could be traced downstream 400 km to near Vancouver (Fig. 9).

Rock debris dams originate from rockslides and occur in mountainous areas around the world (Costa and Schuster, 1988). While rockslide dams may be porous, they are also among the longest-lived natural dams. Figure 10 shows an example of a rockslide that dammed Cathedral Creek and its tributary in Canada's Northwest Territories.

Lava flows have impounded rivers in northwest British Columbia. In 1775 a lava flow in Nass Valley (Cathie Hickson, personal communication) created Lava Lake, which persists to this day.

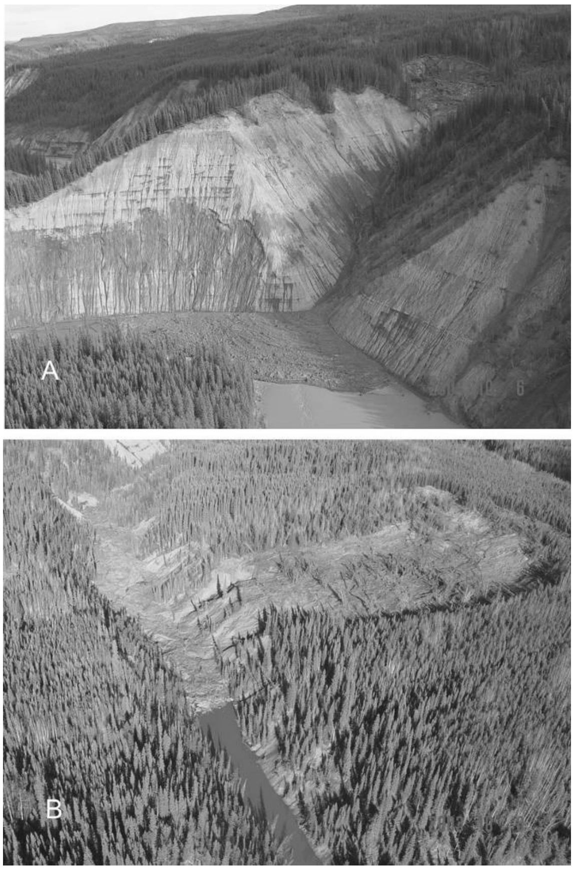

Fig. 7. Contrasting landslide dams on (a) Buckinghorse River and (b) one of its tributaries. The dam on the tributary has existed for more than a decade.

Fig. 8. Lake behind landslide in glacial sediments on Chilcotin River. Photo by Brian Bentley.

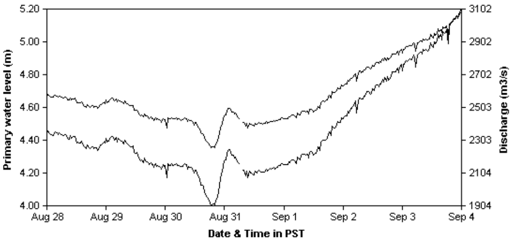

Fig. 9. Water level (upper line) and discharge (lower line) on Fraser River at Hope over a one-week period at the time of a landslide on Chilcotin River in 1964. Data downloaded from http://scitech.pyr.ec.gc.ca/climhydro/mainContent/main

Fig. 10. Rockslide dam impounding Cathedral Creek and its tributary in the Northwest Territories.

Fig. 11. Scoured outlet produced by beaver dam failure at Chudnulida Lake, British Columbia. The flood triggered landslides by toe erosion.

Catastrophic outbursts from landslide dams in western Canada are relatively rare. Commonly dams are gradually incised. Flood volumes may be significant and can be traced on hydrographs. In exceptional cases dam bursts can be catastrophic. In notes from the Hudson Bay Journal, John McLean wrote: "*I observed at one place a tremendous land-slip, caused by the water undermining the soil. Trees were seen in an inverted position, the branches sunk in the ground and the roots uppermost; others with only the branches appearing above the ground; the earth rent and intersected by chasms extending in every direction; while piles of earth and stones intermixed with shattered limbs and trunks of trees, contributed to increase the dreadful confusion of the scene. The half of a huge hill had tumbled into the river, and dammed it across, so that no water escaped for some time. The people of Dunvegan, seeing the river suddenly dry up, were terrified by the phenomenon, but they had not much time to investigate the cause: the river as suddenly reappeared, presenting a front of nearly twenty feet in height, and foaming and rushing down with the noise of thunder.*" The landslide dam and outburst flood likely happened sometime in the 1820s (Ted Binnema, personal communication).

4. Beaver dams

Beaver (*Castor Canadensis*) dams are common in forested areas of western Canada. Beavers construct dams of sticks and mud. Breaches in the dams are continuously repaired by the beaver while local food supplies (the inner bark of deciduous trees) last - usually six to ten years. Dams are abandoned and prone to failure after the food supply is exhausted. Beaver dam failures may cause minor washouts that plague highways and railways. Occasionally, where beavers dam the outlet streams of lakes, failures can be catastrophic. Geertsema and Menounos (2006) investigated a beaver dam failure near Prince George, British Columbia, where the outlet stream of a 60 ha lake was raised 2.5 m. When the dam failed, 1.5 Mm^3 of lake water eroded and rerouted the outlet creek over a distance of 4 km (Fig. 11). 80,000 m^3 of gravel was deposited at the mouth of the stream.

5. Socioeconomic impacts

Natural dams in western Canada occur in a variety of materials and settings. Flooding from ice jams on rivers has the greatest economic cost. Costs related to ice jam flooding in Prince George approached $CDN 20 million. Moraine and glacier dam floods tend to occur in remote areas of western Canada and pose less risk to infrastructure.

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Landslide Management in the UK – Is It Working?

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Abstract.
As a country with limited experience of significant natural disasters, the UK has not developed a sophisticated legal and regulatory framework for the mitigation of landslide hazards. The 1966 Aberfan disaster stimulated academic research into landslide mechanisms but a number of high-profile events and a series of 'near-misses' since then, have had short-lived impact upon political motivation and policy development.
In the UK, landslide events tend to be managed locally, with limited national coordination. Efforts in the 1980s and 90s to make national assessments of geohazards and to provide guidance to planning authorities had some success but ultimately failed to develop into an effective, integrated, national response to landslides. The existing system relies on a combination of planning guidance, which varies between the devolved governments, and building regulations. However, the system offers no framework for the legal or financial responsibilities for hazard management. As a result, landslide management in the UK has been influenced more by planning and political structure than actual risks to the population and, as a consequence, does not provide sufficient safeguard to the population.

Keywords. Management, planning, strategic, responsive

1. Landsliding in the UK

The UK is seismically stable, contains no active volcanoes, has few large-scale landslide or karst failures and, has few problems with droughts or wildfires. Swell-shrink of clay soils causes the largest financial losses (around £3-400 m per year) but does not cause injury or loss of life. Flooding causes similar losses but this is not large relative to mainland Europe. This situation has had a pervasive effect upon the attitudes of the public, planners, politicians and geoscience professionals that is potentially placing citizens at risk.

Landslides are recognized by geoscientists and engineers as a problem in the UK, but are considered to occur locally or under extreme weather conditions and thus pose little threat to life, property and infrastructure. They are also widely considered to be easily mitigated. In 1994, the Government commissioned a study to assess whether this assumption was reasonable. The commissioned desk study identified 8835 landslides; produced the first overview of the pattern of landslides and landslide hazards in the UK and informed the development of planning policy (Jones & Lee 1994). However, as discussed by those authors and elsewhere (Foster et al. this volume), the study was limited and underestimated the landsliding problem in the UK.

Since 2006, BGS has collated information on 'significant' landslide events reported by staff, media or by local authorities (Table 1). Although the information is incomplete, and as yet forms a relatively short record, it shows that there are, on average, 27 significant reported landslides in the UK every year. A further estimate of the extent of the landsliding problem in the UK is gained from analysing the BGS GeoSure dataset that estimates landslide susceptibility across the country (Foster et al., this volume). According to the dataset, 350 000 households in the UK, representing 1% of all housing stock, are in areas considered to have a significant landslide threat.

All recorded deaths due to landsliding the UK have resulted from rock falls and debris flows (Table 2). Most incidents involved citizens involved in leisure pursuits, educational visits, or construction activity (the table does not include those in quarries or from indirect impacts such as car collisions). The largest single landslide event occurred in 1966 when coal waste destroyed a school in the Welsh town of Aberfan (Anon. 1967). Table 2 presents a number of important points that are relevant in understanding the basis of planning in relation to landslides in the UK. First, there are very few fatal landslides in the UK. Second, fatal landslides are very isolated and tend to involve only single persons. Third, there is no consistent pattern from year to year.

Although there is insufficient data to make valid judgement of the data, however, there is a clear trend of increased *reported* fatal landsliding in the UK during and since the 1970s. This is possibly a result of greater numbers of citizens pursuing leisure activities around dangerous coastal sections but may also reflect a general increase in sensitivity to impacts by natural disasters. However, it is difficult to disassociate this trend from the Aberfan disaster that caused 144 fatalities, of which 116 were children. The landslide prompted the first government investigation into a single landslide event and arguably, made citizens more sensitive and aware of landslides as hazards.

Table 1. 'Significant' landslides in the UK 2006-present.

Year	Number of landslides
2008 (to July)	7
2007	38
2006	32
2005 (from Apr)	11

Table 2. Recorded fatal landslides in the UK, by type (debris flow– DF; rockfall– FA) and activity (leisure– L; educational– E; construction– C, Research– R. other work O).

Landslide	Year	Killed	Type	Activity
Whitehaven, Cumbria	2007	1	FA	L
Ben Nevis, Lochaber	2006	1	FA	L
Nefyn, Gwynedd	2001	1	DF	L
Newquay, Cornwall	1986	1	FA	O
Durdle Door, Dorset	1979	1	FA	L
Lulworth Cove, Dorset	1977	3	FA	E
Swanage Bay, Dorset	1976	1	FA	E
Kimmeridge bay, Dorset	1971	1	FA	L
Aberfan, S Wales	1966	144	DF	E
Alum Bay, Isle of Wight	1959	1	FA	L
Boscombe, Dorset,	1925	3	FA	C
Loch Ness, Scotland	1877	1	FA	R

2. Strategic Planning for Landslides in the UK

There is no centralized, legally binding mechanism for the management or mitigation of landslides in the UK. Instead, there is an evolved system of planning regulations, and guidance notes for governmental bodies, and a series of operational regulations and building codes for major companies and utility operators. Landslides planning policy is primarily enshrined in the Town and Country Planning Act, Building Regulations and the Housing Acts and the Health and Safety at Work Act. Further considerations of public safety are made in the Coal Mining (Subsidence) Act, Coal Industry Act and Occupiers Liability Acts. The majority of this legislation places responsibility for ensuring safety from landslides and other natural phenomena with the developer, utility operator or landowner.

The delivery mechanism for the Town and Country Planning Act is a series of Planning Policy Guidance Notes (Anon 1990, 1994). These recommend that slope instability is considered in any planning decision and that, if it is an issue, the developer must provide evidence that any building activity will not exacerbate landslide activity and that the building will be safe. The notes are not legally compulsive. They do state that '*The stability of the ground…. is a material consideration which should be taken into account when deciding a planning application'*. However they go on to state that: '*Many local planning authorities may no…have the required expertise available to them. Where relevant expertise is available…..the local authority should endeavour to make use of it'*. The list does not include geological or geotechnical expertise. There is no legal compulsion for authorities to understand the extent or nature of hazards within their district.

Building regulations provide control on the impact of slope instability requiring that *'The building shall be constructed so that ground movement caused by….land-slip or subsidence…. in so far as the risk can be reasonably foreseen, will not impair the stability of any part of the building'* (Anon 2004). Again, liability is placed upon the developer, but there is no compulsion to seek or use information on landslide hazard around the development. (Brook 2007). Brook & Marker (2008) warned about the threat to even this level of detail in future revisions.

The delivery mechanism for Health and Safety legislation is a complex series of regulations that oblige operators of utilities to protect citizens from any potential harm caused by their operation and to prove that they have done so. For instance, industry specific regulations require that quarry operators, pipeline operators, chemical warehouse operators and a multitude of other such organisations must consider the potential impact of landslides upon their operations and any potential impacts upon 3rd parties. Although this is a complex area, it addresses concerns for specific industries. For instance, operators of chemical warehouses must submit a report that should demonstrate that the probability of a major fire is around 0.01/year. As part of this report, the possibility of a landslide initiating a fire must be considered and shown to be acceptable.

None of these mechanisms provide guidance on the information that should be sought to assess landslide risk, or what measures are appropriate in terms of public safety or long term remediation. The responsibility for this always lies with the operator or their technical expert.

3. Responsive Action to landslides in the UK

As with the planning system, response to landslide events in the UK is essentially a local matter, with little guidance given to the responsibilities or procedures to be followed. In the event of a major landslide, initial response is controlled by the civilian emergency services, police, fire service and medical personnel. A local emergency control centre, usually in the control of the police, is formed to deal with initial rescue and stabilization efforts. Once this has been completed, responsibility for the site will pass to the landowner of the property affected or from where the landslide was sourced. Often this is a local government body or operator of a road or pipeline. They will be responsible for repairing or stabilizing the site to the extent that it will no longer pose any threat.

Events, where a landslide may not cause immediate threat to life or property but may cause some disruption also tend to be dealt with locally. Local failures are typically cleared within a few hours, with no record kept of the nature disruption or repair. The Highways Authority, for instance, which is responsible for the maintenance of major roadways in the UK, does not routinely record landslide events that affect its network; rather, it records that a repair action has occurred at a certain chainage, with little supporting information on the nature, cause or impact of the failure.

3.1 Holbeck Hall Hotel Landslide

The Holbeck Hall Hotel in Scarborough, N England was destroyed by a landslide that took place between the 3rd and 7th of June 1993 (Lee 1999). The hotel had been built in 1880 above a coastal slope known to have been susceptible to movement. Following a day of heavy rain, a relict landslide reactivated on the slopes beneath the hotel, completely undermining and destroying the building (Figure 1). The slide was slow enough to enable the evacuation of all occupants.

UK legislation deems that a landowner owes a duty of care to anyone affected by their land, but only if they know the extent of the problem. There is no requirement for them to fully investigate or understand any problem. In this case, responsibility was ambiguous, there was dispute between three parties: the owner of the hotel; the local authority upon whose land the actual side took place; and a geotechnical consultant who had been commissioned to investigate the potential for slope instability in the area. The legal ambiguity caused a situation where there was no clear responsibility for the event. The subsequent court case [Holbeck Hall Hotel Ltd v. Scarborough Borough Council, English High Court, London, 2000] did little to clarify the situation.

3.2 Glen Ogle Landslide

The Glen Ogle landslide involved two debris flows that crossed the A85 highway, north of Lochearnhead on the 18th August 2004 (Winter et al. 2006). The slopes in this area, are characteristic of a glaciated terrain, with flat, peat covered hills, above steep slopes that lead down into flat bottomed valleys. At Glen Ogle, the A85 road traverses the side of one of these valleys, as a narrow two lane highway. Streams and channels in normal flow are culverted underneath the road.

The flows of 2004 overwhelmed the culverts and blocked the highway, trapping 57 people in 20 vehicles. All 57 people were airlifted to safety helicopter and their vehicles retrieved over the next 2 days. The result of this event can only be described as a success, with all persons safely evacuated from the site. However, disruption to the road was significant and lasted for several days. A significant outcome from this event was the realisation of the Scottish Government that there was insufficient information on the debris flows hazard of Scotland. As a direct result, a study was commissioned which has developed a model of the distribution of potential debris flows in Scotland, and the risks to the roads network associated with them (Winter et al. 2005).

Figure 1 Holbeck Hall Landslide, Scarborough, 1993.

3.3 Nefyn Landslide

The Nefyn slide involved a mass of only 100 m^3 of superficial material, moving 12 m downslope. December 2000 had been characterised by very high rainfall, which had saturated debris accumulated on a concave section of the coastal slope. On January 2nd 2001, a small landslide in the steep upper cliff moved downslope onto the debris accumulation, causing undrained loading (Figure 2). Two debris lobes moved downslope, engulfing parked cars, pushing three over a low sea cliff, resulting in a fatality to an occupant of one of the cars. Emergency response was controlled by local police and fire service officials who made the area safe and allowed access to investigation crews and specialist personnel (Figure 2). A BGS investigation into the cause of the landslide and the surrounding area resulted in a hazard map that provided guidance on future development in the vicinity (Gibson et al. 2002). This recommended that no development be allowed on or below the debris covered slopes. The report allowed prevention of new development, but there is no legal mechanism to prevent such alterations or repair to existing properties so long as there is no risk posed to third parties by the actions of the property owners. Since the 2001 landslide, a number of nearby properties have been damaged by small landslides and have been rebuilt.

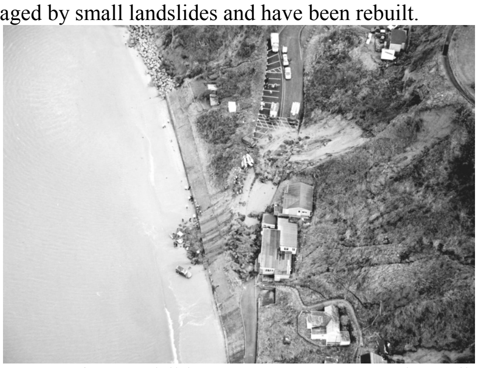

Figure 2. Nefyn Landslide. Image courtesy N Wales Police.

4. Responsive Management of Landslides in the UK

The few examples presented here, have been selected to illustrate an important point. When a significant landslide event occurs in the UK, the response, by the emergency services, military, local government officials and general public is exemplary. Incidents are dealt with promptly in a well-structured and well-considered manner to ensure that public safety is maintained. Each event was followed by some form of investigation or review of the cause and impact of the landslide and led to follow-on actions, usually in the form of a public inquiry followed by a change in local or regional planning policy.

It is difficult to judge the effectiveness of the management of smaller events that are dealt with at a local level. There is no compulsion to record costs or practice or to communicate information to a government audit. As such, there is little valid information that could be used to analyse the true cost of landslides in the UK and, thus, whether management is working. Recent efforts by BGS have such collated such information only since 2006, (Foster et al., this volume).

5. Strategic Management of Landslides in the UK

Assessing the *strategic* management of landslides in the UK is difficult. If we were to judge the effectiveness of landslide management in the UK based upon the number of casualties over recent decades, we may conclude that landslide management in the UK is working. There have been very few fatalities, relatively few injuries and only one event on record that would be considered to be ‘significant’ by international standards. However, the brief examination of recent events presented by this paper shows that there have been on average, 27 significant landslide events in the UK each year since 2006. Several of these events caused significant disruption to important transport links and had financial impacts of several million pounds.

If we were to judge the effectiveness of strategic landslide management in the UK based upon the economic and social impact of significant events, we may conclude that there has been a fair degree of success. The direct economic impact of major landslides in the UK is low. Total economic costs, including emergency response, engineering works, insurance claims, of the Holbeck Hall landslide have been estimated at around £2.5-6M, £2.5M for Glen Ogle, and around £1M for Nefyn. Even if we were to assume that the economic cost of a major landslide in the UK was at the lower end of this range at £1M, and that the actual number of significant landslides in the UK were twice the reported number, the total cost every year would be in the region of only £55 m. Experience of the authors indicates that this is far higher than we would expect the true figure to be, with most reported events costing less than £250 k in direct costs.

Theses figures do not take into account extensive landslide complexes that have a continuing impact upon certain locations. These include the complexes that affect the towns of Ventnor, Lyme Regis, Scarborough and Ironbridge. Investigation and engineering works at Lyme Regis For instance have cost over £30M since 1990. In addition, a government review of the cost of coastal erosion in the UK found that the average annual cost was £126M, a significant part of which must result from landsliding (OST 2003).

BGS estimate that 350 000 households in the UK are in areas where there is a significant landslide hazard. At the time of writing, the average purchase price of a house in the UK is £220 000. This means that, in the worst case, there is, potentially £77 bn pounds worth of housing stock at some risk of landslide damage in the UK. It should be emphasised that this is very much a worst case scenario and that this figure is almost certainly an overestimate by at least one order of magnitude. Again, is it difficult to provide statistically valid figures but it seems likely that even if 1% of those properties receive 1% damage in any given year, the total losses, in the region of £7.7 m per year would be significantly important as to warrant greater concern. It must be concluded that, overall, strategic management of landslides in the UK is working.

6. The Importance of 'Near-Misses'

The case studies presented here were chosen also to illustrate a further point. Each of these events, in themselves highly damaging, one of which was fatal, were, in fact, ‘near-misses’ in the sense that the consequences of the event could have been much more significant.

The Holbeck Hall landslide could have occurred much more rapidly, limiting the possibility of escape for the hotel residents. The Glen Ogle debris flow could very easily have resulted in the deaths of some, or all, of the persons rescued. The timing of the events, where one flow blocked the road, and a second trapped the parked vehicles was extraordinary. Nefyn was a tragic event, leading to a fatality and further serious injuries. However, it is fortunate that only one occupant (of the three vehicles which were displaced) was killed. It was also fortunate that other mudslides did not crush residential or commercial properties.

The authors of this paper have investigated and reported on many landslides that could be considered to be near-misses, and a great many more case studies could have been presented in this paper. However, at some point in the near-future, there will be a more tragic event in the UK that will involve multiple fatalities. As is the experience of many involved in this around the world, the potential for successful rescue from a landslide depends very much upon the nature of the failure as much as human factors such as the speed of response and medical facilities. Although the emergency response to each of the events described here was excellent – timely, structured, and well executed, there has been an amount of good fortune that the slides were of such a nature that rescue was possible and human losses low.

8. Conclusions

Whilst any analyses must try to indicate the real level of the problem, it is difficult to escape the fact that, in the UK, in an average year, an average landslide will cause little long-lasting damage and will be adequately managed by local action and strategy. In this instance, landslide management in the UK is working at both strategic and responsive levels.

However, emergency planning and response could be improved if relevant agencies knew more about geohazards in their area. Similarly, planners and buildings inspectors and utility operators need better access to simple, understandable information on landslides that is directly relevant to their decision making process (Brook & Marker 2008).

There is an important task to be done in making a full assessment of the true landslide hazards in the UK and assessing the spatial, temporal, financial and human risks involved. This would highlight those areas most at risk from landslides, ensure that that risk ‘hot-spots’ could be mitigated, and ensure that best practice is disseminated to reduce overall risks, and hopefully prevent future disasters.

Acknowledgments

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Rapid Assessment of Earthquake-induced Landsliding

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Abstract. We assess the likelihood of earthquake-induced landslides by combining global topographic data and geologic mapping with near-real-time estimates of ground shaking from large earthquakes. Results combined with global population estimates could provide emergency management with timely information on the possible effects of earthquake-induced landslides anywhere in the world. The distribution of topographic slope was calculated at 30-arcsecond spacing (roughly 1 km at the equator) using 3-arcsecond SRTM (Shuttle Radar Topography Mission) data. To calculate threshold acceleration necessary to initiate landsliding, a global assessment of landslide susceptibility was used to assign material strength parameters in a one-dimensional limit-equilibrium slope-stability analysis. This assessment of potential instability is then checked if it is exceeded by an estimate of strong ground motion provided operationally in the form of a "ShakeMap" by the U.S. Geological Survey National Earthquake Information Center. We apply this approach to two historical earthquakes, the 1976 moment magnitude (**M**) 7.6 Guatemala and the 1994 **M** 6.7 Northridge, California earthquakes for which detailed landslide inventories are available. Results capture the broad spatial pattern of earthquake-induced landslides, but the quality of estimates is a function, in part, of the quality and resolution of the input data. We then apply the method to the recent **M** 7.9 earthquake in Eastern Sichuan, China to examine the probable spatial extent of landsliding from this event.

Keywords. Landslide, earthquake, ShakeMap

1. Introduction

Landslides are responsible for a significant part of the societal effects of large earthquakes in mountainous regions of the world (Keefer, 1984). Recent examples from Kashmir in 2005 and Eastern Sichuan, China highlight their direct effects in terms of human loss and damage to the built environment. Because of their impact on transportation networks, particularly mountain roadways, landslides often hinder emergency response efforts in remote areas. Less frequent, but of great potential consequence, are the temporary reservoirs impounded by large landslides that block stream channels.

The U.S. Geological Survey's (USGS) National Earthquake Information Center (NEIC) in Golden, Colorado, reports on more than 30,000 earthquakes a year, 25 of which cause significant damage, injuries, or fatalities. The Prompt Assessment of Global Earthquakes for Response (PAGER http://earthquake.usgs.gov/eqcenter/pager/) system is designed to provide a near-real time estimate of an earthquake's impact on people and the built environment anywhere in the world to governmental and non-governmental relief organizations and the media (Earle and Wald, 2007). One component under development is an estimate of the potential for earthquake-induced landslides. To that end we have applied methods developed for regional landslide hazard zonation (e.g. Wieczorek et al., 1985; Jibson et al., 2000) to produce spatial estimates of the likelihood of landslides resulting from large earthquakes in a global, automated manner. Automated region-specific efforts have been described previously (e.g. Mahadavifar et al., 2008).

2. Methods and Data

We apply a simplified Newmark (1965) stability analysis on a distributed basis using globally available geologic mapping and topography. Such analyses are based on a critical or yield acceleration, a_c, above which ground acceleration is sufficient to overcome basal sliding resistance and initiate downslope movement,

$$a_c = (FS - 1) g \sin\alpha, \tag{1}$$

where FS is the static factor of safety, g, acceleration due to gravity, and α, the topographic slope angle in degrees (Newmark, 1965; Jibson, 1993). We calculated the static factor of safety using an infinite-slope stability analysis neglecting the influence of groundwater. Because earthquake-induced landslides are typically thin failures of surficial soil or regolith (Keefer, 1984) we follow Jibson et al., (2000) and assume a landslide thickness of 2.4 m. The critical acceleration is then checked to see if it is exceeded by the spatially distributed peak ground acceleration (PGA) delivered by the PAGER system using a modified "ShakeMap" approach (Wald et al., 1999) for a specific earthquake. Newmark displacement is then estimated using the regression equation developed by Jibson (2007),

$$\log D_{\mathrm{N}} = 0.215 + \log\left[\left(1 - \frac{a_c}{\mathrm{PGA}}\right)^{2.341} \left(\frac{a_c}{\mathrm{PGA}}\right)^{-1.438}\right] \pm 0.51 \tag{2}$$

where D_{N} is displacement in cm and the last term is the standard deviation of the model in cm. We assume that estimated displacements exceeding 5 cm produce deformation that is potentially hazardous to people and the built environment (e.g. Wieczorek et al., 1985). In what follows we describe the global topographic and geologic databases used for model input.

Global topographic database

Shuttle Radar Topography Mission (SRTM) elevation data were used to create a globally complete slope dataset at 30-arcsecond resolution (see Verdin et al., 2007 for a complete descripion of methods). Topographic slope was first calculated using the full resolution 3-arcsecond dataset (approximately 90 m at the equator), but the summary slope data layers were created at a reduced resolution of 30 arc-seconds. This resolution was chosen to be consistent with the ground-shaking estimates and the population datasets used in the PAGER system. Gaps in the SRTM data were filled using weighted scaling relations developed using the higher resolution (1-arcsecond) National Elevation Dataset (NED) available for the United States and the globally complete GTOPO30 (30-arcsecond) dataset. The topographic database consists of 15 data layers describing the distribution of elevation and topographic slope. The data layers used in the case study examples described below are the 1st, 10th, 30th, 50th, 70th, 90th, and 99th quantiles of topographic slope for each 30-arcsecond grid cell.

Global landslide susceptibility

We rely on a global landslide hazard evaluation presented by Nadim et al., (2006) to assign material strength properties to the land surface. Landslide susceptibility was estimated by ranking the map units that describe geologic age and lithology in a digitally available global geologic map (Hearn et al., 2003). For areas outside the United States, other investigators compiled the geologic database from existing 1:5M scale maps published by UNESCO (Hearn et al., 2003). Larger-scale geologic mapping is readily available for the continental United States (King and Beikman, 1974; Schruben et al., 1998) and Alaska (Beikman, 1980). We modified the Nadim et al., (2006) ranking adding several geologic units to the highest susceptibility category based on work by others examining the influence of lithology on landslide susceptibility (e.g. Parise and Jibson; Wang et al., 2007) and assigned friction angles and cohesion based on published values (e.g. Selby, 1993; Jibson et al, 2000) assigning the greatest material strengths to the least susceptible units in the modified ranking.

For the case study examples described in the next section, critical acceleration (eq. 1) and Newmark displacement (eq. 2) were calculated for each slope quantile. When combined, these calculations yield a spatial estimate of the likelihood of landsliding for a given level of ground shaking.

3. Case study examples

Guatemala 1976 magnitude 7.6

On 4 February 1976 a destructive earthquake struck eastern and central Guatemala killing more than 20,000 people and leaving nearly one fifth of the country's population homeless. Surface rupture along the Motagua fault extended for 230 km from the lower Motagua River valley to the west near Guatemala City (Plafker, 1976). The earthquake generated at least 10,000 landslides spread over an area of about 16,000 km^2 (Fig. 1A) concentrated in an area about 180 km west of the epicenter. Most were rock falls and debris slides of less than 15,000 m^3 in Pleistocene-age pumice deposits, however several larger landslides were identified, some of which blocked stream drainages creating landslide dams that subsequently failed (Harp et al., 1981). Landslides triggered by the earthquake were responsible for several hundred deaths and disrupted transportation on several major highways and the national rail system.

Figure 1B shows the distribution of PGA estimated for the Guatemala earthquake from the ShakeMap Atlas (Allen et al., 2008). Visual comparison of the pattern of modeled landsliding with the mapped landslide inventory (Harp et al., 1981) shows rough agreement of the extent of landsliding (Figs. 1A and 1C), but some areas of localized concentration are only captured by the lowest likelihood estimates. For example, the dense area of landslides north of Guatemala City falls in the 1-10% categories. We attribute this to the small scale of the geologic mapping , the uncertainty associated with the Guatemala ShakeMap, and the coarse scale of the SRTM topographic data. As stated previously, many of the landslides triggered by this earthquake were associated with young volcanic deposits that are not well mapped in this area in the global geologic dataset.

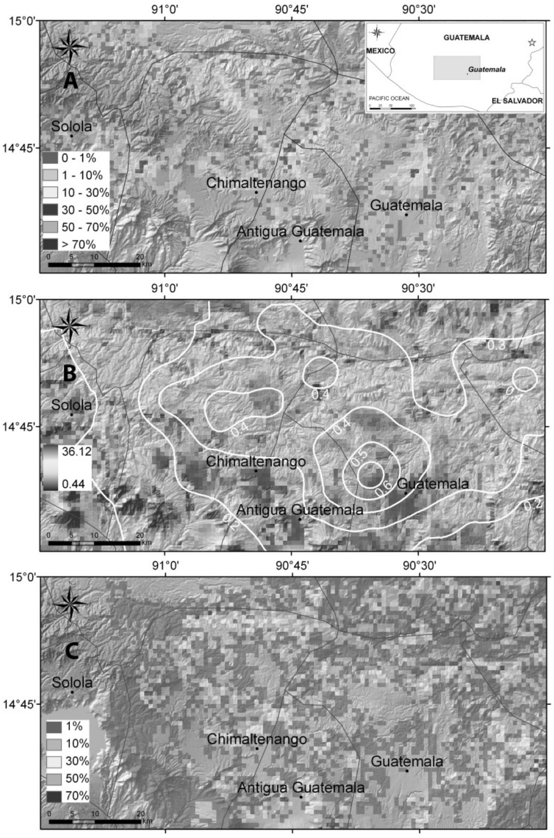

Fig. 1 Maps showing (A) spatial density of landslides as a percentage of 30-arcsecond cell area triggered by the **M** 7.6 Guatemala earthquake, (B) PGA in *g* (contours) and median topographic slope, and (C) estimated likelihood of landsliding.

Northridge 1994 magnitude 6.7

The 17 January 1994 Northridge, California earthquake caused widespread damage and estimated economic losses exceeding $55 billion (2007 $US; estimate from California Governor's Office of Emergency Services). Seventy-two people died as a result of the earthquake and many more were injured. The earthquake occurred at a depth of about 19 km on a blind thrust fault about 30 km northwest of Los Angeles and propagated northwest towards the ground surface (Wald et al., 1996). The earthquake triggered more than 11,000 landslides (Fig. 2A) over a 10,000 km^2 area (Harp and Jibson, 1995; 1996), most of which occurred in a 1000 km^2 area centered on the Santa Susana Mountains in the area of the largest permanent ground displacements (Wald et al., 1996). Most of the landslides were shallow (1-2 m thick) falls and slides of surficial materials overlying highly deformed Late Miocene through Pleistocene-age marine and non-marine sedimentary rocks on slopes ranging from about 25 to 50 degrees (Jibson et al., 1994; Parise and Jibson, 2000).

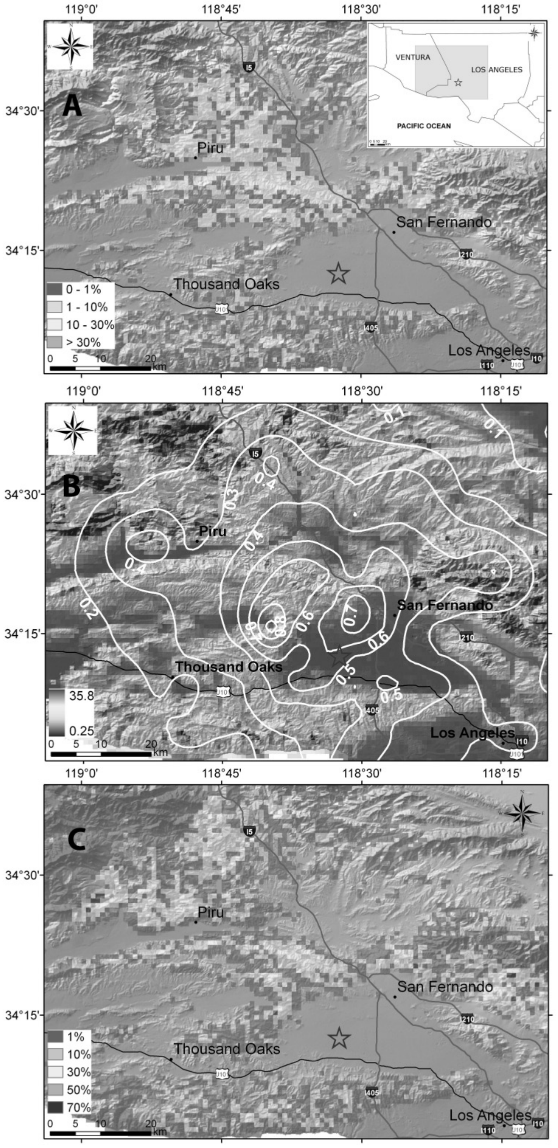

Fig. 2 Maps showing (A) density of landslides as a percentage of 30-arcsecond-cell area triggered by the **M** 6.7 Northridge, California earthquake (B) PGA in *g* (contours) and median topographic slope, and (C) estimated likelihood of landsliding. The stars indicate location of the epicenter.

Figure 2B shows the pattern of PGA associated with the Northridge earthquake created using instrumental data from several hundred strong-motion instruments (Wald et al., 1999). This better constrained distribution of ground shaking, compared to the Guatemala example, combined with larger-scale geologic mapping (King and Beikman, 1974; Schruben et al., 1998) produce an improved estimate of landsliding (Fig. 2C). Visual comparison shows agreement between the broad spatial pattern of landsliding as well as identification of areas of concentrated landslides (Figs. 2A and 2C).

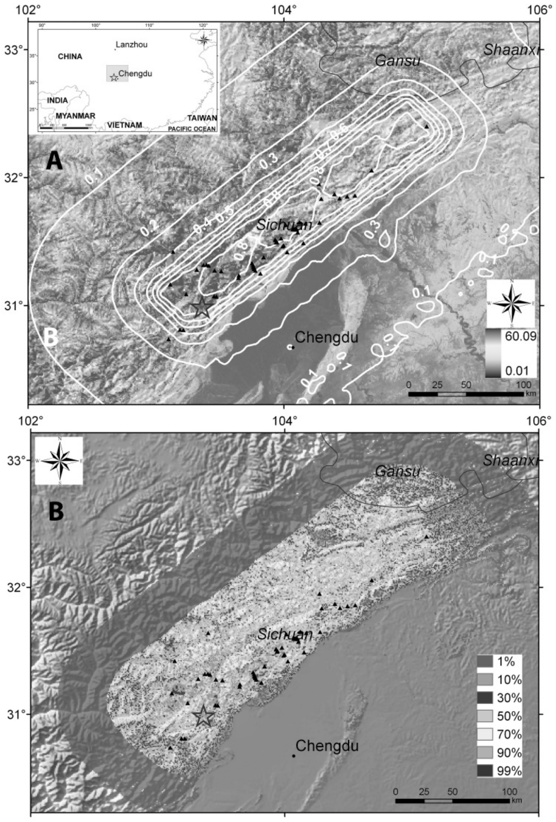

Fig. 3 Maps showing (A) PGA in *g* (contours) and median, topographic slope, and (B) estimated likelihood of landsliding in the Eastern Sichuan, China study area. Black triangles indicate the location of landslide dams identified from ALOS imagery taken in late May 2008. The stars indicate location of the mainshock epicenter.

Eastern Sichuan, China 2008 magnitude 7.9

The devastating earthquake on 12 May 2008 in Eastern Sichuan, China (Fig. 3A) occurred as the result of motion on a northeast striking reverse fault or thrust fault on the northwest margin of the Sichuan Basin (USGS-NEIC). Official figures of loss and damage include nearly 90,00 dead or missing, several hundred thousand injured and more than 5 million left homeless. Tens of thousands of landslides were apparently triggered and more than 100 landslide dams were formed in this region of extreme relief on the margin of the Tibetan Plateau (Burchfiel et al., 2008; Stone, 2008). Figure 3A shows the distribution of PGA. Note that the region of very strong ground motion (PGA > 0.5 *g*) extends for several hundred km along the mountain range front and is in general coincident with the area of high landslide likelihood (Fig.3B). To our knowledge, no landslide inventory is currently available, but we have identified the location of more than 60 large landslide dams using ALOS imagery, which are shown in Figure 3B. These locations generally coincide with the areas predicted to have a high likelihood of landslides.

4. Concluding discussion

Near-real-time assessment of the societal impacts of large earthquakes in mountainous regions require some estimate of landslide occurrence. We present a method for providing such an estimate using globally available digital topographic and geologic information. These data, combined with PAGER/ShakeMap, can provide a rapidly available, first-order assessment of the landslide potential following large earthquakes. Case-study results indicate that the quality of the ground-shaking estimates and the scale of geologic mapping have a substantial, but as of yet, unquantified influence on the accuracy of the estimates of the spatial extent and distribution of landsliding. Results are likely to improve as new, larger-scale, digital geologic mapping (e.g. OneGeology) and additional real-time strong motion data become available.

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Reducing Landslide Hazards through Federal, State, and Local Government Cooperation: The Seattle, Washington, Experience

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Abstract. The Pacific Northwest in the United States including Seattle, Washington, experienced unusually heavy rainfall in the winters of 1995/1996 and 1996/1997, which caused numerous landslides. Following these two winters, the City of Seattle resolved to reduce future landslide losses within its jurisdiction. By coincidence, in 1997 the U.S. Geological Survey (USGS) began a five-year project designed to increase scientific understanding of all the natural hazards facing the Seattle area, including landslides. This article documents the convergence of the efforts of the City of Seattle, the State of Washington, and the USGS to understand the landslide hazards facing the Seattle area and to implement hazard reduction and mitigation of damage from landslides. Specifically, this article identifies how and where USGS information on landslide hazards fit in with efforts already undertaken by the City. This combined effort enabled the City of Seattle to understand its landslide hazards, to formulate public policy, to educate its citizens, and to coordinate the activities of the numerous departments under its jurisdiction with the ultimate goal of lessening the impact of landslides. The City used USGS maps and reports to guide decisions that prioritized funds for siting, maintaining and constructing public facilities in addition to meeting Washington State laws that mandated growth management and environmental review.

Keywords. Land-use planning, landslide hazard mitigation, landslide hazard reduction, landslide public policies

1. Background and Methodology of the Study to Document the Use of USGS Landslide Hazard Information in Seattle, Washington

In the winters of 1995/96 and 1996/1997, the Pacific Northwest in the United States experienced a series of devastating floods and landslides. After the winter storms of 1996/1997, the City of Seattle, Washington, initiated a major effort to reduce losses from landslides. By coincidence, at the time the storms occurred, the U.S. Geological Survey (USGS) was supporting a multi-hazards research project in the region (Gori 1999). The USGS Landslide Hazards Program continued its scientific investigations in the region until 2006. The USGS research complemented and was coordinated with the City of Seattle's efforts. This paper documents the cooperative and complementary efforts of the City of Seattle, the State of Washington, and the USGS to understand the landslide hazards facing the Seattle area and to implement policies that reduce damage from landslides.

It has been long recognized that communities can reduce their vulnerability to disasters, including landslides, through planning and managing land sensibly (Burby 1998). To increase the use of geologic information, USGS collaborated with the American Planning Association on "Landslides and Planning," a report designed to assist land-use planners and public officials to effectively use geologic information in their planning processes in order to reduce losses from landslides (Schwab 2005). For land-use plans to be successful, they must be linked to other decisions made by a community, such as investing in and siting public facilities, subdivision and grading regulations, and other policies concerning land development (Schwab 2005). In 2007, the USGS Landslide Hazard Program enlisted the help of a local planning firm, Planwest Partners, Inc., to help evaluate how research on landslide hazards conducted by USGS in the Seattle area was used (Gori 2008). This paper summarizes the findings of that study.

The methodology of the study included a review by Planwest Partners, Inc., of the research by USGS, the City of Seattle, and its contractor, Shannon & Wilson, Inc., concerning landslide hazards of the region. It also included extensive interviews by Planwest Partners with numerous Seattle public officials and others who were instrumental in landslide hazard reduction policy, including the following Seattle agency representatives: Seattle Public Utilities, Seattle Department of Transportation, Department of Planning and Development, Department of Parks and Recreation, Police Department, and Office of Emergency Management. In addition, two roundtable discussions were organized, the first with the representatives of the above agencies who were involved with setting landslide hazard reduction policies, and the second with USGS scientists who conducted research in the Seattle area. Following the initial interviews and the roundtable discussion with City of Seattle representatives, Planwest Partners reviewed Washington State and Seattle regulations and laws that encouraged passage and enforcement of landslide hazard reduction policies.

2. Use of Landslide Hazard Information in Local Land-Use and other Public Policy Decisions in Seattle, Washington

The United States relies on different levels of government to enact and enforce land-use decisions, which are the basis of numerous landslide hazard mitigation and reduction policies. Land-use and development decisions are for the most part made at the local level. They include decisions about density and type of land-use permitted, how buildings are sited, and the location of public improvements such as roads, parks, schools, and other public amenities. State governments enact general requirements that may facilitate the local policies. At the national level, federal government agencies, such as the USGS, have a minimal role in land-use planning and enforcement but do provide information that may be of use to local governments as they implement land use and hazard reduction policies.

In the Seattle area, each level of government brought different capabilities to the task of reducing the City's exposure to future damage from landslides. When Seattle experienced the impact of two successive winters with abnormally high rainfall, officials decided more stringent approaches to reduce the landslide hazard were needed. A key foundation of the new landslide hazard reduction approach was a scientific one—to understand the landslide hazards and to formulate remedial measures to combat them. Seattle commissioned the consulting firm of Shannon & Wilson to undertake an inventory and landslide characterization study. The inventory was to be used to better define landslide hazard zones within the City, to aid in the landslide policy decisions by City officials, and to increase public knowledge of landslides in the City.

City of Seattle Efforts

Throughout the winter and early spring of 1996/97 the City of Seattle experienced severe weather conditions leading to over 300 reported landslides that inflicted millions of dollars of damage to public and private property (Shannon & Wilson, Inc. 2000). These damaging conditions would also subject the City to exposure to lawsuits. The extent and magnitude of the winter-storm-generated landslides were strong indications to the Seattle City Council of the critical need for a comprehensive program to address the landslide hazard.

Shortly after the disasters, the City prepared a detailed policy and strategy document on landslide hazard mitigation. It also established the legal mandate for actions through three resolutions between April 1997 and June 1998: Resolution # 29575 adopted April 1997 (City of Seattle, 1997) and Resolution # 29694 adopted February 2, 1998 (City of Seattle 1998a) outlined specific actions to be undertaken. The first resolution-- Resolution #29575, which became the City's landslide hazard reduction guidance document, established a framework for an integrated policy of landslide hazard mitigation, including the City as regulator, property owner, provider of utilities and services, and interdepartmental coordinator (Gori 2008). Through the second resolution, Resolution 29694, the City defined principles to guide its goals and policy framework. Actions relating to landslide damage were organized into three categories: 1) Public safety pertaining to emergency management, 2) Infrastructure and service standards pertaining to repair and design, and 3) Risk management to reduce losses to the city's own property.

The City adopted a third resolution on June 22, 1998, Resolution 29774 (City of Seattle, 1998b), to guide development of its programs relating to landslides. City departments were directed to propose programs to the City Council to fulfill policy objectives pertaining to landslide hazard reduction, including, information and education, regulatory reform and enforcement, interdepartmental cooperation, and standards for street improvements and drainage infrastructure. The Resolution also designated Seattle Public Utilities (SPU) as coordinator of the program with specific mandates for landslide hazard reduction, and each department was to address funding priorities (Gori 2008).

Although Seattle has a long history of landslides and landslide awareness, the landslides of 1996/1997 focused attention on the need for a more precise understanding of the landslide hazard as an essential component of a loss reduction program. Prior to the 1995/96 and 1996/97 rainfall seasons, the City of Seattle had among the most comprehensive, historical records of landslides in the U.S. These records were converted into a database that included 1,326 landslide events which occurred over 100 years and was categorized and plotted using GIS. Shannon & Wilson's study characterized four key landslide types and their locations: 1) high bluff peeloff, 2) groundwater blowout, 3) deep-seated landslides, and 4) shallow colluvial (skin slides) (Shannon & Wilson, Inc. 2000). The City of Seattle also commissioned the production of landslide hazard and seismic hazard maps from the USGS and the University of Washington. The City of Seattle completed a comprehensive GIS application, adding the landslide inventory and the hazard maps to their existing municipal information. This information has been placed on maps on the City of Seattle web site at: http://web1.seattle.gov/dpd/dpdgisv2/mapviewer.asp

USGS Efforts

Two key objectives formed the basis of the USGS Seattle Landslide Project. The first was to improve scientific understanding of where landslides could occur and provide a quantitative assessment of landslide occurrence and hazard by estimating the timing and magnitude of hazards. The second objective was to provide information that could be used by public officials and the public for landslide hazard reduction policies.

To achieve the first objective, the USGS monitored geologic and hydrologic processes and studied the evidence of previous events. The following is an annotated list of the major USGS products that resulted from the above research:

1. Shallow Landslide Hazard Map of Seattle, Edwin L. Harp, John A. Michael, and William T. Laprade, USGS Open File Report 2006-1139--Shallow landslides are the most common type of rainfall-induced slope failure in Seattle, and thus were a top priority for the City of Seattle. Products from three prerequisite efforts (geologic mapping, soil strength data and high resolution topographic LIDAR data) were used to evaluate the stability of each slope segment indicated on the base map. The stability was indexed and the results were compared with the landslide data set. The resulting Shallow Landslide Hazard Map indicated relative landslide hazard categories of High, Medium, or Low.
2. Report and Map showing Landslide Susceptibility Estimated from LIDAR Mapping and Historical Landslide Records, Seattle Washington, William Schulz, USGS Open File report 2005-1405--The landslide terrain map shows the geomorphology of the Seattle area for three kinds of landslide features—landslide headscarps, landslide deposits, and denuded slopes. Nearly all of the landslides mapped from the LIDAR data are complexes consisting of numerous individual landslides.
3. Preliminary Map Showing Landslide Densities, Recurrence Intervals and Annual Exceedance Probabilities as Determined from Historic Records,

Seattle, Washington by J.A. Coe, J.A. Mitchael, R.A. Crovelli, and W.Z. Savage, USGS Open File Report 2000-303--Seattle's historical landslide database was used to apply a time dependent probabilistic approach to the evaluation of future landslides. The products include a map showing landslide densities, main recurrence intervals, and annual probability of exceedance as determined from historic records. The analysis indicates annual probabilities for climatically induced landslides.

4. Modeling 3-D Slope Stability of Coastal Bluffs Using 3-D Groundwater Flow, Southwestern Seattle, Washington by Dianne L. Brien and Mark E. Reid, USGS Scientific Investigations Report 2007-5092--Because deep landslides on the coastal bluffs are large, their stability is controlled by three-dimensional effects, including complex, three dimensional groundwater flow as well as variations in strength and topography. The deep landslide hazard analysis indicates the potential for these large landslides by showing the relative stability and instability of slopes on the bluffs.
5. Rainfall Thresholds for Forecasting Landslides in the Seattle, Washington, Area-Exceedance and Probability by Alan F. Chleborard, Rex L. Baum, and Jonathan W. Godt, USGS Open File Report 2006-1064 and Web page showing rainfall conditions relative to landslide thresholds at http://landslides.USGS.gov/monitoring/seattle-- USGS developed a prototype dynamic method to track changing landslide susceptibility as rainfall occurs. The strong association between major landslide events and rainfall as well as increasing needs to anticipate landslide activity to protect public safety and reduce landslide related losses in Seattle motivated the USGS rainfall threshold research for the Seattle area. The rainfall component of the project had three objectives: 1) Summarize a database of historical landslides used to test the thresholds, 2) Summarize their statistical analyses of the rainfall thresholds' exceedance, and 3) Describe estimates of the probability of landslide occurrence given exceedance. This tool is used by City of Seattle emergency personnel every winter as they decide how to stage scarce resources to best respond to the threat of landslides.

An important aspect of the USGS Seattle Landslide Project was that the scientific studies be made available to the non-technical public and community interested in implementation and that City departments be given information about how the USGS prepared its products and how to use them. The following products and activities support the second objective of increasing public outreach and training:

1. Learning to Live with Geologic and Hydrologic Hazards by Paula L. Gori, Carolyn L. Driedger, and Sharon Randall, USGS Water-Resources Investigations Report 99-4182.
2. Landslide Hazards in the Seattle, Washington, Area by Rex L. Baum, Edwin L. Harp and Lynn M Highland. USGS Fact Sheet 2007-35005.
3. Cumulative Precipitation Threshold, Rainfall Intensity-Duration Threshold with link to Real-Time Data at http://landslides.usgs.gov/monitoring/seattle
4. USGS Training Workshop for City Staff on May 16, 2006—Half day workshop attended by 44 local government and private industry representatives. The workshop was sponsored by USGS, Project Impact Seattle, Seattle Public Utilities, and University of Washington to highlight the latest scientific discoveries on landslide issues and to introduce the major new products developed for Seattle.
5. Press Briefing on new USGS and University of Washington products held on May 17, 2006—The USGS, Project Impact Seattle, Seattle Public Utilities, and University of Washington held a press conference that released and explained new landslide hazards maps and resulted in numerous TV and print media articles in the Seattle area.
6. Informal meetings with City staff—During the project, USGS staff met with City staff to explain how to use maps and reports and to refine its products.

Interviews conducted by Planwest Partners with representatives of the City of Seattle revealed that the products developed by the USGS Seattle Landslide Project were integrated into decision making and policy implementation (Gori 2008). These uses include, but are not limited to, rigorous consideration of the potential landslide hazards in relation to decisions on siting and maintaining public facilities such as roads and schools, and implementing the City's Drainage Plan (City of Seattle 2004) and Critical Area Regulations (City of Seattle 2006). These maps and reports were also used in conjunction with environmental review on public and private projects as well as strategic planning for response readiness and tabletop exercises. Interviews also confirmed that the report, "Rainfall Threshold for Forecasting Landslides in the Seattle, Washington, Area" is used as a basis for landslide warnings and alerts by the City of Seattle and that real-time monitoring of landslide conditions is also available to the public on: http:/landslides.USGS.gov/monitoring/seattle (Gori 2008). Also, the City's cooperative approach to funding allowed departments to leverage funds for landslide hazard reduction from multiple funding sources. The new funding mechanism, which authorized the collection of drainage management fees, gave the City of Seattle a new revenue source to implement landslide hazard mitigation.

State of Washington Efforts

The State of Washington contributed to the success of the adoption of landslide hazard reduction policies through the Growth Management Act (GMA) that requires all local jurisdictions, such as Seattle, to identify and regulate geologically hazardous areas (Washington Administrative Code 1992). This statewide law establishes the "demand" for scientifically based products. The State of Washington monitors and enforces local compliance with GMA and has the authority to withhold state funds from communities that do not comply. To achieve the objectives of the law, the GMA requires that communities adopt comprehensive plans, which identify and delineate Environmentally Critical Areas (ECA's), as well as adopt and implement zoning ordinances with development standards to protect the ECA. Critical areas specifically required for identification and delineation include geologically hazardous areas. USGS landslide products were used to identify geologically hazardous areas, ie., steep slopes and landslide prone areas. The Revised Code of Washington (RCW) also stipulates: In designating and protecting critical areas under this chapter, counties and cities "shall include the best available science" in developing policies and development regulations to protect the functions and values of critical areas. (RCW 36.70.172). USGS maps and reports provided a basis for the "best available science" (Gori 2008).

The State also has ultimate authority to evaluate consequences and potential impacts of projects that go through the State Environmental Policy Act (SEPA), which mandates environmental review including identifying the consequences of new construction grading (Washington State 1984). Under the SEPA, state and local agencies conduct an environmental review to identify the potentially significant environmental consequences of an action. Environmental review is required for two types of proposals that involve a government action. One type of action is at the project level, such as construction or grading. The other is action tied to policies, plans, and programs, such as the adoption of a comprehensive plan, development regulations, and a six-year drainage plan. The various USGS products, including Shallow Landslide Susceptibility Map, the Landslide Terrain Map using LIDAR imagery, and the Potential for Deep Landslides have been used in conjunction with administration of the Environmentally Critical Areas Ordinance with SEPA review. Under SEPA, proponents are required to use "best available science" to describe the affected environment, identify impacts, and suggest alternative strategies to mitigate those impacts. Similar to implementation of GMA, USGS maps and reports provided a basis for the "best available science" required under SEPA (Gori 2008).

Conclusion

In the case of Seattle, three levels of government converged on the problem of landslide hazards. New information about the landslide hazards was made available by the USGS, the City of Seattle, and the City's contractor, Shannon & Wilson. Products developed by the USGS were used extensively because they built on the City's own database and were produced as cooperative undertakings between the City and the USGS. The City of Seattle had an extensive inventory of landslides. That inventory together with the LIDAR generated digital elevation model (DEM) significantly improved the ability to define susceptibility and to communicate that susceptibility to decision makers and to the public though public meetings and an interactive web site. The participation of the City as an integral partner with USGS in developing the database and priorities for further analysis has ensured that products responded to the demand for scientifically based information and that the information was widely used. The products of the USGS were meaningful to the City because they were built on the City's own database. Products continue to be updated and extensively used for multiple and evolving purposes (Gori 2008).

Another way that USGS maps and reports were integrated into City of Seattle policies is by providing an additional scientific basis for project review and prioritization, which led to the implementation of a coordinated, dedicated funding stream. Also, the legal mandate in the form of State of Washington regulations, which required loss reduction policies at the local level, reinforced Seattle's desire to implement new land-use policies, new interagency coordination of emergency response, and new sources and methods of allocating funds for new public facilities.

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Analysis of a Slope Failure Triggered by the 2007 Chuetsu Oki Earthquake

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Abstract. The powerful Chuetsu Oki Earthquake with a magnitude 6.6 hit the northwest of Niigata Prefecture, Japan on July 17, 2007. The earthquake caused economic loss as it reportedly destroyed 342 buildings, mostly older wooden structures. A few embankment failures as well as shallow landslides were triggered by the earthquake. The Oumigawa landslide (Fig. 1) seems to have received the most attention from the local government as well as geotechnical community as it blocked the rail track near Oumigawa station JR, suspending the train service in the area for 1 month. A few days after the event, a research group from the University of Tokyo, including the authors, conducted a survey of the site in order to evaluate the structural damage caused by the slide. It was found that the landslide occurred in highly weathered zone of mudstone, which consisted of plastic fine-grained soil with the inclusions of rock fragments. It is interesting to note that, according to the statistics of slope failures triggered by the Niigata Chuetsu earthquake, a strong quake that hit the same prefecture in 2004, seismically-induced slope failures in plastic fine-grained soils are rather rare and significantly outnumbered by slope failures in sandy soils. One of the reasons for this discrepancy is that plastic fine-grained soils have a smaller potential for generation of high pore pressures during cyclic loading and the material retains most of its static undrained strength. Thus, the Oumigawa landslide presents the unique opportunity for geotechnical engineers to study the mechanism of such slides. The procedure used in this study included a series of triaxial tests on soil samples collected from the failure plane, slope stability analysis prior and after the earthquake, and dynamic analysis. On the basis of the obtained results, the mechanism of the Oumigawa landslide was posited. It was also found that only the dynamic analysis provided the location of the most critical sliding surface, which was in a reasonably good agreement with the position of the sliding zone in the slope.

Keywords. slope, earthquake, cyclic loading, weathered mudstone

1. Geological Setting of the Site

On the basis of the field survey and results of previous geological examinations of the area (Kobayashi et al. 1995), a cross-section of the slope prior to the earthquake was reconstructed with a reasonable degree of certainty. As can be seen in Fig. 2, the top layer consisted of sand and gravel of relatively young deposit of Holocene. The slide itself occurred in the weathered part of the massive layer of mudstone and alternating mudstone and volcanic conglomerate of Yoneyama formation dated to Pliocene. It is noted that although the geology of this mass that includes several small inter-bedding layers of conglomerate seems more complex, for convenience of this analysis it shall be treated as a homogeneous body of mudstone. According to Kobayashi et al. (1995), the deposits of Yoneyama formation have a strike in E-W direction and dips about 7-8 degrees. The SPT-test results indicated that N-values of the mudstone mass varied from 20 to 30. According to the borehole examination and SPT tests, the mudstone layer is underlain by layers of hard volcanic conglomerate of Yoneyama formation (N-values >50) and mudstone of Miocene (N-values >50).

Fig. 1 A view of the Oumigawa landslide triggered by the 2007 Chuetsu Oki Earthquake, Niigata Prefecture, Japan

2. Characteristics of soil samples collected from the failure plane

A comprehensive program of laboratory tests, including grain size distribution, Atterberg limits, and X-ray analysis, was conducted to determine the properties of soil samples which were collected from the failure plane. The soil was found to be plastic, with the liquid limit and plasticity index to be 76.5 and 30.3, respectively. A series of consolidated-drained and undrained triaxial tests were carried out to determine the strength characteristics of the soil. For consolidated-drained triaxial tests, the specimens were prepared from slurry, isotropically consolidated to different confining pressures, and subjected to triaxial compression until the failure criterion conventionally defined as 15% axial strain was satisfied.

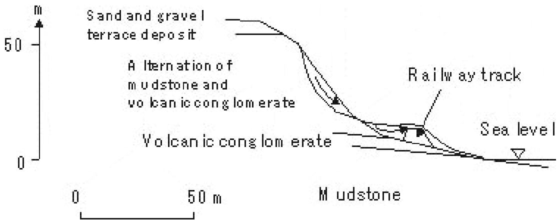

Fig. 2 Geological settings of the Oumigawa landslide site

The dynamic properties of mudstone were evaluated based on the results from a series of cyclic loading triaxial compression tests. The procedure used to carry out cyclic tests as well as the obtained results will be described in detail in the following chapters. After cyclic loading, static compression tests under undrained conditions were performed in order to obtain an indication of the strength remaining after the simulated earthquake loading. From the results of consolidated-drained triaxial compression tests, the strength parameters of the weathered mudstone were found to be as follows: $\phi \approx 30°$, and $c \approx 25$ kPa. The test data obtained from a series of undrained experiments produced the strength envelope that could be characterized by the parameter $\phi \approx 31°$ and $c \approx 6$ kPa. It is noted that the difference between the strength parameters obtained from drained and undrained triaxial tests is very small, and can be seen only in a reduction of cohesion (c), probably due to the earthquake shaking.

3. Stability Analysis of the Slope after the Earthquake

The stability of the slope before the earthquake was evaluated by means of the FEM computer code GUSLOPE developed at Gunma University, Japan. The strength parameters for the mudstone were established based on the test data from consolidated-drained triaxial compression tests. To simplify the analysis it was assumed that these soil characteristics were applicable down to the layer of volcanic conglomerate although in reality the soil was somewhat denser and stronger in the bottom. The stress-strain characteristics of other types of soil were established using published data for similar soils. Results of the slope stability analysis suggested that the slope was in a critical state prior to the earthquake as the safety factor calculated for the most critical failure plane was 1.02.

To evaluate the stability of the slope after the earthquake, the strength parameters obtained from consolidated-undrained triaxial compression tests were used. Results of the slope stability analysis, which are presented in Fig. 3, indicated that the slope became unstable after the earthquake as the safety factor dropped to a value of 0.83. It is interesting to note that the most critical failure plane had different shape and location than that observed immediately after the landslide; that is, it was located deeper, and seemed to extend to the top of the slope. Thus, from the results presented in Fig. 3, it may be inferred that the static analysis did not produce reliable results concerning the dynamics of the slide. For this reason, a different approach, which is referred to as dynamic analysis in this study, was used.

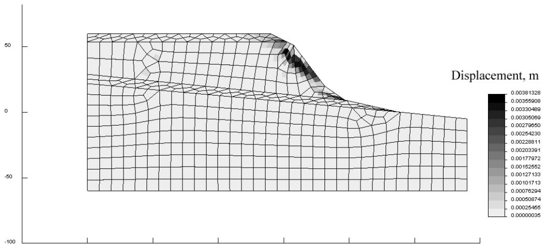

Fig. 3 Results of slope stability analysis conducted by FEM computer code GUSLOPE.

4. Dynamic Analysis

The procedure used in this research was somewhat similar to that developed by Seed et al. (1969, 1975). It can be briefly described as follows: (1) the initial stresses in the slope acting on the potential failure plane before the earthquake were determined; (2) the time history of shear stresses along the potential failure plane during the earthquake were determined, and represented by an equivalent number of regular load cycles (N); (3) the effects of the earthquake-induced stress on soil elements along the potential sliding surface were determined by conducting a series of cyclic triaxial tests on soil samples subjected to the combinations of pre-earthquake and superimposed dynamic stress conditions. (4) The peak shear stresses required to cause failure in N cycles at points along the potential sliding surface were determined and compared with the peak shear stresses induced by the earthquake on the same surface; (5) using the results obtained from cyclic tests, slope stability analysis was conducted to evaluate the safety factor of the slope after the earthquake. Details of this procedure are described in detail below.

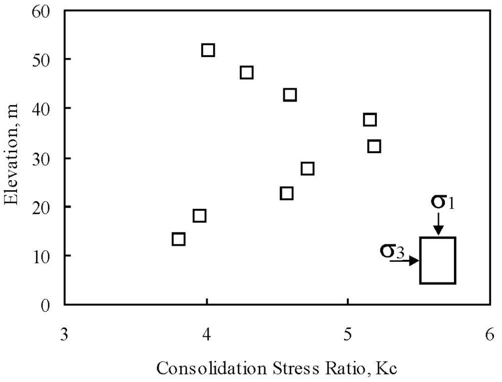

Fig. 4 Distribution of consolidation stress ratio, $K_c = \sigma_1/\sigma_3$, in the slope along the potential failure plane.

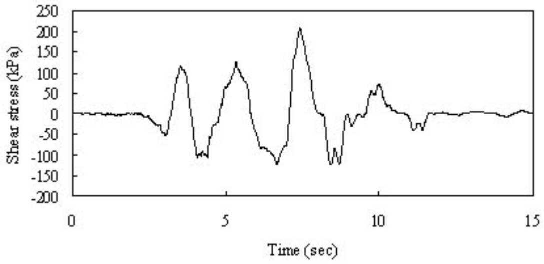

Fig. 5 Time history of shear stresses at the Oumigawa landslide site computed for the depth of 30 m.

(1) The initial stresses, including overburden, lateral and shear stresses, along the failure plane of the mudstone mass before the earthquake were evaluated by finite element computer code“2D Sigma”. These data were further utilized to calculate values of major and minor principal stress, σ_1 and σ_3, parameters which were used in a series of triaxial tests to reproduce the initial stress conditions existing in the slope before the earthquake. In particular, it was found that a consolidation stress ratio, $K_c = \sigma_1/\sigma_3$, varied in the slope from

4 to 5, reaching its maximum at the elevation of 30-40 m (Fig. 4).

(2) To evaluate the stresses acting on the failure plane during the Chuetsu Oki earthquake, the linear equivalent computer code “microShake” with strain-dependent modulus and damping was used. In this analysis, which is also known as “deconvolution” (Towhata 2008), the ground motion record obtained at Kashiwazaki city by a K-net seismograph was first deconvolved to bed rock motion. Considering the distance between Kashiwazaki city and the landslide site, which was estimated to be about 10 km, the bed rock motion record was adjusted and then used to compute the time history of shear stresses at the Oumigawa landslide site. Finally, following up the procedure introduced by Seed et al. (1975), the time history of shear stresses was converted to an equivalent series of uniform cyclic stress applications (N). For example, it was found that the irregular earthquake loading at the elevation of 30 m (Fig. 5) could be represented by 5 regular load cycles with a cyclic stress ratio (CSR) of 0.42, CSR=$(0.65*\tau_{max})/\sigma$).

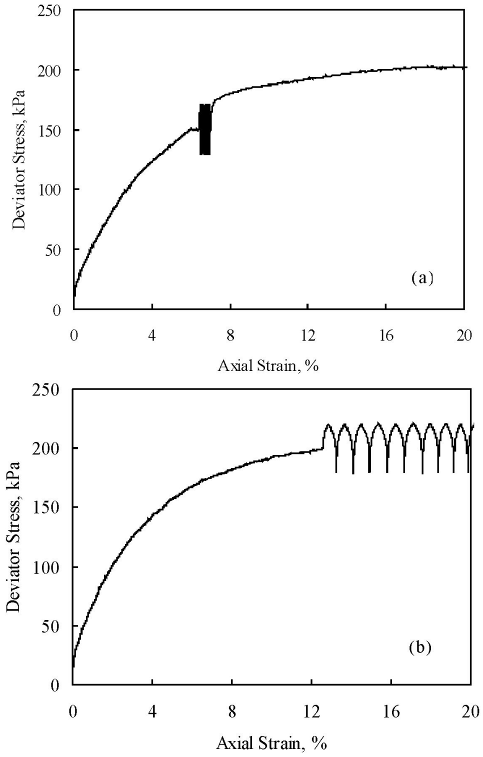

Fig. 6 Results of cyclic loading undrained triaxial tests on anisotropically consolidated specimens: (a) K_c=4.0, σ_3=50 kPa; (b) K_c=5.0, σ_3=50 kPa.

(3) The dynamic properties of mudstone were evaluated by conducting cyclic triaxial compression tests. The specimen prepared from slurry was consolidated to values of effective major and minor principal stresses, σ_1 and σ_3 that would cause the same normal shear stress on the potential failure plane as existed in a corresponding element in the slope. Values of σ_1 and σ_3 were obtained from the plots shown in Fig. 5. Following complete consolidation, the cyclic loading was applied under undrained conditions for 10 cycles or until the sample failed. After 10 cycles of loading, static compression tests under undrained conditions were performed in order to obtain an indication of the strength remaining after the simulated earthquake loading.

The results of two representative tests on specimens anisotropically consolidated to a consolidation stress ratios (K_c) of 4.0 (a), and 5.0 (b) with a confining pressure (σ_3) of 50 kPa are shown in Fig. 6. It is evident from this figure that in the case of K_c=4.0 (Fig. 6a), the soil retained some strength after the application of cyclic loading while, in the case of K_c=5.0 (Fig. 6b), the soil failed as the axial strain exceeded 15% after as few as 3 load cycles.

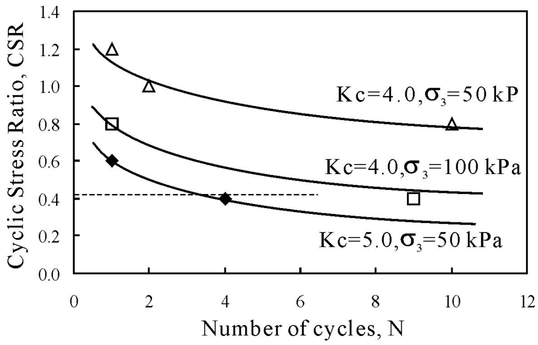

Fig. 7 Results of cyclic loading undrained triaxial compression tests.

(4) By using different values of the cyclic deviator stress (τ_d) and noting the number of cycles required to cause failure (N), the cyclic deviator stresses required to cause failure in 5 cycles were determined for K_c=4.0, and 5.0. Summary of triaxial tests is presented in Fig. 7 in terms of cyclic stress ratio (SCR=$\tau_d/2\sigma_3$) against the number of cycles required to cause failure (N). From this plot it can be inferred that only for K_c=5.0, a parameter that corresponds to the stress conditions existing in the slope before the earthquake at the elevation of 30–40 m, the peak shear stresses induced by the earthquake ($CSR_{N=5}\approx0.42$) exceeded the peak shear stresses ($CSR_{N=5}\approx0.35$) required to cause failure in 5 cycles. This indicates that the earthquake may have triggered the failure at the elevation of 30-40 m.

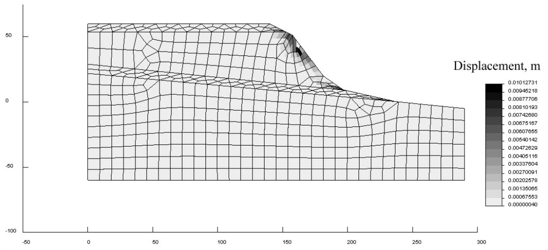

Fig. 8 Results of slope stability analysis conducted by FEM computer code GUSLOPE using the dynamic approach.

(5) Previous studies (Seed et al. 1969, 1975; Lee and Roth 1977) show that the governing parameters for an analysis of a slope after earthquakes are the static gravity driving stresses and the post-earthquake static strength of the soil after it was weakened by seismic shaking. The post-cyclic strength of the soil was obtained from the cyclic tests and post-cyclic undrained compression tests. Considering that the earthquake could have caused the failure of soil only at the elevation of 30-40 m, the post-earthquake stability of the slope was evaluated again by means of FEM procedure, yielding a smaller safety factor of 0.74. Moreover, the location of the most critical post-earthquake failure plane was in a reasonably good agreement with the position of the sliding zone in the slope (Fig. 8).

Conclusions

Results of laboratory tests combined with computer analysis of the stress conditions existing in the slope before, during and after the earthquake indicated that the slope appeared to be in a critical state before the earthquake. The earthquake generated seismic shear stresses that weakened the strength of the soil along the sliding surface. Although the decrease in the strength was not significant, it seemed to be sufficient to cause the slope instability. In addition, the cyclic test data indicated that the failure may have occurred at the elevation of 30-40 m. Finally, a finite element analysis conducted to evaluate the stability of the slope after the earthquake produced a small safety factor of 0.74, and the most critical failure plane, which was in a good agreement with the position of the sliding zone in the slope.

Acknowledgments

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Earthquake Response Analysis of the Catarata 2 Rock Block at Machu Picchu – Peru

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Abstract. Machu Picchu is without doubt one of the most prominent sites on the list of UNESCO World Heritage sites, attracting thousands of tourists every year. On the other hand the Machu Picchu area, including the surrounding mountains, is undoubtedly very prone to gravitational movements including the debris flows which recently claimed lives of 6 people in April 2004. Therefore, the area attracted the attention of scientists from many countries even before, as in 2000 The Japanese landslide expert team conducted landslide investigation in and around Machu Picchu Citadel since March 2000 in cooperation with the Instituto Nacional de Cultura (INC) and the Instituto Nacional de Recursos Naturales (INRENA).

Later, after the establishment of the International Consortium on Landslides (ICL) and the International Programme on Landslides (IPL) in 2002, the initial cooperation agreement on Machu Picchu between the Government of Peru and DPRI/KU has developed to the cooperation between the Government of Peru and the ICL. The International Programme on Landslides (IPL) C101-1 'Landslide investigations in Machu Picchu' consists of six groups including Japanese, Italian, Czech-Slovakian, Peruvian-Canadian groups in 2005. During the last visit of the Slovak team in 2006, the representatives of INC declared the intention to open the Inca trail (so called Zegarra-Wright trail) discovered by Wright in 1998 on the lower east flank of the Machu Picchu to the public. During the path cleaning works a potentially unstable rock block was discovered in the terraces of Catarata 2 region.

There was legitimate concern of the authorities that the block could pose a threat not only to the tourists following the Inca trail along the terraces on their descent to the Urubamba River, but mainly to the busses ascending along the Hiram Bingham road to the Machu Picchu citadel, since the block is located directly above the turn no. 6 of this frequented road. This block seem to be stable, but it clear that the initial displacement was took place sometime in the past and the most probable triggering factor was an earthquake. An earthquake response of the block using the distinct element method in 3D is presented using a scaled down earthquake of Pisco 2007.

The results have shown that the seismic excitation was the most probable cause of the initial displacement of the block, however the intensity of 4 on the MMS intensity scale was not enough to cause such extent of the displacement as could be measured in the reality. Therefore it indicates at several smaller earthquakes or one bigger as was the one which took place near Cusco in 1650 with estimated magnitude of 8.0. The results further support the idea that seismic activity should be investigated at the site together with other triggering factors of landslides.

Keywords. seismic response, rock block stability, Machu Picchu historic site

1. Introduction and Background of the Investigation at Machu Picchu

The landslide investigations at Machu Picchu UNSESCO World heritage site started under auspices of ICL by K.Sassa in 2000 with following slope monitoring using extensometers by the Japanese team of the Disaster Prevention Research Institute of Kyoto University (DPRI/KU) started with cooperation from INC and INRENA from November 2000. After the establishment of the International Consortium on Landslides (ICL) and the International Programme on Landslides (IPL) in 2002, the initial cooperation agreement on Machu Picchu between the Government of Peru and DPRI/KU has developed to the cooperation between the Government of Peru and the ICL. The International Programme on Landslides (IPL) C101-1 'Landslide investigations in Machu Picchu' consists of six groups including Japanese, Italian, Czech-Slovak, Peruvian-Canadian groups in 2005.

In October 2006 during the last visit of Slovak team working under IPL project C101-1-2, the representatives of INC declared the intention to open the Inca trail (so called Zegarra-Wright trail) discovered by Wright in 1998 on the lower east flank of the Machu Picchu to the public.

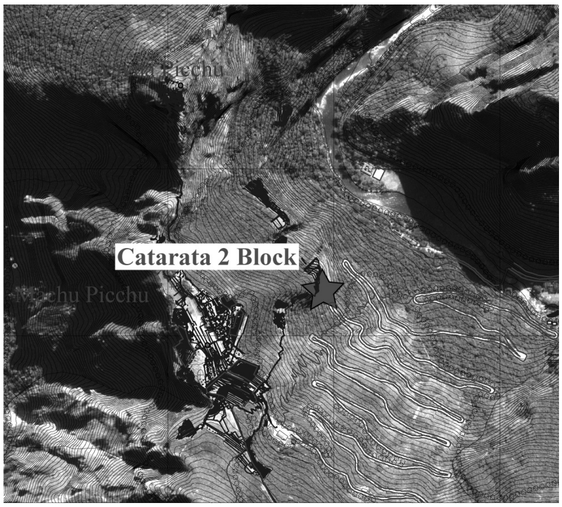

Fig. 1 Satellite photo showing the location of Catarata 2 block

During the path cleaning works a potentially unstable rock block was discovered in the terraces of Catarata 2 region. The reconnaissance works revealed the lateral displacement of the block of about 90 cm in the upper part and the block was detached about 70 cm outwards the steep almost vertical rock slope. There was legitimate concern of the authorities that the block could pose a threat not only to the tourists following the

Inca trail along the terraces on their descent to the Urubamba River, but mainly to the busses ascending along the Hiram Bingham road to the Machu Picchu citadel, since the block is located directly above the turn no. 6 of this frequented road (Fig.2).

Fig. 2 Detail of the Catarata 2 block showing the turn No.6 directly below

2. Seismic Response Model

The detailed structural analysis of the steep slope was carried out with the help of climbing equipment, which revealed the block resting on a platform about 10m wide created by joint intersections; the block was interlocked and thus relatively stable to sliding. However the toppling was still possible mechanism of failure, so an analysis using dynamic excitation was carried out. The area of the Machu Picchu is seismically relatively stable region, with the granitic batholit causing high attenuation of the seismic waves. The Cuzco earthquake of 1950 with magnitude 6.0, which caused the damage of Cuzco cathedral, had in the region of Machu Picchu intensity under 1 on MMS intensity scale (Silgado et al., 1952).

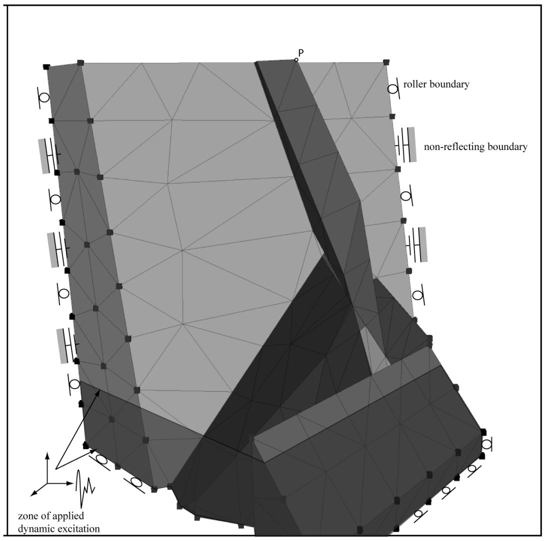

Fig.3 Model of the investigated block with the boundary conditions applied and point (P), where the response of the block was measured

The intensity of 3 is common in this region according (Hurtado et al., 1984). A dynamic response analysis using distinct element method modeling was performed on the block in Catarata 2 using scaled-down earthquake of Pisco 2007. The 3D model of the block was created using distinct element method code 3DEC where also the seismic analysis was carried out. The acceleration data of the Pisco earthquake (M-8.0) which occurred on the August 15th 2007, as recorded by the seismic station at El Callao (Lima) were used for the dynamic response calculation.

The data were first zero corrected and scaled down to the peak velocity corresponding to the 3-4 degree of Modified Mercalli Scale (ABAG) equal to 3.4 cm/s peak velocity. The model was created based on the measured discontinuity and face orientations, while the rock and joints properties were assigned based on the laboratory tests carried out by the Italian team during their investigation in 2003-2004 (Canuti et al., 2005) (Tab.1).

The boundary conditions were applied according to the figure 3, where the outer boundaries were restricted from movement in one direction and non-reflecting boundary was applied as well.

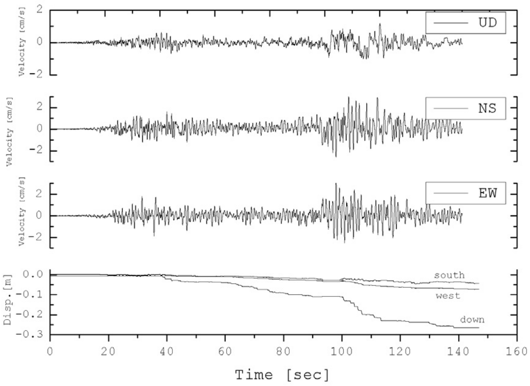

Fig. 4 Dynamic response of the Catarata 2 rock block to the scaled-down Pisco 2007 earthquake (a) showing the 3D displacements of the upper part of the block (b).

Tab. 1 Rock and joints properties used during the simulation

Bulk modulus [GPa]	6.51
Shear modulus [GPa]	5.91
Volume density [kg/m³]	2585
Joint friction angle [°]	42
Normal stiffness [Pa/m]	1e9
Shear stiffness [Pa/m]	1e9

After the application of gravity force the model was first brought to equilibrium, and from there the seismic input was applied in the lower part of the model for the duration of 150 s. Seismic response of the block in Catarata 2 to the excitation due to the scaled-down Pisco 2007 earthquake is shown in the Fig. 4.

During the seismic excitation the response of the top of the block (P) in the form of displacements in three directions was measured as is shown in figure 3.

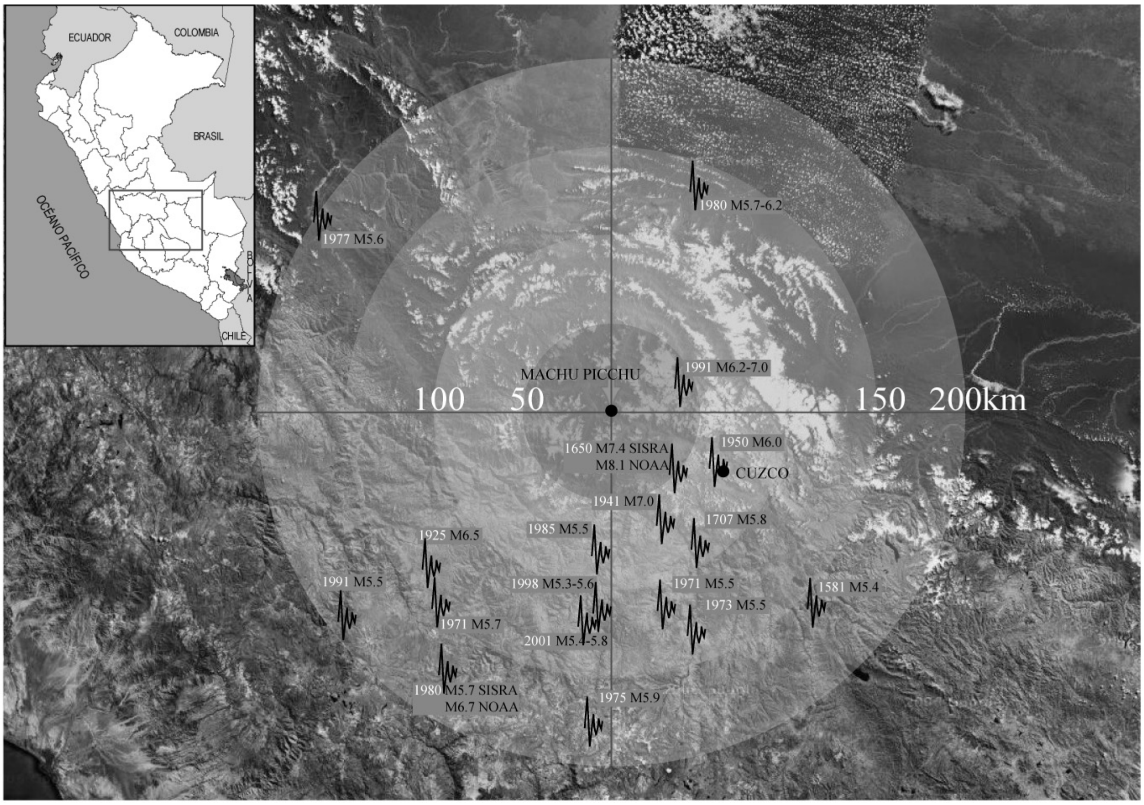

Fig. 5 Historic earthquakes with magnitude larger than 5.5 within the 200km distance from Machu Picchu

3. Results and Discussion

The X, Y and Z displacements observed during the simulation of the earthquake with 3-4 intensity on the MM scale show maximum displacement in downward direction (down) of 26 cm. Further displacements of the upper part of the block were 4cm y-displacement (South) and 7cm z-displacement (West) respectively. The real displacements measured in field suggest that it would take several earthquakes of intensity 3-4 as simulated by the DEM to reach the total displacement of 90 cm, or lower number of stronger earthquakes in the region. Fig. 5 shows all earthquakes from the USGS – SISRA, NOAA and PDE databases within the 200km distance from Machu Picchu since 1471 with magnitudes greater than 5.5. As could be seen the 1950 Cuczo earthquake was not the strongest in the region, but there was a M7.4 (SISRA) earthquake with epicenter much closer to the Machu Picchu in 1650 approximately 100 years after the site was deserted by Incas. As documented by Diego Esquivel y Navia in Anales del Cuzco" 1610-1750 or Vargas Ugarte P.R., 1948) this earthquake caused extensive damage to the large area causing landslides and killing people in remote areas as far as Lima or northern Columbia. It could be feasible to consider this earthquake also the reason of the displacement not only of the Catarata 2 block but to the damage of the Inca structures in the citadel itself.

4. Conclusions

The investigation of the Catarata block at the Machu Picchu archeological site revealed several facts:

1. Although the area is relatively seismically stable earhquakes played most probably important role in the relief formation especially of the ridge parts which is documented not only by the investigated block, but by the presence of the loosened blocks in the topmost parts of both major peaks – Mt. Machu Picchu and Huayna Picchu, as well as occurrence of the cracks in Incan masonry walls, namely the Principal temple and others.
2. The results of the distinct element model were in coincidence with the directions of the block movement in reality
3. The amplitudes of the displacements showed that the total displacement of the block is most probably the product of several (up 10) smaller earthquakes of the MMS intensity 3-4 or lesser number of stronger earthquake.
4. The earthquake of 1650 with its epicenter near Cusco could be the suspected big earthquake wich possibly caused the displacement of the Catarata 2 block, but more importantly also destruction of the walls and buildings of this Incan settlement about 100 years after its abandonment.

All these facts support the necessity to include the seismicity as one of the factors influencing the risk evaluation of this very important site although it is considered seismically not very active area. This is further supported by the suggestion of some researchers indicating that the area commonly known as “quarry”, where the Incas were taking the stone for their buildings could be in fact a product of past earthquake which loosened the granitic blocs on the ridge of the Machu Picchu.

Acknowledgments
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Approaches for Delineating Areas Susceptible to Landslides in the Framework of the European Soil Thematic Strategy

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Abstract. In the framework of the European Soil Thematic Strategy, and the associated preparation of a directive on the protection and sustainable use of soil, landslides were recognized as a soil threat requiring specific strategies for risk assessment and management. The criteria for harmonized risk area delineation proposed by the Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN) adopt a nested geographical approach based on "Tiers" and exploit thematic and environmental data of different type, quality, and resolution using a variety of methodological and technological approaches suitable for the spatial evaluation of any specific soil threat. The main requirement for a continent-wide "Tier 1" assessment for the delineation of areas subject to soil threats in Europe is the availability of relevant input data. At present, such a continent-wide assessment of landslide susceptibility in Europe is feasible only when adopting a qualitative evaluation technique since high-quality, pan-European landslide conditioning- and triggering factor data is available, but a European-wide coverage of landslide locations is missing. "Tier 1" landslide susceptibility evaluations are described to serve for general risk/priority area identification and must at least be able to discriminate areas subjected to more detailed spatial assessments against those where no further action has to be taken. Quantitative evaluations of landslide susceptibility according to a "Tier 2" assessment require the availability of landslide inventory maps and databases. We outline the current advances towards the development of a common methodology for assessing the landslide threat in Europe. We refer to limitations, data needs and future work to be carried out, and present examples of nationwide assessments.

Keywords. European Soil Thematic Strategy, soil threats, continental-scale landslide susceptibility analysis

1. Political background

The European Union's Thematic Strategy for Soil Protection is a long-term political process that led to the formulation of a draft of a European framework directive devoted to the protection and sustainable use of soil in the European Union (Commission of the European Communities 2006a, 2006b). Within this process, eight individual soil threats that are likely to hamper soil functionalities or lead to soil degradation within the European territory have been identified and are subjected to risk/priority area delineation procedures and the implementation of suitable risk mitigation strategies: erosion, organic matter decline, salinisation, compaction, landslides, contamination, sealing and loss of biodiversity. Landslides are recognized as one of these soil threats. The Soil Information Working Group (SIWG) of the European Soil Bureau Network (ESBN) developed a uniform framework for risk area assessments of the first five soil threats mentioned above in such that hierarchically ordered, nested geographical analysis schemes ("Tiers") are envisaged, leaving the issues of data quality, map resolution and costs open to the individual EU member states (Eckelmann et al. 2006). In this context, European-level continent-wide "Tier 1" risk area delineations for individual soil threats should be conducted with already available data, should render a relatively low spatial resolution (tentatively 1:1 Mill.), and should follow a qualitative zonation approach or a model approach combined with thresholds. "Tier 1" assessments are considered to serve for general risk/priority area identification and should be able to delineate zones where no further measures or spatial analysis have to be taken against those that are subjected to more detailed "Tier 2" assessments. "Tier 2" risk area delineations within areas identified by "Tier 1" should thus render higher spatial resolution, could be conducted by quantitative modelling approaches, and will most likely require data not yet available. For each soil threat, the European Commission is searching for a common methodology for risk area delineations that will enable each member state to conduct the analysis. A set of common criteria for spatial analysis procedures was elaborated by SIWG of ESBN and is already annexed in the current draft of the framework directive. The discussion on a common methodology and on data requirements was more recently put forward by the European landslide experts group hosted by JRC Ispra (Hervás et al. 2007).

2. Methods and data requirements

In contrast to the other soil threats, landslides cannot be simply regarded as a soil degradation process but must be considered as a threat posing risk to other vulnerable objects. Therefore, we suggest that the impact of the landslide threat in the context of the Soil Thematic Strategy could be best evaluated with landslide susceptibility and hazard assessments. A wide range of assessment procedures exist, including empirically-based heuristic and statistical as well as physically-based evaluation techniques, each requiring different data and suitable to be implemented at different scales and for different types of landslides (e.g. Guzzetti 2006; Hervás and Bobrowsky 2008). Due to the complexity of landslide phenomena, the highly variable impact of the landslide threat in different European regions, and the differences in data availability, continent-wide "Tier 1" assessments can at the moment only be conducted using a reduced set of data. This should mainly consist of ground conditioning factors and optionally include the most important landslide triggering parameters like climatic and seismic factors. Since a systematic, harmonized coverage of landslide events does not exist throughout Europe, a continent-wide "Tier 1" landslide susceptibility zonation is at the moment only feasible using heuristic, index-based analysis techniques (Günther et al. 2007).

Within the areas susceptible to landslides as delineated through a "Tier 1" model, quantitative, inventory-based statistical landslide susceptibility and hazard modelling can be performed through multivariate statistical analysis (Reichenbach et al. 2007). In Italy, a country with a long tradition in landslide inventorying and spatial landslide hazard and risk assessment, it is shown that national-scale "Tier 2" evaluations can be performed and validated when appropriate mapping units are established and landslide inventory maps with associated databases are available in addition to high resolution ground material, topographic and landslide triggering thematic factor data. It is recommended that quantitative "Tier 2" analysis techniques should be conducted at scales in the order of 1:250,000, implying that mapping units with a higher resolution than the current EUROSTAT regions must be chosen. Even though administrative mapping units do mostly not reflect environmental or geomorphologic conditions, their use for a "Tier 2" assessment is favourable when considering the usability of the resulting maps for spatial planning and environmental protection measures.

The concept of a common methodology for risk area delineations according to soil threats implies the provision of an assessment technique and guidelines on data needs, but does not explicitly account for data resolution and accuracy. It should be left open to individual European countries to use their national datasets when implementing "Tier 2" assessments on the landslide threat. The rationale on methodological approaches presented here show the limitations of "Tier 1" evaluations in countries where landslides are a widespread natural hazard and higher developed evaluations on a national scale exist (e.g., Italy). "Tier 1" must be considered to be important at the continental scale and for those countries where nation-wide landslide inventory data is not available or incomplete (e.g., Germany).

3. "Tier 1" analysis

Recent advances in harmonizing European geological and soil databases resulted in the availability of high-quality thematic data on ground conditioning parameters portraying hydrological, textural and structural properties of the weathered slope zone where most landslides originate. Additionally, continent-wide topographic, land-use, climatic and seismic data are available at resolutions that can be combined with the ground conditioning factor data. The recommendation for preparing a heuristic European "Tier 1" landslide susceptibility model was formulated in such that a suitable weighting and scoring scheme should be elaborated to combine soil/parent material properties, slope angle and land cover to derive a landslide susceptibility index on a grid basis with a cell size fixed by the topographic raster data involved (Hervás et al. 2007). This speculative susceptibility model can be extended to a heuristic landslide hazard map in such that climatic (precipitation sums) and seismic (ground acceleration) landslide triggering factor data can be added. The grid cell-based susceptibility or hazard index values may be aggregated to suitable European administrative regions (e.g., EUROSTAT NUTS regions) using simple zonal statistics in order to combine landslide susceptibility and hazard information with European census data.

In Germany, a national landslide inventory database is not available. However, high-resolution thematic data on topography, lithology, and soil properties are available and were used to prepare a preliminary synoptic landslide susceptibility map (Fig. 1). For this purpose, a three-step, heuristic procedure was adopted. First, the information stored in the German Soil Database (BÜK 1000) was analyzed. The 72 bedrock/soil associations listed in the national database were classified heuristically by expert knowledge into 6 classes, based on their expected susceptibility to landslides. Each bedrock/soil association was classified based on the rock/soil type, the degree of weathering, the soil/regolith thickness, the presence of permeability contrasts and nature of soil/bedrock interfaces, and the presence of discontinuities. Next, a 50 m × 50 m digital elevation model (DGM 50) was used to obtain a map of terrain gradient. The slope map was reclassified into 6 classes, based on the expected propensity to landsliding of each class of topographic gradient. Finally, the landslide susceptibility map based on lithology and soil types, and the susceptibility map based on terrain gradient, were combined. Combination of the two maps was performed on individual pixels (50 m × 50 m), adopting a weighted average technique and assuming the same importance (i.e., equal weight) for the topographic and the lithological/soil information. The pixel values where aggregated to EUROSTAT NUTS 3 regions using the median of the values within each terrain unit (Fig. 1).

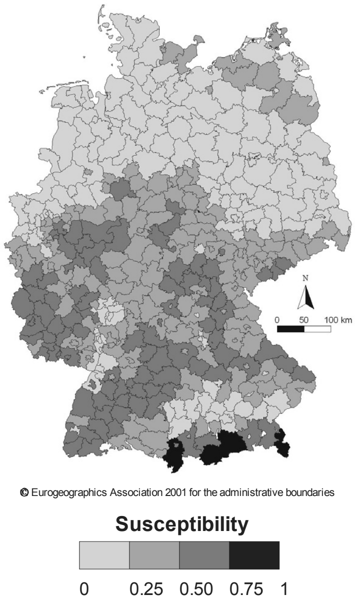

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Fig. 1 Preliminary heuristic landslide susceptibility map for Germany as an example for a "Tier 1" analysis

The map shown in Fig. 1 portrays a qualitative zonation of landslide susceptibility in Germany, based on topographic and lithological/soil information. It is worth pointing out that no information on the location, type, or abundance of landslides was used to prepare the map. This is a limitation that should be considered when using the map. The geographical distribution of the susceptibility classes is in relatively good agreement with published field observations, and with the existing expert knowledge on landslides in Germany (see e.g. Glade and Crozier 2005, and references therein). However, due to the aggregation of the original grid data to relatively coarse administrative units, a significant loss of detail could be observed. The original grid-based map (Günther et al. 2007) largely resembles an earlier qualitative landslide susceptibility map for Germany based on the heuristic analysis of a 1:1,000,000 scale geological map and topographic data prepared by Dikau and Glade (2003).

4. “Tier 2” analysis

Quantitative model-based “Tier 2” assessment of landslide susceptibility requires geographical information on landslides. According to the “tiered” approach for risk area delineations as proposed by SIWG (Eckelmann et al. 2006), quantitative inventory-based evaluations on landslide susceptibility should be conducted in areas identified as critical by a continent-wide “Tier 1” assessment. It is possible to perform quantitative evaluations of landslide susceptibility adopting statistical assessment techniques only where landslide inventories are available.

In Italy, relevant information has become available to attempt a quantitative, nationwide (synoptic) assessment of landslide hazard and of the associated risk to the population. For the definition of landslide hazard municipality boundaries were selected as mapping unit. Two hazard/risk models were prepared exploiting two different catalogues listing historical information on damaging landslides and on landslides with human consequences in Italy. The two catalogues cover the 52-year period from 1950 to 2001 (Guzzetti and Tonelli 2004). For modelling purposes, the catalogues were split in two sub-sets: (i) a training set, covering the 41-year period from 1950 to 1990, and (ii) a validation set, spanning the 11-year period between 1991 and 2001. The spatial probability of landslides (i.e., “where” landslides are expected) was obtained through multivariate analysis of synoptic thematic information (Guzzetti et al. 2005; Guzzetti et al. 2006), including lithological, soil and climate data, and a set of morphometric variables obtained from the SRTM 90 m × 90 m digital elevation model (Fig. 2). Lithological information was obtained from a synoptic geological map published by Compagnoni et al. (1976–1983). For the statistical analysis, the large number of rock units shown in the synoptic geological map (145 units) was grouped into 20 lithological types. Similarly, the 34 soil types shown in the synoptic soil map of Mancini (1966) were grouped into 8 classes of soil thickness and 11 classes of soil parent material. As the dependent variable, the presence or absence of damaging landslides (or of landslides that have resulted in casualties) in each municipality was used. To estimate the temporal probability of landslide occurrence (i.e., “when” or “how frequently” landslide events are expected), first an estimate of the average recurrence of landslide events in each municipality was obtained dividing the total number of damaging landslide events (or the total number of events with casualties) in each municipality by the time span of the investigated period (41 years). Next, the recurrence time of damaging landslide events (of landslide events with casualties) was assumed constant, and a Poisson probability was selected to describe the temporal distribution of damaging landslide events (and of landslide events with casualties). Finally, the exceedance probability of having one or more damaging landslide event (or landslide event with casualties) in each municipality was computed for different periods, from 1 to 20 years. The temporal prediction models and the spatial prediction models were tested using independent landslide information, i.e., information not available to construct the models. Landslide validation sets covering the 11-year period between 1991 and 2001 were used to test the temporal models, the spatial models, and the joint hazard/risk models. The model validation revealed that more than 70.0% of the landslides used as validation set occurred in municipalities classified as unstable (probability > 0.55). The validation thus revealed the ability of the model to predict where future landslides may occur in Italy.

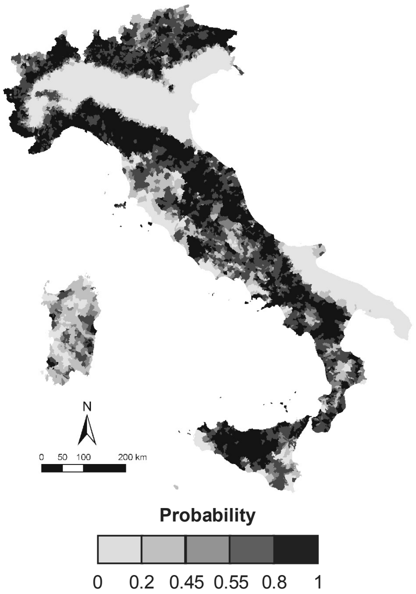

Fig. 2 Probabilistic, inventory-based landslide susceptibility model for Italy as an example for a “Tier 2” analysis

Conclusions

In this contribution, we have outlined the recent approaches towards the establishment of a common methodology for the assessment of the landslide threat within the European Union’s Soil Thematic Strategy. We have referred to the framework and requirements for the spatial assessment of soil threats in general and accordingly described preliminary methodological approaches for “Tier 1” and “Tier 2” assessments of landslide susceptibility.

The preparation of a robust European heuristic “Tier 1” landslide susceptibility or hazard model requires the calibration of suitable weighting and scoring schemes with representative landslide data, and probably also local reclassifications of these to account for specific landslide types in particular European regions. From these circumstances, it is clear that the preparation of a “Tier 1” landslide susceptibility map must be considered as a multiphase approach, requiring input of expert knowledge at each step of model improvement. In any case, even the preliminary "Tier 1" assessments presented herein can be shown to perform much better than the European landslide hazard map produced by ESPON, which is solely based on expert opinion and suffers from data gaps (Schmidt-Thomé 2006).

For the evaluation and calibration of "Tier 1" as well as the preparation of "Tier 2" landslide susceptibility evaluations as described above geographical information on landslides is mandatory. It is recommended that the minimum requirements for a pan-European landslide database consist of location and type of historical landslides. Additionally, this inventory should include date of occurrence, soil/bedrock material involved, surface extent and direct impact of landslide events. Since many European countries do operate and maintain national or regional landslide inventory systems, an attempt should be made to gather and harmonize the minimum required information stated above from these databases to serve as a nucleus for a European landslide event inventory.

Regarding the fact that landslides are more localized and diverse phenomena than all the other soil threats, it is a matter of debate if higher resolution assessment schemes beyond "Tier 2" may be required in a common methodology to assess this particular soil threat. We thus recommend the application of more detailed inventory-based and physically-based landslide susceptibility and hazard models for different types of landslides and triggering factors within areas of high to very high landslide susceptibility as delineated by "Tier 2".

Acknowledgments

We thank Andreas Richter (BGR) for collaborating on the landslide susceptibility classification of the soil/bedrock associations of the German soil database. We are very much indebted to Rainer Baritz (BGR), Fausto Guzzetti (CNR-IRPI) and the members of the European landslide experts group for all the fruitful discussions on the assessment of the landslide threat in the context of the Soil Thematic Strategy.

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Exploiting Earth Observation Technology to Map, Monitor and Forecast Landslides: the ASI MORFEO Project

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Abstract. Advances in space borne, airborne and terrestrial remote sensing technologies have improved our ability to identify, map, and monitor ground deformations, including landslides. In 2001, the Italian Space Agency (ASI) launched a multifaceted call for technological and scientific applications of remote sensing technology to help identify, monitor, forecast, and mitigate natural and manmade hazards, including slope failures. In 2007, ASI lunched the MORFEO project, a coordinated research and development initiative aimed at the development and preliminary implementation of a prototype system to support the Italian National Civil Defence Department activities on landslide risk assessment and mitigation.

MORFEO, an Italian acronym for Monitoring Landslide Risk through Earth Observation technology, is a three-year project aimed at the exploitation of Earth observation (EO) data and technologies, consolidated and innovative ground-based monitoring tools, and existing and new thematic and environmental information, to improve the ability of the Italian National Civil Defence Department to promptly identify, map, monitor, and forecast landslides of different types, and in different physiographic environments. For the purpose, MORFEO implements five functionalities of interest for landslide civil defence:

- *(i)* Identification and mapping of landslides (Ardizzone et al., 2007; Galli et al., 2008), at different geographical scales, through the exploitation of state-of-the-art EO data and technologies, including the dynamic 3-dimensional visualization of landslide areas captured by high and very high resolution satellite optical sensors.
- *(ii)* Landslide monitoring, through the integration of state-of-the-art observation technologies (Ardizzone et al., 2007; Guzzetti et al. 2007a), including satellite and ground-based DInSAR and GPS, for monitoring known landslides, and for the rapid identification of new or incipient movements of natural and manmade slopes.
- *(iii)* Landslide susceptibility, hazard, and risk modelling at different geographical scales and for different landslide types (Guzzetti et al., 2005; 2006a; 2006b), through the use of original models that incorporate information derived from high and very high resolution satellite optical and radar images.
- *(iv)* Forecasting of rainfall induced landslides, through models and thresholds and the exploitation of existing landslide information, quantitative rainfall forecasts, precipitation measurements obtained from networks of rain gauges and weather radars, and estimates of rainfall obtained from meteorological satellites (Guzzetti et al., 2007b, 2008).
- *(v)* Landslide vulnerability and damage assessment (Galli and Guzzetti, 2007), through the design of event scenarios constructed exploiting existing high resolution landslide, topographic and thematic data, and high and very high resolution satellite optical and radar images.

Scientists and engineers working within the MORFEO project will be amongst the first to receive and test data acquired by the ASI COSMO-SkyMed constellation of satellites, equipped with radar sensors that can operate with very short revisiting times. Using this unique constellation of SAR sensors, state-of-the-art DInSAR techniques to monitor slope failures in urban areas and to evaluate the stability of large manmade slopes and embankments will be exploited.

The MORFEO team is headed by Carlo Gavazzi Space (CGS), a leading European company in space technology, and by IRPI, a research institute of the Italian National Research Council leader in landslide investigations. CGS and IRPI are assisted by a unique multi-disciplinary team comprising research institutes, university departments and Italian enterprises collectively experts in landslide identification and mapping, slope monitoring, landslide and environmental hazard and risk assessment and mitigation, and in the innovative exploitation of EO data and technologies. MORFEO is characterized by a significant research component, in terms of institutions involved and planned activities. Innovative research is a key aspect of the project because of the challenging task to successfully exploit multiple satellite, airborne, and ground based EO technologies for landslide risk assessment and mitigation.

Figure 1 and Figure 2 show preliminary results obtained by partners of the MORFEO team. Figure 1, obtained by CNR IFAC, shows 3D-views of the Sarno area, Campania region, affected by multiple catastrophic debris flows on 5 May 1997. Figure 1A shows a high altitude, colour aerial photograph taken shortly after the event. Figure 1B shows a very high resolution satellite image acquired on July 1999. Analysis of the images indicates that combined state-of-the-art optical remote sensing and dynamic visualization technologies can be used to identify and map landslides effectively. Figure 2, prepared by CNR IREA and IRPI, shows surface deformation rate maps in an area of the Assisi Municipality, central Italy, affected by a deep-seated, slow moving landslide. The low resolution (left) and high resolution (right) maps cover the

9-year period from 1992 to 2000, and were obtained processing SAR data acquired by the European Remote Sensing (ERS-1 and ERS-2) satellites along descending orbits. Inspection of the maps reveals a good agreement between the measured surface deformation and the available information on the location and extent of the landslide. This confirms the effectiveness of the space-borne DInSAR technology to investigate slow moving urbanized landslides in selected areas.

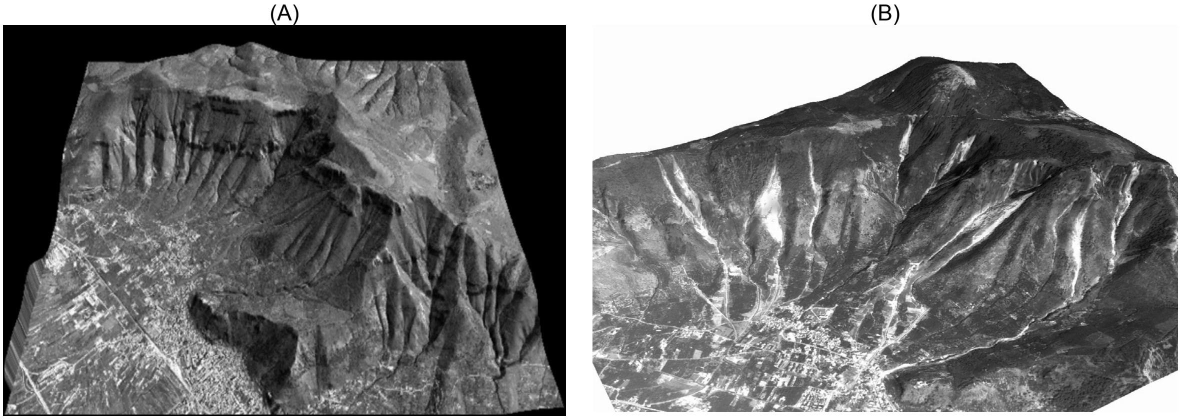

Fig. 1 3D-views of the Sarno area, Campania region, affected by multiple catastrophic debris flows on 5 May 1997. (A) high altitude colour aerial photograph. (B) very high resolution satellite image.

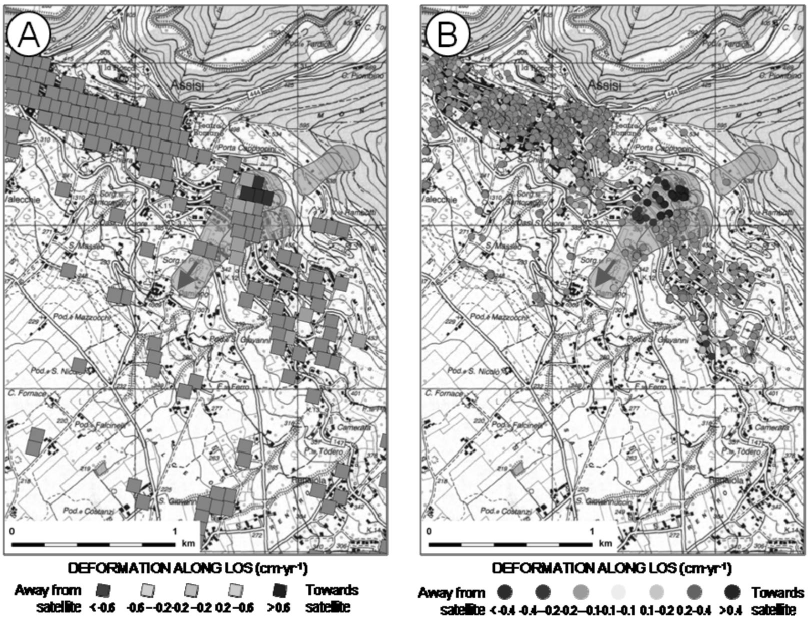

Fig. 2 Surface deformation rate maps for the Ivancich landslide area, Assisi Municipality, Italy, in the period from 1992 to 2000. (A) Low resolution deformation rate map. (B) High resolution deformation rate map. Pink areas show known landslides. Gray arrow shows landslide main direction of motion.

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Matsushima Bay as an Early Holocene coastal Mega-landslide, Northeast Japan

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Abstract. Matsushima, a group of island at Matsushima Bay in Miyagi Prefecture, northeast Japan, is one of the three famous scenic spots of Japan. It is composed of more than 200 islands in Matsushima Bay and the islands just out into the sea. Topographically Matsushima Bay suddenly breaks the gently concaved coastline from Sendai Bay to Ishinomaki Bay. Matsushima and Matsushima Bay have been considered as a typical submerged coast, but they are inferred to have been formed by a coastal mega-landslide in middle Holocene age from geological and topographical evidences.

Keywords. Mega-landslide, Holocene, Jomon transgression, Active fault, topography

1. Introduction

Mega-landslides due to volcanic activities and earthquakes have caused severe damage to the surrounding areas. Sector collapse of volcanoes is one of the most destructive landslides. Debris avalanche deposits from a sector collapse generally form strange topography punctuated by hundreds of small hills, ridges and closed depressions.

The 1792 Mayuyama sector collapse of Unzen volcano in Kyushu, southern Japan, caused debris avalanche which flowed through ancient Shimabara City and entered the sea. As a result, a giant tsunami was generated (Inokuchi, 2006) and more than 15,000 people were killed by the landslide and tsunami. The debris avalanches which entered the sea are characterized hundreds of many small islands and sunken rocks in Shimabara Bay. The locality is now called as Tsukumo-jima and it means 99 islands in Japanese. Usually, with the help of topography and geology, pre-historic sector collapses are recognized. Another example of sector collapses is found in Kisakata, western Tohoku, northern Japan and it is also characterized by a hundred small islands (Tsukumo-jima) scattered in the sea. They are debris avalanche deposits from Mt. Chokai volcano occurred about 2,600 years ago (Inokuchi, 2006).

Mega-landslides in costal area sometimes generate mega-tsunamis. In 1958, a rockslide at Lituya Bay in Alaska, caused by an earthquake of magnitude 7.7, produced a mega-tsunami measuring 524 m high (Miller, 1960). In 1963, mega-landslide at Vajont Dam reservoir in Italy generated a 250 m high mega-tsunami and killed almost 2,000 people (Kiersch, 1964). Although mega-Landslides are rare phenomena, evidence for prehistoric mega-landslides has been found both from land and underwater.

Matsushima in eastern Tohoku is one of the three famous scenic spots of Japan. It is composed of more than 200 islands in Matsushima Bay, which faces the Pacific Ocean (Fig. 1). Matsushima often praised as eastern Matsushima and western Kisakata which faces the Japan Sea. Matsuo Basho, the most famous haiku poet of Edo period in Japan, praised Matsushima as the most beautiful landscape in Japan. He visited both Matsushima and Kisakata. He composed three haiku poems for Kisakata, but he could not express his excitement in a haiku poem for Matsushima.

Matsushima and Matsushima Bay have long been considered as a typical submerged coast, but they are inferred to have been formed by a coastal mega-landslide in middle Holocene age from geological and topographical inferences.

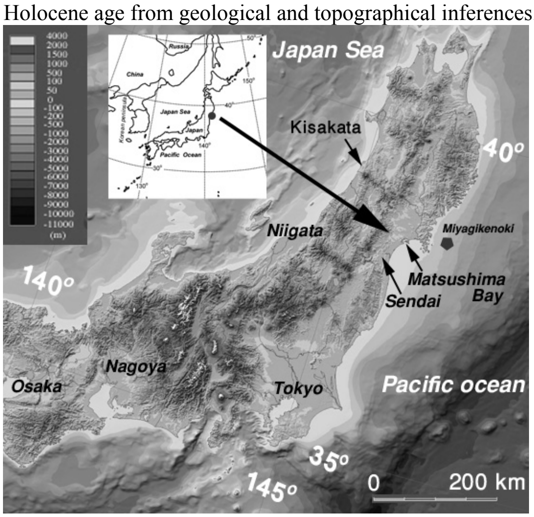

Fig. 1 Locality of Matsushima Bay (modified after Editorial Group for Computer Graphics, Geology of Japanese Islands, 2002)

2. Topography and geology of Matsushima

2.1 Topography

Matsushima is composed of more than 200 islands. Matsushima Bay is a semicircular in shape, with 10 km in EN-SW direction and 5 km in NW-SE direction (Fig. 2). Along the southeastern margin of Matsushima Bay, a number of islands are concentrated from Miyato Island to Shichigahama Peninsula. These islands and peninsula, named as Matsushima Islands, are located between the beach ridges along Sendai and Ishinomaki Bays. It looks like they suddenly interrupt the gently concaved coastline from Sendai Bay to Ishinomaki Bay (Fig. 2). The area of Matsushima Islands is roughly equal to those of Matsushima Bay.

1:25,000 scale topographic map of coastal areas “Matsushima” (Geographical Survey Institute of Japan, 1982) and 1:25,000 scale land condition map of coastal areas “Matsushima” (Geographical Survey Institute of Japan, 1984) have mapped out that Matsushima Bay is flat and less than 4m in depth and a number of sunken rocks are distributed in and to the south of Matsushima Islands (Fig.3).

Summit level of Matsushima Islands are usually about 50m high. On the contrary, inland Matsushima Hill is about 100m high and is about 50m higher than Matsushima Islands.

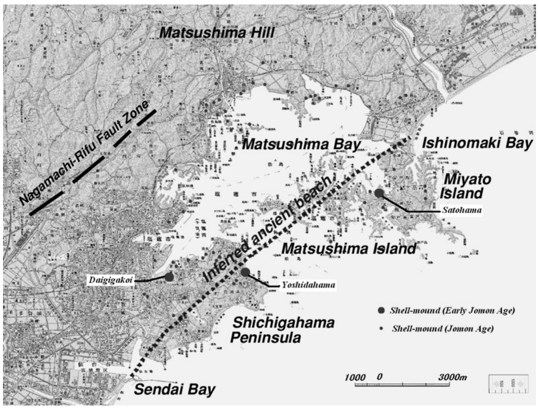

Fig. 2 Topography of Matsushima (Illustrated by Kashimir3D), inferred beach between Sendai Bay to Ishinomaki Bay is also shown in the map

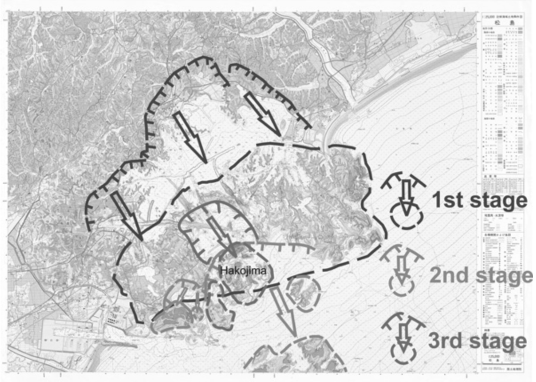

Fig. 3 Topography of Matsushima mega-slide (Modified after Geographical Survey Institute of Japan (1984)

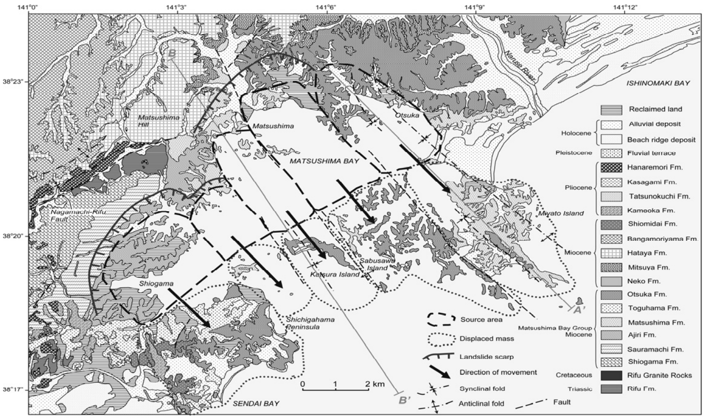

Fig. 4 Geology of Matsushima mega-landslide (modified after Ishii et al.(1982) and Ishii et al.(1983))

2.2 Geology of Matsushima

Matsushima Islands mainly consist of the Miocene Matsushimawan Group which strike NW-SE direction (Ishii et al., 1982; Ishii et al., 1983). Similarly Matsushima Hill is mainly composed of the the Miocene Matsushimawan Group which strike NW-SE direction. The eastern extension of the active Nagamachi-Rifu Fault Zone, which is trending NE-SW, is inferred in Matsushima Hill, but fault topography is not recognized.

The Matsushimawan Group in Matsushima and Matsushima Hill forms similar gentle anticlines and synclines trending from northwest to southeast. The difference of geologic structure of Matsushima Islands from Matsushima Hill is that strike faults are distinct in the Matsushimawan Group in Matsushima Islands (Ishii et al., 1982; Ishii et al., 1983).

Matsushima Bay is underlain mainly by Holocene marine clay sediments which directly cover the Miocene bedrocks (Ishii et al., 1983). The Pleistocene sediments have not been reported.

3. Mega-landslide as the origin of Matsushima

3.1 Topographical restoration

Topography of Matsushima Bay and Matsushima Islands indicate that Matsushima Bay is the source area of a mega-landslide and Matsushima Islands are slide masses. This interpretation indicates that previously, Matsushima Islands including Shichigahama Peninsula were situated on the area of Matsushima Bay and beaches and sand ridges continue from Sendai Bay to Ishinomaki Bay. This restoration suggests that hills which had been located on the area of Matsushima Bay slid about 5km toward southeast direction and have decrease there elevation about 50 m. The sunken rocks also indicate the subsequent secondary slides and third slides (Fig.3)

3.2 Geological restoration

The topographical restoration coincides with the geological restoration by lithology, successions and geologic structures (Fig. 4). This restoration suggests that hills which had been located on the area of Matsushima Bay slid toward southeast direction parallel to the strike of bedrocks without separated into small fragments. Some of strike-slip faults distributed in Matsushima Islands are inferred to have formed by sliding and the sliding hills might be separated into several large masses. The sliding surface is not exposed, but the restoration indicates that the sliding surface is almost horizontal (Fig.5).

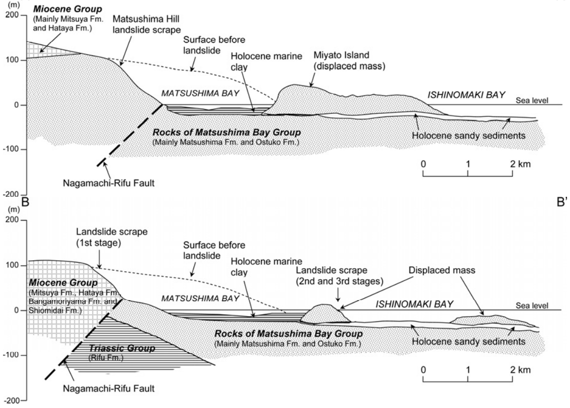

Fig. 5 Schematic profiles of Matsushima mega-slide (Section lines are shown in Fig. 4.)

3.3 Age of Matsushima mega-landslide

Matsushima Bay is underlain mainly by Holocene marine clay sediments which directly cover the Miocene bedrocks (Ishii et al., 1983). This indicates that beginning of deposition of marine clay in Matsushima Bay was just after the occurrence of mega-landslide. As the marine clay attains 20 m at Shiogama, the age of the sediments can be traced back to Early to Middle Holocene. Drilling core of Matsushima Bay is essential to determine the exact time of beginning of sedimentation.

In Matsushima area, shell mounds of Jomon age (early to late Holocene) are found on the hills of Matsushima Island (see Fig. 1). A carbon-14 dating from Daigigakoi shell mound located at the highland (about 40m in height) of Shichigahama Peninsula is 5680±120yrsB.P. (Ito, 2002).

At Satohama shell mounds in Miyato Island, early Jomon settlements had started from highlands and had descended elevation during Jomon age (Fig. 6). Interesting fact is that the percentage of shells on rocky coasts was high at early Jomon age and shells in sandy and silty beaches has gradually increased as dating up to latest Jomon age (Fig. 5). These histories of the shell mounds indicate that the early Jomon people had to start settling down on safe but inconvenient highlands. At that time, rocky coasts were widely distributed in Matsushima Islands. Probably early Jomon people had tried to prevent disasters caused by mega-landslide.

Theses geological and archeological information indicates that the mega-landslide occurred about 6000 yrs B.P. in middle Holocene.

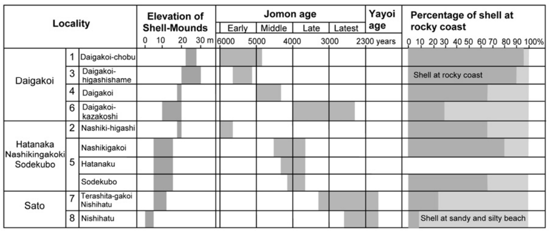

Fig. 6 History of Satomaha shell mound in Miyato Island (modified after Historical Museum of Jomon Village Okumatsushima (2008))

4. Cause and result of mega-landslide

4.1 Tigger of mega-landslide

As Matsushima is not a volcano, a strong earthquake from nearby active fault was the most probable trigger of mega-landslide. Matsushima area has suffered the 1978 Mitagikenoki subduction earthquake (M7.4) and the 2003 Miyagikenhokubu earthquake (M6.4), but no large-scale deep-seated landslide occurred. Recent earthquake-induced large-scale deep-seated landslides support big earthquake caused by nearby active fault is the most probable trigger.

Matsushima Hill is located at the eastern extension of the active Nagamachi-Rifu fault zone whose estimated magnitude is from7.0 to 7.5. Moreover the fault extension coincides with the scar area of the mega-landslide (Fig. 7). Therefore the Nagamachi-Rifu fault is the most probable trigger. The last faulting is estimated after about 16,000 yrs. B.P. (Headquarters of Earthquake Research Promotion, 2002).

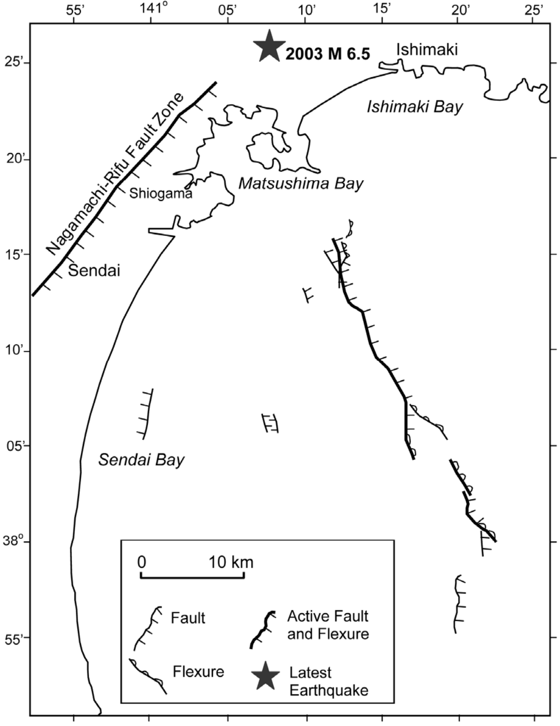

Fig. 7 Active faults of Matsushima area (Compiled after Modified after Headquarters of Earthquake Research Promotion (2002) and Japan Coast Guard (2002))

Another active fault is located in Sendai Bay (Japan Coast Guard, 2002). The submarine active fault is about 33 km in length and is trending NNW-SSE. Matsushima Bay is located northern extension of the submarine fault and the distance is about 10 km.

At present we do not have the precise age of the last faulting and the exact age of mega-landslide.

4.2 Origin of sliding surface

As the sliding surface is inferred to be almost horizontal (see Fig. 5), it must be originated from fault-related plane. At present we do not obtain the material from the sliding surface and further research is necessary for mechanism of the mega-landslide.

4.3 Possibility of landslide-triggered mega-tsunami

The estimated age of the mega-landslide is around 6000 yrs B.P. during middle Holocene age, when the sea-level was nearly or about 1 m above the present level. This suggests that the mega-landslide entered the sea and generated a maga-tsunami, such as Lituya Bay tsunami in Alaska. In Sendai region, the large-scale 869 Jogan tsunami deposits are widely distributed (Minoura et al., 2002), but the large-scale Jomon tsunami deposits remain as future investigation.

Conclusions

The major findings of the investigation are:

1. Matsushima Bay is the source area of a mega-landslide and Matsushima Islands are slide masses. Hills which had been located on the area of Matsushima Bay slid toward southeast direction parallel to the strike of bedrocks without separated into small fragments. The sliding surface is estimated to be almost horizontal (Fig. 4).
2. The mega-landslide is inferred to have occurred around 6000 yrs B.P. in middle Holocene.
3. A strong earthquake from nearby active fault was the most probable trigger of mega-landslide.
4. The mega-landslide must have entered the sea and generated a maga-tsunami.

Acknowledgments

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Early Warning of Landslides Based on Landslide Indoor Experiments

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Abstract. An experiment to induce a fluidized landslide by artificial rainfall has been conducted on an indoor slope. The experimental slope is 10 m long, 1 m wide, and the slope gradients are 10 degree for the lower and 32 degree for the upper slope. A landslide initiated 65440 s (1h49m40s) after the start of sprinkling at a precipitation intensity of 80 mm/h. During this experiment, pore pressure, self-potential, and soil displacement have been measured. The results suggest the relationship among motion of subsurface water, soil displacement, and electrical potential differences. Self-potential method seems to have capability for early warning system for landslides.

Keywords. self-potential method, early warning system for landslide, laboratory experiment, precipitation control

1. Introduction

Rainfall-induced landslides often cause catastrophic disasters. In order to mitigate the disasters, monitoring and forecasting of the landslides are important. There are hydraulic and geotechnical knowledge prior to a landslide based on the indoor and outdoor experiments (Ochiai et al, 2004). They are based on pore pressure and soil displacement using gaugemeters and CCD video cameras, respectively. The obtained facts are as follows; (1) development of the saturated area under the surface, (2) direction of the filtration of water changes from vertical to lateral to the slope, and (3) beginning of the apparent soil displacement about a few tens minutes before the catastrophic slide. On the other hand, the geophysical exploration method is one of powerful tools for subsurface monitoring such as electrical resistivity. The electrical resistivity tomography approach shows the slip surface very precisely and continuous measurements of resistivity could be helpful to identify the water condition under subsurface (Perrone et al., 2004) (Lapenna et al., 2005). Self-potential method is also applicable to monitor underground fluid motion based on the electro kinetic effect (Ishido and Mizutani 1981). Laboratory experiments and geothermal application show the high capability to detect subsurface water motion (Rizzo et al., 2004), (Sasai 2008), (Zlotnicki and Nishida 2003). Self-potential method is passive measurement and simple in comparison with electrical resistivity tomography. In this paper, self-potential approach is conducted to develop an early warning system for landslides. The results of a laboratory experiment under precipitation control show the capability to monitor the underground water condition using self-potential method.

2. The Laboratory Experiment

The laboratory experiment of landslide under the precipitation control has been carried out to investigate electrical properties and understand the physical process associated with landslides. The background of this experiment is as follows. Based on the previous hydraulic knowledge, (1) the rain water penetrates vertically at the initial stage because of the unsaturated condition. (2) As a saturated area is developed, the water flow pattern turns to the lateral to the slope. (3) From geotechnical point of view, significant soil displacement starts about a few tens minutes before the main collapse. Then, a landslide takes place. The purpose of the experiment is to investigate whether electrical potential changes show those of hydraulic and geotechnical conditions.

The overview of the laboratory experiment system is shown in Fig. 1. The angle of an upper slope was 32° and that of a lower slope was 10°. The length and width of a slope are 9 m and 1 m, respectively. The soil density in the slope was almost uniform and the thickness was 70 cm. The soil is weathered granite and averaged grain radius is 0.39 mm. There is a sprinkler for an artificial precipitation. The intensity of the precipitation was controlled by 80 mm/h. 40 mm rain (with 80 mm/h) was precipitated two days before the experiment. It was found that water came out of from the slope very slowly. It means that groundwater system has been created before the experiment. It seems rather natural situation. A rubber sheet is used for insulation.

Pore pressure, self-potential, and soil displacement measurements have been performed. As for self-potential measurements, electrodes (Pb-PbCl$_2$), pasted the bentonite to reduce a contact resistivity, have been installed with intersensor distance of one meter in a depth of 20 cm and 50 cm and the reference electrode has been installed in the depth of 50 cm at the top of the slope. For pore pressure measurements, gauge meters have been set up in a depth 10 cm, 40 cm and 65 cm with one meter spacing. Here,

Fig. 1 Indoor experiment system of an artificial slope under precipitation control

electrodes and pore pressure meters were installed alternately. The electrodes and gauge meters have been connected to the 16 bit AD converter (National Instrument SCXI-1120) and fed to the data acquisition PC. The sampling rate is 100 Hz. Soil displacement has been recorded by CCD video cameras with motion of markers. The total amount of water flowed out from the slope has also been measured.

The landslide occurred at the upper slope 65440 sec (about 110 minutes) later from the beginning of the precipitation. Thus, the total amount of the rain fall was about 145 mm.

3. Observed Data

Figs. 2(a) and (b) illustrate the 2D variation of hydraulic and electrical properties, respectively. The sequence of figure corresponds to the time progress after the precipitation start. The time stamp is given beside the panel. In Fig. 2(a), the color and contour indicate the pore pressure and hydraulic head. In Fig. 2(b), the color and contour show the potential differences the electric field. From Fig. 2(a), we found that filtration of precipitation water was vertical at the initial stage. Saturated area was developing and extending 50 min before the collapse. 20 min before the collapse, we can see the lateral flow of the underground water. 1 sec before the collapse, the lateral flow is significant at the lower part of the upper slope. From Fig. 2(b), it is almost uniform at the beginning of experiment. The saturated area seems to be charged in negative. The most interest point is the appearance of a large electric field around the slip surface area a few tens minutes before the collapse.

A typical example of observed hydraulic and self-potential data is shown in Fig. 3. The position of the corresponding sensor is described at the top panel in the Figs. 2(a) (2 pt.) and (b) (15 ch). The curve of potential shows an interesting behavior. When the wetting front arrives at the position of electrode, the potential indicates the local minimum. While the area of the electrode turns to be saturated, the value shows the local maximum and a dramatic decrease. Furthermore, 30 minutes before the main slide, transient signals cam be seen only in self-potential changes. There is a remarkable step-like change around 90 min and rectangular changes around 105 min. These changes observed

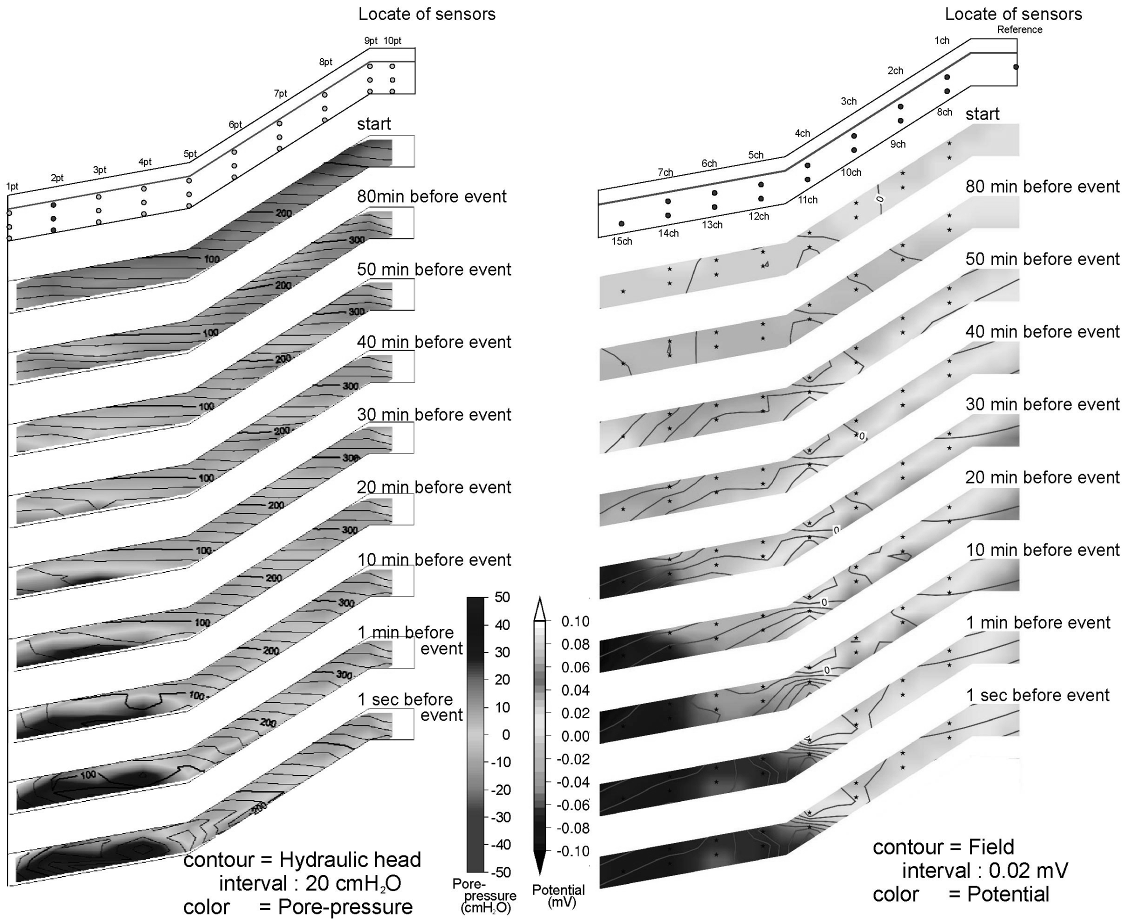

Fig. 2 2 dimensional maps of pore pressure and self-potential with time.
(a) pore pressure and (b) electrical potential difference

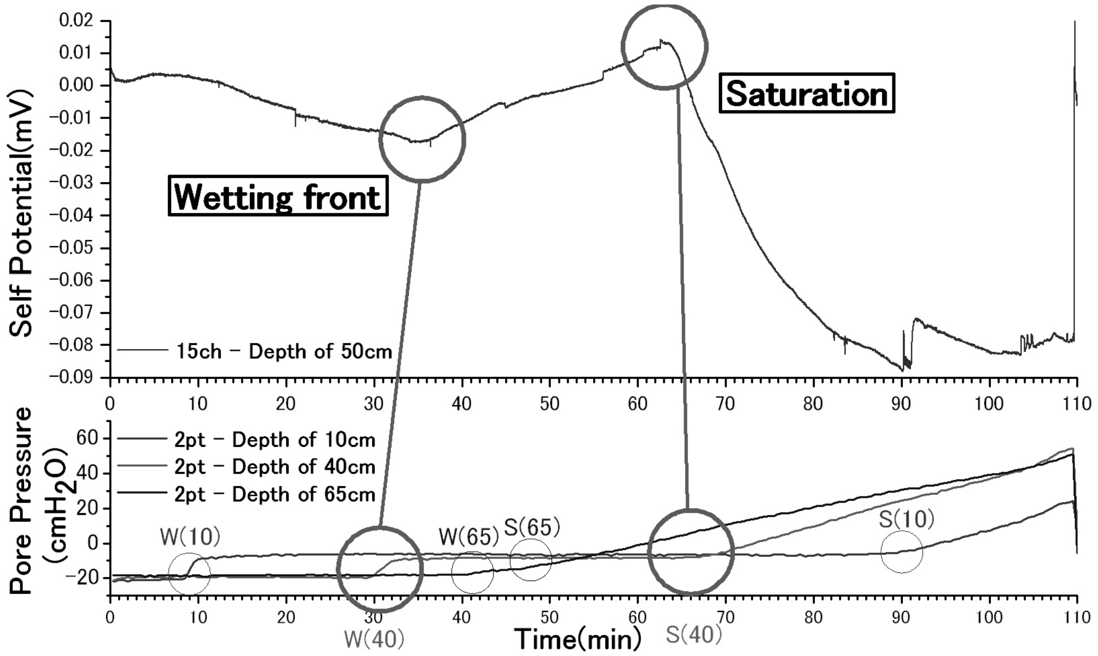

Fig. 3 A typical example of pore pressure and self-potential variation during artificial rainfall experiment. Time of the turning values of self-potential corresponds to the rise-times of pore pressure (wetting front and saturation).

only below the upper boundary of the slipped body. The detected electric field is almost uniform. For the variation of pore pressure, transient signals such as impulsive and step-like changes are not described. The soil displacement data shows that the dislocation of the soil become apparent a few tens minutes before the collapse, so that there is a possibility that these transient signals are associated with dislocation of the soil.

Conclusion

Indoor laboratory experiment with simultaneous measurement of hydraulic, geotechnical, and electromagnetic approaches has been performed to investigate the rain-fall induced landslide process. It is found that self-potential variation seems to show the good relationship between hydrodynamics and electromagnetics and geotechnology and electromagnetics. It means that there is a possibility to monitor the underground water condition or establish an early warning system of landslides with use of self-potential method.

Further analysis and experiments in both laboratory and in-situ field will be required to evaluate the electric phenomena with the hydrological and geotechnical changes. such as pore pressure and the water flow out and geotechnical parameters such as the soil displacement.

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Back Analysis of Landslides to Allow the Design of Cost-effective Mitigation Measures

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Abstract. For many deep-seated landslides adverse and often complex geology and hydrogeology are fundamentally important and this is illustrated through case examples. Back-analysis is the process by which the nature and development of a landslide is determined through a series of deductions. This may involve numerical simulation but need not. Developing a model that can be used to explain all aspects of the landslide is key. Failures in engineered slopes are often particularly revealing in that they demonstrate flaws in thinking, investigation and analysis from which lessons can be learned. Examples presented here include failed slopes that had been investigated using standard ground investigation and instrumentation techniques but where the true mechanism had been overlooked or missed. In terms of mitigation, it is very important that an active landslide is properly understood as a geo-mechanical model to ensure that correct and cost effective mitigation measures are adopted. Monitoring is important for assessing risk but that monitoring needs to be linked to models identified through proper investigation and analysis that can then be tested through prediction and measurement.

Keywords. Back-analysis, geological and hydrogeological models, landslides, remedial measures, Malaysia, Korea, Hong Kong

1. Introduction

Landslides often involve complex geological and hydrogeological situations. The true mechanism of a landslide is often difficult to unravel - there may be many contributing factors and the investigator needs to act as a detective, looking for evidence, developing theories and testing these through further observation, analysis and focused investigation. This whole process which may or may not include numerical simulation of the failure is termed here ‘back-analysis’. One of the key questions is often why a landslide has occurred at a particular location, at a particular time (especially where there is no immediate trigger) and with a particular geometry rather than elsewhere in the same slope or in adjacent slopes. Simple attempts to remedy the situation by cutting back often do not work and can make matters worse. It is argued here that without proper, insightful investigation of landslides, remedial measures may be ineffectual or at least not cost-effective. Numerical calculation may help to establish what is or is not an acceptable solution and for the deduction to be correct, the model must certainly work mechanically at least in principle. The investigation need not be expensive or involve deep drilling to derive a realistic and workable model but it does need to involve knowledgeable and experienced personnel who can recognise geological structures and understand the implications for groundwater partitioning and shear strength. Once working models are derived that explain the features of a landslide, then that model can be tested by additional ground investigation, instrumentation and numerical simulation. Without a proper model the back analysis may be unrepresentative of true conditions and certainly open to numerous alternative explanations.

2. Benefits from Landslide Studies

The benefits from landslide studies can be considered in two categories: generic and site-specific. Aspects that need to be addressed in any slope design include geometry, geology, hydrogeology, mass strength and method of mathematical analysis. Hencher et al (1984) reviewed the then current state of knowledge in Hong Kong with respect to each of these and concluded that the poorest understood were mass strength and hydrogeology and that one of the best ways of advancing knowledge in these areas was by studying landslides. Examples were provided of how landslides studies could be used to improve knowledge in these specific areas. Progress continues to be made, particularly concerning hydrogeological models (Jiao et al., 2005; Hencher et al, 2006). Other generic benefits of systematic landslide studies in Hong Kong such as lessons regarding improved detailing of drainage of slopes are discussed by Ho & Lau (2008).

At an individual site level, it is important to understand the causes of any major landslide before attempting to apply permanent remediation or other action so that such measures can be robust and cost effective. Case examples are presented below that illustrate the need for good geological understanding, for timely investigation and to demonstrate how landslide studies can give insight into complex hydrogeological conditions and other factors, ignorance of which would limit the effectiveness of any remediation works.

3. Pos Selim Landslide: complex geological structure controlling displacement

The Pos Selim landslide is a currently active landslide in Malaysia. Some details are provided by Malone et al (2008). The landslide occurred in one of the many large and steep cut slopes along the new 35km section of the Simpang Pulai – Lojing Highway project and it is pertinent to ask the question why it occurred there rather than somewhere else?

Failure occurred early on in the cut slope and affected the natural slope above the cutting (Figure 1). Progressively the slope was then cut back in response to further failures until the works reached the ridgeline about 250m above the road (Figure 2). The slope has continued to move with huge tension cracks developing near the crest with vertical drop at the main scarp of more than 20 metres in three years.

Fig. 1 Pos Selim Landslide, August 2000

Clearly at the site there are some predisposing factors that are causing instability whereas many other equally steep slopes along the 35 km of new highway show no similar deep seated failures. The general geology of the site is schist but the main foliation actually dips into the slope at about 10 degrees so the common mode of failure associated with such metamorphic rocks of planar sliding on daylighting, adverse schistosity or on shear zones parallel to the schistosity (Deere, 1971) is not an option to explain this landslide. Following detailed face mapping by geologists, review of displacement data and examination of the various stages of failure, a model was derived that can be used to explain the nature of the failure, the vectors of movement and the fact that it has not yet failed catastrophically but is bulging at one section of the toe (Figures 3 & 4). Key aspects of the geology are frequent joints that are oriented roughly orthogonal to the schistosity, three persistent faults cutting across the failure and another major fault to the north of the landslide area. The derived model is of a mechanism of sliding on the short, impersistent joints that combine with offset sections of schistose fabric to form a shear surface. The shearing forces are largely balanced by sliding friction on joints, along the transverse faults and schistosity in one part of the toe where the failure is kicking out. Resistance is also provided by the dilating mass towards the right side toe of the slope (facing). One possible option for remediation that can be derived from this model therefore involves strengthening that toe area by anchoring or otherwise buttressing.

It is to be noted that this model is not numerical but could certainly be used as the basis for a numerical model that would, indeed work for some realistic set of parameters. Without this understanding of geological mechanism, it would be impossible even to begin to design successful remedial measures.

Fig. 2 Pos Selim Landslide, 2002

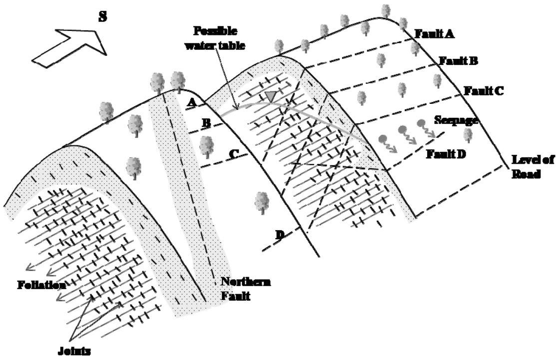

Fig. 3 Block model of main geological features

Currently there is some minor evidence that groundwater is playing a part in the failure (some seepage) and therefore it has been recommended that long, trial raking drains be installed at points of seepage in such a way that they also allow water pressures to be monitored within the slope (a cost-effective combination of ground investigation and remedial measure).

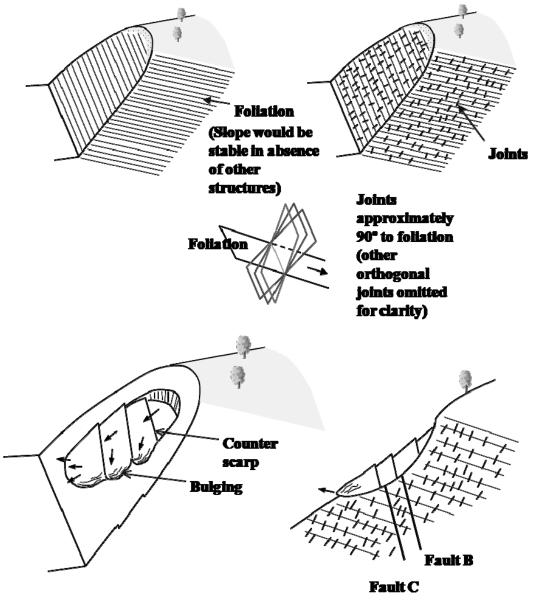

Fig.4 Schematic model for the Pos Selim landslide.

4. Kimhae agricultural complex near Busan, Korea: the need for timely and insightful investigation

The circumstances of this failure are described in detail in Lee & Hencher, 2008. In summary, the original ground investigation and design for the large slopes that were to be cut at the site, in complicated geological conditions, were

Fig.5 Large scale failure near Busan, Korea

deficient and the slope failed during construction.

The slope continued to fail progressively until it finally collapsed catastrophically in August 2002 during heavy rainfall.

During the series of retrogressive failures leading to the final collapse there were 11succesive inspections and reassessments of stability over 9 years. Various techniques were employed in turn in attempts to stabilize the slope using piles, ground anchors and soil nails. Drainage was attempted and retaining walls constructed. As a result of the repeated failures the height of the cut slope was increased from 45 m to 145 m with associated costs rising from 3.3 million to 26 million US dollars. It was not until the complexity of the geology and specifically the importance of fault control was properly identified that the slope could be finally understood. Various assessments prior to then had tried analysing the slope as a soil and one late review attributed the landslide to natural disaster (triggered by a typhoon) without acknowledging the failure of previous studies to go about the investigation in a scientific manner. This example demonstrates that without proper investigation, even after significant failure has occurred, the success or otherwise of remedial measures cannot be relied upon.

5. Ching Cheung Road Landslide, Hong Kong: complex hydrogeology

Cut slopes along Ching Cheung Road in Hong Kong have been the source of several major landslides since the road construction in the early 60's. One of the common features of these landslides has been that they are deep seated and occurred several days after heavy rainfall. The most recent large landslide occurred in 1997 in a section of slope that had recently been investigated and modified to try to improve its stability. This failure was also delayed in that the first major movement occurred four days after heavy rain. The slope continued to deteriorate and eventually, about a month later, collapsed during heavy rain so that the debris blocked both carriageways of this important road. Back analysis of this failure was aimed at explaining why the failure occurred as it did, at that location but also specifically to offer some explanation for the delayed response to heavy rainfall. In terms of why the failure occurred at that location, this seemed to be linked to the fact that the site was the location of previous failure dating back to the 1940's. This had been identified during investigation of a failure in a nearby slope in 1982 (Hudson & Hencher, 1984).

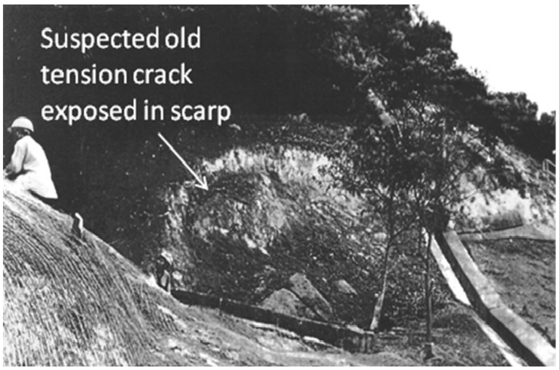

Fig.6 Evidence of previous movement in 1997 scarp

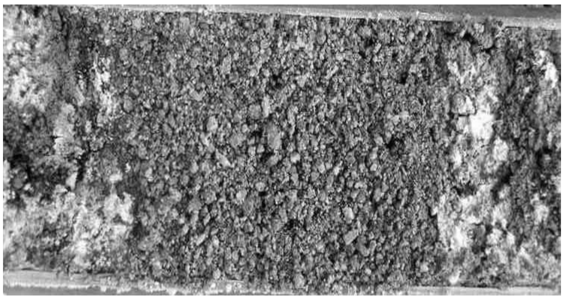

Fig. 7 Alluvial sand recovered in Mazier sample

Signs of previous movement were found during the investigation of the 1997 landslide as illustrated in Figure 6 (HAP, 1998). Detailed mapping of trial pits showed however that the 1997 failure was not a simple reactivation of the earlier landslide but it was still suspected that the location of the 1997 failure was related to the previous distress. Boreholes were put down specifically aimed at achieving 100% recovery using Mazier sampling with foam flush (no in-situ tests were conducted during drilling). Some boreholes were inclined upwards back into the failure scarp. All samples were examined and described. No samples were taken for strength testing because it was considered that current knowledge of the shear strength of such materials was sufficient for numerical simulation and that detailed geological examination was more important for explaining the details of this landslide.

One of the key findings from the investigation was the presence of numerous infilled natural pipes found in borehole samples. Pipe infill included single sized sand (Figure 7) and graded sands (deposited in still water) at great depth within the decomposed granite that makes up the bulk of the slope. It was clear that there was a well developed underground stream system at the landslide site. A leaf was found in one sample and this was dated using 14C enrichment values as 1958 to 1960. It was concluded that the presence of the underground stream and lake system allowed an explanation of deep groundwater recharge over a period of several days and delayed failure. Delayed groundwater response was observable in some piezometers but it was recognised that such observations might be very localised depending on whether or not a particular borehole tapped into an active part of the stream system. Such variation in groundwater flow became evident during the installation of soil nails as part of the remediation works. In order to install the nails, dewatering

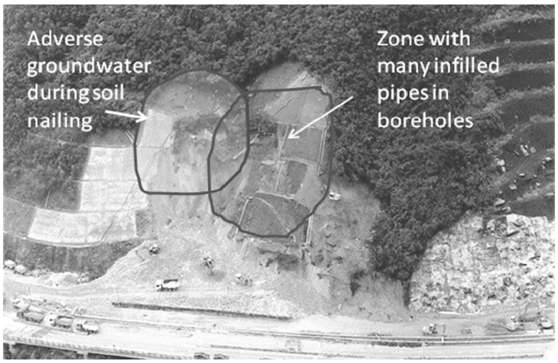

Fig. 8 Ching Cheung Road Landslide 1997

was carried out using 14 wells which extracted 1.2 Ml during the nailing contract. One single well accounted for more than 40% of that volume (HAP, 1999). Interestingly, and totally compatible with the emerging model, in one area of the slope, despite dewatering, water flowed from soil nail holes, some holes collapsed and it was observed that there was a degree of interconnection. The area of problems during soil nailing was not the same as where the majority of sediment choked pipes were encountered during ground investigation (Figure 8). It was interpreted therefore that the underground stream system had migrated with time and was still changing continuously; the sediment filled system represented natural pipes and hollows that had clogged and collapsed during dry spells. Given later intense rainfall and infiltration, other routes for throughflow developed as an open system.

This model for the observations at Ching Cheung Road and elsewhere has ramifications, not only regarding site-specific remediation but more generally. It can be surmised that the presence of such sediment clogged pipes and other sediment infill to joints (HCL, 2002) may be evidence of a long period of deterioration and perhaps imminent collapse (Hencher, 2006). Furthermore such channel systems can be expected to evolve and migrate. Drainage measures adopted for remediation should be expected to show changing performance with time as the groundwater pattern alters and the need for upgrading should be considered periodically.

Conclusions

Landslide studies are extremely important for improving the capability of geotechnical engineers and engineering geologists to make slopes safe and to avoid disastrous failure. The lessons learned may be applicable generally to many slopes or may be used to devise cost-effective solutions for stabilising a specific slope.

The back-analysis process should result in a conceptual model that explains the features of a landslide. For most large landslides this model will involve a detailed representation of structural geology and hydrogeology. Without such understanding landslide mechanisms are likely to be misinterpreted. The model created should work mechanically in the sense that it would be feasible to analyse the failure numerically to help understand how the landslide developed. Numerical modelling may indeed be very helpful in testing the model in that the feasibility can be checked, for example for exploring the necessity or otherwise for invoking temporary adverse water pressures or other triggers. Nevertheless, numerical analysis is unlikely to provide a unique solution because of the many variable parameters and numerical back-analysis, without a proper geological understanding is not to be recommended.

Acknowledgments

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Overview of Catastrophic Mega-rockslides in the Andes of Argentina, Bolivia, Chile, Ecuador and Peru

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Abstract. In the Andes of Argentina, Bolivia, Chile, Ecuador and Peru (ABCEP) there are at least 169 deposits of catastrophic rock slope failures with volumes in access of 10^6 m^3, the largest involving a volume of 50 km^3. Only 25 of these deposits are related to historic events, the Mayunmarca rockslide from 1974 in Peru being by far the largest event with more than 1 km^3. Apart from this event no other historic event exceeded a volume of 10^8 m^3. These historic events caused a debated ~23000 casualties with the Yungay, Peru, rockslide from 1970 being the most disastrous.

Deposits of prehistoric megarockslides are in general larger than the historic events with more than 60% exceeding a volume of 10^8 m^3. Deposits from the collapse of volcanic edifices are in general the largest with volumes in excess of 1 km^3. However there are also 12 events of slope failures not related to volcanic edifices which exceed that volume.

Of the 144 deposits of prehistoric megarockslides only 58 could be dated, the age spreading between 1.4 ka and 5-10 Ma. There are two clusters of dated rockslide deposits, one in NW Argentina, the other along the Argentine/Chilean border in the southern Central Andes around Cerro Aconcagua. In NW Argentina large rockslide deposits lying along neotectonically active mountain fronts beside larger basins are several tens to hundreds of thousand years old. Those lying in narrow valleys are of Late Pleistocene to Holocene age and are clustered during periods characterized more humid climate conditions. In the southern central Andes around Cerro Aconcagua most rockslide deposits in glaciated valleys occurred within the first millennia after the Last Glacial Maximum (LGM). The deposits in valleys not affected by glaciations are in general several tens to more than hundred thousand years old.

There are two regional clusters of historic megarockslides, one in the Sihuas valley in southern Peru lying in close vecinity to the largest irrigation project of the Andes, the other cluster occurs in the immediate vicinity of La Paz, the largest urban centre of Bolivia.

Keywords. Historic rockslides, prehistoric rockslides, temporal distribution, rockslide size

1. Our data set on Megarockslides

This paper is based on more than ten years research on catastrophic prehistoric and historic megarockslides covering the Andes of Argentina, Bolivia, Chile, Ecuador and Peru. Here we define a catastrophic megarockslide as a landslide which initiated in rock material (bedrock or sedimentary rock) which has a volume above one million (megas: Greek) cubic meter that was fast or extremely fast moving (and therefore different to "giant landslide" defined by Korup et al., 2007 as a landslide above 10^8 m^3). Our data base on megarockslides (see distribution of megarockslide in Figure 1) is based upon our own field investigations and research of the scientific literature. More than 70% of the deposits reported here have been visited in the past 15 years and some of the data have been published by us before. It is evident, that the data set is biased by our research activities and does not represent an inventory. For example all events classified as historic have occurred in the past 100 years. Reports on large rockslide also exist from previous centuries, however volume estimates have not been given and deposit associated to these reports could not be clearly identified. Likewise, several historical megarockslides may have occurred in valleys with no or sparse population and have therefore never been reported. In addition, the effort of studying prehistoric events was different in these five Andean countries.

Our volume estimates are based upon field measurements, measurements on maps and satellite images drawn over a digital elevation model or are from the literature and are expected to be within 30% confidence level, however for simplification we report all events here only in 5 classes of magnitude ($> 10^6$ $m^3 = 1$, $> 10^7$ $m^3 = 2$, $>10^8$ $m^3 = 3$, $>10^9$ $m^3 = 4$, $> 10^{10}$ $m^3 = 5$). Our volume estimates are based upon the volume of the deposit. We are well aware that some rockslides in the Andes have significantly increased the volume between rockslide failure and final deposit due to entrainment of material in the path (Evans et al., 2007). However, this fact could not be taken into account in providing this overview.

2. Regional Megarockslide Distribution

Twenty five historic megarockslides have been reported in the ABCEP countries (Figure 1A), with 13 of them in Peru, 5 in Bolivia, 3 in Ecuador, 3 in Chile, and 1 in Argentina. During these events ~ 23000 people lost there life. In Peru two events had casualties in the thousands and two in the hundreds. In Ecuador only one event caused casualties above one hundred while the others caused 35 or less than 10 casualties. Loss of life in megarockslides in Bolivia and Chile have been in the tens or below ten. In Argentina only one historic megarockslide could be documented by comparison of airphotos from the 60s and LandsatTM imagery in a high Andean valley with only temporary settlement; no one was affected by that event. Most of these meagrockslides have been of relative small magnitude with volumes $< 10^8$ m^3 with the exception of the Mayunmarca (Peru) rockslide from 1974 which had a reported volume in access of $> 10^9$ m^3 (Kojan and Hutchinson, 1978). The number of prehistoric documented events is significantly greater from the known historic events (Figure 1B). In Argentina 98 events have been documented, 19 events in Chile, 16 events in Peru, 7 in Bolivia and 4 in Ecuador.

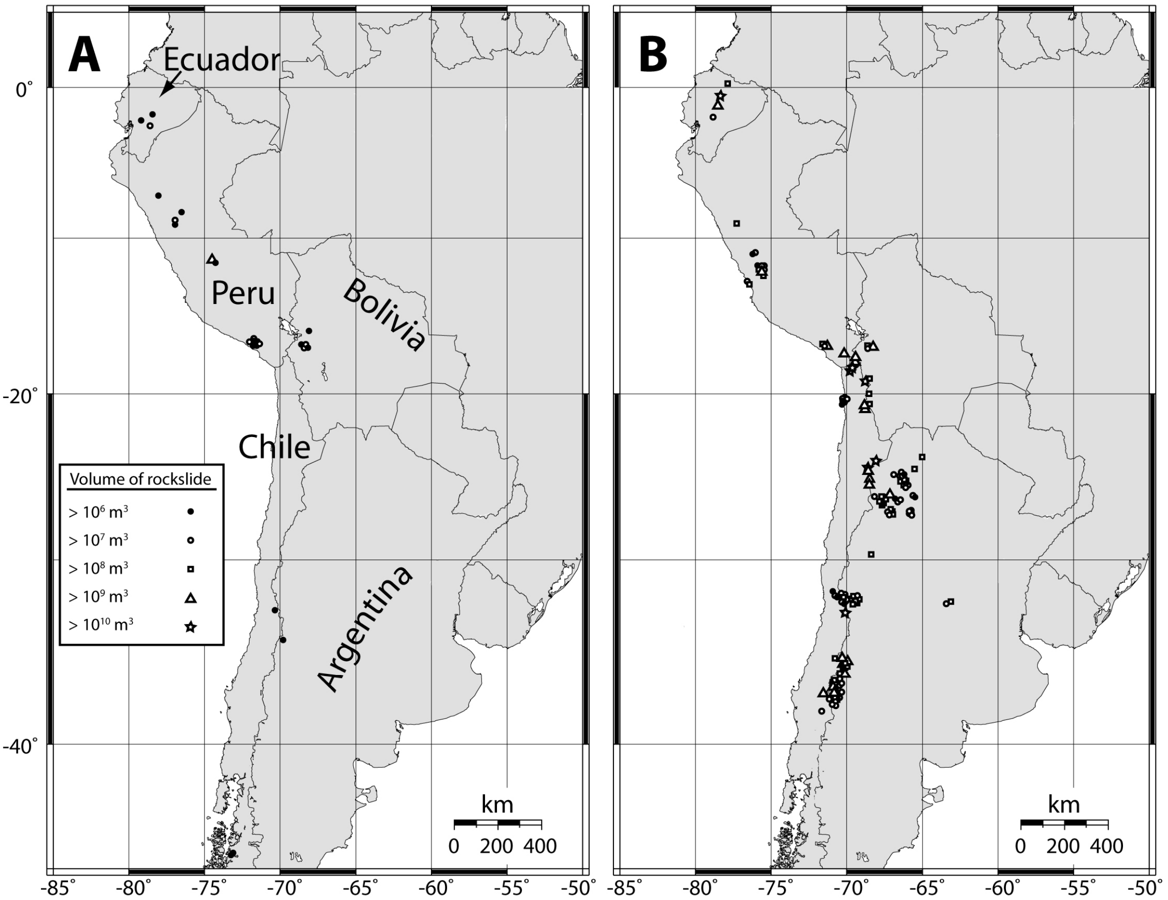

Fig. 1 Overview of distribution of catastrophic megarockslides in the Andes of Argentina, Bolivia, Chile, Ecuador, and Peru, A) historic, B) prehistoric. (Position of some slide locations is slightly changed for better visibility.)

Also the volumes of documented prehistoric rockslides are different from the historical events. There are 7 megarockslides with volumes >10 km^3, 23 with volumes <10 km^3 >1 km^3, 52 with volumes <1 km^3 >10^8 m^3, 49 events with volumes <10^8 >10^7 km^3 and only 13 events with volumes <10^7 km. The very strong bias towards larger events suggests they are unlikely to represent the real distribution but rather the preservation potential is better within the geological record. Among the largest events, with volumes >1km^3 (4 of them with volumes >10 km^3) 13 have been related to the collapse of volcanic edifices. The remaining 12 are related to failure of valley walls (2 of them with volumes >10 km^3, both of them lying in northern Chile (Wörner et al., 2002)).

It is clear that the prehistoric rockslides occurred in clusters probably for two reasons. One is the bias that results from focusing on selected areas where the natural conditions favor occurrence of rockslides. Hence clustering of documented prehistoric rockslides is likely a sign of enhanced rocksliding in the area. However, in the areas where no clusters have been observed, it may be that no systematic studies have been carried out. In addition, similar to prehistoric rockslide clusters found in Argentina, similar clusters are likely to be found also in the remaining Andean countries if systematic studies would be carried out.

2. Temporal Distribution of Prehistoric Megarockslides

From the 144 prehistoric megarockslides only 58 could have been dated so far. Most of dating has been carried out in Argentina with a few cases in each of the ABCEP countries, most of dating has been carried out in Argentina (Figure 2). Ages determined range between 1.4 ka and 5-10 Ma, however most dating resulted in Late Pleistocene to Holocene ages. There are two areas where dating of events has been carried out systematically: NW Argentina and the Central Andes of Argentina and Chile around Cerro Aconcagua. In the first area dating is based on cosmogenic nuclide dating, ^{14}C dating and tephrochronology (Hermanns and Schellenberger, 2008 and references therein). Results indicate that the temporal distribution of megarockslides can be grouped into two geological settings: neotectonic active mountain fronts enclosing larger intramontane basins, and deeply incised valleys cutting mountain fronts. In the first, megarockslides are generally several tens to hundreds of ka old and cannot be correlated with climatic variability. Those events in the narrow valley environment are Late Pleistocene to Holocene in age and cluster during periods characterized by more humid conditions in this region of the Andes.

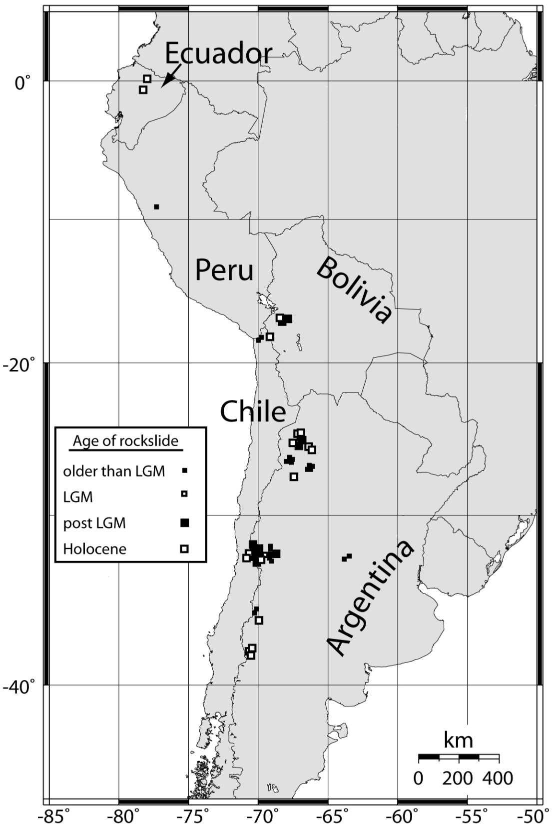

Fig. 2 Distribution of ages of prehistoric megarockslide deposits. (Position of some slide locations is slightly changed for better visibility)

In the valleys in Argentina and Chile surrounding Cerro Aconcagua (the highest mountain of the Andes) 18 megarockslides could be dated (e.g., Fauque et al. 2008, Welkner et al. 2008, Fauque in press.). Most megarockslides in valleys glaciated during the LGM occurred within the first millennia after LGM, while deposits in trunk valleys draining the inner part of the Andes are of LGM age or occurred shortly after LGM. Megarockslides in valleys not affected by glaciations are several tens to more than 100 ka old.

Megarockslides have been found to cluster along neotectonic faults in NW Argentina, in the Aconcagua region but also in northern Patagonia. In all of these Regions also temporal clusters of rockslide ages exist, which we suspect relates to a common seismic trigger. In NW Argentina this interpretation is supported by independent paleoseismic evidence showing that liquefaction and fault offset of lake sediments occurred at the same time as multiple megarocksliding (Hermanns and Niedermann, in press.).

3. Clustering of Historical Megarockslides

There are two clusters of historical megarockslides in the Andes of ABCEP, one in southern Peru in the Sihuas valley, the other in the immediate vicinity of the city of La Paz. Both of these clusters coincide with clusters of prehistoric events. At both sites the prehistoric deposits are up to two orders of magnitude (100 times) larger than the historic events.

The Sihuas valley is incised several 100 m in a coastal plateau at an elevation of ~1200 m altitude. The plateau lies within one of South American driest regions with only rare minor precipitation events separated by dry periods lasting several years. The Sihuas valley itself is green and fertile due to the Sihuas river draining the inner Andean region towards the Pacific. In the past 25 years the coastal plateau has been progressively converted into a large oasis through South America's largest irrigation project.

Within the Sihuas valley there are 3 prehistoric deposits with volumes between 15 x 10^6 m^3 and more than 1 km^3. These deposits have not been dated yet, however their age is expected to be older than the Holocene, because their toe areas are covered by massive deposits of laharic flows from the inner part of the Andes. Within the past 8 years megarockslides occurred in the valley involving volumes up to ~30 x 10^6 m^3. Some of the deposits span the entire width of the valley, forming natural dams. The rockslide deposits have destroyed several km^2 of agricultural land within the valley. The scar areas of most of these slides lie within the northern slope south of the irrigation project, where a large amount of water is seeping out of the valley walls. Infiltration into the subsoil from the irrigation on top of the plateau is interpreted as the main factor triggering these recent rockslides. A new project started in collaboration between INGEMMET and NGU will focus on verifying this interpretation and also understanding the conditions for prehistoric events.

The La Paz valley lies west of the Cordillera Real with elevations reaching 6500 m. The valley is incised up to 800 m into the Altiplano plateau at an elevation of 4100 m. This valley and the edge of the Altiplano plateau has with ~1.8 Mio people the highest population density of Bolivia.

Two large megarockslides are known to have occurred in this area in prehistoric times with surface areas between 8 and 60 km^2. These were dated by Dobrowolny (1962) to an age of 10 ka. We identified another megarockslide with a surface area of ~ 3 km^2 and date it to an age of 1.5 Ka. However, we also mapped 4 megarockslides which have occurred along the edge of the Altiplano plateau and along a ridge oblique to the plateau edge. These have occurred within the past 6 years ranging in volume from 2 to 70 x 10^6 m^3 (Quenta et al., 2007). All of these prehistoric and recent slides occurred within poorly consolidated sedimentary rocks of the La Paz formation with an age > 2.4 Ma and overlying deposits. The distance to the city centre of La Paz of all of these slides is less than 20 km. La Paz and the satellite town of El Alto are build on the same material which formed the megaslides in the past. Historic events have not been related to seismic triggering and occurred in both the rainy and the dry season. The prehistoric events have been associated with the El Alto fault system cutting both of the scarp areas of the largest slide and a seismic triggering is a possibility. Our paleoseismic investigations including trenching of the fault could not confirm this interpretation, as the latest event causing offset of the fault was dated to an age of about 15 ka (Minaya et al., 2008). However, we also cannot exclude seismic triggering for the prehistoric events as there are segments of the El Alto fault and other fault systems in the La Paz region which we could not investigate yet. Therefore the conditions of prehistoric events and historic events are still poorly understood. A new project in collaboration of the Observatorio San Calixto, SERGEOTECMIN, the Simon Fraser University and NGU will focus to get a better understanding of these conditioning factors.

Discussion

Multiple prehistoric and historic megarockslides have occurred in the Andean region of the ABCEP countries. Historic events have caused significant loss of live in most of these countries. Although the largest number of prehistoric events is known in Argentina, this is unlikely to be representative for the hazard level in this country compared to the others. In fact, megarockslide hazard is most likely to be greater in those countries with higher frequency of historic events (Bolivia, Ecuador and Peru). Although our inventory is far from complete it does show that the distribution is uneven in space and time and that geological and climatic conditions control it. Of special note is that while subduction-related megathrust earthquakes have occurred all along the continental margin in historic times, none of the events with volumes in access of 10^8 m^3 have been related to any of these events. This is further supported by observations made after the 2007 M 7.9 Pisco earthquake, Peru. During that event the largest rockslide had a volume of > 10^4 m^3, however in the region affected by landsliding caused by that earthquake 9 prehistoric megarockslides with volumes up to > 1 km^3 have been identified. This suggests that conditions different from today's are likely to have caused megalandslides in the past (Zavala et al. 2008). The discovery that megarockslides occur with a higher frequency during more humid climate periods or at the end of the last LGM in Argentina may well apply to other regions of the Andes. However more investigations have to be carried out to test this hypothesis.

Given that megarockslides occurred in the direct vicinity of large urban areas and effected towns in the Andean history and that conditioning and triggering factors controlling megarockslide distribution are still poorly understood makes clear the need for better understanding. A research efforts in areas where megarockslides would have an impact on Andean communities is strongly recommended.

Megarockslides associated to the collapse of volcanic edifices have been listed in this paper; but we did not focus on them. Moreover, some of the active volcanoes of the Andes also lie close to urban centers. Due to the enormous volume of most of the prehistoric collapses, failure of one of these volcanoes represents one of the highest megarockslide hazards in that region.

Finally, first observations of megarockslides in the Sihuas valley, southern Peru, indicate that human activity can also contribute to the temporal/spatial distribution of megarockslides in the Andes.

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Catastrophic Landslides in Context and Control: Late Quaternary Developments in the Nanga Parbat-Haramosh Massif, Northern Pakistan

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Abstract. The paper concerns catastrophic rock slope failures, their role in morphological developments and landslide hazards in mountain regions. Conditions in the Nanga Parbat-Haramosh Massif (NPHM) are the main focus, and landslides recently discovered there. The Massif has some of the greatest relief on Earth; some of the highest measured rates of uplift, denudation, and river incision in bedrock. Recently, over 310 rock slide-rock avalanches have been identified in the Upper Indus Basin, with more than 120 events within a 100km radius of Nanga Parbat peak. 'Context' refers to conditions in the orogen and mountain environment that influence the incidence and scale of the landslides. 'Control' refers to landslide roles in primary erosion and impacts on landform development. The latter includes the disturbance of glacial processes by masses of landslide materials deposited on ice; and by landslide dams and related developments along river systems. They reinforce the argument for a substantial morphogenetic role of catastrophic landslides in active orogens. They also create urgent problems of determining on-going risks from hitherto unrecognised events and in a rapidly changing regional context.

Keywords. rock avalanches, landslide dams, landslide-fragmented rivers.

1. Introduction

The paper concerns catastrophic rock slope failures, their role in morphological developments and landslide hazards in mountain regions. Conditions in the Nanga Parbat-Haramosh Massif (NPHM) are the main focus, and landslides recently discovered there (Fig. 1). A particular class of landslides is of interest and events that are 'catastrophic' in the sense of sudden occurrence, large magnitude ($>10^6$ m^3), rapid movement (100-250 km/hr), and brief duration (minutes). They combine massive rock slope failures with a rapid run out of crushed and pulverised rock called *rock avalanches* (Mudge, 1965; Hewitt et al, 2008), or "sturzstroms" (Heim, 1932; Hsu, 1975). They can also be 'catastrophic' in that no living thing and very few structures will survive a direct impact. However, secondary hazards such as landslide dams, inundation, sedimentation, or dam break floods may affect more people. They create problems long after the mass movement itself has ceased.

These mass movements are confined to mountain terrain with large areas of steep rock wall and considerable relief; usually reflecting high rates of uplift and denudation. Precursors relate to structures and states of stress in bedrock, and the history of its exposure by erosion. In addition, the travel and emplacement of landslide debris is influenced by the ruggedness of the terrain (Nicoletti and Sorriso-Valvo, 1991; Strom, 1996).

'Control' by landslides refers to their contributions to primary erosion and impacts on landform development. In the NPHM they are important in the unroofing of plutons, denudation rates, the geometry and evolution of interfluves. Moreover, fluvial developments have been disturbed and modified by large masses of resistant landslide materials deposited across valley floors.

The Nanga Parbat-Haramosh Massif (NPHM) comprises the south central part of the Karakoram Himalaya around Haramosh (7,409 m), and northwestern culmination or syntaxis of the Greater Himalaya around Nanga Parbat (8,125 m). It is thought to represent exceptionally rapid uplift and exhumation of a structural antiform, bounded by near vertical fault systems. Many studies have sought to understand how the Massif's morphology relates to geotectonic evolution, glaciations and the history of the Indus streams (Shroder, 1993). However, until 1989 only one catastrophic rock slope failure was documented; partly because many were misidentified as glacial deposits and their impacts attributed to other processes.

2. The Landslides

In recent years over 310 rock slide-rock avalanches have been identified in the Upper Indus Basin (Hewitt, 2006). More than 50 are in or near the NPHM. Some are reported here for the first time (Shroder et al, 1989; Shroder, 1998; and Hewitt, unpubl. field notes). Within a 100km radius of Nanga Parbat peak more than 120 events are now known. Since the surveys are preliminary and do not cover the whole area, it is likely that many more remain to be discovered.

Estimated original volumes of the landslides range from a smallest of 13 x 10^6 m^3, to more than 40 km^3; their deposit areas from less than 2 km^2 to over 55 km^2; heights of fall from 770 m to almost 4.5 km, and run out from 2 to 25 km. Table One provides some dimensions of landslides that exceeded 1 km^3 in volume, so-called "megaslides" (Korup et al, 2006).

The numbers, scales and concentration of events are among the highest yet reported. This is in keeping with the context. Compared to most other regions with concentrations of such events, relief, ruggedness, tectonic activity and topo-climatic variations in the NPHM are more extreme. Height of fall for the landslides is generally greater than reported elsewhere. Looked at as a set, the landslides display great internal diversity of detachment zone features and relations, styles of run out, morphology of landslide deposits and post-landslide histories.

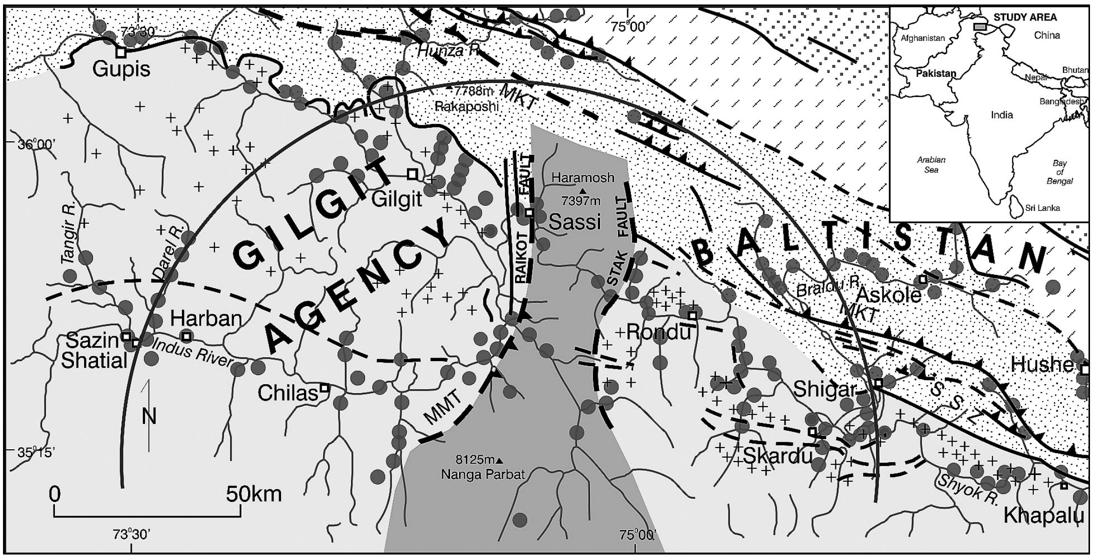

Fig. 1. Rock avalanches (circles) discovered in the Karakoram and Nanga Parbat Himalaya to 2005. Schematic relations to the regional geology shows Indian Plate rocks of the NPHM (centre, dark mass) bounded by active faults (after Searle, 1991). The circle line is the 100 km radius from the summit of Nanga Parbat.

3. Topographic and Topo-climatic Relations

Rock avalanches have great kinetic energy but no cohesion or tensile strength. Topographic irregularities in the path can concentrate, disperse, or split the debris stream. Multiple lobes, transverse and longitudinal ridges may develop, and great variations in deposit thickness (Hewitt, 2006).

A majority of the landslides identified here occurred at relatively low elevations. Most detachment zones lie on low and intermediate valley-side slopes rather than the main mountain edifices, and below 4000 m asl, many below 3000 (Table 1). The debris descended 1000 -2500 m in areas where local relief is between 4000 and 7000 m. Detachment zones are and from rock walls and interfluves carved by valley glaciers. The valleys were filled with ice during the last major glaciation.

However, such landslides have certainly occurred at higher elevations, and may be more frequent there. Nine of eleven historical events for whole Upper Indus basin occurred in today's glacial zone, two in the Nanga Parbat range since 2002. However, they are unlikely to leave remnants readily identified. Rock avalanches deposited in glacier accumulation zones are soon buried; those on ablation zones are quickly reworked and dispersed to the glacier margins (McSaveney, 2002; Hewitt, 2008).

4. The Indus streams in the Nanga Parbat-Haramosh Massif

At least 36 rock avalanches have dammed the Indus in its 310 km course from the Indus-Shyok junction to Sazin west of Nanga Parbat. In the 150 km section across the NPHM from Sazin to Rondu-Mendi, they average one per 6.5 km. Many more tributary valleys have been dammed. Evidence of impoundments includes extensive lacustrine deposits 800 m or more above present river level, and landslide interruptions have strongly affected fluvial activity helping to create a distinctive morphology.

Where the Indus crosses the NPHM the extent of rock bed channel is unusual. Evidently it reflects higher rates of uplift and active faulting.

West of Nanga Parbat down to Sazin, and throughout most of the Karakoram, the rivers flow in valley fill that mainly records impoundment and sedimentation behind landslide dams. There are occasional discontinuous rock-bed sections where the channel has been superimposed onto bedrock spurs or mid-valley outcrops from valley fill, also called "epigentic gorges". They do not represent the pre-landslide channel and are generally not cutting at the deepest levels of Quaternary incision.

In the NPHM there are sharp contrasts between tributary valleys with intact or partially intact barriers ands those unaffected by the landslides, or where their deposits have been removed. The latter tend to be deeply incised and V-shaped, with little or no sediment along the valley floor or lower slopes (Shroder and Bishop, 2000). The former have extensive valley-fill areas and well-developed sediment fans, and flow mainly or wholly alluvial channels. Much of the Tangir and Darel tributaries are aggraded to the height of intact or partly intact landslide dams.

5. Landslide Contribution to Denudation

Landslides for which estimates of volume are available suggest more than 200 km^3 of rock carried, on average through 1,500-2000 m. The events are late Quaternary, and post–date the last major glaciation, probably, as elsewhere in the Northern Hemisphere, around 15-20 ka. A small number of dated landslides are of Holocene age which probably applies to most events reported.

Table 1. Dimensions of rockslide-rock avalanche 'megaslides' (>1 km3) in the Nanga Parbat-Haramosh Massif and vicinity, estimated from ground observations and satellite imagery and, where available, detailed contour maps.

#	Landslide VALLEY	Volume (km^3) Orig.	Remains	Area (km^2) All	(RA)	Fall Max. (km)	Runout Max. (km)	Highest (m asl)	Dam? (Height, m)
1	Nomal Complex, HUNZA	45+	21	65	(37)	1.93	11.0	3450	Yes (1,000)
2	Gor-T'pani Complex INDUS	24	10	55	(44)	3.1	15.5	4200	Yes (800)
3	Rondu-M. A INDUS	23.5	12	56.0	(49.)	1.4	10.0		Yes (1,100)
4	Harban, INDUS	4.7	2.5	32.5	(23.5)	1.92	8.9	2900	Yes (450)
5	Sheko TANGIR	3.7	2.5	28.5	(14.5)	2.59	10.3	3,750	Yes (350+)
6	Batchaloi-Drang, INDUS	3.5	1.5	15.4	(12)	2.4	7.0+	?	Yes (500)
7	Dhak Chauki GILGIT	3.5	3.0	15.0	(6.0)	2.1		3,450	Yes (60 m)
8	Batkor, GILGIT	2.6	1.4	16.5	(12.4)	2.18	8.5+	3100	Yes (350+)
9	Shuta W INDUS	2.5	1.0	14	(10)	2.8	2.5	3700	Yes (?)
10	Batkor, GILGIT	2.5	1.0	18.0	(14)	1.8	9.5	3,090	Yes (250)
11	Jalipur, INDUS	2.25	1.5	29.7	(15.0)	1.5	6.9	2600	Yes (450+)
12	Iskere-Sassi Complex, INDUS	2.2	0.5	29	(21)	4.47	25.0	5,850	Yes (250)
13	Shuta E, INDUS	1.7	0.2	12	(5.7)	2.1	6.5	3400	Yes (?)
14	Doian- 1, INDUS	1.5	0.8	12.0	(10.0)	1.5	5.8	2680	Yes (300+)
15	Kami, TANGIR	1.5+	1.3	3.4	(1.5)	1.0	2.7+	2,850	Yes (50+)
16	Musa, DAREL	1.5	0.8	16.5	(14.5)	1.89	8.3	3,620	Yes (150)
17	Stak III, STAK	1.1	0.7	7.1	(4.2)	2.25	6.5	4850	Yes (150)
18	Lichar Compl. INDUS	1.1	0.6	9.5	(5.7)	2.1	4.5+	3290	Yes (180)
19	Sassi-Hupri, INDUS	1.0+	0.3	>15	(4)	?	?	?	?
20	Gine Compl. INDUS	1.0	0.5	11	(8.0)	2.26	9.2	3290	Yes (200+)

In the glacier zone, recent decades imply around 25-30 rock slide-rock avalanches per century in the Upper Indus Basin. This suggests as many as 2500-3000 events in the Holocene around 300 events on the roughly 1,500 km^2 of glaciers in the NPHM; more than those so far identified in the ice-free areas.

The longer-term impact of landslides complicates their contribution to denudation. Landslide-interruptions have also been a decisive factor in intermontane sedimentation, the volumes of material deposited being two or three orders of magnitude greater than that of the landslides. As landslide barriers are degraded the valley fill, in turn, becomes critical in patterns of sediment release; a problem for estimates of regional denudation based on present-day sediment yields.

Even more challenging, zero net incision applies to the major rivers for most or all of the Holocene. Most landslide barriers are partly or wholly cut through today, but rivers continue to flow in and over deep valley fill, or epigenetic gorges above the lowest rock bed valley floors; but this appears to be a geologically temporary or interglacial phenomenon in an active orogen. This challenges a widely accepted assumption that stream thalwegs and rates of incision are good proxies for rates of tectonic uplift. By impounding, obstructing, and diverting the rivers, landslides disrupt stream continuity, responses to tectonics, climate change and deglaciation.

6. Landsliding and morphogenetic evolution.

The landslide discoveries challenge past interpretations, notably the classic interpretation of Gansser (1964; 1983). He explained a series of terraces above the present Indus channel west of Nanga Parbat as tectonically uplifted; constructional landforms recording the pace and sequence of orogeny. However, the highest of his "uplifted terraces" consist of depositional landforms put in place by the catastrophic landslides, or lacustrine and related sediments recording post-glacial landslide impoundments. He believed they reflect a former landscape of much reduced relief, but the landslide materials clearly travelled over and were emplaced in a landscape essentially similar to today's.

The terraces below Gansser's highest levels are erosional, cut by the river in valley fill. They represent irregular and recurring episodes of incision following temporary landslide interruptions; that is, recovery from periods of intermontane sedimentation not an uplift sequence.

The famous "deformed Jalipur sandstones" were formerly attributed to Quaternary tectonic folding of late Tertiary or very early Pleistocene deposits. Those visited were found to record deformation by mass movements and are probably Holocene in age.

7. Landslide Hazards

The landslide discoveries imply a huge change in the risk environment. Dozens of villages and some small towns, well-known historical and culturally significant sites, are clustered amid the rubble of rock avalanches. Most other settlements are on sites shaped partly or wholly by landslide-related processes. The region's arable land is largely a result of the landslides blocking and modifying river valleys. They enter the risk environment through a variety of secondary and longer term instabilities, including inundation and outbreak floods from dams.

Given the absence of such awareness from most published work or geotechnical investigations, there are urgent implications for the risk environment, including the uncertain but likely future incidence of catastrophic landslides. Hazards are apparent in the vast quantities of landslide and related impoundment materials along the valleys, formerly thought to be glacial and much older. They are involved at many of the sites of frequent collapses or blockage of the mountain highways. There are implications for local people, and millions down-river in the Indus Plains and dependent upon the Indus waters. Several major development projects in and around the NPHM are of special concern, including the Karakoram and Middle Indus Highways. A new high dam is being constructed in the Indus gorge just west of Nanga Parbat that will drown the remnants of more than 15 rock avalanches.

Concluding Remarks

The events reported reinforce and extend the argument for a substantial morphogenetic role of catastrophic landslides in active orogens (Fort and Peulvast, 1993; Hovius and Stark, 2006; Weidinger, 2006). There are parallels in many other high mountain regions.

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An Illustrated Landslide Handbook for Developing Nations

Lynn M. Highland (U.S. Geological Survey) • Peter Bobrowsky (Geological Survey of Canada)

Abstract. As landslides continue to be a hazard that account for large numbers of human and animal casualties, property loss, and infrastructure damage, as well as impacts on the natural environment, it is incumbent on developed nations that resources be allocated to educate affected populations in less developed nations, and provide them with tools to effectively manage this hazard. Given that the engineering, planning and zoning, and mitigation techniques for landslide hazard reduction are more accessible to developed nations, it is crucial that such landslide hazard management tools be communicated to less developed nations in a language that is not overly technical, and provides information on basic scientific explanations on where, why and how landslides occur. The experiences of the United States, Canada, and many other nations demonstrate that, landslide science education, and techniques for reducing damaging landslide impacts may be presented in a manner that can be understood by the layperson. There are various methods through which this may be accomplished–community-level education, technology transfer, and active one-on-one outreach to national and local governments, and non-governmental organizations (NGOs), who disseminate information throughout the general population. The population at large can also benefit from the dissemination of landslide information directly to individual community members. The United States Geological Survey and the Geological Survey of Canada have just published and will distribute a universal landslide handbook that can be easily made available to emergency managers, local governments, and individuals. The handbook, "The Landslide Handbook: A Guide to Understanding Landslides" is initially published as U.S. Geological Survey Circular 1325, in English, available in print, and accessible on the internet. It is liberally illustrated with schematics and photographs, and provides the means for a basic understanding of landslides, with clearly-presented examples and explanations. The handbook will first be translated into Chinese, Spanish, and French and as a "public domain" document, it may be used without copyright issues, and will be free of charge to users. Support for users will be provided by both United States and Canadian geological surveys and those desiring more information will be urged to contact landslide personnel at these two agencies, through several means—email, telephone, and (or) FAX.

Keywords. Landslides, guidebook, education, developing world

1. Introduction

As population expands into rural areas, its impact on the natural environment will be profound. In turn, these changes will strongly affect man and his community life, and the exposure to natural hazards such as landslides will increase. Technological planning for this expansion is no longer a matter of choice; it has become an urgent necessity. Environmental management techniques to combine the physical environment and natural resources with social needs and limitations must be developed and implemented. It is not enough to react to environmental crises when they occur. There must be planning and education in order to anticipate problems and plan for their solution.

To this end, the U.S. Geological Survey, in cooperation with the Geological Survey of Canada, and the International Consortium on Landslides (ICL), (see http://icl.dpri.kyotou.ac.jp/ for more information on ICL) has developed a handbook that provides an introduction for understanding basic principles about landslides, and presents practical steps that homeowners, emergency managers and other decision makers can take to mitigate hazards from landslides. The handbook, "The Landslide Handbook: A Guide to Understanding Landslides," published as U.S. Geological Survey Circular 1135, is aimed at educating people in developing urban and rural communities, and covers information for both the built and natural environments around the world. It can also serve as a useful tool for more developed nations where appropriate. It is written at the level of a layperson, but attempts have been made to keep an appropriate level of technical references. The handbook will be first published in English, Chinese, and Spanish and then translated as funds permit, to other languages, such as French for example. It is hoped that decision makers at the local level will find it a useful tool in imparting knowledge and in disseminating information that they can adapt to the needs and approaches of each particular community. It is planned that a follow-up study be initiated to assess the usefulness of the book–its mode of distribution, whether it is effective in educating people, and what sort of modifications need to be made for future editions, or for ongoing, more effective distribution of the first edition.

Landslides, by their nature, tend to be local events, often involving failure of a single mountainside or hill, and thus do not compete easily with large regional disasters such as earthquakes and hurricanes, for national attention. However, many landslide-prone areas can be managed by land-use planning if landslide susceptibility is known, and by techniques such as avoidance, required grading of slopes, addition of drainage apparatus, instrumental monitoring, warning systems, or conversion of hazardous areas to parks and other public usage. This book will help define the discussions that local communities can have about what type of hazard level and risk from landslides is acceptable and to what extent losses can be mitigated.

2. Overview of Current Landslide Information for the Layperson

There are some similar precedents to this landslide handbook published by various entities, in English, throughout the past 50 years, many of which are aimed at emergency managers, urban planners, and municipal officials–Sidle and Ochiai (2006), Cornforth (2005), Schwab et al. (2005), McInnes (2000), Turner & Schuster (1996), Olshansky (1996), Wold & Jochim (1989), Jochim et al. 1988). Other books of this type are aimed directly at homeowners Creath, (1996), Handy (1995), Tyler (1995), Los Angeles Department of Public Works (1993), and Nuhfer (1993).

There have been a few books published on the subject of Landslide Hazard and Risk, which take the subject of landslides a step further, and present the concepts of risk management solutions–Glade, et al, (2005), Hungr, et al (2005). There may be similar publications in other languages that haven't come to our attention. The 50 United States each fund and maintain a state Geological Survey, and many of these Surveys offer brochures, leaflets, and practical advice for homeowners on the topic of landslides. However, the publications usually do not go into much detail. An example of this type of publication can be viewed on the Pennsylvania Geological Survey's website: http://www.dcnr.state.pa.us/topogeo/hazards/es9.pdf

Many of these homeowner publications provide rudimentary suggestions for homeowners to reduce slope instability, for example, through the implementation of improved drainage, and/or the watering of vegetation away from structural foundations. Some of them describe ground movement indicators such as leaning trees, or newly-formed springs, which can indicate that a problem may be occurring and the homeowner might want to initiate further investigation.

One of the most useful guidebooks is published by Los Angeles Department of Public Works (1993): the Homeowner's Guide for Flood, Debris, and Erosion Control, which contains very practical advice with how-to graphics for improving drainage around a residence, and, for example, recommends the species of native plants that are especially well-suited for strengthening soils, and which thrive in the southern California area. As the book refers to very site-specific methodology for the southern California experience of floods, debris flows and erosion, the Los Angeles authors warn that the book's methods cannot be necessarily applied to every place in the world, as every place has its own unique morphology, soils, rainfall patterns, and vegetation. However, the Los Angeles County book does not present basic information on types or triggering mechanisms of landslides; its aim is primarily simple mitigation solutions for homeowners, and it suggests how the average person can help his own situation by taking a proactive stance.

Several geotechnical and engineering societies feature books for sale on their publications lists that deal with engineering aspects of landslide mitigation, but most are not written for the layperson. Many also deal with only one specialty topic such as landslide monitoring, and it is assumed that readers of these books are well-versed in most aspects of landslide science, as the target audience is engineers, geologists, and soil specialists. The American Society of Civil Engineers, (ASCE) features a comprehensive publications list that those wishing to get more information about one particular topic can purchase (see: https://www.asce.org/bookstore/subject_act.cfm?strSubject=10

Federal agencies such as the Federal Emergency Management Agency (FEMA) and U.S. Geological Survey (USGS) feature pamphlets and websites that are provided for the education of citizens and decision makers, but they do not give a comprehensive presentation of landslide science and mitigation to the extent that this new landslide handbook will.

3. Handbook Contents

The handbook draws on aspects of the previous publications cited here, and includes an introduction to basic landslide science and the causative processes. It includes an extensive glossary of terms, an overview of technologic evaluation methods such as hazard maps and monitoring, and it covers the concept of multiple hazards (how landslides are related to floods, tsunamis, and earthquakes, for example). It contains a section on how managers may communicate landslide hazard through the use of town meetings, warning systems, and public education. It also contains a section about the effects of landslides on the natural environment, as well as the the effects on new construction and (or) the urban environment. As previously mentioned, the unique aspect of this book is that it will be translated into at least four languages, and more, if additional funds can be obtained.

Other unique topics discussed include such phenomenon as landslide dams resulting from landslides which block waterways and suggested approaches to mitigation of such. There is also a section on low-impact, environmentally friendly methods of slope stabilization, for example, planting of Vetiver grass to strengthen the soil on flat land, as well as hillslopes. There has been much research into Vetiver grass as a soil stabilizer, as it is easy to grow, and it thrives in a variety of climate regimes. This type of soil stabilization helps to reduce the costs of expensive engineered reinforcement, where it is impractical or too expensive to use.

The book will be spiral bound, and easy to refer to, as the pages will be smaller than a standard-size publication so that it will be portable and easy to page through.

The following figures are excerpts from the handbook and illustrate the manner of presentation. Figure 1 shows one of many schematics in the book that illustrate, for example, commonly-accepted nomenclature for parts of a landslide. There are other schematics accompanied by photos which show what a rotational, translational, debris-flow, and other types of landslides look like.

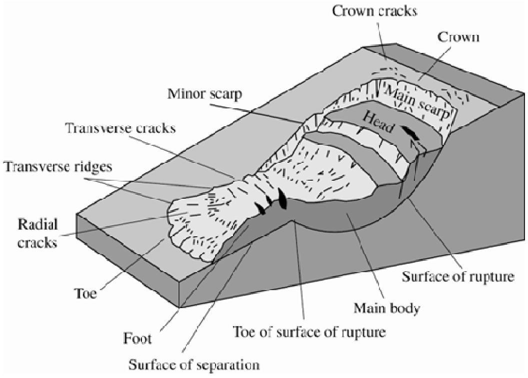


Fig. 1 A simple illustration of a rotational landslide that has evolved into an earthflow. Image illustrates commonly used labels for the parts of a landslide.
(from Varnes, 1978, Reference 43).

Figure 2 shows an example of the types of landslide mapping in use around the world, and the handbook provides examples of mapping that the reader can easily comprehend, and perhaps apply to their own unique situation.

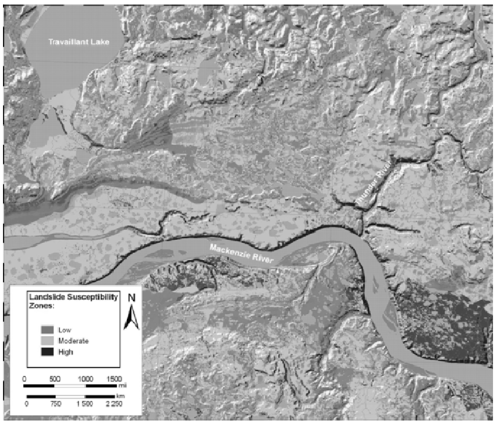


Fig. 2 An example of a landslide susceptibility map. This map shows an area in Canada, the Mackenzie River Valley, Northwest Territories.
Graphic by Réjean Couture, Geological Survey of Canada.

The handbook provides an overview of mitigation methods that can be used in dealing with landslide hazards. The examples can be easily understood and evaluated for applicability to local situations. One example is the illustration of the planting of Vetiver Grass to help stabilize slopes, which has been found to be effective, and encourages the use of bio-engineered, environmentally low-impact methods to lessen the impacts of landslides. Figures 3, 4, and 5 show a succession of Vetiver grass growth, after it was applied to an unstable slope in the Democratic Republic of the Congo in Africa. The handbook provides a reference for the reader to find out more about this method of slope stabilization. The Photos are from the Vetiver Grass website, http://www.vetiver.org

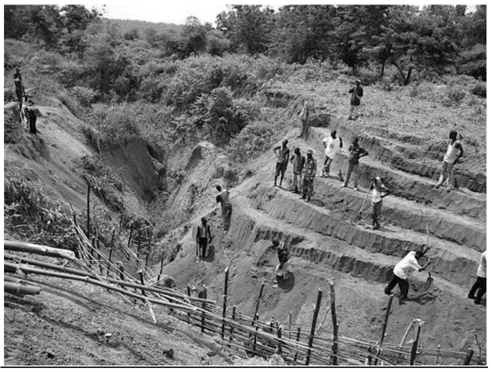


Fig. 3 A Vetiver grass system is being used in the Democratic Republic of the Congo for gully control in urban areas and for Highway stabilization. These gullies are a major problem in this area and other West African countries.

Fig. 4 The same slope now has improved drainage, and the slope has been planted in Vetiver grass.

Fig. 5 This planting of Vetiver grass is about 3 months old. Vetiver grass has been shown to be an effective means of stabilizing slopes in many areas of the world and it is low-cost and relatively easy to apply.

Figure 6 and 7 shows one of a series of schematics that feature examples of materials and methods that can be used to reinforce a dwelling to lessen the impacts of flooding and debris flows.

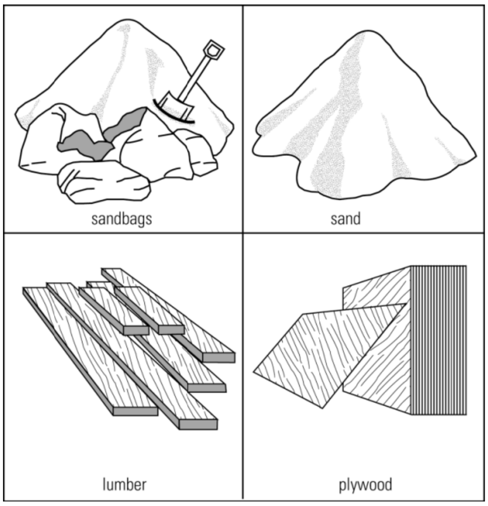


Fig. 6 Typical materials, usually available in many regions of the world, for helping to reduce damage from flood/debris- flow events.

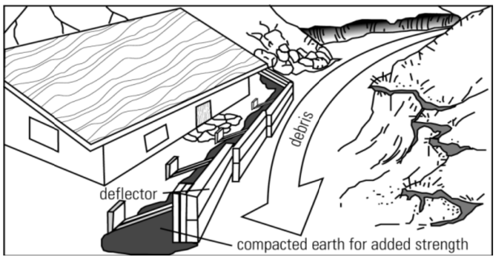
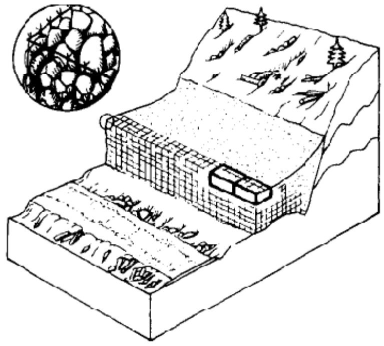


Fig. 7 This is a timber deflector, which is more permanent than sandbags.

The handbook also features an introduction to more traditional engineering methods for slope stability, and shows a series of figures that show the schematic of the method, together with a photograph of the finished structure.



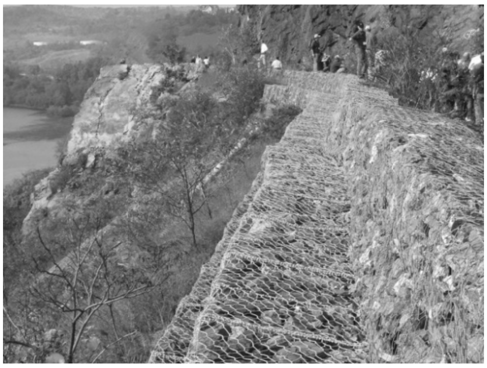


Fig. 8 A schematic and photograph of a Gabion wall along a highway. (Schematic from Reference 11. Photograph of Gabions located in the Pocono Mountains, Pennsylvania, USA by Lynn Highland, U.S. Geological Survey).

The following is a textual excerpt from the Handbook on the topic of Landslide Dams:

Part 4 – Landslide Dam Mitigation

As previously mentioned, the primary hazard from landslide dams is flooding that can occur when a landslide dam fails, or flooding that occurs when the dam is overtopped by the ongoing flow of water backing up behind the dam. The following measures can be implemented when communities are faced with potential hazards from landslide dams:

***1.** Diversion of inflow water before it reaches the lake, formed by the landslide dam—*
This can be done by diverting water from the stream into upstream reservoirs or irrigation systems. Although usually only a temporary measure, diversion

may slow the filling of the lake enough to allow the application of a more long-term solution.

***2.** Temporary drainage from the impoundment by pumps or siphons—*

The rising water level can be controlled temporarily by means of pumps or siphons, causing the water to flow over the low point of the dam. This is usually a short-term (less than 1 to 2 years) measure that provides time for more extensive, long-term solutions.

***3.** Construction of an erosion-resistant spillway—*

The most common method of stabilizing a landslide dam is to construct an erosion-resistant open-channel spillway either across the dam or across an adjacent abutment. When the overtopping by water occurs, flow is controlled by the spillway in much the same way that emergency spillways are constructed on engineered dams works to control water level. An additional advantage of this type of spillway is that it allows for the lowering of the water level behind the dam, which helps lessen the upstream flooding that landslide dams may cause.

Spillways are not always successful in preventing dam breaching and downstream flooding; they sometimes fail due to retrogressive erosion (erosion from the spillway outlet to its intake) caused by high-velocity outlet flow. To prevent erosion by minimizing flow velocity, the spillway should be wide and shallow. If possible, it should be lined with erosion-resistant materials (commonly riprap), especially at the outlet or inlet. Often, check dams are installed along steeper grades of the spillway to prevent erosion. Spillways that fail due to erosion may have been partially successful because they limit the total volume of the water behind the dam, thus reducing total discharge even if the dam breaches entirely.

Open-channel spillways across the landslide dam commonly are excavated by bulldozers; however, draglines, backhoes, explosives, and hand labor all have been used. Excavation can be dangerous in rough terrain, so an access road has to be constructed.

4. Drainage tunnel through an abutment—

A long-term method of preventing overtopping and breaching of a landslide dam is construction of a diversion tunnel through an adjacent dam abutment. Because large landslide dams commonly occur in mountain canyons, they usually have bedrock abutments; thus rock-tunneling methods commonly are used. Figure C53 shows the Thistle, Utah, landslide in the United States, triggered by the El Niño conditions of 1983. Heavy rains the previous autumn and rapid snowmelt caused the massive failure. For further reading please see Reference 31.

4. Distribution of the Handbook

World-wide literacy rates vary widely, especially in developing countries – it is acknowledged by the authors that a landslide handbook will primarily be used by people who can read or write, and who have access to an appropriate translation. Although the book will feature many photos, graphic illustrations, and how-to ideas, (for example, a step-by-step guide to filling and securing sandbags and a section on digging simple drainage ditches), it will probably be mainly distributed to municipal officials, whose job is to provide for the safety of individuals. It may be that the handbook will be distributed to national-level officials, allowing them decide the best way for distribution. An overview of the U.S. Department of State website which provides country profiles of worldwide nations (http://www.state.gov/travelandbusiness/) outlines government structure and literacy rates for most countries in the world, and we plan to begin with a careful evaluation of the most optimum distribution method for the handbook. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) will be a valuable resource for the possible management and distribution of the book, as they are a sponsoring member of the ICL and have an interest in furthering the goals of the ICL in reducing the impacts around the world from natural hazards.

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Geographical Overview of the Three Gorges Dam and Reservoir, China—Geologic Hazards and Environmental Impacts

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Abstract. The Three Gorges Dam and Reservoir on the Yangtze River, China has been an ambitious and controversial project. The dam, the largest in the world as of 2008, will provide hydropower, a management of flood conditions and will enhance the navigational capability of the Yangtze River. However, this massive project has also displaced populations, affected the stability of the banks of the Yangtze, and may intensify the seismic hazard of the area. It has also impacted archaeological investigations and animal populations in the reservoir and dam area. Of great concern are the geologic hazards posed by the construction and future operation of the dam. The hazards are interrelated and occur both naturally and also as direct result of the man-made construction, maintenance, and hydrological routine operations of the dam and its reservoir. Unlike many other large reservoirs around the world, which tend to be located in remote and sparsely populated areas, the Three Gorges reservoir area is so densely-populated that finding the space nearby to resettle people displaced by the reservoir has been difficult. Thus, even a moderate geological disaster in the reservoir area can entail enormous human and property losses. The geologic hazards include landslides and other slope failures, destructive waves in the reservoir area due to landslides, earthquakes and reservoir-induced earthquakes, and due to the construction of the dam, the changed sediment deposition affecting the operation of the dam upstream, and soil and nutrient replenishment of farmlands, downstream.

Keywords: geological hazard, environmental impacts, landslide, rockfall, flood, seismicity, reservoir

Please Note: Much of the information on Three Gorges Dam topics is in Chinese language and has not been translated into English. Much of the English-language background information for this presentation can be found in the official Three Gorges website that is maintained by the government of China. The website also features an up-to-date news link that presents current news and progress of this ongoing project: Official website: http://www.ctgpc.com/

A Short History of the Three Gorges Dam Project

In 1918, Sun Yat-Sen suggested, in his book *Strategy for State, Part II: Industrial Plans,* (Chinese government official website: http://english.gov.cn/2006-5/16/content_281667.htm) a scheme to "improve the upstream from here", that is, "a dam should be set here to let ships go downstream and use the water resource as power." May 1945, Dr. John Lucian Savage, an American expert in dam construction put forward his *Preliminary Report on Development Plans of Three Gorges.* After many, many state councils, and a preliminary small dam was constructed, it was decided the 3 Gorges Dam Construction should go ahead. The city of Sandouping, 7 km (4.3 miles) from the entrance of Xiling Gorge at the lower reaches of the Yangtze River, was selected as the site of the Three Gorges Dam in 1959. The river here is much wider than it is in other areas. There is a small island named Zhongbaodao in the middle of this part of the river. The planning of the project was started in 1993. The actual building of the Dam started on 14 December 1994. Zhongbaodao Island was used to build a dike to dam the river water and to connect the right bank with another dike. In order to build the main part of the Dam and the diversion channel afterwards, foundations were built in the dry riverbed. At the same time, channel construction started. During the 1980s plans were reviewed and modified and the project was approved by the National People's Congress, China. On 14 Dec 1994, the Three Gorges project was officially started. A series of 5 locks to facilitate ship navigation was also started. On 16 June 2003, the trial navigation of ship locks succeeded and on 18 June 2003, the ship lock started to be open to all types of ships. On 10 July 2003, the first generator unit began generating and was connected to the power grid. In September, 2006, secondary filling of the reservoir began. When the reservoir is full, in 2009, the water level is expected to reach 175 meters elevation (525 feet) behind the dam, creating a 632 sq km reservoir that will flood two cities, 11 counties, 116 towns, and the gorges of Qutangxia, Wuxia and Xilingxia. The ongoing dam and reservoir project at the Three Gorges Site a continuous process of construction, maintenance, and monitoring of functions and impacts. The hydropower that is generated is classified as a "renewable" energy source. Figures 1 and 2 show two views of the Three Gorges Dam and its immediate surroundings.

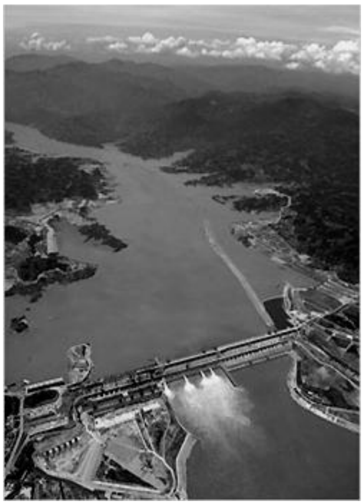

Fig. 1 Aerial photograph of the Three Gorges Dam.

Introduction to Geologic Hazards in the Three Gorges Area

Geologic hazards in the Three Gorges Reservoir area include landslides, rock falls, waves in the surrounding rivers and reservoir resulting from slope failures, earthquakes and reservoir-induced earthquakes, hazards from flood-control activities and changing sediment deposition rates, caused by the construction of the dam and impoundment of large quantities of water.

Landslides and Other Slope Failures

The Three Gorges have been formed by severe incision along narrow fault zones, in response to Quaternary uplift, of massive limestone mountains. These mountains are lower Paleozoic and Mesozoic age. Steep slopes develop on easily erodible or “soft” materials, which are extensive, and landslides are common in these areas (Liao and Tan, 1996). The average winter precipitation, in this part of China, is 100–150 mm (4 - 6 inches) per month, and the spring–summer (March – August) average can be as high as 200–300 mm (7 – 11 inches) per month.

Slope failures in the 3 Gorges area consist of rotational slumps in poorly or unconsolidated materials, translational rock and debris slides, debris flows and complex slides involving more than one type of failure, and several types of material. The area also experiences rock fall from large masses of limestone formations that are interbedded with coal seams which are naturally weak, but that are also in some places, mined and removed, further destabilizing rock these masses (Chen, 1999). Although occurring in incremental steps over a period of years, the raising of the reservoir level to its final height has destabilized old landslides and caused new slope failures to occur, through water pressure and saturation. The future raising and lowering of the reservoir in response to seasonal flood conditions will also cause a wet-dry effect on the unstable slopes, together with the increased pressure from the water, and the release of pressure when the water level is lowered. The extent and recurrence rates of these effects are currently unknown, but are of great concern. Rainfall in the area is also a contributing triggering process for landslides as the March through August average can be as high as 200-300 mm (7 – 11 inches) per month.

Earthquakes

Seismicity in the area is naturally occurring, and evidence also exists for incidences of reservoir-induced seismicity. There is good reason to be concerned about two main fault lines: the Jiuwanxi Fault and the Zigui-Badong Fault. Both are considered likely to produce earthquakes that could have an impact on the dam site, because they are very close to it. There are ample historical accounts of seismicity in the Three Gorges Area. From 1407 to 1631, four medium and strong earthquakes were recorded, with the largest believed to have been magnitude 6.5. From 1855 to the present, six medium and strong earthquakes have been recorded, the biggest having a magnitude of 5.5. Recurrence rates of medium-to-strong earthquakes indicate that 4 or 5 occur every eight to ten years in the Three Gorges area (Hu, et al, 1999).

Reservoir-induced Earthquakes

It is thought that reservoir-induced seismicity has already occurred in the 3 Gorges area. After the reservoir was filled to 135 meters (443 feet) in 2003, seismic activity increased in several sections of the Three Gorges reservoir. A few minor tremors were recorded along the Jiuwanxi Fault, which is located just 17 kilometers (10.5 miles) upstream of the dam. But much more seismic activity occurred along the Zigui-Badong Fault, which lies about 80 kilometers (50 miles) upstream of the dam, with the biggest tremor since the 2003 reservoir impoundment, recorded at a magnitude of 3.4 on the Richter scale. Historically, this fault has produced earthquakes in the magnitude 5 to 6 range on the Richter scale.

Another category of earthquake is that caused by the collapse of limestone (karst) caves, and holes left over from mining activities. Due to karstification, cavities and holes are created in rocks masses, which cause land subsidence, karst collapse, water bursting and reservoir leakage, and then do harm to buildings, tunnels, mining, and reservoirs (China Institute for Geo-Environmental Monitoring, CIGEM, 2003) For example, in the Wu Gorge, where there are many limestone caves, and in the Xiangxi valley, with its concentration of coal mines, minor tremors were recorded after the filling of the reservoir. On Dec. 18 and 19, 2003, minor tremors of magnitude = 1.8 and 2.5 on the Richter scale were recorded at Mazongshan, Guandukou township, Badong county 80 km (50 miles) upstream of the dam, and in Peishi township, Wushan county, 120 km (75 miles) upstream of the dam. In the case of Mazongshan, cracks appeared on the walls of 22 houses. With this kind of earthquake, the tremors are usually shallow, occurring close to the earth's surface, but the degree of damage to lives and property can be tremendous.

Geologic Hazards from Flood Control Methods

Another major concern is the wet-dry zone created by the future operation of the Three Gorges dam. After the project is completed in 2009, the water level in the reservoir is to be kept at 175 meters (525 feet) above sea level during the dry winter months, and lowered to 145 meters (435 feet) for the summer flood season. The 30-meter (90-foot)-high strip of land between those two levels will be covered with water in winter and exposed in summer. This wide ring around the Three Gorges reservoir and along the banks of upstream tributaries could become geologically unstable, seriously polluted and a dangerous source of epidemic disease (Jackson and Sleigh, 2000).

Sediment Problems

The changed sediment deposition patterns of the Yangtze have been altered by the dam and reservoir construction. Excess sediment can block sluice gates and sediment has to be removed manually from upstream areas of the Three Gorges dam. Otherwise, this blockage can lead to dam failure, which has been documented as having occurred, in some of China’s other dams. Sedimentation was a contributing cause of the Banqiao Dam, China failure in 1975. The Banqiao Dam failure precipitated the failure of 61 other dams and resulted in over 26,000 deaths; 5,960,000 buildings collapsed and 11 million residents were affected (Yi, 1998). (Banqiao dam is located on the Ru

River north of the Yangtze). Also, below the dam, the Yangtze is now carrying less silt, and as a result the river is flowing faster, and scouring the banks at an accelerated rate, impacting structures and levees. This reduction of the amount of sediment has in turn, impacted the downstream areas of the dam, as the normal deposition of sediment has been reduced, affecting the historical replenishing and renewal of farmlands that would normally take place after seasonal flooding of the Yangtze.

A Note on Non-geologic Hazards

Other impacts of the dam are social and ecological. There have been mass relocations of people from the banks of the Yangtze, causing changing social conditions for the people that have been moved, and also to the area and people which have absorbed the newly-relocated people. Lost archaeological sites are of great concern as an estimated 1,300 sites and as many as 8,000 unexcavated sites will be inundated by rising water (Chen et al, 2001). Wild goat and monkey populations have been impacted as well as fish, birds and mammals such as the Chinese River Dolphin which as of May 2008, is thought to now be extinct due to the negative changes to its environment, directly caused by the 3 Gorges Dam and Reservoir.

Fig. 2 National Atmospheric and Space Administration (NASA) photo of the Three Gorges Dam, 1987 and 2006.

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Satellite Remote Sensing for Landslide Susceptibility Mapping and Landslide Occurrence Prediction on a Global Basis

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Abstract. Landslides rank among the most devastating natural disasters, causing billions of dollars in property damages and thousands of deaths in most years around the world. However, predicting landslide occurrences is very difficult and expensive in terms of time and money. Drawing upon recent advances of satellite remote sensing technology, an experimental landslide prediction model is developed to identify the timing for landslides induced by heavy rainfall, the primary trigger. This system includes three major modules: (1) zoning the global landslide hotspots from a high-resolution geospatial database; (2) a real-time TRMM-based multi-satellite precipitation estimation system at fine spatio-temporal scales; and (3) a simplified automated decision making procedure which integrates the landslide susceptibility zoning map and the rainfall intensity-duration information to locate the likelihood of landslide occurrence. A trial version of the system is operated at NASA Goddard. Thorough validation is underway through comparison with various inventory databases and retrospective analysis of the 10+ years (and continuing) TRMM rainfall data record. With fine tuning and regional evaluation, ultimate goal of this work is to provide landslide decision support tools that rapidly disseminate landslide alerts for disaster mitigation activities for end users. However, it remains a matter of research to implement these concepts into a cost-effective method for capacity building in landslide risk management for developing countries.

Keywords. Remote sensing, landslide, satellite rainfall estimation, disaster warning

1. Introduction.

Landslides rank among the most devastating natural disasters, causing billions of dollars in property damages and thousands of deaths in most years around the world. Landslide warning systems can save lives and reduce damages if properly implemented in populated areas of landslide-prone nations (Sidle and Ochiai, 2006). However, predicting landslide occurrences is very difficult and expensive in terms of time and money. Growing populations plus related environmental impacts such as deforestation, have put a growing number of people at risk from landslides. At the same time, the required data infrastructure and analysis capabilities required to minimize injuries and deaths due to landslides are not yet practical in most developing countries that need them the most. The challenge facing our science community is to better understand the surface and meteorological processes leading to landslides and determine how new technology and techniques might be applied to reduce the risk of landslides to people. Today, the possibility exists to take advantage of advances in satellite remote sensing and other global data sets in the development of: 1) a global landslide database; 2) global landslide susceptibility maps; and 3) high time resolution, multi-satellite precipitation analyses with sufficient accuracy and availability to be useful for detecting the heavy rainfall events that provoke landslides. This article discusses the use of information from satellite remote sensing in the study of rain-induced landslides on a global basis, with an eye toward developing a system to detect or forecast such events on a global basis.

2. Compiling Landslide Databases and Mapping Landslide Susceptibility

Landslides pose a significant threat to populations worldwide, yet their occurrence and frequency are rarely assembled in a database on a global basis. In a recent study, Kirschbaum et al. (2008) compiled a global landslide inventory for rainfall-triggered events for several years, drawing upon news and scholarly articles, governmental and NGO reports, Relief organization information, and other landslide database sites. While this database is not able to capture all rainfall-triggered landslides that occurred in the evaluated years, it presents a lower boundary on the number of events globally and can provide insight into the statistical trends in landslide spatiotemporal distribution and impact. This inventory can serve as a valuable source for assessing patterns in hazard frequency and for use in validating models and susceptibility maps.

Recent advances in remote sensing techniques contribute to determining landslide susceptibility by providing information on land surface features and characteristics. This global view takes advantage of high resolution DEM data from the NASA Shuttle Radar Topographic Mission (SRTM). The 30-m SRTM data, used to derive topographic factors (slope, aspect etc), provide a major breakthrough in digital elevation mapping of the world. In addition, digital maps of soil characteristics prepared by the Food and Agriculture Organization and satellite-based land cover information (e.g., from NASA's Moderate Resolution Imaging Spectroradiometer [MODIS]) are combined with the information from the SRTM to estimate a static landslide susceptibility index for each point on the globe over land. The satellite precipitation information in this study includes the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA; Huffman et al., 2007). As needed, the various land datasets are downscaled by linear interpolation to the SRTM full resolution grid to provide the susceptibility information at the finest resolution. A global landslide susceptibility map is then derived following Hong et al., (2007a) from these geospatial data based on each factor's relative significance to the sliding processes. Fig. 1 shows the resulting global Landslide Susceptibility Index (LSI) map with a descriptive scale ranging from "negligible" to "high". Excluding permanent snow/ice regions, Fig 1a shows that the low LSI areas cover about half of the land (52%), while the areas of high LSI (4%) are mostly located in tropical or sub-tropical regions: the Pacific Rim, the Himalayan belt, South Asia, the Maritime Continent, Central America, Northwestern USA and Canada, Rocky Mountains, the Appalachian Mountains, the Caucasus region, the Alps, and parts of the Middle East and Africa. The spatial distribution of major landslide occurrences, collected from news reports and other sources during the period of January 2004 through September 2006, generally confirms the regions identified by the derived LSI map.

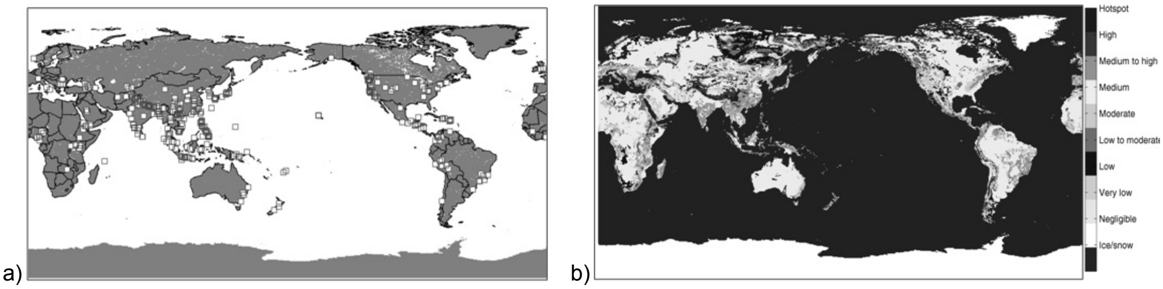

Fig. 1 (a) landslide occurrences collected from news reports and other sources during period of January 2004 through September 2006 and (b) Global Landslide Hazard Index and Hotspots

3. A Real-time Multi-satellite Precipitation Measuring System.

The spatial distribution, duration, and intensity of precipitation play important roles in triggering landslides. Comprehensive modeling of the physical processes involved in landslides helps pinpoint causes of landmass movement (Keefer and Wilson, 1987; Iverson et al., 2000) in relation to rainfall. However, data requirements for implementation of such models can often be prohibitive, leading to simplification of the processes for practical use (Gritzner et al., 2001). In practice, landslide occurrence has been related empirically to rainfall intensity-duration statistics from rain gauge information for specific regions (Larsen and Simon, 1993; Godt et al., 2006) and on a quasi-global basis (Caine, 1980). The recent development of high time resolution, multi-satellite precipitation analyses has provided the potential of detecting heavy rain events associated with landslides in tropical and temperate latitudes without regard for the availability of rain gauges, an issue which frequently limits the application of the previous studies. By using the precipitation information from TMPA, Hong et al. (2006) derived the first satellite-based rainfall Intensity–Duration threshold curve from landslide cases in various climate and geological locations, in parallel to the previous rain-gauge-based studies (Fig. 2). Note that the TMPA-based threshold falls below Caine's threshold, likely because the TMPA is an area-average value, rather than a point accumulation.

4. Preliminary Results and Discussion

Knowledge of landslide susceptibility (the "where" of the problem) and the ability to detect heavy rain events that meet threshold conditions (the "when" of the problem) provide the basis for exploring the potential and limitations for analyzing the occurrences of landslides, and even possibly forecasting them. A trial version of a simplified automated decision making procedure is operationally updated every 3-hour at NASA Goddard TRMM Website by integrating the landslide susceptibility zoning map and TRMM rainfall I-D information to locate the likelihood of landslide occurrence (http://trmm.gsfc.nasa.gov/). In order to perform the model validation, a landslide inventory was compiled for 2003 globally from multiple data sources: the International Landslide Centre and the University of Durham, International Consortium on Landslides, EM-DAT International Disaster Database (CRED), and references and media reports. Results show that 73% of the 223 landslides events fell within susceptibility high to very hot spots. However, the results also indicate that the prototype system fails to identify landslides triggered by short-duration (<3 hours) heavy rainfall events (Hong et al., 2007b). Thorough validation is underway through comparison with various inventory databases and retrospective analysis of the 10+ years (and continuing) TMPA rainfall data record.

Great strides are being made to integrate satellite remote sensing data into landslide hazard assessment. With fine tuning and regional evaluation, these early studies bear promise in approaching landslide hazard assessment globally and opening up the research community to addressing these issues in a broader context. However, it is important to realize the relative scale at which this type of analysis can be executed (Catani et al., 2005). It remains a matter of research to implement these concepts into a cost-effective method for capacity building in landslide risk management for developing countries.

In the future, increasing availability of improved, yet low-cost remote sensing products that can support locally-tuned landslide models will likely benefit disaster prevention for landslide-prone regions. In order to issue landslide warning forecasts, more accurate medium-range rainfall forecasts will be required to foresee the probability of a landslide occurring in high susceptibility regions at lead-times of several days. Prior to achieving that, the challenge facing the research community is to continue to develop techniques to better understand landslide processes that translate into potential warning applications. Such efforts must be practical with respect to local expertise and facilities available. The development should also involve capacity building for the vulnerable countries so that they can take advantage of the technical advances. Wide interdisciplinary efforts and multi-agency collaboration is required for landslide disaster prediction, management, and mitigation activities around the globe.

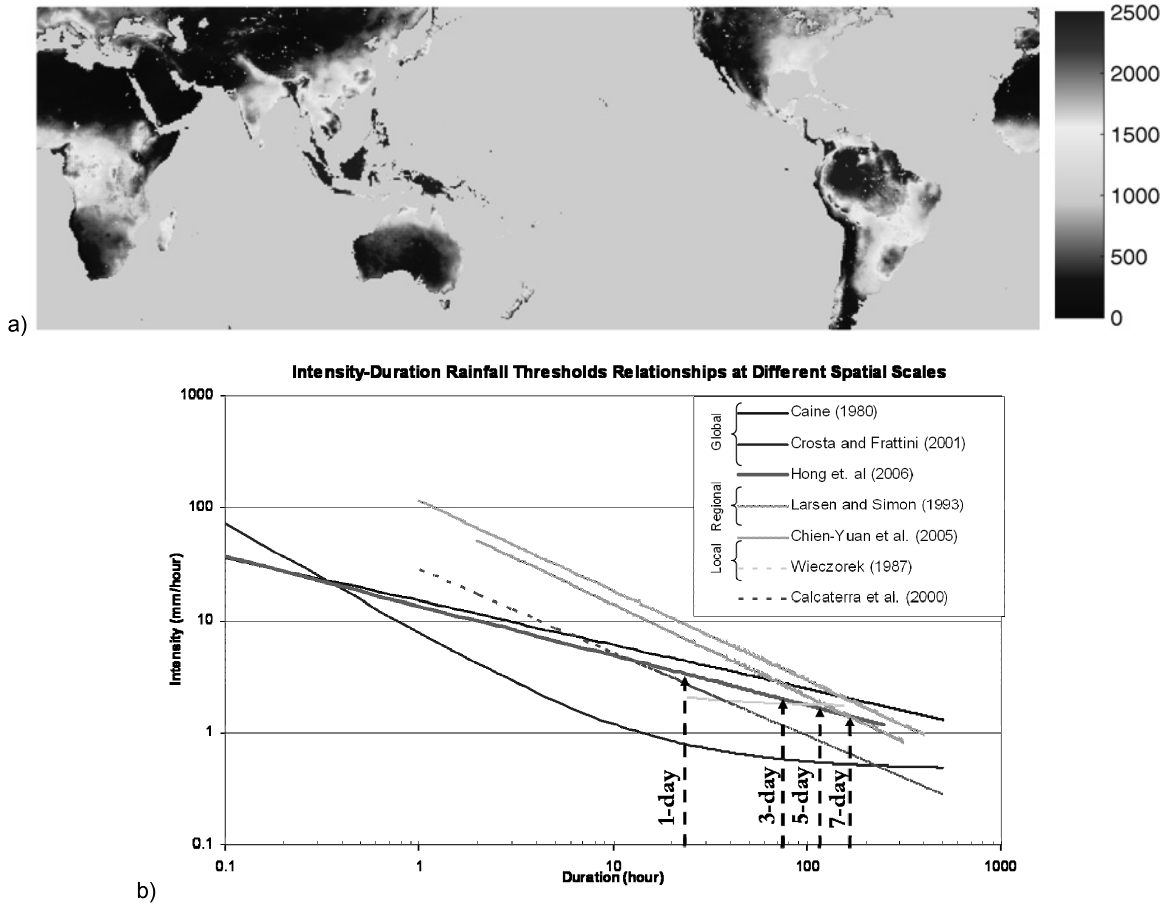

Fig. 2 (a) Annual mean precipitation (mm/year) from TRMM-based Multi-satellite Precipitation Analysis data record of 1998-2007 and (b) rainfall Intensity-Duration threshold at the global regional and local scales as derived from seven different studies. Note the satellite-based rainfall intensity-duration threshold curve (green; Intensity = 12.45 Duration$^{-0.42}$) is adopted from Hong et al. (2006)

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Geoecological Effects of Mass-movements on Habitats – the Case Studies from the Western Carpathians (Czech Republic)

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Abstract. Slope deformations represent one of dominant morphogenetic processes in the Czech part of the Western Carpathians. Landslides significantly participate also in the modification of landscape evolution processes. Entirely new and in many cases unique habitats evolve on the base of the differentiation of originally direct undisturbed slopes caused by landsliding. The study area contains slope deformations of various genesis, size dimensions and time of origin. The study brings knowledge of four different groups of slope deformations; within the deformations it analyses and interprets various reflections of landsliding disturbance, namely in partial landscape components. The slope deformations have created locations of palaeoenvironmental record which represents a valuable source of information (chronological, palynological, etc.) in terms of understanding geoecological aspects of not only the location itself but also a wider surrounding area. Within Miaší Mt and Černá hora Mt slope deformations the study focuses on the imprint of landsliding in soil variability. Evolution of specific geotopes in the extension zone of the Čertův Mlýn Mt deep-seated slope deformation is accompanied by the creation of a trench that was subsequently infilled with organogenic sediments. The occurrence of peat-bog biotopes in the Czech part of the Western Carpathians is often confined to landslides as in the case of the peat-bog on the southern slopes of Groníček Mt. High dynamics of changes of geotope features correlates with the occurrence of flow-like landslides (case study of debris flows in Smrk Mt massif). Habitat formation in areas affected by the catastrophic process of rock avalanche (Ropice Mt) is then considered to be an extreme case.

Keywords. Mass movements, geomorphic disturbance, geotope and landscape evolution, geoecology, palaeoenvironmental change, Flysch Western Carpathians

1. Introduction

Nowadays, the interdisciplinary study of landscape evolution belongs to common approaches both in geoscience and ecology-oriented researches (e.g. Zimmermann and Thom 1982; Minár et al. 2001). Increasing interest in these types of research can be traced also in the increasing number of studies focused in this way, namely in the field of the very geomorphology. Evidence of this was brought by a special issue of the journal of Geomorphology (Vol. 89, No. 1-2, 2007) focused on the problematics of the georelief-ecosystem relationship including the relationship of slope failures and the landscape ecosystem (Geertsema and Pojar 2007).

Areas affected by slope movement activity of diverse mechanism, velocity and genesis undergo transformation of the habitat conditions (e.g. Kirchner and Lacina 2004). Every landslide activity can be considered a disturbance or stressor that changes the initial level of the given geotope via newly introduced topographical conditions. The origin of landforms that differ from the initial level as for quality and quantity turns the state of the given geoecosystem into a new situation. It is evident that georelief plays an important role as a differentiation element of geoecosystems (Minár et al. 2001; Minár and Evans 2008).

The character of landforms influences the movement of water and substances while orientation and inclination have an effect on the habitat microclimate. Thus the georelief creates conditions for pedogenesis and affects vegetation particularly through hydrological, climatic and soil conditions of the habitat. After Geertsema and Pojar (2007), biophysical diversity of terrestrial areas affected by slope failures is of a various scale. The authors discuss site diversity, soil diversity, and their derivative - habitat diversity. Our study concentrates on most of these.

In connection with the knowledge above we will try to outline some of the key landslide effects that are important for the occurrence and evolution of habitats in the territory of the Czech part of the Western Carpathians. As there are slope deformations of various types in the study area, the aim of this paper is to demonstrate specific reflections of their existence in the Carpathian landscape.

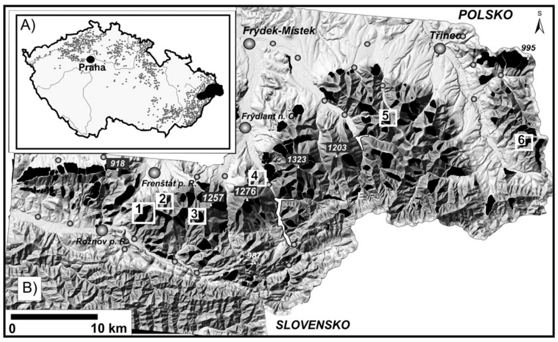

Fig. 1 Localization of the case studies within the Czech Republic (A) and the northern part of Czech part of the Western Carpathians (B): 1 – slope deformation of Mt. Černá hora, 2 – slope deformation of Mt. Miaší, 3 – slope deformation of Mt. Čertův Mlýn, 4 – debris flows of the basin of the Bučací potok Brook, 5 – slope deformation of Mt. Ropice, 6 – slope deformation of Mt.Groníček

In a few case studies we present the impact of slope deformations as a disturbance agent on the landscape components and point out essential displays of geodiversity and biodiversity of selected localities (Fig. 1). The choice of localities reflects not only various genetic types of slope deformations but also various displays of the territory consequent diversity. The study does not deal with predisposition factors and triggering mechanism of individual slope deformations in detail but aims to point out their geoecological connections in the flysch landscape of the Czech part of the Carpathians.

2. Soil variability – case study of the Mt. Miaší and Mt. Černá hora landslides

Mt. Miaší slope deformation is situated on the eastern slope of the northern part of the Radhošťský hřbet Ridge. This rotational-planar block deformation is found at the contact of massive Godula layers and manifold Godula and Lhota layers. The slope deformation was also predisposed by tectonic bedrock disturbance of the NNW-SSE direction. The affected area is c. 600 m long, 420 m wide and the total height difference is 250 m. The area morphology is given by typical block character of the deformation with a few partial headscarps and rotated blocks. The main headscarp, formed by conspicuous rock outcrops, is 880 m a. s. l. A major part of the headscarp is covered by debris detached from the rock outcrops. The headscarp verges on the horizontal surface of a rotated block void of debris. The horizontal surface is divided into two parts the elevations of which differ by 1.5 m. Within the deformation there is a number of specific landforms connected with extension such as trenches of various depth or prolonged depressions. On the contrary, the compression zones contain convex forms.

Deformation of the southern slope of Mt. Černá hora is characterised by richer morphology. It is a more complex, presumably multigenerational slope deformation. Deep-seated deformations subsequently accelerated rather shallow slides and small debris flows. Specific features of the deformation include the absence of rock outcrops as well as thick debris layers in headscarps. Deep slope disintegration is indicated by the presence of pseudokarst landforms (e.g. Volařka Cave).

The above mentioned morphology of slope deformations significantly asserted itself in the transformation of soil conditions. A thorough soil survey in relation to individual landforms showed that within the range of elevations and lithologies direct and undeformed slopes contain a dominant type of Cambisol, namely in two subtypes – Ranker Cambisol and Modal Cambisol. In the area of deformed slopes it is Cryptopodzol that is dominant. This trend is further modified in the area of specific landforms and shows itself by the presence of specific subtypes. Changes within the deformation are not striking only as for the soil type but also the thickness of subhorizons and the total thickness of the soil profile.

3. Palaeogeoecological history of a double-ridge trench - case study of Čertův Mlýn slope deformation

Slope failures have a significant palaeogeoecological potential given by the genesis of sedimentary infills of some depression forms. Varied morphology of the slope deformations and the course of the landslide origin enable the preservation of sedimentary complexes that document the environment quality during the Holocene landscape development. However, there are not always optimal conditions for the genesis of the sediments. Basic condition is the presence of less permeable bedrock layers that cause surface water accumulation. The reason can be the existence of a rock layer with a higher content of clay particles or the development of a soil horizon enriched with clay particles. This phenomenon is sporadically observed in the case of deep-seated slope deformations in the area of massive Godula sandstones. More often impermeable depressions originate in thinly-bedded flysch with a high presence of less permeable rocks (see e.g. works by Margielewski 2006 on the area of Polish Carpathians).

The Čertův Mlýn area is affected by deep-seated gravitational disintegration of the whole range. Massive blocks of Godula sandstones progressively subside into plastic underlying formations of clayey flysch. One of typical processes in progress in this type of deformations is lateral spreading accompanied by the development of double ridges that represent potential space for sediment accumulation. Lateral disintegration of one of the ridges in the lower part of the affected area gave rise to approx. 50-m long and 10 to 20-m wide prolonged depression infilled with 3.6 m of sediments. Radiocarbon dating determined its minimum age to Late Subboreal (3410±120 ^{14}C BP).

Detailed information on the territory conditions was obtained by sediment sampling in the whole profile and pollen diagram construction. Any similar depression in temperate climate undergoes the development that begins with its genesis as a consequence of gravitational spreading of the massif and ends with complete or partial infill of sediment of different character. The pollen diagram shows that the early depression phase involved space for a water body which did not necessarily have to be permanent or too deep, however, it retained water. This is supported by the presence of algae members of *Pediastrum sp.* and also *Diatom algae*. According to Jankovská and Komárek (2000) these groups of organisms indicate the presence of oligodystrophic waters. The depression margins were probably occupied by the vegetation species of *Eguisetum sp*., grass species (*Poa sp.* and *Carex sp.*) and hydrophilic species of *Ranunculaceae* and *Galium sp.* Locations of an increased occurrence of debris and exposed areas were dominated by hygrophilic ferns (*Dryopteris filix-mas*). Sedimentologic analysis shows that further development led to gradual infilling of the whole depression mainly by organic material with a high concentration of fallen trunks.

With regard to probably high forest coverage and location of the deposition area we can expect that a range of indicated herb species grew in the immediate vicinity of the depression, i.e. in the location of the very slope deformation. A few tens of centimetres of the upper layer were typically occupied by the members of *Sphagnum sp.* At present, the peat-bog is no longer active and its surface is dry; sporadically shallow depressions created by animal action can be found. The surrounding area is dominated by spruce monocultures with rare occurrence of beech. The pollen record shows evident gradual development of phytocenoses. The progress of fir (*Abies alba*) was dated to the Subboreal followed by massive beech propagation (*Fagus sylvatica*), namely at the boundary of SA1 and SA2 chronozones. Within the slope deformation the share of maple (esp. *Acer pseudoplatanus*) increased towards the end of the SA1 chronozone which is typically related to debris habitats that have been present in the given location along with the maple vegetation up to this day.

4. Peat-bog habitat - case study of Mt. Groníček slide

In contemporary cultural landscape spruce monocultures can largely be found on forest land. Similar situation can also be observed in the area of the flysch Carpathians. There habitat conditions here do not enable the cultivation of a cultural forest with a dominant spruce.

In a number of cases such habitats originate as a result of failure activity. A unique locality, from this point of view, is a slope deformation on the southern slope of Mt. Groníček (837 m a. s. l.) in the Slezské Beskydy Mts. It is a large slope deformation where conformly bedded layers of Istebna sandstones slid along the underlying clayey complexes of upper Godula layers. The deformation starts just under Mt. Groníček in the elevation of about 830 m and ends above the valley floor of the Kotelnice Brook in the elevation of 575 m. The total length of the studied area is c. 1000 m and the total height difference is 255 m; it reaches 600 m in its widest part. The landslide area is characterised by a relatively rich morphology. The upper part of the area within the elevations of 830 and 700 m has a character of a block field built by a set of moved and rotated blocks accompanied by internal drainage depressions and horizontal surfaces. Right below the upper headscarp there is a slope horizontal surface of the dimensions of 150x100 m built by a sunk and moved block of Istebna sandstones. The lower part of the slide (roughly within 700 and 575 m) comprises the accumulation with signs of lateral levees at the western and eastern limits of the landslide. The slid material is also partially affected by minor failures. The accumulation area shows a characteristic undulated morphology with the presence of internal drainage depressions. A peat-bog of the dimensions of 150x100 m formed in such an internal drainage depression in the elevation of 610 m a. s. l. The central part of the peat-bog revealed the peat thickness of minimally 5 m. Radiocarbon dating of organic remnants at the bottom of the depression determined the minimum disturbance age to 11 813±383 BP indicating probably more phases of the reactivation.

Geodiversity of this area is strictly given by the diversity of landforms (Fig. 2) that predisposed the formation of internal drainage depressions and concentrated the surface runoff of water and substance into their bodies. Landsliding affected the transformation of hydrogeologic conditions whose result is a constantly high groundwater level. Long-term water stagnation in trophically poor substratum led to the formation of peat-bog dominated by the members of *Sphagnum sp.*, *Eriophorum sp., Carex sp.* and *Juncus sp.* Tree vegetation is predominated by *Alnus glutinosa* and *Pinus syslvestris*. That is a typical example of an azonal biotope of a transient peat-bog in which the species composition reflects abiotic conditions controlled by the landforms. While *Abieti-Fageta* populations prevail on the surrounding undeformed slopes, the location of the rotated block with an original intercolluvial depression is occupied by the *Piceeta sphagnosa* population.

5. Ecotopes of high dynamics - case study of Bučací potok Brook and Mt. Ropice

Flow type landslides represent one of the most dynamic processes in the studied area. They particularly comprise displays of debris flows occurring in high concentration in the massif of Mt. Smrk (more e.g. Hradecký and Pánek 2008; Šilhán and Pánek 2007). Generations of debris flows fill the majority of valley forms in the Mt. Smrk area which is built by massive layers of Godula sandstones. One of the most interesting localities from the geoecological point of view is the Bučací potok Brook basin on the northern slopes of Mt. Smrk (1276 m a. s. l.). Debris flows in the studied area show a few basic features: evident debris flow recurrence and the presence of multigenerational landforms related to the processes or typical presence of accumulation and erosion landforms upon which new habitats gradually form. This is a classic example of chronic geomorphologic disturbance that recurred several times under favourable climatic and morphogenetic conditions. A few generations of disturbances were distinguished in the studied area on the base of the testing of the weathering ratio of clastics by the Schmidt Hammer Method (Šilhán and Pánek 2007). Habitats formed in the conditions of chronic disturbance show features of blocked succession with the presence of populations that withstand the recurrent disturbance. A few disturbance zones can be identified according to relative age of the existing accumulation form. We can suppose that the debris flow accumulations have been reactivated a few times and they represented very variable habitats.

A somewhat different type of slope disturbance can be observed in the Mt. Ropice locality. The slope deformation has a character of a flow type landslide or, strictly speaking, a rock avalanche (c. 1 km long; 150 m wide; redislocated material volume estimated at 0.500-0.800 Mm^3) that evolved from a destabilized slope affected by a deep-seated rotational slump in Godula sandstones (Pánek et al. 2008 in press). We assume that unlike debris flows in the Bučací potok Brook basin, only one major event took place in this case having a catastrophic effect on the existing biotopes in the locality. Consequently, a wide range of new quality geotopes evolved. The post-disturbance phase has lasted for approximately 1 500 years and the landforms are still very fresh and untransformed. We can observe the presence of rock walls, transported rock blocks and block fields showing low abundance of vegetation types. These are locations with suppressed pedogenesis and constant gradual rockfall and creep. Aquatic biotopes with both stagnating and running water evolved in the accumulation zone of the deformation. With respect to the presence of very permeable sediments in the accumulation part of the rockfall, the presence of water bodies constitutes an interesting phenomenon.

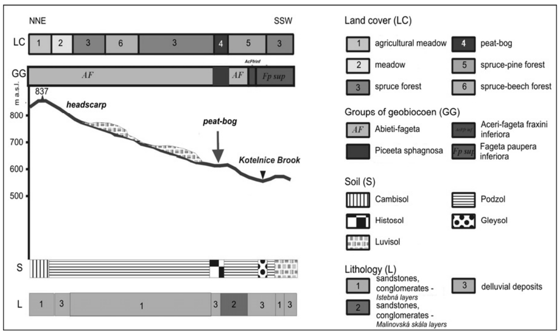

Fig. 2 Geoecological profile of the Groníček Mt slope deformation

Conclusions

Landsliding of various genesis, intensity and spatial extent represents a natural morphogenetic process in the area of the Czech part of the Western Carpathians. At the same time, landsliding asserted itself in landscape evolution processes as a disturbance phenomenon affecting the conditions under which various types of azonal geotopes establish themselves in the landscape from trophically poor and dry geotopes to aquatic and trophically rich geotopes.

Given types of slope deformations in the post-disturbance phase of the evolution of geotopes and landscape show themselves in different ways. Transformation of original slopes by block-type deformation is accompanied by the creation of distinctive discrete boundaries of new landforms concatenated into a system of headscarp – nearscarp depression – rotated block with intercolluvial depression – elevated part of rotated block. The compactness of forms and contrast of boundaries lead to the evolution of specific ecotopes that differ distinctively in the style of pedogenesis. Within the Mt. Miaší and Mt. Černá hora slope deformations increased presence of Cryptopodzols was identified in contrast to Cambisols that dominate undisturbed slopes in the identical elevation, orientation and lithological conditions. At the same time, morphology of the slope deformation limits the evolution of zones of both humus-rich (concave landforms) and humus-poor soils (convex landforms). The evolution of peaty and gley soils (e.g. Mt. Groníček) is typical of intercolluvial depressions and near-scarp depressions. Identical situations are described also by Margielewski (2006) in the Polish Western Carpathians or Hradecký et al. (2007) in Slezské Beskydy Mts. Chronic disturbances of the type of debris flow can limit pedogenesis (the presence of Rankers). This feature can also be observed in locations with exposed headscarps or in colluvial zones of failures with an increased presence of debris (e.g. Mt. Ropice). Given types of geotopes are occupied by specific vegetation populations that indicate different conditions of the habitat in disturbed and undisturbed parts of slope (case study Mt. Groníček).

The presence of azonal geotopes of the type of trench in lateral spreading zones in areas affected by deep-seated slope deformations led to the evolution of a stagnotope, i.e. high bog (case study of Mt. Čertův Mlýn). At the present time, the biotope of peat-bog has reached the regression stage (similar principles present Mather et al. 2003). Generally, these and other depression areas in slope deformations can be considered as suitable locations in terms of the study of the palaeogeoecological evolution of the territory. Despite a relatively high minimum age, some accumulation areas are still characterised by different geotopes. This is given by the permanence of hydric conditions that preserve a high groundwater level within intercolluvial or near-scarp depressions. In the case of Mt. Groníček slope deformation the slide disturbance has already existed in the landscape more than 11 ka.

At present, active displays of debris flows and rock avalanches in the studied area are minimal. In spite of this fact, geoecological effect of their disturbance activity in mountainous geotopes is still evident. The extremity of geotopes formed in this way can be observed in the presence of mainly coarse-grained substratum upon which pedogenesis takes its course very sporadically. Presently, the highest activity of debris flows is connected with high-gradient stream beds. These line geotopes are episodically exposed to high disturbance energy.

Disturbance effect of landslide activity in flysch landscape deserves attention in the future, namely in connection with expected climate change which can bring both climate-conditioned changes in the character of habitats and changes caused by increased dynamics of geomorphologic processes (e.g. Renschler et al. 2007). A highly interesting, but so far little investigated phenomenon is geoecology of Carpathian pseudokarst that evolved on the base of slope instabilities and now it creates absolutely unique habitat conditions.

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Recent, Rapid Development of Large Landslides in Discontinuous Permafrost, Little Salmon Lake, Canada

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Abstract. Little Salmon Lake, located in the Yukon Territory in northern Canada, has been subject to the sudden and rapid development of several landslides within the last decade. Situated in the zone of discontinuous permafrost, this area has been subjected to a steady warming of the climate, which is thought to be a key factor in the landslide initiation process.

Illustrative of the effects of the warming trend in the Little Salmon Lake area are two large active landslides, involving the degradation of ice-rich sediments. The volume of each slide is estimated to be in excess of one million cubic metres of sediments and ice. These landslides share many key geographic, geological and climatic factors; however, their behaviours show considerable contrast. The Magundy River Landslide is an example of a large retrogressive thaw slump, dominated by the exposure and ablation of ice-rich permafrost, forming viscous debris flows. The YT Landslide is a complex slide in that it is displaying rotational, translational and toppling behaviour. Much of the movement is thought to be due to thermal erosion which is undercutting and unloading the toe of the slide. Descriptions of these two landslides are provided in this paper along with a discussion of key causal factors.

The rapid growth and large size of these two landslides highlights the potential for large slope movements to develop as a result of climatic warming in areas of ice-rich permafrost. In anticipation of these warming trends continuing, land-use decisions in the area should take into account the possibility of the increasing occurrence of such landslides, as well as the location of the newly forming slides. Although preliminary landslide susceptibility mapping has been completed in this area, the rate of slide development and retrogression indicate that further study to more completely identify the slide triggering factors is warranted. In addition, data is needed to better define the distribution and presence of the ice-rich permafrost within slide susceptible materials.

Keywords. Permafrost, climatic warming, landslide development and prediction, hazard mapping.

1. Introduction to the Little Salmon Lake Project

Slopes in warm discontinuous permafrost create a potential hazard to development, because human disturbance, or natural processes, which expose ice-rich sediments, can lead to slope failure. Furthermore, increasing average temperatures are expected to accelerate permafrost melting, thereby producing water within the slope masses, and inducing or accelerating failure.

This is the case in the Little Salmon Lake region of the Central Yukon (Fig. 1), where an acceleration of natural landslide processes has taken place in the last decade. Degradation of warm, ice-rich permafrost has been an important factor in two recent landslides in the region: the Magundy River Landslide and the YT Landslide. Although these landslides are found in similar settings, there is a significant contrast in the behaviour and failure processes observed.

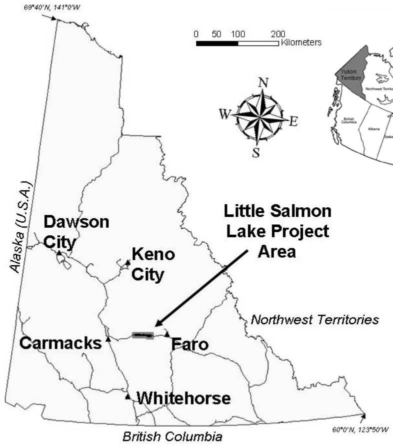

Fig. 1. Site location map for Little Salmon Lake, Yukon Territory, Canada.

2. Description of the study area

A satellite image (Fig. 2) shows some of the key physiographic features of the area, which is part of the Yukon Plateaus. The Little Salmon Lake valley occupies a glacially scoured and over-deepened U-shaped valley that is approximately 33 km long and 2 km wide.

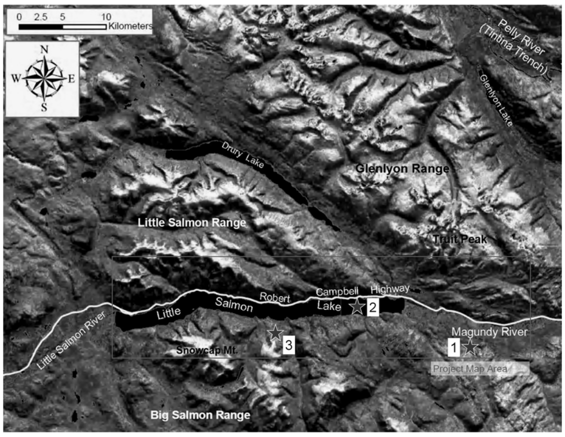

Fig. 2. Physiography of the Little Salmon Lake area, and location of the landslides discussed in this paper.

During the McConnell glaciation, which was the last ice age, the Selwyn lobe of the Cordilleran Ice Sheet covered the Little Salmon Lake area. Glacial retreat occurred very rapidly through ice sheet down-wasting and stagnation (Ward and Jackson 2000). Variable thicknesses of till cover the valley sides and plateau summits, while mixed glaciofluvial, till and glaciolacustrine sediments are found in the valley bottoms. Post-glacial lacustrine, fluvial, organic and colluvial deposits of Holocene age are common in the valley bottoms.

3. Temperature records

The Little Salmon Lake area is within the sub-arctic continental climate zone, which is characterized by long, cold winters, short, warm summers, low relative humidity, and low to moderate precipitation. A temporal plot of average annual temperature for the meteorological stations closest to the study area, Carmacks and Drury Creek, is shown in Figure 3. These data show the climate warming trends also noted by Serreze et al. (2000) and Burn (2004).

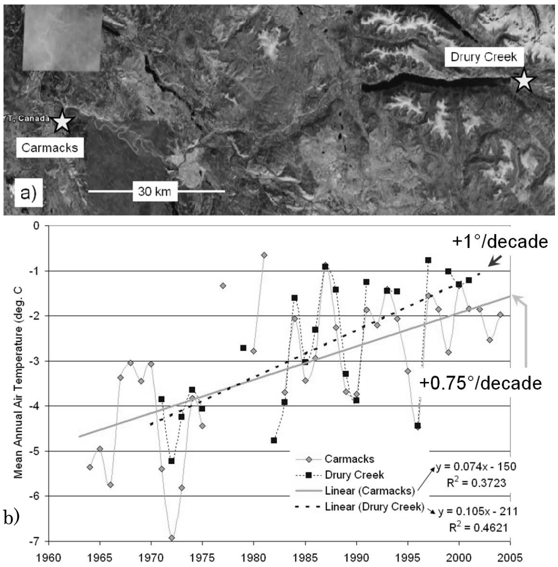

Fig. 3. Climate data for Drury Creek and Carmacks weather stations: a) station locations, and b) data (from Environment Canada, 2005).

4. Permafrost

The Little Salmon Lake area is within the zone of sporadic discontinuous permafrost as defined by Heginbottom et al. (1995), shown in Figure 4.

Primary controls on permafrost distribution include slope aspect, elevation, surficial material type and age, vegetation cover and drainage conditions. Local climatic effects such as snow depth variation and temperature inversions may also control permafrost distribution. In general, permafrost is thicker and more widespread on north-facing slopes where hill-slope shading, thick vegetative mats and poor drainage conditions exist.

In the case of the landslides described here, massive ice was found in the active areas of the two soil slides. Ice lenses and veins averaging 0.5 cm thickness composed up to 50% of the soil volume in several active scarp exposures on the Magundy River Landslide. The material that has moved rapidly within the YT slide during the time of the study is very ice-rich, containing substantial ice lenses.

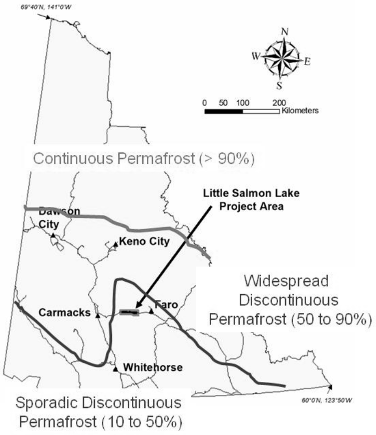

Fig. 4. Permafrost distribution in the Yukon, based on data from Heginbottom et al. (1995).

5. Landslide descriptions

Three distinct landslides are described in this paper. With reference to Figure 2, which shows the location of these landslides, these are: 1) the Magundy River Landslide, a retrogressive thaw slump, 2) the YT slide, a complex soil slide, and 3) the Little Salmon Lake rockslide.

The Magundy River Landslide, shown in Figure 5, is located on a gentle to moderate (10-20°) north-facing slope at 62°08.5'N latitude and 134°11.4'W longitude and 975 m elevation (at the top of the failure). The landslide includes an upper headscarp, where ablation and erosion releases sediment (Fig. 5b), which slides, flows or falls down into a gently inclined mudflow lobe, where it flows away (Fig. 5c). The Magundy River Landslide is classified as either a bi-modal flow (Lyle et al., 2005; Lyle, 2006; Lyle and Hutchinson, 2006; based on McRoberts and Morgenstern (1974)), or a retrogressive thaw slump (based on Everdingen, 1998). The Magundy River Landslide is similar in size and morphology to the Surprise Rapids Landslide (Ward et al., 1992) and Pelly River Landslide (Ward and Jackson, 2000; Mollard and Janes, 1984); these two landslides are also located in the Central Yukon.

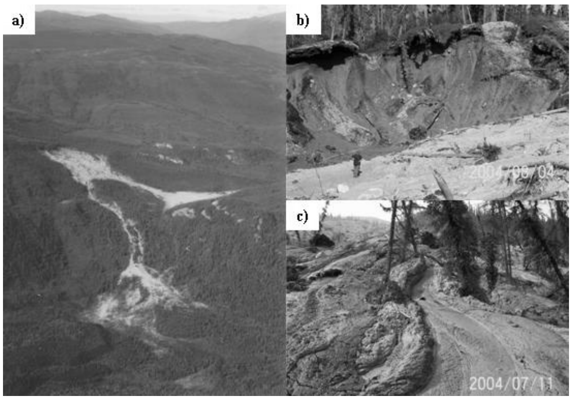

Fig. 5 Magundy River Landslide: a) overview looking south (top scarp is 350 m wide, elevation change from top scarp to

depositional area is about 350 m) b) active thaw slump area (note person for scale); and c) active debris flow (channel width is approximately 1 m across).

The morphology and development of the Magundy River Landslide is described by Lyle et al. (2007), as summarized in Figure 6. Retreat rates have been estimated, based on airphoto analysis, eyewitness reports, and GPS surveying. Retreat rates for the southeast and southwest scarps (Fig. 6) have retreated an average of 12-16 m per year. These rates are consistent with the range of rates calculated by Burn and Lewkowicz (1990) for retrogressive thaw slumps in Canada's northern areas. However, the north scarp (Fig. 5b) has retreated at rates of 30-40 m per year. It is believed that this high rate is due to the south-facing aspect of the slope (increased solar radiation), downslope retreat of the scarp, and lateral ablation. The Magundy River Landslide is considerably further south than any of the slides noted by Burn and Lewkowicz (1990).

The trigger for this landslide is not known. However, the summer of 1995 was one of the warmest on record, followed by the winter of 1996, which was colder than average. In addition, the maximum recorded monthly precipitation (snow and rain) fell in March 1996, followed by the maximum recorded monthly rainfall in April 1996. These record spring precipitation conditions, coupled with the post-Little Ice Age warming trend, likely led to adverse hydrogeological and thermal conditions which were sufficient to initiate the landslide.

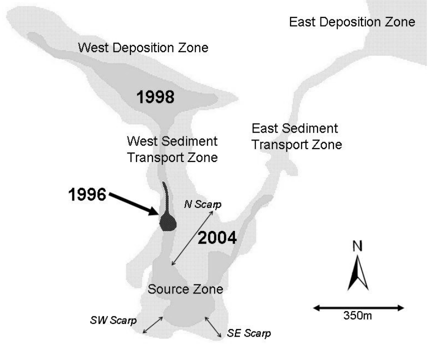

Fig. 6. Footprint of the Magundy River Landslide in 1996 (red), 1998 (green) and 2004 (grey).

The YT Landslide is located on the south shore of Little Salmon Lake, approximately 7.5 km west of the mouth of the Magundy River at the east end of the lake. It is situated at a latitude of 62°10.7'N and a longitude of 134°30.7'W and 700 m elevation (at the top of the failure). The landslide is positioned on a north-facing slope, with the headscarp being approximately 100 m above the lake surface. It continues down to an unknown depth below lake level. At the lateral margins of the landslide, it appears to be bulging out into the lake, while the core of landslide appears to be cut back into the slope. A photographic overview of the landslide is shown in Figure 7.

The landslide is 250 m long, from the lake shore to the top scarp, and 350 m in width. An elevation change of 90 m over the length of the landslide yields an overall angle of 20°. The east side of the landslide covers a land area of about 56,000 m^2 while the overall area is approximately 80 000 m^2. The overall depth of the landslide is not known, as no subsurface exploration has been conducted. The maximum vertical height of the main scarp was measured to be 20.1 m. It is estimated that this landslide involves in excess of 1 million m^3 of sediments and ice.

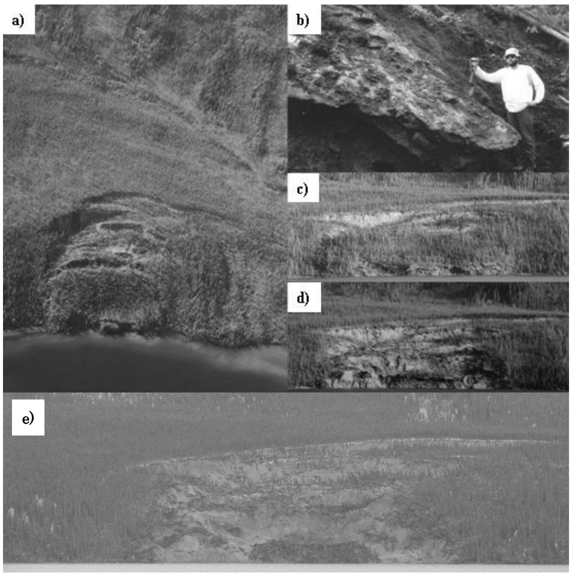

Fig. 7. YT Landslide: a) overview, looking south (Aug. 2004); b) massive ice in sediments exposed in landslide scarp; c, d and e) overview photos, looking south from across Little Salmon Lake on Aug. 3, 2004, Aug. 2, 2005, and Sept. 28, 2007 respectively. The upper scarp in the photos is approximately 350 m long.

The earliest evidence of development of the YT slide is observed in airphotos from 1989. Initiation of the YT Landslide is not clearly understood. However, French (1996) suggests that permafrost creep is most prevalent in ice-rich soils on steep slopes in areas of warm permafrost. Deformation is promoted by the increasingly plastic nature of ice and the high unfrozen water content at these temperatures. The warmer the permafrost, and the greater the amount of ground ice, the greater will be the deformation. These conditions exist in the lower portion of the slope at the YT Landslide. Thus, permafrost creep likely played an important role in the development of the YT Landslide. Post Little Ice-Age climate warming, or perhaps warming in the 20th century (Fig. 3), likely played a role in accelerating permafrost creep, eventually leading to long-term creep rupture of the frozen soil. This would produce a landslide form that would resemble block slides, like those of the original blocks at the YT Landslide.

The Little Salmon Lake rockslide, shown in Figure 8, is located in an area where a scarp from previous slide activity is evident (Fig. 8a). Exact timing of the development of the lower, active slide is not known, but the morphology of the slide in 2004 is shown in Figures 8a), b) and c). It is hypothesized that a hillslope of this elevation, aspect and latitude would likely contain permafrost. However, initial investigations of the slide mass in 2004, were hampered by dangerous conditions, so the presence of ice rich joints within the rockmass was not confirmed or denied. As such, this slide may not be related to degrading permafrost. This slide has received renewed attention due to the observation by local residents of the effects of renewed activity (Fig. 8d). Although the recent surge in slide activity was not observed while it was occurring, local residents indicate that the slide activity occurred during a week of heavy rainfall, in early September. Due to the very recent nature of the slide activity, further investigation of the possible triggers and specific observations of the geometry and morphology of the new slide area have not yet been made.

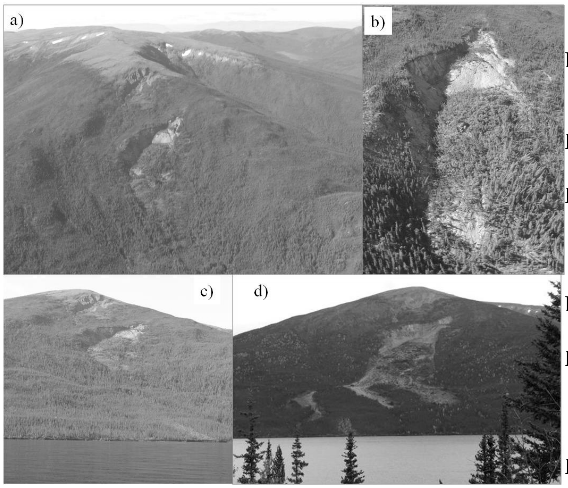

Fig. 8. Little Salmon Lake Rockslide: a) overview looking south, showing the 350 m long side scarp (Aug 2004), and b) scarp area detail from helicopter fly-over (Aug 2004), and c) and d) looking south from across the lake on Aug. 3, 2004 and Sept. 7, 2008. (Fig. 8d – courtesy G. and W. Eberlein).

Conclusions

The YT and Magundy River Landslides are two examples of large, active landslides involving permafrost degradation, however they exhibit contrasting behaviour. The Magundy River Landslide is a retrogressive thaw slump where viscous flow is the primary movement mechanism for thawing sediments. The YT Landslide is complex with overall rotational movement; much of the recent movement appears to be translational due to the thermal erosion at the toe.

Despite the differing behaviour, several important factors are observed in both landslides. They are located within the same physical setting, on north-facing slopes of gentle to moderate angle with similar geological and groundwater regimes. The sites share similar climatological conditions, as they are only 20 km apart at comparable elevations. These two key factors have contributed to the development of ice-rich permafrost at both landslide locations. It is likely that Post-Little Ice Age and recent warming climatic trends are a primary causal factor for the initiation and propagation of both landslides.

The Little Salmon Lake rockslide debris mobilization and scarp retrogression appears to be related to elevation of the water table within the rockmass. This is thought to be due to heavy antecedent rainfall which may have been augmented by degradation of permafrost at the base of the slide.

Acknowledgments

Financial support for this research was provided by the Yukon Geological Survey (YGS), NSERC, GEOIDE, and NSTP. The YGS and EBA Engineering Consultants Ltd. provided field and laboratory logistical and technical support. J. Bond (YGS) provided the initial project idea and introduced us to the area. W.A. Gorman, R. Harrap, Y. Preston, and G. and W. Eberlein all made significant contributions to the project.

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Field and Laboratory Investigation of Soils Affected By the 2007 Chuetsuoki Earthquake

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Abstract. Field and laboratory investigation of the soils affected by the 2007 Chuetsuoki earthquake was undertaken to understand the mechanism of slope failures during undrained loading. The sites investigated were in Kashiwazaki, Niigata. Three categories of soils were encountered – New dune sands, Old dune sands, and clay soils. Analyses showed that the old dune sands were more likely to suffer sudden collapse and liquefaction than the new dune sands. The old dune sands had very low effective stresses at steady state which corresponded to liquefaction. Results showed that the generation of excess water pressure was more rapid in the old dune sands than in the new dune sands. The magnitude of excess pore water pressure generated at any point during the undrained loading in the old dune sands were many values higher than that generated in the new dune sands. In all the old dunes specimens, excess pore water pressure generated in them was equal to the normal stress on the soils. This was not the case in the new dune sands. It was also found that the higher uniformity coefficient in the old dune sands did not correspond to higher shearing strength, so uniformity coefficient as a measure of soil strength appeared to be unreliable. Results from artificially constituted soils showed similar results – higher uniformity coefficients do not always lead to higher shear strengths. The new dunes with a lower uniformity coefficient appeared to be less susceptible to liquefaction in the same way artificially constituted narrow graded sands appeared to be better engineering materials than well graded sands.

Keywords. New dune, old dune, peak strength, steady state strength, liquefaction

1. Introduction

Planners and managers often desire information about hazards on a site before they can approve development. They also desire information about disasters as a way of preventing reoccurrence. Sustainable and efficient land use and development; and minimizing loss of life and property from natural disasters are always the reasons for this desire. One of the most important pieces of information these planners and managers want is geotechnical study related to the stability or instability of the area, and other secondary seismic hazards such as landslide, flow slide, lateral spreading and settlement. In keeping with this, a fieldwork to investigate the soils affected by the March 2007 Chuetsuki earthquake was undertaken. The sites investigated were in Kashiwazaki, Niigata. Three categories of soils were encountered – New dune sands, Old dune sands, and clayey soils. The field investigation revealed that the new dune sands have yet to undergo the level of weathering that the old dune sands have gone through. While the color of the new dune sands is dark, that of the old dune sands is brown to reddish. Fig. 1 shows the location of the sands. Figs. 2 and 3 show the new and old dune sands respectively. Works examining the shear behavior of these sands are scarce. This paper examines the shear behaviors of the new dune and the old dune sands affected by the Chuetsuoki earthquake as a way of understanding the mechanisms of slope failures during undrained loading. It is also hoped that when the shear behavior of the dune sands are compared with that of other sands, the influence of grain size and grain size distribution will be properly understood.

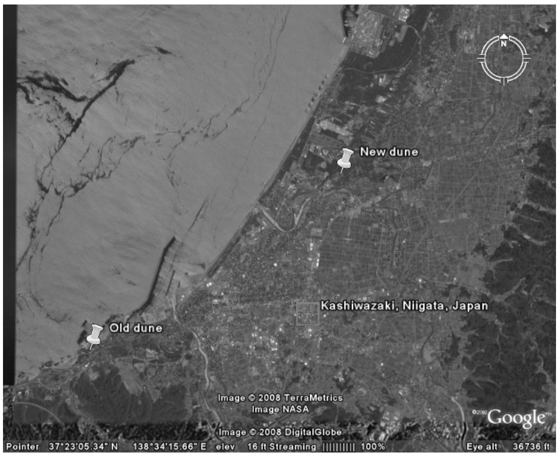

Fig. 1 Location of the sites investigated at Kashiwazaki, Niigata

Fig.2 New dune sands at Kashiwazaki, Niigata

The ring shear apparatus, among other attributes, permits unlimited displacement of soils; and should be suitable for examining the post-failure behavior of granular materials. By allowing the soils to undergo large displacements, conclusions about their steady states could be drawn reliably.

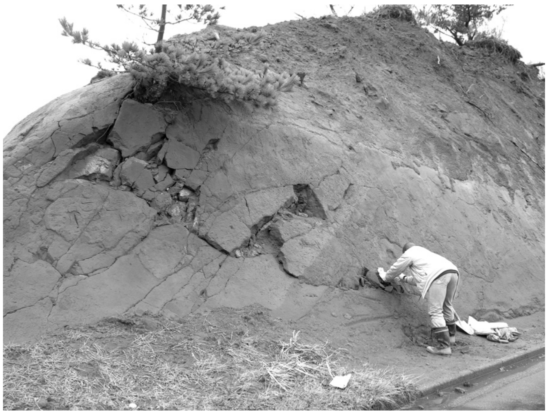

Fig. 3 Old dune sands at Kashiwazaki, Niigata

2. Material, apparatus, and test procedure

Three kinds of specimens were selected for this study. These are, New dune (ND) with $U_C = 1.2$, and Old dune (OD) with $U_C= 3.0$. Industrial sand materials composed of sub-angular to angular quartz and small amount of feldspar reconstituted to a uniformity coefficient of 3.3 can be compared to the sand dunes.

B_D parameter – the ratio of change in pore pressure and change in normal stress ($\Delta u/\Delta\sigma$) over a specified period of time – was the standard parameter used in assessing the degree of saturation of the test samples (Sassa, 1988). A series of undrained, torque-controlled ring shear tests was conducted on fully saturated, normally consolidated specimens. Shearing was performed by incrementally loading shear stress at the rate of 0.098kPa/sec.

The particle size distribution of a soil is usually represented by a parameter known as uniformity coefficient. It is simply the ratio: d_{60} {grain size that is 60% finer by weight} divided by d_{10} {grain size that is 10% finer by weight (effective grain size)}. The general belief is that the higher the ratio, the better graded a soil should be; and that higher U_c values should yield higher shear strengths.

2.1 Testing Apparatus

All the results presented herein are from a capable ring shear apparatus, hereafter referred to as DPRI-5, known as the fifth version of ring shear apparatuses available at Disaster Prevention Research Institute, Kyoto University, Japan (Fig.4). Designed, modified, and vastly improved by Sassa in 1996, DPRI-5 is so refined that it permits switch of test conditions, from drain to undrain, and vice versa, at any point in time during an experiment. The apparatus is structured to eliminate some difficulties commonly encountered with other more conventional apparatuses while studying the mechanism of landslide motion. It is equipped to allow speed-, and stress-controlled tests; and the measurement of very large shear displacement.

Test specimens were saturated with water. To achieve at least 96% saturation (the minimum acceptable level of saturation used in this thesis), carbon dioxide was found to be indispensable. In all the tests, therefore, carbon dioxide was allowed into the samples, at slow rate, for one hour, after which, de-aired water was introduced, again, at slow rate, for at least 16 hours. Oven dried samples were used in the tests.

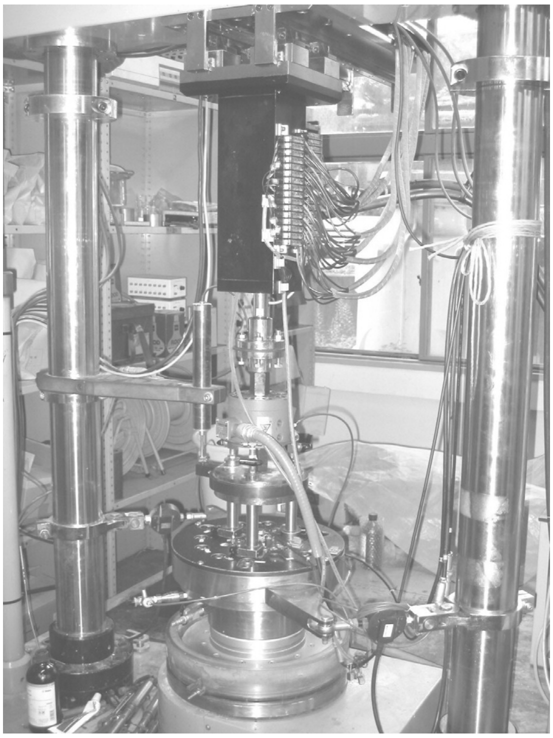

Fig.4 Ring shear apparatus DPRI-5

3. Undrained response of the specimens

3.1 New Dune specimens

A specimen of new dune consolidated to a void ratio of 0.89 is shown in Fig. 5a and b.

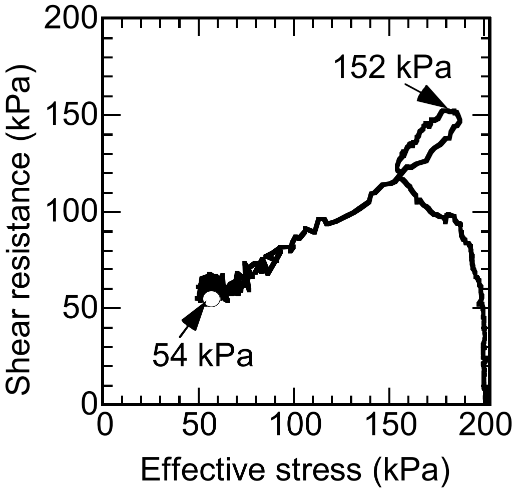

Fig. 5a The stress path of a specimen of new dune with a void ratio of 0.89

The specimen achieved peak strength of 152 kPa before it failed and its strength was reduced to a steady state value of about 54 kPa. Fig. 5b shows that pore pressure decrease occasioned by dilation was the reason the specimen achieved the peak strength of 152 kPa. Some have reported the features observable after shearing. One of these features is grain crushing at the shear zone (Okada et al 2004 observed similar evidence).

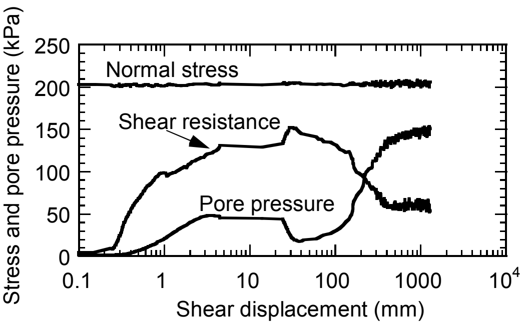

Fig. 5b The relationship between stress and shear displacement of a specimen of new dune with a void ratio of 0.89

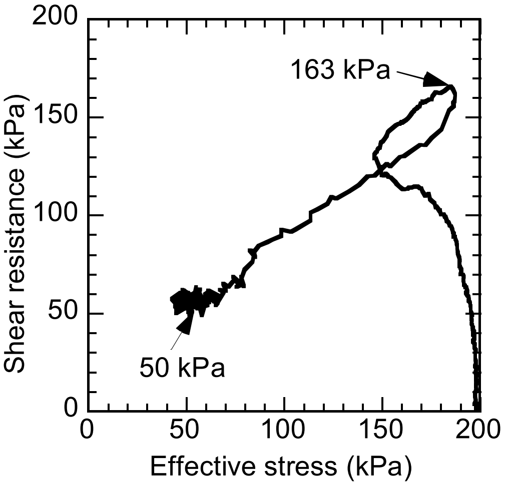

Fig. 6a The stress path of a specimen of new dune with a void ratio of 0.85

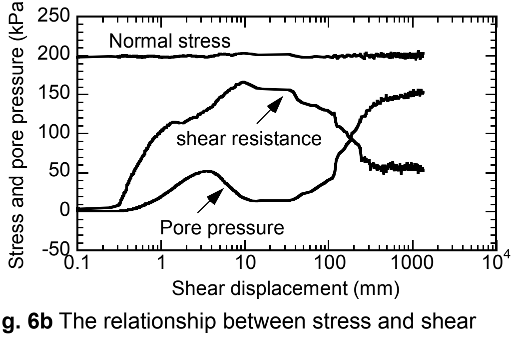

Fig. 6b The relationship between stress and shear displacement of a specimen of new dune with a void ratio of 0.85

Another specimen of New dune consolidated to a void ratio of 0.85 attained peak strength of 163 kPa. The steady state strength is about 50 kPa (Fig. 6a and b). Similar behavior was seen in specimens of New dune consolidated to void ratios of 0.90.

3.2 Old Dune specimens

Fig. 7a shows the stress path of an old dune consolidated to a void ratio of 0.92. Fig. 7b shows the relationship between stress, pore pressure and shear displacement.

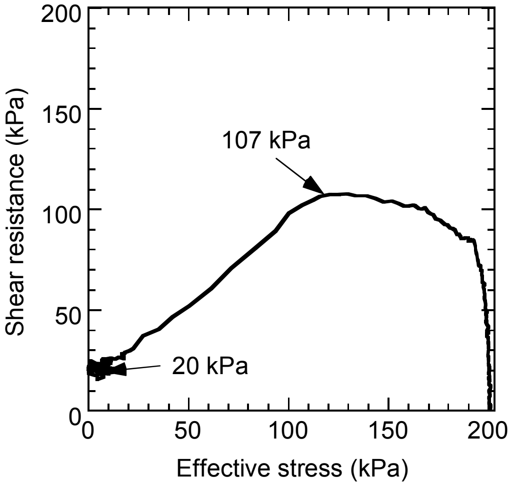

Fig. 7a The stress path of a specimen of old dune with a void ratio of 0.92

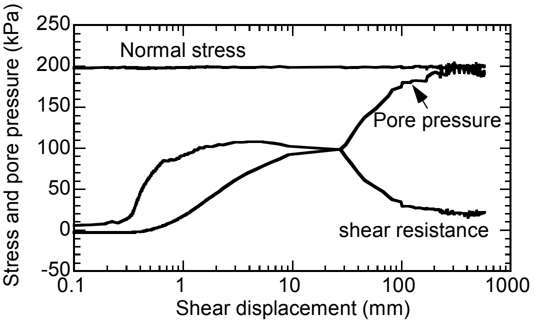

Fig. 7b The relationship between stress and shear displacement of a specimen of old dune with a void ratio of 0.92

From the outset of shearing, pore pressure generation was evidently rapid and eventually reached the same value the normal stress (200 kPa). Unlike the new dune specimens, sudden collapse and liquefaction is more likely to develop in the old dune.

Another specimen with a void ratio of 0.91 showed similar behavior of rapid and high excess pore water generation, Fig. 8a and b. Not only was the generation of pore pressure fast, it was also very high, reaching the value of normal stress. This phenomenon was not observed in the new dune specimens.

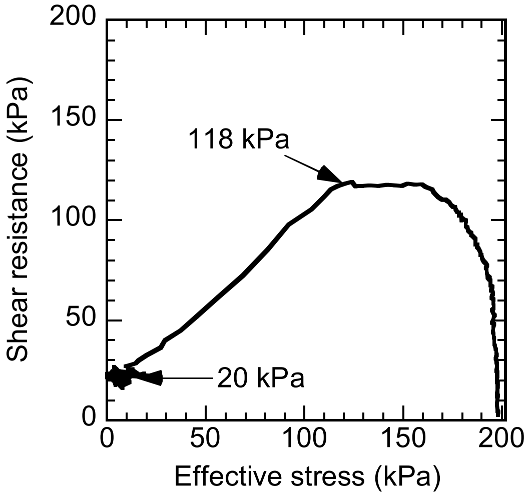

Fig. 8a: the stress path of a specimen of old dune with a void ratio of 0.91

Sassa 1996, Sassa et al., 1996, and Sassa , 1997 have observed similar phenomenon.

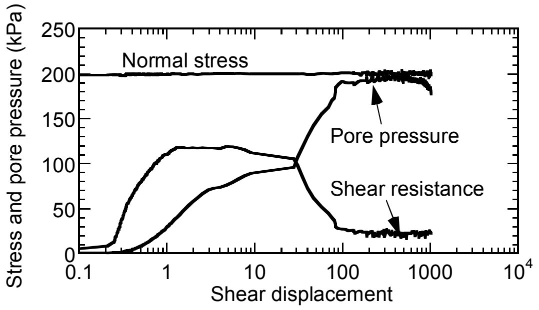

Fig. 8b: the relationship between stress and shear displacement of a specimen of old dune with a void ratio of 0.91

4. Conclusions

1. Under same condition, new dune sands have higher peak strength than the old dune sands.

2. Under same condition, new dune sands have higher steady state strength than the old dune sands.

3. The generation of excess water pressure is more rapid in the old dune sands than in the new dune sands.

4. Excess pore water pressure generated in the old dune sands is equal to the normal stress on them. This is not the case in the new dune sands.

5. Whereas the new dune sands, at any void ratio, almost always dilated, the old dune sands instead show collapse behavior.

6. Old dune sands are more likely to suffer sudden collapse and liquefaction than the new dune sands. In fact, all the old dune sands investigated liquefied because their effective stresses at steady state are very low.

7. The higher uniformity coefficient in the old dune sands did not correspond to higher shearing strength, so uniformity coefficient as a measure of soil strength is not reliable. The new dunes with a lower uniformity coefficient appear to be better engineering materials.

Acknowledgments

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Optimum Design of Landslide Stabilizing Piles by Centrifugal Loading Experiments and FEM

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Abstract. In Japan, from individual experience up to the present, intervals of landslide stabilizing piles has been decided according to landslide depth. In this paper, the authors examined optimum design of landslide-stabilization piles by centrifugal loading experiments and by FEM analysis. This has been tested under varying geo-conditions such as strength, ductility and so on.

This examination showed that under various geo-conditions, maximum intervals of piles can be lessen upto eight (8) times of pile diameter. According to these experiments and numerical analysis, optimum design of landslide stabilizing piles could be established. Authors also conducted 3D slope stability analysis which resulted in moderation of landslides and reduction of about 40% of the pile work costs.

Keywords. Pile interval, centrifugal loading experiments, 3D FEM analysis, maximum shear strain, reduction of costs

１． Introduction

Pile works are one of the effective structural countermeasures against landslides. For an effective designing of stabilizing piles and obtaining high reliability and low construction cost of pile works, optimum design of pile's dimension such as its position and intervals is required.

Based on the past experience and laboratory tests, standard interval according to the landslide depth (Table. 1) for landslide stabilization piles has been determined. （Committee on Guidelines for Design and Construction of Landslide Control Steel Piles, 2003） The concept is to select the intervals so that piles could resist the sliding force without allowing the landslide mass to deform excessively through piles.

Table.1 Relationship between landslide depth and standard intervals of piles

Landslide Depth (m)	Standard Intervals of Piles (m)
＜10	≦ 2.0
10 ～ 20	≦ 3.0
20 ≦	≦ 4.0

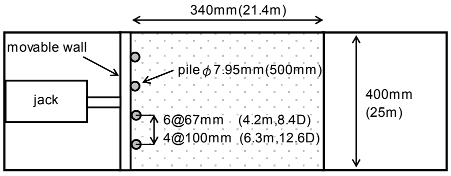
To examine the influence of pile interval and geo-condition of landslide mass on the failure of soils between piles, the authors conducted model tests, by varying the pile interval and using a centrifuge loading device. To simulate the results of centrifuge test and to examine the methods for determining optimum pile interval under given geo-condition, finite element analysis was performed.

２． Basic study of pile interval

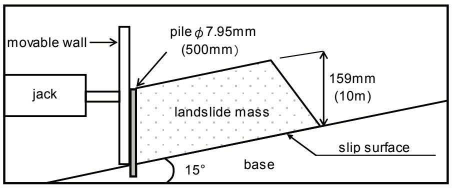
2.1 Centrifuge test

Fig.1 and Photo.1 show the centrifuge test model conducted. The model is composed of landslide mass, slip surface, base and piles.

The thickness of landslide mass was set at 15.9 cm to reflect the actual landslide depth of 10 m in a 63G centrifugal field, while the pile intervals are varied with 8.4D(D: pile diameter)and 12.6D. Steel rods of a diameter of 7.95mm (or 500 mm on a full scale base) were used as piles.



a) Plane view



b)Sectional view

※A number in parenthesis ( ) is size in a centrifuge field of 63G

Fig. 1 Schematic diagram of experimental apparatus

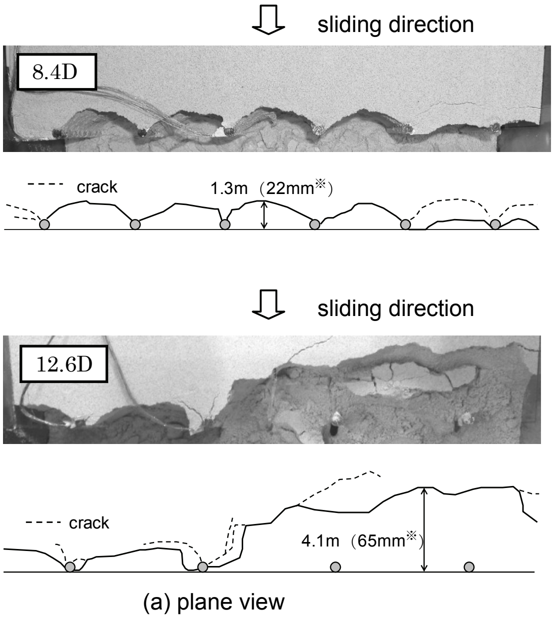
Photo.1 Experimental apparatus

Based on the results of a direct shear test, soil strength parameters were determined. For a mixture with 90% of Toyoura standard sand and 10% of kaolin clay, internal friction angle (φ_d) was 40.1 degrees and cohesion (c_d) was 14.8 kN/m^2.

To maintain stable condition during the initial stage of centrifuge loading under 63G and to induce sliding by drawing the wall away from the landslide mass, movable wall was installed at the lower end of the landslide mass. This testing configuration allowed the landslide mass to slide under its own weight. Strain of piles and the load acting on the movable wall were measured during the test (Fig. 1).

Fig. 2 shows plane views of the upper surface of landslide mass. When tested with a pile interval of 8.4D, the soil between piles indicated an arched failure projecting toward the upper end in plane view. When tested with 12.6D, failure extended beyond the intervals between piles and spread towards the upper end.

These results indicate that interval soils at the interval of piles failed in different manners between those experiments. Thus, for design of pile systems, the interval of piles need to be determined that would not cause the same phenomenon as it occurred in case of 12.6D.



(a) plane view

※A number in parenthesis ( ) is size in a centrifuge field of 63G.

Fig. 2 Failure of landslide mass after centrifuge test

2.2 The validation analysis of 3-D FEM model

The width of the model shown in Fig. 3 is at half the spacing between piles in the centrifuge test (Fig. 1). The 3-D FEM analysis was performed in actual scale converted from the centrifuge test. The pile was modeled as elastic material using solid elements. Landslide mass and the slip surface were modeled as elasto-viscoplastic material, using joint element.

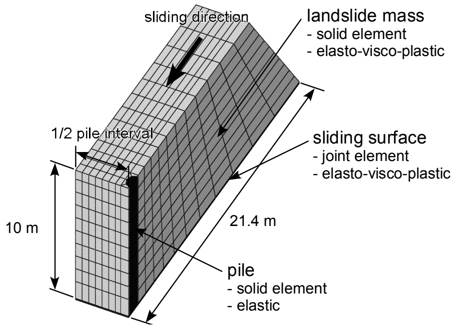


Fig.3 FEM analysis model

Fig. 4 shows the distributions of maximum shear strain on a plane parallel to the slip surface at the depth of 6 m. The figure shows the results obtained with cohesion of 15 kN/m^2 and 20 kN/m^2.

Fig. 4 also shows that an arched zone of high shear strain appeared when the pile interval was set to 10 m with c of 20 kN/m^2 and when the pile interval was more than 8 m with c of 15 kN/m^2. In cases, with smaller pile interval, no zone of high shear strain was found.

Fig. 5 and Fig.6 shows the relationship between the pile interval and the maximum shear strain.

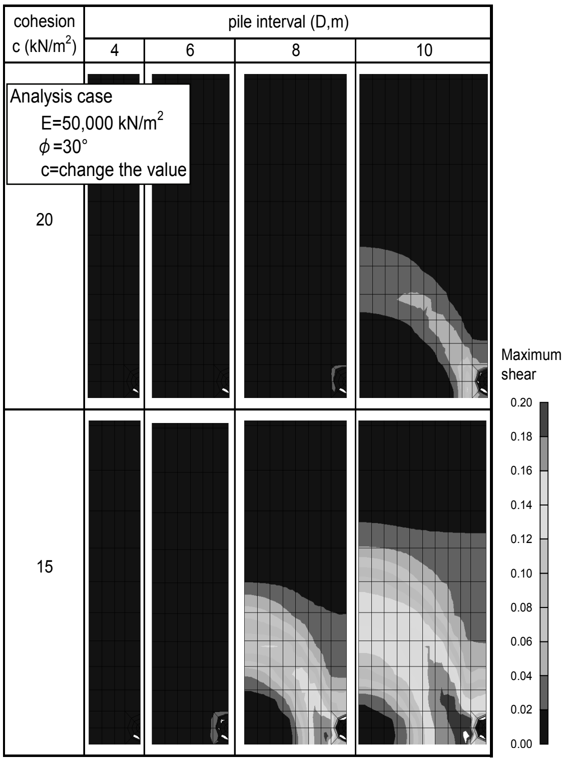


Fig.4 Distribution of maximum shear strain by FEM analysis with various pile intervals and cohesion of landslide mass

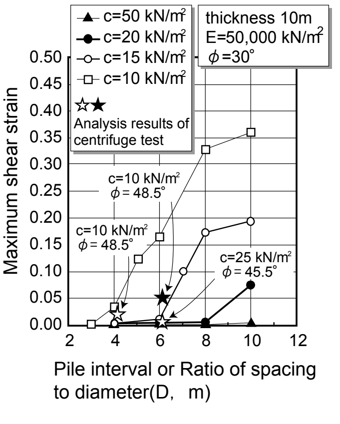


Fig.5 Relationship between cohesion(c) and pile interval

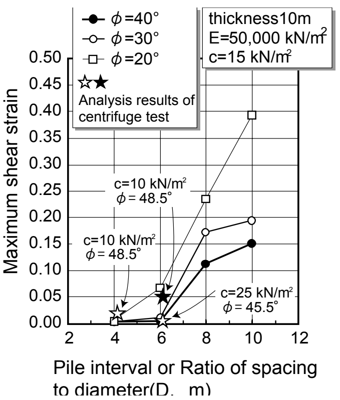


Fig.6 Relationship between internal friction angle (Á) and pile interval

Shear strain increased remarkably when the pile interval exceeded from a certain level. The optimal pile interval should therefore be narrower than the interval that causes large shear strain . Assuming that critical maximum shear strain is 0.02, stable pile interval, for the case shown in Fig.5, must be less than 6D when c is 15 kN/m^2 and 8D when the c is 20 kN/m^2. The maximum pile interval became narrower as cohesion and internal friction angle decreases.

As discussed above, the maximum pile interval varies according to the geo-condition of landslide mass. In the design of landslide stabilizing piles, therefore, the pile interval should be determined considering the maximum shear strain.

3. Application for actual landslide site

3.1 Outline of the area and analysis conditions

The Arahira Landslide is located in Miyazaki Prefecture in western Japan. It is 120m long (south-north direction) and 120m wide (east-west direction) (Figure 7). According to the geological survey, the maximum depth of moving soil mass is about 19m. 2-D slope stability analysis shows that the required load for piles is 668.8 kN/m.

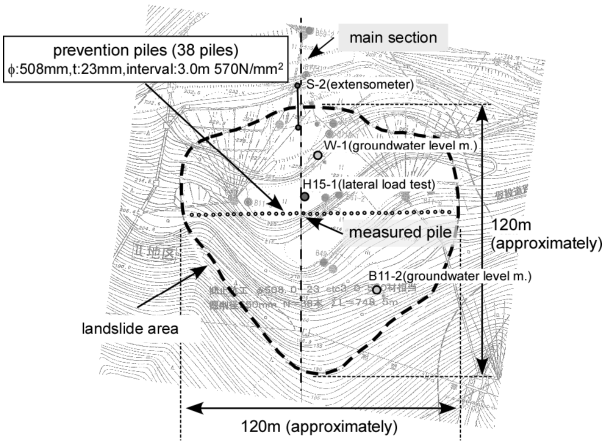


Fig 7. Plane view of Arahira Landslide and location of piles.

As per the landslide depth and the standard pile interval table(Fig.1), the landslide stabilizing piles were installed at interval of 3m. However, considering the geo-condition of landslide mass, results of centrifuge test and 3-D FEM analysis, the proposed pile interval are 6m. Accordingly, the finite element mesh of Arahira landslide is shown Fig 8, in which two cases of pile intervals (3m, 6m) could be analyzed.

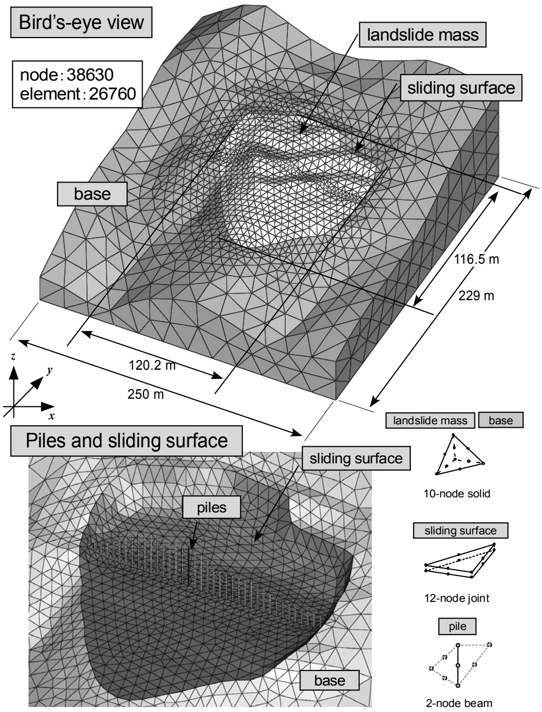


Fig 8 Finite element mesh of Arahira landslide.

3.2 Comparison the construction cost between existent method and 3-D FEM analysis method

Pile dimensions examined by the existent method of 2-D slope stability analysis and 3-D FEM analysis method are shown in Fig.9 and Fig.10. Outer diameter 500mm thickness 13mm, interval 3m and 38piles are the conditions of the existent method. On the other hand, Fig.9 and Fig.10 show that outer diameter 500mm, thickness 16mm, interval 6m and 19piles are the conditions of 3-D FEM analysis method. The landslide is stable even in wider pile intervals than the standard intervals of piles (Table.2).

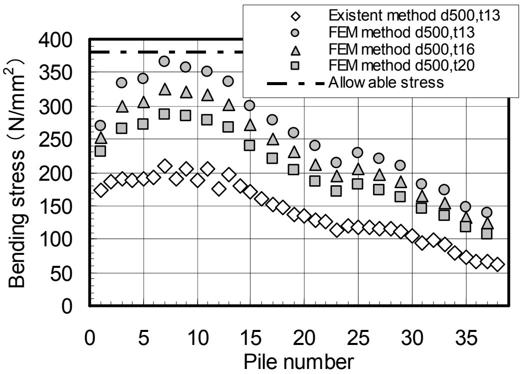


Fig.9 The maximum bending stress distribution of each pile calculated by existent method (interval 3m) and FEM methods (interval 6m).

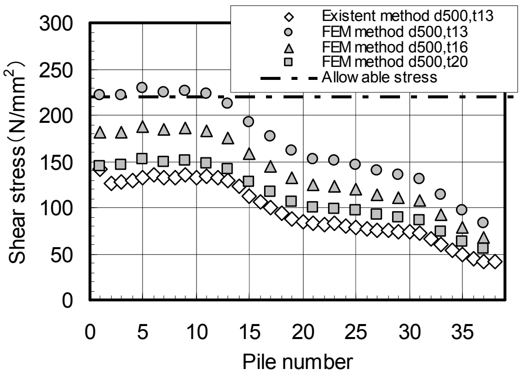


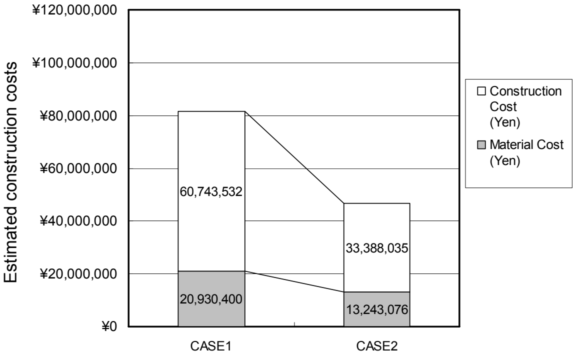
Fig.10 The maximum shear stress distribution of each pile calculated by existent method(interval 3m) and FEM methods (interval 6m).

Table.2 Differences of conditions of landslide stabilizing piles based by analysis methods

	Outer Diameter	Thickness	Interval	pile number
CASE1 (existent method)	500mm	13mm	3.0m	38piles
CASE2 (3-D FEM analysis)	500mm	16mm	6.0m	19piles

The estimated construction cost of each method is shown in Fig. 11. The cost consists mainly of construction cost and material cost. Total cost based on 3-D FEM analysis method results about 40% lower than the existent method.

The authors propose 3-D FEM analysis method as optimum pile design, which is able to reduce the cost of pile works.



CASE1:Landslide Stabilizing Piles based on existent method of 2-D slope analysis
CASE2:Landslide Stabilizing Piles based on 3-D FEM analysis and centrifuge test

Fig.11 Comparison of methods by estimated construction costs.

Conclusions

1. Through centrifugal loading experiments and their back analyses by FEM, it is shown that the maximum pile interval varies according to the geo-condition of landslide mass.
2. Optimum design of landslide stabilizing piles was achieved considering the maximum shear strain. The optimal pile interval should be narrower than the interval that causes shear strain to increase remarkably.
3. The proposed method is able to reduce about 40% of the pile work costs over the existent method.

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Anlesi Landslide in Wanzhou, China: Characteristics and Mechanism of a Gentle Dip Landslide

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Abstract. Many gentle dip landslides have taken place in the Three Gorges Reservoir area. In order to study the mechanism of the gentle dip landslides, the authors selected the Anlesi landslide located in Wanzhou as a typical gentle dip landslide to study in detail. First, Field investigations show that the slip zones of the Anlesi landslide formed from white mudstones in Jurassic red strata by extrusion stress. Laboratory test results show that the main mineral components of the slip zone are composed of montmorillonite, illite, feldspar and quartz. The slip zone soils are silty clay, of medium swelling potential, as shear strength becomes very low once the slip becomes saturated with water. Then, the main factors contributing to the Anlesi landslides are discussed. The recent tectonic activities cause shear failure along the incompetent beds, and joints in the sandstone. With the effect of intensive rainfall, water permeates to the incompetent beds along tectonic fissures, resulting in swelling of the soil material and high hydrostatic pressure in fissures of the strata. Therefore, the Anlesi slope is prone to slide along the incompetent beds. Finally, Flac3D software was used to simulate the mechanism of the Anlesi landslide with the creep properties of soil and rock. The stress, displacement and plastic area changes with creep time varying. The maximum displacement at X direction reaches 7.59 m after 200-year creep. Therefore, the Anlesi slope failed completely indicated by the rheology effect of Jurassic red strata.

Keywords. Three Gorges Reservoir, Anlesi landslide, slip zones, numerical simulation, formation mechanism

1 Background

In order to build and utilize the Three Gorges Dam safely, much work has been done to investigate landslides in the Three Gorges Reservoir area. Five groups of landslides, the Taibaiyan landslides, Anlesi landslides, Caojiezi landslides, Pibaping landslides and Diaoyanping landslides were discovered in Wanzhou which is located in the middle bank area of the Three Gorges Reservoir. These landslides can be divided into two types: gentle dip rock landslides and soil deposit landslides. The dip of the slip surfaces of the gentle dip rock landslides are about 3-6 degrees and most of the soil deposit landslides took place at the toe of the gentle dip rock landslides.

The formation mechanism of the gentle dip rock landslides in Wanzhou is not clear. Many experts and scholars have researched the formation mechanism of these landslides. Collected geological site exploration material and laboratory data of some landslides in Wanzhou was analyzed. The results show that these landslides have multistage platforms and approximately horizontal sliding surfaces (Liu et al. 2002). The properties of sliding deposits and the characteristics of shear failure surfaces of the Heping Square landslide in the same area has been studied in detail. The conclusion reveals that the Heping Square landslide is not a gentle dip bedrock landslide, but a loose mixed accumulation found at the intersection of the Yangtze River and the Zhuxi River (Sun et al. 2002). Research reveals that the landslides in Wanzhou are a group of retrogressive landslides occurring in gentle dip red Jurassic strata, and the main triggering mechanisms are intensive rainfall, incompetent beds and cracks near the crest of the slopes (Wu and Li 1994). Another study shows that the main controlling factor of the landslides sliding along the approximately horizontal dipping Jurassic red strata is the montmorillonite mudstone, and the primary triggering factor is earthquake (Tang 1997). In brief, there are two viewpoints on the formation mechanism of the gentle dip landslides in Wanzhou. One opinion considers that the gentle dip landslides formed along the Jurassic red incompetent strata. Another view is that the gentle dip landslides in Wanzhou mainly formed from the loose deposits. However, few studies have been done on the mechanism of gentle dip rock landslides from creep behavior to sliding of the red beds. The authors used the Anlesi landslide as an example, to study the mechanism of the gentle dip landslides in the red beds changing from creeping to sliding.

2 Characteristics of Anlesi Landslide

The Anlesi landslide is located on the NNW limb of the Wanzhou syncline which trends NEE. The exposed strata are mainly red Jurassic Shaximiao Formation (J_{2s}), and the lithologies are a series of purple red mudstone, silty mudstone, muddy siltstone and grey feldspar sandstone. The Anlesi landslide is about 600m in length (sliding direction), 2100m in width, 10l ×104 m^2 in area, and 2486×104 m^3 in volume (Figure 1). The bedrocks are composed of siltstone and some mudstone with the dip direction about 150 degrees and dip about 4-5 degrees. The depth of the sliding surface ranges from 10 m to 40 m (Cai 1993). The sliding surface is basically parallel to the layers of bedrock (Figures 2). The catchment area of the landslide is large, and several pools are located on the grooved fracturing zone on the head. Several large-scale, loose deposit landslides exist at the Anlesi landslide's foot such as the Xixipu, Yiminju, Nongjijixiao and Yuqiaodong deposits (Jian et al. 2005a).

3 Features of SlipZzones of Anlesi Landslide

3.1 Macroscopic Geological Features of slip zones

In order to evaluate the characteristics of the slip zone of the Anlesi landslide, field investigation was done along the toe of the rupture surface and along a trench that was dug between borings Z13 and Z15 (Figure 1). Two layers of slip zones were exposed (Figure 3) in the trench. The first slip zone (Y1) was at the bottom of the profile. The material in the slip zone is made up of white clay and gravels. The grain size of the gravels is generally in the range 0.5-1.0 cm. The thickness of the slip zone is about 20-35 cm. The overlying rock is sandstone and the underlying rock is silty mudstone (Figure 3a). The sliding surface can be seen clearly at the bottom of the white clay, and the sliding direction shown by striations is 100°. The second slip zone (Y2) is at the top of the profile. The slip zone is composed of grey white clay and gravels with 10-15 cm in thickness. The grey white clay has great stickiness and high water content. The gravels are mainly made of white mudstone. The shape of the gravels is sub-angular or angular. The grain size of the gravels is generally about 0.5-2.0 cm in diameter. The overlying rock is Quaternary yellow clay, and the underlying rock is silty mudstone (Figure 3b). The sliding surface and striations can be seen clearly at the bottom of the white clay (Figure 4), and the direction of the striations is 102°. These macroscopic features indicate that the two layers of slip zones formed from white mudstones by the effect of the tectonic extrusion stress.

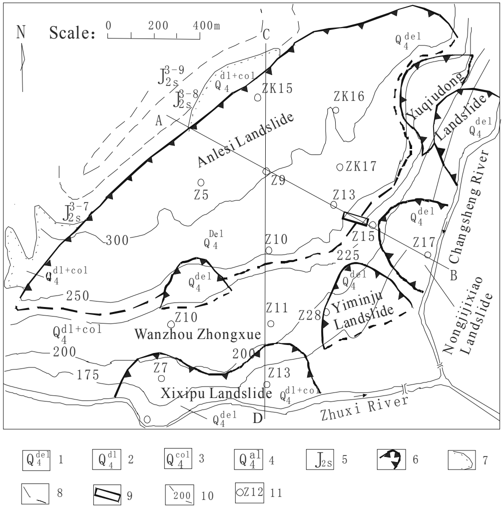

Fig. 1 Geological map of the Anlesi landslide
1. Displaced material by landslide movement; 2. Residual deposits; 3. Colluvial deposits; 4. Alluvial deposits; 5. Jurassic shaximiao formation (J_{2s}); 6. Landslide boundary; 7. Unconformity; 8. Layer boundary; 9. Test trench; 10. Contour; 11. Borehole and its number.

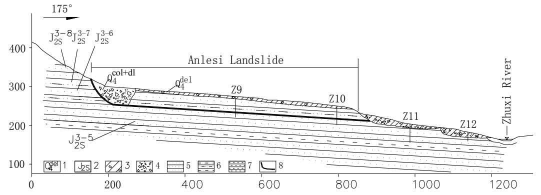

Fig. 2 geological profile of the Anlesi landslide
1. Landslide deposits; 2. Jurassic Shaximiao formation (J2s); 3. Clay with a few gravels; 4. Gravels and boulders; 5. Sandstone; 6. Siltstone 7.Mudstone; 8. Slip surface.

3.2 The Mineral Components of the slip zones of the Anlesi landslide

The X-ray diffraction was carried out at the test center of China University of Geosciences with the X-ray diffraction instrument D/MAX—3A made by a Japan Company. The result shows that the mineral components of Y1 slip zone are made of 75% montmorillonite, 10% illite, 5% quartz, and 10% feldspar, and the mineral components of Y2 slip zone are 65% montmorillonite, 5% illite, 20% feldspar and 10% quartz. Infrared ray analysis (IR) was also carried out with the Fourier Transform Infrared ray instrument MAGNA-IR550 made by Nicolet Company in USA. The main mineral components displayed from the IR analysis are basically consistent with the results of the X-Ray diffraction analysis. These results are almost the same with those of the incompetent beds in Jurassic red strata located in Wanzhou (Jian et al. 2005b).

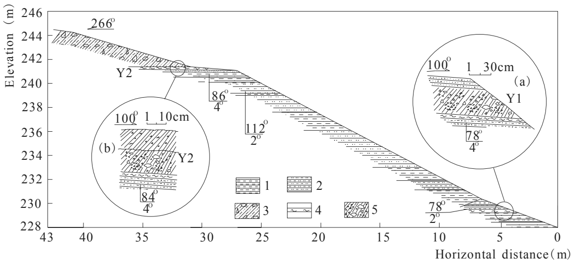

Fig. 3 Geological profile of the slip zones of the Anlesi landslide in the excavated trench
1. Mudstone; 2. Sandstone; 3. Silty clay with a few gravels; 4. Slip zone; 5. White clay with breccias

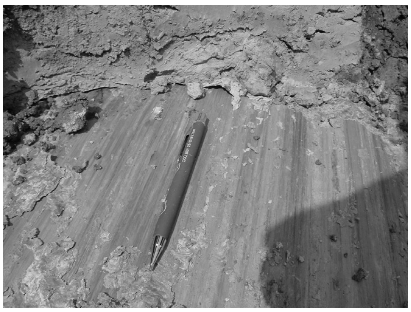

Fig. 4 The striations of Y2 slip zone of the Anlesi landslide

3.3 The Microcosmic Structure Features of Slip Zone

The scanning electron microscope analysis shows that the shapes of the clay mineral crystals are mainly sheet. Some of the minerals in the slip zones are directional to some extent. From the direction perpendicular to sliding direction observed, the minerals obviously have directional layer characteristics, and the oriented sheet minerals in slip zones are approximately parallel to sliding surfaces. From the direction parallel to the observed sliding direction, the direction of the oriented minerals and the most recent sliding direction has an angle of about 30 degrees. It indicates that the slip zones of the Anlesi landslide were extruded and had slid many times. The former sliding direction was about 130°.

3.4 Physical Properties of slip zones

A group of experiments were conducted to obtain the gradation, the liquid and plastic limits, the maximum dry density, the optimum water content and free swelling potential of slip zones of the Anlesi landslide. The samples were obtained from Y1 and Y2 slip zones exposed in the trench shown in Figure 3. The experiments were carried out in accordance with the Standard for Soil Test Method (GB/T 50123 1999). Some test results were shown in Table 1.

Table 1 Physical properties of slip zones

Slip zone name	Y1	Y2
Maximum dry density	1.453 g/cm^3	1.574 g/cm^3
Optimum water content	27.3%	20.8%
Liquid limit	43.2%	34.1%
Plastic limit	29.3%	20.1%
Plastic index	14	14
Free swelling potential	87.5%	57.0%

3.5 Shear strengths of slip zones

In order to study the relationship between the swelling potential and the shear strength, quick shear tests were carried out under the following three conditions: (1) specimens confined around side, the top side and bottom side, (2) specimens confined around side and bottom side, and (3) specimens confined only around side. Specimens were saturated by capillary action. Test conditions and results are shown in Table 2, and illustrate that the values of shear strength parameters c and ϕ reduced rapidly with the slip zone soil swelling potential changing from a natural condition to complete swelling. It is very similar to the shear strength properties of expansive soil in the roadbed (Zhang and Jiang 2001)

Table 2 Quick shear test conditions and results of Y1 slip zone under various conditions

Confined condition	Water content (%)	Density (g/cm3)	Shear strength	
			c (kPa)	ϕ(°)
(1)	34.45	2.02	21.2	10.3
(2)	40.68	1.97	14.2	8.2
(3)	45.73	1.91	2.6	2.6

4 Factors Contributing to the Anlesi Landslide

4.1 Incompetent beds

Several stable, continuous and thick incompetent beds exist in Jurassic red strata in Wanzhou. Several tests were conducted on the specimens of the incompetent beds to obtain the mineral components, the physical and mechanical properties (Jian et al. 2005b). The results show that the main mineral components and properties of the incompetent beds are almost the same as the slip zones soils of the Anlesi landslide.

Under the tectonic stress and unloading effect, the shear displacement occurred along incompetent beds and tectonic fissures perpendicular to the layer surfaces formed in the beds. Underground water permeates to incompetent beds along the tectonic fissures, and results in two effects on incompetent beds. One effect is that the shear strength of the incompetent beds decreased greatly due to swelling after absorbing water. The other effect is that great hydrostatic pressure occurs. Under the two kinds of effects and other loads, the incompetent beds are prone to become sliding surfaces for gentle dip rock landslides under some special conditions.

4.2 latest tectonic activities

The Earth's crust rose intermittently several times after the Tertiary Period in the eastern Sichuan province (Tan and Bo 1991, Gao 1992). A plantation surface and several river terraces formed due to the tectonic activities. When the Earth's crust rose, the mountains were cut down by the erosion of the Yangtze River. As a consequence, the stress field of bank slopes changes, and the sloping sides of the bank valley became unstable. The absolute age of the Anlesi landslide is about 315-384 thousand years (Yang 1988), corresponding to the formation time of terrace 4. Therefore, the formation of the Anlesi landslide in Wanzhou correlates with the latest tectonic activities.

4.3 Intensive rainfall

According to the statistics of the Sanxia (Three Gorges) Weather Department, Wanzhou is the center of abundant precipitation in the Three Gorges Reservoir. Annual rainfall is about 1253 mm. It was recorded that the greatest continuous rainfall reached 488.7 mm, the most 3-day continuous rainfall reached 388.6 mm, and the most rainfall in one day was 243.3 mm. Rainstorms often occur from May to September (Cui, 1993). As is well known, three typical gentle dip landslides, the Tiantaixiang landslide, the Minguochang landslide, and the Qianjiangping landslide were triggered by heavy rainfall. Therefore, the Anlesi slope is prone to slide with the effect of rainfall.

5 Numerical Simulation of the Anlesi Landslide

5.1 Geological model

In order to analyze the formation mechanism of the Anlesi landslide, numerical modeling has been done from the viewpoint of the rheological properties of rock and soil. It is supposed that the topography of the Anlesi slope before sliding is similar to that after sliding. Based on the geological conditions of the Anlesi landslide, a geological profile before the slope slid has been recovered. From the bottom to the top of the profile, seven layers exist.

5.2 Meshes for numerical modeling

Based on the geological model, a two dimensional numerical simulation was conducted on the Anlesi slope with Flac3D software to analyze the stress and deformation of the slope before failure. In order to decrease the error, the range of the slope is much greater than that of the landslide. The coordinates for the model is X (0 , 2500), Y(-260 , 490), and the coordinates of the landslide is X (640 , 1540), Y (220 , 310). There are 2691 elements and 5906 nodes. Figure 5 shows the two dimensional meshes which were generated for the numerical modeling.

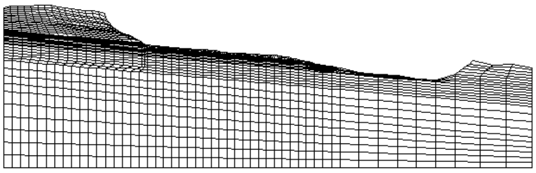

Fig. 5 Meshes for the Anlesi landslide modeling

5.3 Numerical simulation considering the rheological properties of rock and soil

The creep parameters used in the numerical modeling were introduced and illustrated in detail in Chapter 4 in Wang's Ph.D. dissertation (Wang 2008, Wang et al. 2008). Because the Burgers model can describe both stress creep and stress relaxation, the civic model was used to simulate the rheological properties of Anlesi landslide with Flac3D software.

The two dimensional creep calculation began from elastic-plastic equilibrium, and the maximum creep time is 200 years. The principal stress is compressive in most part of the slope after 10-year creep. Only at the steep head, does tensile stress concentrate. Partial shear failure occurs at the main scarp, and the tensile failure occurs in the feldspar quartz sandstone at the head of the slope. The stress on the whole slope is intensive after 50-year creep. The maximum tensile stress is located at the sandstone at the head of the slope, and about 940 kPa. The tensile failure place occurs in the feldspar quartz sandstone at the head of the slope after 50-year creeping and extends to the ground after 100-year of creep. The plastic area extends to the ground and the feldspar quartz sandstone is separated from the bed rock at the head of the slope. The displacement of the slope sliding along incompetent beds is visible after 5-year creep. The displacement at the foot of the slope is greater than that at the head of the slope. The displacement increases with the creep time becoming longer. The maximum displacement at X direction reaches 7.59 m after 200-year creep (Figures 6). Therefore, the Anlesi slope failed completely.

Fig. 6 The displacement in the X direction after 200-year creep in the Anlesi slope

6 Conclusion

(1) The slip zones of the Anlesi landslide are formed from white mudstones in Jurassic red strata by extrusion stress. The main mineral components of the slip zones are composed of montmorillonite, illite, feldspar and quartz. The slip zones are medium-swelling silty clay, and shear strength becomes very low once the slip zone becomes saturated with water.

(2) The main factors contributing to the Anlesi landslides are incompetent beds, recent tectonic activities and intensive rainfall.

(3) The numerical simulation results show that the stress, displacement and plastic area of the Anlesi slope changes with creep time varying. The maximum displacement at X direction reaches 7.59 m after 200-year creep. Therefore, the formation mechanism of Anlesi landslide can be illustrated from the viewpoint of rheological properties of Jurassic red beds.

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Earthquake Risk Assessment of Artificial Fill Slope in Urban Residential Region

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Abstract. Recent destructive earthquakes in urban regions have triggered landslides in many gentle slopes of residential areas in Japan. The earthquake-induced slope instability that has occurred is closely related to these artificial landforms, especially valley fills (embankments). Investigation of past artificial landform changes show that differences in the shape of fills, such as depth, width, inclination angle of the base, and cross-sectional form, may be the key discriminating factors of slope instability. Triggering mechanisms (e.g. earthquakes) need to be considered in the analysis for accurate estimation, however, it is difficult to include earthquake parameters in convenient linear multi-variate analysis. Neural network analysis is applied to assess large fill slope instability in urban residential areas. The developed neural network model including both causative factors (shape of fills, groundwater condition, age of construction) and the triggering factors (distance from the fault, moment magnitude, direction to fault) was independently checked against another data set and sensitivity analysis was conducted. It should be possible to conduct landslide hazard mapping in urban residential areas by using the newly proposed neural network model.

Keywords: hazard mapping, urban area, valley fill, neural network

1. Introduction

Recent destructive earthquakes in urban regions, such as the 1978 Miyagi Off Shore Earthquake, the 1993 Kushiro Off Shore Earthquake and the 1995 Southern Hyogo Prefecture Earthquake, have triggered landslides in many gentle slopes of residential areas around Sendai, Kushiro, Nishinomiya and Kobe. The earthquake-induced slope instability that has occurred is closely related to these artificial landforms, especially valley fills (embankments). More than 60% of the unstable slopes in the Kobe-Nishinomiya urban region are in artificial valley fills. This instability was caused by strong ground movements during the 1995 Hyougoken-nanbu earthquake. Investigation of past artificial landform changes and multi-variate analysis of case studies of past earthquake disasters show that differences in the shape of fills, such as depth, width, inclination angle of the base, and cross-sectional form, may be the key discriminating factors of slope instability (Kamai et al, 2000).

Triggering mechanisms (e.g. earthquakes) need to be considered in the analysis for accurate estimation, however, it is difficult to include earthquake parameters in such linear multi-variate analysis (quantification theory II). Neural network analysis is applied to assess large fill slope instability in urban residential areas. In this paper, the newly developed neural network model for the prediction of the valley fill type landslide is proposed, and the application of this model for the Tokyo metropolitan area is discussed (Kamai et al, 2004).

2. Structure of the Neural Network

The Neural Network is a type of artificial intelligence model representing the neurons in the brain and their connections (networks). One of the characteristics of the Neural Network is the ability learn and self-organize. Neural Network, therefore, is able to adjust itself according to the changes in surrounding conditions. The Neural Network is classified based on the type of neuron connection into "layer-type network" and "mutual bond-type network". In this study, the layer-type network was adopted. In the layer-type network, the neurons are arranged in layers and the signals are transmitted from one layer to another. The output signals are automatically determined by the input signals. The recognition of random patterns requires a minimum of three layers (input-layer, middle-layer and output-layer).

As a specific solution method of the Neural Network, the Back Propagation Method (BP Method) was adopted. One of the advantages of the BP Method is that even if a data set is inconsistent, it is possible to deliver a network model with a minimum of errors. Neurons among the input, middle, and output-layers are closely connected in a BP Method network; however, neurons within the same layer are not(Freeman and Skapura, 1991). Learning patterns developed in the input-layer are transmitted through the middle-layer to the output-layer. In the output-layer, the output (O) and instruction (D, the actual results) are compared. The comparisons are repeated until the smallest error (E) between the output (O) and instruction (D) is obtained. The learning processes continue while the threshold of (S) and bond weights (W) and (V) are being adjusted so that the error (E) between the output (O) and the instruction (D) becomes the smallest. The error (E) is a function of output (O), and the output (O) is a function of the bond weights (V) between of middle-layer and output-layer. In order to minimize the error (E), the model needs to change the bond weights (V) proportional to the partial differential of error (E) produced by bond weights (V). The coefficient of the proportion obtained in the process is defined as learning ratio (α). Similarly, the renewal of the bond weights (W) between the input-layer and the middle-layer are performed. As such signals transmit from the output-layer to the input-layer in order to reduce errors.

3. Main Factors of Failure and Dataset Used in Analysis

3.1 Main Factors of Failure

Six main factors affecting the stability of valley fills (thickness, width, width/thickness ratio, bottom slope, groundwater level, and age) were determined to be significant direct causes of fill failure during the Southern Hyogo Prefecture Earthquake and the Miyagi Off Shore Earthquake. Then, three more inducing factors which are related to seismic ground shaking are added: (1) shortest distance from the causative fault plane; (2) moment magnitude; and (3) direction of the fault plane. The Neural Network was developed using these nine factors. The specific characteristics of the three new factors are discussed.

(1) Shortest Distance from the Causative Fault Plane:

There have been a few experimental formulas for the effect of distance to the maximum seismic velocity which is considered to influence valley fill failure. Parameters used in such formulas are mainly distance and earthquake magnitude. The distance includes distance from the epicenter, distance from the hypocenter, distance from the fault, and the shortest distance from the fault plane. It is easy to develop the data for epicenter and hypocenter; however, in situations where damaged areas are close to the causative fault, such as when the hypocenter is located directly below the populated areas, the distance from the fault plane rather than the distance from the point hypocenter dictates the level of damages. Furthermore, data compiled for this study include many cases from the Southern Hyogo Prefecture Earthquake where the hypocenter was located directly below the populated areas. Because of these reasons, for the factor expressing the effect of the distance, the shortest distance from the fault plane was used. Therefore, the majority of the cases from the Southern Hyogo Prefecture Earthquake were located in the hypocentral region within 7 km from the fault plane.

The maximum seismic velocity decreases as distance from the fault increases, and the same time, the frequency characteristics (predominant period) change. Therefore, this factor indirectly expresses the variation in frequency characteristics of the predominant period by distance.

(2) Moment Magnitude:

Since the shortest distance from the fault plane is used as a factor regarding the distance, moment magnitude (Mw) is used for an earthquake magnitude.

(3) Direction to the Fault Plane:

A long axis of the valley fills with respect to the fault plane is calculated and used as one of the factors. Specifically, it is the inner products of the strike of the fault and the direction of the long axis [cos (angle of fault strike and direction of long axis) of the absolute value]. The seismic vibrations (velocity and amplitude) normal to the fault plane in the hypocentral region during the Southern Hyogo Prefecture Earthquake was predominant. The direction of the long axis of fill with respect to the direction of the fault plane influenced the intensity of ground shaking of the fill.

3.2 Dataset Used in Analysis

The learning dataset for the Neural Network includes Nagata District in Kobe and Mukou City in Kyoto (total of 256 fills of which 117 failed) during the Southern Hyogo Prefecture Earthquake; the Sendai Region (total of 53 fills of which 10 failed) during the Miyagi Off Shore Earthquake; and Kushiro City (total of 4 fills of which 2 failed) during Kushiro Off Shore Earthquake. Figure 2 shows the locations of suspected causative faults, epicenters, and moment magnitudes of each earthquake.

4. Development of the Prediction Model

Parameters which could influence the model include the number of times of the learning process, number of neurons in middle-layer, and the learning rate. For all analyses, the number of times of the learning process is 5000 times, number of neurons in middle-layer is 12, and the learning rate is 0.15.

The number of times of the learning process affects error increases if the number of times of the learning process is too low while if it is too high, the error also increases due to over learning (reduced permeating ability). By observing the changes in rate of error with the numbers of times of the learning process, the minimum error is found at the average errors (E) squared and is the least and stable at about 3 percent with the numbers of times of the learning process of about 5000 times. Thus, this model adopted the numbers of the times of the learning process of 5000 times.

The number of neurons in the middle-layer affects the learning process and is an important factor. Too few neurons and too many neurons will cause learning difficulties. With an increased number of neurons in the middle-layer the total number of bonds jumps drastically. Since the total number of data (number of failure cases) is limited, it is suspected that the learning capacity will increase with a low number of neutrons in the middle-layer. However, as there is no reliable method to determine the optimum number of neurons in the middle-layer, it is common to start with more than adequate numbers and gradually reduce the number by trial and error until the most suitable condition is determined (Freeman and Skapura, 1991). In this study, the number of neurons in the middle-layer was adjusted from 15 to 9. The number of neurons in the middle-layer was selected to be 12, just prior to increasing the average errors (E) squared while running the learning process 5000 times. This number was adopted as the number of the middle-layer for the model.

In the Neural Network, the renewal rate of the bond weights is called the learning rate, and a normal range is between 0.05 and 0.2 (Freeman and Skapura, 1991). In this study, the learning rate was adjusted to 0.1, 0.12, 0.15, and 0.2, to determine the lowest learning rate of the average errors (E) squared while running the learning process 5000 times. The lowest learning rate of 0.15 was adopted.

In the output-layer, two neurons “failure” and “undisturbed” corresponding to the neuron output of “1”, and “0” were used.

5. Results of Learning in the Neural Network

The analysis of the failed and undisturbed valley fills from past earthquakes, which have all been catalogued as learning data (total of 314 cases). It shows the bond weights between the input-layer neurons and middle-layer neurons, the sum of the squared of bond weights, and the threshold. Table 1 shows the bond weights between the middle-layer neurons and output-layer neurons and threshold. The sum of the squared of the bond weights between the input-layer neurons and the middle-layer neurons is a yardstick expressing the average influence of input factors. The “fill thickness” has the largest contribution rate (sum of the squared of the bond weights of factors/total of the sum of the squared of the bond weights). The rate of contribution declines in the order of: (1) direction to the fault plane; (2) fill width; (3) fill width/thickness ratio; (4) the shortest distance from the fault plane; (5) fill bottom slope; (6) moment magnitude (Mw); (7) groundwater level; and lastly (8) age. The total of the rate of contribution of the first 5 factors is about 80 percent. The factors related to the inducing factors (direction to the fault plane, shortest distance to the fault) and factors related to size and configuration of fills (thickness, width, width/thickness ratio) are the controlling factors for fill failure.

Following the learning process of the 314 valley fills, the model correctly identified 305 cases with an accuracy rate (rate of correct interpretation) of 97 percent. For the prediction model using categorical linear prediction method, the upper limits of the accuracy rate was 86 percent, so this is an improvement of about 11 percent. Even for a discrimination problem (failed or undisturbed), it has a very high accuracy rate.

For the accuracy rate of corresponding earthquakes, the Southern Hyogo Prefecture Earthquake is 97 percent (256 cases), the Miyagi Prefecture Off Shore Earthquake is 96 percent (54 cases), and the Kushiro Off Shore Earthquake is 100 percent (4 cases). There are only 9 cases where the model was incorrectly identified.

6. Evaluation of the Prediction Model

The above analysis employed the failure cases of the same earthquake in the same region, statistically using the same population. Therefore, in order to test the effectiveness of the prediction method, it is necessary to verify between different regions and different earthquakes. In 2003 three major earthquakes occurred and caused many fill failures. They are the Miyagi Off Shore Earthquake (Southern Sanriku Earthquake) with a Magnitude of M=7.0 on May 26; the Northern Miyagi Prefecture Earthquake with a Magnitude of M= 6.0 on July 26; and the Tokachi Off Shore Earthquake with a Magnitude of M=8.0 on September 26. Utilizing the Neural Network, fill failures in the above three earthquakes were evaluated. The results are discussed as follows:

There are four valley fills of which one failed near Tateshita in Tsukidate Town during the Miyagi Off Shore Earthquake of 2003. The results of the model verification are the same as the actual outcome.

There are four valley fills of which two failed near Ooshio in Yamoto Town during the Northern Miyagi Prefecture Earthquake. Based on the evaluation, three failures were predicted. A detailed analysis of the mistaken identification of the valley fill revealed that the site was developed as a large-scale industrial development and special care had been exercised in quality control during the fill placement, therefore, it is significantly different from other valley fills for residential developments.

There are four valley fills of which three failed at the Kiyota District in Sapporo City and Midorigaoka in Kushiro City during the Tokachi Off Shore Earthquake. However, the results of the evaluation indicate that all four should have been undisturbed. The valley fill failures in Sapporo and Kushiro were induced by the Tokachi Off Shore Earthquake, whose hypocenter was located over 100km from the sites. This information were not included in learning data. This could be the reason for poor performance of the evaluation.

It is practically impossible to perform a detailed investigation and analysis on every slope problem. A simple and easy instability prediction method that is based on experimental laws is useful in construction of hazard maps in large areas, implementation of mitigation measures, development of evacuation and rescue plans, and development of a real time disaster prediction system for earthquakes. However, as experienced in the Tokachi Off Shore Earthquake, there are serious limitations in the techniques for a type of earthquake which has never been incorporated into the model. Combining the results of reliability evaluations, it is possible to relatively simple to evaluate the risk level of valley fills by utilizing the prediction model, although accuracy results may be skewed because of regional differences in effect of earthquake and topography.

9. Conclusions

The following main conclusions can be made based on the research presented in this paper.

(1) Neural network analysis is applied to assess large fill slope instability in urban residential areas. The developed neural network model including both causative factors (shape of fills, groundwater condition, age of construction) and the triggering factors (distance from the fault, moment magnitude, direction to fault) was independently checked against another data set and sensitivity analysis was conducted. It should be possible to conduct landslide hazard mapping in urban residential areas by using the newly proposed neural network model.

(2) However, there are some problems associated with the Neural Network predictions. The number of earthquakes used for the learning process is still small. It is necessary to continue collecting data and improve accuracy when the method is applied to other areas.

(3) Soil strength has not been used in factor analysis because all fills for residential lots are weak and soft throughout Japan. This is based on valley fills that are shallower than 5 m deep, which is the depth limit of the simplified penetration tests. Many of the subsurface investigations may not have reached to the bottom of the fill. Very weak and soft soils have been identified at the bottoms of some of the fills where subsurface investigations were performed to those depths. For soil strength, it is necessary to obtain and incorporate more data as a factor by using a relatively easy and fast evaluation method.

(4) There are many slope failure prevention facilities and man-made structures on slopes in urban areas. The effect of such structures has been ignored in the preceding analyses and may have caused some misjudgments. This should be considered as areas for future investigation.

(5) It is clear from the case analysis, the failure of valley fills is a phenomena that cannot be determined by a simple 2-dimensional mechanical analysis because the effect of the longitudinal cross-section has to be taken into account. The results of the current analysis also indicate that the direction of the long axis of valley fill with relation to the fault plane affects the failure of valley fills. Thus, future discussions of failure mechanism will be required as 3-dimenssional problems.

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Strategy for Promoting Education for Natural Disaster Reduction in Indonesia and ASEAN Region

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Abstract. Because of the dynamic geological conditions of Indonesia and South East Asia Region, many countries in such region are vulnerable for geological disasters, such as earthquake, tsunami, volcanic eruption, landslide and floods. This paper describes strategy to develop appropriate education program for geological disaster risk reduction in this region. Formal education program, especially at the universities and schools, should be enhanced to provide qualified human resources which capable to improve the resilience of the society in response to any potential geological disaster. Program for public education should also be developed in such effective mechanism by in formal approach. The real challenge of this education strategy is to build up the culture for disaster awareness and prevention, by empowering the society to adapt with the dynamic geological conditions.

Keywords. Geological disaster, education strategy, society resilience, culture for disaster awareness and prevention, adaptive approach.

1. Background of the problems

Because of the active tectonic setting of the region, the risks of geological disasters inevitably increase in Indonesian Archipelagoes and other ASEAN countries. Hundred thousands of people died as the victim of tsunami on the 26th December 2004. Several more thousands of people were also died due to the earthquakes in Yogyakarta, Indonesian (2006) and in China (2008). Indeed, numbers of people buried by landslides and debris flow continuously increases every year. Total socio-economical loss as the results of all those geological disasters has reached billion of US dollars.

Impacts of natural disasters can be prevented or minimized if it can be properly mitigated and managed (Abbot, 2004). It was highlighted in the Hyugo Framework declared in 2005 that development of the nation and society resilience in response to the disaster is MUST. Thus, the right of human being to live safely in their environment should be guaranteed, despite all of the complexity of geological phenomena at the region.

However, it is also impossible to change the nature of geological phenomena in Indonesia and ASEAN, which actively and continuously result in geological disasters. Therefore, there should be some efforts with appropriate strategy to increase the community resilience in the vulnerable areas. Empowering the community living in the vulnerable area **to adapt** with the nature of geology will be rather more feasible, instead of challenging the geological nature. Indeed, **adaptive approach** will be the main consideration, and thus public education on geohazard will be urgently required to empower human resources living in geological disaster vulnerable area (Karnawati and Pramumijoyo, 2005a).

2. Goal of geological education.

Regarding the stated problems above, it becomes an urgent need to develop appropriate geological education with the goal for improving the society resilience in geological disaster prone area, through formal and in formal programs. By conducting such education programs it is expected that the social and economical risks due to geological disaster can be significantly reduced.

3. Design of education program.

Formal Education

At university

Knowledge to anticipate geological disasters, which is required to be delivered in a special subject so called as Geohazard Management, has been introduced for undergraduate program in some universities in ASEAN countries, such as in Indonesia, Malaysia, the Philippine, and Thailand. However, such knowledge has not yet provided in a special subject (Karnawati and Pramumijoyo, 2004). It is only integrated as the topics to be discussed in the subjects of Environmental Geology (under the topic of geohazard management), Soil Mechanic and Geotechnics, (under the topic of slope stability related to landslide prediction and control), Hydrology and/ or Geohydrology (under the topic of groundwater problems), Volcanology (under the topic of mitigation for volcanic eruption) and or Seismology (under the topic of earthquake mitigation). Those topics mainly discuss several issues on factors controlling the hazard occurrence (hazard = potential occurrence of geological disaster), the mechanisms and processes leading to the hazard occurrence, how to predict, mitigate and control such hazard. Unfortunately, quite limited practical exercises and field works can be provided for the students due to the limited concerns on the importance of geohazard education. Similar to the undergraduate education, in the postgraduate program (master program) quite few universities in Indonesia and in some other ASEAN countries provided special courses on Geohazard Management. Moreover, most of the existing geohazard education more emphasizes on the knowledge enhancement, but less effort to provide effective learning method which include appropriate field and laboratory works.

Despite some limitations in conducting geohazard education at the university level, students at the university are considered as the strategic target for human resource empowerment and community resilience in geological disaster prone area. Indeed, the students will become the potential future researcher to develop appropriate technology for disaster prevention and control, as well as the as potential analysts and policy makers to anticipate and to manage geological disaster in their regions. Thus, they should be considered as the seeds for future agents to further develop the national culture for disaster awareness and prevention. Clearly, mechanism and method of geohazard education in the universities need to be further enhanced through several stages as follows:

- Enhancement the syllabus (content) and learning method on geohazard subject, which provide more opportunity for the student to study the real field and society problems related to geological disasters.
- Provide more research opportunities to stimulate the development of appropriate technology for disaster prevention.
- Establish the national and regional education network on geohazard education.

Indeed, the interactive learning method through student working groups by providing case studies needs to be done in order to improve not only the student's knowledge and practical skill but also to develop their attitude and spirit for disaster awareness. Indeed, introduction of real case problem and field work, working group discussion and seminars can be an excellent media for the students to learn to apply their knowledge as well as to creatively improve their analytical skills, and to provide sound decisions to solve complex problems related to geological disaster

Supports from government agency and some other relevant research institutes are also required as the internship program to provide facilities and opportunities for students to explore more knowledge and experiences from the real problems in the field and communities. Interdisciplinary approach also needs to be elaborated by inviting relevant experts from other disciplines as the external resource person, due to the complexity of geohazard management problems.

Obviously, establishment of networks for geohazard educations at national and ASEAN levels are crucial to facilitate the effective learning and research program on geohazard education. Since the year of 2003, ASEAN University Network/ the South East ASEAN Engineering Education Network (AUN/SEED-Net) has also established the Field of Geological Engineering Networks consisting several universities from Member Institution Countries such as from Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippine, Singapore, Thailand and Vietnam as well as from Japan. In this network, education and research on geohazard has been carried out. Due to the leading experience to deal with geohazard problems, Gadjah Mada Universities in Indonesia has been assigned as the Host Institution for the network where students from other countries in the network are now conducting the learning and research on geohazard to obtain Master and Ph.D. Degrees (Karnawati et all, 2005b). Academic and research support from Kyushu Unversity, Kyoto University, Tokyo Institute of Technology and Hokkaido University are available to warrantee the quality and effectiveness of such research and education programs.

Eventhough, since the year 2008, Integrated Fields of Disaster Mitigation has been established by this ASEAN University Network to accommodate the needs to improve research based education for disaster risk reduction.

As a part of this program ***school on the move*** and ***long distance learning program*** now are proposed to further develop the existing research and education programs, especially for postgraduate programs through the ASEAN network. Through this program, students can have opportunity to move from one research institutes to the others, either conducting in their own-country or outside of their countries for having research training in geohazard education. More opportunities for the students to be exposed to the real geohazard problem within the ASEAN regions can also be provided. The student will have quite various experiences on geohazard management before completing their Master degree. Their communication skill and capability to adapt with the new environment also can be improved by having school on the move program.

Nevertheless, financial consideration remains to be the obstacle of this program. Therefore, the cost sharing within the ASEAN countries are required.

At school

Basic and simple knowledge on geology to understand some Geohazards such as flood, landslide, and soil erosion have been introduced as a part of Geography Subject at schools since the primary school in Indonesia (Karnawati and Pramumijoyo, 2004), Vietnam, Cambodia, Laos, Malaysia and Thailand. Meanwhile the knowledge about volcanoes and earthquakes also introduced at schools in Indonesia and Philippine. However, it is apparent that such education has not yet successfully improving student's skill and attitude for geohazard awareness and preparedness. This existing education program mainly emphasize for the development of knowledge aspects related to the definition and the cause of flood, landslides, soil erosion, earthquake and volcanic eruption. The contents and syllabus as well as the method of delivery and learning process of geohazard at schools need to be further evaluated and enhanced.

Fruthermore, Karnawati and Pramumijoyo (2004) suggested that practical knowledge about geohazard mitigation and preparedness should be provided in a simple but attractive method of teaching and learning. The most important aspects need to be learned by the pupils at school include several important points as below:

- Mechanism of occurrence of any geological process that result in geohazard,
- Symptoms of such geohazards,
- Practical knowledge on hazard mitigation, preparedness and emergency responses.

It was also suggested in the National Workshop on Geohazard Education held in Indonesia last August 2005 that the new curricula is not necessary to be developed to provide special subject on geohazard awareness and preparedness at school (Gadjah Mada University, 2005). It was suggested that the knowledge of geohazard can be integrated in the syllabus of the existing subjects such as in the subjects of Geography, Natural Sciences, Language or Religion. Practical exercise for emergency responses is also important to be included in the existing subject of Physical Exercise. Visit to the field and institutions dealing with geohazard management will also be useful to provide students with more visual examples on the real problems of geohazard. In fact, some schools in Indonesia also highlight their needs for obtaining special module on Geohazard Awareness and Preparedness which will be delivered in the extra-curricula activities.

Moreover, some revisions on the content of Geography books are suggested as well by Karnawati and Pramumijoyo (2004), because some un-appropriate explanations of some geological terms and processes related to geohazard. It was found some misleading information about lava and lahar. Correction on the definition of lava and lahar is crucial regarding that some volcanoes in Indonesia are actively produced lava and lahar with different potential impacts. In response to this situation, training for teachers on Geography and Geosciences has been conducted regularly every year during the last five years to improve the teachers' knowledge and skills, as well as to provide the field experience.

Informal education

Approach and mechanism

Lack of information about the phenomena and symptoms of geohazard are one of most critical problem, which leads to low community awareness and finally results in the high numbers of geohazard victims. Despite there have been quite many research outcomes related to geohazard predictions and mitigation, most of the research outcomes and information have not yet reached to the community living in the geohazard prone area. Thus, communication and dissemination of the outcomes of geohazard research should be effectively carried out as a part of the informal education program. As illustrated in Figure 1, effective link between source and receiver of information are crucial to support the effective mechanism of geohazard education program. Research institutes, government agency as well as the universities are the prominent source of information related to geohazard. Meanwhile, the Universities, NGO and some identified key person are very potential to be a media for transferring and disseminating the information of geohazard to the schools, communities, and families. Indeed, the universities also have an important role to enhance the understanding on geohazard phenomena to support public awareness and preparedness.

However, the key persons from the religion, ethnic and community groups who have the traditional knowledge or wisdom are also important to raise the sensitivity of the community to recognize symptoms of geohazards. Thus, integration of knowledge based on modern science delivered from the university and the traditional wisdom exist in the local community is required.

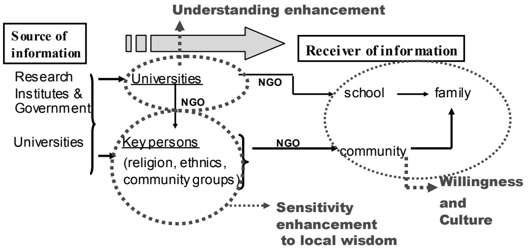

Figure 1. Mechanism on geohazard public education with the emphasize on the effectiveness of communication (Karnawati, et al. 2005a).

Transfer of information by the Government, research institutes and universities to the planner and policy maker should also be effective to support the development of appropriate regional master plan and regulation in geohazard prone areas. Such master plan and regulation should become the guideline to drive the efforts to build up the attitude and culture of the communities, families and individuals to adapt with their nature which is prone to geohazard (Figure 2). It is expected that the improvement of community understanding on geohazard as well as the development of appropriate master plan and regulation will effectively drive the changing behavior and the development of adaptive culture in geohazard prone countries.

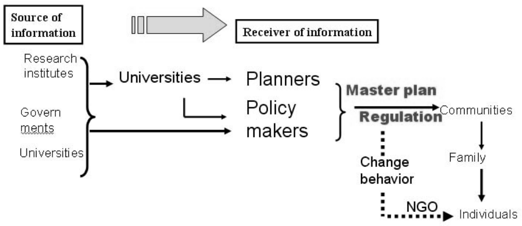

Figure 2. Mechanism of geohazard education by improving communication effectivity (Karnawati, et al. 2005a)

Method of knowledge dissemination

More active involvement of Geologist in disseminating their research outcomes, especially those related to geohazard management is also crucial to raise public awareness. The disseminated materials should include information about mechanism of the geological process leading to geohazard, the symptoms of geohazards, and also practical knowledge on hazard preparedness and emergency responses.

This dissemination should reach the children and the youth at schools, through various mass media, such as leaflets, booklets, popular books (comics, poems, etc), TV, radio, internet (website),or through the several activities such as Boy and Girl Scout and via direct communication with children at schools. Regarding that the cycle of geohazard occurrence can be quite short time (only within few years) and also can be long term cycle (for hundred years), development of museum or exhibition of any geohazard that has been occurred or potentially occur will also be important to transfer and sustain the message of geohazard awareness.

Recently, Indonesian Ministry of National Education has established the Earth Science Olympiad for High Schools as the national agenda that should be conducted annually, with respect to the International Earth Science Olympiade for the high school students established since the year of 2007. Obviously, this Earth Science Olympiad is considered as one strategic mechanism to initiate the improvement of geohazard education program at schools, which finally can also stimulate the school and student awareness for disaster risk reduction.

Conclusions

Appropriate public education for Geohazard awareness and preparedness is the urgent need to empower the community living in geohazard vulnerable areas, and to reduce the numbers of victims and loss. Adaptive approach, instead of challenging approach, is considered to be most appropriate strategy for such education. University has important roles as the resources or provider and also as the media for transferring geohazard information to communities. This education program should be designed to reform the communities' behavior and to build up the culture for geohazard awareness and preparedness.

Acknowledgments

The efforts to elaborate the development of strategy for geohazard education can be undertaken due to the supports from ASEAN University Network/ South East Asean Engineering Education Development Program (AUN/SEED NET) during the period of 2003 - 2012, as well as from the Indonesian National Ministry of Education and Gadjah Mada University.

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Development of Community-based Landslide Early Warning System in Indonesia

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Abstract
This paper highlights the importance of community-based approach in the development of landslide early warning system in Indonesia. Such approach is conducted by integrating both technical and social aspects, to support the landslide risk reduction efforts. The technical aspects include geological surveys for site selection, development of equipment design which is simple (low cost) but effective, determination of early warning levels, process of equipment development and reproduction in the workshop, and finally installment and operation/maintenance at the field site. The social aspects cover several activities such as social mapping and evaluation, as well as community empowerment which include dissemination of early warning program and landslide hazard preparedness, public consultation, technical training and evacuation drill.

Discussion on the three case examples of the implementation of such early warning program are addressed in this paper, as the best practices for Indonesian case, which may also applicable for the other landslide vulnerable areas in other developing countries.

Keywords. Community-based, early warning system, landslide risk reduction.

1. Problem Background

Landslide is one of most major disasters in Indonesia due to the susceptibility of the region and the socio-economical conditions of the country. Since the last 7 years, more than 36 landslide disasters occurred and result in 1226 people died or missing. This disaster costs millions of US Dollars due to the destroyed houses, land and infrastructures. Urgently, some efforts should be done to avoid or reduce the risk of landslides.

As the dynamic volcanic-archipelagoes, more than 60 % of Indonesian region are covered by the mountainous and hilly areas of weathered volcanic rocks, which are intersected by faults and rock joints. These geological conditions give rise to the high landslide susceptibility of the region. Moreover, the high rain precipitation which can exceed 2000 mm to 3000 mm per year, quite frequent earthquake vibrations as well as the extensive landuse changing and deforestation cause the occurrence of landslides frequently increase recently. Most of the landslide types are earth, rock and debris slides, which may also develop as debris flows or debris floods and these can travel to the down-slope area, which is several kilometers away from the source of landslides.

Unfortunately, most landslide susceptible areas have very fertile soils and very good quality and quantity of water. This makes the susceptible areas are densely populated, and it create serious inducement to slope instability. Despite an effort to establish slope protection zone, which is restricted for any development and settlement, the relocation program is not easy to be carried out due to socio-economical constrains. Accordingly, landslide early warning system is urgently required to guarantee the safety of community living in such area.

2. Approach and Steps for Development of the Early Warning System

In order to guarantee the effectiveness of the landslide early warning system, the developed system should be low cost, simple to be operated and appropriately installed in the most suitable sites. Therefore, both technical and social approaches for the system development must be incorporated.

The technical approach mainly focus on the geological survey for site selection, development of equipment design which is simple (low cost) but effective, determination of early warning levels, process of equipment development and reproduction in the workshop, and finally installment and operation/maintenance at the field site.

Meanwhile, the social approach includes social mapping and evaluation, as well as community empowerment which include dissemination of early warning program and landslide hazard preparedness, public consultation, technical training and evacuation drill.

Three pilot areas for landslide early warning system program have been established in Banjarnegara Regency and Karanganyar Regency in Central Java as well as Situbondo Regency East Java. Some lesson learned can be derived from this program that the warning system should be based on community participation. The following sections address the approach and steps of the development of early warning system which was implemented in those three pilot areas.

a.Geological survey and site selection

The geological survey for site selection at the three pilot areas was emphasized on the mountainous slopes which were steeper than 20^o and consisted of two main different types of geological conditions. The first type was the inclined stratigraphic of sediment layers which consist of montmorillonite clay covered by colluvial deposits (at Banjarnegara Regency), whilst the second type was the thick (up to 4 m) weathered volcanic rocks (andesitic breccias) at Karanganyar and Situbondo Regencies. Both types are the most common types of slopes which are susceptible to slide down. Three different sites then were selected at those different geological conditions which are situated at or near the high populated villages. The existence of important infrastructures such as road access was also one main consideration of the site selection.

b. Development of equipment design

Most the landslides occurring in both typical geological characteristics illustrated above are the earth or debris slides which usually are initiated by extension cracks. Thus, the extensometer is considered as the most appropriate monitoring and warning equipment that should be placed by using extension wire across the extension cracks (Figure 1). In one extensometer, the design was developed not only to monitor the lateral movement at the slope surface, but also to allow the monitoring of vertical deformation at the slope surface as well as the rotational direction of sliding. Thus, within one extensometer, three different directions of movements can be monitored by utilizing simple but low cost materials (Figure 2). All of the monitoring system was connected with the siren alarm which can be heard by the community up to the distance of 500 m. The first community group hearing the alarm then should hit the '*thong-thong'* (local warning system made from wood or bamboo) to transfer the warning to the other community groups living in the distance beyond 500 m.

To guarantee such a comprehensive monitoring system, five extensometers need to be installed in one landslide site which cover the area of about 75 to 100 hectares. This five extensometer installment needs to be incorporated with one rain gauge (Figure 3).

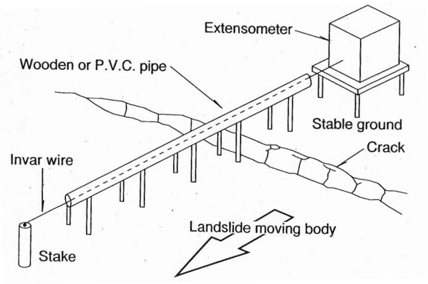
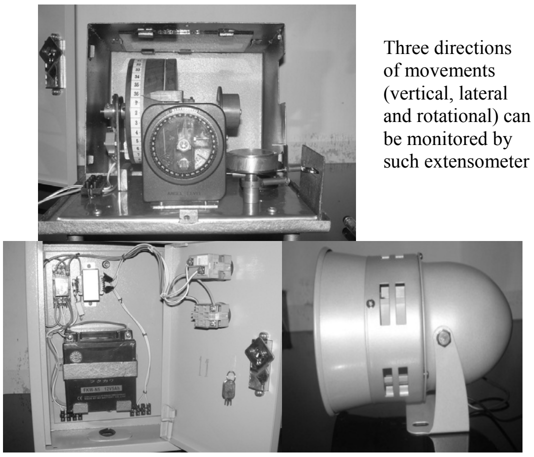


Figure 1. Extensometer installed across the extension crack to monitor the landsliding (Japan Landslde society 1996)



Three directions of movements (vertical, lateral and rotational) can be monitored by such extensometer

Figure 2. Extensometer developed by T.F. Fathani & D.Karnawati, Gadjah Mada University, 2007 (Paten No. P00200800300 and P00200800299).

Figure 3. Raingauge developed by T.F. Fathani & D.Karnawati, Gadjah Mada University, 2007.

c. Determination of early warning levels

The early warning levels were defined based on the previous researches related to the prediction of triggering rainfall characteristics at colluvial soils in Java conducted Karnawati et al (2005), and Su Su Ky (2007). It was suggested that the accumulative or antecedent rainfall which reach 115 mm are the triggering rainfall for landsliding at colluvial slopes. Accordingly, in this early warning system, the first level of warning was defined by setting the rain gauge warning with the critical level of 100 mm, not 115 mm. By setting the lower level of warning, it is expected there will be sufficient time to allow the community to conduct necessary preparation for the evacuation.

Meanwhile, the critical level for lateral extension was determined as 5 cm based on the review on previous investigation conducted by Su Su Ky (2007) and Dinh Tu (2007). However, the community may also adjust this level according to their observation on the real phenomena in the field.

Finally the early warning levels can be set up as listed in Table 1 below:

Table 1. Early warning levels

Level	Critical level	Action	Remarks
1	100 mm accumulative rainfall	Alert	Be ready to leave the site
2	5 cm lateral extension	Danger	Should leave the site as soon as possible.

d. Process of equipment development and reproduction in the workshop

Because of the simplicity of the equipment design, the development of equipment then can be done and reproduced in the local home-workshop. This simplicity will also be beneficial to allow the mass production of such early warning system by the local workshop and local labors. Thus, it is expected the developed early warning system will not only capable to support the landslide risk reduction but also to stimulate the local economical growth of the society. However, technical checking and calibration needs to be performed before the installation of such equipment in the field.

e. Social Mapping and Evaluation

Social mapping needs to be carried out prior to the introduction of early warning system to the community. Social and psychological aspects of community awareness to landslide hazard and preparedness are required to be observed in order to develop most appropriate strategy for the development of warning system.

Several parameters required to be observed and mapped are:

1. Levels of the community knowledge relates to:
    i. The susceptibility of their living area.
    ii. The characteristics of susceptible slope.
    iii. Some simple technical effort can be applied for slope protection.
    iv. The availability and capability of landslide early warning system to protect their living environment.
2. Community perception about the importance of landslide early warning system.
3. Community willingness to operate and maintain the provided early warning system.

According to the field observation and social survey, it was apparent that the level of community knowledge about the landslide susceptibility in their living area is quite low both in the area where the landslide has occurred (Banjarnegara and Karanganyar, Central Java) and in the area where the landslide has not yet occurred (Situbondo, East Java). Eventhough, most of the community (75% of the respondent) has insufficient knowledge on the characteristics of the susceptible slopes which are potential for landsliding. Only few of them (less than 10% of respondent) have enough knowledge how to protect or to prevent the slope from landsliding.

It was also interesting that 95% of the respondent in the area which had been suffered from landslide disaster (i.e. Banjarnegara and Tawangmangu, Central Java) considered that landslide early warning system was urgently required to protect them and more than 80 % of respondent were willing to maintain the provided early warning system equipments, but in the area where no landslide disaster had occurred (Situbondo, East Java), there were some resistance for the installment of landslide early warning system.

f. Community Empowerment

Referring to the social survey and mapping, community empowerment strategy and program accordingly can be developed. Such strategy and program were emphasized to empower and facilitate the selected key person in developing and installing community-based landslide early warning system. The selected key person consists of the local leaders, local young man-power, local teachers, local active-house wives as well as the most respectful leader at the district level. The first step program is the public education by working together with the selected local key person to disseminate the practical knowledge about landslide phenomena and the prevention program. The local key person should be facilitated to empower them to conduct the practical dissemination by themselves (Figure 4). Technical training was also conducted to train the selected local technician to prepare, install, operate and maintain the provided early warning system equipments (Figure 5).

Figure 4. Public education for landslide awareness and preparedness

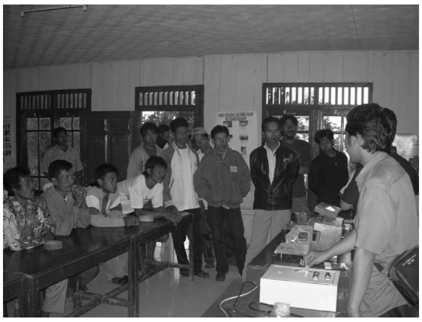


Figure 5. Technical training to empower the local technician.

After the installment of equipments and public education, evacuation drill was carried out to test the performance of equipment and the readiness of the community to utilize such equipments (Figure 6).

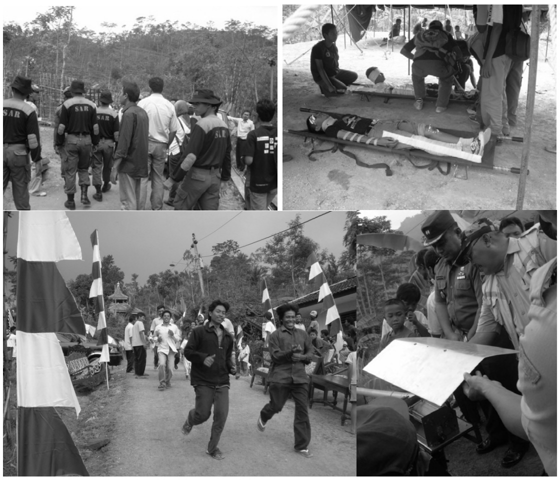


Figure 6. Evacuation drill at Kalitelaga Village, Banjarnegara District, Central Java Province, conducted on September 2007.

3. Success story

It was reported by Faculty of Engineering, Gadjah Mada University and Indonesian Ministry of Development for Disadvantage Regions (2007) that the early warning system equipment has been working properly in Kalitelaga District, at Banjarnegara Regency, Central Java in November 7, 2008. The early warning from rain gauge was on after series of successive rainfall, followed by the alarm from the extensometer. Such alarm made the community move from their homes to the safer places. Four hour later, the landslide occurred resulted in several houses damages and the main road access in the village was buried. Fortunately, 35 families living in such village were safe from this landslide.

4. Lesson learned and the follow up actions

It was learned that both communication skill and technical skill are the main requirements to achieve the success of early warning system program. It should be highlighted that the communication with all stake-holders such as local, regional and national authorities, local leaders, local youth communities, and local non government organization should be established and maintained. The role of scientist or researcher is more like to be the motivator and facilitator, instead of the instructor or manager of program.

The challenge is to implement this early warning system to the landslide susceptible areas where no landslide has occurred yet. Some resistance from the community, especially those related to the provision of land for installing early warning equipment, may be the most difficult problem to tackle. Encouraging the community to maintain the operational and sustainability of early warning equipment may also be considered as another challenge that should be tackled.

Promoting this community based EWS program as the national program without neglecting the local characteristics and resources is the immediate follow-up action. This program is now being proposed and will be evaluated further by the Indonesian National Board for Disaster Management, to be implemented further in some other landslide susceptible areas in Indonesia. Four other pilot areas in Java and Sumatra may be considered as the initiation of National Program on the development of Landslide Community-based Early Warning System in Indonesia.

Conclusions

Community-based landslide early warning system has been proved to be effectively implemented in the landslide susceptible areas in Indonesia. Both technical and social aspects should be considered in order to guarantee the effectiveness of such system. The system should also be simple and cheap to allow the local community to operate and maintain. The most challenging obstacles to implement such system are the land-ownership and efforts to raise the community possessiveness on such system.

Acknowledgements

Acknowledgement should be directed to the Indonesian Ministry of Development for Disadvantage Regions for the financial support and facilities provided to establish the early warning system. Such acknowledgement is also extended to the local Authority of Banjarnegara, Karanganyar and Situbondo Regencies for the cooperation and coordination. Significant and strong support from the community groups at the village of Kalitelaga, Tawangmangu and Campoan should also highly appreciated.

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A Method for Evaluating Landslide-prevention Works at the Yuzurihara Landslide

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Abstract. This paper reports a method for evaluating landslide-prevention works at the Yuzurihara Landslide.

The Yuzurihara Landslide, located at approximately 20 km south of Takasaki city, Gunma prefecture, Japan (36°08'N; 139°02'E), is situated on the southwest side of a mountain ridge and meets the requirements for landslide prevention. It is 600 m long, 1700 m wide, and 40–50 m deep. The Ministry of Construction has applied landslide-prevention works in this area since 1995.

Annual observations and stability analyses are conducted to evaluate the effectiveness of landslide-prevention works. Ground movement in the area is measured using GPS, extensometers, inclinometers, and borehole-type tilting meters, and groundwater levels are measured using groundwater level gauges.

The Kayakabu-Karyu area of the landslide is composed of a large block (Block I), and five smaller-scale blocks are located downhill from this large block. Measurements have shown that Block I and the smaller-scale blocks have become non-active since the control works were initiated.

The safety factor at Block I is calculated using a three-dimensional (3D) analysis, and the safety factor at each smaller-scale block is calculated using a two-dimensional (2D) analysis. The 3D stability analyses are executed under the conditions of two differing groundwater levels: measured groundwater level and simulated groundwater level. A 3D saturated–unsaturated finite element groundwater seepage analysis model was developed to simulate groundwater levels for a return period of 100 years. Stability analyses have revealed that the safety factor at Block I has exceeded 1.10 at high water levels during recent years and will be 1.03 for a return period of 100 years of rainfall. In contrast, analyses have revealed that the safety factors at four of the five smaller-scale blocks will be below 1.00 for a return period of 100 years of rainfall. These results are consistent with measured results, which have shown that this landslide in the Kayakabu-Karyu area is generally non-active.

To optimize public investment, it is important to carry out precise evaluations of the effectiveness of landslide-prevention works. In Japan, the budget for landslide prevention is decreasing, while the need for accurate evaluation techniques to assess landslide stability is increasing. The 3D groundwater seepage analysis and stability analysis of the Kayakabu-Karyu area can ensure accurate safety factor results and prevent overinvestment in landslide-prevention works.

Keywords. Control works, groundwater seepage analysis, stability analysis.

1. Background and History of Landslide-Prevention Works at the Yuzurihara Landslide

Yuzurihara Landslide is located at about 20km south from Takasaki City, Gunma prefecture, Japan (36°08'N; 139°02'E). An aerial and plan view of Yuzurihara Landlide are shown in Fig.1 and 2 respectively. The landslide faces the southwest side of a mountain ridge and has the designated landslide prevention area of 600m long 1700m wide and 40-50m deep. There are about forty residences on the landslide area and the National Road 462 passes in the midst of the landslide. The basement rock of the landslide is crystalline schist belonging to the Sambagawa Belt.

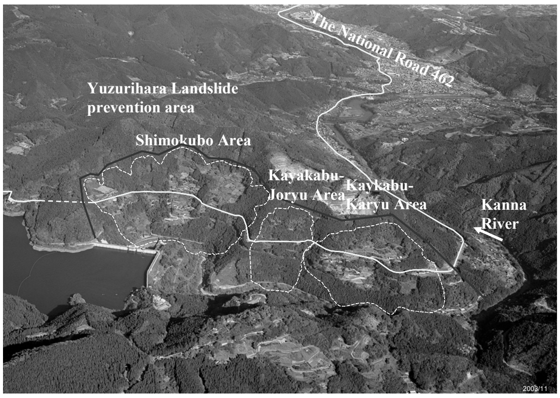


Fig. 1. An aerial view of the Yuzurihara Landslide.

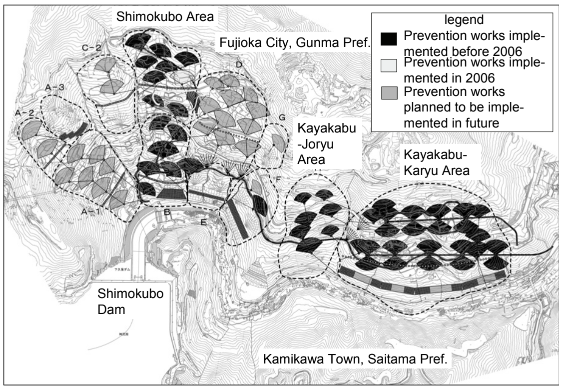


Fig. 2. A diagram of the Yuzurihara Landslide.

The movement of the landslide was activated in 1910, 1938, and 1947. By 1969, the Gunma prefectural government had initiated groundwater drainage works, which deactivated the landslide. In 1991, the landslide was reactivated due to rainfall, damaging the National Road 462 and residential structures. Subsequently, larger-scale landslide-prevention works were initiated, and fell under the direct jurisdiction of the Ministry of Construction in 1995.

The prevention area is divided into three areas: Kayakabu-Karyu, Kayakabu-Joryu, and Shimokubo. The Shimokubo area is composed of 10 blocks. The Kayakabu-Joryu area is composed of one large block, as well as other shallow smaller-scale blocks located in the middle of the area and downhill. The Kayakabu-Karyu area is composed of one large block and five other smaller-scale blocks located downhill from the large block. Prevention works began in the Kayakabu-Karyu area in 1991, after a disaster. Control works have been completed in the Kayakabu-Karyu and Kayakabu-Joryu areas and are currently under construction in the Shimokubo area.

In the Kayakabu-Karyu area, the prefectural government has constructed nine drainage boring works and 14 water catchment wells, and the central government has constructed two drainage boring works, six water catchment wells, and two drainage tunnels (683 and 541 m in length, respectively).

2. A method for evaluating the effectiveness of landslide-prevention works

Annual observations and stability analyses are conducted to evaluate the effectiveness of the landslide-prevention works. Ground movement in the area is measured using GPS, extensometers, inclinometers, and borehole type tilting meters, and groundwater levels are measured using groundwater level gauges.

Movement in each area can be summarized as follows:

a) Shimokubo: Several blocks where prevention works are not constructed move as a result of rainfall.
b) Kayakabu-Joryu: The main block is stable, and displacement is observed at the shallow smaller-scale blocks in the middle.
c) Kayakabu-Karyu: The main block is stable. Several smaller-scale blocks located downhill move after heavy rainfalls.

Measurements have shown that since the control works were carried out, the main block and the smaller-scale blocks located downhill have become non-active. Figure 3 presents an example of changes in groundwater levels as a result of control works in the middle of the Shimokubo area. Groundwater levels decreased by approximately 6 m after the catchment well was completed in 2005.

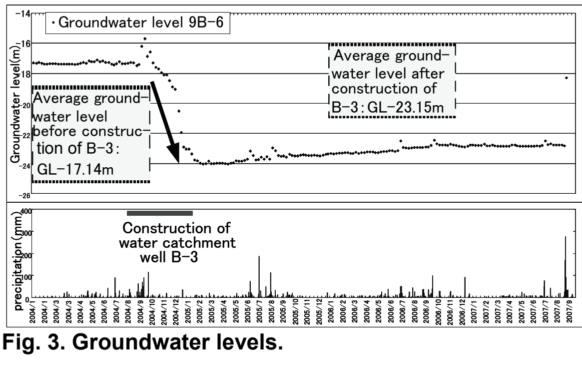


Fig. 3. Groundwater levels.

In addition to measurements, slope stability analysis can be used to provide a quantitative evaluation of the effectiveness of landslide-prevention works. Slope stability analyses also consider countermeasures; the most developed analysis has been conducted in the Kayakabu-Karyu area. Here, the safety factor at Block I is calculated using a three-dimensional (3D) analysis, and the safety factors at the smaller-scale blocks are calculated using a two-dimensional (2D) analysis. The 3D stability analyses are executed under the conditions of two different types of groundwater levels: measured groundwater levels and simulated groundwater levels. In contrast, only 2D stability analyses are executed at the Kayakabu-Joryu and Shimokubo areas, evaluating the safety factors using measured groundwater level. This report describes the methods and results of the slope stability analyses executed for the Kayakabu-Karyu area.

2.1. A three-dimensional saturated–unsaturated finite element groundwater seepage analysis of the Kayakabu-Karyu area

A 3D saturated–unsaturated finite element groundwater seepage analysis was developed to duplicate and forecast groundwater levels at the Kayakabu-Karyu area. As shown below, the Richards formula was used as the basis for the 3D saturated–unsaturated seepage analysis:

$$\frac{\partial}{\partial x}\left[K_x(\theta)\frac{\partial\varphi}{\delta x}\right]+\frac{\partial}{\partial y}\left[K_y(\theta)\frac{\partial\varphi}{\delta y}\right]+\frac{\partial}{\partial z}\left[K_z(\theta)\left(\frac{\partial\varphi}{\delta z}+1\right)\right]=\left[c(\varphi)+\alpha S_s\right]\frac{\partial\varphi}{\delta t}$$

where α is a parameter that is 0 in an unsaturated area and 1 in a saturated area, $K(\theta)_{x,y,z}$ is hydraulic conductivity, φ is pressure head, θ is volume water content, $c(\varphi)$ is differential water capacity, and S_S is differential storage coefficient.

A topographic model composed of 10-m voxels was developed and arranged to fit the laser profiler data (see Fig. 4).

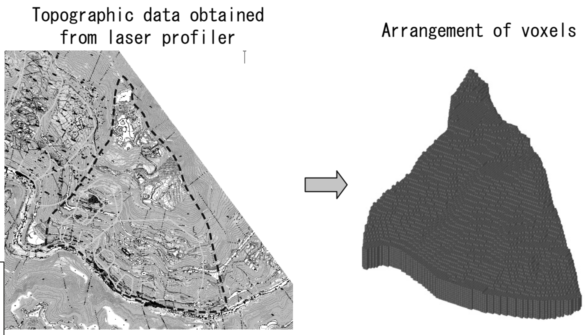


Fig. 4. Arrangement of voxels in the Kayakabu-Karyu area.

To model the effects of water catchment wells and drainage boring works, flat plate elements were arranged near the control works, as shown in Fig. 5. The hydraulic conductivities of the flat plate elements were set relatively high, and the water heads of the nodes, with a coincident position to the control works, were set at 0. For the same purpose, the water heads of voxels at the drainage tunnels were set at 0, and the hydraulic conductivities of the voxels were set relatively high where drainage boring works were conducted. The hydraulic conductivity of each voxel was set by trial and error.

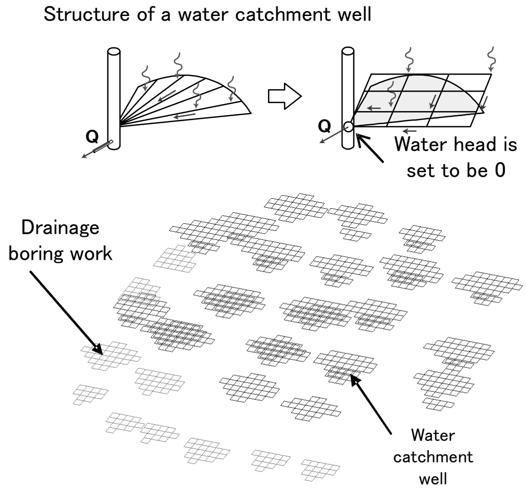


Fig. 5. A schematic model of water catchment wells and drainage boring works.

Figure 6 shows the distribution of observed groundwater levels and simulated groundwater levels; within the parameters sets of the simulation, the absolute value of errors averaged 2.92 m.

In the Kayakabu-Karyu area, two types of groundwater levels were used for slope stability analyses: observed groundwater levels and simulated groundwater levels for a return period of 100 years of rainfall. Values for this return period were calculated using two raingauges in and near the prevention area, and a continuous rainfall of 717.5 mm was used for the slope stability analysis.

2.2. Three-dimensional slope stability analysis at Block I in the Kayakabu-Karyu area

The following simplified Janbu method was used to conduct the slope stability analysis at Block I in the Kayakabu-Karyu area:

$$F_v = \sum_{i=1}^{m} \sum_{j=1}^{n} \Big\{ (c - u_{ij} \tan\phi) \eta \sin\alpha_{yz} \tan^2\alpha_{xz} \cdot \Delta x \Delta y$$

$$+ \Delta W_{ij} \left(F_V / J + \sin\alpha_{yz} \tan\phi \right) / m\alpha \Big\} \Big/ \sum_{i=1}^{m} \sum_{j=1}^{n} \Delta W_{ij}$$

$$J = \sqrt{1 + \tan^2 \alpha_{xz}}$$

$$J'' = \sqrt{1 + (\eta \tan\alpha_{xz})^2}$$

$$m\alpha = (1 + \eta \tan\alpha_{xz}) / J + \sin\alpha_{yz} \tan\alpha / F$$

$$F_h = \sum_{i=1}^{m} \sum_{j=1}^{n} \Big[\big\{ (c - u_{ij} \tan\phi)(1 + \eta \tan^2\alpha_{xz} \cos^2\alpha_{yz}) \Delta x \Delta y$$

$$+ \left(\tan\phi + \eta F_h \sin\alpha_{yz} \tan^2\alpha_{xz} / J \right) \cdot \Delta W_{ij} \big\} / \left(\cos\alpha_{yz} \cdot m\alpha \right) \Big]$$

$$\Big/ \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\tan\alpha_{yz} + K_h \right) \Delta W_{ij}$$

where F_v is the safety factor calculated from vertical balance, F_h is the safety factor calculated from horizontal balance, C is cohesion, R_i is the radius of the slip surface, ϕ is the internal friction angle, W_{ij} is the weight of a column, U_{ij} is the pore water pressure on a slip surface of a column, η is the unknown quantity, α_{xz} is the gradient of the slip surface of a column relative to the x-axis, α_{zy} is the gradient of the slip surface of a column relative to the y-axis, K_h is the horizontal seismic coefficient, and $\Delta x, \Delta y$ are the widths of a mesh on x, y planes of a column.

Figure 7 presents a topographic map of the model. The landslide's soil constants were determined by estimating cohesion from the landslide thickness and then using a back-calculation method to determine the internal friction angle, where the safety factor at the highest groundwater levels (in 1996 and 1997) was 1.10.

Table 1 shows the results of this analysis. At Block I, the safety factor was 1.13 at the 2007 high water level and 1.03 at a return period of 100 years of rainfall.

2.3. Two-dimensional slope stability analysis of the smaller-scale blocks located downhill from the Kayakabu-Karyu area

A 2D limit equilibrium method was used to conduct the slope stability analysis of the smaller-scale blocks located downhill from the Kayakabu-Karyu area. Simulated groundwater levels were extracted from a 3D saturated–unsaturated finite element groundwater seepage analysis. Figure 8 presents a cross-section of the smaller-scale block at traverse line C, and Table 2 lists the results. The results indicate that at traverse line C, the safety factor was above 1.0, and degraded to below 1.0 at a return period of 100 years of rainfall. A similar result was observed for some other blocks.

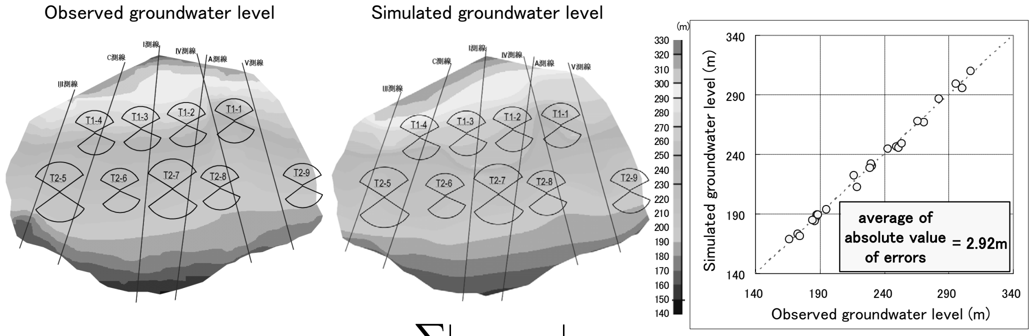
4. Conclusions

A 3D saturated–unsaturated finite element groundwater seepage analysis was conducted in the Kayakabu-Karyu area. To evaluate the landslide slope stability, a 3D slope stability analysis was conducted on Block I, and 2D analyses were conducted on smaller-scale blocks located downhill from Block I.

The results indicated that at Block I the safety factor exceeds 1.1, and exceeds 1.0 for a return period of 100 years of rainfall. In contrast, safety factors in some smaller-scale blocks downhill from Block I fall below 1.0.

The Kayakabu-Karyu area requires additional prevention works at the smaller-scale blocks and continuous evaluation of the landslide site. The Kayakabu-Joryu and Shimokubo areas require continuous landslide evaluation and improved methods of analyses.

To optimize public investment, it is important to carry out precise evaluations of the effectiveness of landslide-prevention works. In Japan, the budget for landslide prevention is decreasing, and the need for accurate evaluation techniques to assess landslide stability is increasing. The 3D groundwater seepage analysis and stability analysis of the Kayakabu-Karyu area can ensure accurate safety factor results and prevent overinvestment in landslide-prevention works.



$$\text{average of absolute value of errors} = \frac{\sum \left| r_{obs} - r_{anl} \right|}{n}$$

r_{obs} : observed groundwater level
r_{anl} : simulated groundwater level
n : number of observations

Fig. 6. Distribution of observed and simulated groundwater levels.

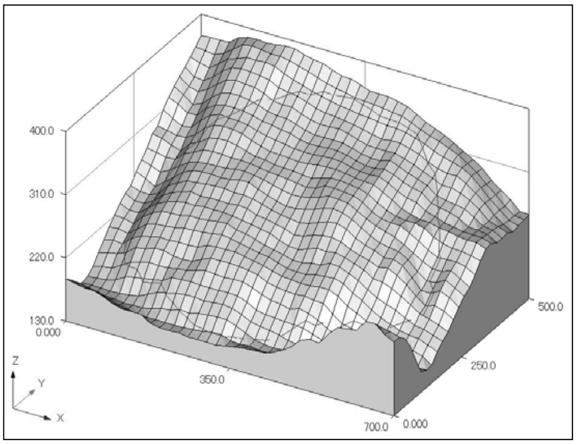


Fig. 7. Topographic map of the Kayakabu-Karyu area.

Table 1. Safety factors for the Kayakabu-Karyu area.

Condition of Grondwater Level	Safety Factor
The highest groundwater level	1.1
An estimated groundwater level at return period of 100 years rainfall	1.0

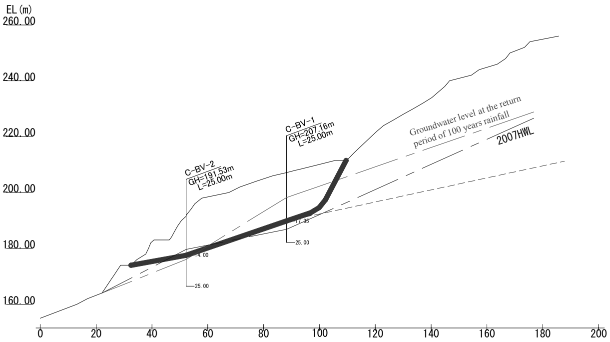


Fig. 8. Cross-section of the small-scale block in the Kayakabu-Karyu area at traverse line C.

Table 2. Safety factors for the smaller-scale block in the Kayakabu-Karyu area at traverse line C.

Condition of Grondwater Level	Safety Factor
The highest groundwater level observed in 2007	1.0
An estimated groundwater level at return period of 100 years rainfall	0.9

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Interrelation of Landscapes and Landsliding on Yugorsky and Yamal Peninsular, Russia

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Abstract. Analysis of field data from three key sites: on Yugorsky Peninsula coast and inland on Central Yamal are presented. Landscape and cryogenic landsliding interrelation is discussed. Vegetation cover change is considered as a major feature of landscape dynamics. Vegetation coverage, height and species diversity tend to grow from the coast landward. Landscape features in relation to cryogenic landsliding depend on the position relative to the sea coast. Active-layer depth is variable from one landscape to another on a local level. Vegetation indicates variability of an active-layer depth. On Yugorsky Peninsula coast two relative levels of process-landscape interrelation are subdivided. On Central Yamal, cryogenic landsliding is a major surface process to control landscape dynamics. Analyzed are distribution of cryogenic landslides, particularly landslides dated to 1989 at "Vaskiny Dachi" key site, depending on their position to geomorphic level, relief element and landscape unit. An estimation of overgrowing of landslide-affected slopes by vegetation at three main landslide elements: shear surface, landslide body and "frontal zone" is suggested as well.

Keywords. Landscapes, cryogenic landslides, vegetation cover, active-layer depth, landslide overgrowing, landslide shear surface, landslide body, "frontal zone"

1. Introduction and Study Area

Landsliding affects landscape features of the area in different ways depending on its position relative to the sea coast. In the coastal zone cryogenic landslides/slumps/earth flows forming thermocirques are the main process affecting the landscape structure while inland active layer detachments assembled in landslide cirques are observed (Leibman, Kizyakov 2007).

Landscape and cryogenic landsliding interrelation in three key sites: coastal ("Pervaya Peschanaya" & "Shpindler" on Yugorsky Peninsula), and inland ("Vaskiny Dachi" on Central Yamal) (Fig.1) is presented.

"Pervaya Peschanaya" and "Shpindler" key sites on Yugorsky peninsula at the southern coast of the Kara sea are located on the Pai-Khoi mountain range piedmont, relief of rolling hills being affected by thermokarst and various slope and coastal processes. "Shpindler" is located west of Hubt'Yakha river at the easternmost end of the 40-km portion of the coastal zone under study. The westernmost end is key site "Pervaya Peschanaya", west of Pervaya Peschanaya river.

According to the records of weather station Amderma, the average annual (summer) temperature for the period of observation is -6.8° C (4.7° C) ("Russia's Weather" Server).

"Vaskiny Dachi" key site is located in the watershed of Se-Yakha and Mordy-Yakha rivers. The area is represented by highly-dissected alluvial-lacustrine-marine plains and terraces.

The closest to "Vaskiny Dachi" climate station is Marresale, about 90 km southwest of Vaskiny Dachi, at the Kara sea coast. The weather here is probably somewhat cooler than at "Vaskiny Dachi". The average annual (summer) air temperature at Marresale is -8.3° C (4.3° C) ("Russia's Weather" Server).

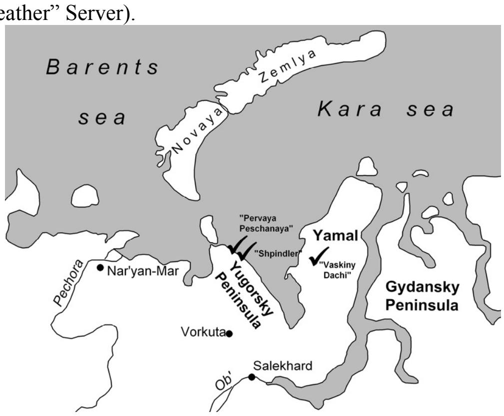

Fig. 1 Key sites

All key sites are located in subarctic tundra. Landscapes are represented by rolling hills, poorly drained, with prevailing herb-moss-shrubs (up to 20 cm high) tundra on Yugorsky Peninsula coast, and herb-moss-shrubs (up to 1.5 m high) tundra on Central Yamal.

Detailed study of differences in vegetation coverage and related active-layer depths at the key sites are the main topic of this study because vegetation is one of the most important components of a landscape complex affecting, along with climate fluctuations, cryogenic landslide formation.

2. Methods

Studies are based on field observations, published data, and remote-sensing data.

Coastal key sites were used to work through methods of estimating coastal retreat rate/landscape unit correlation. To understand landscape-coastal process links, a satellite image was classified and retreat rates of thermocirque edges at the same area measured. Landscapes were characterized as related to identified satellite image classes using field descriptions of 2005-2007 and landscape classification of E.Melnikov (1983). "Vaskiny Dachi" key site laid a bases for several studies: relation of cryogenic landslide activity and active-layer dynamics; a cartographical analysis of cryogenic landslides distribution linked to landscape structure; and landscape succession resulting from cryogenic landsliding.

To estimate vegetation cover dynamics on cryogenic landslides at "Vaskiny Dachi", data published by O.Rebristaya and others (1995) were used. Their observations were done in 1991-1993, and were supplemented by further observations (Leibman et al., 2000, Khomutov, Leibman 2007).

Tentative analysis of active-layer depth variation in different landscapes is carried out using data in Tables 2 and 3. These tables contain data on the thaw depth for most representative landscape units, subdivided at the key sites. Landscape maps with entire landscape coverage, full legend showing spatial distribution of landscape units in tables 2 and 3 for all three key sites are available in WEB Proceedings (Khomutov, 2008).

3. Vegetation Cover Change and Active-Layer Depths Differentiation

Characteristics of vegetation cover at the Yugorsky Peninsula coastal key sites change spatially: vegetation coverage, height and species diversity increase from the coast landward. Coverage tends to grow from bare surface of the beach and coastal bluffs up to 100% of thick moss-shrub-herb landscape complexes of gentle slopes. Height of many plants varies from prostrate forms next to the shoreline, up to 0.5 m high inland. Shrubs are a more presentable formation to show coverage and height change from coast inland. Number of points with shrub coverage exceeding 50 per cent at "Vaskiny Dachi" inland key site is twice higher compared to the number of points at "Pervaya Peschanaya" coastal key site (Tab.1). It is noted that 22 per cent of observation points with plants height more than 40 cm are found at "Vaskiny Dachi", while at "Pervaya Peschanaya" there are no points with such height of plants at all. Shrub species number increases landward as well. Two species of willow (*Salix glauca* and *Salix polaris*), mostly prostrate, with rare specimen of dwarf birch (*Betula nana*) are found within 1 km from the shore. Farther inland both *Salix lanata* and abundant *Betula nana* appear.

Table 1. Coverage and height of vegetation formations at "Pervaya Peschanaya" and "Vaskiny Dachi" key sites

Key site	Pervaya Peschanaya			Vaskiny Dachi		
Year	'05	'06	'07	'05	'06	'07
Number of points	16	20	40	60	55	51
Shrub coverage						
<50 %	13	12	26	31	37	30
≥50 %	1	4	7	25	10	18
Shrub height						
<40 cm	14	16	33	43	39	32
≥40 cm	0	0	0	13	8	16
Herbage coverage						
<50 %	1	9	13	15	27	10
≥50 %	15	11	26	45	28	41
Herbage height						
<20 cm	5	10	21	15	18	9
≥20 cm	11	10	18	45	37	42
Moss coverage						
<50 %	7	8	16	33	27	23
≥50 %	9	12	21	27	27	28
Moss height						
<10 cm	8	15	30	44	31	25
≥10 cm	8	5	7	16	23	26
Lichen coverage						
0 %	7	4	8	5	16	23
>0 %	9	16	32	55	39	28

"Vaskiny Dachi" key site, being 90 km away from the coastline is characterized by domination of complexes with *Salix glauca* and *Salix lanata* up to 2 m high, occupying slopes and small river valleys. Other willow species (S*alix lapponum, Salix polaris, Salix nummularia, Salix phylicifolia*), blueberry (*Vaccinium vitisidaea, Vaccinium corymbosum*), Labrador tea (*Ledum palustre*), prostrate ones, and *Betula nana* up to 0.6 m high are widely presented as well.

It is also important to note that moving landward from the coast one can see increase of the height of herb-grass formation (proportion of the description points at which plant height exceeding 20 cm is observed is three times larger landward).

Active-layer depth has quite evident spatial differentiation on a local level resulting from variations in a landscape structure on the study area. Vegetation cover is the most visible indicator of variability of active-layer depth. It is noted that if moss formation with sedge and cotton-grass is dominant (typical for boggy low flat surfaces, low lake terraces, polygonal peat-bogs), active-layer depth will be the least, just 25-35 cm in the warmest years.

Table 2. Active-layer depths in different landscapes at Yugorsky Peninsula coast ("Pervaya Peschanaya" and "Shpindler" key sites)

Landscape unit	Active-layer depths (dates of measuring)					
	2005 (1-13/08)		2006 (24/07-5/08)		2007 (10/07)	
	I	II	I	II	I	II
8	-	-	80-108	93 (3)	18-30	24 (2)
9	-	-	38-64	46 (12)	-	-
12	31-49	40 (2)	44-75	58 (5)	-	-
13	51-98	68 (8)	-	-	60	60 (1)
14	56-77	64 (3)	33-92	58 (4)	-	-
17	-	-	33-101	71 (5)	19-22	21 (3)
19	56-123	78 (9)	48-80	61 (3)	-	-
20	-	-	28-45	35 (12)	-	-
21	53-95	75 (5)	100-127	112 (3)	-	-
24	-	-	75-94	81 (4)	50	50 (1)
27	47-80	63 (5)	60-87	74 (2)	12-14	13 (3)
28	-	-	-	-	10-17	14 (7)
29	38-105	80 (9)	43-56	51 (3)	-	-
31	32-35	34 (2)	-	-	17-20	19 (3)

I – Active layer depths range
II – Average active-layer depth (number of points)

The deepest active-layer (exceeding 1 m) is typical for the lichen-shrubby (up to 20 cm high) formations dominating on drained convex tops and slopes, along the watershed edges, and in the shrub (willows up to 1.5 m high) formation dominating on concave slopes and ancient landslide shear surfaces.

Temporal variability of the active-layer depth also depends on the nature of vegetation cover and moisture content. Poorly drained or wet moss-covered surfaces (landscape unit 9, 14 partly, 17, 20, 28 and 31 in Table 2) show limited response to temperature variations. Therefore, the range of extreme active-layer depths is narrow, particularly, on a clayey substrate (landscape unit 13, 20, 28, 31 in Table 2 and partly landscape unit 5, 31 and 52 in Table 3).

Table 3. Active-layer depth in different landscape units at "Vaskiny Dachi" key site

Landscape unit	Active-layer depth (date of measurement)					
	2005 (27/08-04/09)		2006 (26/08-03/09)		2007 (26-29/08)	
	I	II	I	II	I	II
1	81-101	94 (10)	-	-	-	-
3	78-90	82 (9)	-	-	-	-
5	-	-	89-110	100 (2)	64	64 (1)
11	91-107	100 (11)	-	-	57	57 (1)
18	79-92	84 (4)	38-76	51 (6)	73-127	107 (5)
22	-	-	86-109	100 (4)	73-93	80 (5)
28	73-121	96 (34’)	31-135	92 (21+ 34’)	31-120	79 (5 +34 +55
29	-	-	79-146	113 (6)	-	-
31	70-92	88 (6)	-	-	83-108	96 (3)
33	71-123	96 (65’)	67-139	92 (24 +65’)	56-109	85 (8 +65)
34	-	-	67-141	109 (11)	-	-
40	72-96	84 (4)	-	-	-	-
52	-	-	44-81	58 (4)	-	-

I – Active layer depth range
II – Average active-layer depth (number of points)

Drained convex surfaces with lichens or low (up to 20 cm high) shrubs usually on a sandy or silty substrate, and covered by spot-medallions (units 8, 21 in Table 2 and units 1, 28 in Table 3) readily respond to temperature change. Active-layer depth on such surfaces can increase noticeably due to a warming effect of heavy summer precipitation because of high filtration capacity of sand. Range of extreme values is high because active-layer depth within spot-medallions is 5-7% higher than on surrounding vegetated surface. Active-layer depths higher than 1 m are found in landscape units 8 and 21 on Yugorsky Peninsula coast, and in units 1 and 28 on Central Yamal. Deeper active-layer on concave slopes (landscape units 5 and 31 on Central Yamal), represented by ancient landslide shear surfaces with high–willow formations is explained by warmer microclimate formed in a landslide-produced concavity, increased snow depth insulating surface from winter cold, and increased water flow into the landslide shear surface depressions (Leibman, Kizyakov 2007).

4. Cryogenic Landslides and Landscapes

On Yugorsky Peninsula coast two levels (maritime and inland) of process-landscape interrelation are subdivided. The first level comprises surfaces in the immediate vicinity of the coastal zone with retreating coasts represented by thermocirques. Vegetation cover degrades there. This level covering first few meters from the bluff edge is controlled by thermoerosion, providing good drainage. Thus, forbs and grasses dominate over moss formation. The second level, farther inland, not experiencing the coastal influence, is affected by cryogenic landsliding. Drainage is poorer there. Mosaic of sites with pioneer (landslide shear surfaces), and mature (landslide bodies and stable slopes) vegetation complexes is observed.

On Central Yamal, cryogenic landsliding is a major surface process to control landscape dynamics. Young landslide shear surfaces are bare; landslide bodies have typical for surrounding landscapes vegetation. Old landslide shear surfaces are overgrown by species having subordinate position in surrounding unchanged landscapes. Landslide bodies hold typical for a stable surface complexes, but depressed. At the ancient landslide sites typical complexes restore partly (units 5, 31 in Table 3).

Cryogenic landslides on Yugorsky Peninsula coast are generally linked to a boundary between high flat wet surfaces with sedge-moss complex (units 13, 17, 24, 27, 28 in Table 2) and wet tussocky slopes with herbs-shrub-moss complex (units 12, 19, 29 in Table 2). This can be explained by dominating of the moss vegetation complex correlated with poor drainage. The zone of minimum resistance of vegetation mat to gravity at the juncture of a hilltop and rather steep slope vegetation mat breaks to form a landslide.

To compare, in area of the best understood landscapes at "Vaskiny Dachi" key site landslides are linked to drained surfaces on slopes under the top and to long gentle slopes. The largest landslides are found on flat drained surfaces of Coastal-marine plain and Third terrace with spot-medallions or wind-blown sands, herbs-shrub-lichen and shrub-herbs complexes on sandy-silty substrate (units 11 and 28 in Table 3). Sometimes, gentle unevenly drained slopes of Coastal-marine plain and Third terrace with herb-moss-shrub complex on sandy-silty/clay substrate (units 18 and 33 in Table 3) are affected by such landslides as well. Long landslides generally are linked to gentle unevenly drained slopes with herb-shrub-lichen, shrub-herb and herb-moss-shrub complexes (units 18, 22, 29, 33 in Table 3). Small landslides widely occur on slopes of more elevated surfaces (flat unevenly drained surfaces and crests of Marine plain with herb-moss-shrub complex on sandy-loam/clay substrate and gentle unevenly drained slopes of Marine plain with herb-moss willow beds on sandy-silty substrate – units 3, 5 and 31 partly in Table 3) and on similar less elevated surfaces (units 33, 34 in Table 3). Numerous small landslides are also linked to boundary between gentle unevenly drained slopes with herb-moss-shrub complexes/herb-moss willow beds (units 5 and 18 in Table 3) and stream valleys with steep slopes (unit 40 in Table 3). Moreover, landslides widely occur on the steeper unevenly drained concave slopes with herb-moss-shrub complexes where height of undisturbed willows is up to 1.5 m (units 5 and 31 in Table 3).

An estimation of vegetation cover dynamics on cryogenic landslides at "Vaskiny Dachi" leads to the following results. Immediately after landsliding in 1989, landslide shear surface was bare without any vegetation, landslide body had initial vegetation, "frontal zone" was under diluted sediment masses. "Frontal zone" formed in front of a landslide body, appears as a result of damming of drainage routes by a landslide body with flooding of the shear surface "upstream" of the landslide body, formation of a sedge-cottongrass meadow there, and swamping downstream (Khomutov, Leibman 2007). By 1993, landslide shear surface got overgrown by species subordinate in surrounding initial landscapes (*Alopecurus alpinus, Festuca ovina, Calamagrostis neglecta, Poa alpigena* ssp. *Alpigena*, etc.). Landslide body was covered by initial communities which got depressed: vitality of *Salix polaris, Vaccinium vitis-idaea* was reduced, dead off moss cover and overgrown *Equiesetum arvense* ssp. *boreale* were presented, pioneer moss species (*Bryum* sp., *Ceratodon purpureus* appropriate for disturbed habitats appeared. In the "frontal zone" transformed initial communities were observed and sedge communities with *Carex glareosa* were developing (Rebristaya et al. 1995). In 2005 landslide shear surface was characterized by abundance of pioneer grass and chamomile-grass with herbs communities on rather dry portions (*Deschampsia borealis, Puccinellia sibirica, Draba hirta, Tanacetum bipinnatum, Senecio congestus*), and sedge (*Carex glaerosa*, *Carex bigelowii* ssp. *arctisibirica*) or cottongrass (*Eriophorum angustifolium, Eriophorim vaginatum*) meadows in depressions, but edges of gentle troughs were overgrowing poorly. On the landslide body, initial moss cover did not recover, on separate blocks crustose lichens developed. However, everywhere in more stable herb-shrub communities with *Salix polaris* typical moss cover formed. In "frontal zone" sedge swamps appeared. Some activation of overgrowing was noted in 2007 in connection with favorable weather conditions with warm summers in preceding 2005-2006.

To compare, on Yugorsky Peninsula coast landslides dated to 1989 are overgrowing more slowly because of steep slopes, massive ground ice exposed on slopes, and poorer drainage of landslide-affected sites. Under such conditions, retrogressive thaw slumps are forming almost permanently, in particular on early stages of overgrowing or due to climate warming. Retrogressive thaw slumps impede fixation of plants and soil formation on a slope.

Conclusions

Farther inland from the Kara sea coast shrub coverage, species diversity and plants height, particularly shrub height, increases. Shrub coverage at the Yugorsky coast is twice less than at Central Yamal, and shrub height is much lower at the coast (40 cm against 2 m in Central Yamal).

Active-layer depths differentiation depends on interrelation between climatic, vegetation and substrate features. Different landscape components respond to climatic fluctuations in different ways. Therefore, active-layer depth fluctuations depend on a landscape component variations. Most prominent examples of such dependence are as follows. Prevailing of mosses results in decrease of both spatial and temporal amplitude of extreme active layer depth fluctuations; while bare surface or with the sparse vegetative cover on spot-medallions cause rise of the amplitude of extremal active-layer depths in a wide range under the climatic fluctuations.

Cryogenic landslide formation is linked to specific landscape complexes. These complexes affected by landslides are different in the coastal and inland zones. Coastal landscapes subject to landsliding are wet, with thick moss cover on clayey substrate, while inland landslides are linked to unevenly drained mostly shrubby surfaces on sandy-silty substrate.

Overgrowing of slopes affected by cryogenic landslides shows itself on landslide elements in different ways. Landslide shear surface is characterized by slow overgrowing with pioneer vegetation. On landslide body initial communities are preserved but depressed, later initial vegetation recovers with the wider grass representation. "Frontal zone" overgrows by sedge complexes, its bogginess increases.

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Potential of Payment for Ecosystem Services Schemes for Landslide Risk Reduction

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Abstract. The concept of Payments for Environmental Services (PES) has received much attention in recent years as an innovative concept to finance environmentally sound management of natural resources, particularly in Latina America and Asia. PES schemes are particularly important in the watershed context, where upstream and downstream people are linked by the hydrological system. In a typical payment scheme, one or more upstream service providers provide a well defined water-related environmental service to downstream beneficiaries, who compensate the providers for the service provision through the payment scheme. Environmental services of interest in watersheds can be divided in services regarding water quality, such as low sediment concentration, and services regarding streamflow, such as the maintenance of a minimum flow by maintaining or improving the infiltration capacity.

The reduction of risk from landslides is a potential environmental service to be included in payment schemes for environmental services. Since direct assessment of water-related environmental services is technically difficult and costly, compensations are usually based on the area covered by land uses assumed to provide the desired service, and calculated on a per-hectare basis. The land uses which are considered under the scheme vary according to the services provided, but typically include forest conservation, reforestation, conservation of natural grassland, and soil and water conserving agricultural practices.

The presentation analyzes the potential of operational PES schemes in Asia and Latin America as to their potential to reduce the risk of landslides in the watershed. Many schemes specifically target forest conservation on steep slopes and close to water courses, which are considered priority zones to achieve the desired environmental services. Thus, PES schemes in practice today may reduce the risk of landslides, even if landslide risk reduction is not specifically included as an objective to be achieved by the scheme. However, PES schemes, as any intervention in the upper watershed, cannot prevent landslides occurring during extreme climatic events and their downstream consequences, and can therefore be one component in a comprehensive approach to prevent downstream consequences of landslides, which must also include monitoring and early warning systems as well as evacuation plans for downstream communities, in order to prevent human damage from landslides.

Keywords. Payments for environmental services, Landslide risk reduction, Watershed management, Latin America, Asia

1. The concept of payment schemes for environmental services

Watersheds provide human societies with many goods and services such as provision of clean water, erosion control, carbon sequestration, conservation of biodiversity and maintenance of landscape beauty. However, their value is rarely expressed in monetary terms and there are no markets where they can be bought or sold. As the providers of these services do not receive any compensation for these services, they do not take them into account when making a land use decision, which may endanger their continued provision in the future.

As environmental services, provided by watershed systems become increasingly scarce, beneficiaries of these services begin to recognize their value and may be willing to invest in a continued provision of these services. Four main services can be distinguished: watershed protection, carbon sequestration, biodiversity conservation, and landscape beauty (Landell-Mills and Porras 2002, Pagiola et al 2002, Wunder 2005).

In the watershed context, the water-related services are of particular importance (FAO 2000, FAO 2004a,b). The following table adapted from Kiersch et al. (2005) summarizes typical water-related services and the users.

These services…	… are required by these users.
Improvement or stabilization of annual water flow.	Drinking water suppliers; hydroelectric facilities with multi-annual storage; irrigation.
Improvement or stabilization of dry-season flows.	Drinking water suppliers; run-of river hydroelectric facilities; irrigation.
Low concentrations of suspended sediments.	Drinking water suppliers; hydroelectric facilities with multi-annual storage; run-of river hydroelectric facilities.
Low concentrations of sediment bedload.	Hydroelectric facilities with multi-annual storage; Irrigation.
Low concentrations of fertilizer and pesticide residues.	Drinking water suppliers.
Improvement of microbial quality.	Drinking water suppliers.

Wunder (2005) offers a definition of PES based on five criteria. PES is

1. a *voluntary* transaction where
2. a *well-defined* environmental service (or a land use likely to secure the service)
3. is being bought by a (minimum one) service *beneficiary*
4. from (minimum one) service *provider*
5. if and only if the service provider secures service provision (*conditionality*).

In the watershed context, a typical PES scheme takes the form depicted in figure 1. One or more upstream service *providers* provide a well defined water-related environmental service to downstream *beneficiaries*, who *compensate* the providers for the service provision through the payment scheme, either directly or through an *intermediary*.

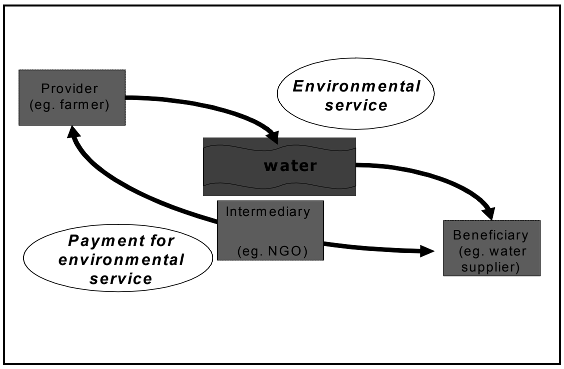

Figure 1. A typical PES scheme in a watershed context

Since direct assessment of water-related environmental services is technically difficult and costly, compensations are usually based on the area covered by land uses assumed to provide the desired service, and calculated on a per-hectare basis. The land uses vary according to the services provided, but typically include the following:

- Forest conservation
- Reforestation
- Conservation of natural grassland
- Soil and water conserving agricultural practices (for example, maintenance of permanent soil cover, mulching, no-burning)
- Reduction of water pollution (for example, treatment of coffee pulp residues, no grazing near watercourses) (Kiersch et al 2005)

Other forms of compensation include covering the administrative costs for protected areas.

The amount for the compensation is generally up to negotiation by the participants. As a minimum, the compensation needs to cover the opportunity cost of the service providers to switch to a more profitable land use. The maximum is set by the willingness to pay of the beneficiaries.

In order for a payment scheme for environmental services to work, a number of prerequisites must be met. First, there must be a general consensus among the stakeholders about which forms of land management provide the environmental services desired by the beneficiaries. Second, a strong institutional framework must be in place to implement the scheme. This must include the possibility to sanction participants who do not comply with their obligations. In the absence of institutions, transaction costs to establish the scheme may become prohibitively high. Third, the land tenure situation of the service providers upstream must be sufficiently secure to provide adequate incentives to participate in the scheme. Fourth, from an economic standpoint, the value of the services to the beneficiaries (and their willingness to pay) must exceed the opportunity costs of the service providers in providing the desired services.

In practice, PES systems in watersheds have been restricted to one of the two following purposes: a) to improve the availability and quality of water for human consumption, mainly in urban areas, and b) to improve the availability and quality of water used in hydroelectric generation. Other potential users such as irrigations schemes have only played a limited role in PES schemes. The payment mechanisms, the system structure and the scale of application show a high degree of variability due to the differing institutional and geographical context where the scheme is implemented. The schemes can be divided as follows:

- Local initiatives with public participation supported by an international donor;
- Local initiatives with public participation, without external support;
- Self-organized private deals at the local level, without external participation;
- Payment programmes at the national level (Kiersch et al 2005)

Local initiatives are financed directly by the service users, such as the municipal water supplier or the hydroelectric company (eg. through an increase in the residents' water charges or part of the electricity sales). Schemes with external support are usually financed through an initial fund provided by the donor(s), which is replenished by contributions of the service users. Donor-financed schemes frequently face challenges in reaching financial sustainability. National PES programmes are frequently financed by cross-sectoral subsidies: for example, in the case of Costa Rica, by a fuel tax, and in Colombia, by taxes on hydropower production, and also may involve international contributions for environmental services other than water-related services. (Kiersch et al. 2005)

2. Landslide prevention as an environmental service

Landslides can have significant impacts on downstream populations. By blocking the streamflow channels, they can disrupt water flows to downstream users and form retention lakes which may pose a considerable flood risk to downstream communities. Landslides may damage water supply infrastructure of downstream users such as canals, tubes and headworks. Finally, they may increase both suspended sediment and bedload in the river channel, posing a problem for downstream reservoirs, irrigation schemes, industries or drinking water suppliers. Thus, the control of landslides is certainly a concern to downstream stakeholders which could potentially be part of a payment scheme for environmental services.

It is important to assess whether and how upstream landholders can provide the environmental service of "landslide prevention". Landslides can occur if the weight of the soil column exceeds the shear forces which hold the soil in place (van Noordwijk 2005). In his extensive review of literature on forest impacts on watersheds, Bruijnzeel (2004) concludes that there is a general consensus that a well-developed tree cover can prevent shallow landslides of up to about 1 m in depth due to the stabilizing forces of the root network. However, the occurrence of deep landslides (> 3 m) is not affected appreciably by forest cover. In cases of extreme climatic events such as hurricanes, trees may actually exacerbate slope instability due to the trees' weight and the susceptibility of particularly high trees to be uprooted during extreme storms, damaging the soil matrix: Bruijnzeel (2004) cites a study on the consequences of a hurricane in Puerto Rico, which found that 77 % of the 285 landslides reported occurred on forested territory. Large trees on streambanks also are a potential risk for triggering landslides and increasing the sediment entry into the river channel, if they are uprooted and lift considerable amounts of soil in the process (van Noordwijk 2005).

Forest or vegetation cover can attenuate the potentially negative downstream effects of landslides. If the vegetation cover of the slope is intact, vegetation downhill of the landslide can act as a filter for dislodged soil, preventing the sediment entry into the river channels. However, during intense rainstorms which exceed the water holding capacity of the soil, or earthquakes, such natural filer mechanisms may fail (van Noordwijk 2005).

In contrast, clear-felling of slopes will increase the probability of landslides occurring, particularly after a few years when the roots are decomposed and lose their stabilizing force. Conversely, reforestation may contribute to the prevention of landslides. However, due to the time it takes for the stabilizing root network to develop, a "substantial length of time of observation" (van Noordwijk 2005), without the occurrence of extreme climatic events, may be required before this effect is noticeable.

In hilly areas where terraced agriculture is practiced, particularly paddy fields, abandonment of the terraces can increase the risk of landslides occurring due to a collapse of the structures (Sakuyama 2006).

Road construction on slopes is a major factor influencing the occurrence of landslides (van Nordwijk 2005). Sediment yields at the watershed scale often increase as much as 10-20 times as a consequence of road building (Bruijnzeel 2004).

In conclusion, the maintenance of forest or deep-rooted vegetation cover on slopes can generally prevent the occurrence of shallow landslides and attenuate the downstream effects of naturally occurring landslides in normal climatic situations. During extreme climatic events, however, the presence of forest on slopes may not affect the susceptibility of the slopes to collapse. In some extreme events, forests may even increase the risk of mass wasting. Furthermore, other disturbances which are not necessarily connected with the land use practices of the upstream landholders, in particular the construction of roads, may have a greater effect on increasing the risk of landslides than the land uses per se. Lastly, the time factor may be critical: Particularly land use changes aimed at improving slope stability and reducing the risk of landslides may take a long time to mature, before the changes become visible. Thus, the inclusion of landslide prevention as an environmental service depends on site-specific factors and must be carefully evaluated before including it in payment schemes for environmental services.

3. Landslide prevention as a factor in current payment schemes for environmental services

The preceding section shows that landslide prevention is a potential environmental service. In practice, however, operational PES schemes in watersheds rarely include this service explicitly as a justification for payments by beneficiaries to service providers. Most experiences of functional PES schemes stem from Latin America and Asia. In a review of operational PES schemes in Latin America, Kiersch et al. (2005) make no reference to landslide prevention as an environmental service, although the cases examined are all situated in mountainous watersheds, where landslide prevention is an important issue. Similarly, in a review of 15 PES programmes in Asia, Huang and Upadhyaya (2007) found that landslide prevention, though considered a relevant environmental service, was not included in any of the schemes. The only explicit reference to landslide prevention is made by Sakuyama (2006) in his review of the payment scheme administered by the Ministry of Agriculture, Forestry and Fisheries in Japan to prevent the further abandonment of farmland.

However, looking at the land uses promoted by the payment programmes in mountainous watersheds, all of the schemes reviewed by Kiersch et al (2005) as well as Huang and Upadhyaya (2007) give incentives to upstream land users for forest conservation or the maintenance of a permanent vegetation cover. Some schemes also provide incentives for reforestation. As discussed in section 2 above, these land uses have a potential to reduce the risk of landslide prevention in addition to the other environmental services typically sought by the downstream beneficiaries in the schemes, i.e. reduction of sediment yield or streamflow maintenance.

Thus, in general terms, it can be argued that current payment schemes for water-related environmental services in hilly and mountainous areas do play a role in landslide prevention, even though landslide prevention is rarely mentioned explicitly as an environmental service. However, it is difficult to estimate to what extent the risk of landslides has been reduced by the schemes. Many schemes, for example, pay the same incentives to upstream land users regardless of the location of their property in the watershed. The risk of landslides, however, is more pronounced on slopes. Therefore, in order to include landslide prevention as an environmental service, PES schemes must be tailored to target specifically those areas in a watershed where the risk of landslides occurring is particularly high (Barrena et al 2007).

4. Conclusion: potential of payment schemes of environmental services for landslide risk reduction

Payment schemes for environmental services have been receiving much attention in recent years as a novel mechanism to improve the management of natural resources at the watershed scale and foster cooperation between upstream and downstream resource users.

Most operational PES schemes give incentives for land uses such as forest conservation and reforestation which are generally considered to reduce the risk of shallow landslides or attenuate the effects of such landslides at the watershed scale such as increasing flood risk or sediment loads. Thus, it is very probable that the schemes have a certain effect on the prevention of such landslides and their negative impacts. However, no empirical study has been conducted as of now to confirm this conclusion.

The inclusion of prevention of shallow landslides as an additional environmental service in watershed-based PES schemes seems feasible, as these, under normal circumstances, can be influenced by land uses in watersheds. In order to include landslide prevention as an explicit environmental service in a PES scheme for which upstream service providers are being compensated by service beneficiaries downstream, a careful evaluation of the watershed is necessary to establish in what ways and in which areas of the watershed landslide risk is influenced by upstream land use. The compensation payments have to be targeted at those areas which present a particularly high incidence of landslides.

However, PES schemes – as well as any watershed management programme which makes interventions in the upper part of the watershed with a view to improving the availability and quality of water resources downstream – will not have an appreciable effect on deep landslides, and landslides occurring during extreme climatic events such as hurricanes, typhoons or prolonged intense rainfall provoked by the El Niño phenomenon as occurring in the Andes. In such events, the effect of land use patterns in the upper watershed on landslides becomes small. As discussed above, in some extreme events, trees which in normal circumstances contribute to landslide prevention may even increase the risks of landslides. If the downstream impacts of landslides in a given location are evaluated over a longer period, it may often be found that just these landslides occurring during extreme climatic events cause the most devastating downstream impacts.

Thus, if landslide prevention were ever made an explicit part of an agreement under a PES scheme, downstream stakeholders must be very clear that by subscribing to the agreement, they do not buy any kind of insurance against the effects of landslides that occur during extremely intense rainstorms or similar unusual climatic phenomena. Therefore, in landslide-prone watersheds, a PES scheme can only be one component in a comprehensive approach to prevent downstream consequences, which must also include monitoring and early warning systems as well as evacuation plans for downstream communities, and the identification of sites which are vulnerable to landslides and avoiding the construction of houses or other infrastructure such as roads or canals on such sites. As van Noordwijk (2005) states: "Reducing human damage by landslides can be achieved first by not building houses on vulnerable sites".

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For further resources on payment schemes for environmental services in watersheds see the following websites:

http://www.ecosystemmarketplace.com
http://www.rlc.fao.org/prior/recnat/foro.htm
www.fao.org/landandwater/watershed
http://www.iied.org/NR/forestry/index.html
http://www.worldagroforestry.org/sea/Networks/RUPES
www.worldbank.org/environmentaleconomics

Evaluation of a Satellite-based Landslide Algorithm Using Global and Regional Landslide Inventories

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Abstract. A global, satellite-based landslide algorithm has been developed using surface information and multi-satellite rainfall data. The technique integrates surface parameters with TRMM multi-satellite precipitation data to obtain an estimate of areas susceptible to landslides in near-real time. This research compares the predictions from the global landslide algorithm run retrospectively for individual years with global landslide inventories to assess both the relative skill of the technique and the value of currently available landslide information on a global scale. It also considers algorithm performance and recalibration at the regional scale, focusing on Central America and the Caribbean region.

This algorithm represents the first phase in identifying landslide hazards at this scale. The evaluation provides the foundation for adjusting the algorithm for improved landslide hazard forecasting at both global and regional scales. With adjustments, this algorithm shows promise in approaching landslide hazard assessment globally and providing information for the research community to address landslide issues in a broader context.

Keywords. Global algorithm, landslide inventory, regional susceptibility analysis

1. Introduction and Background

Landslide hazard assessment research has predominately focused on site investigations, drawing on high resolution surface data as well as detailed landslide inventories and rainfall information to provide an estimate of static landslide hazard susceptibility. Given the large amount of data required for such methodologies, research is generally limited to regions where such data is available, primarily in developed countries. To present a more dynamic representation of landslide hazard risk at larger spatial scales, Hong et al. (2006; 2007) has developed an algorithm which couples a landslide susceptibility map with real-time satellite derived rainfall to forecast areas with high landslide potential.

This algorithm was developed under the assumption that rainfall triggered landslides can be forecasted by employing an empirical relationship between rainfall intensity and duration and landslide occurrence to estimate areas prone to landsliding conditions. The current landslide hazard algorithm represents the first version of this research effort and remains in experimental stages, however, the potential utilization of this algorithm as a forecasting tool has sparked a wide array of interest.

This study evaluates the algorithm using a global landslide inventory database compiled for this purpose. The components of the algorithm are quantitatively evaluated for their relative skill both spatially and temporally. The results are then compared to the input data to identify the limitations and potential application of the algorithm. The goal of this analysis is to provide the information necessary to generate an improved version of this global landslide algorithm and to communicate its applicability to end-users.

2. Algorithm Description

The satellite based global landslide algorithm draws on a range of remote sensing data to develop a landslide susceptibility map and rainfall intensity-duration relationship. The susceptibility map is derived from six input datasets, including slope, soil type, soil texture, land cover, elevation, and drainage density (Fig. 1). A detailed description of the susceptibility map and methodology is available in Hong et al. (2007). A satellite rainfall product is used to establish and evaluate the rainfall intensity-duration threshold conditions necessary for landslide initiation. The TRMM Multi-Satellite Precipitation Analysis (TMPA) product (Huffman et al. 2007) is available at 0.25°, 3-hourly resolution. The algorithm evaluates landslide potential on a pixel-by-pixel basis. If a given pixel has a high susceptibility value (4 or 5) and the rainfall threshold exceeds the 1, 3 or 7 day level, the pixel is denoted as having 'high landslide potential'.

The landslide inventory database was compiled using information from journal articles, existing databases, online news media, and government and relief aid organization reports. The study considers all rapidly-occurring rainfall triggered landslide types in the database and focuses on the years 2003 and 2007 (Kirschbaum et al. submitted, 2008a). The distribution of data for both years is illustrated in Fig. 1.

The landslide event locations in the database are compared to the susceptibility map and the satellite rainfall accumulation information. Approximately 70% of the landslide inventory events for the considered years are located in areas denoted as 'high susceptibility'. High susceptibility areas are difficult to resolve in coastal regions and small islands due to the 0.25° base resolution of the susceptibility map as well as the way in which variables such as slope are calculated and weighted.

Satellite rainfall accumulation is extracted for the landslide events to determine if the existing intensity and duration information exceeds the threshold values at the 1, 3, and 7-day rainfall durations. Approximately 30% of the landslide events were located in areas where the rainfall exceeded the threshold at the designated temporal windows. A larger percentage of the landslides had rainfall accumulations that exceeded thresholds at the sub-daily level and were typically associated with high intensity-short duration rainfall events. A small subset of events did not resolve any significant rainfall for the landslide location, suggesting that the landslide events were improperly mapped.

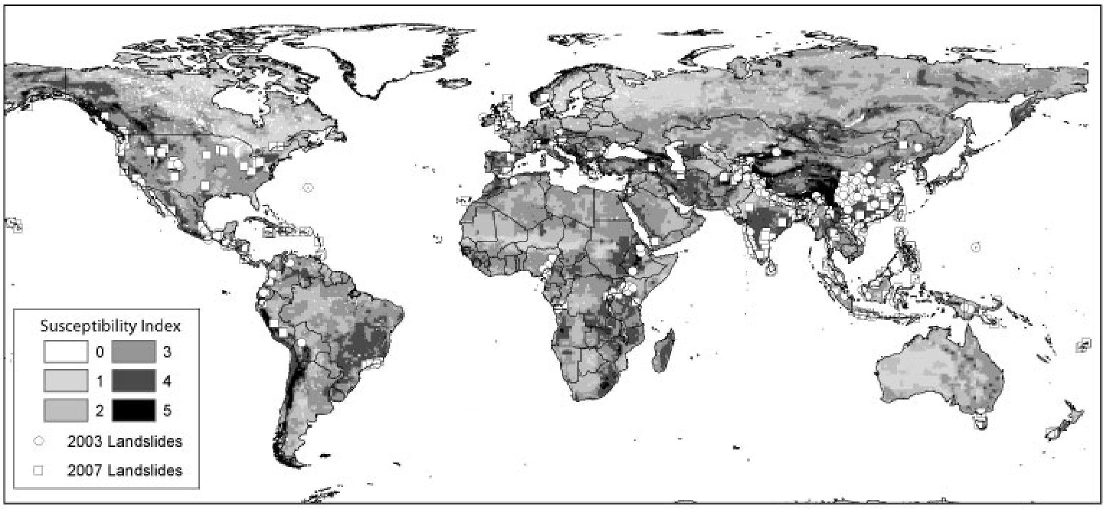

Fig. 1 Global landslide susceptibility index map plotted with 2003 and 2007 landslide inventory data. Index values of 4 and 5 denote areas considered as high susceptibility by the algorithm

3. Results on the global and regional levels

The algorithm was run retrospectively for 2003 and 2007 and forecasts were compared to the landslide events for the corresponding years. In order to accurately categorize the performance of the algorithm, we evaluate the algorithm according to its relative and absolute skill. Fig. 2 illustrates the relative skill of the forecasts and landslide events for 2003 by comparing the percentage of events by month and 10º latitude bands.

The monthly distributions for both years indicate similar seasonal patterns, with a peak in landslide events and forecasts in the Northern Hemisphere summer (June through September). The somewhat parallel distribution of forecasts and landslides does not apply in the southern hemisphere, where there are very few reports compared to the percentage of forecasts. We attribute this discrepancy to potential landslide reporting biases and over-forecasting in certain locations including portions of Brazil and central Africa.

Several statistics are used to describe the spatial and temporal accuracy of the algorithm and include: Skill Ratio (normalized algorithm forecast density over the landslide inventory density at each pixel); Over-forecasts (areas with no reported landslides but a high density of algorithm forecasts); and Missed Landslides (Areas with landslide events and no forecasts). These evaluation indicators were developed for this algorithm in an attempt to accurately characterize the current skill of the system. The absolute skill of the algorithm is calculated according to a Probability of Detection (POD) statistic, representing the actual number of landslides that are successfully predicted by the algorithm forecasts over the total number of landslide events in the record.

The Skill Ratio, Over-forecast (Type 1 Errors), and Missed-Landslide (Type II Errors) statistics are used to illustrate where the algorithm is over-estimating, under-estimating or correctly resolving landslide activity and susceptibility.

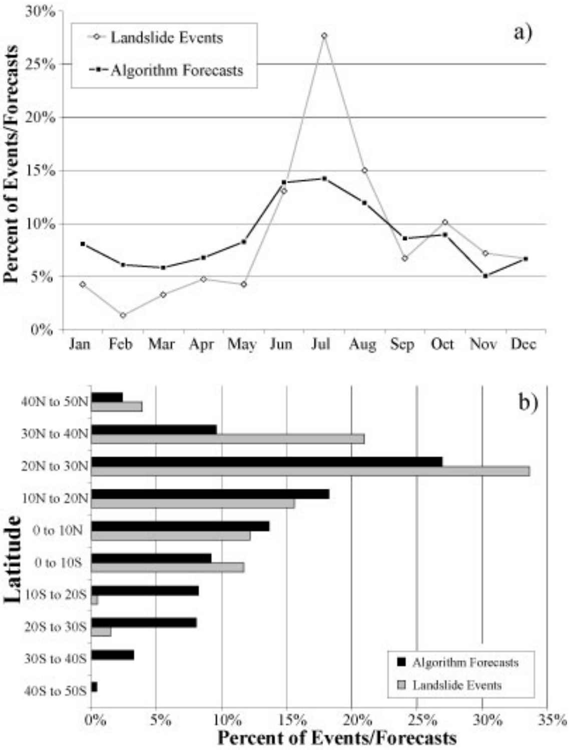

Fig. 2 a) Temporal distribution of 2003 landslide events and algorithm forecasts, b) distribution of landslide events and algorithm forecasts by latitude

Results indicate that the algorithm demonstrates predictive skill over the Himalayan Arc region, portions of Southeast Asia, Central America, and Oceania. There are severe over-reporting issues in the Indian peninsula, Eastern Brazil, and portions of Africa. The high concentration of Type I errors correlate regionally with an over-weighting of soil type and soil texture information in the susceptibility map. In contrast, the slope parameter is generally under-emphasized due to technique for up-scaling slope values from the DEM resolution to 0.25° as well as the weighting of the variable in the susceptibility calculations (Fig. 3). This is particularly true in areas with marginal but nonetheless critical slope gradients. These variables need adjustment to improve the susceptibility map and resulting algorithm skill.

To address these limitations and refine the methodology used to calculate the input variables for the algorithm at the global scale, this research then considers the algorithm components at a regional level focusing on Central America and the Caribbean. The work considers land-surface rain relationship conditions and allows for more extensive validation data for algorithm improvement. Fig. 4 illustrates how the algorithm can be applied at smaller spatial scales, considering the specific case of Hurricane Mitch as it passed over Central America in 1998. The algorithm forecasts are made for the time period when Hurricane Mitch passed through the region, shown in the colored pixels, and are compared to the areas which were surveyed for landslides in the months following this devastating event. It also compares two rainfall gauges to the satellite rainfall for the corresponding pixel to obtain a general idea of how peak rainfall amounts are resolved by each dataset.

This simulation indicates that the algorithm can resolve portions of the mapped landslide areas, such as in Nicaragua, where rainfall totals were generally higher; however, the majority of El Salvador and Guatemala were improperly categorized. Case studies such as this can be used to improve the susceptibility map and rainfall threshold relationship at the regional scale.

This study identifies regional landslide susceptibility by employing several different techniques to calculate a susceptibility map, drawing upon available landslide inventories and higher resolution surface products. The rainfall triggering relationship is also evaluated at the regional scale, considering both in situ and satellite data to better resolve the range of potential rainfall threshold conditions. Additional variables such as soil moisture can be integrated into the susceptibility and rainfall variables to provide a more dynamic estimation of potential landsliding conditions. The results of the regional analysis will be used to adjust the prototype algorithm at the global scale for improved landslide hazard forecasting.

4. Discussion and Conclusions for future work

The current algorithm represents a first version of this global evaluation effort. The algorithm demonstrates skill in forecasting areas of 'high landslide potential' for specific regions; however, several improvements are necessary before the algorithm can become an operational forecasting and susceptibility evaluation tool:

1) Input variables to the susceptibility map must be recalculated and re-weighted according to global and regional sensitivity analyses.
2) Of the input variables, slope requires the most significant attention in better characterizing the physical threshold processes and understanding slope distribution at finer scales.
3) Integrating soil moisture information into the algorithm may provide a more representative realization of global susceptibility and introduce additional memory to the algorithm system.
4) The rainfall intensity-duration threshold curve should be considered against other global studies and possibly recalibrated using additional landslide information.
5) The resolution considered in this algorithm limits the ability to resolve features or processes with comparatively smaller spatial or temporal extents, including smaller topographic features, anthropogenically modified areas, high-intensity short duration rainfall events, and areas exposed to prolonged rainfall that saturates soils (Kirschbaum et al. submitted, 2008b).

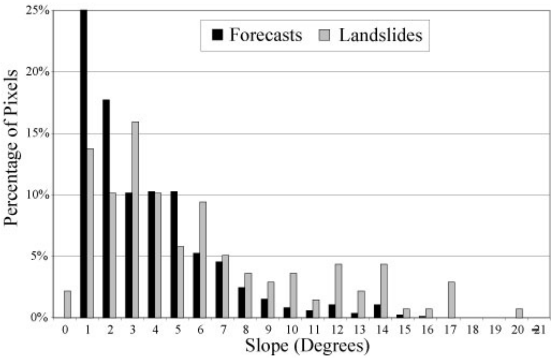

Fig. 3 Slope distribution for 2003 forecasts (black) and landslides (grey), binned into 1 degree categories

The present susceptibility map has skill in resolving landslide events, but the formulation of the susceptibility index employs a weighted linear combination of variables approach which makes it difficult to interpret with actual surface conditions. A regression or sensitivity analysis using available validation data can provide more specific information for defining the contribution of each parameter to overall susceptibility. This regional analysis will help to define the susceptibility calculations according to the variables that maximize the accuracy of the information while minimizing the uncertainty. The results indicate that with the suggested improvements the global landslide algorithm has the potential to serve as a valuable tool for aid and governmental organizations as well as global landslide research in the future.

Acknowledgements

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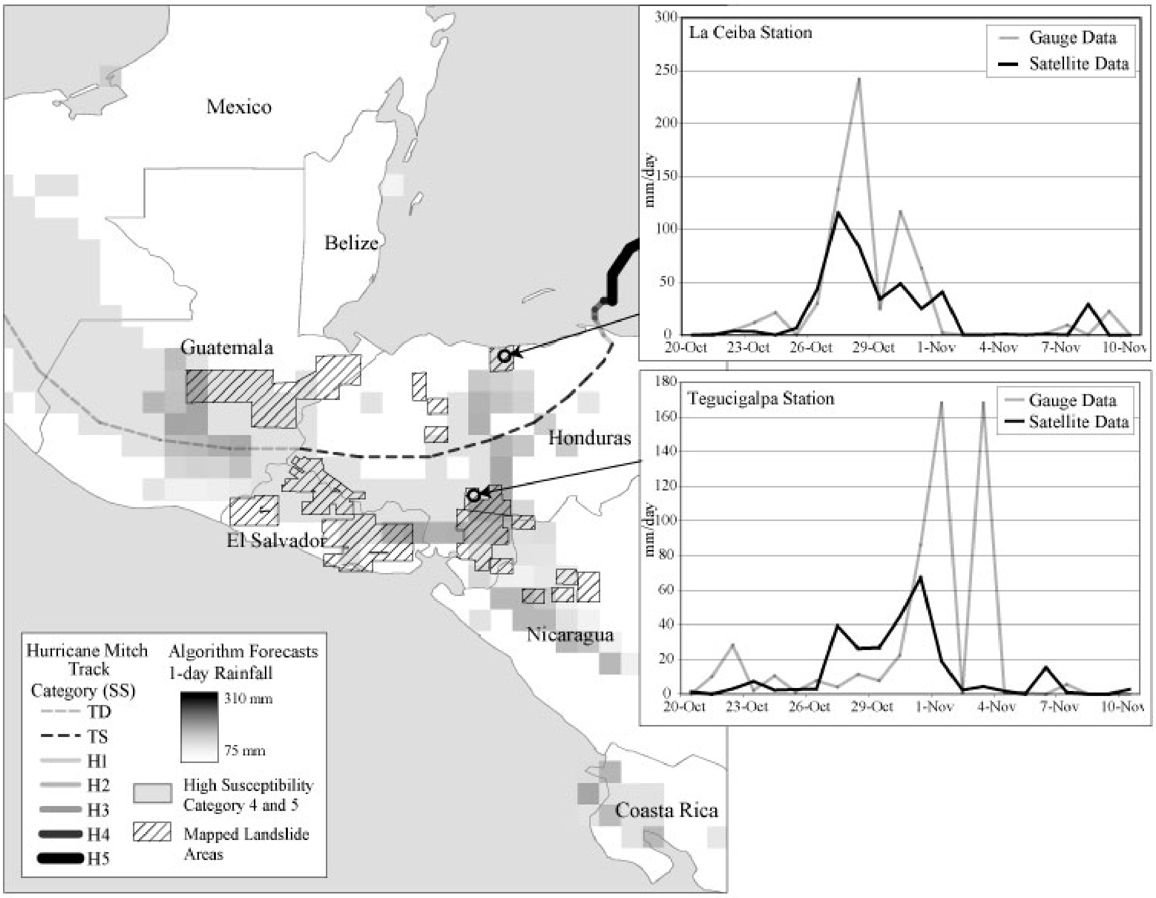


Fig. 4 Example of algorithm performance for Hurricane Mitch in October to November, 1998. Left map shows the path and intensity of the storm according to the Saffir-Simpson scale. The algorithm was run using a 1-day temporal window and forecasts were plotted according to the cumulative rainfall. Forecasts are compared to mapped landslide areas (hatched boxes). Graphs at the right compare daily rainfall accumulation estimates for 2 NCDC gauges in Honduras with TMPA satellite data

The Warning Standard Rain of Sediment Runoff and Shallow Landslides along the Mountainous Torrent

Tetsuya Kubota (Kyushu University, Japan) · Israel Cantu Silva (University of Nuevo Leon, Mexico) · Hasnawir (Kyushu University, Japan; Institute of Forest science in Sulawesi, Indonesia)

Abstract. In the first place, the research is run on a torrent in northern Kyushu whose geology consists of Paleozoic metamorphic rocks (mainly schist) and whose vegetation consists of mainly Japanese cypress and cedar. Soil depth is approximately 50cm in average and permeability is $k=10^{-2}$ order. With data obtained by the monitoring and the observation over 4 years, standard rainfalls for warning and evacuation against the sudden sediment runoffs are analyzed by the sediment runoff intensity theory, the Self Organized Criticality Assumption (SOC), and the Elementary Catastrophe Theory (ETC). Then, the result can be compared with the one in Nuevo Leon (NL) Mexico (geology of schist, slate, $k=10^{-3}$ order) and in southern Sulawesi Island Indonesia (volcanic geology, $k=10^{-3} \sim 10^{-4}$ order)(Fig. 1~2).

Hitherto, various methods were proposed to analyze the warning critical standard rain for landslide disaster or large sediment discharge (Aleotti 2004, Hirano 1992, 1995, Kubota 1995, etc.). In this study, we mainly employ Hirano's method or SOC (Bak 1992).

Keywords: warning, evacuation, standard rain, sediment runoff, torrent, shallow landslide, catastrophe, SOC

１． Theoretical Critical Standard of Large Sediment Runoff RiCL based on the Hirano's Discharge Theory or the Self Organized Criticality (SOC)

RiCL are the critical line of sudden vast sediment runoff given by the equation (4) below. Theoretically, they are derived from equation (1) (Hirano 1992).

$$Q/A = M \cdot Ri(t) \int (P \cdot \cos\theta) dt \quad \cdots\cdots \quad (1)$$

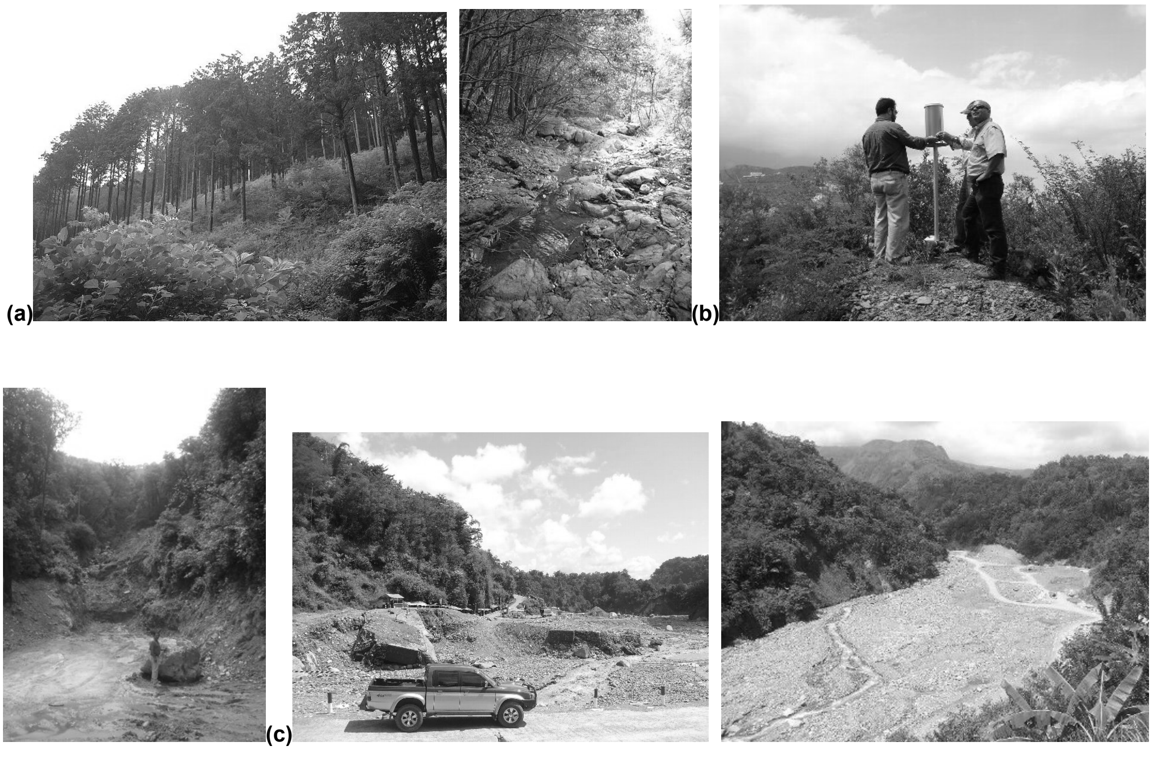
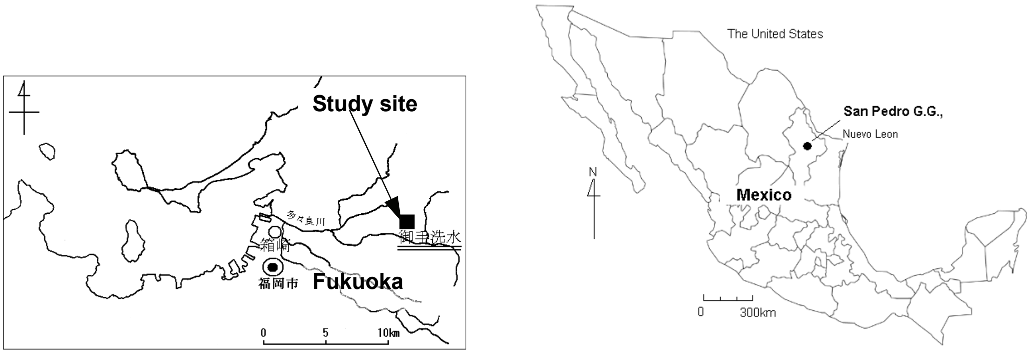
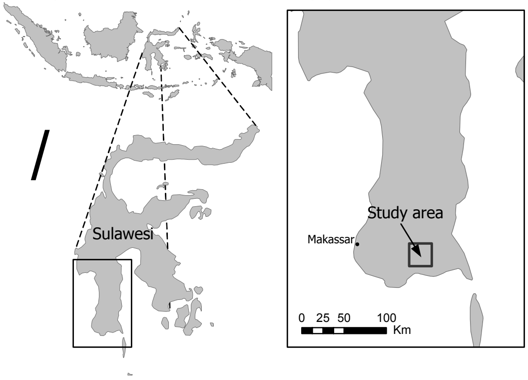


Fig.1 The observation sites: (a)Northern Kyushu, Japan 2003~, (b)Nuevo Leon, Mexico 2005~ and (c)Southern Sulawesi, Indonesia 2006~



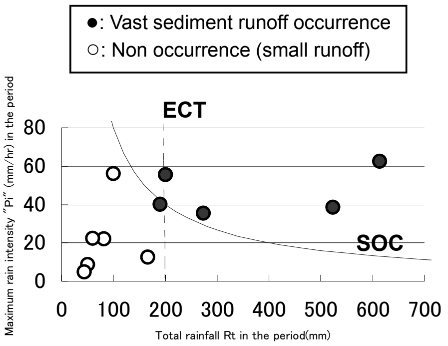
(a) Northern Kyushu, Japan (■:observation site), **(b) Nuevo Leon, Mexico** (●: observation site)



(c) Southern Sulawesi, Indonesia

Fig.2 Location Map of the Observation Sites

Here, Q: sediment runoff discharge, A: watershed area, M: function concerning with sediment deposit features on the upstream torrent or slopes (porosity, torrent bed slope gradient, sediment accumulation length and depth, cohesion), t: time, θ: torrent bed or hillside slope gradient, P: instant precipitation.



Maximum Rain Intensity Ri and Total Rain Rt in Fukuoka, Japan (○: no sediment runoff, ●: sudden sediment runoff occurred, —: CL Pic=8000/Rt, --: CL by ECT)

Fig.3 Critical Rain for Sediment Runoff in northern Kyushu-Fukuoka Japan (C=8000)

If the time integral is made over the rainfall duration,

$$\int(P\cdot\cos\theta)dt = Rt\cdot\cos\theta$$

Rt: total rainfall, Ri: rain intensity in 1 hour. Therefore,

$$\begin{aligned} Q/A/M/\cos\theta &= Ri \int(P\cdot\cos\theta)dt \\ &= Ri \cdot Rt \quad \cdots\cdot \quad (2) \end{aligned}$$

After all,

$$Ric\cdot Rtc = C. \quad \cdots\cdot \quad (3)$$

Hence, evaluating the variable "C" by the empirical way with field observation data, following equation are obtained for the critical line of sudden vast sediment runoff (Fig. 3~5).

$$RiCL = Ric = C/Rtc \quad \cdots\cdot \quad (4)$$

Along the torrents in our study sites (northern Kyushu, Nuevo Leon Mexico and Sulawesi Indonesia), sudden vast sediment runoff should happen in rain events which have the Ri~Rt combination over the RiCL curve given by equation (4). This formula matches the form of the equation derived from SOC that is prescribed by power function (Bak 1996, Hergarten 2002).

Besides, the soil moisture content along the torrent in northern Kyushu i.e. its riparian area is not affected by antecedent rainfall according to our field observation.

２. Theoretical Critical Standard based on the Elementary Catastrophe Theory (ETC) (Fig 3.)

The critical line is described adopting the "cusp type" catastrophe theory. Here, Catastrophe function F is given as equation (5) (Saunders 1980 etc.),

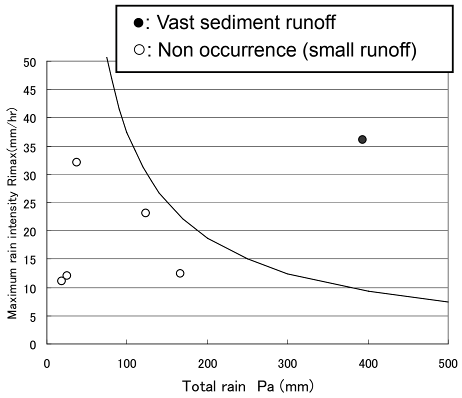


Fig.4 Critical Rain Curve for Sediment Runoff in Nuevo Leon, Mexico (C=3750)

$$F = (p^4)/4 - Rt \cdot (p^2)/2 + Ri \cdot p \quad \cdot\cdot\cdot\cdot \quad (5)$$

here p: probability of sudden runoff. The critical state is described with next equation.

$$\partial^2 F/\partial p^2 = 3p^2 - Rt = 0 \quad \cdot\cdot\cdot\cdot \quad (6)$$

Derived from (5),(6) and with empirical coefficient by observation,

$$Ric= 2828 - Rt^{(3/2)} \cdot\cdot\cdot\cdot \quad (7)$$

However, equation (7) can take impossible "Ri~Rt combination" such as Rt>0 at Ri=0. Therefore, the ETC is not suitable in this case.

3. Critical Standard for Landslides by the Maximum Cumulative Rain in Mexico

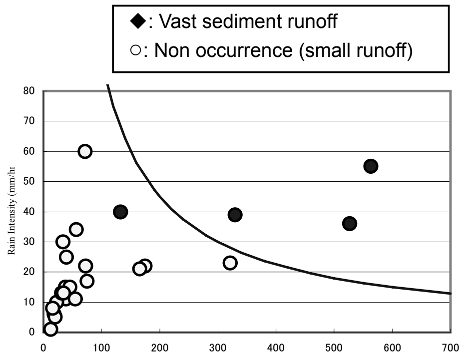
Through our field observation at our study site in Mexico, we found the soil moisture content seems to be affected by antecedent rainfall (Fig. 6). In this condition, it is needed to contemplate another method for the landslide warning in this area.

For the purpose, maximum cumulative rain is applied to the analysis (Hirano 1992,1995) such as Fig. 7.

In this analysis, the maximum cumulative rain (vertical axis in the figure) causing landslides that has minimum gap to the maximum rain curve without landslides can be the critical rain index (Fig.7) (Hirano 1992,1995).

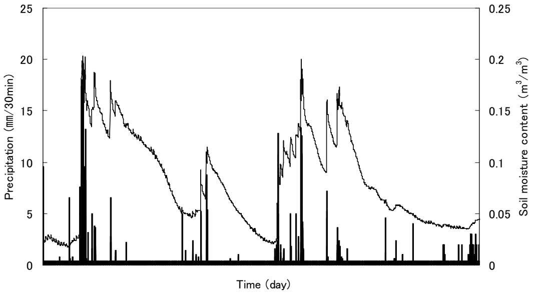
In this case, it is approximately 150mm (accumulating time is about 5 hours), judging from Fig.7.

Comparing to Kyushu, Nuevo Leons's site has high increasing rate and low decline rate of soil moisture content



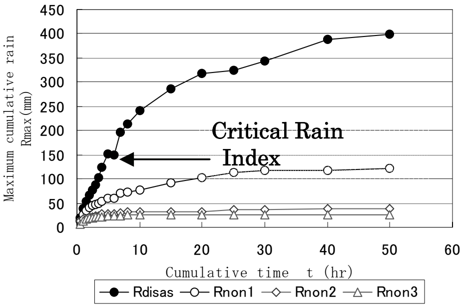
Relation between the Rain Intensity Ri(mm/hr) and the Total Rain Rt, Critical line (CL: Ric=9000/Rt) in Slawesh, Indonesia

Fig.5 Critical Rain for Sediment Runoff in South Sulawesi Indonesia (C=9000) (Hasnawir et.al. 2006)



Relation between Precipitation and Soil Moisture Content
(Canoas-Chipinque, Nuevo Leon, Mexico; bar:rain, solid line: moisture)

Fig.6 Relation between Rain and Soil Moisture Content observed in Nuevo Leon, Mexico



Maximum cumulative rain and cumulative time for critical standard analysis in Nuevo Leon, Mexico (Rdisas: rains inducing disaster, Rnon: rains without disaster)

Fig.7 Critical Cumulative Rain for Landslides in Nuevo Leon, Mexico

(Kubota et.al. 2007). With these observation results, it is necessary to make early warning in this area and mind the aftermath of the each rain event.

4. Conclusion

The critical standard rain for warning and evacuation in local area along the torrent can be given as formula (4) based on theoretical analysis.

According to the field observation results, the sediment runoff from torrent bed, torrent sides and shallow landslides in close vicinity of the torrent (which does not include large landslides) is not affected by antecedent rainfall in the site of northern Kyushu (Kubota et.al. 2007). Hence, formula (4) based on Rt and Ri is rather simple and handy than the other methods to provide the warning criteria.

On the contrary, in the other sites, it might be needed to examine the cumulative rain as well as soil moisture content dynamics by observation. Either way, it was proven in recent study treating "warning system by modified tank model" that antecedent rain don't have any practical impact on shallow landslides (Hioki et.al. 2008). Therefore, we believe the method discussed in the first chapter with formula (4) is indeed wieldy to embody in actual warning system.

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Beauty of the Valley of the Geysers: Before and After Landslide on June 3, 2007 (Kamchatka, Russia)

Yulia Kugaenko (Kamchatka Branch of Geophysical Survey of RAS, Russia)

Abstract. Kamchatka is a huge natural museum of volcanology; its "exhibits" are active and extinct volcanoes as well as different associated formations: geysers, fumaroles, thermal springs etc. Dangerous slope processes (landfalls, landslides) are rather frequent phenomena for present-day hydrothermal fields of Kamchatka. Landfall and landslide forms of different scale and age were recognized here. Thus big landslide on June 3, 2007 is not a unique phenomenon for the Valley of the Geysers. This natural catastrophe has strongly changed the Valley of the Geysers landscape: Geyizernaya River is dammed up by landslide depositions, as a result a new lake has been formed and a part of geysers has been destroyed. Nevertheless the Valley of the Geysers still remains one of the main objects of ecological tourism on Kamchatka.

The photos taken in the Valley of the Geysers in different years before and after landside on June 3, 2007 are presented in this report as an example of environmental impact of the landslide. The characteristic of the Valley of the Geysers as an object of UNESCO World Natural Heritage Site "Volcanoes of Kamchatka" is given. The main information on the landslide which occurred here on June 3, 2007 is briefly summarized.

The unique landscape complex of the Valley of the Geysers did not become less interesting for the visitors. A picturesque lake has appeared here, on the caldera slope now there are nearly vertical parts of dislocation plane (wall length - 800 m, height - about 150 m), one can see some other results of catastrophic landslide.

Keywords. Environmental impact of landslide, the Valley of the Geysers, UNESCO World Natural Heritage Site "Volcanoes of Kamchatka".

1. The Valley of the Geysers - world-famous object of ecological tourism

The Valley of the Geysers is located on the territory of Kronotskiy State Natural Biosphere Reserve. Since 1996 the Valley of the Geysers along with other special nature-conservative territories is included in UNESCO World Natural Heritage Complex Object "Volcanoes of Kamchatka".

The UNESCO World Natural Heritage Object consolidates six separate areas (special nature-conservative territories of the peninsula) with total square 3.8 mln hectares. Taken together they reflect practically all main volcanic landscapes of Kamchatka; at the same time each of them offers an outstanding individuality. In total the object "Volcanoes of Kamchatka" includes 30 active and 300 extinct volcanoes. The status of UNESCO World Natural Heritage Object seems to be very attractive; it gives opportunity for territory to get a number of advantages. One of them is the development of alternative kinds of nature management. In the first turn it is ecologic tourism which attracts resources from international funding sources. At present time development of ecological tourism is realized by The Global Environment Facility (GEF), in collaboration with the United Nations Environment Programme (UNEP).

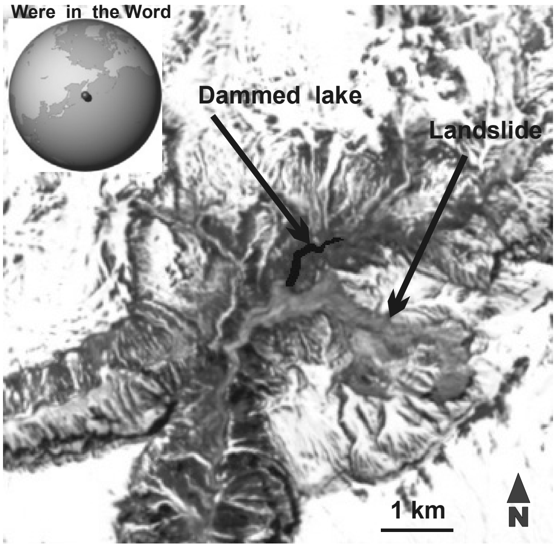

Fig. 1. Landslide on June 3, 2007, Buries Valley of the Geysers. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite captured this infrared-enhanced image on June 11, 2007, a week after the slide. The image shows the valley, the landslide, and the new thermal lake. (Allen, 2007)

2. The Valley of the Geysers - a unique geyser field

The Valley of the Geysers was found accidentally by geologist Tatyana Ustinova in 1941. The discovery of the Valley of the Geysers is considered as one of the most significant discoveries of XX century.

Geysers are rare, nearly unique type of thermal springs with regular flowing rhythm. Their activity resembles in appearance volcano's eruption in miniature. A column of boiling water and steam shoots up on several tens of meters; its suddenness, beauty and power create an amazing impression. Geysers were found only in areas of active of recently extinct volcanoes. Their existence is always connected with special geothermal conditions and presence of magma source.

Geyser regime is realized in narrow diapason of physical conditions. It depends on temperature and pressure as well as on structure of underground channels and correlation of different-temperature water flows, which feed the geyser. Even insignificant change in physical conditions leads to geyser's "dearth": it turns into thermal water spring of steam jet. Cases of geyser's "dearth" were observed in Iceland in connection with development of hydrothermal fields.

Geysers' vulnerability is determined by their closeness to areas of active volcanism and present-day geological activity. A part of geysers in the Valley of the Geysers on Kamchatka also suffered from the increase of geological activity (landslide on June 3, 2007 and a lake formation).

Fig 2. A series of hot springs known as "Vitrazh" ("Stained glass window") in the Valley of the Geysers.
Above: in autumn, 2005. Photo by I. Shpilenok
Below: on June 7, 2007. Water level in new lake is maximal. Photo by I. Delemen.

Concentration of big number of geysers within limited territory (geyser field) is still more unique natural phenomenon. At present four big geyser fields are known on the Earth: Rotorua in New Zealand, Yellowstone geysers in North America, geyser field Haudakalur in the south of Iceland and the Valley of the Geysers on Kamchatka. Isolated geysers exist also in Japan, Tibet and small square with geysers El Tatio is located in mountain area in the north of Chile. The Kamchatka Valley of the Geysers is a picturesque deeply cut mountain river canyon located in out-of-the-way area remote from main infrastructure of the peninsula. Its territory having totally about four square kilometers embraced (before landslide of 03.06.2007) more than 200 thermal springs including about 90 springs of geyser type; 20 of them - are big geysers. The peculiar feature of this geyser field is its landscape appearance: plenty of plants, picturesque valley flanks, variety of colors. Geological, hydrological and morphological features of the Valley of the Geysers along with high geodynamic activity of North-Western Pacific determine increased landslide risk of this territory.

3. Landslide, slope failure and mud-stone avalanche in the Valley of the Geysers

Giant mud-stone avalanche, formed by landslide, descended along Vodopadnyi Stream bed into Geiyzernaya River on June 3, 2007 in the Valley of the Geysers.

Short characteristic of disaster:

Location

The Valley of the Geysers, Kamchatka, Russia (54.44 º N, 160.14 º E)

Date of Slide

June 3, 2007

Size of Slide

Length: 2 km; Width: 200-400 m; Depth: 5–60 m;
Area: 2 km^2; volume: from 8-15×10^6 m^3 to 20 ×10^6 m^3.

Damages

The landslide by lucky chance did not cause human victims. Nevertheless helipads, bridges and household buildings were crushed or partially destroyed. The debris avalanche stopped only in one meter from Visit Center Building of Kronotskiy Reserve. Several beautiful geysers lost forever.

Topographic and Geologic Conditions

The Valley of the Geysers confines to eastern edge of vast complicatedly arranged Uzon-Geyzernaya volcano-tectonic depression elongated in WNW direction. Uzon-Geyzernaya volcano-tectonic depression represents a failure caldera bordered by ring fault - downdip block of general north-western strike. The fault is manifested by scarp in present-day relief. The visible amplitude of displacement along the fault - 300-400 m. The depth of upper edge of supposed magma source beneath the caldera and its diameter are estimated as 7-8 km and 10 km, correspondingly. The Uzon-Geyzernaya volcano-tectonic depression area belongs to Eastern volcanic belt of Kamchatka. It is connected with crossing knot of major faults with north-eastern and latitudinal strikes. A network of faults, oriented in concentrically way around Uzon-Geyzernaya depression was also distinguished. The site area is characterized by steep relief. Thickness of lacustrine sediments destructed by Geysernaia River is about 300 m.

On June 3, 2007 process of gravitational failure and downward propagation of the originated flows lasted about 2.5 min. Complicated multiphase character of failure characterized the landslide in the Valley of the Geysers. According to rocks displacement rate it was a rapid landslide and thus the most dangerous one. The flow rate reached 30-40 km/hour. Three big blocks (ridges and their parts) broken away from caldera slope came down successively. Landslide massif integrity was broken during the movement. The failure on first stage led to mudflow origination due to high watering of the rocks; this mudflow pulled up the trees by the roots on its way. The second stage despite the fact that there was a lot of snow in the moving mass (up to 15-20%) is considered as dry stone avalanche typical for such failures. The debris avalanche of the second phase stopped only in one meter from Visit Center Building of Kronotskiy Reserve; before that the avalanche crushed two helipads and several economic buildings. The third stage of the failure - dry rock landslide characterized by presence of huge rock blocks with linear dimensions up to 10 m and more.

Fig. 3. Pre and post landslide view of the middle part of the Valley of the Geysers. Photo: N.Smelov, I.Abkadyrov and S.Gorshkov

4. Main landslide consequences for environment in the Valley of the Geysers.

The catastrophe has changed everything in the Valley, in some places drastically. Something new appeared, something may restore with time, something is lost forever.

1. A new character appeared in the Valley is mud-stone avalanche, it even became the integral part of landscape. The body of slide consists of debris of mud shale with size ranging from 5-meter rocks to small crushed stones, a mellow water-saturated mass, in which it is easy to fall through waist-deep.

2. A natural rock-fill dam with length about 300 m, height reaching 50-60 m and width from 40-60 m in the most narrow place of the river valley and up to 200-250 m in the widest place originated.

3. A dam lake with length about 2 km appeared. During first days after the catastrophe the water level in the lake rose on 30 m, but later on Geiyzernaya River washed out the upper part of the dam, water level in the lake lowed up to 20 m mark and practically became stabilize.

4. Significant part of the geysers was buried by the avalanche and flooded by originated lake. But the rest geysers remain active. A part of geysers and thermal springs appeared on the surface after water level fall in the lake and recommenced their activity.

5. On the rocky surface of the avalanche some new lakes appeared. Some of them are warm and suitable for bathing.

6. Some impact of landslide upon insect biodiversity was registered, but negative profit is not significant.

Conclusions

The events which occurred in the Valley of the Geysers on June 3, 2007 should not be considered as ecological catastrophe. It is a natural process, an element of geological evolution of the territory. This process introduced certain additions to landscape originality of UNESCO World Natural Heritage Object "Volcanoes of Kamchatka".

The unique landscape complex of the Valley of the Geysers did not become less interesting for the visitors. A picturesque lake has appeared here, on the caldera slope now there are nearly vertical parts of dislocation plane (wall length - 800 m, height - about 150 m), one can see some other results of catastrophic landslide. Lakes origination is observed on the avalanche flow surface.

The reorganization of surface hydrothermal system regime proceeds at present time in the Valley of the Geysers; abrupt alterations of the dam lake level activated further development of landslide processes on the Valley slopes.

The Valley of the Geysers became even more interesting from the scientific point of view. The nature gives investigators a unique possibility to observe and study a wide spectrum of present-day geological processes caused by natural disaster on the geyser field.

Acknowledgments

Author wishes to thank everybody who provided photos and information for this report. In 2007-2008 the investigation of the Valley of the Geysers were supported by Russian Fond of Basic Research.

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Geodynamic Processes as the Risk Factor of 3 June 3 2007 Landslide in the Valley of the Geysers (Kamchatka, Russia)

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Abstract. It is well-known that Kamchatka represents one of the most geodynamicaly active regions of the World. But along with it, its territory is characterized by wide variety of natural hazards; many of them initiate or significantly increase occurrence probability of the others. In particular, the earthquakes initiate tsunamis, accompany or forestall volcanic eruptions, activate slope instability processes such as collapses, landslides and avalanches.

The Valley of the Geysers area is one of the most hazardous on Kamchatka due to intensive development of landslide processes within its territory. The study of landslide generating factors is not less important than investigation of landslides themselves. In this study it is necessary to regard the whole complex of processes, controlling the slope instability development: its geological structure, relief, recent tectonic motions, seismic and volcanic activity of the region, climate and meteorological data, geological, geothermal and geocryology conditions, vegetation and soils, economical activity.

Weight of geodynamic factors in estimation of landslides and landfalls risk significantly increases in regions with high seismic and geodynamic activity, on Kamchatka particularly. The geodynamic risk factors for landslide which occurred on June 3, 2007 in the Valley of the Geysers are presented in this paper.

Keywords. Risk factors, geodynamic processes, The Valley of the Geysers, seismicity, hydrothermal activity, Kamchatka.

1. The Valley of the Geysers in Kamchatka

The Valley of the Geysers is one of the main points of interest in the World. Its territory having totally about four square kilometers embraces more than 200 thermal springs including about 90 springs of geyser type; 20 of them - are big geysers. The Kamchatka Valley of the Geysers is the only one geyser field in Asia. It is a picturesque deeply cut mountain river canyon located in out-of-the-way area remote from main infrastructure of the peninsula. Geological, hydrological and morphological peculiarities of the Valley of the Geysers control both high geodynamic activity and increased landslide risk of this territory. The Valley of the Geysers belongs to Kronotskiy State Natural Biosphere Reserve; it is included in the UNESCO World Natural Heritage Complex Object "Volcanoes of Kamchatka". The Object represents biological and landscape diversity of the Kamchatka Peninsula.

The strategy of ecological tourism development in the Valley of the Geysers and other nature-conservative Kamchatka territories is being elaborated presently in frames of Joint Project of United Nations Development Program (UNDP) & Global Environment Facility (GEF) called "Conservation of Kamchatka Biological Diversity".

2. Natural disaster on June 3, 2007 in the Valley of the Geysers

A natural disaster - big landslide with volume estimated from 8-15×10^6 m^3 to 20 ×10^6 m^3 - occurred on June 3, 2007 in the Valley of the Geysers (Leonov, 2007, Gordeev et al., 2007, Pinegina et al., 2008, Kugaenko, 2008). Complicated multiphase character of failure characterized the landslide in the Valley of the Geysers. According to rocks displacement rate it was a rapid landslide and thus the most dangerous one. The flow rate reached 30-40 km/hour. The height of displacement wall was up to 150 m and its length was about 800 m. Giant mud-stone avalanche, formed by landslide, descended along Vodopadnyi Stream bed into Geisernaya River. A natural rock-fill dam with length about 300 m, height reaching 50-60 m and width up to 250 m in the widest place originated. A dam lake with length about 2 km appeared. Significant part of the geysers was buried by the avalanche and flooded by the lake. The landslide by lucky chance did not cause human victims. Nevertheless helipads, bridges and economic buildings were crushed or partially destroyed. The debris avalanche stopped only in one meter from Visit Center Building of Kronotskiy Reserve.

The origination of big landslide of June 3, 2007 was not a unique event for the Valley of the Geysers. Landslide forms of different age and scale were discovered here. Dangerous slope processes (slope failures, landslides) are the usual phenomena on the present-day hydrothermal fields of Kamchatka.

Fig.1. Overall picture of the Valley of the Geysers photographed from the helicopter on June 6, 2007, with the peak level of water in the dammed lake. On the background: eastern rim of Uzon-Geyzernaya caldera and the most landslide-dangerous areas of slope. Photo by A. Nechaev.

3. Risk as probability of losses

The central place in modern strategy of natural hazards control belongs to development of scientific methods for natural risks estimation.

Natural risk is a quantitative characteristic, probabilistic assessment, characterizing probability of material damage and irretrievable losses caused by development of different dangerous processes. The procedure of risks estimation includes fulfilling of a number of successive operations, namely: identification of hazard, hazard forecasting, estimation of vulnerability, risk estimation. Application of risk conception converts danger into category of measured quantities. To calculate risk estimations in frames of some mathematic model it is necessary to fill it with objective data on specific territory.

Risk analysis for the object (region, territory, and infrastructure) begins with identification of natural hazards. To estimate the risk information on different factors which determine it should be used.

Risk factors are represented by conditions, which does not serve as immediate causes of unwanted results, but increase probability of their origin.

4. Geodynamic factors of landsliding

Geodynamics is a science about deep forces and processes arising due to evolution of Earth as a planet and controlling movements of matter and energy inside the Earth. The geodynamic processes which influence on landslides origin include: present-day earth crust motions, seismicity, volcanism, hydrothermal and geothermal activity. The information on geodynamic processes in the Valley of the Geysers is not full due to absence of basic local observation systems (GPS and seismic networks).

5. Rates of present-day regional neotectonic motions

The mobile belts with high rates and gradients of neotectonic motions are distinguished among mobile structures of continents and oceans. The Kurile-Kamchatka Island Arc is elongated on 2500 km from Hokkaido Island to Northern Kamchatka. The general features of this system are:

- shape of gentle convex (in direction to the ocean) arc;
- lengthwise, i.e. north-eastern, zonality of main structural elements;
- volcanic belt arranged in a complicated manner;
- narrow deep-water trench before the arc front,
- a belt of earthquake hypocenters concentration inclined under the arc, which can be traced deeply into the mantle (Wadati-Zavaritskiy-Benioff seismic focal zone).

Kamchatka Peninsula lies in the north-western part of convergent junction of Eurasian and Pacific plates. The line of lithosphere plates' contact is manifested in the bottom relief by narrow deep-water (up to 8 km) Kamchatka Trench. The Pacific Plate which moves here to the north-west with rate 8-9 cm/year goes under Kamchatka (nearly immovable continental margin of Eurasian Plate). According to GPS data Kamchatka also moves to the north-west but very slowly (with rate less than 1 cm/year). Thus the rate of lithosphere plates' relative convergence here is about 8 cm/year; it determines the subduction rate as well (Minster and Jordan, 1978, Levin et al., 2006).

6. Tectonics and main faults

The Valley of the Geysers confines to eastern edge of vast complicatedly arranged Uzon-Geyzernaya volcano-tectonic depression elongated in WNW direction (Leonov et al., 1991). Uzon-Geyzernaya volcano-tectonic depression represents a failure caldera bordered by ring fault - downdip block of general north-western strike. The fault is manifested by scarp in present-day relief. The visible amplitude of displacement along the fault - 300-400 m. The depth of upper edge of supposed magma source beneath the caldera and its diameter are estimated as 7-8 km and 10 km, correspondingly.

The Uzon-Geyzernaya volcano-tectonic depression area belongs to Eastern volcanic belt of Kamchatka. It is connected with crossing knot of major faults with north-eastern and latitudinal strikes. A network of faults, oriented in concentrically way around Uzon-Geyzernaya depression was also distinguished (Belousov et al., 1984, Masurenkov, 1991).

North-eastern disjunctive dislocations are mainly represented by normal faults with south-eastern low side. Length of separate faults varies from 100-200 m to 1 km and more. Amplitude of vertical displacements varies from several meters to 50 m. The network of north-eastern dislocations in the area reflects large zone of earth crust extension; it has width 20 km and stretches far away from area boundaries. It was named as Vulkanicheskiy Razdvig (Volcanic Gapping). This structure is regarded as deep magma- and fluid-conducting fault of gapping type.

Latitudinal disjunctive dislocations are most distinctly mapped in the central part of the area lying within a belt with width 5-6 km. The belt strike coincides with long axis of Uson-Geyizernaya depression. The length of separate dislocations reaches 4 km and more. Amplitude of vertical displacements varies from first meters to 50-70 m. Total amplitude of downdip along the normal faults system of inner depression block reaches 200 m. Latitudinal faults in the described area trace regional latitudinal Uzono-Valaginskiy fault, which is a deep shear.

Arcuate disjunctive dislocations are oriented concentrically relatively the center of volcanic-tectonic depression and have character of fractures or low-amplitude normal faults. A system of inclined circular dykes was also distinguished; they apparently inherit a system of arcuate fractures. Time of the arcuate disjunctive dislocations system origin in general corresponds to the epoch of caldera forming, i.e. to the second half of Middle Pleistocene.

Two main periods of increased tectonic activity were established. The first period relates to the Middle Pleistocene. The displacements along north-eastern and arcuate dislocations are observed at that time. The close connection between faults origination and magmatic activity is also noted. The second period of active tectonic motions in the area relates to the beginning of Late Pleistocene when the system of latitudinal fractures and normal faults originated and the system of arcuate dislocations partially renewed. The normal faulting led to subsidence of significant part of depression on depth more than 200 m.

It is not improbable that tectonic motions along these systems occurred in Holocene as well.

7. Volcanic activity and present-day local earth crust motions

The Kikhpinych Volcano rises above eastern flank of Uzon-Geyizrnaya depression. The Valley of Geysers conjugates to its south-western slope; its heat supply is connected with water flow uprising from area of volcanic massif magma source (Braitseva et al., 1991).

The Kikhpinych Volcano includes several different-nature and different-age edifices. Its base is the Staryi Kikhpinych Volcano; it was formed before stage of caldera forming in the Eastern volcanic belt (Middle-Upper Pleistocene). The youngest cone was formed about 1400 years ago and is considered active until present time. Its last and the strongest explosive-effusive eruption occurred about 600 years ago. The origination of effusive dome about 400 years ago is connected with the final Kikhpinych eruption.

At present time active Kikhpinych Volcano is characterized by weak fumarole activity and very fresh lava flows. The forecast of future activity of the volcano is ambiguous. There is no information on present seismic activity of this volcano; observations were not conducted here.

The active character of recent earth crust motions in the Kikhpinych Volcano area is an unexpected result (Lundgren, 2006). Satellite interferometry data (InSAR) show that in 2000-2003 the rising on 15 cm was recorded here. The modeling fulfilled by authors of publication (Lundgren, 2006) connects the cause of motion with crust magma source (Belousov et al., 1984). Time irregularity of the rising process was noted: in 1999-2000 and in 2004 InSAR data did not reveal any geodynamic activity. The rising process was not accompanied by essential (on level of regional network registration) seismicity. Apparently weaker seismic events took place here.

The eastern caldera slope rise should be related to one of the determinative factors, which accelerated the process of landslide development during last decade. Possibly this process is connected with hidden increase of volcanic activity: with Kikhpinych Volcano or surface magma source of Uzon-Geizernaya volcanic-tectonic depression.

8. Hydrothermal activity

Present-day hydrothermal activity is observed in Geyizrnaya River valley and in its upper reaches near south-western foot of the Kikhpinych Volcano. Geysers and other forms of hydrothermal activity represent surface manifestations of big hydrothermal field - Geyizernaya. The supposed feeding area of this hydrothermal system is the Kikhpinych volcanic massif (Leonov et al., 1991).

Hydrothermal model of Geyizernaya system represents a upwelling water flow from magma source area of Kikhpinych volcanic massif; it is formed by local infiltration waters and waters of regional groundwater runoff which acquire temperature about 250 °C at certain levels. On the way to the surface they cool adiabatically with loss of vapor and mix with cool groundwater; thus lateral hydrotherm flow with temperature about 180 °C originates. Its main unloading occurs in undercurrent of Geyizrnaya River. Total unloading of thermal waters consists 250-300 l/sec.

The results of landslide investigation show that heated rocks were involved in failure; earlier they composed the mountain massif. *One of the main reasons of landslide is weakening of semi-rock pumice soils due to their steaming during hidden unloading of hydrothermal system* (Pinegina et al., 2008).

9. Seismicity

The beginning of World instrumental seismology relates to the end of XIX century. Detailed seismologic observations on Kamchatka were organized in 1961-1962. The available instrumental data on Kamchatka seismicity form the information base for identification of seismic factor danger in development of slope failure process in the Valley of the Geysers.

Long-term estimation of seismic danger on territory is fulfilled on base of general seismic zoning data (Ulomov et al., 1999). In accordance with probabilistic seismic zoning map the Valley of the Geysers belong to the zone, where intensity of oscillations caused by big earthquakes may reach 9 units.

Seismic effect may be considered as two independent factors having an influence on landslide forming and development processes:

1. Each separate earthquake. Time of influence may be from several seconds to several tens of minutes. During this time seismic oscillations contribute to mechanic destruction of the slope. Along with direct effect of seismic accelerations on the value of destructive forces the soil oscillations may cause decrease of its strength along surface with resistance to slip. Dynamic shear strength of some materials is much less than static one. If there is a water-saturated layer separating landslide body from main massif, cyclic deformation may cause local effect of soil dilution. So trigger effect is possible: earthquake directly initiates landsliding on slopes, which exist in conditions close to instability.
2. Regional seismic process. It exerts influence on development of slope instability during whole time of landslide forming: from several years to several decades. This process has destructive effects on the slope: it activates origination and growth of fractures, changes fracture-pore space configuration and thus promote gradual penetration of cool and geothermal waters into rock massif. Big enough earthquakes may cause intensive earth's crust deformations in zones of present-day faults. In such a way seismic impact act as initial element of "domino effect" causing further chain of destructive events ("domino effect" means that some insignificant change entails linear series of other changes).

During last century the Valley of the Geysers three times suffered quakes with intensity 7-8 units (1923, 1927 and 1959) and three times - with 6 units (1952, 1971 and 1997) according to macroseismic intensity scale MIS-64. The quakes were connected with the greatest (within period of instrumental observations) regional earthquakes with magnitudes M=7.5-9.

Shallow-focus seismic activity of low energy level is typical for Uzon-Geyizernaya depression area. Regional network has recorded several surface earthquakes from this area during period of detailed seismologic observations. Irregularity of events distribution in time attracts one's attention; it points on time-varying character of the process. Earthquake with M=3.2 occurred after 30-year period of "silence" (1968-1998); it was felt in the Valley of the Geysers as "very high-frequency one" (according to the report of eyewitnesses). A series of events apparently connected with local geodynamic stirring up begins with this quake. Due to restricted technical abilities of the regional network only the most srong earthquakes are registered, but existence of local earthquakes in this area was demonstrated even on level of its sensibility; some of these earthquakes could be felt.

The occurrence of local earthquakes in the Valley of the Geysers area was confirmed by short-term instrumental observations of temporal seismic station conducted here in the end of 2007.

There are some data on felt earthquakes from Valley of the Geysers area recorded during last days before the landslide. One communication is directly from Valley of the Geysers. Two others came from close to it places, from members of Kronotsliy Reserve staff, being there at that time. Small (I=2-3) seismic events on May 30 - June 1, 2007 were reported. It is possible that these small earthquakes exerted influence on final stage of June 03, 2007 geological catastrophe preparation.

According to available data the process of landslide and slope instability development lasted for a long time - during several decades and even centuries or longer. In particular, the tectonic fracture along which the dislocation of block of landslide-forming rocks occurred can be seen on airphoto images of 1973 (Pinegina et al., 2008). Investigation fulfilled in 1974 showed that fracture looked fresh, contained small subsidence craters; it justifies recent motion activity and fracture opening. This fracture activity could be connected with seismic impact of earthquake in 1971 (Mw=7.5, I=6). But its origination could occur much earlier, for instance, at the moments of more intensive massif shaking (1923, 1927, 1959, I=7-8).

In calculation of landslide risk (as natural catastrophe) each seismic impact increases its probability because it influences on hidden mechanisms of watering in base of landslide body. It is also known that hydrothermal systems are very sensitive to seismic impact (Manga and Brodsky, 2006). It may be supposed that inner configuration of the Valley of the Geysers hydrothermal field is also sensitive to seismic effect. Let us generalize long-term influence of seismic process on development of the Valley of the Geysers landslide in respect of main collapse reason - massif weakening due to hydrothermal activity. Seismicity may be regarded in context of multi-step "domino effect" acting by scheme:

earthquake → seismic influence on landslide body, cyclic deformation → modification of fracture-pore space configuration → modification of hydrothermal field configuration → hydrothermal massif steaming → weakening of cohesion in some landslide base layer → slope collapse, landslide.

Conclusion

The above presented information is not only of purely scientific interest and relates not only to landslide on June 3, 2007. All listed above geodynamic processes represent the factors which increase risk for other landslide bodies in the Valley of the Geysers as well (their presence and development are supposed, (Pinegina et al., 2008). Thus geodynamic processes are one of the main risk factors of the evolution of slope instability in the Valley of the Geysers.

Local seismic-GPS network in the Valley of the Geysers area must be organized in addition to regional observation system which is aimed on local seismic monitoring and investigation of modern local earth's crust motions. Local microseismicity may be considered as informative factor in aspect of rock massif destruction and the progress of landslide evolution (slope failure).

The Valley of the Geysers is considered as an object of UNESCO World Natural Heritage and ecological tourism. In this respect the estimation of landslide danger of territory taking into account all risk factors should be performed in frames of UNDP/GEF Project. One of the expected results of these works should be the instructions and recommendations for tourist industry management in conditions of landslide risk and on special nature-conservative territories. Traditional landslide protective measures are inapplicable in the Valley of the Geysers, because it is a part of reserve and special nature-conservative object.

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CHASM – The Model to Predict Stability of Gully Walls Along the East-West Highway in Malaysia: A Case Study

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Abstract. The Combined Hydrology and Stability Model (CHASM) was used to predict the stability of gully walls along the East-West highway in Malaysia. The gully geometry for different gully size and shape along the East-West highway was selected for detailed modelling of gully sidewalls. Modelling profiles of the gully sidewall for big gully, small gully, V-shape and U-shape gully were established based on their steepest sidewall angle and their maximum, minimum and common depth. The steepest angle used to model a big gully was 61° with depths of 2 meters, 4 meters and 20 meters while for the small gully the steepest angle 49° with depths of 0.5 meter, 0.8 meter and 8 meters. For a V-shape gully, the steepest sidewall angle used was 49° with depths of 0.5 meter, 2 meters and 20 meters. In the case of U-shape gullies, the steepest angle used was 70° with a depth of 2 meters, 4 meters and 14 meters. Results showed that the sidewall of a big gully is less stable than that of a small gully. A small gully is very stable even at a 50% water table. In terms of gully shape, the sidewall of a U-shaped gully generally is less stable than V-shaped gully.

Keywords. Stability of gully sidewalls, gully size, gully shape, modeling gullied slope.

1. Introduction

It has long been known to geomorphologist and engineers that gullying creates problems to cut slope stability (Beaty, 1950; Yap, 1985 and Bocco 1991). There has been much evidence to suggest that over-steepening of cut slopes resulting from severe gully erosion has caused slope failures in residual soils. Unfortunately, detailed studies on this aspect are overlooked and not fully understood. Under heavy rainfall in the tropics with slope materials conducive to gully erosion, severe gullying will continue to develop and problems of gullied slope failures will increase. The assessment of the stability of slope with gullies lies on the ability to identify the potential mechanisms controlling failure. In the tropics, one of the dominant controls on mass stability is the soil hydrological condition and in particular its variation with time response to storm events. A methodology that allows the incorporation of dynamic hydrology and soil conditions in stability assessment is the Combined Hydrology And Stability Model (CHASM) developed by Anderson and Lloyd (1991).

Gully stability has been approached in this investigation from a soil mechanics and hydrological point of view by using the Combined Hydrology and Slope Stability model (CHASM). These views are used because the relative importance of mass instability would be a function of the properties of the slope materials where gully initiate or grow. Mass instabilities are closely related to a high soil water content. In this sense, it is the amount of rainfall and the antecedent moisture which may be the critical climatic parameter to be included in gully stability research (Bocco, 1991). In the study of gully erosion, mass instabilities have been overlooked compared with fluvial processes. In this paper, mass instability was investigated in terms of gully size (sidewall and headwall) and gully shape.

2. Method of study

2.1 Site investigation

Most of the data in this study were collected from site investigation or field works and laboratory analysis, as data for cut slope stability analysis in the tropics, particularly Malaysia, is very limited. According to Bromhead, an essential step in the detailed investigation of slope stability is to make a visit to the site (Bromhead, 1986). Fredlund (1984) in his review of limit equilibrium methods of slope stability analysis suggested that more attention should be given to site investigation so that a better accuracy of the parameters required for such analysis could be achieved. Therefore, site investigation is necessary to record all the conditions of stability for gullied slopes in the field. In this study, a total number of 100 gullied cut slopes were surveyed over seven months period. Parameters such as gully geometry (shape, depth, width, sidewall angle, headwall angle and length), slope geometry, slope material, water catchment, drainage, shear strength, soil permeability, moisture content and rainfall were measured and recorded on the 'Inventory Data Collection Proforma' for each of the gullied slopes.

2.2 Modelling approach

The usual approach to studying the stability of gullied slopes is to determine the mechanisms governing the stability of the gully sidewall, gully headwall and overall stability of gullied slope and the thresholds that initiate gully wall failures in residual soil through modeling. In the process of gully erosion, a large amount of soil in the channel will be eroded during heavy rainfall leading to steeper gully sidewalls and headwalls which can result in gully walls collapsing.

The results obtained from the field work and analysis enable the most common gully geometry for different gully size and shape along the East-West Highway to be selected for detailed modeling of gully sidewalls. Modeling profiles of the gully sidewall for big gully, small gully, V-shape and U-shape gully were established based on their steepest sidewall angle and their maximum, minimum and common depth. The steepest angle used to model a big gully was 61° with depths of 2 meters, 4 meters and 20 meters while for the small gully the steepest angle 49° with depths of 0.5 meter, 0.8 meter and 8 meters. For a V-shape gully, the steepest sidewall angle used was 49° with depths of 0.5 meter, 2 meters and 20 meters. In the case of U-shape gullies, the steepest angle used was 70° with a depth of 2 meters, 4 meters and 14 meters.

A series of columns consisting of cells of defined width, depth and breadth are drawn and used to represent gully sidewall of different gully size and depth. Small column widths of minimum 0.25 meter are used for shallow gully depth with minimum cell depth of 0.5 meter. Defined water table of 0%, 25%, 50% and 75% of the overall modelled slope height were also given to the profile. The steepest angle of gully sidewall was determined based on the 'Steepest Side Slope Angle Model' proposed by Anderson and Harun (1991). Figure 1 illustrates an example of the gully sidewall profile and the cell arrangement for 61° sidewall angles and 4 meters gully depth which represent the most common big gully along the East-West highway. The dimension of each cell in this profile is 0.25m × 0.5m × 1m (width × depth × breadth).

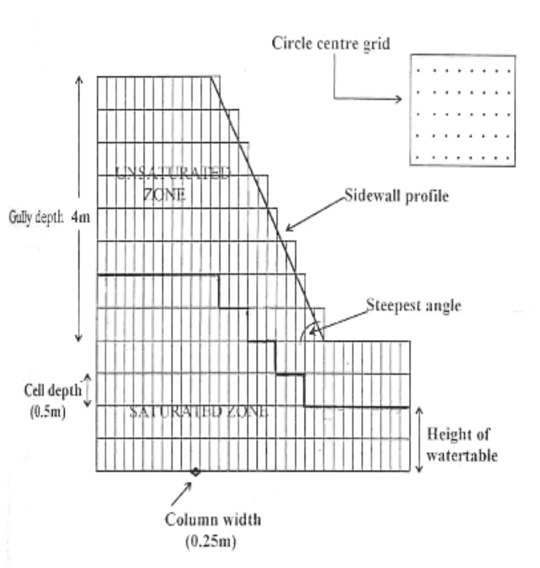

Fig. 1 Example of Gully Sidewall Discretisation for 4 meters Gully Depth

2.2.1 Combined hydrology and stability model (CHASM)

The Combined Hydrology and Stability Model (CHASM) was used to assess the stability of gully walls. CHASM is a 2-dimensional model that contains both hydrology and stability components. The Combined Hydrology and Stability Model was programmed to include a factor of safety for various 'loading' levels, rainfall amount, soil conditions, soil strength and gully depth and then used to compute different gully sizes and shapes at different depths to obtain a better understanding of the range of mechanisms that can lead to the collapse of gully walls. The output format of CHASM was designed such that the factor of safety incorporated in the soil strength and the value of failure weight in kilograms is printed for each hour of the simulated period. The output also was designed to give the minimum factor of safety at the end of each simulation period.

Parameters entered for each gully sidewall profile are hours of simulation, iteration period, detention capacity, starting and ending times of rainstorms, amount of hourly rainfall, number of soil types, permeability, saturated moisture content, saturated bulk density, unsaturated bulk density, values for c' and ø' value, number of points on the suction moisture curve, moisture suction, number of cells in each column of the sidewall profile, number of saturated cells (based on the assumed water table), column width, column breadth, cell depth, maximum suction, soil type, height of water table, method of analysis starting point of (x, y) co-ordinates grid of the failure circle, increment of the grid failure circle in both the x and y directions, number of x and y increments, starting point of circle radius, radius increment, number of surface points of gully wall profile, and co-ordinates of the gully wall profile (x, y). The initial search for the critical failure surface is made at first by using a coarse resolution circle centre grid and radial increment as suggested by Othman (1989). The increment of the circle centre in the x and y direction and the radial increment for each centre within the specified grid are reduced to the minimum value of 0.25 meter depending on the gully profile. Based on the parameters collected, the model was run to investigate the stability of gully sidewalls.

3. Result and discussion

3.1. Stability gully sidewall of different gully size and shape

The results showed that small gullies are very stable even at 50% water table. With less rainfall, the sidewall is very stable with 0% and 25% water table even at low soil strength values, high infiltration rates and maximum depths. However, with higher rainfall events, small gullies with higher infiltration rates and low shear strength are not stable. Big gullies are unstable at maximum depths even at 0% water table. The stability is lowest when rainfall is high and shear strength values are low. Thus, priority attention should be given to big gullies especially those that are deep and occur on slopes with low shear strength values. Precaution and attention should be given to small gullies only when the slope material has a very low shear strength and a high infiltration rate. On the whole, big gullies are at greater risk of slopes instability especially on the East-West Highway. Once gullies become big their impact on mass instability is more dominant and accelerated widening is likely to occur.

The results also showed that the sidewall of U-shaped gully is less stable than V-shape gully. Both V and U sidewall failed if the shear strength is low and permeability is high at maximum and common gully depth with higher rainfall. In both cases (V and U sidewalls), the factor of safety decreases with increasing water table, permeability and rainfalls. A closer look at Figure 2 shows that both U and V-sidewall with minimum gully depth are stable at the higher shear strengths. The V and U-sidewalls are also very stable with less rainfall for shallow gully depth.

3.2 Slip surface failure on gully sidewalls based on modeling

Based on analysis of slip surface failure on gully sidewalls obtained from modeling, cut slope failures subject to gully erosion tend to fall into two main classes: shallow failure processes and deep-seated modes of failures. Shallow failures occur on small and big gullies with low cohesion values and shallow gully depth (gully depth less than 4 meters). Deep-seated failures occur on deep gullies in areas of intense erosion as the intense erosion can cause the gully to become deeper by lowering its channel base. These conclusions are consistent with the work done by Hutchinson (1973) on the London clay cliffs who found that shallow slide movements take place in response to moderate rates of erosion and that cyclical, deep-seated landslides take place in areas of intense erosion.

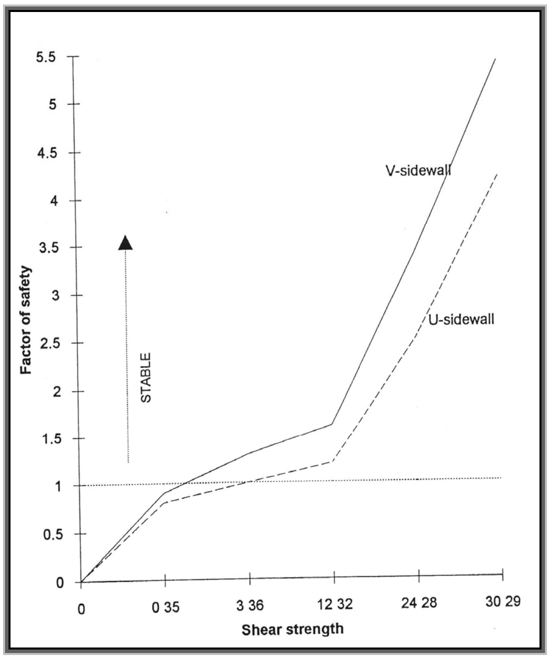

Fig. 2 Factor of Safety against Shear Strength for 'U' and 'V' Sidewall

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4. Conclusions

Combined Hydrology And Stability Model (CHASM) has the potential for identifying the stability of gully walls of different sizes and shapes. U-shaped gully is less stable than V-shaped gully. Generally, the stability of gully sidewall is critical for big gullies. Thus it is essential to prevent gullies from getting bigger as this will have a significant impact on slope stability. A small gully is very stable even at 50% water table. The factor of safety of gully sidewalls is more sensitive to rainfall. With less rainfall, the sidewall is very stable with 0% and 25% water table and even at low soil strength values, high infiltration rates and maximum depths. Hence in any remedial design of cut slopes in tropical residual soils the design must include measures which can stop gullying from further growing.

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Landslide Mitigation and Risk Reduction Practice in Korea

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Abstract. This paper describes the characteristics of natural landslides and cut-slope failures in Korea and discusses the current situation regarding slope management. Problems associated with investigation and designs have been identified through a review of standards and reports on cut-slope construction in Korea. It is concluded that many failures can be attributed to poor understanding of geological factors and related conditions. The need for improved standards for slope construction and maintenance in Korea and for an integrated slope management system are presented.

Keywords. Landslides, cut-slope failures, slope failures, Korean slope management

1. Korean Conditions

South Korea is a peninsula located in the middle part of eastern Asia and situated between China and Japan, covering an area of 99,600km^2. The capital is Seoul and the population is about 50 million. In general, the peninsular is mountainous (about 70% of the total area) but rarely exceeding 1,200m in altitude. The climate of Korea has four distinct seasons. The mean annual temperature is 10°C with a maximum of 30°C in summer and minimum of -15°C in winter. The average annual rainfall is about 1,200mm, 60% of which generally falls during the summer period from June to August. Vegetation cover is about 70% of the total area of Korea.

The geology of Korea is complex with rocks from Pre-Cambrian to Recent although there are no known glacial deposits. The predominant soils are derived from *in situ* weathering. Regardless of rock type, the depth of weathering is generally limited to a few metres (Lee & deFreitas 1989). The rate of erosion, associated with seasonal heavy rainfall, ranges from 15 to 20mm per year on hillsides with inclination of 20^o to 30^o (Lee 1987).

2. Characteristics of Slope Failure

Most failures in Korea, in both natural and man-made cut slopes, are triggered by intense rainfall during the three month period from July to September. There is no recorded case of slope failure triggered by earthquakes (Lee 1993, 1994). Risk to life and property is increasing as more development takes place on sites close to steep natural slopes in mountainous areas. On average 60 lives, damage to property valued at 500~1,000million US dollars and considerable traffic disruption can be attributed to slope failures annually in Korea. This is a high proportion of damage from all natural disasters (10 to 20%). The scale of damage due to landslides has been rapidly increasing in recent years in parallel with urban growth and transport infrastructure.

Natural slope failures include debris flows and debris avalanches and these occur generally in hill slopes inclined at 20^o to 40^o. Most hill slope failures are relatively small scale with run out length of up to 20 to 30m, and width less than 10m. Failure depth is typically less than 1m (Fig. 1a). Landslides often occur along valley sections dipping at 30^o on average and with various lengths from 100 to 500m. Considerable damage is associated with erosion along such watercourses (Figs. 1b and c) (Lee 1987, 1988, 1994, Lee et al. 2008b, Shin 2009).

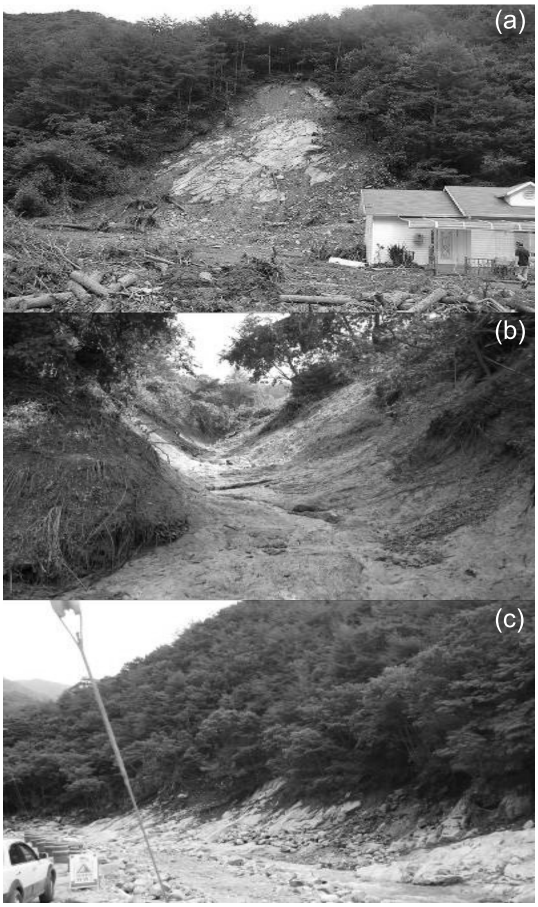

Fig. 1 Typical landslides in Korea (July 2006). (a) Hill slope failure involving sliding of shallow soil horizon on rock, (b) Intense landsliding in lower valley sides, (c) Debris flow along river.

Many cut-slopes, both public and private, fail during and after construction with consequent injuries, loss of life and economic loss (Fig. 2). Although Korea has standards for the survey and design of slopes developed by individual agencies, the geological input to design tends to be poor. Following a review of 100 design reports, less than 10% were identified as having a sufficient geological input for design (Lee et al. 2007d, 2008b). It is the opinion of the authors that lack of geological input poor geological modelling for slope design may account for between 30% and 50% of failures that take place during slope construction (Lee & Hencher 2007a, 2008a). In one case a slope failed six times at the same place due to poor original design and lack of appreciation of key aspects of the geology during safety inspections and reassessments after each collapse (Lee & Hencher 2007b).

Fig. 2 Realities of cut slopes in Korea. (a) Steep and high cut-slopes in mountainous areas, (b) Cut-slope failure, (c) Retaining wall failure.

3. Slope Management Status by Agencies.

Landslides have been studied over recent decades by Korean government organizations such as the Korea Forest Research Institute (KFRI), the Korea Institute of Geosciences and Mineral Resources (KIGAM) and the National Institute for Disaster Prevention (NIDP), however these studies are at an early stage for developing a good understanding of landslide mechanisms in Korea such that the consequences may be properly mitigated (KFRI 2000, KIGAM 2006, NIDP 2005).

Poor specification for geological survey and design together with inadequate and inexpert investigation post failure means that the causes of collapses are rarely properly identified. Most landslides are therefore attributed to "natural disaster" (KBS 2001, 2002). As a consequence the costs of remedial works are generally paid by the Korean government and those affected by failures are not indemnified in the majority of cases. For future improvement it is important that the main factors causing slope failure are better investigated and that measures are taken to reduce the incidence of slope failure. The whole process of cutting slopes needs to be addressed and improved through from design to construction and to maintenance following construction.

Following increasing criticism that cut-slope management in Korea is generally poor (MBC 1997), the Korean government has begun to take more interest in the stability of cut-slopes. Since 1998 road cut slopes have been investigated by government organizations under the auspices of the Ministry of Construction and Transportation (MOCT). In particular the Korea Expressway Corporation (KEC) has investigated 4,800 cut slopes along express ways and the Korea Infrastructure Safety and Technology Corporation (KISTC) together with the Korea Institute of Construction Technology (KICT) has investigated 12,650 cut slopes along other national roads. Finally 299 slope sites along railway routes have been investigated by the Korea Railroad Research Institute (KRRI). Furthermore a "Special Law Related to Safety Management of Facilities" was introduced in 2003 and now large retaining walls are managed by KISTEC (Korea Infrastructure Safety and Technology Corporation) (KICT 2005, ETTI 2004, KRRI 2004, KISTEC 2003).

These measures were initiated generally to prioritize remedial works and conducted on the basis of perceived stability using simple data-sheets or tables but without detailed geological mapping or assessment. The data sheets, tables and methodologies deployed are distinct to each organization and as such, they are not interchangeable. Furthermore attention has been focused only on the stability of the cut-slopes themselves with little or no consideration given to the stability of the terrain above and adjacent to the cut-slopes. It is of some concern that despite the fact that agencies have been managing slopes along national roads, expressways and railroads systematically since 1998, the reality is that the number of failures per year has not been significantly reduced. Furthermore some slopes that have been assessed as low risk have collapsed resulting in a number of human casualties.

4. Future Objectives

It is estimated that there are more than 700,000 cut slopes along roads and in housing areas in the urban and rural regions of South Korea. The responsibility for the management and maintenance of these cut slopes belongs to local government and private entities but the system has not been properly controlled by the government, partly due to a lack of regulations with respect to the stability of cut slopes. The government does not currently have detailed information on the distribution and stability condition of cut slopes throughout the country.

The National Emergency Management Agency (NEMA), an organization under the Ministry of Government Administration and Home Affairs (MOGAHA), was established in 2004. 1n 2007 the "Law Related to the Prevention of Steep Slope Disasters" was introduced to help reduce human casualties and economic loss in relation to slope failure including both local government and privately owned ones. Research related to this law is being performed by the LRC (Landslide Research Centre) under a research project entitled "Prediction of Slope Failure and Development of Slope Management Technology". The LRC intends to review methods for site investigation of slopes, soil and rock testing, determination of geotechnical parameters, design methods, landslide preventive measures, cut slope data basing, risk rating techniques and, finally, to develop a real-time streaming-based slope disaster information forecasting system. It is a step towards allowing the Korean government to examine and control, systematically, the stability of cut slopes across the nation according to unified investigation techniques.

Conclusions

Characteristics and causes of typical slope failures in Korea have been analysed and presented. It is noted that, despite the application of independent standards of various management agencies, a considerable number of failures have continued to occur associated with rapid industrialization. It is considered that this is partly because standards for slope design and management have not been well developed. The establishment and management of organizations to perform integrated management of slopes and standardized criteria (investigation, design, and construction technology) are necessary in order to minimize future slope damage. In 2006, NEMA has commenced a study into slope failure prediction and the technology for reducing the risk from slope failures with a target to reduce incidentsNgoc Anh Ha below 70% of the 2006 level by 2016. This is being conducted, as a national study, to provide an integrated approach to the management of various slope types that are currently the responsibility of various agencies. Part of this initiative has been the establishment in July 2007 of "The Law Related to the Prevention of Steep Slope Disasters". The establishment of an integrated management system to support this initiative requires continuing research.

Acknowledgments

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Development of Community-based Early Warning System against Debris Flow at Mt. Merapi, Indonesia

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Abstract: Mt. Merapi, which is laid at Central Java Province and Yogyakarta Special Province, is one of some active volcanoes in the world, with the high population at its surrounding. In almost every eruption period, Mt. Merapi produces large number of sediment volume in which could move downstream in various ways or mechanisms, such as landslides and debris avalanche. Furthermore, such material migrates downstream through the steep slope torrential streams in what it is called debris flow. Such debris flow may contribute the destructive power then causing damage on the river banks, bridges, houses, etc. It was reported that the 2006 Mt. Merapi eruption (from April thru October 2006), has produced approximately 8.0 million m^3 of sediment, potentially to move downstream towards the southern part of the mountain. A number of 600,000 m^3 debris avalanche in the form of hot pyroclastic material flown down in June 14, 2006 in less than two hours, devastating tourist area and two casualties. There was no rainfall occurrence has been found to trig the phenomenon, it means the debris avalanche is purely caused by instability of the lava dome.

In almost all cases of the occurrence of the debris avalanche, rainfall at certain intensity contributes significant influence on its phenomenon. Therefore, the prediction of the debris flow occurrence in the stream may be approximated through identifying the rainfall characteristics at the corresponding catchment area. This paper presents the result of the study on the correlation between the rainfall characteristics with the occurrence of the debris avalanche at Mt. Merapi area, Indonesia. The study covers the characteristic of Mt. Merapi sediment in various conditions such as its distribution, slope instability parameters, as well as property change due to its variation in time. The rainfall characteristics study is focused in the short duration intensity in several locations at Mt. Merapi area. The result is anticipated to contribute necessary information for the development of the community-based debris flow early warning system.

Keywords: community-based, debris flow disaster, Early Warning System (EWS)

Introduction

Mt. Merapi has produced a large amount of volcanic material as ash falls, lava flows and pyroclastic flows. In early stage, Merapi Volcano was characterized by basaltic effusive eruptions (Yachiyo Engineering Consultant, 2001). The magma then changed to more siliceous and viscous material. Recently, the magma is so viscous that it extrudes and accumulates at the base of the crater as a lava dome. This dome may grow randomly and at certain condition become unstable and easy to collapse, accompanied by hot pyroclastic cloud as a primary disaster (Gadjah Mada University, 2006). The collapse of the dome would later be a sediment source of some tributaries on the slope of Mt. Merapi, which through the trigger of the heavy rainfall may cause debris flow as a secondary disaster. The tributaries on the slope of Mt. Merapi are Pabelan, Apu, Trising, Senowo, Lamat, Blongkeng, Putih, Batang, Bebeng, Krasak, Boyong, Kuning, and Gendol Rivers as shown in Figure 1. Considering the high rainfall intensity during rainy season, which normally occurs from October to March, Gadjah Mada University in cooperation with local government was then trying to develop the community-based early warning system against the debris flow. Such early warning system comprises of two rainfall sensors, one wire sensor, and five sirens. This integrated early warning system is based on the measurement on the rainfall intensity at the location of debris deposit at the upstream. This measurement proposes quick information, although the data do not directly indicate the occurrence of debris flow. The debris flow at the river channel has been monitored as well by the installation of wire sensor with three level of warning. The data could directly inform the occurrence of debris flow; however it gives a limited time for local community to conduct the evacuation. All of the monitoring data from rainfall gage and wire sensor will be sent to the computer in the central station by radio or cellular communication system.

Fig. 1. Lava dome at June 2006 (YEC, 206)

Early Warning System Development through Collaborative Research

The Hydraulics Laboratory of Civil Engineering and Environmental Department, Faculty of Engineering, Gadjah Mada University has about ten years experience in developing instrumentation and telemetry system in cooperation with the other relevant laboratories in the university. In the mid of 1990 – 2000, there was an action research supported by the Indonesia Railway Agency and by the Department of Public Works of the Government of Indonesia. The first research was conducted to develop and install the telemetry system to monitor the scour around the railway bridge pier. The second research was conducted to monitor rainfall intensity at some river basin and water level at its corresponding control point. The system used radio link for the data communication. Since then the Hydraulic Laboratory initiated collaboration with the Instrumentation Laboratory in the Nuclear Engineering Department (now changed into Physical Engineering Department). Starting 2006, such collaboration was then expanded with Geotechnical Laboratory of Civil and Environmental Engineering Department. The increase of natural disaster occurrence within has invited the collaborative research to contribute various roles.

Instrumentation Laboratory has a lot of experience in both laboratory scale and full scale products such as medical instrumentation, robots, weather sensors and other measuring and control devices. The on going collaboration with the Hydraulic Laboratory is the development of field scale measurement devices, i.e.; the water level, the rainfall, and a siren system as warning system for Mt. Merapi, in cooperation work with the Sleman District. The system utilized the mobile phone as the data communication media. The rainfall gauge being developed is a direct type, therefore is not compatible with the previous system. Table 1 shows the experience of the Hydraulics Laboratory of GMU on the hydraulics data monitoring and acquisition including the EWS-related system during the last decade.

Table 1. List of EWS-related Studies and Projects at Hydraulics Laboratory of GMU

Year	Description
2008	Development of the Early Warning System (EWS) for debris flow disaster in Boyong River of Mt. Merapi
2006	Development of the EWS for debris flow disaster in Gendol River of Mt. Merapi
2005	Development of the rain gauge use the siphon type
2005	Development of the water level data logger (laboratory scale)
1997	Development of Rain Gage & Automatic Water Level Recorder (AWLR) in Kupang, Timor Island
1996	Development of AWLR and Railway Bridge Scour Gauge in Cilacap

The Development of Community-based EWS

The EWS that has been installed at Gendol and Opak River in December 2006 has performed its good advantage that people has better awareness in anticipating the possible debris flow danger that may arise at both rivers. The above effort was a progressive strategy triggered by Mount Merapi eruption in 2006, in which more than 6 million m^3 of pyroclastic material may contribute debris flow at the southern part of the mountain (Boyong, Kuning, Gendol, and Woro River) as shown in Figure 2.

This activity comprises of field observation to identify the suitability of the placement of tower for monitoring system (rainfall monitoring system and siren), its power system, as well as the ease of the implementation of community participation upon operational of the system. The community condition is very important to be identified, since the sustainability of the system depends upon the community perception, aspiration, and behaviour. Current practice done by community on their way in anticipating debris flow disaster is also aspects to be considered in the system development. Such aspects include the use of 'thong-thong'- a traditional siren, to spread the information of the debris flow occurrence to the community. The EWS installation covers the installation of towers, rain gauge, siren, as well as its communication system from and to centre of disaster management at Sleman District.

To obtain its sustainability, a training to introduce the system to related institutions and community was carried out. Training includes the dissemination of the operation procedure of the system application as well as evacuation drills. The role of the university is then being a mirror of the process of the monitoring and acquisition of the EWS system.

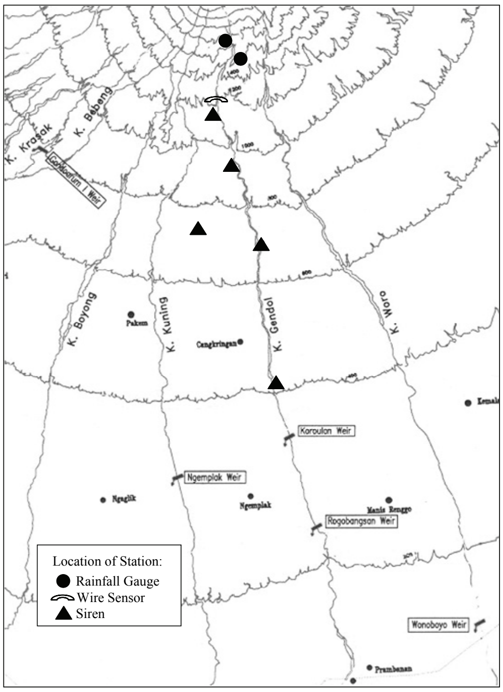
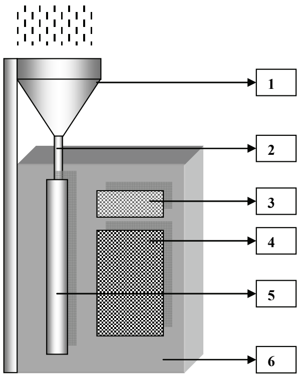


Fig. 2. EWS of Gendol River, Mt. Merapi

Rain Gauge Sensor

In almost all of the rainfall gauge equipment development, the tipping bucket type the considered the most common, whereas the following one would be the siphon type. As it is commonly encountered on the development, majority problem arises in the form of the range of the rainfall data that would be recorded (Proakis, 1996 and Luecke, 2005); the wider the range would be the more difficult. In Mt. Merapi area, the rainfall characteristics may range from the order of 5 mm/hour to 300 mm/hour. Such characteristic was considered in the rain gauge sensor development and an electric drain type was then used (see Figure 3).



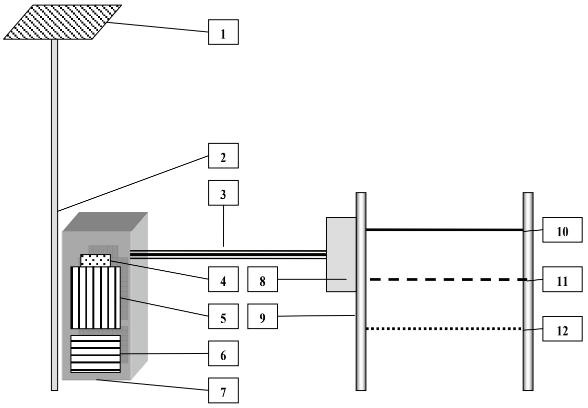
Remarks:

1. Rainfall collector
2. Connection pipe
3. Transmitter module
4. Electronic component
5. Measurement tube
6. Equipment box

Fig. 3 Rain Gauge Sketch

Wire Sensor

Wire sensor is a debris flow contact sensor which is supposed to be very simple, easy to install and very accurate information to show the occurrence of the debris flow. The only weakness of such sensor type arises in the form of relatively too often in replacing the wire every time after the debris flow hit the wire (see Figure 4).



Remarks:
1. Solar panel
2. Support tower
3. Transmission cable
4. Transmitter
5. Micro-controller
6. Battery
7. Equipment box
8. Connector box
9. Cable support
10. Top level cable (Level 3)
11. Mid level cable (Level 2)
12. Bottom level cable (Level 1)

Fig. 4 Wire Sensor Sketch

Discussions

In order to maintain sustainability and to increase the benefit of the system then a frequent evacuation drill, at least once a year is conducted. This evacuation drill involves a number of local people and related institutions and organizations such Red Cross, Non Government Organization (NGO), village authority, school children, etc. Figure 5 shows the local people carrying out the evacuation drill utilizing the EWS. Prior to the implementation of evacuation drill, socialization on how the system works to local people was carried out, comments and aspirations (such as type of sirens ring, and its connection with the traditional warning system) were considered to improve the community acceptance to the presence of the system.

Fig.5 Evacuation drill at village level

In order to maximize the function of the EWS system, community is also supposed to maintain the installed system, i.e. reporting any damage due to physical phenomena including safety against thieves to the district agency. A good example illustrating the performance of the system was obtained when the sensor cable was broken due to physical phenomena (see tabulated records in Table 2). The Level 1 and Level 2 records were supposed due to be stolen, whereas Level 3 record was due to high debris flow occurrence.

Table 2. Records on Debris Flow Occurrence

11/11/2006	16:43:18	Level 1 (stolen)
20/11/2006	19:06:51	Level 2 (stolen)
01/12/2006	15:32:35	Level 1 (stolen)
01/12/2006	15:32:43	Level 2 (stolen)
04/12/2006	17:03:06	Level 3 (debris flow occurrence)

The reinstallation of the wire is designed in such to be very simple, cheap, and need relatively short time. However, the debris flow occurrence on December 4, 2006 was really unexpected that all supports were broken; reinstallation may require relatively big effort. Other methods of debris flow occurrence identification such as vibration method, camera method, etc., are being focus for further development. Figure 6 shows sketch of the community-based EWS system installed at Gendol River.

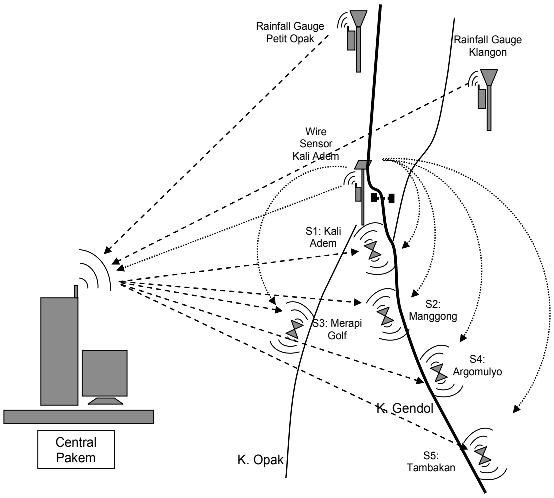


Fig. 6 Sketch of Community-based EWS position

Acknowledgments

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Centrifuge Modelling of Reservoir Landslides in Three Gorges, China

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Abstract. In recent years, much more attention has been paid to the reservoir landslides in China. In Three Gorges Especially, the reservoir landslides will damage settlements and infrastructure sited at the crests of slopes or they can cause reservoir overtopping and flooding. It is a special characteristic that the landslides along the reservoir are inevitably influenced by rise and fall of water level. As we know, Centrifuge testing has been regarded as a very effective method for the study of geotechnical problems. In order to investigate the influence of impoundment and water level fluctuation on the reservoir slope stability in Three Gorges, China, a centrifugal testing method simulating the rise and fall of reservoir water level, based on the prototype of the Muzishu landslide, is introduced in this paper. During the procedure of each test conducted at 100g, the water level in front of the slope and pore pressure are measured at a determined interval, and digital images for slope deformation analysis are taken as well. Based on GeoPIV (Geotechnical Particle Image Velocimety) analysis, the slope displacement, crack propagation, failure surfaces and failure modes are obtained. It will provide direct meaningful data for evaluating the slope failure mechanism. In addition, from the comparison of two tests with different change magnitude of reservoir water level, further significant results indicate that different water fluctuation magnitudes will have different impacts on slope movements.

Keywords. Centrifuge modelling, reservoir landslide, Three Gorges, rise and fall of water level, GeoPIV

1. Introduction

Water has been identified as one of the main factors which directly trigger landslides. There is no doubt that impoundment and change of reservoir water level will have great influence on slope stability (Huang 2007). Especially in the reservoir area of Three Gorges in China, the maximum level of impoundment is up to 40m, and seasonal changes of water level in reservoirs reaches 10m high. The reservoir water fluctuation levels that are bounded by large natural slopes may cause large slope displacements which damage settlements and infrastructure sited at the crest of the slopes or can cause reservoir overtopping and flooding. According to some rough statistics in 2007, there are 15 counties along the reservoir area of Chongqing city which will meet the criteria of a potentially serious landslide disaster area. The total number of potential landslide disasters is approximately 11 to 784.

Centrifuge testing has been identified as a very effective method for geotechnical problems. The use of a centrifuge in conducting model tests solves many of the problems associated with small-scale modelling of large geotechnical problems. These problems are chiefly associated with the reduction in soil volume in the model, which reduces the self-weight stresses at analogous points in the model and equivalent full-scale slope. The enhanced gravity field generated by spinning the centrifuge increases the weight of the model and compensates for the reduction in volume due to the geometrical scaling (i.e. a 1:100 scale model slope tested at 100g in the centrifuge will behave in the same way as the full-scale slope). Thus, such a physical testing technique has been widely applied for the study of slope stability for the following four aspects.

(1) Modelling the influence of slope toe excavation (Yao et al. 2006, Liu et al. 2007)
(2) Simulating rainfall and change of underground water table (Chen et al. 2007, Timpong et al. 2007)
(3) Seismic effect on slope stability (Taboada et al. 2002, Stewart et al. 1994)
(4) Vegetation stabilization of slopes (Sonnenberg et al. 2007, Greenwood et al. 2004)

Due to the difficulty of controlling water level when the centrifuge machine spins at a very high speed, no related testing research on reservoir landslides simulating the influence of water fluctuation has been found until now. In order to understand the influence of this kind of water condition on landslide stability, a watering system has been built base on a model box and a centrifuge machine. These components can simulate the impoundment and the reservoir drawdown and recharge, as well. A typical landslide in Three Gorges is selected as the prototype, and as outlined in this paper involves two tests (SL10, SL05) on natural fallow slopes affected by different change levels of water level, the detailed centrifuge testing methods and corresponding results are to be described as follows.

2. Centrifuge Modelling

The tests were conducted at the Division of Civil engineering, University of Dundee, Scotland. The Actidyn C67 centrifuge has the capacity of 150 g/t, the effective rotating diameter is 6.5m, the maximum gravity acceleration reaches 150g, and the geometry of model container is 1.0 m×0.8 m×0.8 m.

2.1 Model design

Based on the geometry of the prototype, the gravity acceleration is designed to 100g, so the slope model is determined as shown in Figure 1. It consists of two geological strata; the upper is soil and the bottom is bedrock.

The bedrock is stable concrete which is made up of fine sand, kaolin and cement. The soil was made using a mixture by mass of 77.5% fine sand Clay (Ca-Montmorillonite) and 2.5% organic Coir fibres milled to a fine powder (Sonnenberg et al. 2007). The moisture content of the soil was about 20.1%, similar to that of the prototype. To construct the soil slope, the soil was compacted with a reduced energy per unit volume, E_P = 114.7 kJ/m^3, using a standard Proctor compaction hammer. This produced a soil with a dry density of ρ_d = 1.24 g/cm^3 and the void ration is 0.64. The final slope model in container is shown in Figure 2.

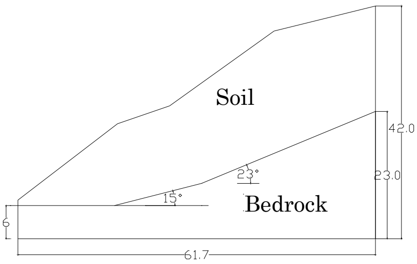

Fig.1 Geometry of the centrifuge landslide model in the reservoir area(Unit: cm)

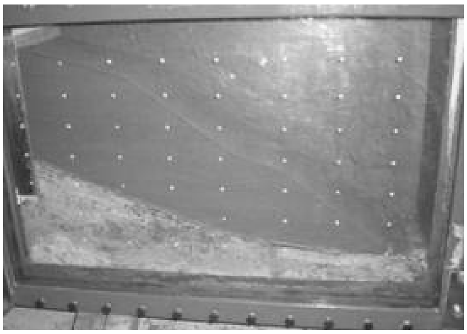

Fig.2 Photograph of the centrifugal model for the reservoir landslide

2.2 In-flight control system of water level

In order to simulate the change of water level in front of the slope toe, an in-flight control system of water level is designed.

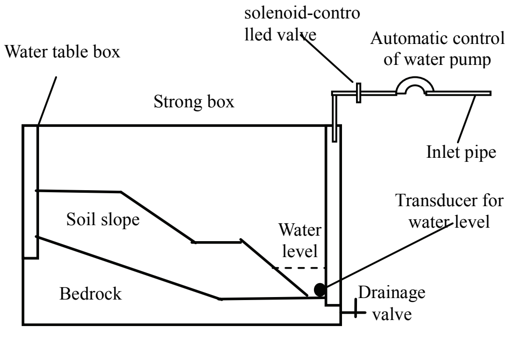

Fig.3 Schematic diagram of control system of water level for centrifugal test

The main components consist of inlet water pipe, an automatic control water pump, a solenoid-controlled valve, a drainage valve and water pressure transducers. During the test, reservoir water level will be raised if the water pump is switched on, whereas if the water pump is turned off, the reservoir water will go out of the box, because the drainage valve is always partially opened.

2.4 Monitoring facilities and GeoPIV

Standard miniature PPTs (Pore Pressure Transducers) with a pressure range of 0-100 kPa were used to measure the positive pore pressures at the interface of soil and bedrock. In addition, the water pressure transducers with a bigger capacity of 1.0 MPa were used to measure the reservoir water level.

The centrifuge strong box has two transparent side faces made of Perspex (50 mm thickness) to allow visual analysis. Through the Perspex, a digital camera is located beside the strong box and will photograph images at an interval of 20s.

Based on a series of digital images, GeoPIV(Geotechincal Particle Image Velocimety, White et al. 2003) is used for slope displacement analysis. The basic principal is based on the image analysis technique.

3. Test Procedure and Results Analysis

3.1 Test procedure

According to the test design, the procedure of test SL10 is divided into the following five stages:

(1) Centrifuge machine spins up to 100g
(2) Continuous consolidation for slope soil and water is on under 100g
(3) Reservoir impoundment to a certain water level (55 mm) under 100g
(4) Normal cycles of reservoir water fluctuation(25 mm~55 mm) under 100g
(5) Update cycles of reservoir water fluctuation(25 mm~65 mm) under 100g and test ends

The whole procedure of test SL10 represented by varying water level can be shown in Figure 4.

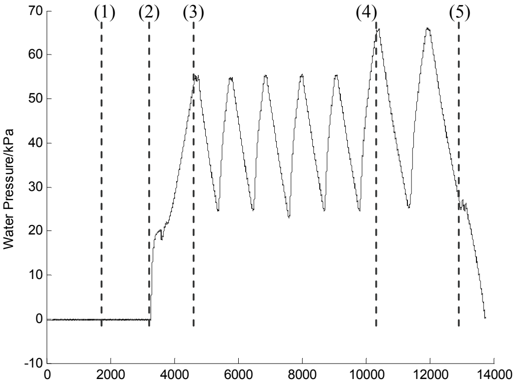

Fig.4 Test procedure of reservoir water fluctuation ranging from 25 mm to 55 mm and 65 mm

As we know, in a real reservoir water condition, the fluctuation level will change as according to the different seasonal climate. Therefore, another test SL05 was conducted to investigate the influence of different impoundment and reservoir fluctuation levels on slope movements. The detailed test procedure for SL05 is also shown in Figure 5.

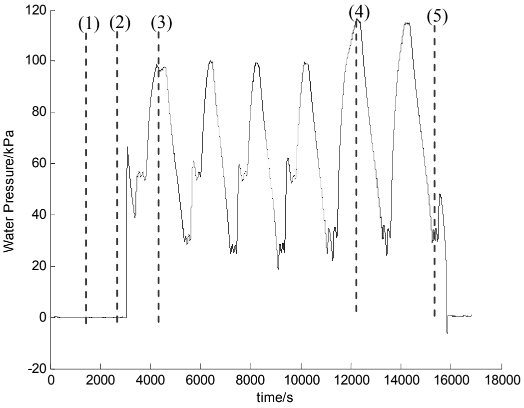

Fig.5 Test procedure of reservoir water fluctuation ranging from 35 mm to 100 mm and 120 mm

3.2 Features of slope displacement

As the discussion mentioned above, slope displacement was obtained by image analysis of GeoPIV. In order to analyze the feature of slope displacement, there are four typical surface points plotted in Figure 6. The settlement of each point is shown in Figure 7.

In this case, SL10-P02 was taken as the example. At the stage (1), the centrifuge machine spun up to 100g, the slope soil was consolidated, and the relationship between the displacement and time was almost linear. At stage (2), the acceleration was kept constant at 100g, slope soil consolidation continued, but the procedure finished soon and the settlement was kept constant afterwards. At stage (3), the reservoir was charged for the first time, the slope deformed immediately, the largest settlement happened at the first cycle of rise and fall of water level, and the total settlement increment reached 1.1mm. After this stage, three cycles of rise and fall of water level continued, but the slope only took on slow creep deformation at stage (4), and the total settlement increment was 0.6mm. In the last stage (5), two cycles with increased water level, the slope still kept the creep deformation, and the settlement increment was only 0.3mmm. But for the surface point of SL10-P04, the maximum settlement increment in the last stage became 0.7mm, this is due to the local deformation that happened at the slope toe.

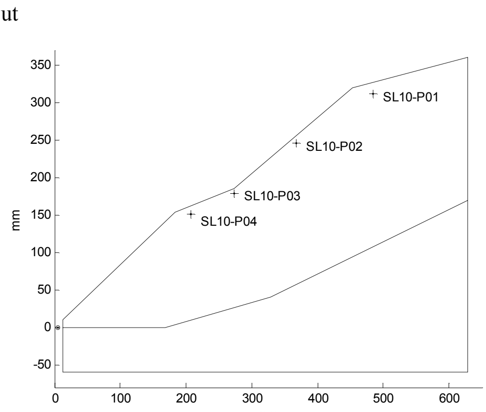

Fig.6 Surface points for displacement analysis

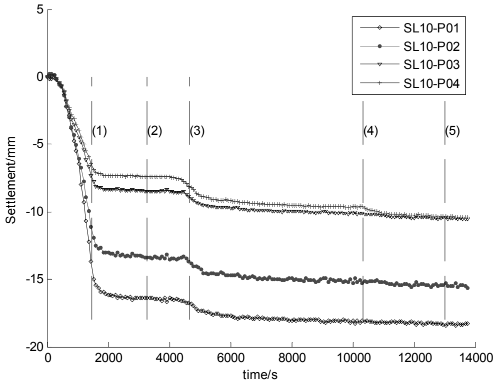

Fig.7 Settlement of typical points in test SL10

Obviously, the relative settlement becomes bigger from the slope bottom to top, SL10-P04 shows the minimum settlement but SL10-P01 shows the maximum. And the test results of SL05 show almost the same character (Figure 8). In this test, the maximum settlement increment still happened at the first water cycle, afterwards, the slope kept on its creep deformation. There was nearly the same deformation features as that of SL10, but the displacement magnitude was totally different. The total settlement of each point after 100g and soil consolidation in two tests is shown in Table 1. The total settlement of each point in SL10 is less than that in SL05, and it indicates that the bigger magnitude of impoundment and water fluctuation, the bigger deformation will take place.

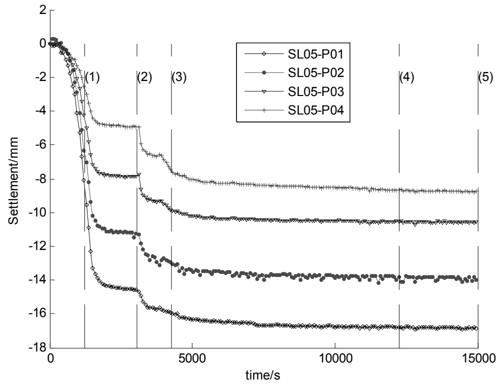

Fig.8 Settlement of typical points in test SL05

Table 1 Comparison of settlement increment for test SL10 and SL05 (Unit: mm)

	P01	P02	P03	P04
SL10	1.69	1.83	1.93	2.94
SL05	2.29	2.66	2.7	3.8

3.3 Failure modes

Although the full failure surfaces were not obtained in these two tests, they still can be analyzed by GeoPIV results, the typical slope displacement vectors due to the change of reservoir water level are shown in Figure 9. The result indicates there are two clear failure surfaces in this section, and the polygonal shapes are plotted in Figure 9 as well.

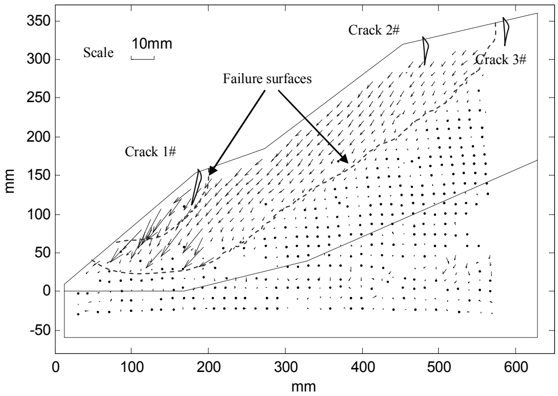

Fig.9 Slope displacement vectors measured in centrifuge test SL05 using GeoPIV image analysis techniques

During the test, several cracks were observed. Normally, there are two big cracks that developed on the crest (crack 1#) and top (crack 2# or crack 3#) of the slope respectively, and some other small cracks also developed in the middle of the slope. The photograph of SL05 in Figure 10 shows the final form of the cracks.

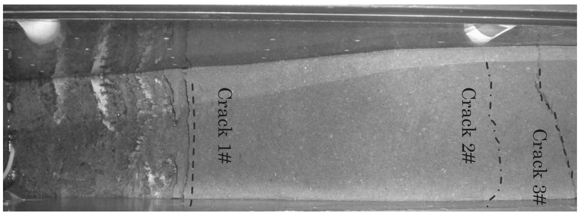

Fig.10 Photograph of cracks developing in the centrifuge slope model (Top view)

However, all the failure surfaces or cracks did not turn up at the same time, as some of them were found earlier at the slope foreside. With the rise and fall of reservoir water level, the slope deformation developed to the rear gradually and behaved as a typical pull-type failure mode.

4. Conclusions

This paper reports the centrifuge tests on reservoir landslides influenced by impoundment and reservoir water level fluctuation. From the results mentioned above, some conclusions can be drawn as follow:

An in-flight control system of water level has been set up for centrifuge tests, and it can be adopted to simulate the impoundment and change of reservoir water level. This makes it possible to conduct centrifuge tests on the reservoir landslides which reflect the real water condition.

The biggest slope displacement only happens at the first change in reservoir level and at the first cycle of rise and fall of water level After this, the slope will keep to the slow creep deformation. On the other hand, two tests with different heights of water fluctuation indicate that the larger theheight, the bigger sthe lope displacement will be.

For the reservoir landslides influenced by rise and fall of water level, the failure always develops from the bottom to the top, and this kind of landslides perform a typical pull-type failure mode. There are often more than two failure surfaces and a lot of cracks accompanying them.

Acknowledgments

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Research on the Geohazards Induced by “5.12” Wenchuan Earthquake in China

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Abstract: Based on the field investigation in emergency, interpret of remote sensing images from aerial flight and satellite and historic geo-data, author puts forward a basic estimation about geo-hazards situation induced by “5.12” Wenchuan earthquakes in China. The basic parameters and destructive properties of the wenchuan earthquake have been introduced on the geology. Some types of geo-hazards, such as some typical examples about rock/soil-falls, landslides, debris, ground fissures and surface collapses, have been described. The distribution of geo-hazards has been divided into three types which consist of the high, middle and low development areas according to the density of geo-hazard points. Author believes that some recognition from this research is of significant to make scrutiny for the acceptability of geo-safety and risk of geo-hazards.

Key words: Wenchuan earthquakes, geohazards, geological environments, risk of geo-hazards.

1. INTRODUCTION

May 12, 14:28, 2008, Wenchuan earthquake tragedy occurred in Sichuan province of southwest China. According to assignment from MLR (ministry of land and resource, China) and CGS(China geological survey), author early or late looked at the disaster area in the Sichuan and Gansu provinces, took charge of the situation estimation of the disaster, coordination of field investigation and compilation of special plan to control geohazards caused by Wenchuan earthquake. In the working process more than 60 days, some recognitions about the geohazards in the quake region has been gotten, and some problems are considered to response disaster crisis of geo-environment changes and elude risk of geohazards.

2. THE BASIC SITUATION OF THE WENCHUAN TRAGEDY

It is not quite from statistics, the fatalities, i.e. the total overrun 8.7×10^4 caused by “5.12” Wenchuan earthquakes. The more than 400 counties are impacted, about 40×10^4km^2 involved, about 4624×10^4 persons hit and 1511×10^4 persons have to be relocated over again. The quake produced a great deal of new rock-falls, landslides, debris and ground fissures, total perhaps more than 2.0×10^4 points, and these geo-hazards threat the life safety about 120×10^4 persons who are in the 86 counties located in a contiguous region to live under Sichuan, Gansu and Shaanxi provinces. The proportion of landslides, rock-falls, debris and ground fissures account 52%, 30%, 6% and 12% for separately its total number。The distribution proportion of the total number is about 70% in Sichuan, 25% in Gansu and 5% in Shaanxi。The personnel in the dangerous environment is about 60% in Sichuan, 33% in Gansu and 7% in Shaanxi。In the scale of the volume for landslides, it is about 1%, 9%, 24% and 66% which is huge ($V\geq10\times10^6$m^3), large (10×10^6m^3$>V\geq1\times10^6$m^3), middle (1×10^6m^3$>V\geq1\times10^5$m^3), and small ($V<1\times10^5$m^3).

In the existing events, the geo-hazards threaten 13577 residential points which include 18county seats and 247 towns, breakdown highway 2482 segments about 636km, locked and silting riverway 2044 segments about 466km, damaged large size of bridge 21 seats and made 69 cases to be in risk of bursting of dam and 310 cases in dangerous in some kind of extent, such as Zipingpu hydraulic power plant. Moreover, the destroyed farming and forest land are about 1.24×10^4ha.

3. GEOLOGY OF THE EARTHQUAKE

The earthquake epicenter is located at 30.94°N，103.47°E, Richter magnitude 8.0, depth 19km。The causative faults, i.e. Longmen Mt. faults, make track for 50°, dip for northwest, angle of inclination 40° and its moving style is thrusting and right-lateral slip. Its rupture length is about 300km to occur at the ground surface which is a single to the northeast.

The rupture speed is 2.8~3.1km/s, 120 seconds for total sustainable time and 70s for its energy liberation. The fault slippage more than 5m occurs in the extent about 90km long where 20km locates in southwest at the epicenter, but 70km in the northeast. So, the rupture time is about 90s in northeast direction at the epicenter but 30s in the southwest direction. Accordingly, there is a extensiveness area of shocking sensation in the northeast direction at the epicenter but little in the southwest.

The distribution area of the loosed slopes reaches to 15×10^4km^2 which is of great potential dangerous to occur with geo-hazards. For example, the longest fissure is 500m in Qingchuan county seat; the crack is about 300m long and more than 2m wide in mountain top of Renjiaping village in Beichuan; the large and deep cracks densely cover the region around Wenchuan county seat, the longest fissure is about 1km; the crack is about 1.5km long in Bailu town in Pengzhou city.

On the other hand, there is a wide range and serious disasters in Yingxiu, Wenchuan, Beichuan, Qingchuan and Wenxian located in the northwest at the hangingwall of the faults, but the weaker fairly in Chengdu and Mianyang in the southeast at the underlying unit of it. This is a typical example about "hanging-underlying influence".

4. GEO-HAZARDS IN THE WENCHUAN EARTHQUAKE AREA

4.1 THE TYPES OF GEOHAZARDS

Five types of geo-hazards have been put forward in this paper:

（1）Ground fissures or failures, include surface displacement along Longmen Mt. faults made in Wenchuan earthquakes and general geo-fractures to destroy house building and job facilities；

（2）Dangerous rockmasses in slope cliff to crack, topple and further collapse；

（3）Landslides，happened in the back-fall area or old landslide to revive；

（4）Debris，dry debris flow caused directly by the earthquakes or outburst of the rockfalls or landslide dams blocked rivers；

（5）Caving in，occur in the existing underground space or weak zones resulted from human activity and other causation.

4.2 SOME TYPICAL EXAMPLES

(1)The casualties from oversize of geo-hazards

A series of the serious casualty （more than 30 persons of death or missing caused by a individual event）resulted from the oversize of geo-hazards at Qingchuan, Pingwu, Beichuan, Pengzhou and Dujiangyan Counties in the Sichuan province in meizoseismal area induced by Wenchuan earthquakes (table.1).

(2)The geo-tragedy happened in the highroad between jushui and Gaochuan in Anxian County

There happened 34 rockfalls and landslides, of which 8 points are large scale about 18km among a section of highway 24km long, from Jushui to Gaochuan in Anxian county region. Particularly, that a segment called "tiger mouth" is mountain high, valley deep and densely cover dangerous rockmasses so that it is one with the hardest job to be restored. When earthquake happened, more than 120 persons and ten cars or vehicles detained are destroyed in the section.

Tab.1 "5.12" earthquakes triggered off heavy landslides disasters in Sichuan province

（more than 30 persons death or missing caused by a individual event）

NO.	Hazard types	placement	volume （10^4m^3）	fatalities	Direct loss （million yuan）
1	Dayanqiao Rockfall	Quhe town, Qingchuan	70	41	2
2	Donghekou Landslide	Hongguang town, Qingchuan	3000	600	50
3	Zhengjiashan Landslides	Nanba town, Pingwu	1250	60	50
4	Ma'anshi Landslides	Shuiguan town, Pingwu	400	34	80
5	Wangjiayan Landslide	Qushan town, Beichuan	1000	1600	16
6	Yingtaogou Landslide	Chenjiaba town, Beichuan	188	906	15
7	Luanshijiao Landslide	Qushan town, Beichuan	1000	700	12
8	Chenjiaba No.1 Landslide	Chenjiaba town, In Beichuan	1200	400	5
9	Hongyan Landslide	Chenjiaba town, Beichuan	480	141	1.2
10	Taihong No.2 Landslide	Chenjiaba town, Beichuan	500	100	1.1
11	Hanjiashan Landslides	Guixi town, Beichuan	30	50	1.30
12	Xiejiadian Landslide	Jiufeng Village, Pengzhou	400	100	40
13	Xiaolongtan Rockfall	Yinchanggou Park, Pengzhou	5.4	100	80
14	Dalongtan Rockfall	Yinchanggou Park, Pengzhou	10	100	80
15	Liangaiping Landslide	Tuanshan Village, Pengzhou	40	30	8
16	Liming Landslide	Zipingpu town, Dujiangyan	20	120	5
17	Tai'an Landslides	Qingchengshan, Dujiangyan	120	62	8
total			9713.4	5144	454.6

Remark: the data from the bureau of land and resource, Sichuan province, 2008.7

(3)Rockfall disaster resulted in railway interrupt from Baoji to Chengdu

Wenchuan earthquakes caused three topple breakdowns of limestone rockmasses in 1km to be apart from Huixian station of Gansu province on railway from Baoji to Chengdu. The locomotive engine of a list of train with oil and cargo is heated in which is in tunnel exit. The disaster made the engine on fire, driver injury, railway transport interrupt with one month, and severe harm to Jialing River and highway from Gansu to Shaan provinces.

(4)Loess avalanches and landslides at the Wudu city in the Gansu province

The cracks and collapses occur in loess acclivities along its northern mountain at Anhua town and Wudu city in Wudu district, Gansu province. The crack is about 1.8km long and 15~25cm wide in the loess slope. Three persons are deaths and the living safety of more than 800 persons is threatened in Ganshuwan village. A flat-topped ridge called Zui'erya in Aiwan village cracked and broke down to both sides of free face, which destroyed folk buildings.

Many avalanches and cave-house collapse occur in loess acclivities at Wudu city seat. There is about 500m long along its northern mountain from western Lianhua temple, cemetery to eastern arboretum, but fortunately, no person is death or injury.

(5)Rockfalls, landslides and dry debris flows at Wenxian county in the Gansu province

Wenxian county area is the most serious area which is impacted by Wenchuan earthquakes in Gansu province. It is discovered in which occur 150 landslides caused 41 persons deaths from preliminary investigation. Bikou reservoir is damaged in some extent and some deformation and sinking phenomena occur in the earth dam.

5. DIVISION MAP OF DEVELOPMENT DENSITY FOR GEO-HAZARDS

Geohazads data is from the field investigation in emergency, interpret of remote sensing images from aerial flight and satellite and historic geo-data to aim at "5.12" Wenchuan earthquake region, where is the 86 counties (cities or zones) located in a contiguous region to live under Sichuan, Gansu and Shaanxi provinces.

The evaluation result is obtained through a county grade administrative area as a basic unit, gain, just than unite overall 86 counties to form a density distribution map of geo-hazards caused by Wenchuan earthquakes. The total region is divided three types of area, i.e. high, middle, and low development areas to take stand on density geohazard points（fig.1）。

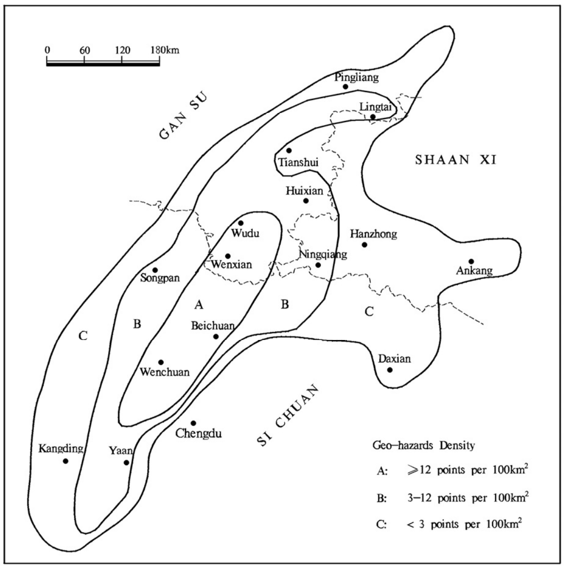

Fig.1 Division map of geo-hazards development density induced by "5.12"Wenchuan earthquakes

Area A: High grade of development area of geo-hazards, the point density of geo-hazards D≥12 points/100sq.km. It involve with 17 counties which hold total population 636×10^4 and cover with $4.47\times10^4 km^2$ where locate in a contiguous region to live under Sichuan and Gansu provinces. Area A in major part distributes in a region with the strongest seismic intensity, i.e. IX, X and XI grades of region located along Longmen Mt. seismic faults. Among 17 counties, 15 counties locate in the Sichuan province, i.e. Shifang, Mianzhu, Wenchuan, Anxian, Beichuan, Pengzhou, Huaying, Chongzhou, Lushan, Maoxian, Wangchang, Qingchuan, Hanyuan, Dujiangyan and Pingwu, and 2 counties are in the Gansu province, i.e. wenxian and wudu.

There are 12853 geo-hazard points in the area A. The greatest density is 29points/100sq.km. There are 8113 residential areas, 2035 segments about 596km highway destroyed in the region. It is worthiness for explanation that the region is high geo-hazards development area, densely inhabited district, important economic area, famous scenic sites, key facilities and lifeline engineering construction area before Wenchuan earthquakes happened.

Area B: Middle grade of development area of geo-hazards, the point density of geo-hazards is 12 points/100sq.km.＞D≥3 points/100sq.km. It involve with 32 counties or cities which hold total population 1072×10^4 and cover with 7.56×10^4km^2 where locate in a contiguous region to live under Sichuan (18 counties or cities), Gansu(11 counties or cities) and Shaaxi (3 counties or cities) for three provinces. Area B in major part distributes in a region with the stronger seismic intensity, i.e. VII and VIII grades of region. There are 3811 geo-hazard points in the area B. There are 5500 residential areas, and 812 segments about 192km highway destroyed in the region. Still, the region is high geo-hazards development area and densely inhabited district before Wenchuan earthquakes happened.

Area C: Low grade of development area of geo-hazards, the point density of geo-hazards is D＜3 points/100sq.km. It involve with 37 counties or cities which hold total population 1413×10^4 and cover with 11.15×10^4km^2 where locate in a contiguous region to live under Sichuan (11 counties or cities), Gansu(10 counties or cities) and Shaaxi (16 counties or cities) for three provinces. Area C in major part distributes in a region with VI grades of seismic intensity and loess area. There are 683 geo-hazard points in the area C. There are 137 residential areas and 234 segments about 29km highway destroyed in the region. Still, the region is low geo-hazards development area before Wenchuan earthquakes happened.

6. BASIC CONCLUSIONS

(1)The earthquake itself is a natural phenomenon and a sort of format to release strongly energy from Earth's interior. The effect of it mainly manifested as surface fractures, mountainous landslides and building failures. So then, “the killer” is not earthquake, but rather dilapidated house constructions and landslides caused by the shocks.

(2)The forms of slope destruction are crack, toppling, rockfall and landslide predominatingly that result from to pull apart on it in lateral action of the quake. And that debris is as against secondary disasters from rainstorm or outburst of barrier lake. No doubt, it is still related with its geological structures and steepness of the slopes.

(3)The slope destructions distribute mainly in the four types of region, i.e. the earthquake area to take on the high intensity, loess area, danger rock area and the strong weathering area of bedrocks.

(4)“5.12” Wenchuan earthquakes have not only activated on the existing of geohazard points, but produce the more new geohazards and its potential state. Thus, the harms of the geohazards on human in the quake region would be last out relative long period.

(5)The geohazards would be happened in future to result from quakes, raining, wind erosion, humidity or aridity changes and engineering activities, etc.

Acknowledgement: In the working process, author gets many advices and helps from Dr. Jiang Jianjun, director-general of geo-environment department, MLR of China, Dr. Zhong Ziran, deputy director-general of CGS, Dr. Li Yuan and Dr. Liu Yanhui from China Institute for Geo-Environmental Monitoring and the offices of land and resource of Sichuan, Gansu and Shaanxi provinces. Especially thanks to them mentioned above and etc.

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Rock Slope Failure in Weak Rocks: Two Case Studies

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Abstract. Extensive studies of rock slope failure areas support the role of weak rocks in the definition of the type, geometry, deformation mechanism and also stability of the landslide.

This paper investigates two particular case studies in order to define the role of weak rocks, in particular fault rocks, in the landslide characterization.

This paper deals with two famous cases in the North of Italy, Spriana and Pruna Landslide.

The presence of weak rocks is important in the definition of the safety factor but first of all in the landslide classification, in the 3D model reconstruction and also in the interpretation of the monitoring data.

Spriana and Pruna landslides are two extensive cases and the hydrogeological risk is very high for the bordering areas. These landslides are classified as deep-seated rock slope failures and they are the most catastrophic typology of landslides due to the high rates and to the extensions. The deep seated rock slope failure is often preceded by long phases of creep. For this purpose this paper deals with the reconstruction of the different phases of the failure mechanism and try to redefine the landslide typology observing the presence, the localization and the thickness of the fault rocks. Only with the results of a detailed analysis of fault rocks, geological investigations and the analysis of monitoring data it is possible to define the failure mechanism, the evolution and the thresholds of the hydrogeological risk. Before the final crack is important to understand the different creep phases of the landslides. Only in this way it could be possible to define or try to develop a methodology for rock slope forecasting. This paper deals with this type of problems and tries with two cases to define the role of weak rocks in the evolution, cinematic behaviour and analysis of failure time.

We analyse two particular case studies in order to develop a new approach to define the typology of the landslides and also the 3D conceptual model. These features are necessary to define the methods for stability of the slope studying but also to develop the right monitoring system.

All of this information are the basis for the correct evaluation of the susceptibility of the territory to a new movement. The paper introduces a new landslide classification for the two cases and investigates the best numerical model for simulate the stability of these slopes with two different histories but with the presence in different place of fault rocks.

Due to the high risk of these two landslides is necessary to develop a dynamic triggering thresholds and for this purpose is necessary to know in detail the 3D model, to use the correct monitoring system and all of this information could help in the interpretation of monitoring data. The deformation mechanism is the most important feature in order to assess the dynamic triggering threshold that is the unique solution for the best emergency management in the North of Italy where a lot of urban areas are nearest with some important hydro geological areas.

By examining the common features of these landslides it must be possible to recognize the different role of fault rocks in increased and generated potential failure.

Keywords. Weak rock, fault rock, paleo slide, physical model

1. Weak rock

The identification, characterisation and study of weak rocks has in the past been subject to examination and is still considered notably problematic. To classify weak rocks, various terms have been used: weak weathered and broken rocks indurate soil and soft rock (Oliveira 1990, Johnston 1986). Weak rocks are defined as part of the spectrum of material between rock and terrain. In relation to soil, weak rocks are harder, they have a more fragile action and are more discontinued; compared to other rocks they are softer, have a more plastic action, are more compressed and more influenced by variations caused by changes in agent forces on them (Johnston 1986). Rocks can be weak either because the material that constitutes them is weak, or because the mass is fractured; therefore, weak rocks are those which for states of alteration, of fracturing or for lithologic nature present scarce resistance to the forces subjected on them, caused by their unstable technical properties: low cohesion, reduced friction and low resistance to compression. Based on the type of origin, lithologic formation or tectonic structure to which they can be associated, weak rocks are divided into four principal groups:

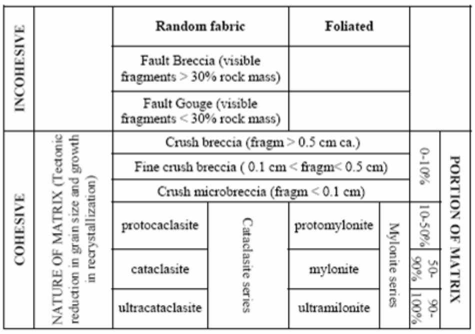
- weak rocks due to lithology ;
- weak rocks undergoing deep processes of chemical or physical alteration;
- weak rocks due to tectonic phenomena;
- weak rocks due to increased presence of cavities.

Below, in the two case studies a particular type of weak rock is analysed, that is those rocks intensely fractured by tectonic phenomena relative to the movement of faults and shear fractures.

Faults and fracture zones are areas characterised by notable weakness, since the reciprocal movement among plates determines the fracture of rocks lying along a belt distributed more or less symmetrically within the surface of the fracture. Between the two plates that have undergone reciprocal movement, shattered rock subsequently re-cemented from surrounding substances along the surface of the break can be found. The break has the aspect of breaches formed by more or less fragments. These new rocks that form are characteristic of weak rocks, with unstable mechanical properties, some of which are often unable to satisfy the safety factors relative to resisting a load of civil engineering works or natural loads that destabilise a slope. Fault rocks include all types of metamorphic rock, deriving from phenomena of dynamic metamorphism.

Dynamic metamorphism is a type of metamorphism of rocky masses caused by shear forces along a surface of a fracture. These forces produce elevated deformations in the rock, pulverising it through the friction of the two passing plates. In Sibson R.H (1977) (fig.1) is defined the term “fault rocks” to describe those rocks formed in the surface or deeper part of the terrestrial crust following shear forces.

Contained in this denomination are both the origin of such rocks and the structural properties relative to them. From the analysis of some studies in literature, it is possible to affirm that the presence of rocks which for lithology, alteration or fracture can be defined as weak constitutes a predominant cause in problems relative to the instability of slopes. The presence of weak rocks in fact determines a higher pre-disposition to the damage of rocky masses and consequently renders more frequent the separation of material of varying volumes. Given this, recognising the terrain and its characteristics has a fundamental role in evaluating geological risk. It is therefore necessary, through adequate investigative methodology, to be able to determine with precision the genesis, geotechnical characteristics and their distribution.



INCOHESIVE		Random fabric		Foliated			
		Fault Breccia (visible fragments > 30% rock mass)					
		Fault Gouge (visible fragments < 30% rock mass)					
COHESIVE	NATURE OF MATRIX (Tectonic reduction in grain size and growth in recrystallization)	Crush breccia (fragm > 0.5 cm ca.)				0-10%	PORTION OF MATRIX
		Fine crush breccia (0.1 cm < fragm< 0.5 cm)					
		Crush microbreccia (fragm < 0.1 cm)					
		protocaclasite	Cataclasite series	protomylonite	Mylonite series	10-50%	
		cataclasite		mylonite		50-90%	
		ultracataclasite		ultramilonite		90-100%	

Fig. 1 Classification of fault rocks (Sibson, 1977)

2. Two case studies

This paper deals with the relationship between landslide problem and the presence of weak rocks. As reported in the previous paragraph there are a lot of different types of weak rocks. In this paper fault rocks, a particular type of weak rocks, is considered. In order to understand the importance of fractured zones in the stability problems two case studies were analyzed. For this purpose the two cases are localized in the North of Italy, faulted by important regional fault-systems. These fault-systems and the related mylonitic and cataclastic rocks may produce weak areas responsible of some instabilities. This paper is focused on this two cases: Spriana and Pruna Landslides (fig.2). These landslides are classified as deep-seated rock slope failures and they are the most catastrophic typology of landslide. The goal is to understand the role of fault rocks for stability problem of these two cases.

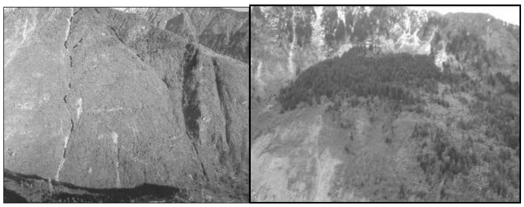


Fig. 2 Spriana and Pruna landslide.

2.1 Spriana Landslide

Spriana landslide is located in the North of Italy, in Valmalenco. It’s a very large instability, with a volume of about 40 million cubic meters. The instabily involve the right side of the valley with a vertical extension between 700 and 1400 m on the sea level with two main crowns. The instability includes fracturated and alterated gneiss and micaschist of the Monte Canale geological formation, covered by a layer of debris due to the succession of deformations and with the local presence of river and glacial debris. This hydro geological problem is a paleo slide due to the acient geological evolution of this valley. The main triggering factor of this paleo slide was the glacial activity. The first displacements occurred in 1900. Then the slope was subjected to continuous displacements from the toe to upper levels till 1400 m on sea level, where is located the upper crown. The figure 3 shows the two crowns, the flanks and the toe of the landslide. There are a lot of data available for the characterization of Spriana landslide: some pluviometers are localized on the main body, some geognostic investigations were made on the slope, some monitoring systems are active on the landslide (inclinometers, topographic instruments etc…). The analysis of these data is real complex due to the particular geomorphological condition. By the analysis of monitoring data, field surveys and geological investigations, a 3D model of this landslide is here defined. From pluviometric and piezometric data it’s possible to afford that there is a strong relationship between intense meteorological events and landslide displacements. But the displacements are not uniformed localized on the slope and this is due to the complex geomorphologic situation. After the geological investigation by the analysis of the samples drilled on the slope, some field surveys on the slope and also in the tunnel built for this aim, it was possible to observe the presence of heavily fractured zones and faulted rocks, with very low mechanical properties. Also in the boreholes samples it was possible to observe the breccia alternated to fractured gneiss under the debris layer. Summing all data available it was possible to define a new structure for this landslide.

It’ s a wedge failure with two different planes of fracture:

-one plane characterized by fault rocks due to the presence of important fault lineament. This plane is totally broken.

-second plane characterized by fractured rock due to glacier action. This plane is subjected to a different creep movement due to the presence of the other plane.

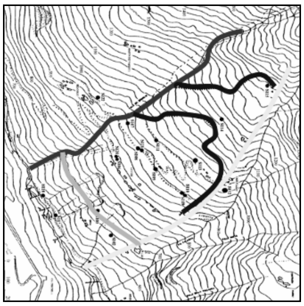


Fig. 3 Spriana landslide: the crown, the flanks and the toe of landslide.

The plane characterized by the presence of fault rocks is subjected by more displacements during meteorological events. This is due to the presence of a complete broken plane (fault) instead the other one is characterized by a progressive creep caused by the continuous displacements of the previous plane.

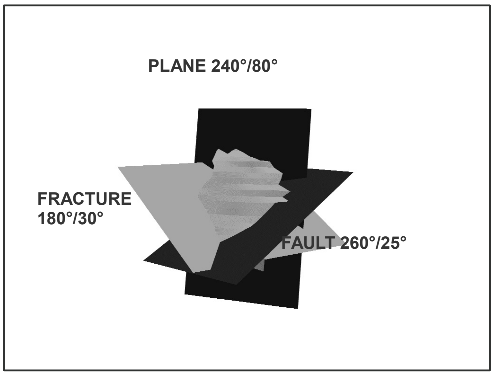


Fig. 4 Wedge slide: definition of the surfaces of rupture for Spriana landslide.

2.2 Pruna Landslide

This remarkable landslide is active in Val Tartano, tributary of an important river in the North of Italy. The landslide movement tends to dam the Tartano stream and to transport a large amount of debris. This debris feeds the alluvial fan of the river and can generate a lot of hydrogeological problem. For this risk it's important to define the amount of material that can detach from that instable slope. It's important to define the different risk scenario: the possibility to have only the low part active or the probability to have a complete movement of the old slide.

The goal in the study of Pruna landslide is to define these scenarios and the thresholds that can generate some hydrogeological problems.

The only formation outcropping in the studied area is a metamorphic one, called "Gneiss di Morbegno". The general trend of the foliation is downslope, the dip being higher than the slope angle; moreover, a large number of faults are also present. They are assembled in three sets, the directions being respectively NNE-SSW, NE-SW and NW-SE.

Mylonitic and cataclastic rocks are associated to fault zones, so contributing to increase the instability of the area. The steep zone, the dip direction of the rocks and the joints, and especially, the diffusion of mylonites and cataclastic rocks are the main intrinsic factors causing the slide. The term "Pizzo della Pruna" landslide applies both to a very large and old quiescent landslide (about 0.7 km long and 0.6 km wide) and to a smaller active landslide, corresponding to the lower and superficial part of the former one (about 270 m long and 200 m wide). Most of the main slide surface is covered by slope debris; inclination increase in the lower part of the hillslope, where the slide is still active; paragneiss outcrop both at the toe, along the Tartano river, and along the upper part of the slope, where blocks and slabs continuously break off the overhanging rocky wall.

At an elevation of 1100 m, an acient cleat, now partly covered by debris, separates these latter from the rocks. It can represent the "old scarp" of the main slide, now quiescent. Moreover, at an elevation of 900-950 m, a continuous crack can be observed. This crack, and the presence of springs situated at the debris/rock interface at the toe of the slide area, confirm that the lower part of the hillslope is subjected to movement.

Some other geophysicals, topographical climatological and hydrological investigations were made. Summing up, all the analysis demonstrate that the Pizzo della Pruna hillslope is characterized by an extreme instability. In normal climatic and meteorological conditions, an almost continuous feeding of debris to the Tartano river occurs. This causes an abnormal growing of the alluvial fan. Under extreme climatic conditions, the mobilization of a large slope mass should take place.

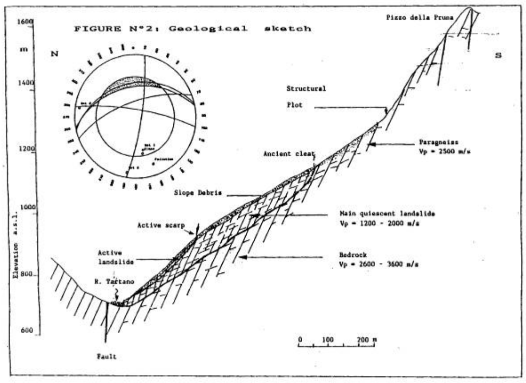


Fig.5.Geological sketch of Pruna landslide (Papini 1998)

2.3 The role of weak rocks in landslide problems.

The analysis of the two case studies show the presence of fault rocks that increasing the instability of the slopes. In order to understand the real safety factor, the triggering causes, the best monitoring systems, the right numerical model to use for simulations etc…the definition of weak rock role is necessary. There are some important questions for the definition of the importance of the weak rock in a instable slope.

The first question is about the localization of the weak area. It's important to identify if the weak area is diffused on the slope or if it's localized in one part and where. There are some difference in the localization also in the two cases presented above.

In Spriana landslide the fractured zones (due to the presence of fault rocks) is localized on one of the two planes that generate a wedge structure (it is the main mechanism of failure of this landslide). The presence of fault rocks in this part of the slope is real dangerous in terms of safety factor. This assessment is supported by the monitoring data and by the geognostic investigation. It's real important to analyze the monitoring data of the two planes of the instable wedge. The figure 4 shows the wedge and the two planes. Collected datasets positioned on the fault rocks band show continuous displacements instead on the other surface of discontinuity there are few displacements. In Pruna Landslide fault rocks are not localized in a particular part of the landslide but they are diffused on the slope. The diffusion is not casual but the weak rocks follow the fault lineaments. The surface of rupture of Pruna landslide is not positioned on fault lineament and so the situation is different with the previous case. Fault rocks are diffused and so decrease the geomechanical properties of the whole landslide main body. One part of the hillslope reach in weak zones is the crown of the Pruna. This lineament of weak rocks generates some local detachments that caused important rock fall of single block.

If the two cases were analyzed it's possible to understand that the presence of weak rocks in different position plays a diverse role in instability of the slope. The localization of the fault rocks on one surface of rupture is the most dangerous case.

The two landslides are deep seated slide and this type of landslide is often proceeded by long phase of creep. Spriana Landslide has a particular phase of creep governed by the presence on two different surface of rupture:

-the first one is positioned on the fault rocks

-the second one is subjected to a progressive creep due to the action of the other surface that induced the progressive creep. When also this second surface breaks the landslide will happen.

The second landslide (Pruna landslide) is different in the mechanism of failure. The landslide is a deep seated rock slope landslide but the surface of rupture is not characterized by a defined lineament but is localized in a very fracturated band of rocks. The fracturation is not due to the presence of a fault but is due to glacial action during the past. In this case the role of weak rock is secondary and the real role is to decrease the geotechnical properties. Instead in Spriana landslide the movement is governed by the presence of this weak zone.

Also for the definition of the risk scenarios with the evaluation of the triggering threshold is necessary to understand the role of weak rocks. In Pruna landslide the fault rock contributing in the instability with the decreasing of the properties instead in Spriana landslide the thresholds consider that one surface of rupture in completely broken and there, for example, water plays an important role.

Also in the definition of the best numerical methods to use in simulation is necessary to understand the role of weak rocks. In literature it is possible to use different methods: continuum modeling, discontinuum and hybrid/coupled methods. To define the best methods for the case study is necessary to understand the parameter, the geological condition and the advantage/disadvantages of each method.

Pruna landslide is characterized by the presence of rock and the role of weak rocks is only to decrease the geotechnical properties; for these features the discutinuum models is the best in order to simulate the behavior of the landslide. Instead for Spriana landslide the situation is more difficult. The slope is characterized by the presence of rock but for the complex geological structure due to the weak rocks on the surface of rupture continuum modeling is the best numerical method in order to understand the long phase of creep. For Pruna landslide the unique method is discuntinuum model; for Spriana it depends on the purpose. If the scope is to understand the different phases of creep is necessary to use continuum model; if the scope is to define the safety factor maybe the best method is hybrid one.

Now some new simulations are in progress and after the results new data will be available in order to understand the role of the weak rocks in the landslide evolution.

Conclusions

With the comparison of these two cases the role of weak rocks was analyzed. The result obtained showed the importance of the presence of fault rocks in the instability evaluation. It's important to define the localization of the weak areas in order to define the real role played in the instability. In Spriana landslide the surface of rupture is positioned on the weak band due to the presence of an important fault. This is the worst case that can evolve in a real dangerous event because one of the two surface of rupture of the wedge is totally broken (with continuity). For this the deep seated rock slope movement can evolve with a progressive phase of creep in a rock avalanche. Instead in Pruna landslide the spread diffusion of weak rocks plays a different role: decrease the geotechnical properties.

When weak rocks are present, it is important to define a 3D physical model in order to understand the localization and the role of these complex structure. After this it's possible to choose the best methods for evaluating the risk scenarios, the triggering factors, to forecast the event and so on. Moreover, the understanding of the role of these rocks is also useful to understand the best monitoring system for that case and also to understand the monitoring data for prediction of landslide movements.

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The First Emergency Management for Landslides in Urbanized Areas

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Abstract. The research project is born as an attempt to target the composite problem of emergency management due to hydrogeological risks that may involve urbanized areas, and that can also be extended to other risk typologies (seismic, industrial, chemical, etc). During initial emergency management activities, the organizations that provide first aid have to apply suitable technical and organizational procedures finalized to save the highest number of persons. In order to reach this objective, it is compulsory to implement an intensive research activity finalized to the evaluation of secondary collapse from which the first aid units may be affected. It is also necessary to develop decision-support instruments and technological solutions which may provide information concerning residual risks. At the same time, there is a need to identify the most promising areas where to find survivors by intersecting demographic population information, with geographical and visual information coming from the emergency site. In fact, the project is founded on a synergic evaluation of several parameters:

- the detection of signs that can give predictive indications on the residual risk;
- the inherent analyses related to structural aspects of affected buildings (designing solutions for the penetrability of the rescuers within damaged buildings);
- managerial and organizational considerations with the final attempt "to plan" the aid activities.

This project is a component of the Urban Search and Rescue international project that requested the scientific and technological contribution from the Politecnico di Milano to support the National Fire Department to optimize the first emergency management during disasters such as landslides affecting strongly urbanized areas. The main objective of the project is to define operative and technological instruments which should provide real support to managers when conducting the first emergency operations in case of landslides. It's important to develop procedures, technical solutions and decision support system that can contribute to ensure efficiency during the operations.

This paper presents a new approach targeting residual risk evaluation. The paper describes the first results of the whole project: a decision support tool, based on Bayesian Belief Network (BBN), for residual risk evaluation during rock fall. The variables in the model allow both the representation of the causal structure of physical phenomenon and the assessment of other context factors affecting emergency planning and management. The quantification of this advanced Decision Support System (DSS) is based on data gathered from available monitoring system and on experts' judgements. The paper starts describing the Bayesian-based approach, showing the ability of the model to integrate different data-sets in different steps of the analysis (from the preliminary definition of the hydro-geological influences to the integration of expert's observation into the model). Finally, a brief case study is presented referring to a rock fall event in an urban area, where the capability of the BBN is shown incorporating direct historical observations and describing a real case of rock fall.

Keywords. Risk evaluation, prediction, first emergency, Bayesian belief network

1. Hazard management and public protection project at Politecnico di Milano

Recent catastrophic events demonstrate the importance of post-disaster interventions where management of rescue operations and recovery assistance to citizens, coordination of several organizations and allocation of proper resources are truly critical issues.

For this purpose, in 2005 the Politecnico di Milano (Italy) university started an international project (PROMETEO) focusing on different research fields on the theme of hazard management and public protection. The basic aim was to establish several multi-disciplinary investigation teams collecting different resources (instruments, knowledge and people) working inside the university. One of the components of this project, called GPE ("Gestione della prima emergenza per frane in aree urbanizzate" – The first emergency management for landslide in urbanized areas), is focused on establishing criteria to optimize aid actions related to a hydrogeological disaster. This project is focused on a particular problem that can involve urban areas: landslides. Landslide is a real common problem in mountain areas and sometimes the complex geological conditions make it quite impossible to forecast the events. The project aims to develop several operative and technological instruments to provide real support to the management of the first emergency in case of landslides.

The problem of preventing or reducing damages related to landslides is complex, due to the very large number of feasible scenarios, with the local morphology of the site providing an additional degree of freedom. Due to this complexity, several competences are needed to address at the best methods and investigation techniques. The development of new technical instruments is not enough for a landslide problem. It's also necessary to improve the operative and organizational logistics of the managers in charge of technical rescue to save the higher number of human lives involved in a hydrogeological event.

Due to the complexity of the situation after a hydrogeological event and the amount of information to be processed, specific decision-support tools are needed that allow decision maker to provide prompt responses and effective coordination of all the actors within the Civil Defense System.

In this paper the first segment of this decision support system is reported: the DSS related to the residual risk evaluation.

There are many different landslide typologies. Among landslides, rockfall is one of the most dangerous phenomenon when it comes to the safety of the people. A rock fall consist of blocks that fall due to slope traction or shear joints and the phenomenon can be divided in different steps: detachment, free falling, impact bouncing and sliding. The number of events that may cause a fall is wide and almost unpredictable. Risk of damages to infrastructure due to rock fall is really high (fig. 1) and another problem is due to the large areas of danger that administration have to evaluate. For this purpose during the project a particular decision support system was created in order to develop a support-tool to assess and manage rock fall disasters.

Fig. 1 Rockfall in the North of Italy.

2. The Bayesian Network (BBN) for rockfall evaluation

The BBN definition for rockfall is necessary for the complexity of the situation and for the amount of information available to forecast the rockfall event. The variables in the model allow both the representation of the causal chain of physical phenomena and the assessment of other context factors affecting emergency planning and management. The quantification of this advanced Decision Support System (DSS) is based on data gathered from available monitoring system and on experts' judgments. The first paragraph starts describing the Bayesian-based approach, showing the ability of the model to integrate different data-sets in different steps of the analysis (from the preliminary definition of the hydro-geological phenomenon to the integration of expert's observation into the model). In the next paragraphs a brief case study is showed.

The construction of a BBN is made up of two fundamental steps: 1) the definition of the variables and of the links between variables, 2) the quantification of the links in terms of conditional properties. In both steps the contribution of experts is required to define the knowledge space, both in qualitative terms and quantitative terms. The logic of procedure is comparable to the construction of a cognitive map, since it is possible to proceed by identifying which causes may lead to some effects and vice versa.

For the BBN construction a real detailed analysis of rock fall phenomena was necessary. The evaluation of rock fall risk requires information regarding precursor phenomena, geomorphologic assessment, climate conditions, monitoring of the ground deformation etc. Without such information, it's impossible to forecast a rock fall. Another important problem is data processing. In this case a methodology for the analysis of all data are proposed. The literature on the topic includes a lot of methods which can be used to forecast rock fall. The goal of this project is to develop a new method that takes into consideration all the useful information concerning rock fall evaluation. The Bayesian Network is an approach to integrate geological and monitoring data. Table I presents all the information considered in the BBN.

Table I. Data used for BBN

MACRO SITUATION	IMMEDIATE EFFECT	IN SITO CONDITION	EFFECT	EVENT
•Rainfall •Landslide •Earthquake •Snow melting •Wind •Erosion •Cryoclastism	•Runoff •Vibration •Sail effect •Water level (piezometric)	•Geological condition -lithology -Weak zones •Vegetation •Morphologic condition	•Erosion •Hydraulic aperture •Crack generation •Pressure	Rockfall

As presented in table I, the BBN construction starts with the analysis of the macro situation (for example the climatic condition, triggering factors), then continues with the assessment of an immediate effect that can generate the final events. In this context, it is important to analyze the geomorphologic condition of the single case which may be characterized in terms of geologic conditions, the presence of particular vegetation (that can play an important rule in risk analysis) and the morphologic situation of the slope. Subsequently it's necessary to observe the effect due to the combination of triggering factors and predisposing situation of the single case. All this information may then be used to forecast a rock fall. The first step in the construction of the BBN was the definition of variable (table I) as well as the links, obtaining the hydrogeological BBN shown in figure 2.

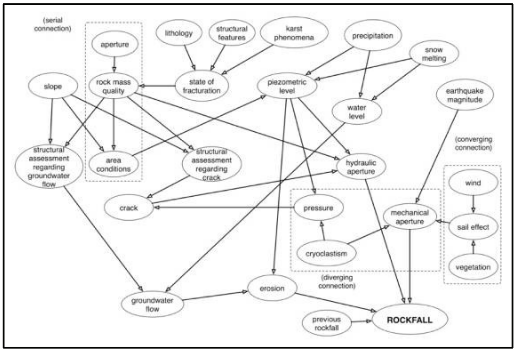


Fig. 2 The hydrogeological BBN for forecasting rock fall.

In the second step all the links were quantified: the method adopted for the quantification of the Conditional Probability Tables (Table II) is largely based on the elicitation of experts' judgments (fig. 3).

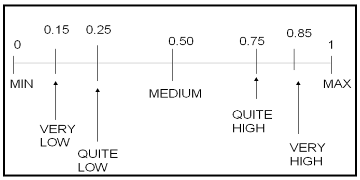
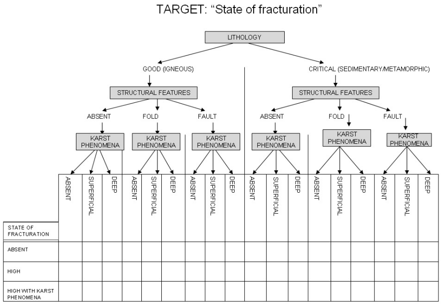


Fig. 3 Example of comparative judgments scale.

Table II. Example of table for state of fracturation target



STATE OF FRACTURATION	ABSENT	SUPERFICIAL	DEEP	ABSENT	SUPERFICIAL	DEEP	ABSENT	SUPERFICIAL	DEEP	ABSENT	SUPERFICIAL	DEEP	ABSENT	SUPERFICIAL	DEEP	ABSENT	SUPERFICIAL	DEEP
ABSENT																		
HIGH																		
HIGH WITH KARST PHENOMENA																		

The qualitative topology of the network is translated into a quantitative model of relationships between variable by the Conditional Probability Tables, which are generated for each variable in the network that has input nodes (fig.3 and table II).

After the quantification of the variables the BBN is now capable of returning the probability that a rock fall may take place in a specific case.

3. Case Study: the Varenna rock fall

This part of the article presents the model employed in the rock fall that involved the Varenna built up area for evaluating in back analysis the probability of a rock fall. The area implicated in rock fall was classified as unstable ever since; the territory frequently collapses and slopes above Varenna, Fiumelatte and Pino built up areas are intensely jointed.

“At 5 PM, on November 13th, 2004; in an elevation of the order of 600m above the sea level, a rock collapse took place in the Foppe Mountain, displacing 15000 m^3 or material towards Fiumelatte (fig. 4). The rock fall destroyed two houses and seriously damaged five buildings. Furthermore the railway segment Milano-Lecco-Sondrio-Tirano was interrupted because of rocks on the tracks and two electrical power lines were damaged. The biggest rock ($110m^3$) killed two persons. (Lombardy region report, Zaccaone A. Bonalumi G.).

Fig. 4 A case of rockfall happened at Fiumelatte di Varenna (North of Italy).

With the predisposing conditions quantified and with the addition of the values corresponding to the environmental conditions (triggering factors), the BBN returns a very high value for the probability of rock fall (P (Rock fall) = 95,15%).

In particular the contribution of the environmental conditions observed is about 30%. The variables “mechanical aperture of discontinuities” and “hydraulic aperture of discontinuities” have great impact on the BBN model. For example, a fissure increase in the order of centimeters per day (or week) measured with a fissure gauge is an extremely important warning signal, as such an information could be employed to promote the evacuation of the surrounding urban areas in case of imminent rock fall.

The case study brings out the fact that the combination of the strong wind recorded on the 13th of November, and the presence of tall, leafy trees (conifers), generated a strong sail effect destabilizing the mountainside and producing the rock fall. In addition to the external mechanical stress due to the sail effect, the case under analysis reveals the presence of an area which is intrinsically predisposed to landslide and rock fall.

The sedimentary lithology, the presence of numerous discontinuities, and the steep gradient are characteristics which can strongly predispose the detachment of material. In short, when the observations carried out in the simulation lead to a value in the order of millimeters being associated to the daily variation of the apertures, the network returns a probability P (Rock fall) = 68%, whereas if (for example with monitoring instruments) an evolution of the phenomenon in the order of centimeters is observed, the BBN returns an extremely high probability value, that is to say an almost certain occurrence of the rock fall.

The simulation run using the BBN therefore proves to be consistent with the true evolution of the phenomenon as described on the basis of the data available for the Varenna rock fall.

Conclusions

The result obtained following the simulation has allowed the following objectives to be met: 1) to obtain an initial validation of the model and 2) to provide initial information which can be used to support the decision making process in the early stages of emergency. The preliminary results provided by this case study do quantitatively confirm the validity of the knowledge space of the BBN: marginal probabilities returned by the model are consistent with the qualitative description of the real event. Finally, what is more interesting from an operational point of view, the BBN model of a rock fall demonstrated a good sensitivity with respect to the type and amount of available information. Indeed, the analysis pointed out that the simple observation of the predisposing environmental conditions leads to a limited variation in the probability of occurrence of the rock fall – information that is marginal in decision making terms –, but the analysis also demonstrated that the improvement of the BBN knowledge about rock fall phenomenology (e.g. aperture discontinuity), either direct or via network computation, returns clear and unambiguous assessments (in the case study the rock fall probability increased over 95%). This leads to the conclusion that the BBN is able to exploit all the knowledge made available by the experts on the ground and by monitoring devices.

In the case of environmental conditions favouring rock fall (persistent rain, seismic phenomena, steep slope of mountainside etc.) the proposed model can be jointly used with predefined threshold values to identify critical situations or areas and to release early warnings and alerts. Thanks to early warnings, anticipated inspections can be scheduled, obtaining more precise information and observations on the actual site conditions, which can be used to update the corresponding variables in the BBN.

Further steps of the research project will focus on the development of a fully integrated system for monitoring, improved situational awareness, and decision-making, during emergency management.

This paper show the decision support system built for the residual risk analysis. In this project some new technologies were developed and at the end of the project a new complete decision support system (not only with the probability of rock fall but also with the chosen of monitoring system etc.) will be shown.

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A Unsaturated Hydro-Mechanical Framework for Infiltration-Induced Shallow Landslides

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Abstract Infiltration-induced shallow landslides occur every year in mountainous regions around the world. Infiltrating water resulting from heavy precipitation typically passes through the vadose (unsaturated) zone before it reaches the water table. This process is transient and a function of precipitation intensity and duration, the initial moisture conditions and hydraulic properties of hillside materials, and the hillslope morphology, geology, and vegetation. Consequently, soil suction, moisture content, and effective stress vary dynamically over seasonal and shorter timescales. We present a rigorous hydro-mechanical framework to quantitatively account for this spatial and temporal coupled process in hillslope environments. A transient two-dimensional unsaturated flow field is quantified by solving Richards' equation with appropriate initial and boundary conditions. The resulting suction and moisture fields will then be used for solving the transient effective stress field using a novel concept for generalized effective stress called "suction stress." We demonstrate, through a case study analysis, that this simple framework is capable of accurately predicting the timing of real landslides induced by infiltration.

Keywords. Infiltration, shallow landslides, stress analysis, unsaturated flow, landslide prediction

1. Introduction

Infiltration-induced shallow landslides are dynamic coupled hydro-mechanical processes. As rainwater infiltrates into hillslopes, soil moisture and suction vary spatially and temporally. Consequently, soil weight and stress fields vary dynamically. When the state of stress within a hillslope reaches its strength, landslide failure occurs. While the afore-mentioned hydro-mechanical processes have been recognized in the past, comprehensive quantitative frameworks rigorously describing these physical processes are still lacking. For example, classical slope stability analysis typically assumes that hillslopes are either completely saturated or dry, in which Terzaghi's effective stress principle is practically valid. In recent years, the understanding of unsaturated flow processes in the zone between the ground surface and the water table has been greatly expanded. However, most frameworks for stability analysis incorporating the effects of the unsaturated zones are not rigorous. Some explicitly consider unsaturated hydrology but still employ Terzaghi's effective stress principle, which is invalid for describing effective stress in the unsaturated zone. Others modify the shear strength of hillslope materials under unsaturated conditions. Frameworks that modify soil shear strength suffer from an inconsistency in dealing with the saturated and unsaturated zones, as Terzaghi's effective stress principle is used below the water table and total stress approach is used above the water table. Because the water table can vary both in space and time and slope failure may occur in either or both zones, a framework employing a consistent effective stress principle for both unsaturated and saturated hillslope materials is attractive. An effective stress principle for variably saturated materials also eliminates the need to modify shear strength, as it should be invariant relative to material's saturation. This paper attempts to provide a comprehensive quantitative framework capable of simulating and predicting the occurrence of infiltration-induced shallow landslides.

2. Framework

The framework consists of four coupled components: an unsaturated seepage field, an unsaturated effective stress, a stress field of unsaturated poro-elasticity, and a shear strength criterion (Mohr-Coulomb) for stability determination, as described below.

2.1 Unsaturated seepage theory

We use the widely accepted Richards' equation to quantify spatial (x_1, x_2, x_3-gravitational direction) and temporal (t) variations of soil suction and saturation. If soil matric suction head h_m is considered as the dependent variable, the governing equation can be written as:

$$\frac{\partial}{\partial x_j}\left[k_j(h_m)\left(\frac{\partial h_m}{\partial x_j}+\delta_{3j}\right)\right]=\frac{\partial \theta}{\partial h_m}\frac{\partial h_m}{\partial t} \tag{1}$$

where soil moisture content θ is characteristically related to soil matric suction head via the concept of the soil-water retention function $\theta = \theta(h_m)$. The soil-water retention function is considered as one of the two hydrologic properties of hillslopes. The other property is the hydraulic conductivity functions $k_1(h_m)$, $k_2(h_m)$, and $k_3(h_m)$. For homogeneous and isotropic materials, the three hydraulic conductivity functions reduce to one. The following widely used closed-form functions for soil-water retention (van Genuchten (1980) and hydraulic conductivity (Mualem, 1978) will be implemented:

$$\frac{\theta-\theta_r}{\theta_s-\theta_r}=\left\{\frac{1}{1+\left[\alpha\left(u_a-u_w\right)\right]^n}\right\}^{1-1/n} \tag{2a}$$

$$k=\frac{\left\{1-\left[\alpha\left(u_a-u_w\right)^{n-1}\right]\left[1+\left(\alpha\left(u_a-u_w\right)^n\right)^{1/n-1}\right]\right\}^2}{\left[1+\left(\alpha\left(u_a-u_w\right)\right)^n\right]^{(n-1)/2n}} \tag{2b}$$

where θ_r and θ_s are the residual and saturated volumetric moisture contents, n and α are parameters of unsaturated porous materials, and the quantity $(u_a - u_w)$ is called matric suction in pressure units and is equal to $-\gamma h_m$ with g being the unit weight of hillslope material.

The governing equation (1), together with the two hydrologic functions (equation (2)), appropriate surface topography, subsurface geometry and of flow, and infiltration conditions, forms a well-defined boundary value problem that completely defines transient fields of soil suction and moisture. The field of soil suction will be used to solve the effective stress field under variably-saturated condition as described below.

2.2 Effectives stress principle for unsaturated soil

The novel and core part of this framework is the implementation of the unified effective stress principle recently established by Lu and Likos (2006). It can be considered as an expansion of Terzaghi's effective stress into unsaturated conditions and unification of the classical soil mechanics and modern soil suction concept. The generalized effective stress that unifies both saturated and unsaturated conditions via the concept of suction stress can be expressed as (Lu and Likos (2006):

$$\sigma_{ij}'=\left(\sigma_{ij}-u_a\right)-\delta_{ij}\sigma^s \tag{3}$$

where u_a is the pore air pressure, and σ^s is defined as the suction stress characteristic curve of the hillslope materials with a general functional form of:

$$\sigma^s=-(u_a-u_w) \qquad u_a-u_w\le 0 \tag{4a}$$

$$\sigma^s=-\frac{\left(u_a-u_w\right)}{\left(1+\left[\alpha\left(u_a-u_w\right)\right]^n\right)^{(n-1)/n}} \qquad u_a-u_w\ge 0 \tag{4b}$$

Lu et al. (2008) show that the transition between the saturated and unsaturated states in the above equations is smooth, and Terzaghi's effective stress can be deduced under the saturated condition. Once the suction stress field is obtained, it can be used in a linear poro-elasticity theory to obtain stress field as follows.

2.3 Poro-elasticity

The linear poro-elasticity cast in terms of effective stress is developed for stress distribution in hillslopes. In the case of two-dimensional plane strain (j = 1, 3), the following three equations completely define three stress components (σ_{11}, σ_{13}, σ_{33}):

$$\frac{\partial\sigma_{ij}'}{\partial x_j}-\delta_{ij}\frac{\partial\sigma^s}{\partial x_j}-\delta_{3j}\left(\gamma-\gamma_w\right)=0 \tag{5a}$$

$$\left(\frac{\partial^2}{\partial {x_j}^2}\right)\sigma_{jj}'-\frac{1}{1-\nu}\left(\frac{\partial^2\sigma^s}{\partial x_j}+\delta_{3j}\frac{\partial\gamma}{\partial x_j}\right)=0 \tag{5b}$$

where ν is the drained Poisson's ratio of the material, γ_w is the water unit weight, and γ is the bulk unit weight. The bulk unit weight field in the unsaturated zone varies and can be related to the soil moisture content field if soil's specific gravity G_s, porosity m, and water unit weight γ_w are known:

$$\gamma=\left[(1-m)G_s+\theta\right]\gamma_w \tag{6}$$

The boundary conditions at the surface are typically stress-free (zero stress), and within the subsurface are displacement conditions that can be directly calculated by employing linear strain-displacement relationship and Hooke's law (*e.g.*, Reid, 1997).

2.4 Hillslope stability analysis

With the knowledge of the effective stress field, shear stress at any point can be calculated and checked against the Mohr-Coulomb failure criterion to see if failure occurs within a hillslope. This is typically done by defining the factor of safety at any point within a hillslope as below:

$$FS\big|_{\max}=\frac{\tau_f(\beta)}{\tau(\beta)}=\frac{c+\sigma_\beta\tan\phi}{\tau(\beta)}\quad 0\le\beta\le 360^o \tag{7}$$

In summary, the coupled hydro-mechanical framework, equations (1)-(6), completely define the transient fields of suction, moisture content, wet unit weight, and effective stresses. There are 8 necessary material parameters (functions), namely, α, n, m, c', ϕ', ν, G_s, and γ_w needed to be determined by either laboratory, or field testing, or modeling synthesis. These fields are necessary and sufficient for analyzing and predicting infiltration-induced landslides by equation (7). Equations (1)-(7) are implemented in a finite difference code VS2DS (Variably-Saturated 2-Dimensional Stress), which is an extension of the USGS (U. S. Geological Survey) code VS2DI (Hsieh et al., 2000) for simulation of 2-dimensional unsaturated flow.

3. Case Illustration

For illustration, we use a field site located near Seattle, Washington, US (Godt et al., 2005). The cross-sectional geometry is shown in Figure 1a, along with the finite-difference mesh and BC conditions. Figure 1a shows a 50% reduction of the full scale, i.e., 15 indicates 30 m and the slope is about 30 m in height. The measured hydro-mechanical properties of the slope are shown in Table 1. The simulated infiltration boundary conditions are listed Table 2. The recharge conditions consist of 270 days of evaporation and infiltration to reach some steady-state conditions, and 97 days of episodic precipitation that occurred during October to January 2006.

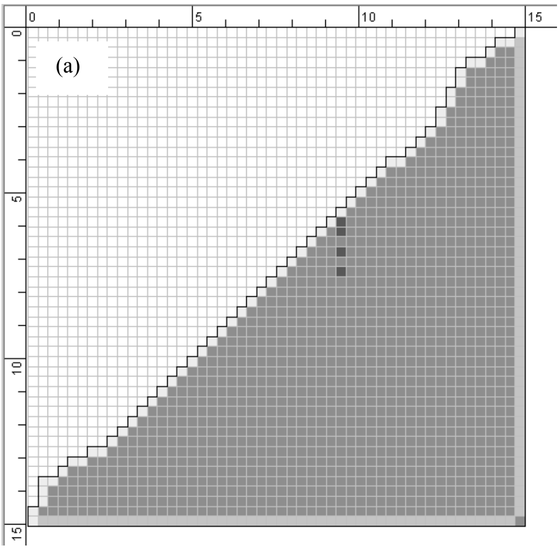
Table 1. Hydro-mechanical properties of the slope.

Soil Properties

Van Genuchten parameters	α	9.67
	n	2.69
Residual water content	θr	0.066
Saturated water content	θs	0.48
Saturated hydraulic conductivity	Ks (m/s)	5E-05
Friction angle	ϕ' (deg.)	33.6
Cohesion	c' (kPa)	4.33

Table 2. Infiltration conditions.

Period	Time (day)	B.C.	Magnitude (m/hr)	Note
1	90	Evap.	9.72E-05	
2	180	Infiltration	1.15E-04	
4	1	Infiltration	1.08E-02	Measured
5	27	Infiltration	2.99E-03	Measured
6	28	Infiltration	2.16E-03	Measured
7	14	Evap.	9.72E-05	Measured
8	27	Infiltration	3.96E-03	Measured



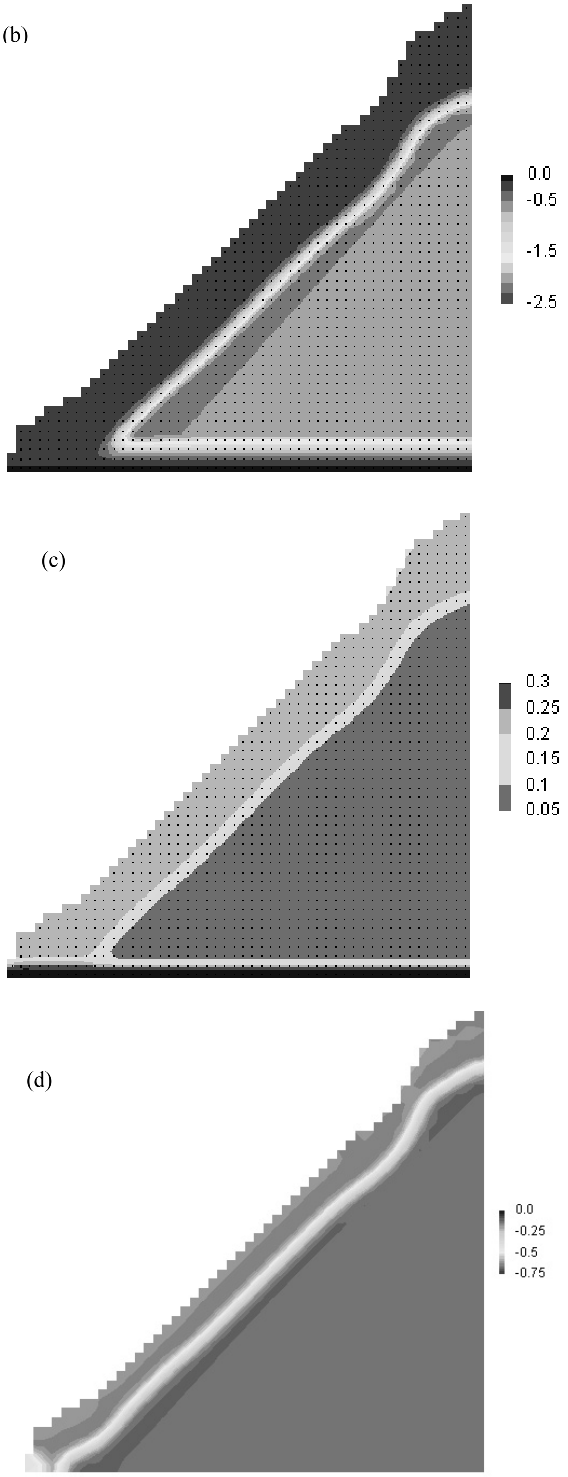


Fig. 1 (a) geometry and finite difference mesh of the slope, (b) soil suction head field in meters, (c) soil moisture content field, and (d) suction stress field in kPa. Figures 1b-1d are the transient fields at 290 days when the failure occurs at the depth of 1.9 m.

Figures 1b-1d provides a snapshot of the transient solutions of fields of soil moisture (Figure 1b), soil suction (Figure 1c), and changes in effective stress (suction stress, Figure 1d). The steady-state condition is established during the first 270 days as is shown in the soil water content (Figure 2b), suction (Figure 2c), and suction stress (Figure 2d) sampled at different depths. Within the 2-m thick surficial mantle of slope, soil water content is about 0.1, soil suction head varies from -2.35 to -2.6 m, and suction stress is relatively homogeneously distributed with a value of about -0.11 kPa.

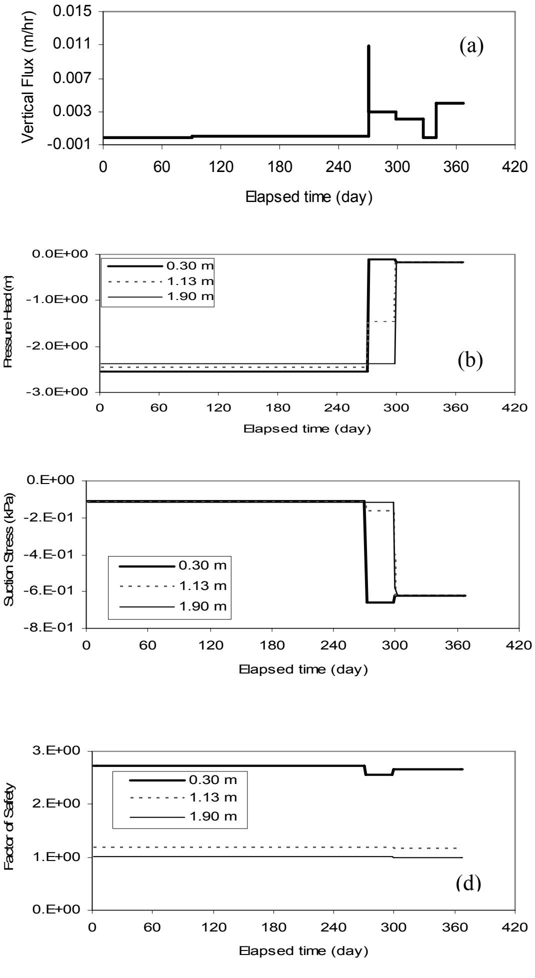


Fig. 2 Time-series for: (a) rainfall rate in meters per hour, (b) pressure heads, (c) suction stresses, and (d) factor of safety at the depths of 0.3, 1.13, and 1.90 m.

As the rainfall period begins, a wetting front moves rapidly down and can be seen from the suction head increase shown in Figure 2b. Consequently, suction stress varies progressively downward (Figure 2c). Suction stress also increases (or becomes less negative, Figure 2c), leading to a decrease in effective stress along the wetting front, and resulting reductions in the factor of safety at these locations (Figure 2d). At about 20 days after the beginning of the rainfall episode, the slope fails at a depth of 1.8 m (Figure 2d). Both the depth and timing of the failure agree well with the in-situ failure observed at this site (Godt et al, 2007).

4. Summary and Conclusions

We show that infiltration-induced shallow landslides can be quantitatively understood using a coupled hydro-mechanical framework. This framework can be applied in two-dimensional hillslopes with properly defined geometry, initial and boundary conditions. A total of 7 governing equations are needed to solve transient fields of soil moisture, soil pressure head, effective stress, and factor of safety. In an idealized homogeneous slope, 8 hydro-mechanical parameters are needed. We use a case study to illustrate that the proposed hydro-mechanical framework is capable of predicting the occurrence of infiltration induced landslide in both space and time.

Acknowledgements

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A Study of Landslide Mechanism in the Three Gorges Reservoir Area

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Abstract. Three Gorges Project is the largest water conservancy pivotal project in the world. It is beneficial for flood control, power generation, navigation and so on. Conversely, it causes problems such as landslides in the reservoir area. With the rise of the reservoir level, the landslide activity in the Three Gorges reservoir region has increased. A study on the causative mechanism of these landslides is provided for purposes of decision-making for landslide prevention. Using the Qianjiangping landslide as a case study, the pore pressure, earth pressure and displacement behavior in consideration with the influences of the reservoir impoundment and the rainfall are discussed, as well as the application of model test simulation analyses and soil tests under different stress paths. The results clarify the causative mechanism, which is useful for field monitoring of the landslides.

Keywords. Three Gorges Project , Reservoir landslide, causative mechanism, model test, three-dimensional limit equilibrium analysis, wet-dry cycle, Dead Load test

1 Introduction of Three Gorges Project

The Three Gorges Project (TGP) consists of three major structures, including the dam, the powerhouses and the ship locks. The dam is 3035 meters long, with the crest at an elevation of 185 meters. The powerhouses have been equipped with 26 units of generators of 700,000 kW each, with a total capacity of 18.2 million kW and annual output of nearly 84.7 billion kWh. The dam has been equipped with twin 5-flight ship locks.

Proposals for constructing Three Gorges were passed in April 3, 1992. On December 14, 1994, the TGP was started formally. TGP is divided to three phases, which encompass a total period of 18 years. In the first phase (1992-1997), the main channel of TGP was dammed, and the stage impoundment of the reservoir reached 88 meters, an increase from 68 meters. In the second phase (1998-2003), the third damming of the main channel was carried out in the Diversion Ditch of the TGP. The 5-stage permanent ship locks of TGP went into operation, which enabled navigation through the Three Gorges. The first power generator of TGP connected to the power grid to begin generating electricity, and at this stage, impoundment of the reservoir reached 135 meters. In the third phase (2003-2009), the water level of the Three Gorges Reservoir will have reached 156 meters in 2006, and will increase to 175 meters in 2009.

The Three Gorges Project, the largest water conservancy pivotal project in the world today, can fully exploit the hydraulic resources in the Three Gorges of the Yangtze River. When the TGP is completed, it will be beneficial in flood control, power generation, navigation, ecological protection, environmental purification and so on. The dam will allow for the elevation of the water level of the upper reach of the Yangtze River of 80 meters in the flood season and 110 meters in the dry season. It can improve the navigating route for Chongqing city of 660 km and increase the shipping capacity from 10 million tons to 50 million tons.

The TGP involves a wide field of challenges, at a large scale, with many complex technical problems. Much attention must be paid to the mud-sand, landslides, earthquake-induced landslides, pivotal project technical problems, diversion and navigation, river closure, environment, emigration, investment, cost/benefit and other issues. In this paper, the landslide issue is discussed.

2 Characteristic of geological hazards in the Three Gorges reservoir area

The Three Gorges reservoir, the super large scaled reservoir, is located at Sandouping, Yichang city in the middle part of Xiling Gorge. The geological condition of the reservoir consists of three parts: from the dam to Miaohe (20 km), is a wide and gentle river valley of lower mountain and hill area consisted of pre-Genesis crystalline rocks and metamorphosed rocks; from Miaohe to Fengjie (140 km), a gorge of medium-high mountains consisting of Genesis to Jurassic limestone and sand-mudstone; from Fengjie to the end of the reservoir (450km), a wide and gentle river valley of lower elevation mountain and hill area consisting of Jurassic sand-mudstone.

Fig. 1 Views of the Qianjiangping landslide

Historic records revealed that in the Three Gorges Reservoir area more than 2000 landslides and rock falls had occurred and more than 90 debris flow sites were identified. As reservoir impoundment will raise the water level rapidly and disturb the balance of the geology, it is anticipated that the impoundment of the Three Gorges Reservoir may cause further landslides and rock falls, as well as erosion of the banks of the reservoir. Many slopes began to show noticeable deformation after the first stage of impoundment in 2003 and some landslides occurred during intense rainfalls. The Qianjiangping landslide (Figure 1), for example, occurred after the first stage of impoundment (starting from 68 m a.s.l. on June 1, 2003, and reaching 135 m a.s.l. on June 15, 2003) of the Three Gorges Reservoir. During the same period, there was heavy rainfall (162.7 mm, from June 21 to July 11) (Dai et al 2004, Wang et al 2004, Ministry of Land and Resources 2003, Wang et al 2003, Zhang et al 2004). As the water level of the Three Gorges Reservoir reaches 156 m in 2006, and 175 m in 2009, the frequency of landslides and rock falls in the Three Gorges Reservoir area is expected to increase further. Therefore, research on landslide and rock fall in this area has become quite urgent. As a case study on the causative mechanism of Qianjiangping landslide, the results are significantly important for later landslide controlling and forecasting in the area.

3 Mechanism of Qianjiangping landslide

The Qianjiangping landslide resulted from the low dip angle layered structure of rock, bedding plane shear band, foreside low dip angle fault, and steep dip fissure fault of strike SE in both eastern and western sides of the slope. Its geomorphic features, geologic constitution and structure, and the material composition are very typical in the Three Gorges Reservoir area. Since the landslide happened during the rainy season and the first impoundment of the reservoir, it is natural to associate rainfalls and reservoir water with potential causes of the landslide. Considering these two factors that were quite common throughout the Three Gorges Reservoir area, we contend that further research on the causative mechanism of the landslide was of considerable significance for landslide control and forecasting in this area. The causative mechanics of the landslide have been studied by means of the model study, simulation analyses and soil tests under different stress paths, etc.

3.1 The model study on the Qianjiangping landslide

Fig. 2 Landslide model test system

Based on site exploration and test, a geologic model and a physics model for the Qianjiangping landslide were established. The test system is composed of a flume and lifting system, artificial rainfall system, water supply system, and a comprehensive measuring system (Figure 2). 4 observation sections are setup for the different positions of the landslide, in which there were 8 earth pressure transducers, 8 pore pressure sensors, 4 surface displacement sensors, 12 displacement measurement points measured with optical methods, and 12 measurement points for water content (γ-ray method) (Figure 3). Similarity model test analysis on the pore water pressure, earth pressure and distortion features of the landslide under the influences of reservoir impoundment and rainfall infiltration either respectively or jointly are presented. Based on all these analyses, the causative mechanism of the Qianjiangping landslide was finally revealed.

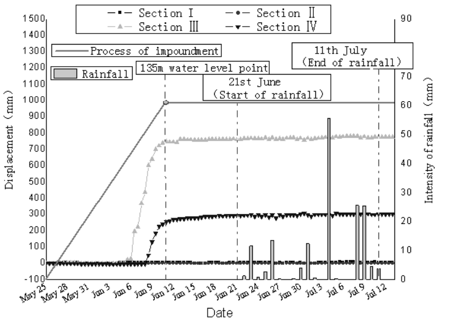


Fig. 4 Displacement of all sections

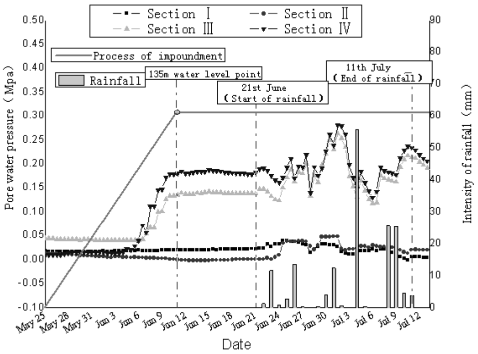
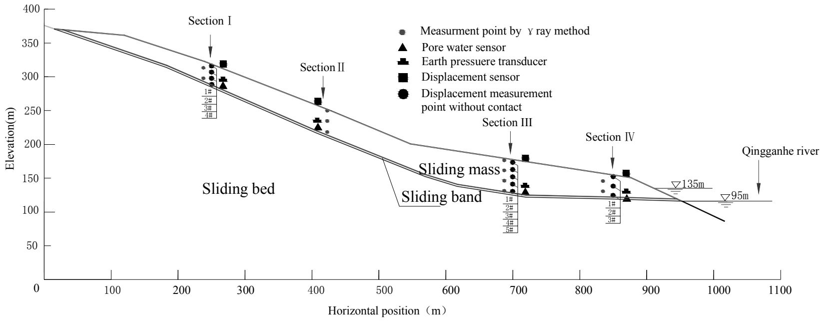


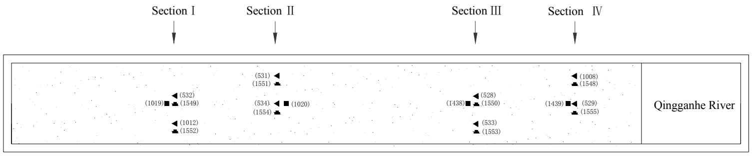
Fig. 5 Pore pressure of all sections

From the model test results (Figure 4, 5), we have the following conclusions: (1) The pore water pressures in the foreside of the slope increased with the reservoir water level, and fluctuated and later increased with rainfall. It is shown that the rainfall and impoundment have distinct influences on the pore water pressures. (2) The earth pressures of slope increased with the reservoir water level, and fluctuated with the rainfall. It is shown that the rainfall and impoundment have distinct influences on the earth pressures. (3) During the impoundment of the reservoir, the displacements in the foreside of the slope increased abruptly and greatly. It is shown that the impoundment of the reservoir has strong influence on the displacement of the landslide. (4) The first slide in the model occurred, distinctly motivated by the impoundment. It shows the same characteristics as the first landslide of the Qianjiangping slope. (5) The second landslide in the model didn't occur due to strong friction on the surface of the two sides of flume. It is necessary to reduce the friction

to trigger the landslide in the future.



(a) Side view on Qiangjiangping landslide model



(b) Planform of Qianjiangping landslide model

Fig. 3 Layout of measurement points

3.2 Simulation analyses of the Qianjiangping landslide

GEO-SEEP is adopted to analyze and calculate the groundwater movement, the conditions of rainfall and that of the reservoir water impoundment respectively (Figure 6). The results (Luo et al 2007) show that when the rainfall and the reservoir impounding effects coupled, we get results different from when these two factors were considered respectively. Coupled effects of these two factors within the horizontal distance ranging from 600 m to 900 m made the groundwater level rise by a considerable figure, which was bigger than the summation of that caused by them respectively. The rainfall had been acting solely on the slope for 20 days. However, few noticeable variations in the groundwater table in this horizontal distance had been seen. On the 50th day (i.e. July 20, 2003), the groundwater table ascended to nearly 135 m. When reservoir water and rainfall affected the slope together, the groundwater table ascended to around 137 m, 2 m higher than the summation of groundwater ascending caused by the rainfall and reservoir water respectively. In the horizontal distance ranging from 600~700 m, coupled action caused a 4~6 m –higher rising of the groundwater table than that stirred by the two factors respectively. Rainfall chiefly affected the groundwater table in the posterior part of the slope. When coupled with the reservoir-impounding influence, however, it rose higher than that caused by single rainfall action. In the horizontal distance ranging from 200~500 m, a similar result, a 2～3 m dependency was found (Figure 7).

A new three-dimensional limit equilibrium analysis method is developed to analyze the stability of the Qianjiangping landslide when reservoir impoundment and rainfall were acting respectively and jointly (Jiang et al 2003). The results show that if the reservoir impounding acted on the Qianjiangping landslide solely, though the safety factor was reduced to 1.22 and the declining ratio was to 14%, the slope was still stable. When affected by reservoir impounding and prolonged rainfall, the safety factor was reduced to 0.998 and the declining ratio was 27~30%. This was the condition in which the Qianjiangping landslide inevitably occurred.

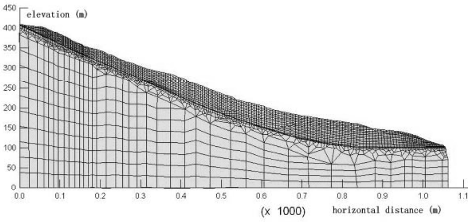


Fig. 6 Element mesh for the Qianjiangping seepage analysis

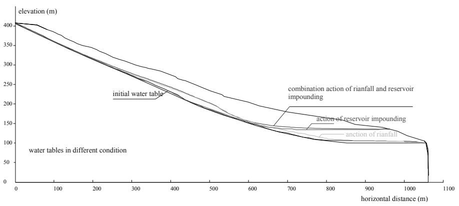


Fig. 7 Water table comparisons for different conditions

3.3 The soil tests of the slide band soil under different stress path

3.3.1 Experimental study on strength properties of the Qianjiangping landslide band soil under the Wet-Dry-Cycle condition

The instability of the landslide in the Three Gorges Reservoir area is caused by the rise and fall of the reservoir water level, atmospheric precipitation and other factors arising from the impact of human activities. Among these causes, the weakening of strength of the slide band soil, which comes from slide band soil being immersed in water repeatedly, is a primary cause of both a large number of ancient landslides reactivating and the initiation of new landslides. The result of the Consolidated-Undrained triaxial test is $c' = 15.7kPa$, $\phi' = 26.6°$. The results of soil samples after four cycles of wetting and drying (Figure 8) is $c' = 11.19kPa$, $\varphi' = 21.6°$. When comparing the soil samples without cycles of wetting and drying in the same condition, the cohesion declined 28.7% and the angle of internal friction degree decreased 18.8%. It is clear that the actual shear strength of the band under both the annual rainfall and water level fluctuations will be continually decreased, until it reaches instability.

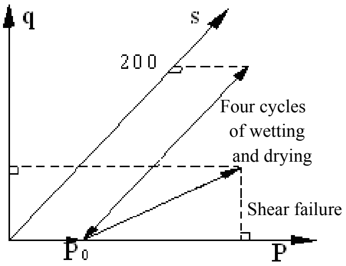


Fig. 8 Stress path of the Wet- Dry-Cycle

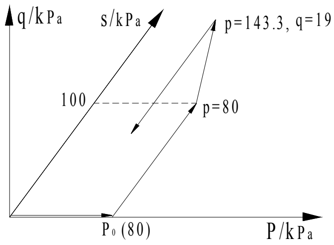


Fig. 9 Stress path of the DL test

3.3.2 Study on the failure mechanism under Dead Load of slipping zone soil

The failure mechanism of the Qianjiangping landslide are explored through the Dead Load test (DL test), where σ1, σ3 consolidation pressure are kept unaltered, to simulate the deformation behavior and strength characteristics of the landside slipping zone soil while matrix suction is decreasing. The stress path is showed as Figure 9. The results (Luo et al 2008) show that in case of $\sigma_1 - u_a = 270kPa$, $\sigma_3 - u_a = 80kPa$, the soil reaches collapse when the suction $u_a - u_w$ is from 100 kPa to 5 kPa, while the shear stress acting on the shear failure surface of the soil mass is $\tau = 86.96kPa$. The shear strength is $\tau_f = 84.05kPa$, when $\sigma_1 - u_a = 270kPa$, $\sigma_3 - u_a = 80kPa$, $u_a - u_w = 5kPa$. It is suggested that moisture hydroscopic of the soil mass caused by the rainfall and rising reservoir water (increasing pore water pressure and decreasing matrix suction $u_a - u_w$) would lead to the failure of soil mass as well as unbalance of the slope.

4 Conclusion and discussion

Based on all analyses mentioned above, the failure mechanism of the Qianjiangping landslide was finally revealed. During the course of the 135m water level rise due to the impoundment of Three Gorges Reservoir, The pore water pressures in the foreside of the slope increased with the reservoir water level, and the strength of the slipping zone soil decreased with the decrease of matrix suction, which caused the displacements in the foreside of slope to increase abruptly and largely, so it is obvious that the displacement of the Qingjiangping landslide was induced by the 135m water level impoundment of Three Gorges Reservoir and also caused by the shear strength decrease of low-dip-angle fault in the anterior. After the stage of 135m water level impoundment of Three Gorges Reservoir from June 01 to June 10, 2003, the Qingjiangping landslide was subjected to discontinuous rainfall from June 21 to July 11, 2003, the groundwater level of the slope rose higher than that caused by either reservoir impounding or rainfall individually. The pore water pressures in the middle and the back of the slope fluctuated with discontinuous rainfall but was greater than that before the discontinuous rainfall at large, which made the strength of rock and soil of the slope decrease continuously, including the area in the foreside (reservoir water influence) , middle and back (rainfall influence) of the slope. Under these circumstances the bedding plane shear band in the middle and back of the slope, an approximately level crannied fractures at the foreside of the slope, and the deep angle crannied fracture of SE strike of the slope, formed a run-through slipping surface which caused the failure of the slope.

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Landslide Hazard Activities in the United States

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Abstract. Landslides occur in all 50 states of the United States of America and cause on average 25 to 50 fatalities and damage of at least 3 billion U.S. dollars and an average of several dozen deaths annually. The indirect socioeconomic impacts are considerably greater, but are not satisfactorily documented. In 2003 the U.S. Geological Survey (USGS), in concert with its many partners in hazard mitigation efforts in the United States, published the National Landslide Hazards Mitigation Strategy—A Framework for Loss Reduction. This document briefly summarized current landslide research, mitigation activities, and defined the roles of various U.S. federal and state agencies, as well as groups within academia and the private sector. It recommended a long-term strategy that called for significantly increased funding, educational outreach, and development of partnerships to strengthen basic research into landslide processes, emergency preparedness, real-time monitoring, and training. Furthermore, the USGS has also entered into a long-term partnership with the National Weather Service (NWS) to develop a protocol for delivering debris flow warnings in several research areas in southern California. The USGS information about debris flow rainfall thresholds is added to the well established NWS Flash Flood Watches and Warnings system. This has been a success and the USGS/NOAA partnership is exploring several other areas within the United States to expand landslide research and the debris flow warning system. . Recently several state geological surveys, and regional coalitions of counties, have achieved significant milestones in obtaining statewide or regional LiDAR coverages thus enabling these agencies to better inventory, delineate and study deep-seated landslides.

Keywords. Landslide, USGS

1. Introduction

This paper briefly describes the landslide activities of the U.S. Geological Survey (USGS) and its governmental partners at the federal and state levels in the United States. It does not attempt to discuss the excellent landslide research being carried out at many universities and colleges. The USGS leadership role in landslide hazards mitigation arises from the Disaster Relief Act of 1974 (Stafford Act), which delegates to the Director of the USGS the responsibility to issue disaster warnings for an earthquake, volcanic eruption, landslide, or other geologic catastrophe.

Annual losses directly attributable to landslides cost the United States a minimum of 3 billion U.S. dollars (USD) and an average of several dozen deaths (Schuster 1996; Schuster and Highland 2001). If indirect costs, such as disruptions to business and transportation, are included the loss estimates are clearly much larger. In the United States, the earthquake hazard scientific community is able to effectively influence national policy by having their national seismic hazard maps incorporated into national building codes, thus having a major life-saving impact. In the case of landslide hazards, most of the mitigation is accomplished at the local government level through zoning or permitting regulations. Therefore it is important for the USGS and its partners to look for ways to educate and influence local citizens or community zoning officials. This paper will describe several examples of recent education campaigns.

Due to limited budgets and staff, the USGS and its state partners are able to issue warnings in a very limited number of locations throughout the United States, primarily only in those areas where considerable research has taken place, and where requisite information such as rainfall-intensity duration threshold values, detailed geologic maps, and accurate real-time precipitation information is available. This paper will briefly describe progress that the USGS and National Weather Service (an agency within the National Oceanic and Atmospheric Administration (NOAA) have made in implementing a pilot debris flow warning system in southern California.

While landslide inventories of specific areas or modestly-sized regions have been carried out within the United States, there has been no serious attempt to inventory all of the nation's landslides. This paper will refer to a few of the local examples, and will also describe an exploratory meeting of landslide scientists at the USGS and a number of state geological surveys that was recently held to explore ways to implement common protocols and standards for landslide inventories and databases, so that these worthwhile efforts may be more easily aggregated and used by others.

2. National landslide hazards mitigation strategy

In 2003 the USGS developed a comprehensive, multi-sector and multi-agency strategy to mitigate landslide hazards for the United States (Spiker and Gori 2003). The strategy focused on nine major areas and suggested that $20 million USD would be needed annual to succeed. The nine areas include:

1. Research
2. Hazard mapping and assessments
3. Real-time monitoring
4. Loss assessment
5. Information collection, interpretation, and dissemination
6. Guidelines and training
7. Public awareness and education
8. Implementation of loss-reduction measures
9. Emergency preparedness, response, and recovery.

In 2007 the "Landslide Exchange Group" was formed, which consists of landslide scientists from the USGS, AASG and the Federal Highway Administration. The mission of this group is to develop common protocols for collecting landslide inventory information, and look for ways to better leverage and aggregate our information and make it available on the Internet. These cooperative projects in a few selected areas of the United States have been quite successful and show the types of excellent research that could be accomplished with the eventual creation of the cooperative grant programs.

3. Public awareness and education

The USGS is involved in several important education efforts to transfer landslide hazard research and mitigation techniques to the people who most need them. In an attempt to make planning officials more aware of how to use landslide hazard scientific information, the USGS has recently worked with the American Planning Association (APA) to produce a primer on landslide hazards, and to present a number of case studies of how specific communities have successfully incorporated landslide hazard information into their planning and zoning regulations (Schwab et al. 2005). The USGS is also working under the auspices of the International Consortium on Landslides and cooperatively with the Geological Survey of Canada to create a handbook on best practices for landslide hazard mitigation. This book is being created for the public in general, and will contain straight-forward definitions of landslides, illustrations and photographs to illustrate mitigation methods and tools, and will share some best practices to use around one's home or business.

4. Inventories and hazard mapping

The USGS has traditionally focused its landslide hazards research in specific geographic areas, such as the Pacific Northwest or southern California, and applied a broad spectrum of our scientific expertise to intensive studies. By taking this approach, and working with state and local partners, USGS is able to make significant advances in landslide process research, inventories of modern and ancient landslides, production of probabilistic hazard maps, and refinement of sophisticated landslide models.

Radbruch-Hall and others (1983) prepared a landslide overview map of the conterminous U.S. at a scale of 1;7,500,000. This map, which has recently been released in digital format (Godt 1997) depicts areas where large number of landslides exist, and attempts to classify geologic units according to high, medium, or low landslide susceptibility. The USGS has compiled larger scale landslide inventory maps for many regions in the U.S. that document locations, types, and in some cases, relative ages of landslides. Some of these inventories document landslides triggered by single events such as a storm or earthquake These products have proved particularly useful in understanding what geologic, topographic or hydrologic factors contribute to triggering the landslides, thus allowing better understanding of the landslide process.

Landslide susceptibility maps are another common product produced by the USGS in the last few decades (e.g., Brabb et al. 1972; Pike et al. 2001; Pomeroy 1977). These products provide local governments with more useful information on which to base land-use decisions even though they do not assess the temporal frequency or probability of landslides. In cooperation with the California Geological Survey, the USGS prepared maps showing relative susceptibility of slopes to rainfall-induced debris flows in southern California (Morton et al. 2003). These maps were produced by analyzing six sets of aerial photographs taken during rainy seasons that produced many debris flows, and using digital elevation models of the areas to define the spatial characteristics of the debris-flow initiation locations.

5. Warning systems

Several important efforts to assess the likely frequency of landslides or probabilistic depiction of the likelihood of landslides have been carried out by the USGS (Bernknopf et al. 1988; Mark 1992; Campbell et al 1998; Jibson et al. 1998; Coe et al. 2000). By tying these sorts of products to real-time precipitation measurements and robust weather forecasts aided by new generations of radar, the USGS and its partner, the National Weather Service, has twice developed debris flow warning systems. And a pilot area was chosen in southern California to test the concept and develop an intensive research study area. The USGS has committed to assess the potential for debris flow, to identify infrastructure that may be at risk, and summarize these results in a statement called an Outlook. The USGS also defines, and continually refines, the rainfall intensity-duration warning thresholds. NWS forecasters then analyze measured rainfall and forecast rainfall and issue combined flash-flood and debris-flow watches or warnings for the burned areas. Warnings are broadcast through the NWS Advanced Weather Interactive Processing System (AWIPS) to local emergency managers, flood control districts, and the media.

Conclusions

Much excellent landslide hazard research is being conducted in the United States, by the USGS, its partners in the state geological surveys, academia, and by others. Much of this work is being used to effectively educate community planning officials and the public in general. However, to successfully implement the national landslide hazards mitigation strategy envisioned by the USGS and its partners (Spiker and Gori 2003), significant expansion of our current workforce will be necessary.

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Analysis for Stability of Loess Slope under Structural Loads

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Abstract. Deformation and instability of a slope under loads on the top of slope is a common phenomenon in loess plateau. Movement of a slope is always generated by the loads of structure or building materials stacking on the top of the slope. How to estimate or calculate the limit load which cause the slope failing is an important issue, and limit load as a critical value is also valuable to the slope risk predication. The Phoenix Mountain slope, a loess slope in Shaanxi Province of China is introduced, and two analytical methods are used to determine the limit load and analyze the stability of the slope under top loads. One method is the ultimate bearing capacity method based on the limit equilibrium theory and the other is limit loads method based on limit analysis. The calculated results from the two methods are compared with each other. To verify the results from the two methods, FEM numerical simulation of the slope is carried out. Finally, according to the result of calculations and numerical simulation, the range of limit load of Phoenix Mountain slope is determined. It may have some reference value on stability study of loess slopes.

Keywords. Loess slope, stability analysis, ultimate bearing capacity, limit load, numerical simulation

1. Introduction

In China, loess landslides are widely distributed in the loess plateau. Because the risks of loess landslides induced by engineering activity are becoming more serious, it is of great significance to analyze the stability of loess slope under loads on the top of them. The calculation of ultimate bearing capacity based on theory of limit equilibrium is widely used in the field of geotechnical engineering or engineering geology to analyze the stability of landslide. However, the hypothesis of the limit equilibrium theory is too much idealized, and moreover, it does not take into account the yield condition and constitutive relationship of soil (R.F. Craig et al. 1983). Limit analysis method based on theory of plasticity calculates the limit load when a slope fails, but it can't calculate the stress-strain state of soil mass in the slope (W.F. Chen et al. 1991, J.Salecon et al. 1976). Compared to analytical method, numerical simulation may have better effect on the analysis of slope stability.

2. A Case of Loess Slope

The Phoenix Mountain loess slope is located in the north of Shaanxi Province (Fig.1). The landform around the Phoenix Mountain slope is shown in Fig.2. The top of the Phoenix Mountain slope has been excavated to construct a residential quarter of an oil field. The excavated loess was pushed to the upper part of the slope and it caused some active soil pressure on the slope. The loads of structures were also acting on the top of the slope after construction of the residential quarter (Fig.3). The dimensions of the Phoenix Mountain slope are 120-150 m in length and 102 m in height and the slope angle is 30-50°(Fig.4). Fig.5 is the geological map of the Phoenix Mountain slope. Some parameters for three soil layers are shown in Table 1 (Yanxun Song et al. 2005).

Table 1 Physical properties of soil layers

Soil layers	Indexes	Range of data	Average values
1	ρ (g/cm^3)	1.36-1.73	1.53
	c (kPa)	13-29	18.83
	φ (°)	16.9-26.2	20.09
2	ρ (g/cm^3)	1.4 -1.67	1.52
	c (kPa)	25.1-32	30.29
	φ (°)	19.3-25.6	22.56
3	ρ (g/cm^3)	1.46-2.18	1.69
	c (kPa)	36.2-58.6	52.78
	φ (°)	19.1-23.5	21.09

3. Analytical Methods

Two methods are used to analyze the stability of the Phoenix Mountain loess slope. One is the ultimate bearing capacity method based on the limit equilibrium theory, it is used to determine the ultimate bearing capacity of a slope in limit equilibrium state (Xiaoping Zhou et al. 2004, Wen Fan et al. 2005), and the other is the limit load method based on limit analysis theory use the dissipated energy principle to calculate the limit load.

3.1 Basic assumption

(1) The soil mass of the slope is homogeneous. The failure mechanism of the slope is the same as the Prandtl's grand failure mechanism. The whole slip zone of the slope is shown in Fig.6. Wedge *A'AB* is an active Rankine zone (Xueyan Zhang et al. 1993, T. William Lambe et al.1969, M. Jahanandish et al, 2005).

(2) The whole soil mass of the slip zone is in elastic state except for the zone *ABC*. Wedge *ACD* is a passive Rankine zone (Xueyan Zhang et al. 1993, T. William Lambe et al.1969, M. Jahanandish et al. 2005, Yang Xiaoli et al. 2005). The surface *BC* is a logarithmic spiral, which can be formulated as

$$r = r_0 \exp(\theta \tan \varphi) \tag{1}$$

where r_0 is the initial radius of *ABC*, θ is the angle between any r_0, φ is the internal friction angle. The stress state of *A'AB* is shown in Fig.7.

(3) As shown in Fig.6, the rigid body velocity of wedges *A'AB* and *ACD* are v_0 and v_1 respectively. According to the flowing rule, the angle between plastic strain rate and plastic shear strain rate is φ. Because *A'AB* and *ACD* is rigid block, the plastic shear deformation only yielded on planes *A'B* or *CD*, the angles between v_0 and *A'B* or v_1 and *CD* are both φ. If radius of r_0 rotates with an angle of θ about point *A* in wedge *ABC*, velocity can be written as

$$v = v_0 \cdot \exp(\theta \tan \varphi) \tag{2}$$

The angle between the *A'B* and *A'A* is $\frac{\pi}{4}+\frac{\varphi}{2}$.

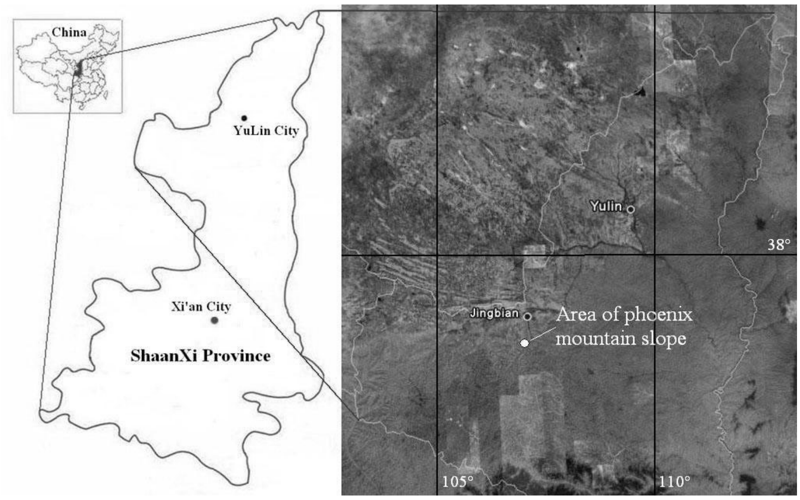

Fig. 1. Location of the Phoenix Mountain loess slope (It located in the loess plateau of the north area of Shaanxi Province, and closed to JingBian town, YuLin City (70km to JingBian town, 37º23'N, 108º46'E). There are some deserts in the west region of this area.)

Fig. 2 The landform around the Phoenix Mountain slope

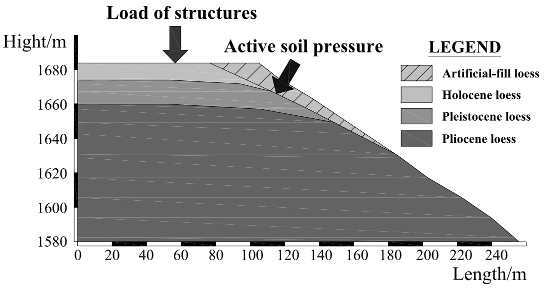

Fig. 3. Sketch showing the geological section and loads

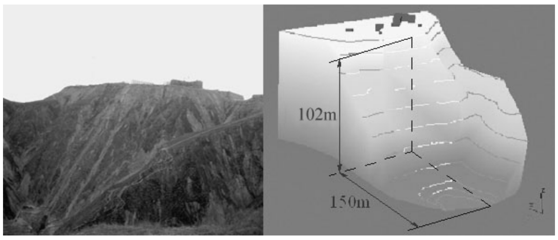

Fig. 4. Field photo and 3D diagrammatic view of slope

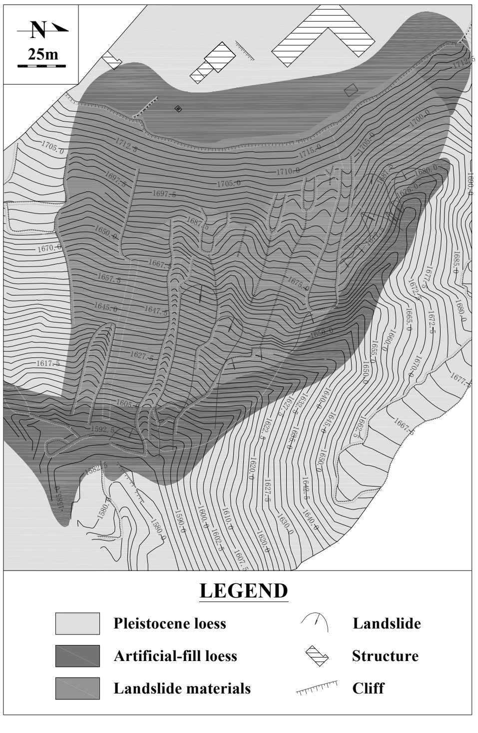

Fig. 5. Geological map of Phoenix Mountain slope

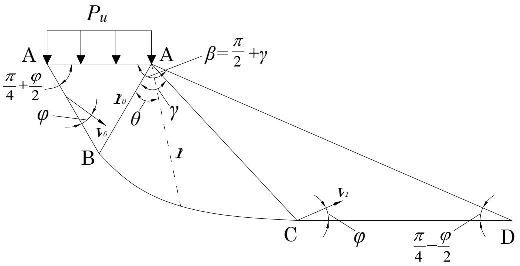

Fig. 6. Failure mechanism of soil slope

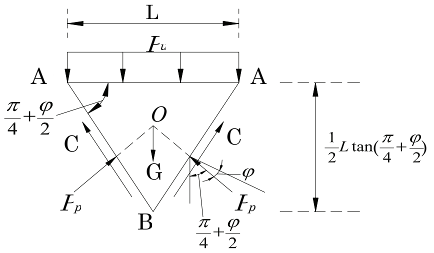

Fig. 7. Stress state of wedge in the upper slope

3.2 Calculating Equations

(1) The ultimate bearing capacity method.

According to the basic assumption and the equilibrium condition of the triangular wedge (Fig.7), the pressure on the top of the slope is

$$Q_u = 2P_p\cos\left(\frac{\pi}{4}-\frac{\varphi}{2}\right) + cL\tan\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) - \frac{1}{4}\gamma L^2\tan\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) \quad (3)$$

where $P_p=P_{pc}+P_{pr}$, P_{pc} is the passive earth pressure yield from cohesion, $P_{p\gamma}$ is the passive earth pressure yield from gravity. P_P is the resultant force of passive earth pressures acting on boundaries *A'B* and *AB* of the wedge *A'AB*, it given by

$$P_p = \frac{L}{2\cos^2\varphi}\left(ck_{pc} + \frac{1}{4}\gamma L\tan\varphi k_{p\gamma}\right) \quad (4)$$

where k_{pr} is the passive earth pressure coefficient of gravity, k_{pc} is the passive earth pressure coefficient of cohesion.

$$k_{pc} = \frac{\cos^2\varphi\left[e^{\pi\tan\varphi}(1+\sin\varphi_t)-1\right]}{\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\sin\varphi} \quad (5)$$

k_{pr} is determined by try-and-error method.

When the slope reaches the state of limit equilibrium, the pressure on the top of the slope is the ultimate load. Substituting Eqs.(4) and (5) into Eq.(3) and simplifying, the ultimate bearing capacity can be obtained as follows:

$$P_u = \frac{Q_u}{L} = cN_c + \frac{1}{2}\gamma LN_\gamma \quad (6)$$

where

$$N_c = \tan\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) + \frac{\cos\left(\frac{\pi}{4}-\frac{\varphi}{2}\right)\left[e^{\pi\tan\varphi}(1+\sin\varphi)-1\right]}{\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\sin\varphi} \quad (7)$$

$$N_\gamma = \frac{\tan\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\left[k_{p\gamma}\cos\left(\frac{\pi}{4}-\frac{\varphi}{2}\right) - \cos\varphi\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\right]}{2\cos\varphi\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)} \quad (8)$$

the N_r proposed by Terzaghi is:

$$N_\gamma = 1.8\left[e^{\pi\tan\varphi}\tan^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)-1\right]\tan\varphi \quad (9)$$

(2) The limit load method

The power of external force P_u is:

$$\dot{W}_{p_U} = 2r_0\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\cdot p_u\cdot v_0\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right) \quad (10)$$

$2r_0\cos(\frac{\pi}{4}+\frac{\varphi}{2})\cdot p_u$ is the force on *A'A*, $v_0\cos(\frac{\pi}{4}+\frac{\varphi}{2})$ is velocity projection on the y direction of *A'AB*。

The dissipated power of friction force on planes *A'B*, *CD* and *BC* is given by

$$\dot{W}_{A'B} = c_t r_0 v_0\cos\varphi_t \quad (11)$$

$$\dot{W}_{CD} = c_t r_0 v_0\exp(2\gamma\tan\varphi_t) \quad (12)$$

$$\dot{W}_{BC} = \int_0^\gamma c_t v\cos\varphi_t dl_{BC} = \int_0^\gamma c_t v\cos\varphi_t\frac{rd\theta}{\cos\varphi_t} \quad (13)$$

$$= \int_0^\gamma c_t vrd\theta = \frac{1}{2}c_t r_0 v_0\cot\varphi_t[\exp(2\gamma\tan\varphi_t)-1]$$

The dissipated power of wedge *ABC*'s deformation is

$$\dot{W}_{ABC} = \int_0^\theta\int_0^r c_t\Delta v\cos\varphi_t dl_{BC} = \int_0^\theta\int_0^r c_t\Delta vrd\theta \quad (14)$$

$$= \frac{1}{2}c_t r_0 v_0\cot\varphi_t[\exp(2\gamma\tan\varphi_t)-1]$$

γ is the angle *BAC*, l_{BC} is the arc length of *BC*.

According to the conservation of energy, the power of external force must be equal to the dissipated power of internal energy as follows:

$$\dot{W}_{p_U} = \dot{W}_{A'B} + \dot{W}_{CD} + \dot{W}_{BC} + \dot{W}_{ABC} \quad (15)$$

Simplifying Eq. (15) and limit load of the slope can be written as

$$p_u = c\cot\varphi[\tan^2(\frac{\pi}{4}+\frac{\varphi}{2})e^{2\gamma\tan\varphi}-1] \quad (16)$$

4. Analytical calculation and Numerical Simulation

According to the above first basic assumption, the physical and mechanical parameters of the second soil layer are selected for calculation. Fig.8 is the calculation model. Based on Eqs.(6) and (16), the limit load value from the ultimate bearing capacity method is 944.5kPa and that from the limit load method is 265kPa.

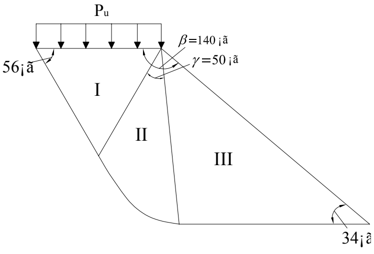

Fig. 8. The calculation model

To verify the result of the two methods, FEM numerical simulation of the slope is carried out. ANSYS software is used to perform the numerical simulation for the Phoenix Mountain slope. Plane strain model and Drucker-Prager criterion are selected. Soil mass of the slope is homogeneous and the parameters for the elastic-plastic finite element method are the same as calculations of the two methods' except for *E* and *v* (*E*= 64 MPa, *v*=0.32).

The limit load of the Phoenix Mountain slope is computed by numerical method. The computation can't converge when the load P_u on the top of the slope increased to 724kPa. Figs.9~11 show the contours of plastic strain in each direction under the load of 724kPa. Fig.11 shows a large plastic shear strain (near 0.103) in the base of the slope and the slope will fail in this situation. The result of numerical simulation is between the results of the two analytical methods. Because the ultimate bearing capacity method is based on theory of limit equilibrium and it does not take into account the yield condition and constitutive relationship, the ultimate bearing capacity method has some deviation. The limit load method is based on theory of limit analysis, but it doesn't consider the stress-strain state in the slope. Refer to the result of numerical simulation, the limit load of the Phoenix Mountain slope at failure is between 265kPa and 724kPa (Fig.12).

5. Conclusion

A case of loess slope is introduced and determination of limit load for this slope is studied in this paper. Firstly, the bearing capacity of the slope is analytically analyzed by two analytical calculation methods, and then, numerical simulation of FEM is carried out. The results of analytical calculation show that the method of ultimate bearing capacity has more deviation for the stability analysis of Phoenix Mountain slope and the limit load of the slope may be refer to the result of the limit load method and numerical simulation. Results of the two analytical calculation methods show that the result from ultimate bearing capacity method is much higher. Because the stress-strain state of soil in the slope is uncertain, the result from limit loads method may have some deviation. According to the result of numerical simulation, the limit load which causes failure of the slope may between 265 kPa and 724 kPa. Therefore, residential quarter constructing on top of Phoenix Mountain loess slope may reference to the range of limit load (265~724 kPa). Determining limit load reasonably is also significant for the slope risk predication.

Acknowledgments

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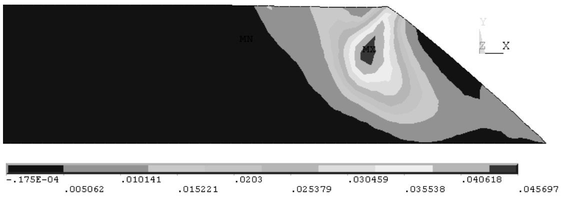

Fig. 9. Contour of plastic strain in x direction

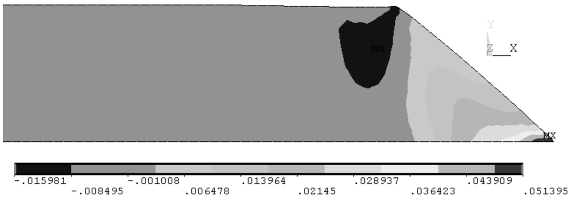

Fig. 10. Contour of plastic strain in y direction

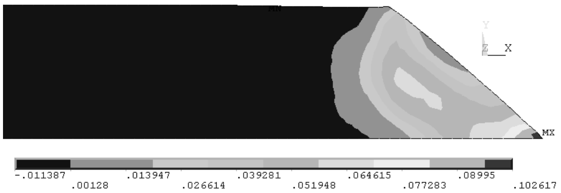

Fig. 11. Contour of plastic shear strain in xy direction

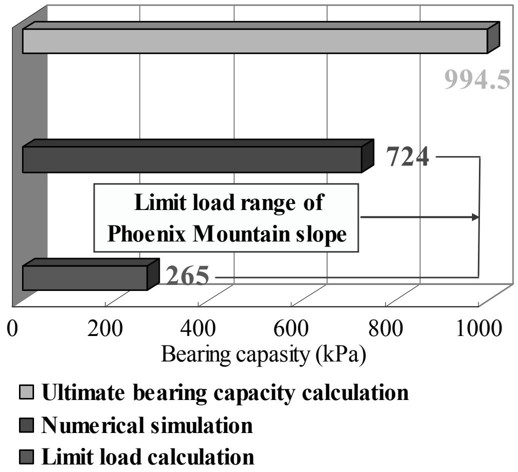

Fig. 12. Result of calculation and the range limit load

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Sediment Production and Delivery from Wildfires: Processes and Mitigation

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Abstract. Few changes in forested areas can have as dramatic an effect on runoff and erosion rates as high-severity wildfires. The flooding, sedimentation, and degradation of water quality after high-severity wildfires is of increasing concern due to the increase in downstream property values, the growing demand for high-quality water, and the projected increases in burned area as a result of climate change.

Surface erosion is the predominant source of post-fire sediment, although debris flows and landslides can be locally important. Process-based studies indicate that the large increases in surface runoff after high-severity fires are due primarily to the loss of vegetative cover, loss of aggregate stability, and resultant soil sealing. The increased volume and velocity of surface runoff causes extensive rilling and a rapid expansion of the stream channel network. The sediment generated in headwater areas causes extensive sedimentation in lower-gradient, downstream reaches.

Since post-fire sediment production is most closely related to the amount of bare soil, it follows that the most effective treatments are those that immediately increase the amount of ground cover, such as mulching. In the absence of any treatment, vegetative regrowth causes hillslope runoff and erosion rates to return to near-background levels within 1-4 years. This decrease in runoff limits the ability of downstream channels to export the accumulated sediment, and in downstream areas post-fire recovery may require several decades or even centuries.

Regional comparisons show that post-fire sediment yields tend to be substantially lower in Mediterranean Europe relative to comparable areas in North America. This difference is attributed to the longer-term soil degradation as a result of repeated fires, forest clearing, and human cultivation. The large increases in erosion means that repeated wildfires can be a major cause of land degradation and desertification.

1. Introduction

High-severity wildfires in forests and shrublands can greatly increase runoff and erosion rates relative to most other land uses (e.g., MacDonald and Stednick, 2003). In most cases the increases in erosion are due to debris flows and mass movements, while in other cases the increases are due to a sequence of surface erosion processes (rainsplash, sheetwash, rilling, and channel incision/bank erosion). The observed increases in runoff and erosion can greatly affect site productivity and downstream resources. The purpose of this paper are to: (1) identify the key processes by which fires increase runoff and erosion rates; (2) compare the relative importance of landslides, debris flows, and surface erosion processes and the process domains where each is likely to dominate; and (3) use this information to assess the potential for different management techniques to mitigate the adverse on- and off-site impacts of high-severity wildfires.

In most undisturbed or minimally disturbed forests infiltration rates are greater than rainfall intensities. The high infiltration rate means that most or all of the precipitation infiltrates into the soil and is delivered to the stream network by relatively slow-moving subsurface stormflow (although some water may be forced to the surface in topographically convergent areas). Forests also have a protective litter layer on the soil surface, and this absorbs the raindrop impact and protects the underlying mineral soil against rainsplash and soil sealing. The predominance of subsurface flow—when combined with the presence of a protective litter layer—causes sediment yields from forest lands to be lower than other vegetation types and land uses.

High-severity fires are the disturbance of greatest concern in many forested areas because they can greatly increase surface runoff and erosion rates, and because relatively large areas can be affected (Figure 1). In Colorado USA, for example, the 2002 Hayman wildfire burned 550 km^2 of forest land. In the areas burned at high severity the infiltration rate decreased from more than 60 mm hr^{-1} prior to burning to only 7-10 mm hr^{-1} for the first couple of years after burning. This 10-fold decrease in infiltration increased the size of peak flows by two or more orders of magnitude, and similar increases have been observed in other areas. The increase in surface runoff caused hillslope-scale sediment yields to increase from almost nothing prior to burning to a mean of 10 Mg ha^{-1} yr^{-1} for the first three years after burning (Pietraszek, 2006). This means that larger fires can sharply increase the size of peak flows, surface erosion rates, and sediment yields at both the hillslope and large catchment scales. The resulting downstream effects include loss of human life and property, degradation of water quality and aquatic habitat, and large declines in reservoir storage capacity (e.g., Rinne, 1996; Agnew et al., 1997).

Fig. 1. View over a portion of the 2002 Hayman wildfire in Colorado, which burned 550 km^2.

The effects of high-severity wildfires on runoff and erosion rates are of increasing concern for two main reasons. First, the rapid population growth in downstream areas is greatly increasing the values at risk. This includes the direct risk to human life as well as the increased risk to property and the increasing demand for high-quality water. Second, the frequency, extent, and severity of wildfires are projected to sharply increase as a result of global warming. This warming will increase the length and severity of the summer dry season and hence the likelihood of large, high-severity wildfires. In parts of the northwestern U.S. peak snowmelt is already occurring up to three weeks earlier, and this effectively increases the length of the summer dry season and has been correlated with an increase in the area burned by wildfires (Westerling et al., 2006). Other areas, such as the southwestern U.S., are expected to become drier as a result of global climate change.

In general, global climate change will increase the likelihood of large wildfires in historically fire-prone areas such as Australia and the Mediterranean, and also increase the likelihood of severe forest fires in areas that historically have not been subjected to frequent wildfires, such as eastern Europe. This means that post-fire runoff and erosion are an increasing concern for both the public and resource managers (NRC, 2008)

2. Processes by Which Fires Increase Runoff and Erosion

An understanding of the mechanisms by which wildfires increase runoff and erosion is essential for predicting the likely effects of current and future fires, and for developing effective post-fire mitigation techniques. The large increases in runoff and sediment yields after burning have been attributed to three types of erosion, and these are: (1) surface erosion (i.e., rainsplash, sheetwash, rilling, and gullying); (2) debris flows; and (3) landslides.

Each of these mechanisms varies in its spatial frequency, temporal extent, and the proportion of a watershed that is likely to be affected, and this in turn controls the likely magnitude of downstream effects. The importance of each mechanism also will vary according to the specific landscape conditions, and any efforts to mitigate these changes has to be based on an understanding of the underlying processes plus the relative likelihood of each of these three types of erosion. Hence the following sections discuss each mechanism in more detail, their relative importance, and the potential for mitigating the adverse effects.

2.1. Surface erosion

The increases in surface erosion after high-severity wildfires are generally due to the decrease in infiltration and loss of surface cover. More specifically, the observed decrease in infiltration and corresponding increase in surface runoff have been attributed to different processes, including: the development of a fire-induced water repellent layer at or near the soil surface; the loss of surface cover; the loss of aggregate stability; a decrease in surface roughness; and soil sealing.

The role of soil water repellency has historically been emphasized, as this is relatively easy to document after a fire, and it provides a logical explanation for the observed increases in runoff. However, recent studies have emphasized the rapid decay of fire-induced soil water repellency, the large spatial and temporal variability in post-fire soil water repellency, and the presence of soil water repellency in unburned areas (particularly coniferous forests and certain types of shrublands) (Doerr et al., 2008). The implication of is that some other process besides soil water repellency must be helping to cause the observed increases in runoff and surface erosion after high-severity fires.

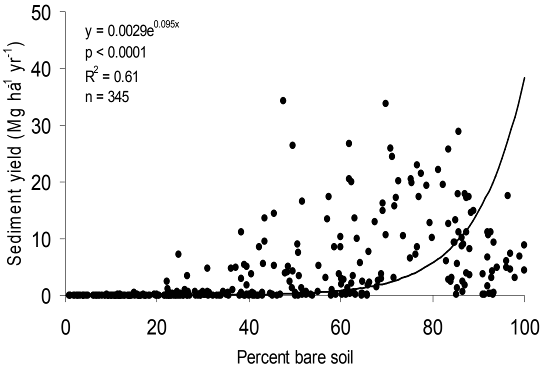

Fig. 2 Relationship between percent bare soil and sediment production for seven wild and three prescribed fires in the Colorado Front Range, USA.

Several studies have found a strong empirical relationship between the amount of exposed mineral soil and post-fire erosion rates (Figure 2) (Benavides-Solorio and MacDonald, 2005), and similar results have been reported from agricultural studies. Rainfall simulations on bare soils and soils with litter or other ground cover suggest that the development of a structural soil seal may be the primary cause of the observed decrease in infiltration after a high-severity fire (Larsen et al., in press). A field experiment in the Colorado Front Range also showed no significant differences in surface erosion between hillslopes burned by a high-severity wildfire and three unburned hillslopes where the litter was removed to expose the mineral soil (Larsen et al., in press). All of these studies indicate that percent ground cover is the primary control on surface runoff, and that post-fire soil water repellency plays a much smaller role than is commonly assumed.

The loss of the litter layer by burning is further exacerbated by the loss of soil organic matter, disaggregation of the soil aggregates, and resulting increase in soil erodibility. Burning the surface litter and vegetation also decreases the surface roughness, which increases the overland flow velocity. The surface sealing, increase in soil erodibility, and decrease in surface roughness all combine to greatly increase the amount and velocity of overland flow. These same factors cause a tremendous increase in rainsplash detachment, sheetwash, and rilling, resulting in a rapid upslope expansion of the stream channel network (Figure 3).

In the Colorado Front Range, for example, storms with only 10-15 mm of rainfall caused extensive rilling in formerly unchannelled swales, and these rills extended to within 5 or 10 m of the ridgetops (Figure 3). Detailed volumetric measurements of the newly-formed rills over successive storms indicated that about 80% of the measured hillslope sediment yield is due to rill incision rather than rainsplash and sheetwash (Pietraszek, 2006). Channel incision extended downslope until the channel gradient decreased to around 10%, at which point some of the post-fire sediment was deposited (Figure 4) with the remainder being transported further downstream. The downstream delivery of ash and sediment can cause severe aggradation and degrade water quality.

Regional comparisons show that post-fire surface erosion

Figure 3. Rill erosion in a formerly unchanneled swale.

rates tend to be substantially lower in Mediterranean Europe relative to comparable areas in North America. The lower erosion rates in countries such as Portugal and Spain are attributed to the long-term soil degradation as a result of repeated forest clearing, human cultivation, and fires. The observed differences in post-fire erosion rates suggest that frequent wildfires are a major cause of land degradation and desertification.

2.2. Debris Flows

In some areas debris flows can be an important mechanism for post-fire erosion. The underlying processes that cause the initial increase in runoff should be identical to the processes discussed in the previous section on surface erosion, but the main difference is the extent to which the concentrated runoff scours channels and transforms into debris flows. Post-fire debris flows occur when 30-minute rainfall intensities exceed 10-15 mm h^{-1}, which is similar to or slightly greater than the 8-10 mm h^{-1} needed to initiate surface runoff and erosion (Cannon et al., 2008). Empirical models indicate that debris flows only occur when channel gradients exceed 15-30% and the upslope contributing areas are greater than 0.1-1 ha (Gabet and Bookter, 2008; Gartner et al., 2008). Although they typically occupy a much smaller proportion of the drainage basin than the rainsplash, sheetwash, rilling and gullying discussed in section 2.1, debris flows can deliver comparable volumes of sediment to downstream channels and alluvial fans.

Fig. 4. After a high-severity fire there is extensive channel incision in the steeper upslope areas, and deposition occurs when the channel gradient drops from around 16% to 10%

2.3. Landslides

High-severity wildfires consume or kill the vegetation. This will decrease transpiration and interception, thereby increasing soil moisture levels and the likelihood of shallow landslides by increasing pore pressures. In steep forest and shrubland areas the post-fire loss of root strength is often a more important concern, as root cohesion is often a primary contributor to slope stability (Montgomery and Dietrich, 1994). However, post-fire landsliding has generally been reported only after extreme storms (e.g., Meyer et al., 2001). Relative to surface erosion and debris flows, landslides are much less frequently cited as a primary source of post-fire sediment, and there are at least four main reasons for this.

First, high-severity fires will kill the dominant vegetation, but it generally takes 3-15 years before root decay reduces root cohesion and slope stability to a minimum (Sidle and Ochiai, 2006). Second, as the time since burning increases vegetative regrowth will progressively restore on-site water use and reduced the likelihood of excess pore pressures. Third, there usually is a rapid decline in the frequency and intensity of post-fire measurements, and this means that post-fire landsliding is less likely to be documented relative to the surface erosion and debris flows that occur in the first 1-3 years after burning. Fourth, the basic physical processes mean that most landslides occur on steep hillslopes with convergent topography, but in many burned areas the slopes are not steep enough and the geologic conditions are not conducive to shallow landslides.

This means that post-fire landsliding will only be important in selected geographic terranes, while post-fire surface erosion can occur on almost any sloping surface. The relatively widespread occurrence of surface erosion processes is supported by the much greater number of studies devoted to post-fire surface erosion relative to landslides.

3. Post-fire Treatments

The differences in these three erosion mechanisms have important implications for the design of treatments to minimize post-fire erosion. With respect to surface erosion, the critical change is the decrease in infiltration and the most critical variable is the amount of surface cover. This means that the most effective treatments are those that immediately increase the amount of ground cover and thereby reduce soil sealing. Studies in different areas consistently show that mulching with straw, wood chips, or wood fiber products can reduce post-fire sediment yields by around 90% for the first couple of years after burning (Bautista et al., 1996; Wagenbrenner et al., 2006). Other types of mulch treatments, such as hydromulch, have had mixed success, and this may be due to the variations in matching the specific hydromulch formulation to local site conditions (Rough, 2007).

In contrast to mulching, seeding is rarely effective in reducing post-fire erosion, as this generally does not increase ground cover relative to untreated plots (e.g., Wagenbrenner et al., 2006). Similarly, efforts to physically break up the water repellent layer (“scarification”) have not been successful in reducing post-fire erosion. The effectiveness of a surface binding agent (i.e., a polyacrylamide) also has not been proven, as this also will require a careful matching of the polyacrylamide to the specific site conditions (Rough, 2007).

The same principles for reducing post-fire surface erosion should also apply to debris flows, as these also result from the post-fire decrease in infiltration. The problem is that few studies have evaluated post-fire debris flow mitigation treatments, but in southwestern Colorado a combination of watershed-scale hillslope and channel treatments reduced debris flow volumes by several orders of magnitude relative to untreated watersheds (deWolfe et al., 2008).

The potential treatments to minimize post-fire landslides are very different because of the differences in the causal processes. Since a primary cause of post-fire landslides is the increase in soil wetness and pore water pressures after burning, the primary objective is to reduce rather than increase infiltration. Maintaining a high percent bare soil would be the most effective means for reducing infiltration, but this has the obvious trade-off of increasing surface runoff and erosion with the resulting adverse effects on water quality and downstream resources. The installation of subsurface drains could prevent the development of high pore pressures, but this is very expensive and could only be done on a few high-risk hillslopes that are a direct threat to life and property. A more effective procedure would probably be to maximize the regrowth of deep-rooted species, as this would both increase transpiration and quickly restore root strength. Given the uncertainty over which slopes will fail and the magnitude of future storm events, managers generally have very limited possibilities for substantially reducing post-fire landsliding.

4. Conclusions

High-severity fires can increase runoff and erosion rates in forested areas by several orders of magnitude. These large increases can be attributed to the sharp decrease in infiltration as a result of soil sealing and other processes. High-severity fires also remove the protective litter layer, increase soil erodibility by consuming soil organic matter, and decrease surface roughness. The increase in the amount and velocity of overland flow induces severe rilling and gullying. Because these surface erosion processes can occur over large portions of a watershed, fires can have larger-scale effects on flooding, water quality, and aquatic habitat than most other disturbances in forested areas.

Debris flows and landslides also can occur after high-severity fires, but these are more dependent on extreme storm events and generally occur in specific, limited locations. Hence these two types of post-fire erosion are less common and are not as important as the more ubiquitous changes in surface erosion.

Mitigation techniques that immediately restore the ground cover, such as mulching, are most effective in reducing surface erosion. In contrast, there is relatively little potential for mitigating or reducing post-fire landslides. Repeated fires can lead to severe degradation and desertification, and the effects of fires are an increasing concern as a result of global climate change and the increasing value of the resources at risk.

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Road Sediment Production and Delivery: Processes and Management

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1. Introduction

Unpaved roads are one of the most common types of man-induced disturbances. Roads induce surface runoff and can alter subsurface flow on hillslopes, and this can affect the magnitude and timing of surface runoff (Jones et al., 2000; Wemple et al., 2001). By exposing the soil surface and increasing and concentrating runoff, surface erosion can occur on each part of the road prism (i.e., cutslope, travelway, and fillslope) (Figure 1). The surface runoff from roads also can initiate gully erosion below the road prism. Roads also can increase landsliding on road cutslopes, fillslopes, and hillslopes by altering flowpaths as well as altering the strength, loading, and pores water pressures on hillslopes (Megahan et al., 2001; Wemple et al., 2001).

The magnitude and relative dominance of these different road erosion processes is driven by variations in climate, geology, physiography, road design, road construction, and road maintenance practices (Jones et al. 2000, Wemple et al. 2001). As such, there can be considerable variation in the type, magnitude, and frequency of road-related sediment production within and between regions. Hence the objectives of this paper are to: 1) describe the underlying processes of road sediment production from surface erosion and landsliding; 2) compare road sediment production rates from surface erosion and landslides in different environments; 3) compare the delivery and potential off-site effects of road-related sediment from surface erosion and mass movements, respectively; and 4) indicate the extent to which best management practices (BMPs) can minimize road sediment production and delivery from these road-related processes.

2. Sediment production from forest roads

2.1. Surface erosion from forest roads

The high infiltration rates and dense vegetative cover on most undisturbed forested hilllslopes means that surface runoff is relatively rare and hillslope erosion rates are very low. In contrast, unpaved roads can increase surface erosion rates by two or more orders of magnitude relative to undisturbed hillslopes (MacDonald and Coe, 2007). Research over the past three decades in a variety of environments has led to a relatively good understanding of road runoff and erosion processes.

Road travelways are highly compacted and have very low infiltration rates (typically less than 2-5 mm hr^{-1}). This results in the generation of infiltration-excess (Horton) overland flow even during small rainfall events. In addition, road cutslopes can intercept transient hillslope groundwater (i.e., subsurface stormflow). In some cases the interception of subsurface stormflow can account for more than 90% of the road surface runoff (Wemple and Jones, 2003).

The amount and energy of surface runoff determines the erosive force applied to the road prism by overland flow. The road prism can be broken into different process domains for surface erosion based on the interaction of flowpath length, which largely controls the amount of runoff, and slope, which is the primary control on the energy of the runoff. On road cutslopes and road fillslopes the slope can be very steep (Figure 1), but the limited slope length limits the amount of flow accumulation and hence the potential for hydraulic erosion.

The slope of the travelway is usually no more than about 10-12% in order to facilitate traffic and maximize safety, but runoff can accumulate along the travelway unless it is strongly outsloped or insloped (Figure 1). In many cases road runoff is prevented from running off the travelway by wheel ruts, and this can result in extensive rill or gully erosion on the road surface. The large volumes of water draining from longer road segments also can induce gully erosion on fillslopes or below drainage outlets.

The erodibility of the road prism varies according to the time since construction or grading, soil texture, ground cover, and traffic (Ramos-Scharrón and MacDonald, 2005). Sediment production rates for cutslopes, travelways, and fillslopes are highest immediately after road construction, with erosion rates declining rapidly within 1-2 years. Fine-textured soils are the most susceptible to surface erosion, with siltier soils producing 4-9 times more sediment than soils dominated by sand or gravel. Soils with higher rock content typically have lower erosion rates (Sugden and Woods, 2007).

Figure 1. A picture of a reconstructed outsloped native surface road on a highly erodible, weathered granodioritic hillslope in northern California, USA. The road prism is comprised of the cutslope, travelway, and fillslope, and the arrows show the potential length of overland flow for each of these pathways. Note how the rill networks on the travelway concentrate the road surface runoff before it is discharged onto the fillslope. The extensive rilling is due to poor compaction during road reconstruction.

Vegetative cover can protect the soil against surface erosion, and erosion from cutslopes and fillslopes declines over time as they revegetate. Road travelways and inboard ditches are subjected to maintenance activities such as grading, and this removes the surface cover and can greatly increase the supply of easily-erodible sediment. Grading can increase erosion rates from 70% to more than an order of magnitude relative to ungraded roads (Ramos-Scharrón and MacDonald, 2005). Surface erosion rates decline exponentially to a baseline erosion rate following initial construction or grading, and this rapid decline is due to the rapid depletion of the readily erodible material and surface armoring. Higher traffic levels increase the supply of fine material, and this is a major reason why traffic can increase sediment production rates by 2-1000 times (Ramos-Scharrón and MacDonald, 2005).

The variations in rainfall, soil texture, traffic, and other controlling factors mean that road surface erosion rates can vary over several orders of magnitude. Both empirical and physically-based road surface erosion models have been developed, and these typically include key variables such as precipitation or rainfall erosivity, road slope, road area or length, road surface slope, soil texture, time since grading, and traffic. Unfortunately it is still very difficult to accurately predict road surface erosion, and the lack of calibration and validation studies means that the models are most useful for predicting relative rather than absolute road surface erosion rates.

2.2. Landslide erosion from forest roads

Forest roads increase landsliding by disrupting the balance of driving and resisting forces acting upon and within hillslopes. As shown in Figure 2, road-related increases in landsliding are commonly attributed to: 1) oversteepening and/or overloading of downslope areas by road fills; 2) removing support for unstable hillslopes by undercutting road cutslopes; and 3) concentrating road surface runoff onto potentially unstable portions of the road fillslope and lower hillslopes (Sidle and Ochiai, 2006).

Road-induced landsliding is generally only an issue in relatively steep terrain, with most road-initiated failures occurring on hillslopes greater than 31-39° (i.e., 60-80%). In such areas landsliding from roads can exceed natural landsliding rates by 10-100 times, and most reported values in landslide-prone terranes range from 4-60 Mg ha^{-1} yr^{-1} (Sidle and Ochiai, 2006).

Cutslope failures are a common occurrence in steep areas as a result of the oversteepened hillslopes (Figure 2). By reducing the support at the toe of unstable features (i.e., undercutting), cutslopes can increase the likelihood of rotational slides. Cutslopes also expose the hillslope to weathering, which can progressively decrease the strength of the hillslope materials.

Fill material is particularly unstable when it is placed on slopes greater than 35° and on unstable landforms such as colluvial hollows and inner gorges. Fillslope failures can be largely eliminated by the more costly approach of full bench construction, but this generates a much higher cutslope.

In many cases the increase in landsliding due to roads is a result of the changes in surface runoff. The routing of concentrated road runoff onto fillslopes or hillslopes can greatly decrease their stability as a result of the additional weight and the increase in pore water pressures. Catastrophic failure of the road fill and the initiation of debris flows or landslides can occur when culverts plug or overtop during storms.

The prediction of road-related landsliding is difficult given the stochastic nature of landslide initiation, variability in road design and construction, and the inability to represent many of the causal processes for road-landslide interactions. Slope stability models such as SHALSTAB and SINMAP are useful for predicting the relative risk of failure and as landscape stratification tools. For management purposes these spatially-explicit estimates must be followed by field-based slope stability assessments to better identify and minimize the landslide risk for a specific area.

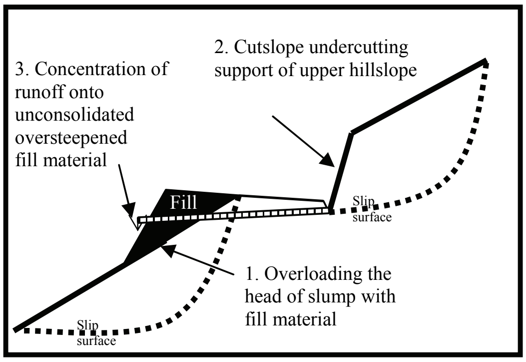

Figure 2. Schematic showing how a road increases the likelihood of landsliding.

3. Sediment delivery from forest roads

3.1. Sediment delivery from road-related surface erosion

The delivery of road-related surface erosion is of concern because it is generally fine-grained (sand sized or smaller) (Ramos-Scharron and MacDonald, 2005), and this material is particularly detrimental to many aquatic organisms (Waters 1995). Connectivity refers to the proportion of roads that drain directly to streams or other water bodies. The proportion of connected roads is strongly controlled by road location, road design, and the factors that control the amount of road runoff. In the western U.S. road-stream crossings account for 30-75% of the connected road length. It follows that road sediment delivery is highly dependent on stream density, as this affects both the number of road-stream crossings and the proximity of the roads to the stream channel network.

The delivery of road runoff and sediment to streams generally decreases as the distance between a road and a stream increases. If the road runoff is dispersed, the sediment from road surface erosion rarely travels more than 30 m on vegetated hillslopes. However, if the road runoff is concentrated into a single drainage outlet, the runoff and sediment can induce gullying and travel 3-4 times further than when it is dispersed.

The development of gullies as a result of concentrated runoff is the second most important mechanism for road-stream connectivity, as 9-35% of the total road length can be connected to the channel network via this process. Since longer road segments result in more runoff and more erosive power below road drainage outlets, roads with inadequate drainage are much more likely to induce gullies and be connected to the stream channel network that roads with dispersed or more frequent drainage.

A meta-analysis of the available data indicates that road-stream connectivity is a relatively simple function of annual precipitation and the presence of engineered drainage structures (Coe, 2006). The empirical predictive equation developed from 11 studies in different parts of the world is:

$$C = 12.9 + 0.016P + 39.5M \qquad (1)$$

where C is the percent of road length or road segments that are connected to the channel network, P is the mean annual precipitation in millimeters, and M is a binary variable with 0 representing roads with drainage structures, and 1 representing roads without drainage structures ($R^2=0.92$; $p<0.0001$). This predictive equation indicates the importance of precipitation in controlling both the amount of runoff and the density of the stream network. The binary variable indicates that well-designed roads with regular drainage will decrease road connectedness and hence road sediment delivery by at least 40%.

3.2. Sediment delivery from road-related landslides

The downstream delivery of road-induced landslides is dependent on their location relative to the channel network, road design, and the travel distance of the failure (MacDonald and Coe, 2007). Road-induced slope failures in colluvial hollows have a higher likelihood of delivering sediment to the channel network because these areas are located directly above first-order channels (Figure 3). Similarly, road-related failures in inner gorge landforms have a high probability of delivering sediment to streams because these areas are typically very steep and the slopes feed directly into the stream channels that carved these features (MacDonald and Coe, 2007). Sediment delivery is also high when flood flows overtop road-channel crossings and initiate landslides or debris flows.

Road-induced landslides deliver both fine and coarse sediment to the channel network. The episodic delivery of this sediment can induce debris fans, valley terrace formation, channel avulsion, channel aggradation, substrate fining, channel widening, and pool infilling (MacDonald and Coe, 2007). These sediment-induced changes in channel morphology can increase downstream flooding and bank erosion by reducing the channel capacity, and also can adversely affect water quality and fish habitat (MacDonald and Coe, 2007).

In summary, roads not only induce landslides at a very high rate relative to forests or clearcuts, but they also have a greater potential to deliver this sediment to the stream network. In the Oregon Coast Range in the western USA, road-induced mass failures traveled on average three times farther than in a mature forest. The combination of a much higher mass-failure rate and a higher sediment delivery means that road-induced mass failures can increase the amount of sediment being delivered to the channel network by nearly five times relative to mature forests (May, 2002).

Figure 3. Road-induced debris flows in northwest Washington state, USA. The debris flows initiated in the colluvial hollows on the upper road were triggered by road runoff, and these triggered the failures at the road-stream crossings on the lower road. The road was built prior to the implementation of best management practices and large fill volumes were placed within colluvial hollow and inner gorge landforms.

4. Management implications

The mitigation of road-related sediment production and delivery will vary according to the dominant road erosion process (Figure 4). A knowledge and understanding of these different process domains is essential to the proper selection and implementation of best management practices (BMPs), and the likely effectiveness. Without this understanding managers are more likely to treat the symptoms rather than the underlying causes.

Road surface sediment production can be readily reduced by improving road drainage, as this will decrease

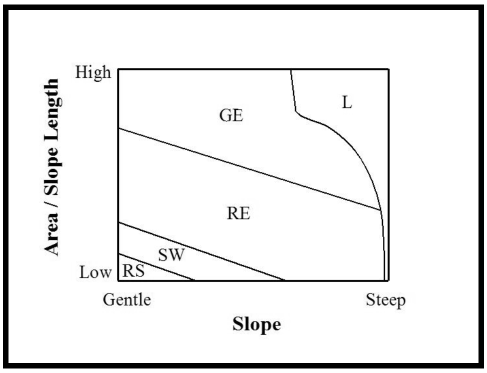

Figure 4. Conceptual process domains for rainsplash erosion (RS), sheetwash erosion (SW), rill erosion (RE), gully erosion (GE), and landsliding (L) as a function of flowpath slope and the amount of runoff as a function of flowpath area or length. The effectiveness of BMPs can be maximized by understanding and applying these process regimes.

the amount of of accumulated runoff and the erosive force applied to the road prism. Road drainage can be improved by increasing the frequency of road drainage structures such as waterbars, rolling dips, or cross-relief culverts. Outsloping the travelway is effective for decreasing flowpath length, dispersing runoff, and minimizing sediment production.

Surface erosion from roads also can be minimized by increasing the resistance of the road prism to the erosive forces of rainsplash and overland flow. Rocking the travelway can reduce sediment production by more than an order of magnitude. The addition of groundcover (e.g. mulching) to cutslopes and fillslopes can decrease sediment production (Megahan et al., 2001). Placing energy dissipators such as rocks or logging slash below road drainage outlets can greatly reduce surface erosion on fillslopes. Grading of the road travelway should be minimized, and the need for grading can be greatly reduced if adequate drainage is put in place and wet weather driving is restricted. Grading of inboard ditches also should be avoided unless absolutely necessary.

Similarly, the delivery of road surface erosion is best prevented by draining the road travelway frequently before road-stream crossings. Gully initiation below drainage outlets can be prevented by frequently draining the road and by placing energy dissipators below the outlets.

In areas dominated by road-related landsliding, road surface erosion may only represent 1-10% of the road-related sediment production. Priority in such areas should be to reduce road-related landsliding.

Slope stability problems can be minimized by: 1) reducing the length and width of roads on steep and unstable hillslopes; 2) minimizing the size of cut and fill slopes; 3) dispersing road runoff and only putting concentrated runoff onto stable hillslopes and channels; and 4) minimizing the number of road-stream crossings and carefully designing the unavoidable stream crossings. It should be clear that improving road drainage is critical to reducing and preventing road-related landslides**.** Road runoff should not be drained onto unstable fillslopes or onto unstable areas such as colluvial hollows, inner gorges, or the scarps of deep-seated landslides. Roads across slopes greater than 60-70% should be fully benched.

Landsliding and gullying at road-stream crossings can be prevented by minimizing the potential for culvert failures and the resulting diversions of streamflow. If possible, armored low water crossings should be used instead of culverts to preclude overtopping and plugging by sediment or debris. If the potential for stream diversion exists, an armored dip should be installed immediately below the crossing to quickly route the diverted streamflow back into the channel.

The BMPs used to mitigate road sediment production and delivery also will depend upon the resource of concern and the relative cost-benefit ratios. It should be recognized that reducing surface erosion may have immediate benefits, while efforts to reduce landsliding may not pay off until the next large storm event that could have caused a slope failure in the absence of any treatment. There also may be a substantial time lag between a reduction in sediment production and any improvement in downstream conditions (MacDonald and Coe, 2007).

5. Conclusions

Roads are important, chronic sources of runoff and sediment. This sediment is generated by both surface erosion and road-induced landslides. The surface erosion comes primarily from the road travelway as a result of rainsplash, sheetwash and rilling. Road surface erosion rates are highly variable, and depend on the contributing area, slope, precipitation intensity, soil type, soil rock content, and traffic. This sediment is delivered to the stream channel network primarily at road-stream crossings. Mean annual precipitation appears to be the primary control on road-stream connectivity.

Road-induced landslides can generate more sediment in some steep, humid areas than road surface erosion. An understanding of the process domains for road runoff and erosion is essential for reducing road sediment production and delivery. A range of best management practices have been developed to reduce road sediment production and delivery. In general it is easier to reduce road surface erosion than the number and size of road-induced landslides.

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What is a Hydrothermal Alteration Zone Landslide? The Relationship Between Ancient Landslides and Point Load Strength of Hydrothermal Alteration Zone Rocks in Hokkaido, Japan

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Abstract. The topographic expression of two ancient landslides, the Ohekisawa and Shikerebenbetsugawa Slides, in the Teshikaga district, Hokkaido, Japan, has been identified in the southern part of the Okushunbetsu landslide area. These landslides are hydrothermal alteration zone landslides and the bedrock has been intensely affected by Pliocene hydrothermal alteration and mineralization.

The Ohekisawa Slide formed upon a dip slope of coarse tuff and tuffaceous medium sandstone from the Upper Miocene Shikerepe Formation. These rocks are hydrothermally altered, and have a mineral assemblage indicating smectite and mordenite zones. The point load strength of rocks in the smectite zone is 1.7 MPa.

The Shikerebenbetsugawa Slide developed upon a dip slope of fine tuff, mudstone and lapilli tuff from the Upper Miocene Hanakushibe Formation. These rocks are also hydrothermally altered, and include smectite and laumontite zones. The point load strength of rocks in the laumontite zone is 2.4 MPa.

The hydrothermal alteration products, smectite, mordenite and laumontite are closely associated with the ancient landslides, suggesting that landslide potential within a hydrothermal area can be assessed on the basis of hydrothermal alteration type.

The hydrothermal alteration zone landslides developed within very weak hydrothermally altered soft rocks such as those of the smectite, interstratified illite/smectite minerals, illite, mordenite, stilbite, heulandite, and laumontite zones.

Keywords. Hydrothermal alteration zone landslide, hydrothermal alteration type, hydrothermally altered soft rock, very weak rock, point load strength

1. Introduction

Landslides in the Teshikaga district, Hokkaido, Japan, have been studied primarily by the Hokkaido Branch of Japan Landslide Society, ed. (1993), Yamagishi et al. (1996), Maeda and Sasaki (1997), Maeda et al. (1997), Sasaki and Maeda (1999), and Sasaki et al. (2000).

Two ancient landslides have been identified, on the basis of topography, in the southern part of the Okushunbetsu landslide area of Teshikaga district. We have tentatively named these ancient landslides the Ohekisawa and Shikerebenbetsugawa Slides.

The Ohekisawa Slide is 350 m wide and 410 m long, while the Shikerebenbetsugawa Slide is 175 to 450 m wide and 595 m long (Table 1). These landslides are classified as weathered rock slides on the basis of the sliding material (Fujiwara, 1970; Watari and Sakai, 1975).

Table 1 Analysis of ancient landslides in southern part of Okushunbetsu landslide area

Items	Ohekisawa Slide	Shikerebenbetsugawa Slide
Total length (m)	410	595
Width (m)	350	175 (foot)-450 (main body)
Angle of slope	10-20°	10-25°
Bedrock geology	Shikerepe Formation Coarse tuff and tuffaceous medium sandstone	Hanakushibe Formation Mudstone and fine tuff
Geological structure	Dip slope structure	Dip slope structure
Hydrothermal alteration zone	Smectite and mordenite zones	Smectite and laumontite zones

Two other ancient landslides in the Sattomonai landslide area, and another in the northern part of the Okushunbetsu landslide area occurred within hydrothermal interstratified illite/smectite minerals zone and smectite zone, respectively (Maeda and Sasaki, 1997). These landslides are classified as hydrothermal alteration zone landslides on the basis of their bedrock geology (Maeda, 1996, 1999).

From the Middle Miocene to Late Pliocene, the Sattomonai-Okushunbetsu landslide area was subject to intense terrestrial volcanic-hydrothermal activity.

The purpose of this study is to clarify the geological structure and hydrothermal alteration within the southern part of the Okushunbetsu landslide area, and discuss the close relationship between ancient landslides and hydrothermal alteration zones.

2. Methods and Equipment

A total of 776 specimens of hydrothermally altered rocks were collected from the southern part of the Okushunbetsu landslide area. The whole-rock mineralogy of each specimen was determined principally by X-ray powder diffraction (XRD).

Clay minerals in the hydrothermally altered rocks were identified from the diffraction patterns of untreated, ethylene glycol-treated, and HCl-treated oriented samples. Opal-CT was determined according to the XRD patterns of Jones and Segnit (1971). XRD was performed using a Rigaku RAD-3R type diffractometer (30 kV, 20 mA) equipped with a Cu tube, an Ni filter, a 0.3-mm receiving slit, and 1° divergence and scattering slits.

Point load testing of 55 samples was performed using a Honma-Denki-Seisakusho point load test equipment and a Tokyo-Kohkisha universal testing machine. The samples were tested after drying in an electric oven at 105±3℃ for 24 hours.

3. Geologic Setting

The Teshikaga district is within the inner belt of the Kurile arc (Minato et al., 1956). The geology of this district has been described by Katsui (1962), Satoh and Kakimi (1967), Matsunami and Yahata (1989), MITI (1990, 1991), Hirose and Nakagawa (1995) and Yahata et al. (1995).

The geology consists mainly of the Neogene and Quaternary Systems, as well as Neogene intrusive rocks. The Neogene System can be divided, in order of ascending stratigraphy, into the Middle Miocene Ikurushibe Formation, Upper Miocene Oteshikaushinai, Hanakushibe and Shikerepe Formations, the Upper Pliocene Ikurushibeyama and Shikerepeyama Lavas, Shikerepempetsu Formation and Pekere Lava (NEDO, 1985; MITI, 1990, 1991; Hirose and Nakagawa, 1995). Generally these formations have undergone extensive hydrothermal alteration and mineralization during the Pliocene (Maeda and Cai, 1994, 1997). The rock facies and geological structure of the Neogene formations in the southern part of the Okushunbetsu landslide area are as follows:

The Oteshikaushinai Formation consists mainly of alternating andesitic to dacitic lapilli tuff, tuff breccia and tuff, with basal tuffaceous conglomerate, sandstone and mudstone.

The Hanakushibe Formation, which conformably overlies the Oteshikaushinai Formation, is composed chiefly of mudstone, alternating mudstone and fine tuff, and andesitic volcaniclastic rocks.

The Shikerepe Formation conformably overlies the Hanakushibe Formation, and consists mainly of andesitic to dacitic volcaniclastic rocks, tuffaceous sandstone and mudstone, and dacitic welded tuff.

The Shikerepeyama Lava, which unconformably overlies the Shikerepe Formation, consists mainly of dacitic lava flows.

The Shikerepempetsu Formation unconformably overlies the Shikerepeyama Lava, and consists of basal conglomerate, dacitic pumice tuff and alternating tuffaceous sandstone, conglomerate, lapilli tuff, fine tuff and pebbly mudstone.

The Quaternary System can be subdivided, in ascending stratigraphic order, into the Teshikaga Volcano Somma Lava, higher river terrace deposits, lower river terrace deposits, talus deposits, landslide deposits and alluvial river deposits.

Neogene intrusive rocks consist chiefly of andesite dikes, with lesser basalt and rhyolite dikes (MITI, 1991). These dikes are generally affected by hydrothermal alteration and mineralization. K-Ar ages of 2.43±0.45 and 2.3±0.8 Ma for the andesite dikes (MITI, 1991) are believed to indicate the time of the hydrothermal alteration and mineralization.

An NW-SE trending anticline can be mapped in the lower reaches of the Oteshikaushinaisawa Creek and Hanakushibegawa River at the northwestern part of the study area. An ENE-WSW trending syncline folds rocks in the middle reaches of the Hanakushibegawa River at the western part of the study area. Folds of several hundred meters wavelength and ENE-WSW fold axes are common in the middle reaches of the Shikerebenbetsugawa River at the southern part of the study area. Comparable folds with NNE-SSW to ENE-WSW axes are mapped in the upper reaches of the Shikerebenbetsugawa River at the southern part of the study area..

The Shikerepe Formation in the northeastern part of the study area is characterized by an NNW-SSE to NW-SE striking homocline, and dips less than 10° to the NE.

Fault sets occur in NE-SW, NNE-SSW and NW-SE orientations.

4. Hydrothermal Alteration

Hydrothermal alteration minerals identified in this study include quartz, opal-CT, K-feldspar, albite, chlorite, illite, interstratified illite/smectite minerals, smectite, nacrite, dickite, kaolinite, analcite, wairakite, laumontite, heulandite-clinoptilolite series minerals, mordenite, chabazite, stilbite, calcite, alunite, minamiite, natroalunite and pyrite.

Areas of hydrothermal alteration can be subdivided into zones on the basis of characteristic minerals such as silica minerals, feldspars, clay minerals, zeolites and alunite. The following hydrothermal alteration zones have been identified in the study area on the basis of mineral assemblage: the propylitic, wairakite, laumontite, heulandite, analcite, mordenite, stilbite, smectite, interstratified illite/smectite minerals, illite, K-feldspar and alunite-quartz zones.

Zones of hydrothermal alteration are oblique to bedding planes within the Oteshikaushinai, Hanakushibe, Shikerepe and Shikerepempetsu Formations. The distribution and point load strengths of different hydrothermal alteration zones documented in the study area are now described. The alunite-quartz zone, which is a silicification zone, occurs mainly within the Shikerepeyama Lava in the central part of the study area, and has a point load strength of 23.8 MPa. The K-feldspar zone occurs as a narrow band within the illite zone. The illite zone has an NE-SW trend, and is in contact with the laumontite, analcite, mordenite and propylitic zones in the southwestern part of the study area. The point load strength of illite zone rocks ranges from 1.4 to 10.0 MPa, with an average of 3.8 MPa. The interstratified illite/smectite minerals zone has an NE-SW trend within the illite zone in the southwest, and an NNW-SSE trend in contact with laumontite and smectite zones or analcite and mordenite zones in the west of the study area. The point load strength ranges from 3.5 to 10.8 MPa, with an average of 6.0 MPa. The propylitic zone formed within volcaniclastic rocks, and is distributed mainly within the laumontite and smectite zones in the northwest and within the illite zone in the southwest of the study area. The point load strength varies from 3.7 to 19.2 MPa, with an average of 7.9 MPa. The laumontite zone is widely distributed in the western part of the study area, and has a point load strength of 0.6 to 3.2 MPa, with an average of 1.8 MPa. The analcite zone has a wide distribution in the western part of the study area, and a point load strength of 4.1 to 20.1 MPa, with an average of 11.7 MPa. The heulandite zone is closely associated with the stilbite zone, and occurs locally in the laumontite and smectite zones. The point load strength varies from 1.7 to 7.4 MPa, with an average of 5.0 MPa. The mordenite zone is relatively widely distributed in eastern areas, and occurs locally in western areas of the study area. The point load strengrh of mordenite zone rocks is 5.8 MPa. The stilbite zone occurs locally in contact with the heulandite zone, and has a point load strength of 5.4 MPa. The smectite zone occurs mainly in the northeastern and southwestern parts of the study area, and has a point load strength of 1.0 to 16.5 MPa, with an average of 6.6 MPa.

5. Landslides

On the basis of point load strength, the hydrothermally altered rocks of the study area can be classified as soft or semi-hard rocks with the exception of strongly silicified hard rock of the alunite-quartz zone characterized by a quartz-alunite-pyrite assemblage.

The bedrock of the Ohekisawa Slide in the southern part of the Okushunbetsu landslide area is hydrothermally altered soft rock of coarse tuff and tuffaceous medium sandstone of the Upper Miocene Shikerepe Formation. The landslide has a dip slope structure with an NNW-SSE strike and dip 7° E (Table 1). The main scarp of the Ohekisawa Slide consists of an N-S striking andesite dike, 125 m in width and 325 m in length. The upper part of the sliding material is mordenite zone rocks, while the middle and lower parts of the sliding material consist of smectite zone rocks (Table 1). The point load strength of the bedrock is 1.7 MPa, as measured from weakly weathered tuffaceous medium sandstone of the smectite zone.

The bedrock of the Shikerebenbetsugawa Slide is also hydrothermally altered soft rock, and consists mainly of fine tuff, mudstone and lapilli tuff of the Upper Miocene Hanakushibe Formation. The landslide has a dip slope structure as a whole because the bedrock has a synclinal structure about an ENE-WSW axis, and the dip of the upper and middle parts of the moving material is 10° SE, while the lower part dips 0 to 5° NW. The bedrock of the upper part of the moving material is smectite zone rocks, while the middle and lower parts are laumontite zone rocks (Table 1). The point load strength of the bedrock is 2.4 MPa, as measured from lapilli tuff of the laumontite zone.

Three ancient landslides are known to have occurred in the Sattomonai-Okushunbetsu landslide area (Maeda and Sasaki, 1997). One landslide in the northern part of the Okushunbetsu landslide area developed within mordenite zone fine tuff of the Upper Miocene Hanakushibe Formation. The other two, within the Sattomonai landslide area, formed within lapilli tuff of the Lower Pliocene Ikurushibeyama Lava, within the interstratified illite/smectite minerals zone.

In the Sattomonai-Okushunbetsu landslide area, five ancient landslides occurred within hydrothermal smectite, interstratified illite/smectite minerals, mordenite and laumontite zones. All these landslides developed within very weak rocks characterized by a point load strength of 1.7-2.4 MPa. This indicates that hydrothermal alteration zone landslides occur within very weak hydrothermally altered soft rocks such as those of the smectite, interstratified illite/smectite minerals, illite, heulandite and laumontite zones. Landslide potential within a hydrothermal area can therefore be assessed by the hydrothermal alteration type.

6. Concluding Remarks

The geological characteristics of two ancient landslides in the southern part of the Okushunbetsu landslide area, the Ohekisawa and Shikerebenbetsugawa Slides, are as follows:

(1) The landslides developed within zones of Pliocene hydrothermal alteration in the tuffaceous clastic rocks and volcaniclastic rocks of the Upper Miocene Hanakushibe and Shikerepe Formations. These landslides are classified as hydrothermal alteration zone landslides on the basis of their bedrock geology.

(2) The Ohekisawa Slide is closely associated with the hydrothermal smectite and mordenite zones. The point load strength of the smectite zone rocks is 1.7 MPa.

(3) The Shikerebenbetsugawa Slide is also closely associated with the hydrothermal smectite and laumontite zones. The point load strength of the laumontite zone rocks is 2.4 MPa.

(4) Both of the landslides developed upon dip slopes of very weak rock in hydrothermally altered soft rocks.

(5) The hydrothermal alteration zone landslides developed within very weak hydrothermally altered soft rocks such as those of the smectite, interstratified illite/smectite minerals, illite, heulandite and laumontite zones.

(6) Landslide potential within a hydrothermal field can be assessed on the basis of hydrothermal alteration type.

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Prevention Policies for the Protection Against Hydrogeological Disasters in Italy

Claudio Margottini (ISPRA)

Abstract. The Italian Ministry of Environment, Land and Sea and connected Agencies such as ISPRA (High Institute for Research and Environment Protection) are in charge to develop policies and sustain with adequate financial support, the initiative of preventing and mitigating the consequences of natural hazards such as landslides, flood, subsidence, coast erosion and desertification.

Many advancement has been produced in recent years, after the first zoning of risk areas in 1908. Nevertheless, the many increasing problems, also connected with climate change, are posing serious problem to a comprehensive and financially complete plan for securing the Country from hydrogeological disasters. The missing of scientific knowledge in some step of the process, the missing of funding and, some time, the missing of coordination between local and central authorities, allowed the realization of the National Observatory for the Soil and Water Protection. This Observatory, recently approved and constituted by representatives of the Ministry of Environment, Land and Sea, of the ISPRA, of the Civil Protection, of local Administration, of the River Basin Authorities and the national scientific Community, it is born really with the purpose to hold an accounting of the flows of expense, of the typologies of the works, of the capability of expenditure and the necessary times for the realizations. The Observatory wants also to develop a role of proposition for new methodologies and technologies to adopt in the soil protection and mitigation of hydrogeological disasters.

Following is a brief history into the Italian state of art in terms of natural disasters, the economic costs sustained and the legislation in action, showing good results and future needs.

Keywords. Flood, landslide, prevention policies, Italy

1. The state of the Country

The Italian territory, for its morphological and geologic conformation, as well as for its geographical and climatic position, has always been affected by floods and landslide of high intensity and risk.

As an example it can be mentioned that in Between 1279 and 2002, the AVI catalogue (CNR-IRPI) filler 4521 events with damages, of which 2366 related to landslides (52.3%), 2070 to floodings (45.8%), and 85 to avalanches (1.9%). In the same period 13,8 victims for year in occasion of landslide phenomena and 49,6 for year for those alluvial have been reported. In last the 50 years victims to hydraulic phenomena are decreasing (31 victims year), but with an exponential increasing of the associated economic costs (APAT, Annuario dei dati Ambientali, 2006).

The survey performed by the River Basin Authorities in application of the D.L. 180/1998 (so called "Sarno Law") have underlined the presence, in Italy, of around 13.000 areas to high and very high risk for floods, landslides and avalanches (figure 1). These areas are equal to 29.517 Kmqs and they represent 9.8% (4,1 floods; 5,2 landslides; 0,5 avalanches) of the national territory, involving 6.352 common Italians (81.9%), with centers urban and important infrastructures and productive areas, tightly connected with the social and economic development of the Country (Source Minister of Environment).

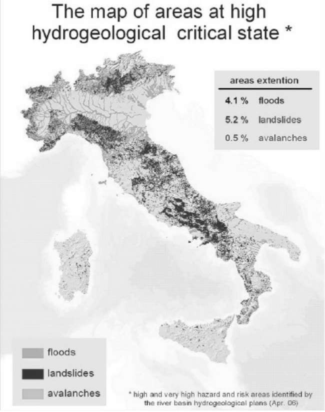

Fig. 1 The map of high and very high risk areas in Italy (Source Italian Ministry of Environment, Land and Sea)

The project IFFI of the APAT (APAT, 2007; www.mais.sinanet.apat.it/cartanetiffi/) has realized a complete and homogeneous picture of landslide distribution on the national territory, also when not striking urban and territorial infrastructures (areas to risk). The project identify 461.083 phenomenons of mass movement, in average 153 events every 100 kmq, for a total of 19.686 kmqs of affected territory, equal to the 6,5% of the whole national territory (figure 2).

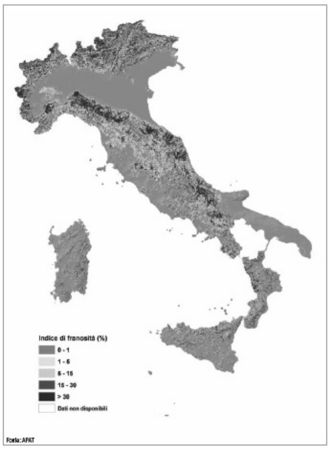

Fig. 2 The distribution of landslide density in Italy (APAT, www.mais.sinanet.apat.it/cartanetiffi/ 2007)

The economic and social costs sustained by the Italian State to sustain the consequent damages to floods and landslides are not yet clear: in the period 1968 to 1992 have been esteemed in 75 Million €, with an average value of 3 Million €/year (source Official Gazette of the Senate, 1992; costs updated to 1992). Limitedly to the alluvial phenomenons, the yearbook of the Environmental Data of the APAT (APAT, 2006) it brings a total of 16 Million € in the period 1951-2005, with an annual average equal to 0,293 Million €/year that becomes 0,773 Million €/anno in the period 1990 - 2005. Still less clear they are the costs for the prevention: it is worthy of note as the distribution of the public works in Italy, in the period 2000 - 2005, underline for the Category N04 " protection of the environment, hydrogeological disasters and water resources ", a public expenditure for 9.338.928.387,00, second alone to the category N01 "roads" (source Authority for the Vigilance on the Public Contracts). Limitedly to the laws that are financing prevention works against Hydrogeological diasters (D.L. 180/98 and s.m.i. and L. 179/02) and directly managed from the Minister of Environment, Land and Sea, they underline, in the period 1998-2005, a total amount of € 1.491.538.585,00 related to 1959 interventions (Source APAT, project RENDIS). In 2006 and 2007, the Ministry of Environment, Land and Sea, has funded public works for 240 Million of €, to implement 354 work areas for prevention and mitigation of hydrogeological disasters.

2. The Italian legislation for preventing hydrogeological disasters

The first example of zoning hydrogeological disasters in Italy goes up to 1908 when the L. 445/1908 established, with respect to the more than 8.000 municipalities, 323 were to be abandoned and 1606 to be stabilized. It dealt with a product that was born from the emergency activities planned after the 1905 Calabria earthquake and that to set up the bases for a policy of prevention based on the knowledge of the areas of higher potential risk.

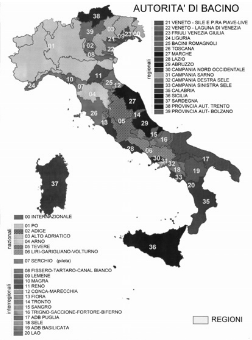

Fig. 3 The River Basin Authorities, defined by the Law 183/89.

Subsequently, despite the great job of the "Commissione De Marchi", consequent to the floods of the Polesine in 1951 and 1966 Florence, only after the 1987 Valtellina rock slide, a legislative initiative aiming at protecting the Country from floods and landslides comes up. The law 183/89 "Norms for the organizational and functional rearrangement of the soil protection" come up and, also through a series of further connected legislative initiatives (L. 253/90, L. 493/93, D.L. 275/93, L. 36/94 L. 112/98), it founded the River Basin Authorities (figure 3) and it detailed the operational assignments of them.

The tool of fundamental planning, in hydrogeological disaster prevention, had foreseen since 183/89 in the Plan of Basin (art. 17). It is composed of two parts lists: a first part of cognitive organization of the territory and his unbalances; a second part of planning of interventions, on the base of the emergencies underlined in the preceding cognitive phase. Considering the vastness and the complexity of a Plan so structured, the following law 493/93 have introduced the possibility to articulate the Plans of Basin for single Plans (Piani Stralcio), concerning specific sectors of intervention on the territory or specific portions of it; the Plans for the mitigation and prevention of hydrogeological hazards (PAI) are particularly dealing risk reduction in the field of hydrogeological disasters.

Such legislative tool will poorly result, unfortunately, incisive in the policies of soil protection in Italy. The reasons for the difficult realization of this law can be brought back to two orders of factors, outside and insides to the same law.

After the Sarno Mud slide, in 1998, the realization of the Plan for the mitigation and prevention of hydrogeological hazards (PAI) become compulsory all over the Country. Due to the difficulties to have a standard methodologies, a technical document (Decree of Presidency of Council of Ministers 29/09/98), has been produced with the purpose to allow local administrations to realise output as most as possible homogeneous and methodological comparable at national level. The decree identify a simplified methodology to support mainly the local administrations at the beginning of knowledge activity. This last include:

- Territorial analisys, at scale 1/25.000, collecting all possible available information, aerophotogeology, or direct survey. This last must be developed following the card prepared by National Technical Surveys. All data must be syntethized in a inventory map.
- Delimitation and evaluation of risk levels, through comparison with vulnerable anthropic elements (map of exposed elements).
- Planning risk mitigation, through analysis and elaborations, also graphic,to identify the typology of restoration works to be realized for mitigating or removing risk situations.

The legenda for risk assessment comprises:

- <u>R1 - moderate</u>: marginal social and economical damages:
- <u>R2 - medium</u>: possible minor damage to buildings and infrustructures, not to compromise people safety, buildings safe access, and functionality of economic activities.
- <u>R3 - high</u>: possibly proplems for the safe of people, functional damage to buildings and infrustructures and cosequent limitation in usage and interruption of socio-economic activities;
- <u>R4 – very high</u>: possibly injured and victims, heavy damages to buildings and infrustructures, destruction of socio-economic activities.

Because of the above limitation, and also in receiving the EU directive on water protection, Italy is presently changing the legislation on mitigation and prevention of hydrogeological hazards, modifying the River Basin Authorities and roles and duties.

3. Prevention policies in the Italian Minister of Environment and linked Agencies

The Italian Minister of Environment, land and sea, and related Agencies such as the High Institute for Research and Environment Protection, are responsible for policies for preventing and mitigating the consequences of hydrogeological hazards. This because soil protection prefigures the overcoming of the separation among the single interventions on the territory and on the environment, but is rather part of a more comprehensive and environmentally sustainable planning. This behind the awareness of the complexity of the interdependences and connections among natural trials, order and use of the territory, urbanistic and territorial planning, also in presence of demografic dynamics that, in the general diminution of the antropic pressure, have the tendency to assemble the population in few important main municipalities; such connections are dramatically evident on the occasion of the great catastrophic events.

In fact, in the last years, also following the climatic variations and to the modifications occurred in land use, the frequency and the gravity of the extreme events, such as floods and drought, they seem to increase from which the necessity of a raising of the politics of soil protection and safeguard of the water resources that protects in more effective way the populations and the territory affected.

Considering the inevitability of such events, and in presence of increasing physical consequences and, above all, economic and social, it was decided to coordinate more precisely all the mitigation works funded in the Country, setting up a series of measures, among which mainly:

- the "restoration" of the river environments, of the slopes and of the coasts recovering to them, anywhere possible, its own natural characteristics, through changes of land use also to level of basin, the re-organisation of river drainage network, recovering sediment transportation for the coast accretion and engineering works with limited environmental impact;
- to reduce the degree of exposure to the risks delocalizing districts/infrastructures and applying, only in case of effective necessity, passive defense techniques;
- to safeguard the water resources assuring the correct destination of it, in the respect of the priorities of use, of the correctness of the gathering and the real requirements in economic and environmental terms;
- to define a shared list of priority of short and middle term interventions, assembling on them the available financial and organizational resources;
- to encourage the inter-institutional collaboration, activating, in the respect of the roles and the responsibilities, all the possible and valid synergies to the goals of a sustainable development of the territory.

4. Future fundings and perpectives

In the period 2007, 2008 and 2009, there are available 265 Million of €/year for implementing initiatives aimed at reducing the risk of hydrogeological disasters in Italy.

Since assigning resources is getting a very critical task, with respect to the large request of funding coming from the territory, the following items were established to define a grid of priorities (not in hierarchical order):

- falling of the candidate site within the classifications of very high risk of the River Basin Authorities;
- interventions of completion and co-funding;
- degree of integration between measures of land use and structural interventions;
- use of techniques with low environmental impact, such as green engineering;
- availability of the execution project, coordinated among the actors responsible for land use planning and management;
- safeguard of not urban areas;
- low ratio betwen the costs of intervention and the effectiveness attended of reduction of the risk;
- greater degree of functionality of the sub-project, inside a complex one;
- coordination with the interventions financed by other sources (es. Ministry of Agricultural and Forest), with particular reference to the UE fundings;
- verification of the capabilities of expenditure and the effectiveness shown by the assigned agency (e.g. municipality);

All the funded intervention, should fall into the activities of the new National Observatory for the Soil and Water Protection. This Observatory, recently approved and constituted by representatives of the Ministry of Environment, Land and Sea, of the ISPRA, of the Civil Protection, of local Administration, of the River Basin Authorities and the national scientific Community, it is born really with the purpose to hold an accounting of the flows of expense, of the typologies of the works, of the capability of expenditure and the necessary times for the realizations. In other words the Ministry is looking for a correct public expenditure from local municipalities, and also to stimulate the ability of expense of the involved administrations. The Observatory wants besides to develop a role of proposition for new methodologies and technologies to adopt in the soil protection and mitigation of hydrogeological disasters. Particularly, the Observatory operates in the protection of the territory from the landslides, flood, subsidence, coast erosion and desertification, with the followings responsabilities:

- it handles the realization of an information system for the census of the principal natural hazards at national level, of the infrastructural, social and economic losses associates to the phenomenon and of the preliminary financial request for securing the sites;
- it develops the economic monitoring of the interventions, through the implementation of an information system on the initiatives in progress, at various stage of completeness, both in the prevention phase and in emergency, also describing the regularity of the financial flows and the ability of expense of the in charge institution;
- it develops the technical monitoring of the interventions implementing a data base containing the geographical parameters and typology of adopted solutions; the data base will also have to describe the environmental and landscape compatibility of the selected solutions and the relationship of these with respect to the entire River basin;
- it verifies the effectiveness, the cost-benefits relationship, the efficiency in time of the proposed solution, both for the single initiative and to scale of basin, annually analyzing the relationship between investments and results;

- it elaborates evolutionary sceneries on the relationship between soil protection and necessary economic resources, also to the light of the climate changes and the evolution of society;
- it supports the Ministry of Environment, Land and Sea, in the elaboration and permanent updating of methodologies and criterions for a) definition of the areas at risk b) typologies of the interventions c) priorities in financing the interventions d) compatibility and synergy of the interventions with respect to the protection of entire basin, in collaboration with the River Basin Authorities and related institutions thematically and territorially;
- it proposes to the Minister of the Environment Land and Sea revision and/or modification of some legislative tools and policies for soil protection in Italy;
- it prepares an annual report that describes the results of the monitoring, in terms of state of the hazards, investments, interventions, evolution of the relationship among investments and interventions in the time and in the different geographical areas, the potential pattern for future necessities;
- it collaborates with the Minister of the Environment Land and Sea, the Regions and the River Basin Authorities, to the predisposition, edited by the Minister itself of a document on a) the tools adopted for stimulating a land use planning and management aimed at proper soil protection, also in the light of landscape values of the sites and b) the conditions of hydraulic, hydrologic and geomorphologic order to be included the report on the state of the environment;
- it collaborates to the diffusion of the environmental information on the policies of soil protection, encouraging data sharing among all the involved actors.

5. Climate change

Among the different sectors of interest, hydrogeological disasters were deeply investigated in order to implement the most appropriate adaptation plan suitable to minimize the effects of Climate Change. The process included a site workshop on floods and landslides, in Naples in July 2007, as well as a thematic session in the National Conference in September 2007 (Margottini et alii, 2007).

The method pursued in practical activity included the following:

- implementing the knowledge on hazard and risk assessment, focusing on the role of rainfall, as main triggering mechanism of floods and landslides;
- understanding the meteorological trends in Italy in the last 200 yy;
- analysing hazard mapping in relationship to land use and triggering mechanisms;
- evaluating long term scenarios as input for potential modification of triggering mechanisms:
- understanding the impact of modification of future scenario to present day hazard map;
- delineate the main issues for an adaptation plan, suitable to minimise, from now, the adverse effects of Climate Change strengthening as well the resilience.

Major conclusions of the Rome Conference, to implement in the near future included:

- in the field of basic research:
    a. implementing data bases, knowledge,
    b. developing more accurate modelling and non stationary recurrence time estimations;
    c. increasing socio-economic data bases of damages and remediation costs;
- in the field of impact of Climate Change on hydrogeological disasters:
    a. better understanding of the relationship of physical processes connecting climate change to floods and landslides;
    b. better understanding of the anthropogenic system response and causative forcing to occurrence of disasters;
    c. better understanding of the economic impact of climate change on hydrogeological disasters;
- in the field of territorial vulnerability to climate change:
    a. developing appropriate land use planning and management tools;
    b. establishing new legislation, public information and knowledge on climate;
    c. implementing inter-institutional dialogue in planning and implementing the procedures;
    d. implementing more accurate monitoring system and early warning, as prevention measures against rapid onset of disasters.

The conclusions and proposals are the reference for the creation of a national adaptation strategy and will start to receive attention, likely, since the 2008 Italian financial law.

Conclusions

According to the previous chapters the following element can be raised:

- Risk assessment is mainly based on landslide inventory, so it doesn't consider occurrence of new phenomena (relevant for rapid mass movements)
- Detail basic data are often missing (e.g. detail geology; soil thickness)
- There is need of *state of art* (guidelines and procedures) to support different local authorities
- Citizens from different parts of the Country benefit of a different level of protection
- There is a need of strong coordination among different local authorities
- Climate change it is not properly taken into consideration in hazard and risk assessment.

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Risk Mitigation from Landslides for Cultural Heritage in Umbria Region: Some Applications

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Abstract. Umbria is the green heart of Italy, and the wealth of natural and artistic wonders of this Region seems almost inexhaustible. The risk related to landslides and hydro-geological instabilities is prevalently due to the historic development of the towns around castles, towers or medieval villages situated at the top of hills, as well as to the natural erosion increased by the land urbanization of the hillsides**.** For this critical situation Region and Government were obligated to intervene for the private and public safety by approving 41 laws to consolidate unstable towns. The Hydro-geological Assessment Plan of Tevere River basin (*PAI – Piano per l'assetto idrogeologico*), in order to protect present and future residential and infrastructural activities from risk, identified 174 sites for landslides characterized by really high (R4) and high risk (R3). This Plan represents the main tool for territorial planning and it is finalized to establish conditions that guarantee equilibrium and compatibility between hydro-geological dynamics and growing anthropogenic pressures on the land. In this panorama, a lot of identified sites concerns sacred and archaeological sites, as well as historic settlement and town centers, among the others: 1. Orvieto, Pale and Rocca Ripesena (historic settlements and town centers); 2.S. Eutizio (sacred site); 3.Marmore Falls and Spoleto town (archaeological, historic settlements and town center).

Keywords. Hydro-geological risk, Urban planning, Cultural Heritage, Umbria Region

1. Orvieto town and Rocca Ripesena

"Yesterday and today crucial moments [...] arrived at Orvieto, sited like Salzburg Castle, you ascend with the funicular from the station. City of solid stone, multi-coloured Duomo! Etruscan tombs, bought antique objects, enchanting view [...] Orvieto superb [...] Health very satisfying".

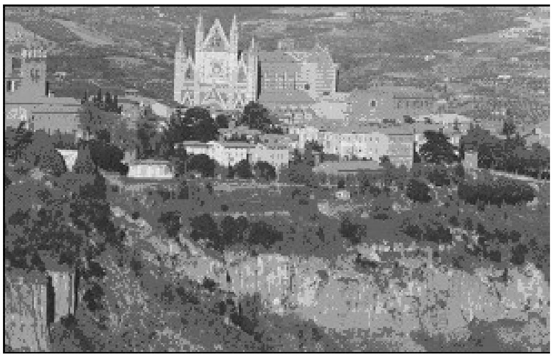

Fig. 1 Orvieto, Cannicella landslide, 1977

This is what Sigmund Freud wrote about Orvieto to his sister Martha on a postcard from Bolsena dated 9 September 1897.

Orvieto is situated on the borders between Umbria, to which it belongs, Tuscany and Latium. Built on the top of a steep cliff of tuff, it has always been a majestic and fascinating city. Its strong points are, indeed, its central position and the fact that it is a small city of art on a human scale. It has been one of the most important Etruscan cities. The Middle Ages and the Renaissance have determined the city most salient characteristics.

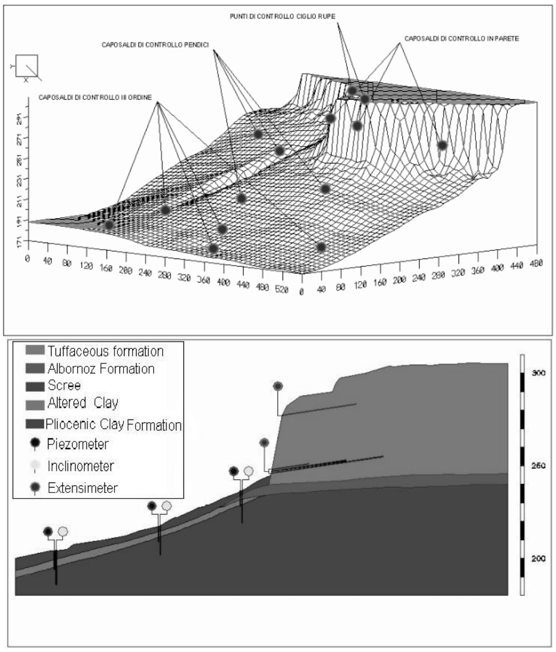

Fig. 2 Schemes of the geotechnical monitoring net

Orvieto is sited at the top of an ellipsoidal tufaceous rock plateau, rising above the alluvial plain ofthe River Paglia in the Province of Terni. The geological formation of the hill is formed of a bottom layer of Pliocene marine clay covered by a series of fluvial-Iacustral rings made up of sandy, clay and volcanic sediments, topped by the tufa of the Orvieto cliff.

Orvieto town in the 1937 was included in Italian State Inventory of city needing consolidation works. From 1972 (Regione Constitution) Regione Umbria faced the Orvieto landslides through new and deepened studies, in collaboration with the National Research Council and University.

After a landslides in the Gonfaloniera area in 1972, near the hospital in 1977, and in the Cannicella area in 1979, the

Umbrian regional authorities carried out a number of consolidation projects to prevent or reduce the risk of further landslides, relining the water and sewerage network, waterproofing and relaying roads, fixing and anchoring the tufa walls, re-facing and restoring the walls by the cliff, draining and readjusting the upper edge and the foot of the cliff, repairing the ditches that descend towards the valley, draining the landslides along the slopes and reinforcing all the unstable caves and grottoes.

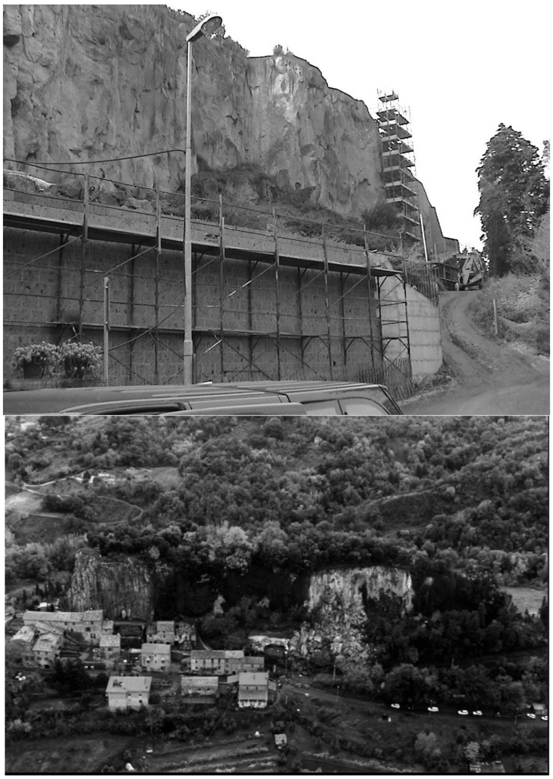

Fig. 3 Rocca Ripesena, the “little sister” of Orvieto case history. It represents what could happen in Orvieto without mitigation works

An "Observatory" has been set up to monitor and maintain these interventions and the reinforced areas. It uses a complex system of geotechnical instrumentation to monitor how the situation evolves and carry out any subsequent maintenance work required on the cliff and slopes.

The monitoring net is costitued by extensimeters, inclinometers, a geodetic net and piezometeres.

2. Pale village (Foligno, Perugia)

Pale is located on the right hand side of the Menotre River, at the foot of the calcareous mountain termed as Sasso di Pale.

During the XIV century, in this village growed up an important paper mill, thanks to the richness in water and so in energy. The first printed version of the Dante’s Divina Comoedia was printed in Foligno (Perugia) on the paper coming from the Pale’s industry.

After the heavy earthquake of 1997, many rockfall processes occurred along the travertine cliff, on the west side of the village. Due to these events, all the houses situated in proximity of the edge of the cliff lied in a really high risk situation.

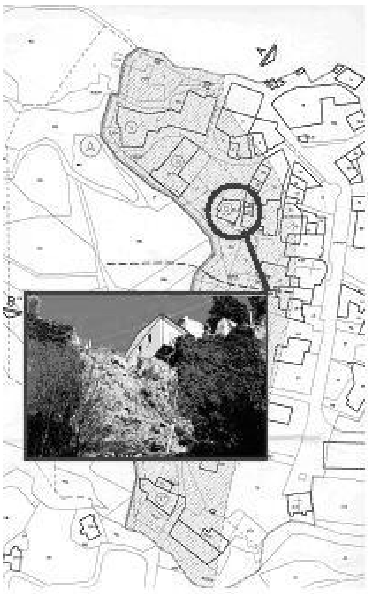

Fig. 4 Pale, the house over the cliff

The countermeasure works realized, related to the consolidation of the cliff, were: a) unstable rocks removing; b) anchoring of the cliff, by 5 m nails arranged in a grid of 1 m step; c) deep anchoring of the cliff, with a grid of 4 m step; d) sub-horizontal drainage.

3. The St. Eutizio Abbey

The Saint Eutizio Abbey was founded in the 5th century by the syrian monks who were the spiritual father of San Benedict. Nearby there are the Hermits Caves with an enchanting trail that leads to Norcia. In this Abbey the Precian surgery school was founded, and it constitutes one of the first surgery school of the world. The Abbey is built on the foot of a travertine formation.

Fig. 5 Saint Eutizio Abbey

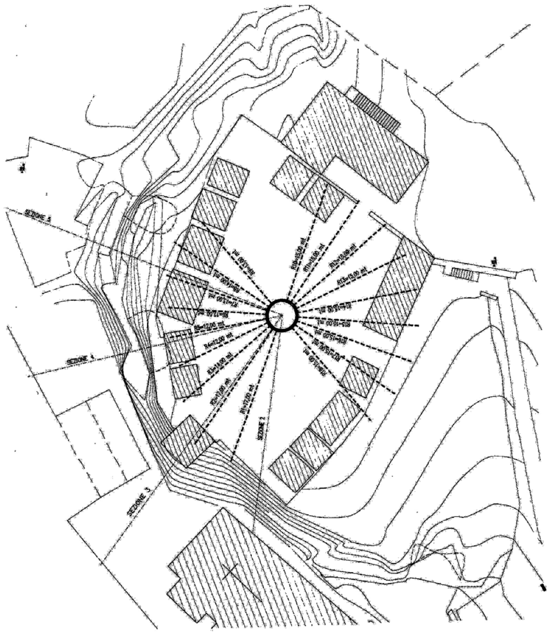

Fig. 6 Saint Eutizio Abbey: anchor well

After the 1997 earthquake, the incremented risk of rockfall needed prevention and protection designs for the risk reduction.

The countermeasure works realized were: a) unstable rocks removing; b) anchoring of the cliff, by nails; c) digging of a well with a diameter of 3,4 m and 14m depth; d) anchoring of the cliff to the well; e) hydraulic works.

4. The Marmore Falls

Marmore Falls, with its astonishing beauty, comes into view as a roaring water column divided into 3 falls, covering a drop of 165 metres which wraps up the luxuriant vegetation into a cloud of white foam. The breath-taking scenery is the result of over two thousand years of work by the part of man who, from the beginning of the Roman period, tried to canalize the waters of the Velino river to them flow into the Nera river.

Its history began in 271 b.Ch., when the Roman consul Manlius Curios Dentato did a land reclamation of the Reatina Plain creating a channel of over 2 kilometres which ended at the edge of a cliff.

During the last twenty years of the XIX century, the Falls became, for the growing industry, a regulation instrument of the hydroelectric system for energy purposes, and the use of its waters for industrial purposes predominates on the naturalistic, intellectual and tourist conntations.

The Marmore Fall is included in the hydro-geological Plan of Tevere river basin, as one of the most dangerous areas. Due to the geological and geomorphological particular character of the area, it needs constant control activity, landslide reclamation and constant maintenance.

Regione Umbria decided to reinforce the mountain ridge by realization of 11 elliptic wells of 5 x 9 m, 30 m deep. On the wall of the wells were fit in some tie-beams made of "Dywidag" bar with iron plate, they are allocated in 9 series, each one made of a halo of 13 tie-beams.

At this moment, it has been realized n. 9 wells on the right part of the fall. Moreover, on the left side of the river (*Campacci* resort) it has been realized works for consolidation, development of the public parks and was built a panoramic way. It was developed a real time monitoring system for verifying the safety condition.

Fig. 7 Marmore Falls: remediation works

5. The *Giro dei Condotti*, Spoleto town

The *Giro dei Condotti* area is classified as SIC – Site of European Community Importance– and it lies in front of Spoleto Town, a typical mediaeval city, also known for the Festival dei Due Mondi. The area is connected to the town by the Tower Bridge (Ponte delle Torri), which wondered Goethe during his Italian Journey.

The *Giro dei Condotti*, a small footpath created for the water-pipeline maintenance works, is classified as really high risk site for rockfalls. During 2003 some rockfalls caused the temporarily closing of the footpath, that was redeveloped after removing the blocks.

Fig. 8 Spoleto, "Ponte delle Torri"

During 2004 a similar event occurred, consequently the planning for risk reduction started, involving 1,3 Km of footpath between the bridge and the S. Leonardo Hermitage. The site is characterized by a vertical 30 m high cliff 60m over the footpath level. Due to this characterizations, and to the artistic and natural conditions, it is complicated finding suitable risk mitigation works that minimize the perturbation of the high environmental and artistic characterization of the heritage.

Fig. 7 Rockfalls on the Giro dei Condotti footpath

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Emergency Measures and Risk Management after Landslide Disasters Caused by the 2004 Mid-Niigata Prefecture Earthquake in Japan

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Abstract: Strong earthquakes often cause a large number of landslides, including large-scale landslides, in mountainous areas. It is not uncommon that such large-scale landslides cause river blockage and form natural dams, which are vulnerable to collapse by overtopping and breaching. The sudden collapse of landslide dam causes a catastrophic flood in downward area. In those catastrophic cases, it is necessary to pay special attention to extremely high threats to vulnerable settlements in hazardous areas. The risk assessment of such complicated combined landslide disasters is a significant step for identifying the appropriate mitigation strategy against catastrophic damage. In recent decades we have experienced remarkable disasters induced by landslides. For example, a huge number of landslides were induced by the Chi-Chi earthquake in Taiwan (1999), by the Mid-Niigata Prefecture earthquake in Japan (2004) and the Northern Pakistan earthquake (2005). Most recently the Sichuan earthquake occurred with magnitude 8.0 in central part of China on May 12, 2008. This gigantic earthquake also caused a tremendous number of landslides. Emergency measure and risk management operations illustrated in this contribution can serve mitigation of future landslide disasters induced by earthquakes.

Keywords. Earthquake, landslide dam, emergency measures

1. Introduction: Various unforeseen phenomena have been observed and newly recognized as a result of the 2004 Mid-Niigata Prefecture Earthquake. This earthquake was the first catastrophic earthquake which occurred in the landslide prone area in Japan after the necessary management and preparation to apply modern research and investigation methods on landslide occurrence. Therefore, the Japan Landslide Society organized a research committee and carried out detailed and comprehensive field researches and investigations in the severely devastated areas by a huge number of landslides caused by this earthquake. As a result of the series of intensive geotechnical analyses successive to the preceding geomorphological and geological analyses, we have been convinced that it is absolutely necessary to develop new theory on earthquake-induced landslides.

It was a remarkable aspect that a tremendous number of landslides were triggered by the 2004 Mid-Niigata Prefecture Earthquake. Because the epicenter was located at shallow depth of 13km just in the landslide prone area of central part of the Niigata Prefecture, severe damage were caused by the earthquake-induced landslides. Furthermore many landslide dams were formed mainly in the watershed of the Imogawa-River by the displaced soil mass of the earthquake-induced landslides. Some large landslide dams should pose a great threat of flood and debris flow in case of dam collapse to the settlement of the Ryuko-District in the downstream area of the watershed. It was urgently needed to arrange the emergency operations to avoid the destructive collapse of the major landslide dams. This contribution illustrates overview of earthquake-induced landslides, river blockage by landslide dams and emergency operations against dam collapse and further of integral recovery works to inhibit future disasters.

2. The 2004 Mid-Niigata Prefecture Earthquake

On 23 October 2004, an earthquake with magnitude 6.8 occurred in central part of the Niigata Prefecture, namely 70 km south of Niigata City. As a consequence of the earthquake, 46 people were killed, about 4700 people were injured, and 2800 houses were completely and 10,000 houses were partially damaged by structural failures, landslides and so on. Furthermore important public infrastructures like railways and highways as well as other major roads were also heavily damaged. About 100,000 people were to be evacuated to 600 refuges soon after the earthquake. The total amount of the material damage was estimated to be about thirty billion dollars.

The hypocenter of the 2004 Mid-Niigata Prefecture Earthquake was located at shallow depth (13km) in an active fault and fold system overlain by thick sediments of geologically young formations. An earthquake intensity of 7.0 (by Japan Meteorological Agency) was recorded in Kawaguchi Town close to the hypocenter for the first time since beginning of its recording using seismometers. The event was followed by strong aftershocks in rapid succession. The area suffered much successively from four major aftershocks with a magnitude of 6 or greater within 38 minutes after the main shock. The aftershocks were distributed 35km along the NNE-SSW strike of the geological structure within a 20km-wide zone between the Yukyuzan fault and the Shibata-Koide tectonic line. National Research Institute for Earth Science and Disaster Prevention has analyzed the distribution of asperities by using seismic waveform data observed by strong motion seismographs. The area with the highest asperity at eastern side of the epicenter corresponds to the watershed of the Imogawa-River, where especially many landslides occurred.

3. Characteristics of the Earthquake-induced Landslides

The earthquake triggered about 3800 landslides in various types and dimensions, causing extensive damage to settlements, farmlands and infrastructures. It was general understanding until then that because of strong ground shaking during earthquakes a lot of slope failures occur on steep slopes with concave shape but only few reactivated landslides occur on relatively gentle slopes. However, this time also many reactivated landslides occurred in consequence of the Mid Niigata Earthquake in the neighborhood of the epicenters including strong aftershocks especially on hillslopes in the Yamakoshi Village. Landslides occurred especially densely in the watershed of the Imogawa-River along the Kajigane-Syncline (Fig. 1). The geology of the area consists of thick sequence of Pliocene to lower Pleistocene sediments. Many landslides occurred along dip direction of geological formations. Originally, heavily landslide prone areas are widely distributed in the Tertiary mudstone areas in Niigata Prefecture. Usually reactivated landslides occur frequently in the northwestern part of the Yamakoshi Village which consists of mudstone. This time, however, most of landslides occurred in the southeastern part of the Yamakoshi Village which consists of sandstone and sandy siltstone.

Slope displacements induced by the earthquake can be classified mainly into the following categories: ①Shallow slope failures on steep slopes near ridges, ②Shallow slope failures on steep slopes along river channels, ③Reactivated landslides on relatively gentle hillslopes, ④Landslide dams formed by the displaced soils mass by the previous three categories of slope movements. For the mitigation of subsequent disasters, it was a matter of great urgency to implement emergency countermeasures against overtopping and successive failure of the landslide dams. Furthermore, abnormally heavy snowfall since 1986 years struck the heavily damaged area by the earthquake. It was also necessary to pay attention to the landslides caused by snowmelt.

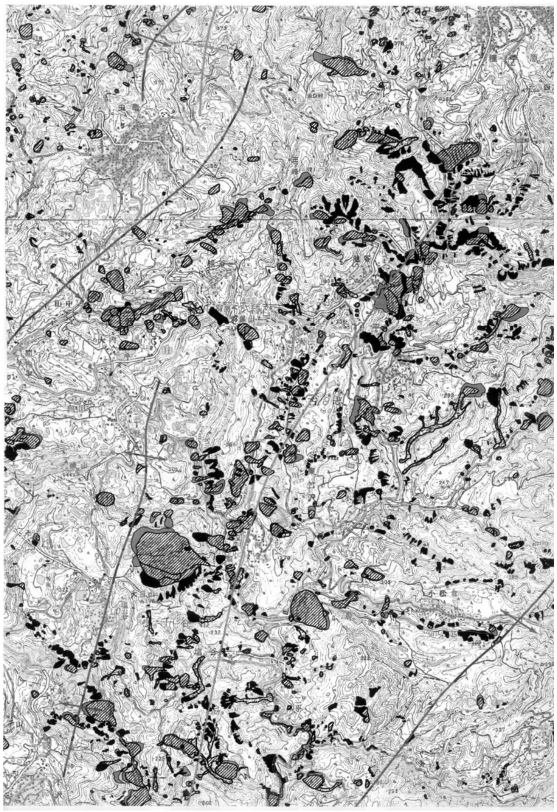

Fig. 1 Landslide distribution in the Imo-River watershed. (after interpretation by Prof. Yagi)

4. River Blockages by Landslide Dams

More than 50 landslide dams were formed along the main channel of the Imogawa-River and its tributaries by the earthquake-induced landslides. Many of them were naturally overtopped soon after their formation without catastrophic collapse. However, there were two critical landslide dams among them because of their dimensions, namely Higashi-Takezawa landslide dam and Terano landslide dam. Both of them have a length of about 350m and a volume of more than 1 million m^3. Generally, the stability of landslide dam against collapse should be evaluated on three mechanism, namely on collapse by water pressure, by piping and by overtopping. In both cases of river blockages, the length of the buried river channel is about ten times of the maximum water depth of the reservoir. Therefore, the possibility of the destructive collapse of either dam by water pressure and/or piping was estimated to be low.

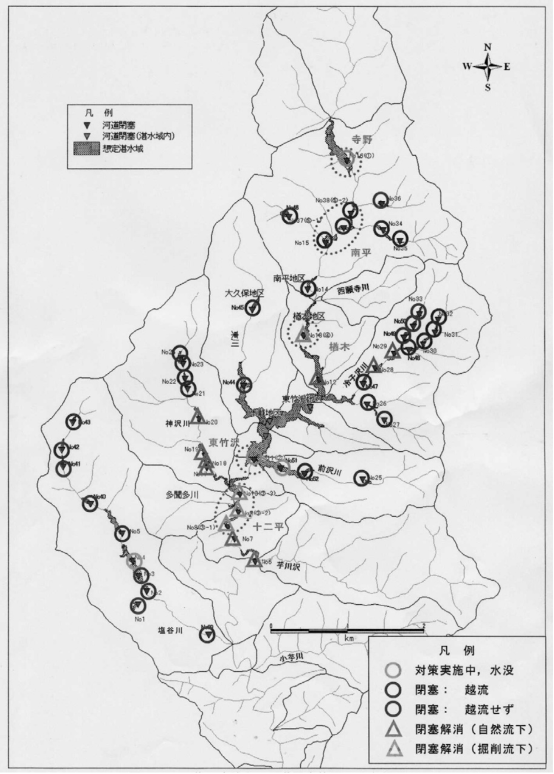

Fig. 2 Distribution of landslide dams (Hokuriku Regional Development Bureau)(situation on March 2005).

Legends:

Blue color areas along river channels are reservoirs.
Landslide dams are shown by *circles* and *triangles*.
Circles show river channel blockages which are still existing.
Orange circles: countermeasures installed
Blue circles: with overtopping
Red circles: without overtopping
Triangles show river channel blockages which are already solved.
Green triangles: naturally washed away
Violet triangles: artificially excavated

Fig. 3 Main scarp of the Higashi-Takezawa landslide.

However, the water levels of the both reservoirs were quickly raised up soon after the blockage of the river channel by continuous rainfall. The settlement of Kogomo-District in the upward area was inundated and many houses were damaged by inundation with impounded water. There remained apparent danger of overtopping and successive collapse of one or both of dams, because the water level of the reservoir has significantly risen. Collapse of these landslides dams could cause outburst floods or debris flows which would endanger the downstream residential areas at Ryuko-District. Therefore, the inhabitants of the downstream areas had to evacuate.

Fig. 4 River blockage by the Higashi-Takezawa landslide and reservoir.

It was urgently necessary to lower the water table of the reservoir. Emergency measures to prevent collapse of the landslide dams were carried out by the Ministry of Land, Infrastructure and Transportation. The reservoir at Higashi-Takezawa, which was formed by the largest landslides dam along the main channel of the Imogawa-River, has a critical significance. In order to reduce the danger of overtopping, the following emergency measures were undertaken. First of all, the water table was tried to lower by means of pumps and siphons. At the beginning 6 pumps and after then additional 6 pumps were installed. It was not suitable to use drainage pumps for the long term; thus they should be used for only emergency purpose in the initial stages. Because of maintenance problems for the pumps, diversion pipelines were installed as an additional alternative measure to inhibit overtopping. These alternative diversion pipelines were quite effective. As a result, the water table was kept lower than the overflow elevation and lowered to a safer level. Finally, an open channel with a sufficient cross-sectional area for water discharge including snow melt during early spring was constructed.

5. Monitoring and Observation System

Parallel to the countermeasures to prevent the collapse of the landslide dams, monitoring and observation systems were installed for the case of emergency (Fig. 5). For the security of the inhabitants at the Ryuko-District, a monitoring system including water level gauge, debris flow sensor and monitoring camera was installed around the Higashi-Takezawa landslide dam and the Terano landslide dam respectively. A necessary information transfer system was arranged for evacuation of inhabitants in case of debris flow occurrence. Monitoring on secondary displacement of soil mass was also carried out for the security during the construction works for the stabilization of the Higashi-Takezawa and the Terano landslide.

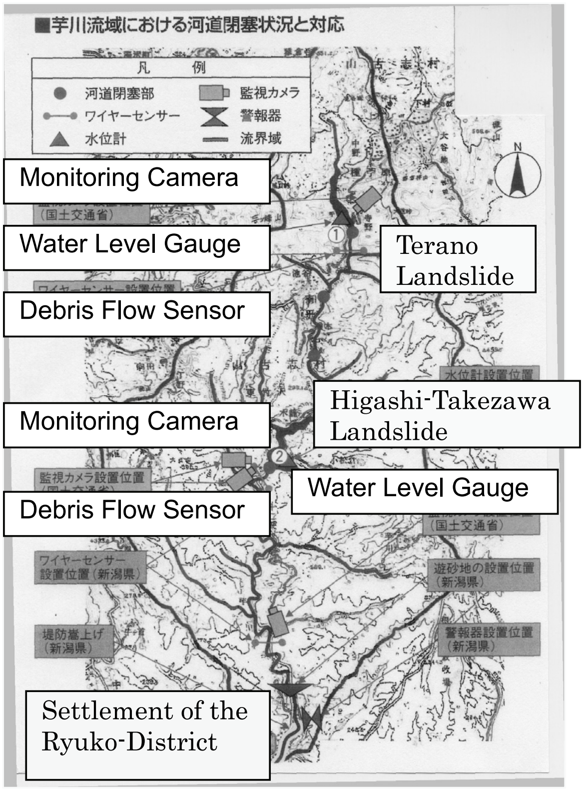

Fig. 5 Monitoring system in the watershed of the Imo-River.

6. Integrated Recovery Works

It was absolutely necessary to retain the stability of the displaced soil mass by the earthquake-induced landslides against secondary landslide motion during construction of the open channel. Therefore, excavation of the upper part of the displaced soil mass was immediately carried out for security during the construction works. In addition, a successive slope failure with a volume of several 10,000 m^3 was caused by snowmelt at the main scarp of the Higashi-Takezawa landside at the last stage of spring. This slope failure itself gave no significant effect to the safety factor of the displaced soil mass by the earthquake-induced landslides. However, there still remained rest risks of subsequent movement or displacement around the both landslide areas. Therefore, integral recovery works for these areas with sufficient comprehensive permanent measures in due consideration of rest risks were carried out (Fig. 6).

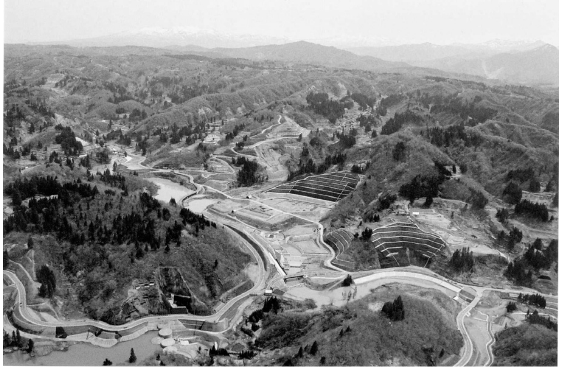

Fig. 6 Integral recovery works around the Higashi-Takezawa landslide area.

Remarks:

1) The displaced soil mass was completely stabilized by three consolidation dams.
2) The steep old landslide scarp behind the main scarp of the earthquake-induced landslide was reshaped into gentle gradient and covered by vegetation.

7. Remarks for mitigation of future disasters

In relation to hazard mitigation on subsequent landslides and slope failures it is urgently necessary to carry out field reconnaissance of slope deformations and assessment of slope instability immediately after the earthquake as a first step. Furthermore, it is again necessary to carry out the same reconnaissance of slope deformations and assessment of slope instability after snowmelt.

In recovery planning of heavily damaged roads by earthquake-induced landslides, it is necessary to consider the alteration of the original route plan in case that the road is extremely heavily damaged at many places. In some cases stabilization of landslides is an essential prerequisite condition for reconstruction works of damaged roads.

Besides assessment of instability of individual slopes, it is also necessary to assess the danger degree on possible future disasters by transport of unstable debris materials along river channels in various torrent watersheds after the earthquake. The potential of the movement of unstable materials in torrent watersheds near to the epicenter should be completely changed because of the strong influence of the earthquake.

Further, it is also an important task to develop appropriate methods of hazard zoning for prediction of landslides induced by future earthquakes.

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Description of the Dam Breach Sequence that Initiated the 18th March 2007 Ruapehu Crater Lake Lahar, New Zealand

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Abstract. Eruptions in 1995 and 1996 emptied the summit crater lake on Mt Ruapehu, a 2797 m high, persistently snow-capped active volcano in the central North Island of New Zealand. Re-filling of the crater over the following 11 years formed a lake whose upper levels were impounded behind a 7 m to 10 m high barrier composed of unconsolidated tephra.

At 11:22 (NZST) on 18 March 2007, the tephra barrier breached rapidly before the lake was full, releasing c.1.3 million m^3 of water over 2.5 hours. This flood of water eroded and entrained ice and scree from the upper flanks of the volcano, along with colluvium and alluvium in the steep upper gorge of the Whangaehu River to form a volcanic debris flow, or lahar. The lahar front reached the coast some 15 hours later, after traveling 155 km. Initial estimates indicate the 2007 lahar was c.25 % larger than the dambreak lahar in 1953. The 1953 lahar was notable as it resulted in New Zealand's worst volcanic disaster with the loss of 151 lives after it washed away the Tangiwai rail bridge.

The barrier failed through two sequential failure mechanisms. The first phase began at 09:53 (NZST), with rapid retreat of one of the erosion scarps on the downstream slope of the barrier, initiated by internal erosion. Headward erosion of the scarp into the barrier formed an initial breach, after which water flowing through the breach lead to erosion and undercutting of the wider downstream toe of the barrier. The final large-scale breach of the dam occurred between 11:21 and 11:22 as slope instability caused retrogressive failure of the remaining barrier.

Keywords. Dam breach, lahar, terrestrial laser scanning, tephra barrier.

1. Introduction

Mt Ruapehu is a 2797 m high, persistently snow-capped active andesitic volcano in the central North Island of New Zealand (Fig. 1). In 1995-96, the largest eruption sequence in 50 years expelled the summit crater lake (Manville, et al. 2007). As well as generating a series of eruption-and rain-triggered lahars, this episode constructed an approximate 7 m to 10 m thick barrier of unconsolidated tephra at the lowest point in the crater rim. The tephra was deposited on top of the c. 60 m wide stable lava rock ledge, the elevation of which controlled the overflow from the crater lake prior to the 1995-96 eruptions (Hancox, 1997). Over the following 11 years the c. 9 million m^3 lake refilled at an irregular rate from a combination of precipitation and juvenile inputs, mediated by climatic and geothermal heating cycles (Manville, et al. 2007).

To monitor the development of the hazard posed by the refilling lake, the Department of Conservation (DOC) installed monitoring equipment comprising: geophones and a trip wire in the tephra barrier; and a sensor to monitor the lake level rise. This equipment formed an integral part of the Eastern Ruapehu Lahar Warning System (ERLAWS), which also included geophones along the Whangaehu River, the potential lahar flow path (Keys, 2004).

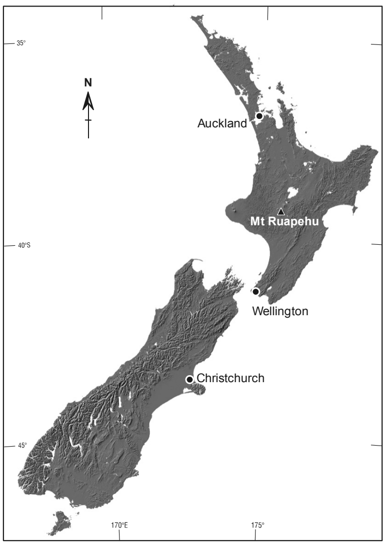

Fig 1. Location of Mt Ruapehu, New Zealand

This paper provides an account of the 2007 dam breach sequence and failure mechanisms based on monitoring data recorded by the ELRAWS equipment and additional research equipment installed by the Institute of Geological and Nuclear Science (GNS Science), and investigations on the barrier including terrestrial laser scanning (TLS) and detailed geological field mapping, carried out over several months leading up to and immediately following the failure.

2. The tephra barrier geological model

A geological model of the tephra barrier was first developed by Hancox, et al (1997 and 2001) based mainly on surface geological mapping. More detailed investigations, including dynamic cone penetrometer (DCP) testing, test pitting, sampling, particle size analysis and ground penetrating radar (GPR) surveys were carried out jointly by GNS and the Department of Conservation (DOC), on behalf of the Crater

Lake Scientific and Technical Advisory Panel (STAP) set up by DOC (Keys, 2003), and were used to modify the model, (Keys, 2003. and Fell and Foster, 2003). The model was further refined in 2007 based on the results of topographic surveying using TLS and detailed field mapping pre- and post-failure.

Cross sections through the tephra barrier are shown in Figure 2. The detailed logging by Houghton (2007) shows the existence of 17 different material layers in the barrier, which can be grouped into two main types, based on geotechnical properties in Fell and Foster (2003). These materials are: 1) Fine tephra (tephra) – fine to coarse SAND, with 2% to 10% fine gravel and 5% to 13% silt; and 2) Coarse tephra (Lapilli) – fine to coarse GRAVEL) with 1% to 7% silt. Both materials are cohesionless and based on insitu testing and DCP probing the lapilli had a higher relative density (dense) than the tephra (medium dense), (NZGS, 2005).

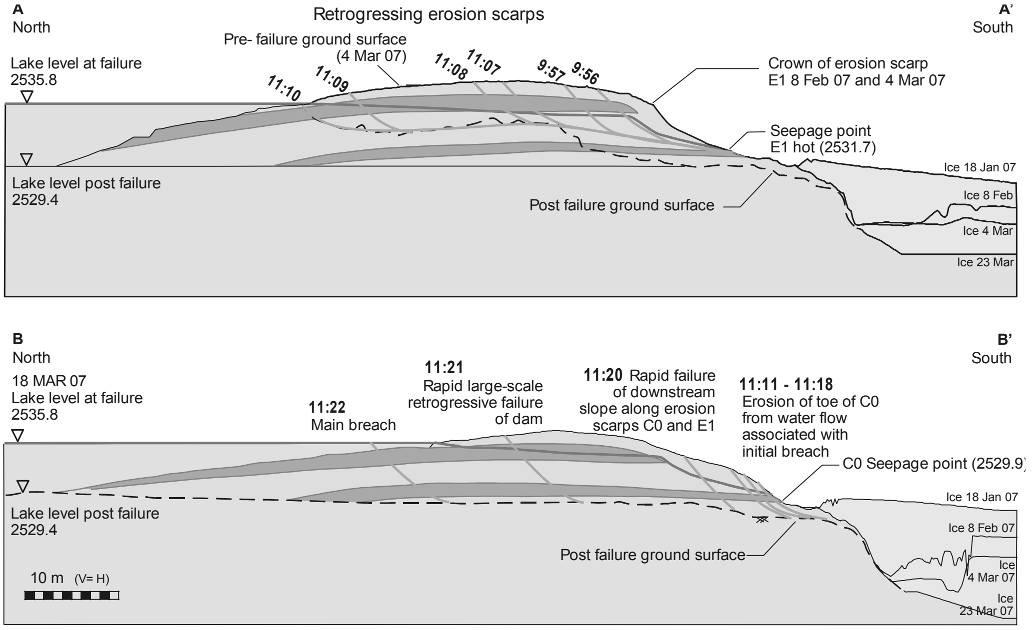

Fig 2. Cross sections through the tephra barrier summarising its failure sequence.

The lapilli form two distinct laterally continuous layers within the barrier. The lower lapilli layer varies in thickness, typically from 0.5 m to 1.0 m and outcrops at the toe of the downstream slope of the barrier. The upper lapilli layer is thicker, typically ranging from 1.5 m to 2.0 m in thickness, and while extending into the upstream slope of the barrier does not outcrop on the downstream slope.

The tephra and lapilli layers overlie lava from pre-1945 eruptions, with the base of the tephra from 1995-96 eruptions determined originally from DCP testing (Keys, 2003) and updated from TLS surveys carried out post barrier failure. There was close agreement between the level estimated prior to the barrier failure (2529.3 m AMSL +/-0.5m, Keys, 2003), and that derived from TLS surveys carried out post barrier failure (2529.3 m AMSL +/- 0.2m).

3. Observations made during lake filling

The rate of infilling, and the impounded crater lake level were monitored routinely by DOC supported by GNS. The first lake level survey was on 21/9/1996 and the last on 19/3/2007, the day after the breach, although less frequent monitoring has continued. Measurements were carried out at a frequency of one to two surveys per month. These surveys used an Abney level referenced to stable survey marks located off the tephra barrier.

On 1/2/2006 the lake level reached the elevation of the lava lip (2529.3 m AMSL), that formed the overflow channel prior to the 1995-96 eruptions, and the base of the tephra (and lapilli) forming the new barrier, triggering the ERLAWS warning level 1b (DOC, 2006). The rising lake level formed an important part of ERLAWS, as the warning levels were based on increasing lake levels derived from a probabilistic assessment of various failure scenarios (Fell and Foster, 2003).

As the lake level continued to rise, additional monitoring equipment was installed on the margins of the Crater Lake. This equipment included a bubble-in lake level system logging lake level to 3 mm precision at 10 second intervals, and an automatic digital still camera overlooking the downstream slope of the tephra barrier, storing images to an on-site flashcard at 1 minute intervals during daylight hours.

Following summer snow melt observations by DOC and GNS staff between 29/12/2006 and 5/1/2007, when the lake level was at 2534.2 m AMSL, identified areas of seepage and localised erosion on the downstream slope of the tephra barrier (erosion scarps C0, E1, E3, E4, W1, W4 and W6, Fig. 4), (DOC, 2007). To quantify the rate and extent of this erosion a series of TLS surveys of the barrier were carried out by GNS, combined with field measurements carried out by DOC. TLS surveys of the barrier commenced on 18/1/2007, with additional surveys on 8/2/2007 and 4/3/2007, and the last on 23/3/2007, 5 days after failure. Difference models extracted from the TLS survey data were used to examine the evolution of the erosion scarps, which indicated northerly retrogression into the barrier, up-slope towards the crest of the barrier and lake. The maximum retrogression was 4.7 m towards the NNE, recorded between 18/1/2007 and 8/2/2007 for erosion scarp E1, with only minor retrogression (0.5 m), of the same scarp recorded between the 8/2/2007 and 4/3/2007 surveys. The maximum retrogression of erosion scarp E1 was recorded during a period when the lake level rose from 2534.9 to 2535.5 m AMSL, with the minor retrogression recorded during a period when the lake level was stable between 2535.4 and 2535.5 m AMSL.

Field observations made at the same time as the TLS surveys indicated that the erosion appeared to have initiated through confined seepage within the lower layer of coarse tephra (lapilli), outcropping on the down stream slope (Fig 2). At the time of the 4/1/2007 inspection, seepage through this flow path was eroding and transporting material from the overlying fine tephra (Fig 2), which was in turn leading to localised slumping and development of the erosion scarps on the downstream slope. Active erosion was also observed on 18/1/2007, however, on 8/2/2007 and 4/3/2007 water seeping from the lapilli layer was relatively clear and erosion appeared to have stopped.

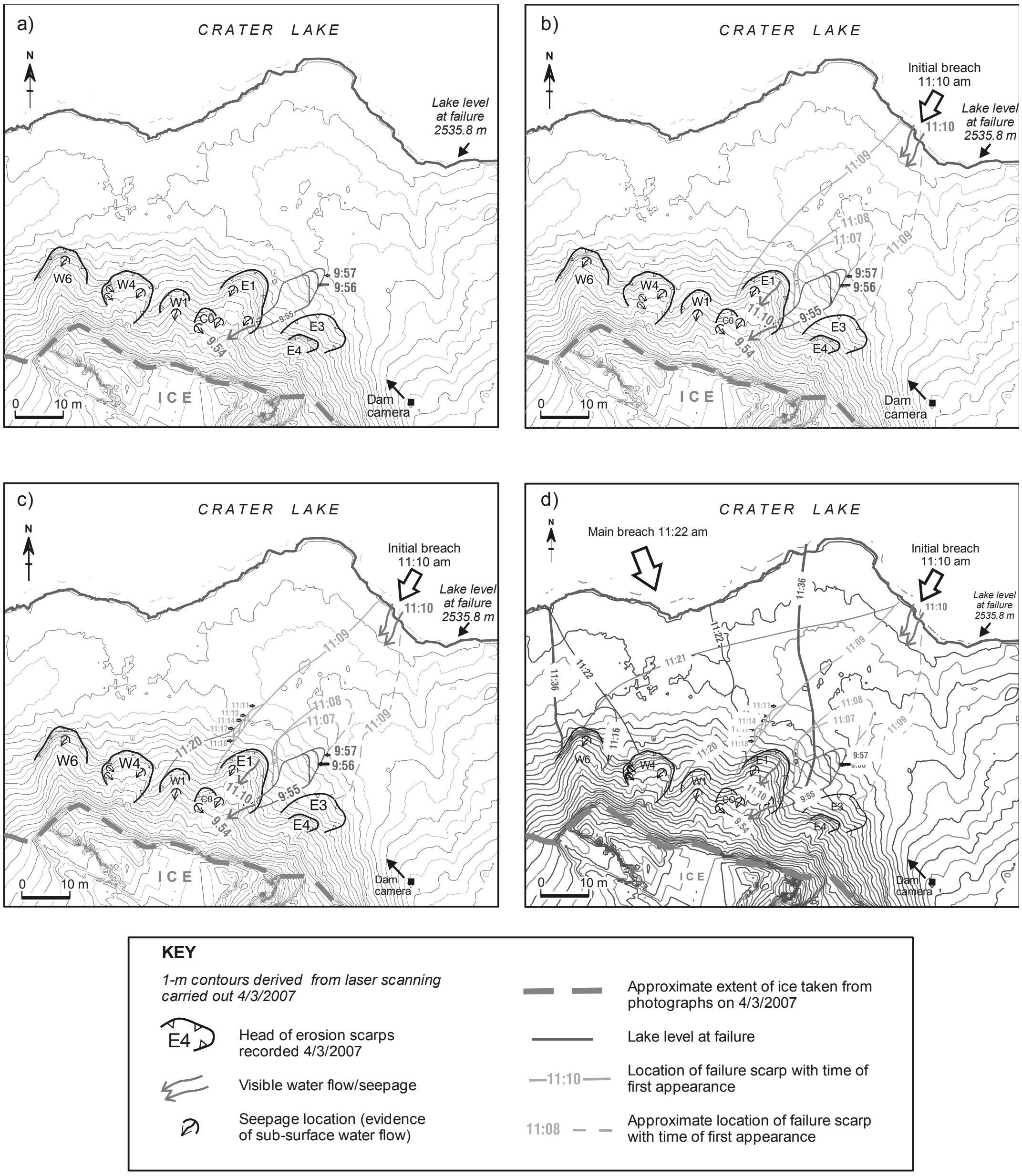

Fig 3. Barrier failure sequence derived from the monitoring equipment installed on the barrier.

4. Barrier failure sequence

On Sunday 18 March 2007, the tephra barrier breached following a prolonged period of wet weather. On the morning of 18/3/2007 a rainstorm caused the lake level to rise from approximately 2535.4 to 2535.8 m AMSL (Manville, et al. 2007). Despite poor weather conditions, the fixed camera captured a time-lapse sequence of the failure, while lake-level drawdown was obtained from both the bubble-in and

ERLAWS lake-level sensors. Meanwhile ERLAWS geophones at the tephra barrier detected vibrations caused by the sequential collapse of the tephra dam and the escaping water (Manville, et al. 2007). These data were analysed to infer the barrier failure sequence, Fig 3.

5. Barrier failure mechanisms

Data analyses indicate that the barrier failed sequentially, and involved two main failure mechanisms. The rapid failure sequence appears to have been initiated by the rising lake level caused by a rainstorm on the morning of 18/3/2007. The failure sequence began at 09:53 (NZST), by rapid retreat of erosion scarp E1, initiated by internal erosion, (Figure 3), following the appearance of seepage from the toe of erosion scarp E1. The time-lapse photographs indicate that erosion continued retrogressing upslope into the barrier towards the lake, forming a narrow channel, which eventually reached the lake. This lead to an initial breach at 11:10 (NZST) and a minor lowering of the lake-level of 0.03 m in 8 minutes (Manville, et al. 2007).

Between 11:15 and 11:20 (NZST), flow of water through the breach appeared to have initiated undercutting and erosion along its western flank (right-hand, looking downstream), with the eastern flank being outside the camera field-of-view. This removal of toe support appears to have initiated further instability of the down-stream slope, as a series of very rapid large-scale slope failures occurred between 11:20 and 11:21, which retrogressed towards the crest of the barrier. The final large-scale breach of the dam occurred at 11:22 as the retrogressive slope failures led to complete loss of toe support and the failure of the remaining barrier. This created a breach approximately 35 m wide, enlarging to 45 m at 11:26, which extended down to the top of the lava, resulting in a peak outflow of c. 530 m^3/s (Manville, et al. 2007).

Observations and measurements made in the days and weeks following the failure indicated that backward erosion, which created the initial breach at 11:10 (NZST), initiated within the upper lapilli layer, creating a narrow (15 m wide) terrace, with the level of the erosion terrace corresponding to the fine tephra underlying the upper lappili layer. Geomorphic mapping of the barrier after failure indicated that this terrace had been subsequently incised along its western flank by the large outflows, associated with the main failure of the barrier at 11:22 (NZST).

6. Discussion

The response to lake level filling and failure mechanisms of the tephra barrier derived from detailed assessment of information obtained leading up to and during failure of the barrier were similar to those identified in the initial report by Hancox., et al (1997), and refined later by STAP (2003). The conclusions of STAP (2003) and Fell and Foster (2003), were:

1. the barrier was unlikely to breach at lower lake levels (2531m AMSL);
2. the barrier was almost certain to breach when the lake levels approach 2536 m (AMSL) or higher;
3. At lower lake-levels the major contributors to likely failure where assessed as being earthquake induced liquefaction, and waves caused by rockfall, ice carving and tephra sliding from the flanks of the crater lake.
4. At higher lake levels, slope instability was assessed as the major contributor, followed by overtopping (by wind induced waves), internal erosion and piping, phreatic eruption wave, and waves caused by a tephra slide.

7. Conclusions

The failure sequence of the tephra dam impounding the Ruapehu crater lake occurred when the lake was c. 1.1 m below its crest (overtopping level 2536.9 m AMSL), recorded along Section B-B’, Figure 2. The failure mechanism was backward erosion, initiated by internal erosion, within the upper lapilli layer when the lake level rose from 2535.4 to 2535.8 m AMSL, leading to an initial minor breach of the barrier. Water flowing through the breach channel triggered erosion and undercutting of the downstream slope of the barrier, initiating large-scale, and rapid (11:20 to 11:22 NZST) slope instability, which led to the main breach of the barrier and the peak outflows of c. 530 m^3/s (Manville et al, 2007).

Acknowledgments

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Landslide Monitoring Data and Its Application to Risk Management, an Example from New Zealand

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Abstract

As a result of increasing global population pressures, housing and infrastructure are being developed at an accelerating pace, in areas of marginal land which are often in landslide prone areas. As a consequence there is an increasing need to assess the landslide hazards and manage the risks which arise from development on marginal land. New Zealand, with its active geological processes, steep terrain and young sediments has experienced a number of fatalities and substantial economic loss due to landslides. A case study is presented from Taihape, central North Island, New Zealand, which utilises a landslide monitoring network as a tool for mitigating landslide risk.

1. Introduction

Management of landslide risk poses many difficulties due to the complexity in assessing the landslide hazard and vulnerability of the infrastructure and buildings located on them or in their path. Glade (2003) identified several important factors: lack of accurate data for reliable hazard analysis; site specific nature of landslides; and difficulties in quantifying spatial and temporal landslide hazards. Monitoring of specific landslide hazards can provide quantitative data for the purposes of risk management. The Australian Geomechanics Society (AGS, 2007), provide a framework for landslide risk management, which includes the application of landslide monitoring data in two ways. First, a risk assessment approach involves investigating and assessing the landslide features, e.g. depth of movement, extent and patterns of movement, runout distance and triggering thresholds. Second, a risk management strategy is adopted which typically comprises (1) restricting development in landslide prone areas, (2) implementing building codes, (3) design of physical mitigation works and (4) developing and installing landslide monitoring and warning systems (Schuster and Highland, 2007).

In order to design an effective landslide warning system, some assessment of the risk posed by the landslide is required. The risk assessment typically comprises an analysis of the rates and patterns of landslide movement for particular triggering rainfall intensity-duration thresholds to establish a set of landslide warning levels, which are then used as inputs for the hazard warning system (Figure 1).

Traditionally, investigation and interpretation of landslide movement patterns have been undertaken using a wide range of techniques, including the use of survey marks; extensometers; inclinometers; analogue and digital photogrammetry, both terrestrial and aerial; synthetic aperture radar interferometry (InSAR) (Petley. et al., 2004) and more recently terrestrial and airborne LiDAR surveys. Rainfall intensity-duration thresholds, in combination with rainfall forecasts and real-time rainfall measurements have been the basis for operational landslide warning systems in several areas of the world including Hong Kong (Chan. *et al*, 2003) America (Keefer. *et al*, 1987) and the UK (Cole and Davis, 2002). These systems operate over broad regions or in specific areas where people and infrastructure are at risk from landslides (NOAA-USGS, 2005). Although new movement monitoring techniques have improved the understanding of landslide movement patterns in recent years, these techniques suffer from serious shortcomings in terms of spatial and temporal resolution (Petley. et al., 2004) and as a result many monitoring programmes fail to link specific periods of landslide movement to the triggering factor. Other shortcomings in landslide monitoring, especially for landslide warning systems, are the ways in which the monitoring data are collected, transferred, processed and displayed. This paper discusses a case study from New Zealand where near-real time landslide monitoring data is being used to assess the nature and causes of landslide displacement as an aid to managing the risk posed by the landslide risk.

RESEARCH: (Sciences of monitoring systems, sources, propagation, inundation, risk assessment; and of awareness, and eff effective response)	**1.**	**EARLY WARNING SYSTEM**: Hardware, electronics, communications and planning necessary to effectively detect a hazard, generate warning messages and transmit them to at-risk regions (including any use of public notification hardware)	**EFFECTIVENESS EVALUATION**
	2.	**PLANNING:** Decision-making tools: thresholds, evacuation routes and maps, inter-organisational relationships and communication channels.	
	3.	**COOPERATION, DISCUSSION AND COMMUNICATION:** Preplanned and exercised communication between central government agencies, local emergency management agency staff, scientists and community representatives. Renewal of contacts must be regular and permanently sustained, to overcome common high staff turnover.	
	4.	**EDUCATION:** Public education, staff training, maps, and signs.	
	5.	**EXERCISES:** Scenario development and simulations — table-top and full, with observation and feedback.	

Fig. 1. Model showing the main components of an effective hazard warning system (after Webb, 2005)

2. The Taihape Landslide

2.1 Landslide setting

Fig.2. Site map

The Taihape landslide is located in central North Island, New Zealand (Figure 2). It consists of a large, deep-seated, translational slide that has developed in Tertiary-age sandstones. It is estimated to have originated between 1,800 to 11,000 years ago (Thompson 1982) and is presently active. The landslide covers approximately 45 hectares and includes 209 households, 388 residents and a primary school (Massey and Palmer, 2007). The regional geological structure exerts a strong control on the occurrence and location of landslides on the Tertiary age rocks, with many landslides being bedding controlled. At Taihape, the landslide slip plane has been identified from various ground investigations and ranges from 22m below ground level in the toe of the landslide to 34m depth near the back scarp of the landslide and comprises a thin (5 to 10mm) layer of slickensided clay material (Massey and Palmer, 2008), thought to represent a volcanic deposit. The historical direction of landslide movement (bearing 160°) is coincident with the regional dip direction of bedding (Thompson, 1982). A schematic engineering geological cross section through the landslide is shown in Figure 3.

2.2 Landslide background

The Taihape landslide has been studied for scientific and property insurance purposes since 1971, when significant ground movements were first noticed. Monitoring began in 1984 with the installation of 2 standpipe piezometers and 3 inclinometers and a ground deformation network was established in 1985 comprising 25 survey marks. Routine monitoring of the deformation network in 2004 identified that the movement rate of the landslide had increased significantly and signs of surface deformation had started to appear in the infrastructure around the landslide toe. As a result, an additional 5 inclinometers and standpipe piezometers were installed in 2005/2006 (Massey and Palmer, 2008). Although some good quality historical monitoring data are available for this landslide, the temporal resolution of this information is poor because the data was downloaded and processed manually, at sporadic intervals. In addition, the measurement frequency of the surface deformation network has varied from 6 months to 5 years. More recently the 2005/2006 inclinometers have been used to determine landslide movement (Williams. et al., 2007), however, the spatial resolution of these is limited to a line through the landslide and so it is not possible to determine movement patterns from these data alone.

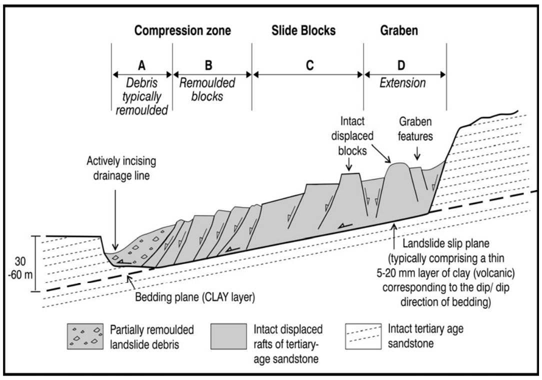

Fig. 3. Schematic engineering geological cross section through the Taihape landslide

The historical monitoring data have been compared to rainfall, and more recently earthquake records in an attempt to link periods of landslide movement with potential triggering events. Making these links has been difficult due to the lack of site-specific rainfall and ground acceleration data combined with the poor temporal resolution of the monitoring data. In July 2006 monitoring network was designed and installed, which operas in a near-real time framework providing high resolution spatial and temporal monitoring of the landslide movement and also to monitor the triggering events.

3. The monitoring network

3.1 Equipment

Equipment has been installed to monitor: rainfall; ground-shaking intensity; ground-water levels; and surface movement. A key component is the movement-monitoring system, which utilises 35 prism reflectors located across the landslide to provide a high level of spatial resolution. High temporal resolutions are achieved through a robotic total-survey station that seeks and measures the location of each reflector at hourly intervals. Rainfall is recorded by two tipping-bucket rain gauges located on the toe and near the back scarp of the landslides, and groundwater levels acting along the slip plane of the landslide are recorded at five-minute intervals using 4 downhole vibrating wire piezometers. Due to the proximity of the landslide to the active Taupo

Volcanic Zone, any movement triggered by earthquake events is being monitored using a strong motion accelerograph installed in Taihape Rural Hospital. All the monitoring equipment has been installed as a semi permanent set up, with power for all the equipment being generated from photovoltaic cells without any need for mains power.

3.2 Data transfer, processing and display

The monitoring network operates in a near-real time framework (defined as: the delay introduced, by automated data processing or network transmission, between the occurrence of an event and the use of the processed data), with an approximate site to office delay of one hour. Wireless transfer of data from the robotic total station, rain gauges, piezometers and strong motion sensor is achieved via radio link to the Taihape Town Hall and then via the internet to GNS Science buildings located near Wellington , 250km south of Taihape. The data are automatically processed, formatted, checked and made available in both human and machine-readable formats. The results are presented in an intuitive, interactive web-based chart, which is updated at 15-minute intervals and can be viewed via the GeoNet website: www.geonet.org.nz, which allows the data to be viewed easily by the end user. Faults in the equipment and network are monitored using existing GeoNet tools and so the integrities of the equipment and data are also remotely monitored.

4. Movement patterns of the Taihape Landslide

The approach commonly adopted for the description of landslide movement derived from monitoring data concentrates on the analysis of movement velocities and cumulative displacements in an attempt to classify the patterns of landslide movement (Allison and Brunsden, 1990). Taihape is a complex landslide formed from a series of discrete slide-blocks. Analysis of the movement data suggests that the movement patterns within the landslide fall into two distinct types, both in the magnitude of the total displacement and the pattern of movement observed. The movement patterns specifically identified at Taihape landslide typically comprise: Type I. Creep – characterised by displacements rates typically less than 0.1 mm/day sustained over many weeks; and Type 2. Accelerated creep – characterised by more rapid displacements rates typically greater than 2 mm/day over short periods of time (days rather than weeks).

The spatial resolution of the movement monitoring equipment has allowed these movement patterns to be correlated with the different slide-blocks forming the landslide, and their location within the overall landslide. At present the active area of the landslide is confined to the toe and lower central slide-blocks. The temporal resolution of the monitoring data has enabled the periods of displacement to be linked to the triggering factor. Comprising periods of prolonged rainfall (cumulative rainfall of over 55m over a consecutive 3-day period), causing increases in the groundwater levels along the slip plane of the landslide.

5. Conclusions

The increased spatial and temporal resolution of the near-real time monitoring network is allowing a better understanding of the landslide movement rates and patterns to be developed and is allowing periods of movement to be linked to the triggering factors, giving an improved basis for defining movement triggering rainfall intensity/duration and groundwater thresholds. The movement data has indicated those areas of the landslide which are at greatest risk of undergoing movement during specific triggering rainfall events as being located at the toe and in the central portion of the slide. These movement triggering thresholds and movement rates are now being used as a principal input to help develop a warning system for the landslide, comprising a series of warning levels to aid preparedness and help manage the risk posed by the landslide. In addition, the increased spatial coverage of the movement data may allow local councils to better manage the landslide risk by reassessing planning restrictions on those parts of the landslide which are shown to be stable.

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Causes and Mitigation of Large Rainfall-triggered Landslides and Debris Flows in Last years in Slovenia

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Abstract. In Slovenia, a small central Europe country in the S Alps, land sliding is in important erosive factor and limiting factor when planning different land uses. Now and again, large landslides (with a volume around or more than 1 M m^3) occur and their mitigation is definitely a state affair.

In the last decade, several large landslides were triggered in Slovenia, some of them associated with debris flows. The main triggering factor was prolonged rainfall or short but intense rain showers. The most catastrophic of them was the Stože landslide and the following debris flow, causing 7 casualties in the small alpine village of Log pod Mangartom. This event caused a re-organization at the state level when dealing with natural hazards. A special governmental commission helped by a professional committee was nominated in order to help with their mitigation. This paper summarizes experiences with the mitigation of large landslides in Slovenia gained since the year 2000.

Keywords. Rainfall-triggered landslides, debris flows, mathematical modeling, monitoring, prevention, mitigation

1. Introduction

In Slovenia, a small central European country (area of 20,273 km^2), the estimated direct (economic) damages caused by natural disasters are on average above 2% of GDP (in 2007 the GDP was close to 34 billion Euro or 16,532 Euro per capita, reaching 90 % of the average of the EU-27) with some exceptional years, as in 1990, when the flood-related economic damage itself, caused by heavy floods, was above 20% of the annual national GDP (ACPDR, 2005).

Most hazardous natural disasters in Slovenia, apart from earthquakes, fires in the natural environment (on average more than 1,000 in a year), and droughts/heat waves (causing the highest damages in the last decade!), are rock falls, land slides, and fluvial erosion processes in many torrents and rivers. Mass wasting and soil erosion are noticeable on 43% of Slovenian territory (around 8,800 km^2 of labile and potentially unstable slopes; Mikoš et al., 2004a). This area is crossed by some 8,000 km of torrents that drain nearly 400 torrential watersheds. Floods and landslides are complex natural phenomena caused by local natural conditions and, with further development, more and more influenced by human activity. In Slovenia, generally speaking, unfavorable geological conditions, steep terrain and abundance of precipitation (rainfall) are the major causes of these disasters (Mikoš et al., 2004a).

2. Landsliding in Slovenia

Minor landslides in Slovenia are of different forms (mainly shallow landslides, with abundance of smaller slides and slumps). The order of their average volume is 1000 m^3, rarely 10,000 m^3. Some of them have already been stabilized using technical measures, others are still active. Unfavorable geological conditions are the main causes for such a high slide density (> 1slide/10km^2), despite good vegetation conditions in Slovenia (more than 60% covered by forests) (Mikoš et al., 2004a). The next contributing factor is the abundance of precipitation and high number of days with daily totals above 20 mm.

In Slovenia, over 6000 mainly minor landslides have been registered so far. Not all of them are part of the official landslide inventory cadastre that was incorporated into the GIS environment, i.e. software application called GIS-UJME, developed and maintained by the Ministry of Defense. The landslide inventory maps include more than 3500 landslides, but not rock falls and rock slides, and are one of the 85 geo-referenced databases incorporated in this system – such as databases on infrastructure, flood hazard maps, avalanche cadastre, earthquake hazard maps, fire hazard maps, etc.

This electronic database is used as an internet application by the Ministry of Defense in regional Notification Centers for coordination purposes during immediate disaster relief actions led by the Civil Defense units, and as an intranet application being the information basis for their training in the Protection and Rescue Education, and Training Center and for preparation of civil protection and disaster relief plans in the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief. Unfortunately, this database is (still) not directly used for planning activities in the Ministry of the Environment and Spatial Planning in the field of hazard prevention.

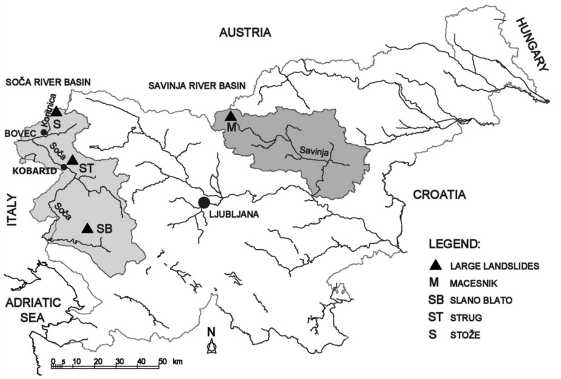

Fig. 1 Locations of the four active large landslides in Slovenia, presented in this paper

3. Large landslides in Slovenia

Experiences with mitigation of large landslides were rare until the last decade, when four large landslides (Stože, Slano Blato, Strug, Macesnik, Fig. 1) with volumes of the order of 1 million m^3 were triggered and urged for fast mitigation. They can be placed in the category of rainfall-induced landslides that became active in unfavorable geological conditions.

Some of them were associated with fast-flowing debris flows.

3.1 Macesnik Landslide

In 1989, above the village of Solčava in N Slovenia, the Macesnik Landslide was triggered on a forested slope. Firstly, the landslide destroyed state road, and a new pontoon bridge had to be built instead. In 1996, the landslide advanced and destroyed a turn on the same state road. In 1999, a large rock outcrop stopped the advancement of the landslide. In 2008, the landslide is only 1000 m away from the Savinja River and the village of Solčava. It is 2500 m long and up to more than 100 wide with an estimated volume in excess of 2 million m^3. Its depth is not constant: on average it is 10 to 15 m deep, but in the area of the toe it reaches the depth of 30 m. The unstable mass consists of water-saturated and highly-weathered carboniferous formations. The presently active landslide lies within the fossil landslide which is up to 350 m wide and 50 m deep with the total volume estimated at close to 10 million m^3.

Till 1994 there were no mitigation activities on the landslide. The construction of mitigation works was made difficult in the 1990's due to intensive landslide movements that could reach up to 50 cm/day. Since 2000, the landslide has been investigated by 36 boreholes, and 28 of them were equipped with inclinometer casings, serving as piezometers. Surface movements have been monitored geodetically in 20 cross sections. Since 2001, surface drainage works in the form of open surface drains (Fig. 2) have mainly been completed around the circumference of the landslide as the first phase of the stepwise mitigation. The final mitigation solution is a combination of subsurface drainage works in the form of deep drains with retaining works in the form of reinforced concrete (RC) deep wells built below the sliding surface and functioning as water wells to drain the landslide, and as dowels to stop the landslide movement (Mikoš et al., 2005a).

In the 800 m long uppermost section of the landslide, 3 parallel deep drain trenches were executed in the autumn of 2003 that enabled the construction of two 5 m wide and 22 m deep RC wells, finished in early 2005. The monitoring results show that the landslide displacements have been drastically reduced to less than 1 cm/day. In 2007, 2 RC wells have been constructed in the middle section of the landslide to support the road crossing. At the landslide toe, a support construction is planned to prevent further landslide advancement that would destroy several farmhouses on its way down the valley towards the Savinja River. Possible damming of this alpine river would cause a catastrophic flooding.

Fig. 2 The photo of the Macesnik Landslide in its upper part showing the execution of surface drainage works taken by R. Fazarinc in 2004

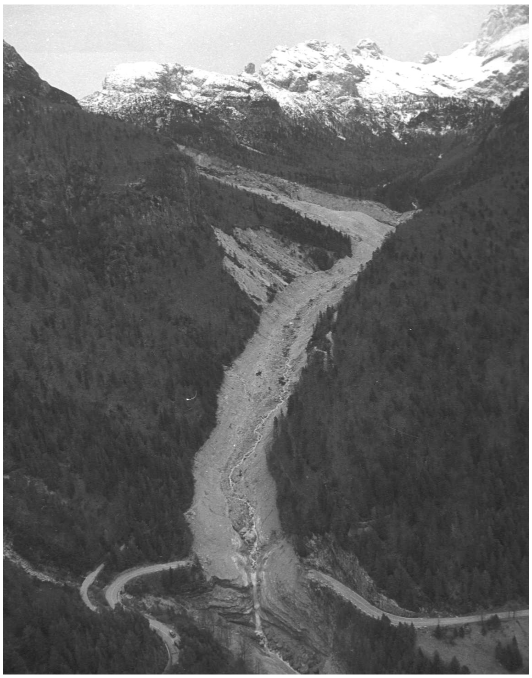

Fig. 3 The photo of the Stože debris-flow pathway from the Stože slope across the regional road Bovec-Tarvisio (Italy), taken by M. Mikos in November 2000

3.2 Stože Landslide

The Stože Landslide with a volume of around 1.5 million m^3 was initiated in November 2000 as a debris landslide on the Stože slope in a moraine (glacial till) above the village of Log pod Mangartom in W Slovenia after a wet autumn period (1638.4 mm in 48 days before the event, more than 60 % of the average annual precipitation) with no snow accumulation but rising runoff coefficients. It turned from a debris landslide on a hill slope (possibly caused by artesian pressures) into a catastrophic debris flow (Fig. 3) due to low inertial shear stress caused by high water content (Mikoš et al., 2004b). The Stože debris flow had two phases: the first (dry) one ended after less than 1 km in the channel of the Mangart Creek, and the second (wet) one initiated after 35 hours by rainfall and infiltration, when it traveled through a narrow channel of the Predelica Torrent for 4 km to Log pod Mangartom and further downstream to the Koritnica River valley, stopping after 7 km. The remaining masses on the Stože slope are the main reason for concern and possible new debris flows in the future.

One- and two-dimensional mathematical modeling of debris flows (Četina et al., 2006) was used for optimization of the two main river channel form in the area (Predelica Torrent and Koritnica River) to convey debris flows and floods (Fazarinc et al., 2006), and to prepare the hazard map for the village of Log pod Mangartom (Mikoš et al., 2006b). This map was used to declare safe areas for construction of buildings (houses) destroyed by the November 2000 debris flow. In 2008, the mitigation is slowly coming to its end; the one major issue left is the construction of a new 110-m long arch bridge across the Mangart Creek that was destroyed by the debris flow in November 2000 (Fig. 3).

3.3 Slano Blato Landslide

The Slano Blato Landslide also formed in fossil landslide masses on a contact of calcareous (high karst plateau) and flysch formations on a hill slope (Fig. 4) during wet autumn period in November 2000 (Logar et al., 2005). It is ever since progressively enlarging behind the main scarp via retrogressive slumping of new and freshly weathered flysch material that due to high water pore pressures turns into a viscous earth flow.

The executed mitigation works in the upper part of the landslide so far are a combination of surface and deep drainage works and a curtain of six RC deep wells. The deep wells were executed in two phases. In the first phase the same technique was used as successfully applied on the Macesnik Landslide. In November 2004, the 3 RC deep wells were still not executed below the sliding surface, and during intense rainfall they slide together with the landslide mass for around 20 meters and were tilted backwards. Two of them were nevertheless executed to the full depth and their primary coating of 25 cm was in the inside finished by an 85 cm thick secondary coating. The third deep well was finished by applying a different technology. As a primary coating, eight 150 cm wide Benotto piles were drilled to the full depth of 24 m (well below the sliding surface), and then connected at their top by a 2-m high concrete beam. The inside part was excavated to the depth of 15 m were a 3-m thick concrete foundation plate was executed. The deep wells were connected and a drainage pipe was drilled from one of them to the surface to drain ground water captured by deep wells.

Whereas in its lower part, around 260,000 m^3 of landslide masses were removed in 2001 and 2002 and put to a dumping site in order to control the advancement of the viscous earth flow. Furthermore, the channel of the Grajšček stream that springs in the landslide area was enlarged downstream of the landslide toe in order to convey occasional very muddy flows from the bare landslide area through the village of Lokavec. In the upper part of the landslide, the finalization of the curtain of more than 10 RC deep wells all together is expected.

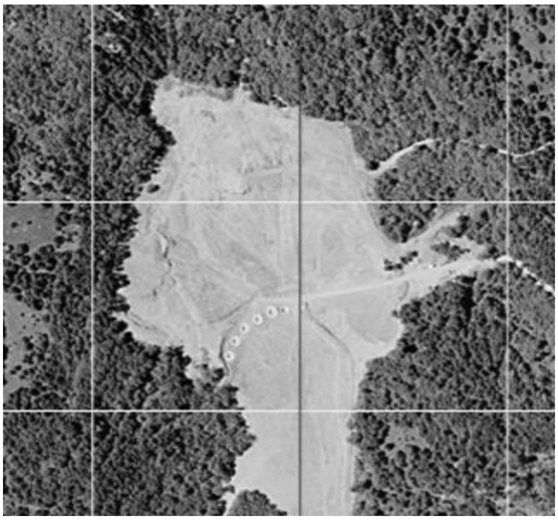

Fig. 4 The aerial photo of the upper part of the Slano Blato Landslide showing the executed RC deep wells (1 square is 100 x 100 m) taken in 2005

3.4 Strug Landslide

The Strug Landslide is a very good example of a complex slope movement, which started in December 2001 as a rockslide with a consequent rock fall that triggered secondary landslides and caused occasional debris flows (Fig. 5). These were triggered in the rock-fall debris below the rockslide face. In 2002, over 20 debris flows were registered in the village of Koseč below the Strug Landslide. This happened mainly on days with a daily rainfall accumulation of 20 to 30 mm (Mikoš et al., 2006a). Since 2002, no further debris flows could be observed; therefore these events in the Strug landslide area were defined as material-driven and not rainfall-driven events. This decrease of rock fall activity was studied by field measurements of erosion processes in the rock-fall deposits using laser scanner technique (Mikoš et al., 2005b).

One- and two-dimensional mathematical modeling of debris flows (Mikoš et al., 2006c) was used to prepare the hazard map for the village of Koseč. The same mathematical models were used as successfully applied for the Stože Landslide case (Četina et al., 2006). For the determination of the designed debris-flow with the total volume of 25,000 m^3, hydrological modeling was applied (Sodnik & Mikoš, 2006).

Using the results of mathematical modeling, the proposed enlargement of the channel of the Brusnik Creek through the village of Koseč was optimized. In 2002, the major part of the reforming of a torrential channel to a parabolic shape has been successfully executed, and the channel withstood all debris flows in 2002. The debris-flow modeling showed that some minor corrections should be done in order to secure the village of Koseč the safety against the designed debris flow with the total volume of 25,000 m^3. As an additional measure, two retention basins are planned to be built in the lower reach of the Ročica Torrent (of which the Brusnik Creek is a tributary) to protect the village of Ladra from possible hyper-concentrated sediment flows.

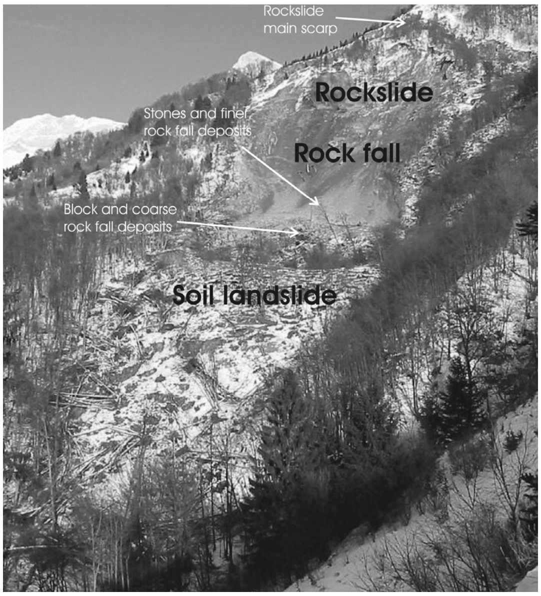

Fig. 5 The photo of the Strug Landslide source area taken by M. Ribičič in December 2001

4. Conclusions

In Slovenia, the RC deep wells, well known from road construction, were successfully used in two different designed forms for the first time as supportive and draining construction for large landslide mitigation. Before applying this mitigation technique, it was at utmost importance to stabilize a landslide to such an extent by e.g. deep drainage trenches and surface drainage works that the execution of deep wells was made possible.

In the last years, several debris flows (Stože, Strug) draw attention and as a response to them, torrent and river channels were optimized to convey water and sediment flows as well as rare debris flows using the results of one- and two-dimensional mathematical modeling of debris flows.

In Slovenia, the ongoing mitigation of the large landslides is subjected to a special law adopted in 2002 (revised in 2005). The final mitigation is planned to be finished before the end of 2010, with estimated total costs of 60.5 Mio € for all activities planned. These costs should be added to the estimated sum of 83.5 Mio € as the final remediation costs for all other registered active small-sized landslides in Slovenia. Because the mitigation process of large landslides is due to restricted financial resources not finished in a year or two, the organizational aspect becomes very important.

A special governmental (inter-ministerial) commission is leading all activities on large landslides, which is helped by a professional committee (experts in the fields of engineering geology, geotechnical and hydraulic engineering).

Possible measures on large landslides before their final mitigation can be divided into intervention measures (mechanical removal of landslide or debris-flow mass, temporary evacuation of inhabitants, and daily observations) in case of emergency (heavy rainfall, large landslide displacements) and final mitigation measures. The latter are a chain of very different activities:

- field and laboratory investigations (aerophotogrammetry, geological maps, boreholes, inclinometers, geophysical methods, infiltration tests, discharge measurements, material properties ...);
- modeling (slope stability, debris flows, mudflows);
- future hazard assessment (possible scenarios);
- mitigation measures (proposing solutions, project documentation, construction);
- post-mitigation observations (surveying and remote sensing, warning systems).

In Slovenia, practical experiences with mitigation of large landslides up to now show that only a strict and insightful co-ordination, interdisciplinary approach and adequate financial support may lead to successful large landslide mitigation.

Because the national legislation covering the mitigation of large landslides is not up-to-date, we suffer from long-lasting mitigation process. The main cause is on one hand the restrictive annual budget that can be applied, and on the other hand the rather complicated planning procedures needed for executing proposed structural mitigation measures in the field. Such an approach might help to carefully propose and design adequate structural measures, but it also causes additional costs because landslides are active, they enlarge according to their own dynamics and ask for higher financial resources for their mitigation if the mitigation spreads over a longer period of several years.

Acknowledgments

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Managing Landslides in Guatemala, Critical Issues

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Abstract. Throughout the centuries, landslides, debris flows, and lahars have provoked a variety of disasters in Guatemala. Triggered by rainfall associated with hurricanes and thunderstorms, by earthquakes, or as a consequence of volcanic activity, these mass movements have provoked injuries and fatalities; damaged or destroyed infrastructure; and affected livelihoods in both urban and rural areas. In several cases, the severity of such mass movements and their impacts has forced governments to relocate the affected communities to less hazardous places.

While it is important to understand and model both the susceptibility of slopes in places where such landslides and mass movements can occur, their triggering mechanisms, and their dynamics; the social, institutional, and political aspects related to the response, rehabilitation, and reconstruction processes of affected communities deserve equal attention. For example, while some agencies within the Presidency of the Republic may wish to begin the reconstruction of destroyed houses in the same place where they were destroyed, the National Coordinating Agency for Disaster Reduction (CONRED) has been promoting hazard assessments in order to outline land-use strategies in the affected area and its neighborhood, in order to ensure a safer reconstruction process in an effort to avoid the reconstruction of the risk by reconstructing houses and infrastructure in the same place where they had been destroyed.

The Panabaj debris-flow triggered by hurricane Stan on the foothills of Toliman volcano in September 2005 in Guatemala demonstrated the difficulties which may arise in the social, economic, and political arenas when such a hazard assessment takes too long to be completed, as the government is then blamed for not starting the reconstruction process as soon as the relief efforts have been completed. In addition, this experience displayed the unfortunate economical aspects related to the sudden rise in the monetary value of land when people started hearing gossip concerning the need for government to seek lands in the neighborhood to carry out the resettlement process.

This article presents an overview of several historic and recent examples of such disasters in Guatemala, highlighting critical issues which emerge when such relocation processes take place. An analysis of such examples in the framework of risk management and governance has led to the identification of some of the existing complexities which arise when conducting either reconstruction processes or relocations, and possibilities to improve such processes in the near future. The article concludes with a summary of policy-relevant conclusions targeting government agencies, the private sector, and civil society.

Keywords. Landslide risk, risk assessment, risk management, hazard assessment, recovery and reconstruction.

1. Introduction: Landslides in the Guatemalan context.

Guatemala is one of the six Central American countries of the Central American Isthmus. Located at the intersection of three active tectonic plates and in the path of typical hurricanes in the Caribbean region of the American hemisphere, most of the country has been experiencing disasters throughout the centuries. As a product of the interaction between the Cocos, Caribbean, and North American plates, major earthquakes have destroyed communities and livelihoods; damaged or destroyed essential infrastructure for transportation, health, education; and provoked economic losses surpassing hundreds of millions of dollars. The most recent earthquake on the 4th of February 1976 provoked over 23,000 fatalities and affected more than 5 million inhabitants throughout the country (OFDA-CRED, 2008). Hurricanes have also provoked disasters in the country provoking heavy impacts in the agricultural sector and on road infrastructure. The latest episode is hurricane Stan which occurred in September 2005, just seven years after hurricane Mitch which also impacted the rest of Central America in October and November 1998. Landslides and debris flows, triggered either by intense rainfall or earthquakes, are feared due to their capacity to bury entire communities.

1.1 Historical landslides in Guatemala

The first written accounts of landslides within Guatemala can be traced to the year 1541 during the period of the invasion by Spanish conquistadores. On the 11th of September 1541, torrential rainfall which could be associated with a typical hurricane triggered a massive landslide that buried the town of Santiago de los Caballeros which was the seat of the Spanish government at the time in Central America (Juarros 1936). The town had originally been located on the foothills of Agua volcano, and as a consequence of the disaster, the Government decided to relocate the city and its survivors to the central part of the valley and farther away from the slopes of this volcano.

Two centuries later, in October 1762, a combination of a flood and a debris-flow destroyed the Village of Petapa which was located on the shores of the Villa Lobos River. In an effort to avoid future disasters of this kind, the government established a new town called Villa Nueva (New Village) and relocated survivors to this new site situated on a plateau far away from the floodplains of this river (Juarros 1936).

Examples such as these illustrate the fact that new settlers often have no perception regarding natural hazards which may be present in the locations they choose for settlement, and only realize their exposition to such hazards through disasters.

2. Dealing with landslides and debris-flows in Guatemala: recent cases

In 1983, the town of El Palmar, which is located on the foothills of Santiaguito volcano on the western part of the country, began to suffer the impacts of lahars associated with rivers Nima 1 and Nima 2. Triggered by intense rainfall on the active cone of Santiaguito volcano, lahars propagating along these rivers gradually provoked the destruction of one segment of the town, forcing the government to declare a State of Calamity on the 5th of May, 1987 (Government of Guatemala 1987) and leading it initiate efforts to relocate the community to a new site. The new El Palmar village was inaugurated on July 12, 1988 (CEUR 1989), and concluded with the relocation of 1117 families by 1989. Nearly a decade later, the National Coordinating Agency for Disaster Reduction, CONRED, declared El Palmar as a "High-Risk Zone" on the 5th of June, 1997 in order to inhibit its former citizens for settling there again (CONRED 1997).

In January 2000, the Government of Guatemala began to relocate citizens of the rural town Santa Catarina Ixtahaucan due to severe problems associated with mass movements and potential landslides. Unlike other cases, this relocation process took place based on scientific evidence concerning a potential disaster, but not as a consequence of a disaster per-se. In this process coordinated by the Executive Coordination Secretariat of the Presidency, 625 families were relocated to a new site.

In the year 2003, 45 of the 95 families residing in the village of El Chim, located on the foothills of Tacaná volcano, close to the border with Mexico, were relocated due to the destruction of their houses by a massive landslide triggered by torrential rainfall.

The latest effort in terms of relocating people is taking place in Panabaj, one of the neighborhoods of Santiago Atitlan. Located on the foothills of the Tolimán volcano, most of Panabaj was buried by a debris flow triggered by torrential rainfalls associated with hurricane Stan in October 2005.

While in these cases relocations have been carried out as a means to cope with the situation, a weakness which has been present in all cases is the lack of legislation to deal with such relocation processes, manifested through an institutional void in terms of which agency should be responsible to manage such a process and the procedures which should be followed to reach such a decision. Unfortunately, despite such experiences, the Government of Guatemala has not institutionalized such processes, and thus improvised solutions are typically the case.

An example of social issues which must be confronted in relocation processes is related to land ownership, particularly in the case of communal lands. In the case of Santa Catarina Ixtahuacan social tension grew among ethnic groups with respect to a piece of land proposed to be used for such a relocation purpose. One potential site which was targeted by the settlers from Santa Catarina Ixtahuacan was a plateau not inhabited at that time, considered as "safe" with respect to such mass movements, and viable under the perception that such a land belonged to their forefathers. Unfortunately, this land was equally claimed by citizens of the neighbouring community Nahuala for the same reason; and thus, an initial occupation of this site led to a violent conflict which provoked injuries and few fatalities as both groups were claiming ownership. As a consequence of this conflict, the national government had to intervene and facilitate the new settlement in this high plateau with support of the international community.

The case of El Chim presents a similar situation regarding the lack of capacity of government and the communities to find adequate solutions to the needs concerning relocation. While initial geologic problems were identified by members of the community in October 1998, it took nearly one year for the National Institute of Seismology, Vulcanology, Meteorology and Hydrology (INSIVUMEH) to conduct an inspection due to institutional weaknesses and nearly five years for CONRED to send a member of its risk-management division to assess the risk faced by this community associated with landslides and mass movements. Both INSIVUMEH and CONRED coincided in their recommendation concerning the relocation of the community to a safer site and the Major of the Municipal District of San Pedro Sacatepequez in the Department of San Marcos was approached with the results of these institutional assessments in order to place him in charge of dealing with the issue of relocation. In this case, problems faced by the Major could be summarized as follows:

- ❖ The Municipal Government in this municipal district had no access to public land, as most of the land was owned by individual citizens or by the private sector.
- ❖ There is a lack of policies concerning how to deal with such aspects at this municipal level. In most cases, relocations have been managed by the government at the national level.
- ❖ CONRED has a national fund established to cope with disasters, but may not be used to deal with risks.

In this case, the Major needed to target social funds such as those provided by the National Social Fund, or the National Fund for Peace, both managed by the Presidency of the Republic. Unfortunately, the disaster took place before such Social Funds could provide the required funding for such a costly relocation process.

In the other extreme, Panabaj reflects the complexities of implementing a risk management process in the middle of a reconstruction process, where government agencies in charge of the reconstruction process (Social Funds) wish to react fast but not necessarily taking into consideration the most adequate solutions from the point of view of risk management. Panabaj represents an example of a circumstance where the assessment of risk conducted at the request of CONRED took longer than the time government agencies were willing to wait before proceeding with the reconstruction process. In this particular case, one of the Social Funds of the Presidency began to rebuild houses in an area that was later determined to be highly exposed to future events of this kind. The hazard assessment conducted by an engineering firm with experience in geology and hydro-geology took over 8 months to be completed due to the existing bureaucracy related to procedures associated with purchases and acquisitions established by the Government to deal with corruption years before. In this case, issues which were confronted were:

- ❖ The need to maintain an image of good governance by the ruling party, in terms of beginning reconstruction processes as quickly as possible to avoid criticism by the media for not conducting such a reconstruction process as quickly as possible.
- ❖ The need to conduct hazard assessments during the reconstruction process in order to determine areas where it may be safe to carry out reconstruction processes, and areas which should be considered as unsafe.
- ❖ The lack of experiences in expediting hazard assessments

of this kind as quickly as possible to provide useful information to be employed during the reconstruction process.

As expected, a quick response by the Government is desirable by government officers who wish to keep the good image or to avoid the deterioration of such an image. Any delays in the reconstruction process are viewed by the media as potential defects and as reasons to criticize such government officers. Such was the case in Panabaj during various months, as the reconstruction process was literally stopped to allow geologists to carry out the hazard assessment.

3. Governance in the context of landslides

As it has been shown in previous sections, Guatemala has undergone disasters associated with mass movements which have forced the government to relocate entire communities displacing citizens permanently to new sites; or disasters where such relocation process has not been needed. Relocations can be viewed as positive from the point of view that such disasters will be avoided in the future by removing the exposition of the new communities to the hazards. However, in the case of disasters which have taken place centuries ago, there is evidence that people may at times reconstruct existing levels of risk by settling again in places which were destroyed centuries ago.

In all cases where these relocation processes have taken place, the support of the national government has been essential, as a considerable amount of resources is required to carry out such processes. The experience in the village of El Chim is an interesting example where the community was ready to relocate to a different site, but such a decision was not taken at the national level quickly enough. In parallel, the example of Santa Catarina Ixtahuacan suggests that the relocation process must take into consideration claims on lands which may be used for such relocation processes. Efforts taking place just at a local level in terms of the relocation of a community may be jeopardized by conflicts associated with such territorial claims. While centuries ago land may have been available for such purposes, in recent times it may be more difficult to identify potential lands for such purposes.

A third conclusion which has been identified when analyzing the way in which recent disasters have been handled is the fact that while such process may take place more frequently than anticipated, the government has not really carried out a systematization process in order to design both policies and rules regarding how to deal with such situations, As a consequence, improvisations are usually made, leading either to delays in the process, or to inefficient use of resources.

A fourth conclusion which is drawn from the experience in the relocation process in El Palmar is related to expectations which the affected people may have concerning such a process that may not materialize as expected. In the case of El Palmar, the relocation process meant that the Government would exchange houses in the old site by houses in the new site. However, in some cases, there were two or even three families living in one house in the old El Palmar, each of which had the expectation of receiving its own house, rather than having to share a new house as before in the new El Palmar.

One critical aspect which has received little attention in such cases is the ownership of land that is vacated. During the relocation process, families are provided titles with respect to the new houses which they are receiving, but in many cases they have not been asked to relinquish their claims on properties which were destroyed or affected by the disaster that led to the relocation. A case in point is Santa Catarina Ixtahuacan, where the former village is beginning to be occupied through two parallel processes:

- ❖ New residents migrating from other areas, who purchase old property rights from families which were benefited with houses in the new village.
- ❖ Former residents or relatives, who may wish to take advantage of the fact that the old site did not undergo yet the foreseen disaster and who may also wish to continue benefiting from the new land. In essence, this means that families who undergo a disaster may end up with claims to properties both in the old and in the new sites.

Such processes have also been taking place in other regions of Central America which have been devastated by earthquakes, and are highlighting a void with respect to how to manage such issues.

4. Policy-relevant recommendations

Taking into consideration critical aspects mentioned in previous sections related to relocation processes, the following policy-relevant recommendations stand out:

- ❖ Appropriate governance policies and rules are required to delegate the responsibility concerning such relocations processes to either a single government agency, or to a group of agencies which need to cooperate in order to complete the relocation processes adequately. Such policies should dictate how governments at different levels, and particularly with different autonomies, should work together with local communities and civil society in order to conduct such relocation processes efficiently and timely
- ❖ Operational procedures within the Social Funds operated by the Presidency of the Republic should be modified so that risk management is incorporated within the funding practices, so that relocation processes can be considered and implemented when such a need arises.
- ❖ Awareness campaigns targeted at the population to make them aware of risks they are facing; as well as to keep the social memory of historic events, so that such events do not repeat themselves in terms of catastrophic consequences.

The first recommendation should address the following questions:

- ❖ Which agency should be responsible for starting such processes?
- ❖ When a group of concerned citizens is willing to promote such a process, which agency should they target so that their request can be conveyed to the proper agency in charge of such processes?
- ❖ What should be the role of different organizations belonging to the Civil Society, such as the Church?

The second recommendation targets those agencies of the national government which are entrusted with financial resources to carry out projects which should promote sustainable development. In this context, it is equally important to assess the role of such funding programs in promoting the use of information concerning risks to assess the need to relocate communities or not.

The last recommendation is aimed at ensuring that the population is aware of the risks which lead to particular disasters so that such conditions of risk are not recreated as a result of lack of awareness.

Conclusions

As stated in the introduction, due to its geographical location and topography, Guatemala is exposed to a variety of hazards which have triggered disasters that have led to temporary and permanent displacements of families and communities. Historical and recent relocation processes resulting from landslides and debris flows have been handled by the national government, but the lack of systematization and proper institutionalization of such processes continues to inhibit the government from conducting such processes in an efficient and timely way.

As stated by the International Organization for Migrations, (IOM, 2001), migration and relocation processes are constrained by factors such as their dimension, social organization, political aspects, and local development. An analysis of this complex problem of relocations has led to the identification of policy-relevant recommendations, which should be taken as inputs by government agencies in Guatemala, as well as in countries which face similar problems, to conduct such processes in a more efficient way in the future, particularly as the degradation of the environment will surely contribute more and more to phenomena such as landslides in rural and urban areas, that are at the root of such forced relocation processes.

Acknowledgments

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Huge Landslide Triggered by Earthquake at the Aratozawa Dam Area, Tohoku, Japan

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Abstract. The Miyagi-Iwate inland earthquake of 2008, magnitude 7.2, happened on 14 June at the eastern foot of the Ohu back born range, Tohoku district. The acceleration velocity of the earthquake at Aratozawa Dam area reached over 1000 gal. This earthquake caused a huge landslide at the upper reach of Aratozawa Dam. The total volume of the landslide is 67 million m^3. The direction of the movement was stretched obliquely by the lake, and fortunately the huge sliding mass did not surge in the lake, though a part of the land mass slipped. However, in the following 10 – 20 minutes of the main event, the toe part of the landslide body broke into smaller blocks, and slid into the lake. These collapses led to a Tsunami which had the height of 2.7 m. Fortunately, the Tsunami didn't overflow the top of the dam body. On the other hand, the amount of sediment deposited in the lake by the landslide amounted to 3.7 million m^3. Its volume reached 26% of the maximum water volume of the dam. The various kinds of countermeasures to mitigate the hazard are being discussed now.

Keywords : Huge landslide, Aratozawa dam, Block glide, Landform deformation, Earthquake

1. Introduction

Over a thousand landslides and slope failures were seen in the narrow area around the origin fault of the earthquake, and the distribution concentrates only on the upper plate in an area 30 km long and 10 km wide. The various types of slope disaster are scattered and concentrated in the area. One reason behind this is the geological, geomorphic and environmental circumstances of Tohoku region as its land is in the humid orogenic zone (Miyagi et al 2004, Miyagi 2008).

Fig.1 Before and after the huge landslide disaster that affected the Aratozawa Dam water reservoir

Figure 2 illustrates the geomorphic and geologic characteristics and the spatial distribution of erosion process in Tohoku district. Furthermore, it also illustrates the tendency of slope disaster was mostly due to the geologic structure and the strong acceleration caused The Aratozawa Landslide, rather than the geomorphic structure in the area. Here, we would like to discuss about the fact of the landslide movement and the affect on the lake.

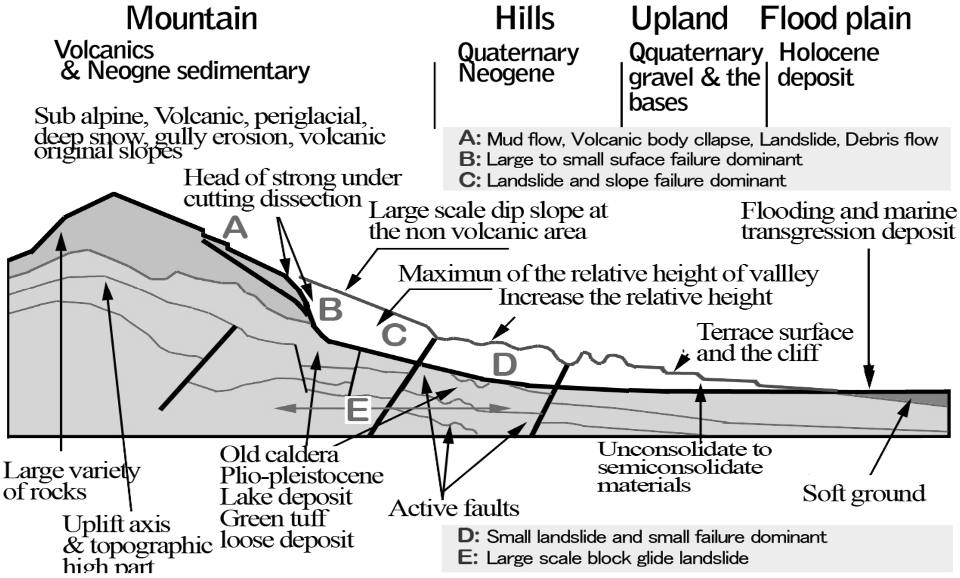

Fig.2 The outline of major landform structure and the geology of Northeastern Japan and the main landslide phenomenon in the area of interest

2. The Outline of Aratozawa Landslide

The size of this landslide is 1.3 km long, 0.9 km wide, 150 m thickness at the maximum, and 80 m deep on average to the slip surface (Figs. 3 and 4). The total amount of the landslide volume is 67 million m^3. The area of the landslide overlapped onto the fossil landslide topography, and the landslide activity has repeated, historically. The geology of the area is Quaternary welded tuff, Neogene non-consolidated pumicieous tuff, semi-consolidated sandy tuff and the sand and silt alternate layers in descending order. The slip surface developed in the silt layer. There are clear sheer surface that appear in a number of boring cores. The landslide type is considered to be a Block glide based on the analysis of land form deformation and the distribution of slip surface: the entire landmass slid at once on the 2 degree platy slip surface. The general tendency of the geologic structure in this area is about 4 degree to the east, but the orientation of the landslide did not overlap the maximum direction of the structure. At the toe of this huge landslide body, secondary landslides and mudflows were developed, and outpoured into the lake and causing small outbreaks of Tsunamis, which eventually deposited the sediment amount of 3.6 million m^3.

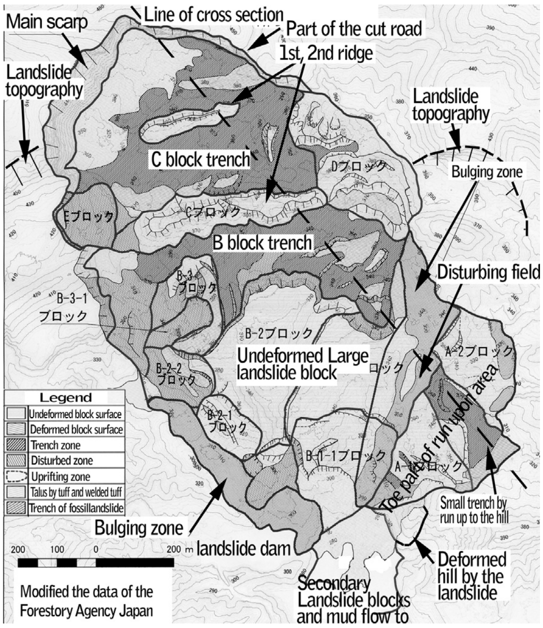

Fig.3 Micro landform distribution of the Aratozawa Landslide area

3. Impacts to the Aratozawa Dam Outline of the Aratozawa Dam

Type of the dam: Center core type rock fill dam. Height of bank: 74.4m, length of bank: 413.7m, area of reservoir: 0.76 km^2.

Total water volume: 14,130,000 m^3, effective water volume: 13,510,000 m^3, Effective capacity of sedimentation: 620,000 m^3. The comparison of effect of the landslide sedimentation: 75,000 m^3 (0.51%, year 2007), 3,706,429 m^3 (26.23%, year 2008) (Photo 1).

The landslide caused the catastrophic severe damage to the Aratozawa dam lake, because of the direction of the movement was slightly oblique to the lake. However, several effects appear now.

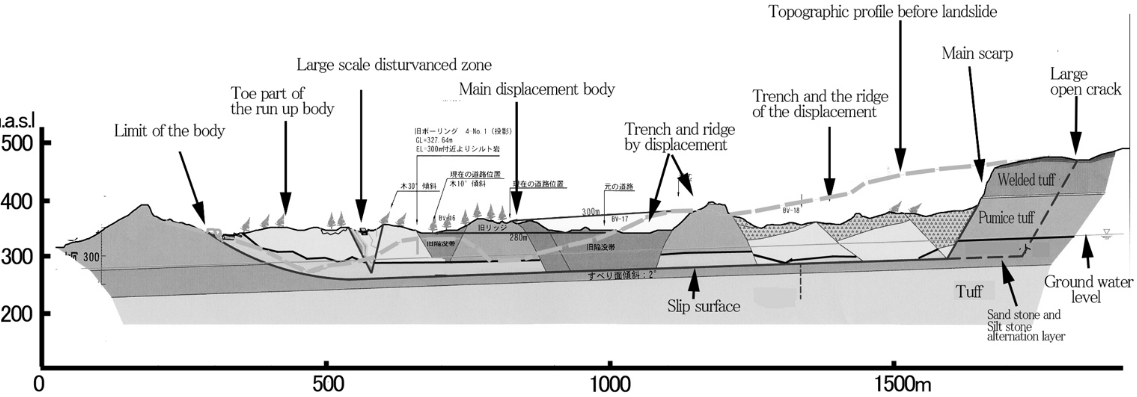

Fig.4 Cross- section of the Aratozawa landslide area (Location of the line is shown in Fig.2)

Secondary landslides to the lake: The large disturbance field (0.1 by 1 km) was due to the break back and push up the materials. The toe part extended on the hill and the hill deformed. Such deformations developed in the very unstable landslide block. The block collapsed to the lake via two landslides and one mudflow. The total volume of these landslides amounts to 1.5 million m^3. The total deposit in the lake is 4.2 million m^3. The unstable block still remains stable.

Tsunami by landslides: At the moment of secondary landslides, three tsunamis were generated in the lake. The heights were up to 2.7 meters, and the water over-topped the Spillway.

The breaching of the landslide: Several landslide dams were established by the landslide. One small landslide dam collapsed about one month later, after the earthquake. Several water surfaces appeared at the inside and the side of the landslide body. The accumulated water will infiltrate into the body and the spilled water with suspension will move to the lake. Surface erosion of soft and semi consolidated materials also will seriously affect the lake because of the size of the landslide.

Possibility of counter measures: The maximum planned volume of impoundment for the Aratozawa water reservoir is 15 million m^3. The capacity is used for flood control and agricultural water use, etc. The total decrease of water capacity due to the event amounted to 15 % of the volume. This is a very severe impact to the dam. The government is considering a set-up for the most efficient countermeasures. In case of the sediment discharge to the outside, there are many risks such as dumping ground preparation, the huge volume and the period for operation, and the increases of instability of the remaining landslide body. The planning committee is envisioning some combination of works, for example the partial discharge of the sediment, other deterrents, restraining works and improvement of the dam functions.

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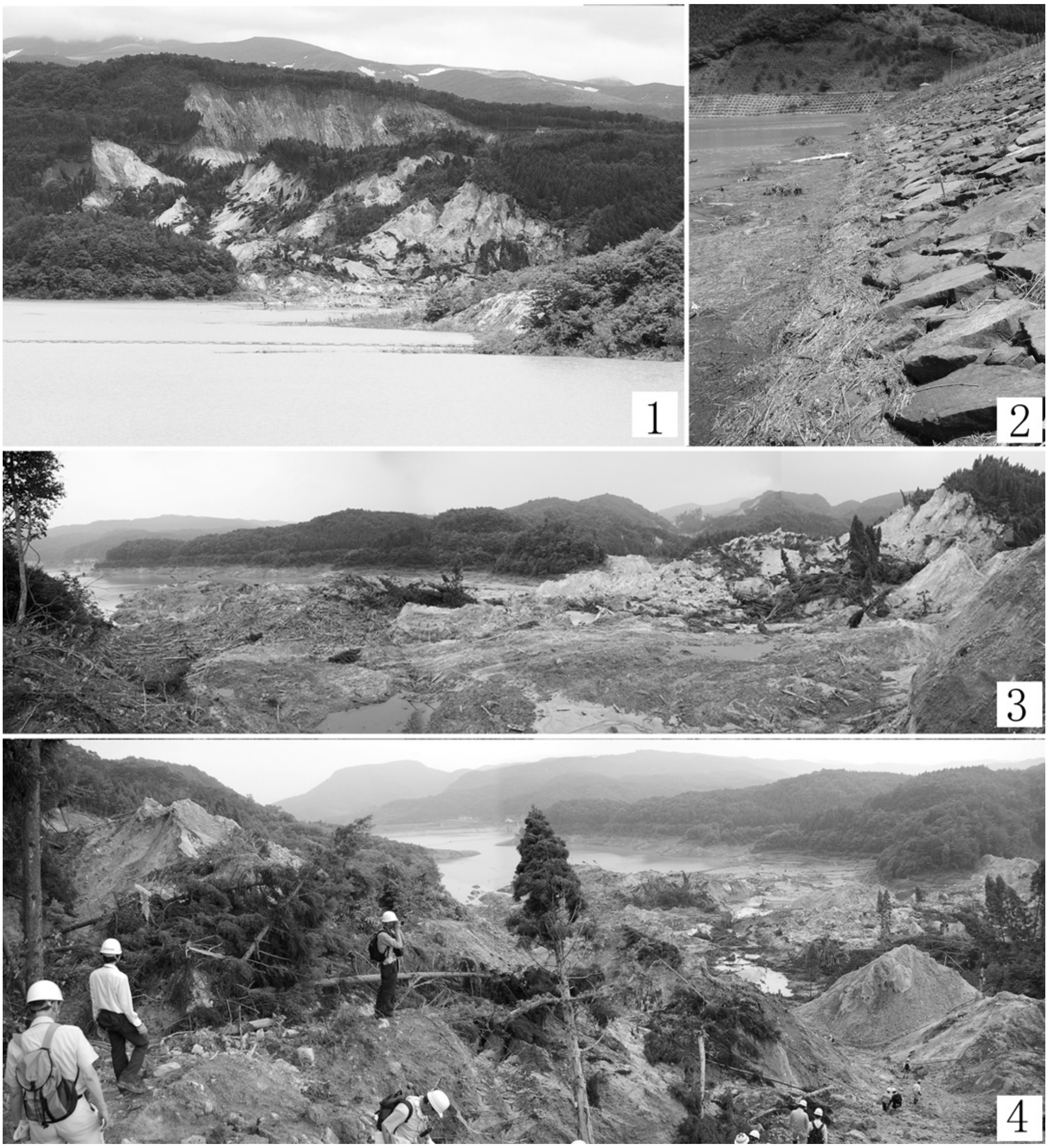

Photo 1 the Aratozawa Landslide and the water reservoir.

1. Overview from the Top of the Aratozawa Dam; 2. Trace of the Tsunami; 3. Landslide and mudflow to the lake; 4. Toe part of the landslide and the lake.

JAXA Activities on Space Utilization and Information Sharing for Disaster/Crisis Management

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Abstract. It is in Asia that the scale of damages caused by disasters has been tremendous. Asia occupies 60% of the total number of disasters in the world, 70% of the total economic losses and 90% of the total casualties. The reasons why Asia has been suffered from disasters include; i) concentration of meteorological phenomena which cause natural disasters due to geographical factors, ii) the circum-Pacific volcanic zone, or "Pacific Rim of Fire" and complicated plate-tectonics, and iii) the vulnerable to natural disasters magnifying the impact thereof. In other words, such factors are derived from problems; i) disaster warnings or information on evacuation are not properly delivered, ii) knowledge and actions to avoid risks of disasters are not sufficiently shared among people, and iii) disaster-tolerant and invulnerable social structures have not been prepared in the region.

At the second Earth Observation Summit held in April 2004, hosted by Prime Minister KOIZUMI Junichiro, delegates and participants of the Summit deliberated upon how science and technology can contribute to disaster reduction. Space technologies were focused on as a means of observing wider areas repeatedly. Thus, at the Summit, i) that countries possessing artificial satellites should collaborate on construction of international collaborative schemes for disaster prevention/reduction was agreed upon, and ii) that a system for monitoring disasters and environmental changes should be constructed within 10 years since then was decided upon. In conjunction with such moves, JAXA announced a long-term space development vision for the next 20 years, "JAXA Vision -- JAXA 2025 --," describing the JAXA decision that JAXA is determined to actively use aerospace technology to build a secure and prosperous society, through establishment of a priority system for natural disaster management.

Keywords: disaster minotoring, satellite, JAXA vision

1. Daichi and disaster observation

JAXA will set up various frameworks to use the Advanced Land Observing Satellite (ALOS) "Daichi" (Fig.1) for precise regional land coverage observation, launched in January 2006, and implement verification experiments utilizing thereof. "Daichi" has three high-performance sensors, including the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), which is comprised of three sets of optical systems to measure precise land elevation with 2.5-meter spatial resolution and the Phased Array type L-band Synthetic Aperture Radar (PALSAR), which enables day-and-night and all-weather land observation. By combining data obtained from those sensors, JAXA can swiftly grasp real situations of disaster stricken areas. Dichi accepts emergency observation request and distribute processed image to the disaster authorities in the region.

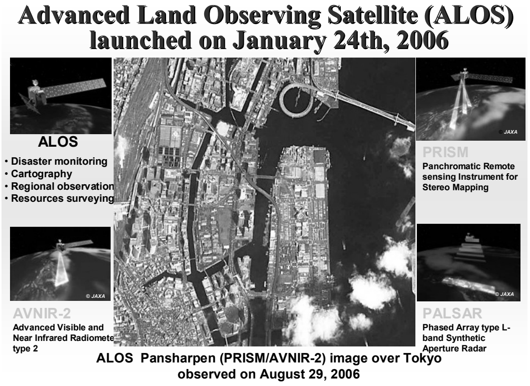
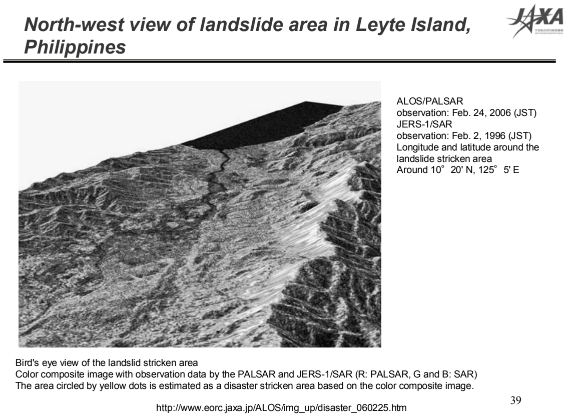


Fig.1 “Daichi” characteristics

With regard to the use of data acquired through "Daichi" observation, the following items are expected:

i) Large-scale crustal deformations triggered by earthquakes
ii) Collapse of or fire at a number of buildings
iii) Detection of flooded areas
iv) Changes in the shape of a mountain, pyroclastic flows, ash falls, or changes in volcanic craters through volcanic activities
v) Large-scale landslides (Fig.2)
vi) Marine pollution, including oil drifts
vii) Extractions of information on geographical, terrain and land surface changes for post-disaster restoration activities after disasters.

The image of the large scale land slide in Leyte island, Philippines, are shown in Fig.2. This image is processed by comparison of JERS-1 and Daichi PALSAR. Birds eye-view of the land slide striken area are clealy identified by comparison of before and after disaster images. This is the color composit image with observation data by PALSAR(R),JERS-1 SAR(GandB).



North-west view of landslide area in Leyte Island, Philippines

ALOS/PALSAR
observation: Feb. 24, 2006 (JST)
JERS-1/SAR
observation: Feb. 2, 1996 (JST)
Longitude and latitude around the landslide stricken area
Around 10° 20' N, 125° 5' E

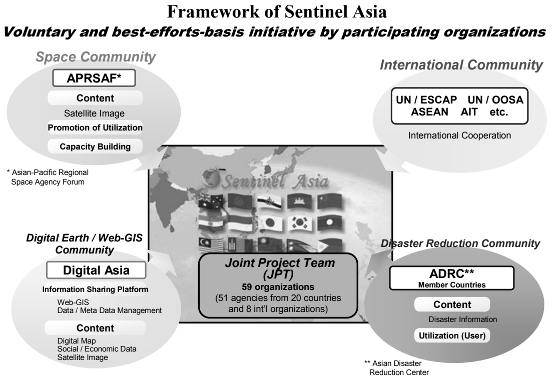
Bird's eye view of the landslid stricken area
Color composite image with observation data by the PALSAR and JERS-1/SAR (R: PALSAR, G and B: SAR)
The area circled by yellow dots is estimated as a disaster stricken area based on the color composite image.

http://www.eorc.jaxa.jp/ALOS/img_up/disaster_060225.htm

Fig.2 Example of the successful detection of large scale landslide by comparison with JERS-1 and ALOS/PALSAR over Leyte Island, Philippines

The "Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters (in short, International Charter on Space and Major Disasters)" is a framework that i) upon devastating disasters, organizations possessing earth observation satellites implement observation on a voluntary basis or upon request, and ii) the organizations immediately provide disaster-stricken countries or relevant organizations with disaster information free of charge. Upon the huge landslide disaster on Leyte Island that occurred in February 2006, "Daichi" acquired images of the disaster, and the observation data as well as analysis information were provided to the International Charter Secretariat and ADRC. JAXA has been carried out emergency observation by responding the activation by member countries / agencies on an best effort bases, and distribute data and analysis results to the user as fast as possible. The average time to distribute data to users is about 1 to 3 hours after the data acquisition. In case the damage looks like serious, the observation will be carried out several times as needed.

In Asia, the international charter is difficult to activate, because very limited registerd/approved agency only can do. JAXA cooperated with MEXT, organizing APRSAF(Asia Pacific Space Agency Forum) to promote space utilization among Asian countries. The Sentinel Asia is disaster information sharing network endorsed by APRSAF, to accept emergency observation and distribute data free of charge in case of disaster occured. The member of Sentinel Asia is 18 countries, 50 disaster agencies and 8 international organizations such as UN-ESCAP, UN-OOSA. The satellite image data is provided via internet, and also planning to use communications satellite such as WINDS, for quick access. Fig.3 shows the framework of Sentinel Asia.



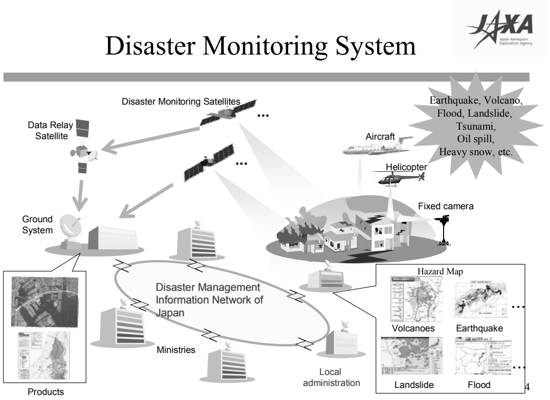
Framework of Sentinel Asia

Voluntary and best-efforts-basis initiative by participating organizations

Fig.3 Framework of Sentinel Asia

2.Future disaster monitoring system

Daichi satellite conditions are very good, and expected to continue operation more than 5 years. For disaster use, long term continuous monitoring is essential to retreave desaster signal by comparison of before and after images. JAXA is now studying underway the follow-on of Daichi, much more dedicated to the disaster aplication. In our study, users requirement from space is less than 3 hours after disaster occures. In order to respond the users requirement, the sensor should be SAR to achieve all weather and night time observation. In addition, 4 satellites in differen orbit will be required. Fig.4 shows the concept of disaster monitoring satellite. The first satellite will be L-band SAR. L-band is much better for surface deformation monitoring by interferometory.



Disaster Monitoring System

Fig.4 Future disaster monitoring from space

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Submarine Slides and Their Consequences

Farrokh Nadim (International Centre for Geohazards / NGI)

Abstract. Submarine slides are common and very effective mechanisms of sediment transfer from the shelf and upper slope to deep-sea basins. Typically such events last from less than an hour to several days and can severely damage fixed platforms, pipelines, submarine cables and other seafloor installations. Research on understanding the mechanisms behind and the risks posed by submarine slides has intensified in the past decade, mainly because of the increasing number of deep-water petroleum fields that have been discovered and in some cases developed. Production from offshore fields in areas with earlier sliding activity is ongoing in the Norwegian margin, Gulf of Mexico, offshore Brazil, the Caspian Sea and West Africa. Large submarine slides may generate tsunamis with potential for severe damage along the coastline.

The paper reviews the recent advances in assessment and analysis of the risk associated with submarine slides and make recommendations regarding the procedure to be followed in risk assessment for submarine slides.

Keywords. Submarine slide, risk evaluation, tsunami.

1. Background

Submarine landslides occur frequently on both passive and active continental margins, especially on the continental slopes. Despite the generally low slope angles, these are areas of sloping stratigraphy, often with more active and vigorous geological processes, including seismicity, than those found in the shallow, sub-horizontal continental shelf areas. The shelf edge and slope area contain the most recently deposited materials, and in areas with high deposition rate, underconsolidation / excess pore pressure may exist. During one single event enormous sediment volumes can be transported on very gentle slopes with inclinations in the range 0.5 to 3°, over distances exceeding hundreds of kilometers. The excess pore pressure often plays a major role in destabilization of submarine slopes. The expenses of finding and developing new fields in deep water are very high, and this greatly increases the economic consequence part of the risk aspect connected to submarine slides in the continental margin settings.

2. Tsunamis triggered by submarine slides

The assessment of the risk associated with submarine mass movements is thus not just a matter related to commercial interests of oil companies. The societal and environmental consequences of such events could also be enormous for coastal communities. For instance, large submarine slides may generate tsunamis with potential for severe damage along the coastline. The tsunami generated by the earthquake-triggered Grand Banks slide in 1929 killed 27 people in Newfoundland. The 15-m tsunami that killed more than 2000 people in Papua New Guinea in 1998 was also a result of an earthquake-triggered submarine slide.

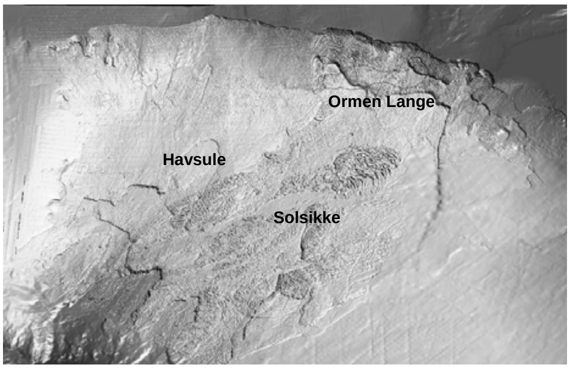

Fig. 1 Storegga slide and boundary of Ormen Lange gas field in the North Sea.

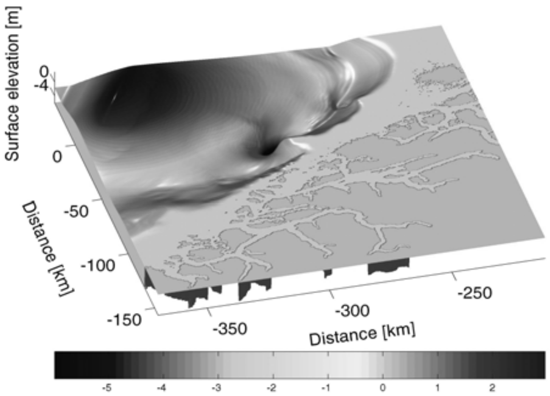

Fig. 2 Simulation of the tsunami triggered by the Storegga slide approaching the west coast of Norway.

The ongoing development of the Ormen Lange field, which is the second largest gas field on the Norwegian Continental Shelf, has contributed greatly to the understanding of the offshore geohazards. The Ormen Lange gas field is located in the Norwegian Sea in water depths of about 800 to 1,100 m, approximately 120 km from the coastline, within the scar of the prehistoric Storegga slide (Fig. 1). The Storegga slide, which took place 8,200 years ago, is one of the world's largest known submarine slides with an estimated slide volume in excess of 3,000 km^3. Evidence of a major tsunami generated by the Storegga slide has been found along the coasts of Norway, Scotland and the Faeroe Islands (Fig. 2). Considering the enormity of the Storegga slide and the potentially catastrophic consequences of a similar event today, it was essential to clarify and quantify the risks associated with submarine slides in the area to obtain approval for field development from the authorities. A major effort was therefore undertaken to evaluate the stability situation of the slopes in the Ormen Lange area today, and quantify the potential risks associated with the field development in the future. The numerous studies carried out in the Ormen Lange offshore geohazards project were summarized in a special volume of Marine and Petroleum Geology journal in 2005. These studies represent the state-of-the-art in quantitative risk assessment for submarine slides.

3. Issues to be considered in risk assessment

The Assessment of the risk posed by a potential submarine slide requires identification and analysis of the relevant failure scenarios, i.e. failure modes, trigger-ing sources and related failure consequences, which have a significant contribution to the total risk. The triggering mechanisms could be natural, such as earthquake, tectonic faulting, temperature increase caused by climate change, excess pore pressure due to rapid sedimentation and gas hydrate melting due to climate change with increased sea water temperature after glacial periods; or man-made, such as anchor forces from ships or floating platforms, rock-filling for pipeline supports, temperature change around oil and gas wells in the offshore field development area, underground blow-out, and reservoir depletion and subsidence (including induced seismicity). The key issue in the slide risk assessment is the identification of potential triggers and their probability of occurrence, the associated failure modes and their consequences.

Evaluation of the stability of natural or man-made slopes has traditionally been based on a deterministic approach where the margin of safety is quantified by the safety factor. Many of the parameters that are used in a stability analysis, in particular the soil shear strength and the earthquake load effects (for seismic stability evaluation), are inherently uncertain. The uncertainties involved in assessment of site and soil conditions are in many cases amplified by the spatial extent and depth of the sediments and geological units involved, the presence of gas in sediments, and the practical and economical limitation of the site investigations. In a deterministic stability evaluation, the geotechnical engineer tries to deal with the uncertainties by choosing reasonably conservative parameters through the use of partial load and material coefficients. The deterministic approach, however, fails to address the problem of dealing with uncertainties properly.

Reliability theory and probabilistic analyses pro-vide a rational framework for estimating the probability of slope failure and are powerful tools for quantitative risk assessment. However, reliability methods require more data and estimates of the variances in significant parameters. This can be expensive and it will also require expert judgment. The cost and judgment are part of the price paid for a better answer. This tends to make the reliability methods more useful for major projects than for routine work. For this reason, application of reliability methods for evaluation of stability of soil slopes is more common in offshore geohazards studies than in traditional land-based geotechnical engineering.

Risk quantification has to be based on site investigations with mapping of topography and local gradients, identification of different geological/geotechnical units, assessment of soil and/or rock properties and in situ stresses, pore pressure and temperature conditions. An understanding of the regional and local geology, ongoing geological processes, and type, locations and extent of anomalies is required to quantify the potential impact and rate or frequency of ongoing natural processes (Nadim and Locat 2005). This element is significant since one must be able to answer the question about whether or not a given process is active and in which direction it is going (Locat 2001).

Going from hazard to risk requires other considerations as shown by the general framework for risk assessment for submarine slides provided in Figure 3.

Detailed mapping and extensive studies of sub-marine slides in recent years have increased our knowledge immensely regarding slide morphology, extent and volume. However, there are still many unknowns concerning the triggering, development and dynamics of submarine slides and how various mechanisms relate to the geological setting.

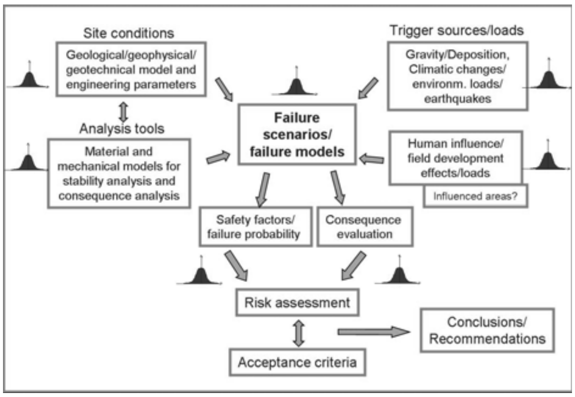

Fig. 3 General framework for risk assessment for submarine slides.

3. Recommended approach for risk assessment

The approach adopted for risk assessment for submarine slides and other offshore geohazards depends on the elements at risk and consequences of sliding. A general approach that could be applied in all situations is neither logical nor desirable.

Typically, offshore geohazards evaluation requires a staged approach. In the first phase a close cooperation among geologist, geotechnical engineers, geophysicists, and seismologists is required to:

- Establish the geological model of region (age and source of sediments)
- Evaluate in-line and cross-line shallow and deep seismics in region
- Identify main stratigraphy and buried features
- Identify signs of slide activity. Are the slides re-cent, or older buried features?
- Identify active faults in the area of interest
- Evaluate bathymetric information and seabed inclination and morphology
- Identify recent slide scars, fluid escape features, pock marks, mud volcanoes
- Look for signs of seabed instability, special features etc. upslope and downslope of the area of interest
- Establish whether there is earthquake activity in area

The first assessment of geohazard situation is done on the basis of above evaluations and should address the following questions:

- Are there elements at risk, locally or regionally, from submarine mass movements?
- What are the potential triggering mechanisms for seabed instability?
- What is slope stability situation in high gradient areas?
- Is there need for better information?

The second phase of evaluations typically includes:

- Evaluation of 3D seismics, well logs, detailed shallow seismics, detailed bathymetry and side scan sonar.
- Re-interpretation of seabed morphology and potential signs of instability and slide mechanisms
- Evaluation of pore pressure conditions, signs of overpressure.
- Planning and drilling geo-borings to acquire site-specific soil data. Focus should be on shear strength and brittleness (sensitivity) of soils.
- Assessment of deposition rate and potential for ex-cess pore pressure.
- Establish occurrence frequency vs. magnitude of earthquakes, mud volcano eruptions etc.
- Establish whether other ongoing natural processes, such as erosion and diapir displacements, are present.

Depending on the outcome of the second geohazards assessment, a final geohazards evaluation may be required. This involves the following steps:

- Select relevant failure scenarios and associated trigger mechanisms
- Identify, describe and quantify relevant trigger sources; magnitude and frequency
- Develop geo-model of the area: stratigraphy, bathymetry, relevant soil data and their uncertainty
- Apply geomechanical models for analysis of failure scenarios (stability analyses, finite element analysis, fluid flow, heat flow, slide run-out, etc.) and assess model uncertainty
- Evaluate annual probability of failure
- Evaluate physical consequences of failure (loss of support, slide run-out and impact, tsunami generation and impact, etc.) and associated damage
- Calculate risk contribution of all geohazard failure scenarios
- Are the calculated probabilities and risk within clients' and authorities' acceptance criteria? If not, what actions could be taken to mitigate the risk?

Conclusions

Submarine slides are common and very effective mechanisms of sediment transfer from the shelf and upper slope to deep-sea basins. They could occur on very gentle slopes and they have the potential for triggering a tsunami.

The increasing activity on the deepwater part of the continental slopes has set focus on the need for a systematic treatment of the risk associated with submarine slides. Risk assessment requires quantitative description of geology and soil properties, identification of possible failure events, triggering sources and mechanisms and ability to judge the likelihood of occurrence and the damage potential involved.

Acknowledgments

The author wishes to thank his many colleagues at NGI, ICG, and elsewhere, whose valuable contributions receive only a passing mention in the paper.

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New Approach to Estimating the Paleoseismicity and Topography Changes on the Basis of Landslide Study

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Abstract. Estimating earthquake magnitudes and topography changes using instrumental data and historic accounts can give information about the seismicity of mountain provinces during relatively short time period. The method of paleoseismogeology (Solonenko 1966) developed in Russia since the 1960s can give this information for the time period of 10^4 years. The key point of the method is analysis of geomorphically expressed surface displacement of evidently seismic origin. So far most of research has focused on coseismic fault motion. The seismogravitational dislocations have been used mainly for establishing epicentral zones and the timing of old earthquakes. At the same time using the parameters of seismically induced landslides for estimating earthquake's magnitudes can essentially improve the analysis of seismotectonic dislocations. In this case, the largest earthquake-induced landslide is the most interesting target.

Using the largest seismically induced landslides allow us to estimate magnitudes of prehistoric earthquakes, calculate the total volume of earthquake triggered landslides, the contribution of landslides caused by aftershocks and erosion rate due to seismically induced landslides. We tested this approach for the mountainous, seismically active SE part of Russian Altai where there are many large Holocene seismically induced landslides and the 2003 Chuya earthquake ($M_S = 7.3$) took place.

It should be noted that different parameters of earthquake triggered landslides are not simply a functions of earthquake magnitude. There are additional factors related both to geomorphic and earthquake mechanism considerations such as roughness of topography, rock type, hydrological conditions, earthquake type and depth, direction of energy focusing, regional morphotectonic structure and so on. Some of these were considered by Keefer (1984, 1994, 2002). We believe that all of them play important role in seismic triggering of landslides but as soon as landslide event has occurred the statistical approach appears to be the most promising tool. It gives universal laws for landslide events in any conditions and allows correlating different parameters irrespective of their functional links. Our statistical investigation of the largest seismically induced landslides caused by strong earthquakes all over the world gives similar results.

Despite several objective difficulties including: 1) establishing the seismic origin of paleolandslides; 2) estimating the typical size of the largest landslides for particular region and time period; 3) determination of the landslide parameters where the joining of several detachments or considerable change of landslide's body has occurred, this approach demonstrates the principle possibility of using the largest seismically induced landslides for estimating the paleoseismicity and topography changes.

Keywords. landslides, seismicity, erosion rate, Altai, Holocene

1. Introduction

The evolution of paleoseismological studies clearly demonstrates that in order to properly understand the seismic potential of a region, and to assess the associated topography changes, extensive studies are necessary to take full advantage from the geological evidence of past earthquakes. A major line of paleoseismic investigation is detailed study of coseismic effects in the natural environment and quantitative assessment of the topography changes depending on earthquake magnitude.

Seismically induced landslides are especially important agents of denudation in tectonically active zones. In spite of diversity in climatic, geological, geomorphological conditions and peculiarities of seismic process for different areas, landslides of various types can be triggered even by the moderate seismic shocks with the smallest approximate magnitudes 4 - 5. Since about 1/5 of the Earth's surface is affected by earthquakes, estimating the topography changes caused by these processes is a matter of vital importance.

By now there are some well developed methods, estimated the seismic risk hazard, which are based on seismological data (Gubin 1950, Belousov 1954, Gzovskij 1957a, Gzovskij 1957b). But along with all advantages these approaches have some weaknesses too. Thus for forecasting the intensity of seismic shocks for specific active area it is necessary to extrapolate the registered seismisity from one seismically active area to another. The applicability of these methods is limited by the seismostatistical data. There are also difficulties in revealing the correlation between seismisity and geological structure of a region. Moreover, estimating earthquake magnitudes using instrumental data and historic accounts can only give information about the seismicity of mountain provinces during relatively short time period. Using these methods it is practically impossible estimate the seismic risk hazard for unstudied areas, evaluate the upper bound of seismic potential of specific seismogenerative structures and obtain information about location of epicenters and recurrence time period for strong earthquakes.

The method of paleoseismogeology developed in Russia since the 1960s (Solonenko 1966, Solonenko 1973, Florensov 1978) can fill the gap in this knowledge and give such information for the time period of about 10^4 years. The key point of the method is analysis of geomorphically expressed surface displacement (slope failure or fault scarps) of evidently seismic origin. Each strong earthquake source creates a signature on the geology and the geomorphology of an area. The sizes and patterns of prehistoric and historic ground failure have direct implications for the magnitude of their triggers. So detailed study on relations between various categories of coseismic effects in the natural environment and earthquake magnitude can provide the assessment of associated seismic risk hazards, estimating the paleoseismicity and topography changes in mountain provinces. In the classification by Solonenko (1973), earthquakes can cause slip on faults (tectonic effects), slope movements such as landslides, rockfalls, debris flows, etc. (gravity effects), or events of mixed gravity-tectonic origin.

So far most of research has focused on coseismic fault motion, and a number of empirical correlations have been obtained for the earthquake magnitudes and fault scarp parameters (Tocher 1958, Solonenko 1973, Khromovskikh et al. 1979, Nikonov et al. 1983, Wells and Coppersmith 1994 and many others). This opened up possibilities to make seismic risk zoning on the basis of estimated earthquake magnitudes. There are, however, natural problems in fault scarp studies (Nikonov et al. 1983): it is difficult to predict the origin and geometry of old fault scarps in rugged terrains, to time and distinguish prehistoric events in multiple scarps, or to discriminate between scarps produced by the main shock, foreshocks, or aftershocks. The latter objective is critical for empirical relationships used to estimate the magnitudes of paleoearthquakes.

The largest earthquake-induced landslides rarely pose such problems, and these largest earthquake-induced landslides are the most interesting target for paleoseismisity study in mountain provinces for several reasons. First, they leave the most persistent imprint on landforms and thus represent the longest period of seismic activity. Second, each specific seismic event can produce many smaller landslides and only a single largest one. Our data on strong modern and prehistoric earthquakes for Altai-Sayan mountain province (Russia) show that the largest landslide volume is several times or even orders of magnitude greater than the volume of the next one. Thus in this case, the largest landslide each stands for a separate trigger unlike faults or smaller landslides. Another advantage, especially important for hardly accessible terrains, is that large landslides are well resolved in remote sensing imagery.

Giant seismically induced paleolandslides are evidence of high regional seismicity. Numerical evaluations of magnitudes of prehistoric earthquakes from the largest landslides data allows to amplify and refine available assessments of associated seismic risk hazards. These estimates can form the basis for seismic risk zoning in poorly studied regions with the shortage of seismological and historical data. Moreover the largest landslides data can be used for estimating the total volume of associated landslides induced by a single earthquake, calculating the contribution of aftershock induced landslides to the total volume of seismically triggered landslides, and finally calculating the erosion rate due to seismically induced landslides.

2. Estimating earthquake magnitudes from landslide data

Recently, complete landslide-event inventories have become possible due to advanced methods and facilities, including analysis of high resolution satellite images, interpretation of aerial photographs and extensive field investigations that use a variety of techniques and tools pertaining to geomorphology, engineering geology and geotechnical engineering (Wieczorek 1984). Using these complete inventories Malamud et al. (2004a) suggested a statistical landslide probability distribution function. The new data made it possible to relate the landslide parameters to the trigger magnitude. Relationship (1) shows the correlation between M - the magnitude of an earthquake, and V_{Lmax} - the volume of the largest landslide it causes (Malamud et al. 2004b):

$$\log V_{L\max} = 1.36M - 11.58(\pm 0.49) \qquad (1)$$

with V_{Lmax} in km^3. The error bounds represent the standard deviations of the fit. Equation (1) is valid for medium and large earthquakes that generate at least one landslide and has important paleoseismological implications for mountain provinces where there are many large earthquake induced landslides.

The applicability of the empirical correlation (1) to the SE part of Russian Altai (the Altai neotectonic uplift is the part of Central-Asian collision belt) has been proved due to the 2003 Chuya earthquake (M_S = 7.3) which triggered a great landslide. This data as well as data of the 1957 Gobi-Altai earthquake (M_S= 8.1) (Florensov and Solonenko 1965) show a perfect fit to Eq.(1): the corresponding points in the landslide volume - magnitude coordinates fall within the error band.

At present, seismostatistical data base for Russian Altai is quite limited. The 2003 event has been historical the only instance in the SE Altai when the magnitude of a large earthquake could be numerically correlated with the associated ground failure. Perhaps future researches can give new opportunities to test this relation. Anyway, it would be unwise to neglect relationships reported from other seismically active areas because the recurrence of large earthquakes in the mountains flanking the Kurai-Chuya system of intermontane depressions (SE part of Russian Altai) is 500-900 yr (Rogozhin et al. 2007). Moreover our statistical investigation of the largest seismically induced landslides caused by thirteen strong modern earthquakes all over the world gives similar results.

While estimating paleoearthquake magnitudes from the largest landslides data equation (1) provides the low-bound limit of the value as immediately following the event the landslide size begins to reduce by wasting processes (ice degradation in permafrost, erosion, etc.). Therefore, deriving the upper-bound limit of the paleoearthquake trigger magnitude for old landslides, which have different ages and have been wasted to different degrees, requires a parameter not involved in the landslide deposition area. The detachment length can be used as this parameter. According to the landslide type the detachment length has its own size defined by the landslide surface area. Landslide body naturally tends to a certain geometry, more or less isometric depending on the slope, geologic environments, etc., and thus cannot stretch too far in any dimension (Vazhenin 2000, Burbank 2002). Inasmuch as later surface processes most often increase the length of the initial detachment surface, the magnitude derived from detachment length corresponds to the upper limit. Proceeding from the 2003 Chuya earthquake data, we estimated the maximum magnitudes of prehistoric earthquakes for Chagan-Uzun river basin (SE Altai, Russia) using a linear relationship. This approach is applicable for the greatest prehistoric landslides in the immediate vicinity of the largest Chuya earthquake landslide because they share similar origin and evolution patterns. It should be emphasized that this simplification may work only for paleoearthquakes of a comparable magnitude, and its applicability to other active areas requires a special study.

The paleoearthquake magnitudes obtained from the largest landslide data - from 6.9 to the largest possible in nature - indicate high seismic activity of SE Altai through the Holocene and its seismotectonic identity with the Mongolian Altai. The intensity of the earthquakes that triggered all the studied giant landslides, by analogy with the consequences of the 2003 Chuya earthquake (M_S = 7.3, I = 9-10), can be estimated to be 9 - 12 units on the MSK-64 scale. This fact, along with recent discoveries, argues for the greater seismic activity of this region than it was supposed before.

3. Estimating topography changes from landslide data

Quantitative assessment of earthquake induced topography changes can be done using the total volume of associated landslides - V_{LT}. The relationship between V_{LT} and earthquake magnitude M (Eq. 1) is given in Malamud et al. (2004a) on the basis of total volume of landslide material generated by 15 historical earthquakes (Keefer 1994) along with the 1994 Northridge earthquake data (Harp and Jibson 1996):

$$\log V_{LT} = 1.42M - 11.26(\pm 0.52)\,, \qquad (2)$$

with V_{LT} in km^3. This equation gives the best fit for modern earthquakes with instrumental measured magnitude, but the historical database of strong earthquakes in SE Altai is quite poor and the period of seismological regional studies is short. Along with old ruptures, the only evidence of the high Holocene seismicity in this area is the giant paleolandslides.

Combining Eqs. (1) and (2) we can obtain the correspondence between V_{LT} and V_{Lmax}:

$$\log V_{LT} = 1.04 \log V_{L\max} + 0.83\,, \qquad (3)$$

with the expected standard deviations less than 1.03. Both V_{LT} and V_{Lmax} are in km^3. This relation (Eq. (3)) is best applied for prehistoric earthquakes that caused giant landslides in SE Altai.

Equations (2) and (3) define the destructive effect of earthquakes leading to topography changes, which can be evaluated by erosion due to seismically induced landslides. The rate at which earthquakes contribute to erosion can be estimated on the basis of different approaches. To make a calculation for the Holocene earthquakes in SE Altai we use Eq. (4):

$$\dot{h} = \frac{\sum V_{LT}}{S \cdot T}\,. \qquad (4)$$

Here $\dot{h}$ is the erosion rate due to seismically induced landslides, $\sum V_{LT}$ is the sum of total volume of landslides triggered by each individual earthquake in a region with the surface area S, during time interval T. For more accurate estimating all strong earthquakes over this time period should be taken into account. Moreover T should be much longer than the recurrence interval for strong earthquakes. For SE Altai we can take the Holocene as the corresponding time period because the recurrence interval here is about 500-900 years (Rogozhin et al. 2007). Another reason is that Holocene landslides are morphologically "fresh" and so make it possible to estimate the erosion rate more correctly. All studied landslides have Holocene ages because the youngest displaced rocks are Late Pleistocene moraine and fluvioglacial deposits that cover the valleys sides at the depression-range transition (Agatova 2005). It should be taken into account that there are certain areas affected by landslides in earthquakes. Although there are a lot of factors such as focal depth, specific ground motion characteristics of individual earthquake, geological conditions and so on, this area correlates with the earthquake magnitude and so can be estimated (Keefer 2002, Keefer and Wilson 1989). Therefore when calculating erosion rate the studied area S should be compared in the proper way with areas affected by landslides in the earthquakes.

We consider only strong earthquakes that gives as a result the low-bound estimation of erosion rate. But this estimation closely relates to the real value because of the much more significant influence of strong earthquakes on mountain topography in comparison with the same of moderate seismic shaking. Our calculations show the difference in corresponding erosion produced by strong and moderate seismic shocks of about 2 orders. The main problem under such an approach is ascertaining the typical size of the largest paleolandslides for a specified active area over concerned time period.

Using our approach the largest seismically induced landslides allow us to calculate the total volume of earthquake triggered landslides, the contribution of landslides caused by aftershocks and finally the Holocene erosion rate due to seismically induced landslides for the mountain, seismically active SE part of Russian Altai by the example of Chagan-Uzun river basin. This Holocene erosion rate due to seismically induced landslides is $\dot{h} = 3 \cdot 10^{-5}$ m year $^{-1}$ and as shown above, is the low-bound estimation. It is in agreement with estimates obtained with different techniques for other seismically active regions.

Conclusions

The suggested approach (Fig. 1) was tested for the mountainous, seismically active SE part of Russian Altai where there are many large Holocene seismically induced landslides (Devyatkin 1965, Rogozhin and Platonova 2002, Agatova et al. 2006) and the 2003 Chuya earthquake (M_S = 7.3) took place.

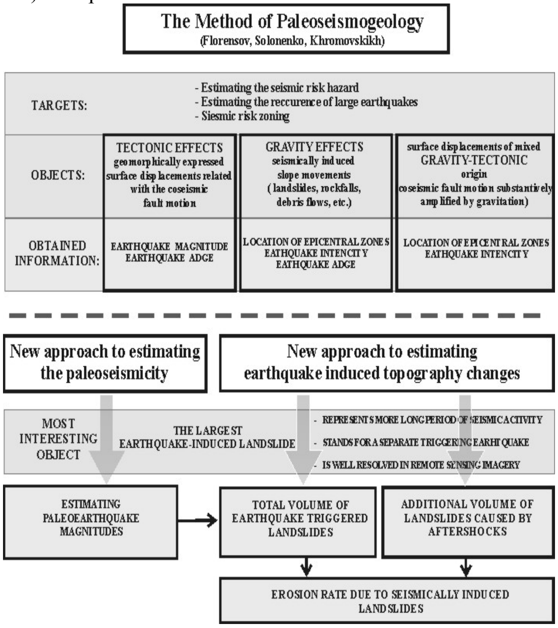

Fig. 1 New approach to estimating the paleoseismicity and seismically induced topography changes

Despite several objective difficulties including: 1) establishing the seismic origin of paleolandslides; 2) estimating the typical size of the largest landslides for particular region and time period; 3) determination of the landslide parameters where the joining of several detachments or considerable change of landslide's body has occurred, this approach demonstrates the principle possibility of using the largest seismically induced landslides for estimating the paleoseismicity and topography changes.

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Monitoring Rock Slope Deformation Following an Alpine Rock Slide in the Southern Japanese Alps

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Abstract. The head area of the Aresawa rock slide, located at about 3000 m a.s.l. in the southern Japanese Alps, has experienced significant rock slope deformation associated with opening of a number of tension cracks that were produced by a partial collapse in the spring of 2004. The deformation process of the rock slope was monitored with a total station between October 2006 and July 2008. Meteorological parameters were concurrently monitored. The total station network consisting of 38 points revealed spatial and seasonal variations in slope movement. The rate of movement differed significantly between the upper slope (more than ca. 40 m upslope from the head scarp) and the lower slope (within 40 m from the head scarp). The two areas are separated by a downhill-facing scarp 3 to 5 m high, 60 m long and parallel to the head scarp. The lower slope moved downslope at about 60 cm yr^{-1}, whereas the upper slope moved at less than 10 cm yr^{-1}. Mapping of displacement indicates the presence of a slip plane dipping downslope at about 40° to 50° below the downhill-facing scarp. Downslope movement was very slow (<1 mm day^{-1}) in the snow-accumulated period during which ground surface temperature (GST) remained below 0°C (November to May). In contrast, the movement accelerated in the snow-melting and snow-free periods during which GST showed just 0°C or rose above 0°C (June to October). Thus, the snow cover and underlying seasonally frozen ground that prevent infiltration of water contribute to the slope stability, whereas snow melting in spring and subsequent rainfalls in the snow-melting and snow-free periods promote water infiltration in the bedrock and accelerate rock slip. The snow regime controlling water infiltration condition plays an important role in seasonal variations of the rock slope deformation.

Keywords. Rock slide, tension crack, monitoring, seasonal variation, snow regime

1. Introduction

Many rock slides and avalanches occur episodically, which have generally prevented monitoring and understanding of pre-failure rock conditions, with recent notable exceptions of detailed geophysical observations (Willenberg et al. 2008a, b; Ganerød et al. 2008). Some studies reported that patterns of pre-failure surface movements depend on the advance of fractures and changes in stress condition in the rock mass (Saito, 1965; Petley et al. 2005). Therefore, the prediction of the progressive rock slope deformation requires detailed geodetic survey of spatial and temporal variations in surface movements on rock slopes. This paper describes rock slope deformation in the head area of a rock slide, which was activated by a recent rock slope failure. The rock slope is located in an alpine zone which is characterized by a seasonal snow cover and frozen ground. Based on the geodetic survey and continuous monitoring of meteorological parameters, including precipitation, air and ground temperatures and snowmelt conditions, discussion is focused on the dynamics of rock slope and controls on variations in the surface velocity.

2. The Aresawa rock slide

The Aresawa rock slide is located on the eastern slope of Mt. Ainodake (3189 m a.s.l.), southern Japanese Alps, which is mainly composed of Cretaceous shale and sandstone (Fig. 1).

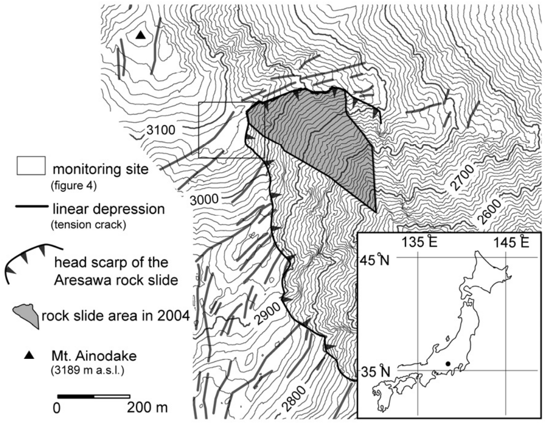

Fig. 1 Location of the study area. Contour interval 10 m

The rock strata run in the NE-SW direction and dip steeply at 50°−90°. The mean annual air temperature is about -2°C at 3070 m a.s.l. (Matsuoka and Sakai, 1999) and permafrost is possibly present only on the north-facing steep slopes (Ishikawa et al. 2003). The Norogawa observatory (1130 m a.s.l.), located 6 km east of Mt. Ainodake, has mean annual precipitation of about 2200 mm (1990 to 1995). The study area is covered with snow from late November to middle June. Landforms resulting from local rock mass deformation, including tension cracks, uphill-facing scarps and downhill-facing scarps (sackung features), widely develop on the main ridge (Matsuoka, 1985). A number of tension cracks were produced on the head area of the rock slide in the spring of 2004. The rock slide was 400 m high, 250 m wide and 13 m in the mean depth (ca. 40 m in the maximum depth). Post-failure movements were monitored on this head area 100 m × 100 m wide, including a distinct downhill-facing scarp 3 to 5 m high and 60 m long, and small tension cracks having originated during the rock slide.

3. Methods

The rock mass deformation in the head area was measured using a total station, the prism-type (PR) Leica

TC405 or non-prism-type (NPR) TCR 405ultra. The geodetic surveys were performed 7 times between 14 October 2006 and 14 June 2008 with PR and twice between 14 June 2008 and 1 July 2008 with NPR. The instrument was changed to avoid a possible risk by progressive slope instability. Two benchmarks were placed on the bedrock by anchoring a steel bolt. The geodetic network consisted of 38 points. The error of the most survey points was less than 2 cm, which was confirmed by the comparison between the directly measured distances and triangulation-derived distances. In the snow-melting period, snow cover prevented the measurement of several points.

Precipitation and ground surface temperature (GST) were recorded with a data logger every 6 h from 14 October 2006 to 1 July 2008, although the precipitation data were unavailable during the snow-accumulated period. The snow-melting regime of the central part of the head area was visually monitored every 2 h from 6:00 to 18:00 from 8 May 2008 (0:00) to 27 June 2008 (12:00) with an automatic digital camera (KADEC-EYE2, Kona, Japan). A survey pole included in the images provided a scale of the snow depth. A manual snow depth survey and the measurement of the snow density in a snow pit 150 cm in depth was performed at the monitoring site on 7 May 2008.

4. Result

Meteorological parameters

The passages of the polar front and typhoons induced large precipitation events during July, September and October (Fig. 2). GST continued at 0°C or slightly lower values lacking diurnal fluctuation from late November to late June, indicating the presence of the snow cover. GST remained at just 0°C between early May and late June (often called "zero curtain"), resulting from wetting and melting of the snow cover. Freeze-thaw alternations occurred on the ground surface several times from late October to early November, whereas they were absent in spring under the late-lying snow cover. Thus, based on the snow regime and GST, the monitored period was classified into the snow-accumulated (late November to early May), snow-melting (early May to late June) and snow-free periods (late June to late November), though the periods partly overlap. Fig. 3 shows the mean daily air temperature and cumulative snowmelt in the snow-melting period (2008). The mean daily air temperature rose above 0°C in middle May, and concurrently snowmelt progressed. In total, 255 cm-thick snow melted from 8 May to 27 June. The snow density was about 0.5 $\mathrm{g\ cm^{-3}}$.

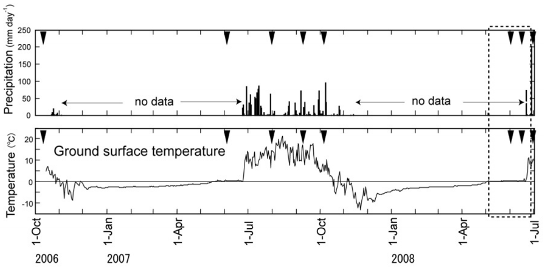

Fig. 2 Precipitation and ground surface temperature from 14 October 2006 to 1 July 2008. Arrows indicate the date of geodetic survey. Dashed square indicates the period shown in Figure 3.

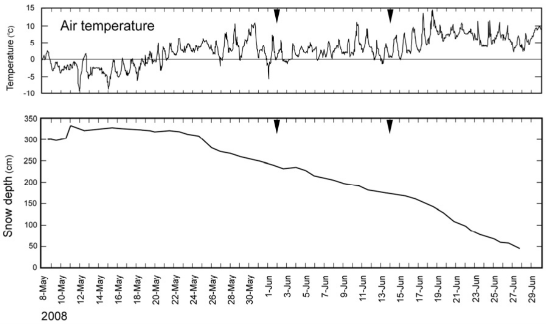

Fig. 3 Air temperature and snow depth in snow-melting period (2008). Arrows indicate the date of geodetic survey.

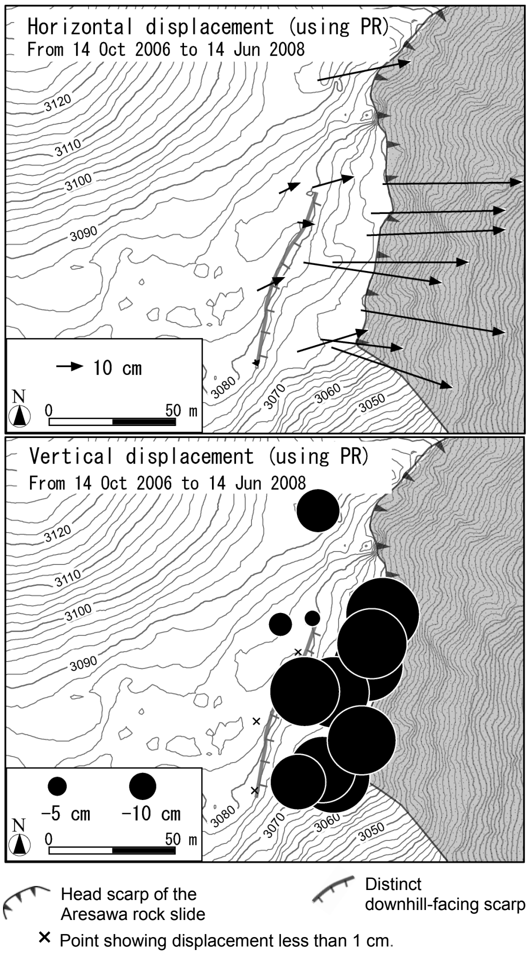

Fig. 4 The cumulative horizontal and vertical displacements from 14 October 2006 to 14 June 2008. Contour interval 2 m.

Spatial variation in displacement

Contrasting surface displacement patterns were observed between the upper and lower slopes separated by the downhill-facing scarp (Fig. 4). The lower slope (within 40 m from the head scarp) moved much faster than the upper slope (more than 40 m upslope from the head scarp). The lower slope moved downslope by about 60 cm in both horizontal and vertical components, over the whole survey period. In contrast, the upper slope moved horizontally by 10 cm and vertically less than 10 cm. The rock mass moved, on the whole, toward the maximum gradient of the failure slope.

Temporal variation in displacement

The surface velocity, determined from the horizontal and the vertical components, indicated a significant seasonal and inter-annual variations (Fig. 5). The surface velocity was small (<1 mm day-1) and similar between points on the upper and lower slopes in the snow-accumulated period. Then, the velocity suddenly accelerated with a large spatial variation on the lower slope in the snow-melting period. The velocities in the snow-melting and snow-free periods were several times as large as the values in the snow-accumulated period. Much faster movements (>10 times of velocities in the snow-accumulated period) were recorded during the snow-melting period in 2008. Thus, the geodetic survey demonstrates the periodic motion of the rock mass, especially below the downhill-facing scarp.

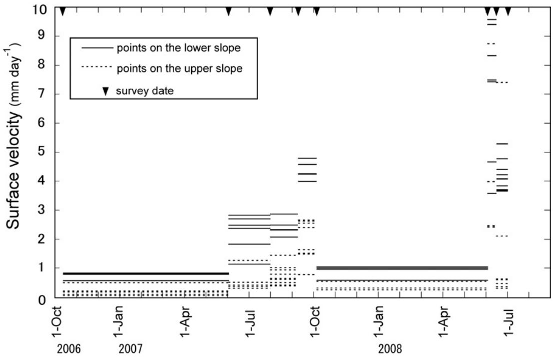

Fig. 5 Seasonal changes in surface velocities at monitored points.

5. Discussion

Dynamics of the rock slope

The lower slope moved about six times faster than the upper slope. Mapping of horizontal and vertical displacements shows that the discontinuity of the displacement occurred on the downhill-facing scarp which suggests the presence of a slip plane dipping downslope at 40° to 50° below the downhill-facing scarp. This implies that sliding along this slip plane has dominated the rock slope deformation and expanded the unstable area.

The controlling factors on the seasonal variation in rock slope deformation

The surface movement was much slow (<1 mm day^{-1}) in the snow-accumulated period during which GST remained below 0°C for half a year, while it accelerated in the snow-melting and snow-free periods during which GST showed just 0°C or rose above 0°C. During the snow-accumulated period, the snow cover and underlying seasonally frozen ground (indicated by the subzero surface temperatures) would prevent the infiltration of water in the bedrock, which contributes to the slope stability. In contrast, the rock slope would become wet by infiltration of the snowmelt water in the snow-melting period, as indicated by the ablation of snow by 255 cm from 8 May to 27 June. Thus a large amount of meltwater, equivalent to precipitation of 1275 mm, which was estimated from the melted snow depth (255 cm) and the snow density (0.5 g cm^{-3}), was supplied for 51 days in the ground around the slip plane. This water condition favored the acceleration of the rock mass slip. Moreover, water infiltration from rainfalls in the snow-free period (2007) also contributed rock slope deformation. The acceleration of the movement coincided with GST reaching and rising above 0°C. Thus, the seasonal variation in the surface velocity is considered to depend primarily on the snow regime which controls water infiltration in the rock slope.

6. Conclusions

The head area of the Aresawa rock slide indicates distinct spatial and temporal variations in surface movements. The major movement occurs along a slip plane dipping downslope at 40° to 50°, which accentuates a downhill-facing scarp. The seasonal variation in rock slope deformation is caused by water infiltration, mainly associated with the snow regime. The thick snow cover and underlying frozen ground that prevent infiltration of water maintain the rock slope relatively stable throughout winter, whereas snow melting in spring and subsequent rainfalls in summer promote water infiltration in the bedrock and accelerate rock slip.

Acknowledgements

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PS Interferometry-based Studies of Landslides at Regional Scale

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Abstract. This work presents an application of PSInSAR™ technique for detecting and monitoring ground displacements in the Piemonte Region. The aim of the project, supported by ARPA Piemonte and the National Civil Protection Department, is to apply and test the PSInSAR™ technique in order to: develop a methodological approach for the geological interpretation of the data at regional scale, verify the potentials and limitations of the technique for the detection of ground movements in relation to the different natural/anthropogenic processes and to the different geological environments, identify areas with ground deformations, where local authorities may concentrate future detailed geological studies and risk mitigation actions, and monitor large areas at relatively low costs. A sequences of operations is proposed in order to help the interpretation of the PSInSAR^{TM} data at the large spatial scale, easy to use by the public administrations and by civil protection authorities.

Keywords. SAR interferometry, Permanent Scatterer, landslide, Piemonte

1. Introduction

This paper presents an application of PSInSAR™ technique (Ferretti et al. 2001) for detecting and monitoring ground displacements at regional scale in the Piemonte Region. The aim of the project, supported by ARPA Piemonte and the National Civil Protection Department, is to apply and test the PSInSAR™ technique in order to: develop a methodological approach for the geological interpretation of the data at regional scale, verify the potentials and limitations of the technique for the detection of landslides movements in relation to the different natural / anthropogenic processes and to the different geological environments, identify areas with ground deformations, where local authorities may concentrate future detailed geological studies and risk mitigation actions, and monitor large areas at relatively low costs.

2. Geological setting of the study area.

The Piemonte Region, located in northwest Italy, has an extension of 25,000 km^2 and it is significant with respect to different geological contexts (Alps, Apennines, Langhe and Monferrato and Plain). The IFFI project (national landslide inventory) identified, for this region, more than 34,000 slope instabilities (Colombo et al. 2005), of various typologies related to the different geological settings. The alpine environment is characterized by the presence of rock-falls/topples, large complex landslides and deep seated gravitational deformations. In the Langhe area translational rock-block slides and shallow landslides make up the majority of landslides. The hilly southeastern part of Piemonte (Apennines/Torino hill) is affected by slow flows and complex landslides. About 300 landslides are monitored. The monitoring network includes many sites with few conventional instruments (inclinometers, piezometers, extensometers and topographic benchmarks). Many of them were installed in the Langhe after the November 1994 strong rainfall event. At a limited number of sites, where major landslides threaten large built-up areas or important structures, monitoring systems are more complex and include several types of instruments, with automated data recording and transmission, generally installed after 2000.

3. Methods for geological interpretation.

The high number of PS data (more than 2,000,000) and the large extension (25,000 km^2) of the study area require the development of a methodology for the geological interpretation of the PSInSAR^{TM} data at regional scale. A methodology, easy to use by the public administrations and by civil protection authorities, is here proposed (Fig. 1). The PSInSAR^{TM} data interpretation is done into three steps.

The first step corresponds to the deformation accuracy assessment and the identification of the areas with significant movements, the so-called “anomalous areas”. Ortho-rectified aerial photo and cartographic data layers have been used to check the planimetric accuracy. The reference points were controlled in the field to verify if they really correspond to “geologically” motionless point. The “anomalous areas” consist of clusters of minimum 3 PS with a maximum distance of 50 meters among, characterized by displacement rates over to -/+2 mm/yr that are above a significant threshold background related to the technique precision. The identification of such areas is done through an automatic procedure in a G.I.S. environment. The automatic anomalous areas do not have, of course, a geological significance, but they are useful to quick and systematic identify sectors in the studied area where the PSInSAR analysis detects ground deformation and where the attention of the geologist has to be focused.

In the second step a preliminary interpretation of the anomalous areas is done through the integration in a GIS environment of the PS data with information, which might have relevance in explaining the patterns of motions of PS points: topographic maps at 1:10,000 scale, aerial orthophotos acquired at 1:10,000 scale during 2000, geology, DEM (20x20m), landslide inventory and geotechnical database. Terrain slope and aspect maps were derived from the DEM for the interpretation of directions of ground movements measured by InSAR. In fact PS technology provides only the component of the real displacement vector measured along the satellite's line of sight (LOS). In order to estimate the movement direction compatible with the PS measurements in mountain and hilly areas, it is necessary to combine the LOS information (different for ascending and descending orbits) with the topographic features (e.g. slope and aspect). In addition, the sign of the measured displacements (positive values indicate movement towards the satellite along its LOS, while negative values indicate movement away from the sensor) has to be interpreted considering the terrain slope. The landslide inventory was done by ARPA Piemonte, following the Italian national methodology (APAT, 2007), through a detailed photo-interpretation on the whole regional area, the collection of existing data and field surveys. Classification of landslides (type, general features, etc…) was made referring to the international literature (Cruden and Varnes, 1996). In order to simplify the cartographic interpretation of numerous and very small single phenomena that affected homogeneous areas an additional term was also introduced. With the term "areas affected by..." it was possible to classify slope sectors affected by seasonal widespread falls/topples and by shallow landslides/rapid flows. The evaluation of state of activity, where geological surveys and instrumental data were not available, was done through a morphological approach based on airphoto interpretation of different periods; this fact complicates the comparison between the state of activity of landslides and the PSInSAR data. The overlying of the anomalous areas with all the other layers and the experience of the geologist allow to group with a visual procedure some anomalous areas that seems to belong to the same geological process (e.g. different anomalous areas in correspondence of the same slope instability) or to divide those areas, whose movement appears to be related to different geological processes. Finally the anomalous areas are selected on the basis of the ratio between moving PS and total PS contained in the area (generally where this ratio is less than 20 % the area is rejected). A GIS-based database is created containing the information about these areas: location, geological and geomorphological characteristics of the areas, SAR data (sensor, track, frame, dataset, reference point), typology of radar targets (man-made structure, rock, debris), statistical data (minimum, maximum and average coherence and LOS velocity, ratio between moving PS and total PS), and preliminary interpretation. The database is available to all potential users (professionals, public agencies, local authorities) through the ARPA Web-GIS services.

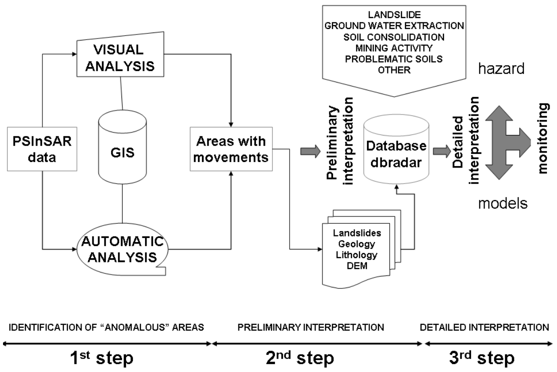

Fig. 1 Flow chart showing the study method

Detailed geomorphological, geological and geotechnical studies and field checks in the interpreted areas allow to obtain the detailed interpretation of the displacements identified in the PSInSAR™ analysis in the third step. We present some results concerning the first and second step of the proposed methodology.

Conclusions

The interpretation of the PSInSAR data depends on the typology of geological processes, particularly their velocity and type of movement (vertical, horizontal, linear, non-linear). The main causes of movements detected by PS data in Piemonte region are represented by landslides (15% - 20% of interpreted areas respectively in the Alps-Apennines and in the Langhe sectors). In order to highlight the percentage of information coming from the PSInSAR™ technique and to evaluate its effectiveness in slope movement identification a simple statistical analysis of the number of landslide with PS information was firstly performed. For this purpose the PS were overlaid upon the pre-existing IFFI landslide inventory.

The landslides with PS information are represented by extremely slow to slow movements, for which the 90% have at least 1 PS (Fig.2).

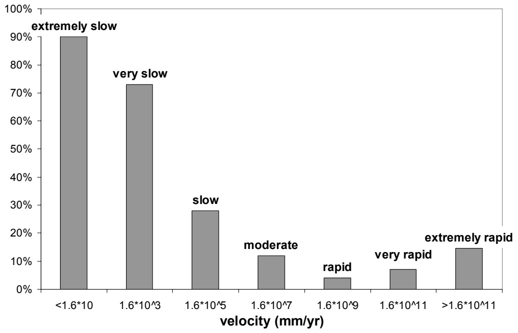

Fig. 2 Landslides with at least 1 PS vs. landslide velocity

In the alpine region 20% of the landslides have PS information while 12% and 8% of the originally mapped landslides have PS information respectively in the Apennine and in the Langhe areas. These are quite good results compared with similar studies in the Apennines (Farina et al, 2006) found only 6% of the landslide with PS information. Then, the interpreted areas were overlaid upon the landslide inventory. 30-40% of them is within or close to mapped mass movements and could also give information about the state of activity of the landslides in the period 1992-2001. Only 2-3 % of the interpreted areas correspond to possible new mass movements. The 30% of monitored landslides has PS information and only for few of them the monitoring period corresponds with that of the interferometric analysis.

In order to illustrate the capability of the technique to identify different mechanisms of movements related to slope instabilities some notes related to the main typologies of landslides in Piemonte in relation to the different geological context will presented.

In the Alps, 14% of landslides with PS information have anomalous areas and they correspond to complex landslide and to deep seated gravitational slope deformation (DSGD), that are considered as large landslides with a surface extension greater than 0.2 km^2. The observed movements are generally from extremely slow to slow (from a few millimeters to several centimeters per year); they are fairly regular with some occasional acceleration. Secondary landslides (rock falls, toppling, rock-slides, debris flows, rock avalanches) are often associated and they result in significant direct and indirect damages. Their specificity (surface extension and gentle morphology) induce the population to use this apparently favorable land for settling villages on slopes and building infrastructure such as roads. The probability of a critical global movement of the whole mass is very low, whereas the consequences may be catastrophic. The risk induced by such phenomena is especially related to serious climatic events of high intensity or long duration, which may bring about a momentary acceleration and an increase of movements. The problems related to their study are the difficulty to characterize their boundaries and their rates of movement and then to understand their kinematics. Due to their extension and to the low movements, which are close to the detection limit of traditional monitoring equipment, they are also difficult to monitor. The landslide slope faces west and north-west, which make the exploitation of descending mode ideal for interferometric purposes. One limitation of the PSInSAR technique in the Alps is that a limited number of PS corresponds to rock and the most part of PS correspond to talus debris, which is a very good reflector. This debris generally correspond to areas affected by falls/topples and explains the relatively high number of PS detected on extremely rapid landslides. It will be useful to distinguish between shallow seasonal movement of the debris and deformations related to deeper seated gravity.

The Langhe hills are located in the southern Piemonte. Fine-grained argillaceous rocks, including claystone, mudstone, siltstone and shale dominate the region and usually occur as alternating sequences with sandstones. The gentler hillsides are affected by "rock block slides"; the unstable mass slides along a surface coinciding with bedding planes dipping from 8° to 18°. These phenomena involve the bedrock from depths of a few meters, up to 30 meters. Sliding surface corresponds to where sandy-arenaceous and marly-silty levels meet, which is the area where infiltration water is mostly concentrated. These slides took place over a period ranging from a few minutes to some hours, after strong rainfall events. Most of the observed landslides turned out to be reactivations of similar phenomena already identified in the past. Due to high deformation rates (during the peak phase, movements reached speeds varying from a few decimeters up to some hundreds meters per hours) no PS were detected in correspondence of the landslides triggered by November 1994 strong rainfall. Nevertheless some anomalous areas corresponds to the so-called “sectors”, which are zones with some geomorphological evidences of past landslide activities. The PS show a displacement rate of -2/-5 mm/yr, which could reflect the long term post-failure slope deformations. In the Langhe environment it could be sometimes difficult to distinguish and separate different processes, as the slope movements and the settlement of engineered structures, which have comparable velocities.

In order to survey the displacements in the Langhe region after the November 1994 crisis, a monitoring system was installed, it consists in several inclinometers and piezometers.

In Fig. 3 the velocity measured by the inclinometers in the period 1994-2000 was compared with PS measurements converted along the slope (Vprj). This was possible because the deformation (rock block slide) is translational and parallel to the slope. The average deformation rates along the slope (Vprj) range between -3 and -5 mm/yr. The PS motions are consistent with the ones inferred from in-situ measurements and a deformation rate map was obtained by interpolating the PS.

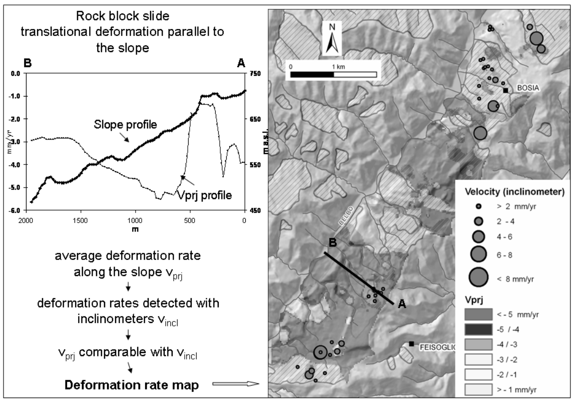

Fig. 3 Comparison between the velocity measured by the inclinometers and the velocity of PS along the slope

As already stated landslide with PS in Apennine are lower than the Alps due especially to a more developed vegetation cover. The most important movements in Apennine correspond to complex landslides dominated by a rotational component in the upper part evolving to a slow flow. They generally occur on multiple shear surfaces. This add another problem with a robust determination of displacement vectors. In general the activity of the landslides is characterized by slow continuous movements with seasonal remobilizations of slope typically related to rainfall events. The study of the temporal evolution of the landslides on the basis of PS displacement is difficult in this environment for the existence of other superimposed factors related to the subsoil processes (e.g. swelling/shrinkage of clay soils) and to the behaviour of man-made structures which correspond to PS radar targets, which often present similar displacement rates.

In synthesis , the success of the technique depends also on the typology of landslides and their related kinematics. The PSInSAR^{TM} method is best suited for assessing the temporal evolution of slow and extremely slow landslides with constant velocity deformations (the SPSA assumes a linear model), as large landslide in the Alps. Thanks to the high PS density it was possible to identify some areas with different displacement rates. Landslides with intermittent behaviour, such as that triggered by rainfall, are difficult to detect (rock block slides in the Langhe, complex movements in Apennines), nevertheless an application of the technique could be envisaged in the detection of collapse precursors or post-failure movements (rock block slide in some Langhe sectors). The PS density depends on the topography, vegetation, presence of man-made structures, this results that in some environment, e.g. Apennine, the PS are distributed along the valley bottom where the density of man-made structures is the highest. An other problem is the difficulty in discriminating ground deformation due to different processes, as local settlement of man-made structure (e.g. Apennine and Langhe) or the shallow deformations caused by seasonal processes in debris (Alps). The comparison between in situ-instrumental monitoring data and the PSInSAR results requires that PS measurements are converted along the slope. This is possible for translational deformation parallel to the slope, as rock block slide. Generally there is a good agreement with the PS displacement rates and the in-situ measurements. The PS provides only the component of the displacement vector measured along the satellite line of sight. In order to estimate the real movement it is necessary to resolve the LOS deformations with the kinematics of the slope movement (slide surface geometry). Due to the high radar viewing angles, only a fraction of the horizontal component of the movements can be detected. Therefore, a quantitative exploitation of the PS technique for the understanding of the landslide mechanism need in situ data. Such regional interpretation of PS data identifies areas with ground deformations, where local authorities may concentrate risk mitigation actions, and provides the basis for additional studies at local scale (third level of the proposed methodology).

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The 20 July 2003 Landslide Swarms within the Bambouto Caldera and Their Effects

Edwin Ntasin, Ayonghe Samuel, Suh Emmanuel (Buea University, Cameroon)

Abstract. The Bambouto caldera on July 20th 2003, witnessed a spontaneous swarm of more than 120 landslides that killed 23 people and resulted in the destruction of properties. It is located between longitudes 9°56'E and 10°06'E and latitudes 5°38'N and 5°45'N along the Cameroon volcanic Line (CVL) and is 16 km long in the east-west direction and 5 to 7 km wide in the north-south direction. The basal plutonic syenite complex occupies the central position of the caldera. The overlying volcanic complex, previously not well defined, is made up of successions of volcanic tephra and lava flows that alternate from more silicic varieties at the base to more basic rocks towards the top. Intensive weathering of the volcanic rocks resulted in an increase in Al_2O_3, Fe_2O_3, total water (H_2O+LOI) and SiO_2 and a decrease in the K_2O, Na_2O and MgO. This resulted in the formation of perched aquifers with gibbsite or montmorillonite bands constituting the aquiclude base. The liquefaction of these perched aquifers resulted in numerous spontaneous slopes failure across the entire caldera.

The need to establish new fertile farms, in order to improve on the yearly yield, attracted many families to settle within the highly fertile caldera region. The development of the region resulted in deforestation, undercutting of slopes for structures (houses, roads and bridges), soil disintegration and increase in the rate of weathering. The 2003 landslides killed 23 people and produced large volumes of regolith charged with tree trunks, rock boulders, and objects (corrugated zinc sheets, broken furniture) derived from destroyed houses. The resultant sloth produced from the regolith caused floods in the streams which feed the River Meyi. The floods increased the rate of lateral erosion of the banks of the river at its lower courses, and together with the landslides destroyed 261 houses, 52 bridges, 86 culverts, 496 farms, 385 livestock killed, 229 families displaced and 1015 persons displaced. The caldera was completely cut off from the surrounding regions.

Keywords: Caldera, liquefaction, aquifer, aquiclude, slope failure

1. Geology

The study area is made up of two rock types, the plutonic syenite complex found at the central region and the Tertiary volcanics that unconformably overlie it (Fig. 1). Granites and gneisses constitute the plutonic complex (5%) and basanites, rhyolites, trachytes and phonolites the volcanic complex (95%). The syenite complex is immediately overlain by the thick saprolitic unit with varying thicknesses across the caldera. The volcanic complex can be separated into two; an older series and the younger series. The older series is composed of an alteration of falls and flows when viewed in profile; and it unconformably overly the saprolitic unit. The younger volcanics mainly basanites and trachytes occur in areas around the rims of the caldera, and are relatively less affected by weathering when compared with the older volcanics.

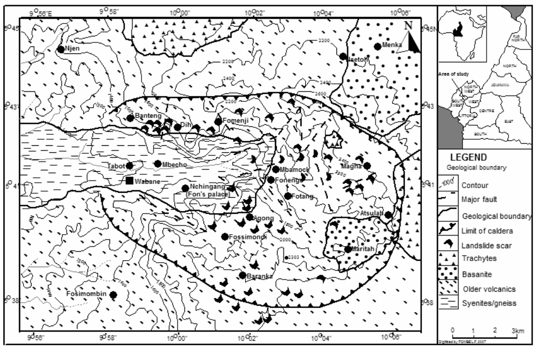

Fig 1: Geology and distribution of landslide scars with the Study Area.

Tectonically the rocks are highly fractured with some major stress relief fractures highly affected by the process of weathering. The plutonic series show a dominantly NE-SW trend whiles the volcanics exhibit a circular pattern, also showing a dominantly NE-SW trend. The two trends are concordant with the regional (CVL) trend. This suggests that the older plutonic complex imposed its trend on the volcanic during a possible reactivation process.

2. Causes of the Landslides

The Bambouto landslides occurred due to high intensity (140 mm/week) rainfall and exceptionally long periods of over three days of intermittent rainfall and three days of continuous rainfall. This prolonged rainfall caused the saturated zone to develop, with elevated pore-water pressure in the substrate, resulting in the destabilisation of the regolith and subsequently the occurrence of the landslides. Polemio et al. (2000) indicated that such heavy rainfall over a long period leads to a high rate of infiltration thereby triggering landslides.

Prolonged and intensive rainfall plus the influence of geology, structural framework, topography and increased pore pressure resulted in the initiation of these massive landslides. Many old landslides scars were reactivated. According to Santaloia et al. (2001) the reactivation of ancient landslides may follow slow progressive plastic straining, with either the formation of new slip surfaces, or the slipping of the soil mass along a pre-existing slip surface. Rainfall statistics indicated that the region suffered from a long period of scarce rainfall from 1991 to 1999 with a high inter-annual variability in 1996. Such a long period of dryness must have resulted in changes in the physical properties of the weathered materials, particularly the development of contraction joints (Ntasin 2007). This was succeeded by a period of heavy rainfall from

2000 to 2002, causing high infiltration within the weathered regolith.

Daily rainfall data in July 2003 indicate three days of periodic rainfall (14th – 17^{th}) followed by continuous rainfall for three days (18^{th} – 20^{th}) which preceded the event of the 20^{th} July 2003. These data indicate that 140 mm/week of rainfall was collected as compared to the weekly average of 58 mm/week in this area. Olivry (1986) confirmed that such variations sometimes occurred along the Cameroon Volcanic Line. According to Polloni et al. (1996) such antecedent rainfall controls the soil moisture and is critical in initiating debris flow on slopes of 30^o to 40^o. Rainfall from the early days of July 2003 suggested continuous infiltration and based on the other geological factors, such as pore water pressure that varied within the subsurface, it is clear that where the variation was significant, the occurrence of landslides were eminent (Ntasin 2007). Transient perched groundwater tables formed under such conditions produced the contact springs observed at Magha prior to, and after the event. In some cases fountains were observed, indicating the high pore-water pressure within the subsurface.

Data from two important wire vibrating equipment, Vibrating Wire Displacement meter, model 4427 and Vibrating Wire Peizometer, model 4500S installed on an aborted landslide with a well defined gibbsitic band was very useful. This was intended to correlate the behaviour of the slope with respect to changes in displacement, pore water pressure and rainfall from May to December 2005. Although the rainfall was relatively quantified it gave a good picture of the influence of moisture on slopes stability. The displacement meter measured the linear movement across two points on the surface. The piezometer measured the fluctuation in the pore water pressure. It was evident that displacement and high pore water pressure were greatest during the months of June, July and August/September which usually represent the peak of the rainy session (Fig 2).

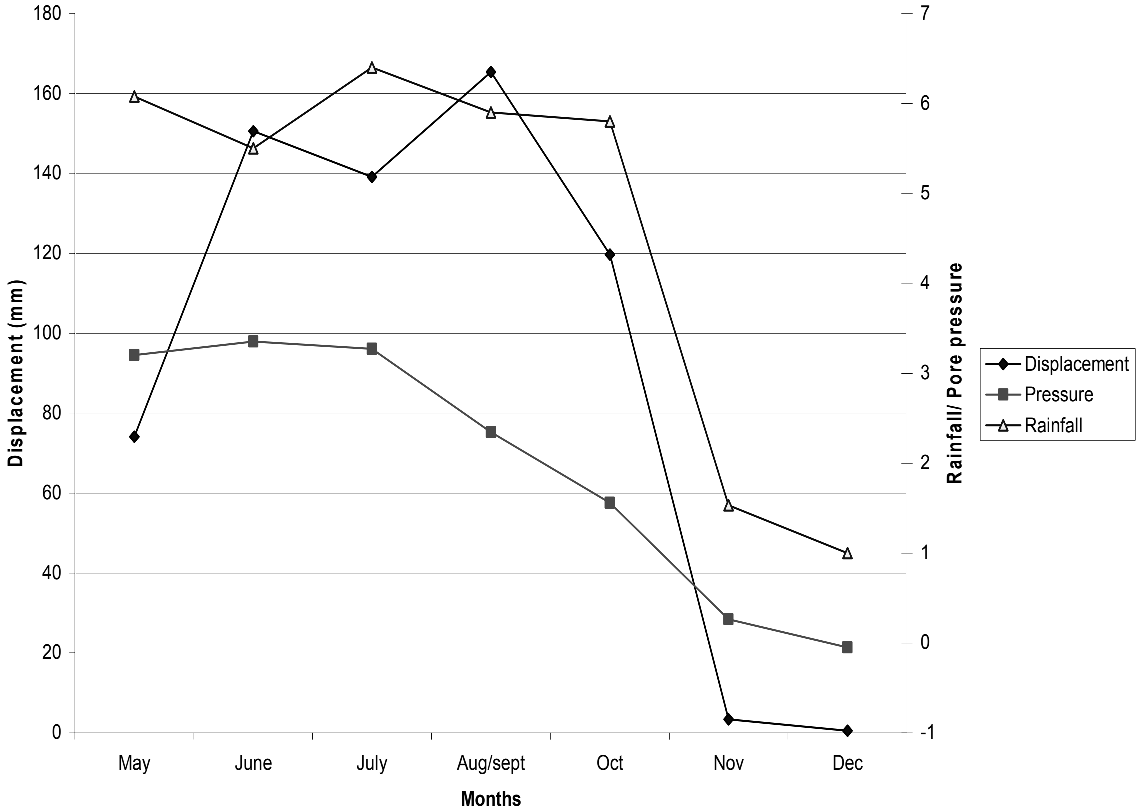

Fig 2. Summary of the monthly changes in displacement, pore pressure and rainfall from May to December 2005

The brownish bands observed on the slide surfaces proved to be the most important remote causes. These bands located at the base of the weathered regoliths were mainly gibbsite or montmorillonite in composition and constituted the impermeable units. These bands resulted from intensive weathering at such interfaces and were richer in Al_2O_3 content and poor in Na_2O and K_2O. Ntasin (2007); Ayonghe et al. (2004) and Yue and Lee (2002) reported similar impervious bottom layers in thick sandstones in south west China and in volcanic cones in Limbe, Cameroon, respectively.

3. Damage Caused

Regolith from numerous landslide scars, charged with tree trucks, boulders and mud (Fig 3) produced high flooding in the streams which fed the River Meyi.

This led to the flooding of dry valleys, brooks, streams and rivers and resulted in the destruction of houses, farmland, palm nurseries and the loss of lives. A total of 23 people were killed within the caldera. In order to have a clear picture of the extent of the damage, some quantification was made by considering the damage suffered by the different regions. The statistics indicated that 23 people were killed, 4 were injured, 229 families displaced and a total of 1015 people displaced; 496 farms were destroyed and 385 livestock killed. In terms of infrastructures 261 houses were destroyed; 52 bridges and 86 culverts destroyed. The floods are reported to have killed 57 people two days after the event in the Cross River State, Nigeria, located downstream.

Fig 3. Villagers standing of the regolith from the larges slide that killed 20 people.

Conclusions

The major conclusions established at the end of the work were that:

1) The alternation of pyroclastics and lava flows together with the highly fractured nature of the rocks remain one of the highly destabilizing factors. This setting helped in the formation of numerous perched water aquifers responsible for the initiation of the huge slides

2) The extensive occurrence of the 120 landslides resulted from intensive and prolonged rainfall as the immediate factor and the existence of gibbsitic and montmorillonite bands constituted the remote causes. The distribution of these bands determined the distribution of the landslide scars.

3) The caldera as a whole suffered from extensive human and material damage, due to the sliding and the flooding of the rivers. Regions that have suffered deforestation and intensive farming were greatly affected.

4) There is need for intensive investigations in regions with settlements along the CVL to ensure that the risk from future hazards is greatly reduce.

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Landslide and Debris Flow Experiments on Artificial and Natural Slopes

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Abstract. A large-scale model slope was used to study the initiation process of landslide fluidisation during torrential rain. Experiments were conducted by filling an inclined flume with loose sand under the rainfall simulator to induce the sand to collapse. Both the movement, shear strain and the pore-water pressure of the sand were monitored throughout the experiments, from the start of spraying to the cessation of the landslide. These experiments showed: (1) Shear strains were heterogeneous in the sandy layer, larger strains were observed in the shallow layer than deep layer in some parts, but different in other parts. Landslide initiation was not always taking place where the shear strains were large; (2) Landslide initiated where a water table was formed, seepage forces due to subsurface water movement were in downslope direction, and the maximum shear strain was also in general agreement with the downslope direction; (3) Landslide fluidisation caused by undrained rapid loading underwent three stages: compaction of the sand layer by the sliding mass from upper slope, generation of excess pore-water pressure in saturated zone, and induction of fast shearing; (4) Fluidisation at the collapse source area also underwent three stages: destruction and compaction of sand layer skeleton by outbreak of shearing; increase of pore-water pressure in saturated zone; and shift to high-speed shearing, these three stages take place almost simultaneously.

Also an experiment to induce a fluidised landslide by artificial rainfall was conducted on a natural slope at Mt. Kaba-san, Yamato village, Ibaraki prefecture, Japan. The experimental slope was 30 m long, 5 m wide, and the average slope gradient was 33 degrees. A landslide initiated 24627.5 seconds (410 minutes 27.5 seconds) after the commencement of sprinkling at a rainfall intensity of 78 mm hr^{-1}. The landslide mass was 14 m long and 1.3 m deep (at maximum). It first slid, then fluidised and changed into a debris flow. The travel distance was up to 50 m in 17 seconds. An equivalent friction angle of the fluidised landslide was 16.7 degrees. Formation of sliding surface was detected by soil-strain probes. Motion of the surface of the failed landslide mass was determined by stereo photogrammetry.

Keywords. Landslide fluidisation, pore-water pressure, sliding surface formation, stereo photogrammetry

1. Introduction

Fluidised landslides, which travel long distances at high speed, are one of the most dangerous types of landslides (Sassa 2000). Fluidised slope movement takes place both in artificial cut slopes and natural slopes and often results in extensive property damage and significant loss of life (Sassa 1984, 1998). Many fluidised landslides have been observed in Japan, some of them have caused great disasters.

A debris flow that occurred in 1996 in Gamahara-zawa, Nagano prefecture, Japan, is an example of fluidised landslide. The debris flow was triggered by the collapse at around 1 300 m in altitude, moved approximately 39 000 m^3 of soil, of which 8 000 m^3 was deposited around the foot of the landslide and 31 000 m^3 travel down a slope 16.4 degrees in mean inclination along a river for about 3 km. The debris flow eroded another 37 000 m^3 of soil, of which 15 000 m^3 was captured by a check dam. As a result, approximately 53 000 m^3 of soil reached the alluvial fan, which is 300 m in altitude, and 14 people were killed (Committee Investigation for Gamahara-zawa Debris Flow Damage on December 6, 1997). As the soil-volume balance shows, the debris flow expanded the volume while traveling down the slope by gathering up river-bed sediment, and almost doubled in the amount of soil. Sassa (1998) called this phenomenon a landslide-induced debris flow. The fludisation of the river-bed sediment was caused by the rapid loading of the landslide mass and expanded moving mass lead to the further fluidisation of the lower part which increased the volume.

Liquefaction is an important mechanism in causing the fluidised motion of some landslides, where fluidisation occurs along a sliding surface or within a sliding zone, after a rise in the pore-water pressure which reduces shear resistance by decreasing the effective normal stress. Bishop (1973) noted that fluidisation can be distinguished from general sliding, which usually has an intact soil mass above the sliding surface. Hutchinson (1986) noted that flow-like motion subsequent to fluidisation is a neglected and little-understood group of movements with confusing terminology. Liquefaction phenomenon as a cyclic loading have received much attention from many researchers since the drastic effects of liquefaction were noted after the 1964 Niigata earthquake Japan. Seed and Lee (1966), Seed (1979), Ishihara (1993) discuss extensive laboratory soil tests attempting to reveal the liquefaction mechanism. Effects such as rainfall, as well as motion effects, can trigger fluidised landslides (Eckersley 1985, 1990; Sassa et al. 2004).

In order to reproduce a fluidised landslide and to investigate its fluidisation mechanisms, the landslide experiment on a natural slope was conducted by sprinkling, in which natural slope has a more complex and heterogeneous characteristics than the indoor models. A focus was placed on the sliding surface formation, hydrological characteristics, dynamic movements of the soil surface. The experimental slope was 30 m long and 5 m wide, and mainly covered by weathered disintegrated granite sand. Soil-surface movements were monitored by using stereo photogrammetry. Hence white-coloured targets were placed on the experimental slopes and the movements of these targets were traced by image analysis. To detect the formation of the sliding surface, soil-strain probes were inserted into the soil to 2 m depth at deepest. Tensiometers were used to measure changes in pore-water pressures within the soil.

2. Large-scale Indoor Experiments

A large-scale indoor model-slope (Fig. 1) was 1 m wide, 1 m high, and 9 m long consisting of two slope sections (steep slope of 32 degrees and gentle slope of 10 degrees). In the tests, positive and negative pore-water pressures and strains in the sand layer were carefully monitored to examine the relationship between sandy water conditions and strains followed by the landslide initiation. The sample used was the river sand. The density of sand grains (ρ_s) was 2620 kg m^{-3}, the mean diameter (D_{50}) was 0.50 mm, the uniformity coefficient (U_c) was 4.31, the coefficient of curvature (U_c’) was 0.93. Since it is impossible to show all of the test results having been conducted, results of the test with 0.7 m deep layer of river sand at the rainfall intensity of 100 mm hr^{-1} are introduced.

Fig. 1 Model-slope before collapse

The first shallow (about 0.25 m deep) landslide occurred around the lower part of the steep slope portion 4 000 seconds after the commencement of sprinkling. And then the second deep landslide was triggered at 4 001 seconds around the whole steep slope portion because the sand layer at lower part failed resulting in the loss of strength. From about 500 seconds before the first landslide, water table started to form around the lower half of steep slope portion. After that, the water table was extended to upper half of gentle slope section until the first landslide. The water table was also formed at the horizontal section. When a wetting front moved downward after the commencement of sprinkling, the equi-potential lines should be almost horizontal. However, when the water table was formed, the equi-potential lines were curved such that they normally intersected the bottom surface of model-slope, in which the subsurface water in the deep sand layer tended to move parallel to the bottom surface of model-slope. As the water table extended, the equi-potential lines were curved and the subsurface water were subject to flow in a downslope direction in 4 - 8 m lengthwise portion which is in agreement with the direction of landslide initiation. On the other hand, the equi-potential lines in gentle slope section did not change much irrespective of the water table formation.

Strains were calculated by tracing the markers embedded in the sand layer. Assuming the plane strain conditions, shear strain, normal strains can be calculated based on the infinitesimal deformation theory as following:

$$\Delta V_i = \frac{\partial V}{\partial v} \times V_i + \frac{\partial V}{\partial h} \times H_i \text{ , } \Delta H_i = \frac{\partial H}{\partial v} \times V_i + \frac{\partial H}{\partial h} \times H_i$$

in which $\frac{1}{2}\gamma_{hv} = -\frac{1}{2}\left(\frac{\partial H}{\partial v} + \frac{\partial V}{\partial h}\right)$, $\varepsilon_v = -\frac{\partial V}{\partial v}$, $\varepsilon_h = -\frac{\partial H}{\partial h}$

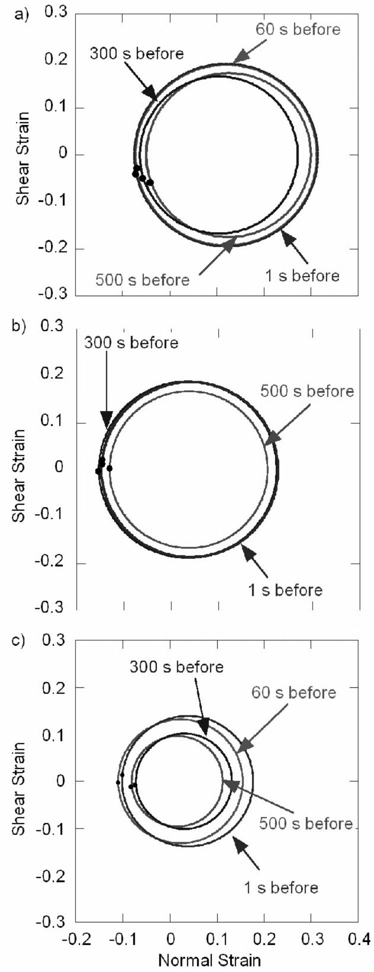


Fig. 2 Changes in strains at 6.5 m position. a) shallow, b) middle, and c) deep layer

Since a head scarp of the first landslide appeared at around 6 m lengthwise position, strains at 5.5 and 6.5 m position are examined in the form of Mohr’s strain circles at 500, 300, 60 and 1 second before the first landslide: a) shallow part; b) middle part; c) deep part. At 6.5 m lengthwise position, the shear strains ($\gamma_{hv}/2$) were negative in shallow layer, and almost zero below the middle parts (Fig. 2, as shown by black dots). The size of Mohr’s circles in shallow layer and middle layer were almost the same. Whereas, the Mohr’s circles in deep layer were smaller than the others, the strains in deep layer were smaller. Regarding the strains at 5.5 m lengthwise position, although the shear strains in shallow layer were almost zero, those bellow the middle layers remained positive. The size of Mohr’s circles became larger from shallow to deep layers, indicative that the strains increased in the vertical direction at 5.5 m lengthwise position. These proved that the strains in the sand layer were not homogeneous before the first landslide. Comparing the size of Mohr's circles at 5.5 and 6.5 m lengthwise positions, those of shallow and middle layers at 6.5 m were larger than 5.5 m positions, indicating the strains were, in general, larger at 6.5 m position than 5.5 m position. However the first landslide occurred at 5.5 m position but not at 6.5 m position. This could be related to the direction of strain conditions.

The close analyses on pore-water pressure behaviours and the soil movements during the fluidisation showed:

- Fluidisation that is caused by undrained sudden loading of landslide mass undergoes three stages: compaction of the sand layer by the collapse, generation of excess pore-water pressure in saturated soil sections, and induction of rapid shearing.
- Pore-water pressure increases more rapidly in saturated area than in unsaturated through rapid compaction. This is mainly because the void between sand particles absorbs a volumetric shrinkage in unsaturated conditions.
- Sections that suffered excessive pore-water pressure showed a positive correlation between the thickness of the overlying sand and pore-water pressure. This is likely attributable to water pressure supporting the overlying load. This also means that a large-scale landslide reduces effective stress ratio on the shear plane, thus shows a gentle slope of compensation and long travel distance.

Also close analyses around the slip surface showed:

- The process of fluidisation in the collapse source progresses in three steps: the destruction of sand particle skeleton and volumetric compaction with shear, rise in pore-water pressure, and rapid shearing around the slip surface, these steps occurred almost simultaneously.
- With conversion to high speed shearing, the velocity gradient from slip surface to sandy layer surface arises, and the sand layer thickness decreases.
- In high-speed shearing area at the collapse source, pressure head greatly did not rise, as it exceeded the sand layer thickness. This seems to be because that decreasing of thickness and disturbing of sand layer by high-speed shearing do not maintain the undrainage conditions.

3. Experiment on a Natural Slope

A natural slope in the Koido National Forest at Mt. Kaba-san, Yamato village, 25 km north of Tsukuba city, Ibaraki prefecture, Japan was selected for the controlled experiment on landslide and possible fluidisation in cooperation with the Forestry Agency of Japan. The selected portion of hillslope (Fig. 3) was 30 m long, with an average slope gradient of 33 degrees (maximum 35 degrees.) The soil was 1 to 3 metres deep. A 5 m wide experimental slope was isolated from its surroundings by driving thin steel plates about 1 m deep into the soil. These plates prevented lateral diffusion of infiltrated rain water and cut the lateral tree root network that imparts resistance within the soil layer. The surface of the slope was covered by straw matting to prevent surface erosion and promote rainfall infiltration. Surface material on the slope consisted of fine weathered disintegrated granite sand, called "Masa" in Japan. Loamy soil blanketed the upper portion of the regolith to a depth of about 1 m; this soil mainly originated from tephra of Mt. Fuji, Mt. Akagi, and other volcanoes west of Mt. Kaba-san. Artificial rain at the rate of 78 mm hr^{-1} was applied to the slope segment during the experiment by way of a rainfall simulator. The simulator consisted of a framework of steel pipes with 24 sprinkling nozzles arranged 2 m above the soil surface. Soil-surface movement was measured by means of stereo photogrammetry. To obtain information on the formation of sliding surface, soil-strain probes were inserted into the soil. To measure saturation conditions within the soil, tensiometers with porous ceramic cups were set into the slope. Tensiometer can measure negative pore-water pressure in unsaturated soils and positive pore-water pressure in saturated conditions.

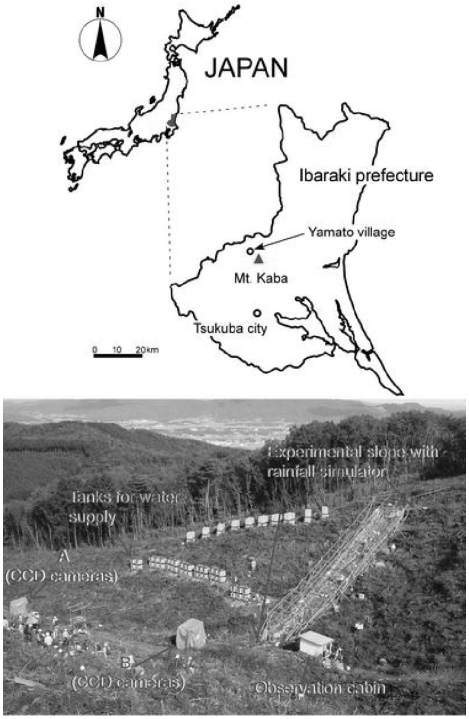
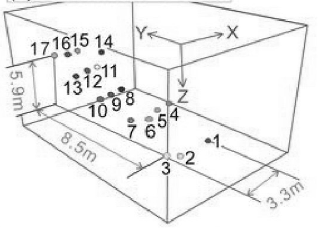


Fig. 3 View of experiment site at Mr. Kaba-san

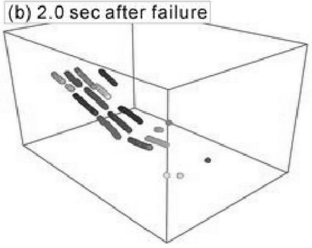
The experiment was conducted on 14 November 2003. Artificial rainfall was started from 9:13, the slope deformation was detected from around 15:00, then a clear movement was observed to start at 16:03. The initiated landslide was a type of an expected fluidised landslide, the landslide mass rapidly moved and traveled long. The cover of tensiometer started to incline downslope at 24 627.5 seconds (410 minutes 27.5 seconds) after sprinkling commenced. We interpret this as indicating that slope failure initiated at 24 627.5 seconds. As soil surface movement increased, a tension crack became visible at the head, and a compressive bulge resulting from downslope movement was observed 5 m above the base of the slope. The bulge enlarged before the main landslide mass began to undulate and rapidly enter the stream. The compressive bulge was observed only in the left part of the landslide. The failed landslide mass had entered the stream and was about to collide with the confronting slope. After collision, the fluidised landslide turned to the right, changed into a debris flow, and traveled downstream for 10 seconds on a less-than 10-degree gradient, as much as 30 m. It took about 17 seconds from the initiation of the landslide to the end of deposition.

Snapshots of the three-dimensional movements of the targets are shown in Fig. 4. Fig. 4a is 0.5 second before failure (24627 s), Fig. 4b is two seconds after failure (24629.5 s), and Fig. 4c is 3.5 seconds after failure (24631 s). Targets 6 and 7, located just above the foot of the landslide, followed curved paths, which could not have been determined by conventional displacement measurement using extensometers. Fig. 4 shows that the landslide mass overrode the slope around targets 2 and 3 and then moved rapidly into the stream at the foot of the experimental slope.

(a) 0.5 sec before failure



(b) 2.0 sec after failure



(c) 3.5 sec after failure

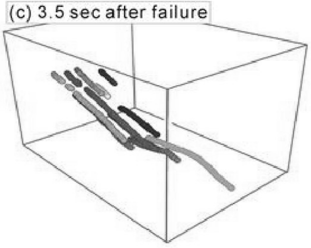


Fig. 4 Snapshots of the three-dimensional movements of the targets. a) 0.5 second before failure (24 627 s), b) 2 seconds after failure (24 929.5 s), and c) 3.5 seconds after failure (24 631 s).

When a sliding surface forms, soil above the sliding surface tends to move downslope, whereas soil below it remains stable. In this case, soil-strain gauge shows paired positive and negative values indicating sliding surface formation. At around the middle part of the landslide mass, the changes in strain gauges started to be observed around 1.15 m depth from about 300 minutes after the sprinkling. At around the lower part, the gradual changes in strain gauges were observed at 0.75 m depth from about 20 minutes. The changes in strain gauges were greatly accelerated from about 350 minutes after sprinkling began at both positions.

Pore-water pressure (0.5, 1.0, 1.5, 2.0, 2.5, and 2.9 m) at around the upper part of the landslide showed negative value at the start of the sprinkling, indicating that the soil at all depths were unsaturated or partly saturated. When the wetting front passed, the tensiometers showed increases in pore-water pressure in sequence of the depths. At 410 minutes, when the failure took place, all of the tensiometers showed positive pore-water pressures. The pore-water pressure of the deepest tensiometer (2.9 m) rapidly increased its values from about 290 minutes. This almost coincided with the time when the strain gauge at 1.1 m depth in the strain probe (middle part of the landslide) started to show strain. Hence, it can be deduced that general slope instability increased from 290 minutes, before final failure at 410 minutes.

Acknowledgments

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Threats of Glacial Lake Outburst Floods to Mountain Communities: A Hidden Scientific Truth

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Abstract. The Sabai Tsho glacial lake outburst flood, which occurred on 3rd September 1998 in the Mt. Everest region of Nepal, is one of the devastating events in GLOF history. This event is studied to understand the GLOF characteristics. The study found that the human and economic losses due to the Sabai Tsho GLOF are not necessarily caused by the released flow of water from the lake but significantly by the associated massive flow of sediment, which in the same scale, can be triggered by relatively small water discharge. Since a small-scale glacial lake outburst flow can cause huge damage to the locality, it is not necessarily important to identify dangerous lakes in terms of lake water volume. The study also found that the Inkhu River was eroded heavily in its upstream area during the GLOF, which once produced a large-scale debris flow with the maximum eroded depth of about 10 m. Erosion and deposition took place intermittently; however a huge amount of deposition exists about 14 km downstream from the lake mouth. The flood characteristics were greatly governed by river-bed slopes and hydraulic pooling due to the narrow valleys. Results were compared with satellite images, field observation and recorded data.

Keywords. Sabai Tsho Lake, moraine dam failure, flood attenuation, debris flow, disasters risk management, Himalaya

1. Background

Melting glaciers contribute to the development of glacial lakes, which may eventually burst due to a variety of reasons and cause enormous damage to the communities. Among different glacial hazards (Rechardson and Reyonlds, 2000; Kaab et al., 2006), Glacial Lake Outburst Floods (GLOFs) have been considered the largest and most extensive hazard in terms of disaster and damage (UNEP, 2007). Communities residing in the Himalayas as well as in the North American Rockies, European Alps, Tieh Shan, Pamirs, Caucasus Mountains and Andes are considered highly vulnerable to GLOF disasters (RGSL, 2003). The Sangwang-Cho GLOF event in 1954, which released 300 million cubic meters of water with a peak discharge of 10 000 m^3/sec and a 40-meter-high surge in the Nyang Qu River, damaged the city of Gyangze in Tibet about 120 km away (ICIMOD, 2008). In Peru, many worst events ever recorded in the GLOF history occurred in the Cordillera Blanca mountains, located in the heart of the tropical Andes. All together 30 major glacier disasters have killed nearly 30 000 people in this region since 1941 (Carey, 2007) and remarkably a single event claimed 20000 lives in the town of Yungay in 1971 (Lliboutry et al., 1977). The outbursts of the Zhangzangbo lake in 1981 and the Dig Tsho Lake in 1985, both in Nepal, were also among the most outrageous events not only in terms of human causalities but also in terms of economic damage, especially damage to the infrastructures, such as hydro-electric plants, bridges, roads and other public as well as private facilities (WWF, 2005).

There are very limited numbers of scientific reports on GLOFs. Discussions available are mostly on historical accounts of past events, satellite observation, damage assessment, early warning and control measures; few focus on the hydrodynamic characteristics and continuum mechanics of GLOF. Without sufficient knowledge on the GLOF mechanics, it is difficult to say how destructive GLOFs are and how they can be effectively prevented. Therefore, there is an urgent need for studies that have objectives to contribute to updating scientific norms and filling the current knowledge gap, especially to develop new approaches for GLOF disaster prevention and mitigation. This paper discusses on the mechanics of Sabai Tsho GLOF, which occurred in September 1998 in Nepal's Khumbu (Mt. Everest) region. It is hoped that the conclusions drawn from this study will be helpful to improve the understanding of GLOF and to formulate effective strategies for GLOF disaster mitigation and the sustainable development of mountain communities.

2. Study Area

The Sabai Tsho Glacial Lake, which is also known as Tam Pokhari, is situated at an altitude of 4420 m in the upper Hinku valley in the Solukhubu district, Nepal (Fig. 1). On 3rd September 1998, a moraine dam of the Sabai Tsho Glacial Lake breached. The kidney-shape Sabai Tsho Lake is 1 km long along the centerline and 350 m wide at the middle part of the lake. Landsat satellite images that were taken on 17 November 1992 and 17 February 2002 and field measurement suggest that the surface area of the lake has been reduced by 44% after the 1998 dam break event (Fig. 2). The total water volume discharged during the event was about 18x106 m^3, which was calculated based on the sink depth (50m) and the water surface area difference (Fig. 2 and 3).

A small stream named the Inkhu River originates from the lake mouth. The longitudinal bed profile of the Inkhu River is very irregular, and the average bed slope of the upper 7 km reach is less than that of the lower part. In average, Inkhu flows at an average slope of six degrees up to the confluence with the Dudh Koshi River, which is about 40 km downstream from the Sabai Tsho Lake. The watershed area of the Inkhu River at the Inkhu-Dudh Kosi confluence is about 316 km^2. Though river bed width varies throughout the reach, it is wider in upper 10 km than downstream. The river bed width of the upper Inkhu is mostly more than 150 m whereas the lower reach is narrow and in many parts less than 50 m.

3. Methodology

In this paper, three different physical processes associated with GLOF were analyzed, i.e. a) a moraine dam breach process, b) hydrological characteristics of GLOF, and c) debris flow.

A peak dam-break flow can be estimated using a simple dam-break equation (1) developed by the National Weather Service (NWS), USA (Wetmore and Fread, 1984).

$$Q_b = Q_o + 3.1B_r(C/(T_f + C/\sqrt{H}))^3 \qquad (1)$$

In equation 1, Q_b is a total flow, i.e. breach flow and non-breach flow (cfs), Q_o is non-breach flow (cfs), B_r is final average breach width (ft), C is a coefficient that can be calculated as C=23.4*A_s/B_r, A_s is a reservoir surface area (acre) at maximum pool level, H is selected failure depth (ft) above final breach elevation, T_f is time to failure (hrs). Since the dam breach shape, especially widths and height, is measured in the field, only the time of breach is necessary to be calculated. A statistically derived predictor (Eq. 2) for the time of dam failure developed by Froelich (1995) is used.

$$T_f = 0.59(V_s^{0.47})/(H^{0.91}) \qquad (2)$$

Where T_f is time of failure (hrs), only includes vertical erosion of dam, V_s is storage volume (ac-ft) and H is height (ft) of water over breach bottom.

The estimated peak flow can be used to compare with the hydrograph produced by the Hydrologic Engineering Center-River Analysis system (HEC-RAS) model developed by the HEC of the United States Army Corp of Engineers. In HEC-RAS, only an unknown parameter necessary for calculation is the full breached formation duration, which was calculated by eq. 2. The dam breach model in HEC-RAS was used in the overtopping failure mode, and therefore the geometry of the breached portion of the lake was also very critical in the calculation. HEC-RAS can perform full unsteady flow routing through the reservoir pool and downstream of the dam (U.S. Corps of Engineers, 2002).

The local topography was derived from the Advanced Land Observing Satellite's Panchromatic Remote-sensing Sensor (ALOS-PRISM) image provided by the Japan Aerospace Exploration Agency (JAXA). The ALOS-DEM data has 10 m spatial resolution with a relative accuracy of 5 m (RESTEC, 2008). The original longitudinal bed profile of the Inkhu River was derived from a DEM which was developed from a 1:25,000-scale topographical map made by the Survey Department of Nepal after the accomplishment of an airborne survey in 1996. The spatial resolution of the data is about 20 m with a permissible error of 6.25 m, i.e. a horizontal distance error in the contour.

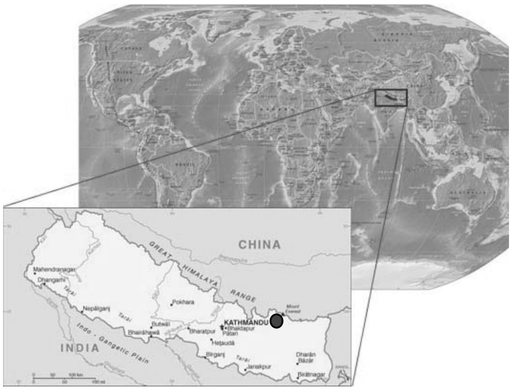

Fig 1. Location map of Sabai Tsho glacial lake, Inkhu watershed and damage situation after GLOF 1998.

A computer program HEC-RAS was used to perform one-dimensional, unsteady-flow calculation, providing dam breach hydrographs as an upstream boundary condition. The Inkhu River was divided into 11 river zones (1.7, 3.6, 4.5, 4.7, 2.6, 0.20, 4.9, 0.86, 6.4, 9.1 and 2.10 km) based on their drainage features, which helped not only improve the stability of unsteady flow simulations in HEC-RAS, but also calculate an outflow hydrograph at the end of each section which can be used as the upper boundary condition for the next run of simulation for its adjoining downstream section.

In order to simulate the debris flow, one-dimensional governing equations (Osti and Egashira, 2008) for the flow of sediment-water mixture are employed and the constitutive equations developed by Egashira et al. (1997) were used to solve the equations.

4. Results and Discussion

Based on the approximated lake water volume, the breach hydrographs (Fig. 4) was computed by using a HEC-RAS model. The NWS Simplified Dam Break Model based result suggests a peak discharge of about 10 000 m^3/sec, which fairly agrees with the HEC-RAS-produced breach hydrograph. The time required for the full formation of the breach was estimated at 45 minutes by equation 2, which was used as the full breach formation time in HEC-RAS computation.

Fig 2. Landsat-Thematic Mapper and Enhanced Thematic Mapper Plus satellite images of the area taken before and after the Tam Pokhari GLOF event

An outflow hydrograph at the end of each river zone was calculated, and three of them are plotted in Figure 4. The hydrodynamic routing procedure has translated an upstream hydrograph into a subsequent downstream hydrograph, and attenuated the peak of the hydrograph to account for hydraulic pooling and storage in the channel. The peak flow at 25 km from the lake mouth is found to be almost half of the peak of the dam breach hydrograph. These remarkable changes in flow characteristics were basically caused by hydraulic pooling at very narrow intermittent cross sections. The GLOF depth ranged from 5 to 15 m with an exceptional depth of up to 30 m at some points.

However, these findings so far discussed were not the cases. The Sabai Tsho GLOF was dominated by a massive flow of sediment that was developed mainly after the flood water eroded the river bed material. In upper river reach up to 14 km, bed erosion was active with some intermittent depositions and the river bed slope configuration was significantly changed. Therefore the channel conveyance capacity was increased, and at the same time, the effect of hydraulic pooling was minimized. Erosion and deposition took place intermittently and a large flux of sediment passed through the river channel (Fig. 5). The calculated debris flow velocity indicates a much higher rate of up to 18 m/sec in comparison to 6 m/sec for the water-only flow case. When water and sediment flow together, the sediment acts as a means of transportation for water. A sediment hydrograph calculated at 12 km shows a peak of about 6,000 m^3/sec, and the total sediment supplied at this cross section was estimated at 480 000 m^3 (Fig. 5). A huge amount of sediment was deposited in the river reach between 14 and 14.5 km with an estimated deposition of 400 000 m^3 (Fig. 6), which assumingly contributed to the reduction of the peak discharge of sediment-water mixture as well as the total supplied sediment volume in the downstream cross sections. It has been found that the peak discharge of the sediment and water mixture at the 14.4 km section was about 30 000 m^3/sec, which is about six times larger than the water-only flow.

The trend of GLOF occurrence in the Nepalese Himalayas indicates that GLOF was very active in the 1960s and 1980s. In most cases, GLOFs occurred in the months of July-September (Yamada, 1998), high temperature and an intensive monsoon rain season in the region. Although it is not clear that how influential monsoon rain on GLOF events, studies are yet to be carried out to unveil the relationship.

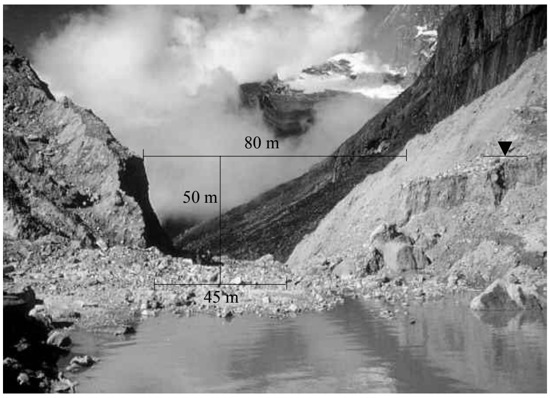

Fig. 3. Breached portion of moraine dam at Sabai Tsho.glacial lake

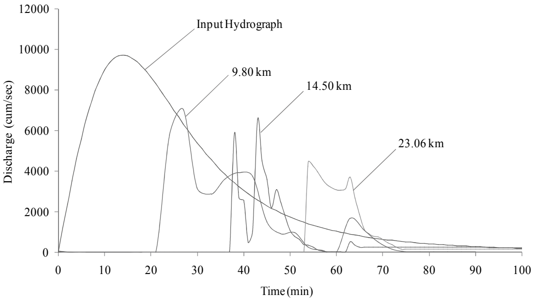

Fig. 4 Calculated hydrographs at the lake mouth and at different river stations

There are some current monitoring practices in which researchers are trying to identify potentially dangerous lakes based on the a)conditions of moraine dams, b)size of lakes, and c)topographical features around lakes (Yamada, 1998, ICIMOD, 2002), aiming to prevent and mitigate GLOF disasters in a long run. However the research results presented in this paper clearly show that such GLOF disaster management strategies are yet to be revised because even a very small lake can cause a huge disaster and a very large lake may not always cause much harm. On the other hand, glacial-lake formation/disappearance (not necessarily bursts) processes are very dynamic (Quincey et. al., 2007). A new lake can emerge in a totally new area and cause a catastrophic disaster in the near future. A mountainous area, which at present is not considered GLOF-prone, could be identified as a highly prone in the near future or vice versa. Before the Sabai Tsho GLOF event, the lake was not listed as a dangerous lake while the Dudh Kunda Lake in the same river basin was defined as most dangerous (Yamada, 1998). There is a very high uncertainty in such predictions. This leads to an idea that the GLOF disaster management should focus more on the topographical, geological, glaciological, environmental, other geo-hazards, socio-economic settings of the area. Moreover, there is a difficult question whether to invest huge amount of money in structural measures to safeguard moraine dams and to lower the water levels of all glacial lakes unless these lakes are of other importance. Instead of dangerous lakes, priority should be given to the identification of GLOF-sensitive areas or regions considering their local topography, geology and socio-economic settings along with general features of glacial lakes and potential GLOF extension. Effective planning and the mitigation of GLOF impacts in a long run require further detailed scientific studies.

Conclusions

Along with the increasing severity of climate change, glacial lake outburst floods are becoming a serious threat to the mountain societies. In order to understand the GLOF development processes and therefore to mitigate effectively the GLOF disaster risks in the long run, the fundamental studies especially the GLOF mechanics are prerequisite. A case study on the 1998 Sabai Tsho Glacial Lake outburst flood in Nepal explains that the size and scale of GLOF are less influenced by the amount of water released from the lake but greatly governed by the amount of unstable sediment distributed throughout the river reach. Moreover, the formation and disappearance of glacial lakes is a dynamic process, and therefore it is more relevant to identify GLOF-prone areas based on local topography, geology, glaciology, environmental, other geo-hazards and socio-economic conditions of the locality. The regular monitoring of GLOF-prone areas along with that of glacial lakes and their spatial and temporal variations should be carried out to prepare better for GLOF disaster risk mitigation in a long run. Regular monitoring is also required to budget unstable sediment that is potential for erosion. Structural/non-structural or hardware/software countermeasures for GLOF disaster mitigation should be planned with great care by considering above mentioned factors.

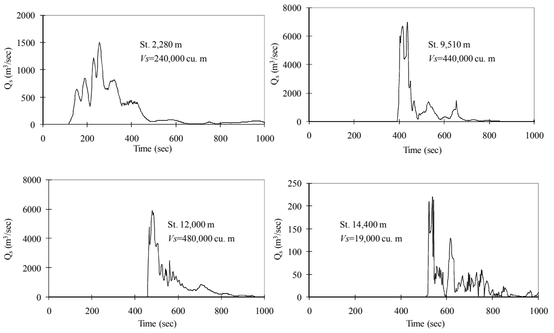

Fig. 5 Calculated sediment hydrographs at different control points

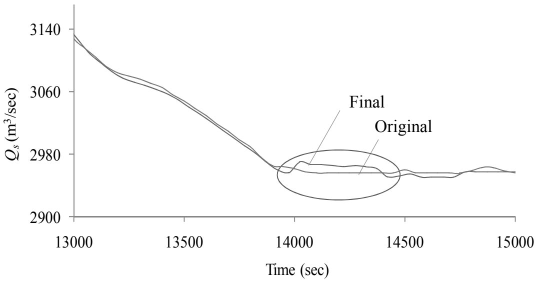

Fig. 6 Original and final bed profiles of Inkhu river showing heavy deposition in between 14 to 14.5 km

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Connecting Diverse Landslide Inventories for Improved Landslide Information in Australia

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Abstract. The evolution of the Australian Landslide Database (ALD) was driven by the need for a nationally consistent system of data collection in order to develop a sound knowledge base on landslide hazard and inform landslide mitigation strategies. The use of 'networked service-oriented interoperability' to connect disparate landslide inventories into a single 'virtual' national database, promotes a culture of working together and sharing data to ensure landslide information is easily accessible and discoverable to those who need it.

The ALD overcomes obstacles that traditionally hamper efforts of exchanging data, such as variations in data format and levels of detail, to establish the foundation for a very powerful and extensible coordinated landslide resource in Australia. Such a resource synthesises the capabilities of specific single-purpose inventories and provides a suitable basis for further investment in data collection and analysis.

The approach is centred upon a 'common data model' that addresses aspects of landslides captured by different agencies. The methodology brings four distinct components together: a landslide application schema; a landslide domain model; web service implementations and a user interface.

The successful implementation of these components is demonstrated in connecting three physically separate and unique landslide event databases via the web. This allows users to simultaneously search and query remote databases in real time and view data consistently. The ALD is now a joint initiative across local, state and national levels with all levels contributing to a national picture. At implementation, this approach resulted in an immediate 70 per cent increase in the total number of landslide events reported nationally.

The interoperable approach establishes a platform to support improved landslide risk assessments and informed mitigation decisions through its ability to collate and characterise large volumes of information. In using a common data modelling methodology the landslide domain model provides the capacity to extend the approach across other natural hazard databases, and also to integrate data from other domains. A key example is the potential to directly link the landslides model with the international 'GeoSciML' geosciences data model for geology.

Keywords. Landslides, common data model, interoperability, inventory database, standards, national approach, distributed search, Australia.

1. Policy toward a co-ordinated approach in Australia

In 2001 the Council of Australian Governments (COAG) commissioned a review to identify the strengths and weaknesses of arrangements for managing natural disasters in Australia. Their review into disaster relief and mitigation identified the need for a co-ordinated and more comprehensive approach to natural disaster management. It also advocated a fundamental shift in focus beyond relief and recovery towards cost-effective and evidence-based disaster mitigation (COAG 2004). The COAG review specifically highlighted the need to establish a nationally consistent system of data collection, research and analysis across all three levels of Australian government for a greater understanding of natural disasters and disaster mitigation. Such a reform in data collection requires new, innovative approaches in both the governance and the science of natural disaster management and requires consideration of both 'top-down' and 'bottom-up' approaches for implementation.

Geoscience Australia instigated the Landslide Database Interoperability Project (LDIP) in 2005 as a pilot study to demonstrate that networked service-oriented interoperability can play a pivotal role in the implementation of such a reform while also significantly increasing the functionality and usefulness of data.

2. Brief overview of interoperability and the LDIP

Interoperability is the ability for components of system to work together in a common way. It provides the means to link data, information and processing tools between different applications, regardless of their underlying software, hardware systems and geographic location. Interoperable databases, in this bottom-up context, can therefore be described as multiple data sources that exist in different locations and are owned by different agencies but can be accessed through a common web interface and present data using common semantics and terminology. Individual database custodians maintain full ownership, management and the original format of their data, as there is no need for additional configuration or functionality modification by custodians to enable interoperability.

Three unique landslide databases were selected as part of the interoperability pilot study. These included the national database managed by Geoscience Australia, a regional (state-wide) database managed by Mineral Resources Tasmania and a local database managed by the University of Wollongong. The landslide databases range in geographic scope and levels of detail. While common themes are apparent between databases the methods by which data are organised and described vary considerably.

The pilot sought to establish a common data service standard across the three agencies holding landslide inventories and was also explicitly designed to exercise and consolidate an emerging methodology for designing such data services.

3. The evolution of the ALD

The 'evolution of the ALD' describes the shift from a single organisation developing and maintaining a national database to a collaborative and shared approach. The ALD is now a 'virtual' landslide database, enabled via a web interface, which presents disparate information from three data providers at the same time in a consistent fashion. The ALD can be accessed from: www.ga.gov.au/hazards/landslides.

This initiative reflects a small part of a vision which is much greater for the way in which landslide and other natural hazard datasets in Australia could be managed. This vision is aligned with several stated visions of the INSPIRE initiative underway in the European Union, including that data should be collected once and maintained at the level where this can be done most effectively, it should be possible to combine spatial information and share it between many users and applications, and, it should be possible for information at one level to be shared between all different levels (INSPIRE, accessed 24 July 2008). This means that responsibility for developing and maintaining up-to-date information does not fall to a single organisation, but is a distributed and shared goal.

The evolution of the ALD was presented with a series of requirements that included:

1. Facilitate consistent data collection nationally, whilst acknowledging and incorporating existing data collection efforts.

2. Develop models and tools to support those collecting data and also those seeking to establish landslide databases.

3. Reduce resource requirements for the development, implementation and maintenance of databases in future.

4. Facilitate extensions to the database to allow for the capture of new or additional landslide detail.

5. Support the implementation of a range of alternative data formats.

6. Support linking the ALD to other separate, but related datasets to allow the query of relationships between landslide events with datasets such as earthquake occurrences, rainfall, soils, geomorphology and geology to aid susceptibility, hazard and risk assessments.

7. Consider broader objectives, including the type of landslide or other hazard information required in future, and how landslide databases might be later utilised or called upon to support these requirements.

8. Provide a data model within an 'all hazard' scope for capacity building across other natural hazard domains.

4. Overview of project methodology

The key enablers of the interoperable approach adopted by Geoscience Australia were the decisions to establish the system upon a common *conceptual data model* and adopt *common vocabularies* for key aspects of this data model. The project methodology needed to address a process of reaching agreement on the semantic content (i.e. model and vocabularies) and common data transfer formats capable of expressing this content.

In determining how landslide data is structured and expressed for the ALD as an application schema, it was necessary to synthesise many specific landslide models into one common 'rich' landslide model. The rich model identifies similar information described uniquely across a range of databases and draws out the common elements to label data consistently, implementing international standards where available, and using agreed vocabularies in lieu of international standards. For example the schema adopts the work of the International Association of Engineering Geology (IAEG), International Geotechnical Societies UNESCO Working Party on World Landslide Inventory (WP/WLI) and the International Union of Geological Sciences Working Group on Landslides (IUGS/WGL). Cruden and Varnes (1996) and recommendations of AGS (2007a; AGS, 2007b) were also incorporated. It is acknowledged that international developments or updated baseline modules may replace components of the application schema in future.

Adopting International Standards Organisation (ISO) Models

The ALD adopted a best practice codified by the International Standards Organisation (ISO). The core of the interoperability approach selected is a common *conceptual model* developed in Unified Modelling Language (UML). The adoption of these standards means the data model is established using a specific methodology, which in turn allows the automated production of implementation schemas which themselves follow standards that software vendors can support. Specialisation of the common model from this point for landslide inventory requirements was still needed; but it was significantly simpler than modelling the whole evidence-based observational process.

Adopting Open Geospatial Consortium (OGC) Models

Many databases, irrespective of subject matter, require the same type of information to be described (consider for example the expression of location, position, scale, dimensions etc.). These components are not specific to landslide databases, but generic to the way any spatial data is stored. Therefore, developments in geospatial standards were leveraged for the ALD through the adoption of the Open Geospatial Consortium (OGC) Observations and Measurements (O&M) model to provide a common pattern for describing evidence-based observations. This decision encapsulated much of the typical metadata scattered through different databases into a single, powerful component of the data model.

Customising the common data model for landslides

It was acknowledged that different parts of the model will be defined by different processes and communities, and that interoperability is required within the landslides domain and between landslide data and related information sources.

The methodology that emerged during this project refines the basic ISO approach by developing the model as clearly defined 'packages' which reflect this separation between landslide-specific concepts and potentially re-usable models for certain aspects. This allows for particular components to be addressed as separate modules or packages within a formal data model. For example, direct and indirect landslide cost and damage are described within the ALD, but it is acknowledged cost and damage are a requirement of many other natural hazard databases. Therefore, these components could be standardised internationally, as an available model component, and applied across all natural hazard domains or all other domains that deal with cost/loss and damage.

Where external standards exist for these packages they can be directly referenced. However some local definitions were created for interim solution purposes which can be replaced with a more fully modelled packages owned by the relevant communities of interest.

5. Landslides Model

The core of the Landslides Model is a summarised characterisation of an inventory record, linked to a rich model of landslip events using an 'observation based evidence pattern'. This means that a landslide can be linked to a history of landslip 'events' and at least one event is assumed for all landslides. This event can be linked to detailed information about the observation procedure, primary evidence and multi-media resources.

The Landslide Model provides for observations about landslip events, such as when, why and how much. It also provides for observations directly on the current state of the landslip such as the type of material involved, style of movement, and the state of landslide activity (active, suspended etc.) for example. Finally, it supports a class of observations which summarise the event history, through a series of procedures which may be standardised in the future.

The model is then implemented using an inventory record structure incorporating each characteristic that is desired to be searchable within the inventory through a user interface, as well as a rich chain of standardised observation records linked to these different aspects. Such a model turns out to be quite simple to implement and highly flexible.

The final sophistication proposed is to provide a basic pattern for linking between the landslide inventory and other application domains through a *contextual setting* object that can be populated with cross references to any information deemed relevant to the geospatial setting of the landslide.

6. Web services implementation

The use of the ISO data modelling approach allows the generation of Geographic Mark-up Language (GML) application schemas for XML base data transfer. Alternatives could have been created, but such ad-hoc approaches often create difficulties for wider adoption, and require the maintenance of a new set of specifications and also the creation of specialised software.

Requirements for ensuring compatibility with other databases and datasets dictated the use of Open Geospatial Consortium (OGC) Web Services, and in particular Web Feature Services (WFS) and Web Map Services (WMS). Web services expose functionality and data through the web and provide users with on demand access to spatial map data. An XML representation of data using GML is at the core of various web-service interfaces defined for access to geospatial data by OGC such as WFS. GML is an XML specification for spatial information.

An open-source implementation (Geoserver) was adopted for the pilot due to the availability of plug-in capabilities to support GML application schemas, and in particular the OGC O&M model, the most complex part of the model. Therefore, an advantage in using standard modelling methodology is that it allows the use of off-the-shelf model components and implementation technologies.

7. User interface

The user interface acts as a 'spatial index' of available landslide data and enables reporting, download and mapping functions. The availability of these functions demonstrates that interoperability between disparate landslide databases is achieved.

Three point-of-truth databases with different data models were mapped completely using a single web feature service and application schema and implemented using an IMF web mapping platform. A web-based application supports the query, mapping and reporting of national landslide data by seamlessly querying the three point-of-truth landslide databases (i.e. the 'virtual' national landslide database).

The interface is where landslide data from each host database is mapped to the common schema (i.e. the 'rich' model) and translated into the commonly agreed format. This process is what allows a user to view information from different databases in a consistent fashion.

8. Query and reporting functionality

Users are able to select the number of databases included in the query and have the option of executing a basic or advanced search. Users can define the spatial extent of their search in several ways; by drawing a bounding box, searching the map extent or selecting a predefined region. Queries can also be filtered to reduce the number of landslides returned. For example, filters currently include landslide ID, landslide date and also information related to landslide type (movement type and material class), cause (both human and natural contributing factors and trigger factors) and damage (such as number buildings damaged, buildings destroyed, fatalities, injuries, and type of direct and indirect damage). For example, this means a search can be defined to locate all debris slides or flows that occurred with a contributing factor of wave erosion within a certain timeframe.

The reporting functionality includes tabular and cross tabular reports which can be downloaded in a range of data formats. For numerical fields, a count is also displayed. Pre-defined queries were adopted for maps, reports and download and several pre-canned reports allow for quick reference to the most common reports required.

9. Advantages of adopting interoperability to users

The most important advantage of the interoperable approach adopted for users is the increased volume of information it enables. A range of additional benefits are also described.

- Provides an automatically updated single point of access to landslide information available, increasing the availability, accessibility and discoverability of data.

- Users are able to simultaneously search and query remote landslide inventories regardless of where they are hosted or how different are their spatial coverages, scales and data models.

- Data is accessed in real time, through live links. Therefore, data presented is as up-to-date as each of the host databases. This means that all new landslide events or updated details added by database custodians are available immediately.

- Data is presented consistently to users, enabling the comparison of data across databases, landslide characteristics or locations. This allows data to be compared and contrasted within a landslide domain.

- Detailed information can be accessed for detailed purposes (such as a single landslide event) or generic information can be accessed and aggregated for strategic purposes (in aggregating details for many landslide events), providing basic, intermediate and sophisticated levels of data.

- Drill down functionality means that all levels of government, geotechnical professionals, emergency managers, land use planners, academics and also the public are able to access different levels of information from the same source data.

- Removes the need to locate, access and interrogate isolated landslide databases or to separately identify and contact multiple individuals whenever information is needed.

- Overcomes technical difficulties to promote the sharing of data, and broadens the capabilities and usefulness of information captured at a range of different scales.

- Results can be displayed as reports, tables, maps and also potentially graphs and statistics and users can access multi-media such as photographs, videos, published papers, landslide risk management reports, site studies, sketches etc.

- Data can also be queried against datasets such as topography, geology, rainfall and geomorphology (this aspect was outside the scope of the pilot project).

- There is no limit to the number of landslide databases that can be linked into the ALD interface (the interface neither stores or records data).

- Enables more sophisticated client interaction and promotes a culture of coordinating, sharing, aggregating and making information available. It also strengthens relationships and enhances collaboration between scientists and decision makers.

- A series of next steps and tools are being developed at Geoscience Australia, which seek to reduce maintenance requirements and encourage landslide data capture.

Conclusions

Information management methodologies can play a powerful role in collating and characterising baseline information, and as such, provides one option for the implementation of data collection reforms outlined as part of the COAG review.

The LDIP provides an insight into the outcomes possible when agencies interact and work with one another and has demonstrated how disparate landslide inventories can be brought together to establish ‘virtual’ national consistency in data collection. In particular, the implementation of networked service-oriented interoperability provides a successful model for this and the leveraging of international standards has allowed useful and relevant exchange of information.

While a bottom-up approach is feasible for a small number of databases to display data in a consistent format in a pilot environment, it may present some challenges when being applied across many data sources. A top-down approach that encourages the use of standards in the establishment of new databases would be more favourable to interoperability on a greater scale, while also allowing for greater functionality and usefulness of landslide information.

A common data model approach has the potential to become the basis for the establishment of comprehensive ‘all hazard’ databases in Australia, and also provides a solid foundation for greater investment in data collection.

Collecting data once, maintaining it at the most effective level, and then sharing information across all levels and between different users and applications, would benefit not only the natural disaster community but other domains as well.

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Landslides, Livelihoods and Risk: Vulnerability and Decision-making in Central Nepal

Katie Oven・ David Petley・ Jonathan Rigg・ Christine Dunn・ Nick Rosser (Durham University, UK)

Abstract. The occurrence of fatal landslides in Nepal is increasing with time, faster than the effects of monsoonal variations. Possible explanations for the trends observed include land-use change, population growth, and civil war –each of which impacts on household and community vulnerability. In addition, the impact of climate change on monsoon intensity (which strongly controls landsliding) is poorly understood, raising questions regarding future vulnerability in Nepal. To address these issues, the research discussed in this paper takes an interdisciplinary, bottom-up approach to answer four questions: who is vulnerable to landslides; why do people occupy landslide prone areas; how is landslide risk perceived and understood in these locations; and, finally, how do people respond both immediately and in the long-term to landslide hazard and risk?

The findings highlight the impact of infrastructure projects in rural Nepal. Within the Upper Bhotekoshi Valley clear transitions in settlement patterns and rural livelihoods (and thus the occupation of landslide prone areas), have been seen over time. Households occupy hazard prone areas through lack of choice, as fixed assets bind them to a particular location; but also through choice to take advantage of a roadside location. Often, in these cases, households view their pressing, everyday concerns as far more immediate threats than comparatively infrequent landslides and debris flows. There were both natural and supra-natural explanations for the causes of landslide activity, with responses including risk denial/rejection, passive acceptance of risk, or taking action to reduce further losses.

Based on these findings, the second phase of the research explores how scientists and policy experts view landslide hazard and risk and how policy is subsequently informed and shaped. In doing so, this research challenges the traditional top-down, technocratic approach to disaster management and seeks to explore the ways in which local understanding can be developed and combined with outside specialist knowledge to increase household and community resilience.

Keywords. Nepal, landslide, hazard, risk perception and social vulnerability.

1. Introduction

The occurrence of fatal landslides in Nepal is increasing with time, faster than the effects of monsoon variations (Petley *et al.* 2007). This trend has been variously attributed to the effects of population growth and urbanisation; land-use change; infrastructure development beyond the capacity of the slopes; and the effects of (anthropogenic) climate change, which may be changing rainfall patterns and intensities. However, there is little quantitative evidence to support these postulated causes and, indeed, very little research into the nature of vulnerability to landslides in the Nepalese context. Thus, this paper seeks to address the following questions: who is vulnerable to landslides; why do people occupy landslide prone areas; how is landslide risk perceived and understood in these locations; and, finally, how do people respond both immediately and in the long-term to landslide hazard and risk? The implications of these findings are subsequently discussed with a view to developing effective policy and practice for landslide risk reduction.

2. Study Sites

The research has been conducted in the Upper Bhote Koshi Valley, Sindhupalchok District, in the Central Development Region of Nepal. The catchment is drained by the Upper Sunkoshi River and its main tributary, the Bhote Koshi River. The Upper Bhote Koshi Valley forms the route of the main Arniko Highway to Tibet and is characterised by a complex tectonic sequence of steeply dipping quartzite, phyllite and schist formations. These are overlaid with highly weathered colluvial and alluvial deposits. Large, often creeping, deep seated translational slides are common, in addition to extensive gully erosion above and below the road particularly during the monsoon season. In addition, the main central thrust (MCT) zone,

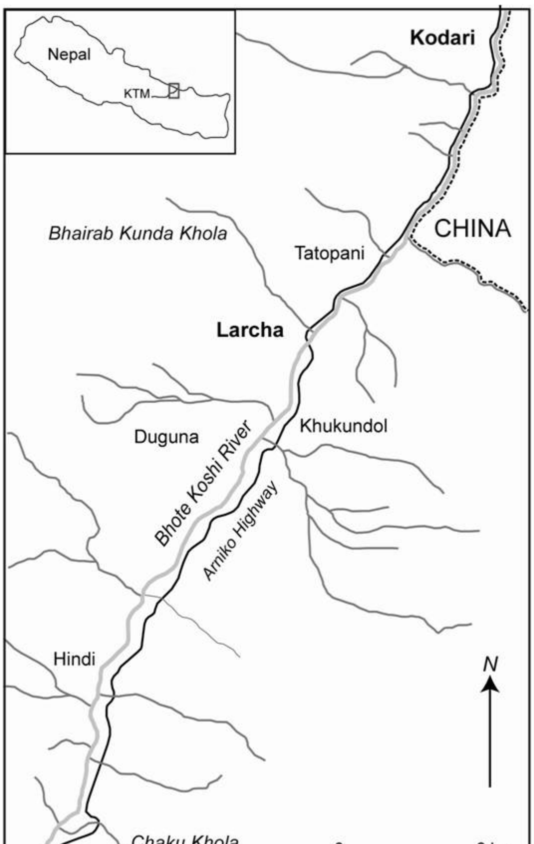

Fig. 1 The Upper Bhote Koshi Valley, Sindhupalchok District, Central Nepal.

which marks the boundary between the Lesser and Higher Himalaya, traverses the valley. This broad zone of disturbance is characterised by highly fractured material, with high susceptibility to rock falls and slides. The study focuses on a 10 km stretch of highway where a number of landslide prone settlements have been identified. These include the three case study settlements of Chaku, Larcha and Kodari (fig. 1).

Chaku is at risk from imminent, catastrophic slope failure from an active translational slide. Five houses were destroyed here following a landslide in June 2001 caused by heavy and prolonged monsoon rainfall. The remaining four brick houses at the foot of the slope and a single house on the crown remain occupied despite evidence of continued slope movement. This is a complex slide, with successive failures retrogressing up the slope, putting a wider area and more houses at risk.

The settlement of Larcha is located at the confluence of the Bhairab Kunda Stream and the Bhote Koshi River, in the base of a steep sided gorge. Larcha is at risk from landslide dam-break flood events and debris flow hazards. On the 22 July 1996, a channelised debris flow killed 54 people and destroyed 16 houses, 150 m of highway, a highway bridge and agricultural land. A combination of rainfall, runoff and stream undercutting triggered the slope failure ~500 m upstream of the settlement. The landslide debris dammed the channel of the Bhairab Kunda Stream and was subsequently breached, inundating the village of Larcha.

The settlement of Kodari was destroyed approximately 60 years ago by a landslide and was subsequently rebuilt. The slope (~500 m wide) failed catastrophically again in 1981 following a flood and incision by the Bhote Koshi River destroying 15 houses, a post office and farmland. The houses and farmland were subsequently abandoned with the displaced population resettled by the government onto adjacent public land. Construction on the slope began approximately five years ago, with the family originally displaced constructing houses to let but continuous incision by the Bhote Koshi maintains the activity of the slope.

3. Conceptual frameworks

The vulnerability paradigm evolved out of the social sciences and was introduced as a response to the purely hazard-orientated approach that dominated disaster thinking in the 1970s (O'Keefe et al. 1976). Cutter (2006) identified three distinct themes in vulnerability research. These are:

1. Vulnerability as a pre-existing human condition
   The focus here is on the distribution of landslide hazard, the human occupancy of the hazardous zone and the degree of loss associated with a particular landslide event or series of events.
2. Vulnerability as a social response
   This perspective highlights the social construction of vulnerability and its root causes here focusing upon what makes individuals, households and communities vulnerable to landslides. Consideration is also given to the coping capacity and resilience of the exposed population.
3. Vulnerability as hazard of place
   Here, vulnerability is conceived as both a physical risk from landslide activity as well as a social response within a specific geographic domain.

The aim of this study is to move beyond a simple exposure assessment in an attempt to develop understanding of the causal linkages associated with landslide vulnerability in the Nepal Himalaya. As noted by Alexander (2005) much is now known about landslide hazards, but landslide vulnerability remains a more elusive concept as it depends upon complex patterns of decision-making and behaviour. With this in mind, Cutter's (2006) 'hazards of place model' of vulnerability has provided the conceptual framework for this study.

4. Methodology

In the research presented here, a livelihoods based approach is adopted which focuses on the social aspects of vulnerability. To investigate the vulnerability of rural communities it is necessary to gather data on landslide occurrence and susceptibility, exposure, response capabilities and mitigation. The field research began with a geomorphological assessment of landslides along the highway and within the case study villages. Baseline surveys were subsequently conducted in each case study village to determine who occupies the landslide prone areas and a 'snowball sampling' method adopted to select information-rich cases for more in-depth analysis. Household surveys were conducted with the aim of gaining an appreciation of the underlying dynamics of the household. In order to address the issues of risk perception and response, a participatory based approach was adopted involving qualitative engagement with communities. This involved in-depth semi-structured interviews, oral histories, and participatory mapping sessions.

5. Research outcomes

Who is vulnerable to landslides?

The settlements of Chaku, Larcha and Kodari are predominantly settled by Tamang and Sherpa (hill tribe) groups (58% of the sample households) interspersed with high caste Chhetri and Newar households (32%), low/occupational caste households (8%), and a household of the Bhaun-Chhetri terai caste (2%). These findings reflect the historical settlement pattern in Sindhupalchok District. The Tamang were amongst the early settlers (their arrival dating back to the eighteenth century) followed much later by the Chhetri and Newar peoples from the Kathmandu Valley who claimed and cleared forest land for agriculture and engaged in the salt trade. The 'exposed' households were found to be both relatively rich and relatively poor. However, and perhaps surprisingly, there appears to be no strong correlation between poverty level and caste/ethnic grouping. These findings suggest that landslide prone areas are not always occupied by the 'most-marginalised' groups (i.e. the destitute, low caste households) as anecdotal evidence would suggest.

Why do people occupy landslide prone areas?

Households were seen to occupy landslide prone areas through limited/no choice, whereby their assets tie them to a particular place (a process largely reflecting age-old land-tenure systems which favoured the high castes); or through choice to take advantage of a roadside location, whereby the economic/livelihood advantages outweigh the risks associated with landslide activity (box 1). While traditionally people have made provision for environmental hazards in terms of settlement layout, inhabiting the more stable ridge tops and cultivating the more fertile land on the flat valley floor, the construction of the roads in the valley bottom is leading to outmigration in the hill area and resettlement by the road. Such migration has been observed in the Upper Bhote Koshi Valley following the construction of the Arniko Highway in the 1960s. Here, roadside land has be purchased, leased or, in some cases, illegally encroached upon, resulting in the expansion of settlements in the valley bottom where the landslide hazard is most acute.

Box 1. Case Studies

No choice

Case Study: A relatively poor Tamang household in Chaku

The family house is located above an active translational slide. The head of the household was born in the village and inherited land. They own their house but their farmland was swept away by a landslide approximately five years ago. The husband and wife sharecrop land belonging to a wealthy Chaku landlord, keeping half the crops grown. Their only direct source of cash income is from the husband's day wage labour in the nearby stone quarry. There is clear evidence of slope movement with cracks appearing in the house and the surrounding terraced farmland moving down slope. However, while they are aware of the risk of landslide activity they cannot afford to move. Their house is their only asset and it ties them to their location.

Choice

Case Study: A middle income Sherpa household in Larcha.

The household migrated to the roadside to take advantage of the business opportunities. They purchased the land in Larcha just before the 1996 debris flow disaster and constructed their house approximately one month after the event. While the head of the household is concerned that a debris flow may recur, the land is now worth very little due to the risk of debris flow activity. The family could return to their hill village but the livelihood and economic opportunities are better at the roadside.

Risk perception

Two overarching themes have emerged with regard to indigenous people's perceptions of risks from landslides: a natural/scientific and a supra-natural understanding of landslide hazard and risk. In general, local people are aware that they live in a landslide prone environment and make clear links between steep slopes, heavy monsoon rainfall and landslide activity. Links were also made between deforestation, the quarrying of slate and, in some cases, road construction and mass movement. These findings are likely to reflect the strong social-environmental interaction inherent in mountain communities. However, roadside migration is also exposing people to unfamiliar hazards different from those in the high hills (for example debris flows). In some cases households were found to be unaware of the risk of landslide/debris flow activity in their new location (reflecting the absence of inter-generational knowledge on past landslide activity) and did not recognise the warning signs associated with an unfamiliar hazard. This was a particular issue for the residents of Larcha and Kodari.

Supra-natural explanations based on Hindu and Buddhist mythology were also given. In this context, landslides were viewed as the work of the deities or gods who reside in the mountains and trigger landslides when angered by the sinful acts of the community and the disrespect of the natural environment. However, supra-natural understanding does not go unquestioned by the sample households but equally the ideas are not totally dismissed. This reflects everyday life in Nepal which is traditionally interwoven with religion. Supra-natural explanations were seen to emerge when there was no obvious physical trigger for a landslide or when the events are deemed beyond the control of the community.

In general, the sample households were seen to attach only minimal importance to landslide risk. Instead, they were found to have more pressing everyday livelihood concerns which were viewed as far more immediate threats than relatively infrequent landslide and debris flow events. Frequently cited examples include a good, reliable income; education for the children; and access to medical treatment.

Risk response

Responses to landslide risk at the individual and household level were seen to broadly fit the behaviour patterns of Burton et al (1993). These can be categorised into 'no action' (reflecting risk denial/rejection and the passive acceptance of risk) and 'taking action to reduce loss'. For some people doing nothing is driven by a lack of awareness of the hazard; for others it is indicative of powerlessness; while for others it is a positive decision to 'do nothing' having considered the alternatives. For example, what at first appeared to be 'risky actions' (for example, constructing a house on government land at the bottom of a steep, unstable slope prone to failure), were in fact well thought out with underlying reasons. These households were often adopting 'risk-averse strategies' but these were undertaken in the context of the everyday risks they face (Blaikie et al. 2002) rather than in the context of geological hazards.

Only a limited number of households within the case study communities were seen to take action to reduce loss and these were the households with the capacity to do so. Examples include the construction of protective gabion walls and the migration of a family to Kathmandu during the monsoon months. Instead, the case study households largely considered landslides to be beyond their control. They do, however, believe the government could provide external control and do something to lessen the impact. Frequently cited examples include the construction of gabion walls and check dams.

6. Discussion: landslide policy and practice

The research briefly summarised here highlights the changing geography of risk in the Upper Bhote Koshi Valley. For some households their occupation of landslide prone areas is historically contingent reflecting age old land-tenure systems and agricultural feudalism. However, for the majority of case study households their decision was driven by the road which has undoubtedly influenced livelihood trajectories and brought about social change. Reflecting upon these findings we must now turn our attention towards policy and practice with a view to increasing the resilience of communities to landslides.

When roads are constructed and access is given, the process of outmigration and roadside resettlement is inevitable. The Government of Nepal states clearly in the country's Tenth Development Plan (National Planning Commission 2002) that temporary and permanent settlements around major highways are illegal. However, while this legislation has not been enforced along the Arniko Highway, little is being done by the government or the multi- and bilateral agencies funding the road construction projects to increase the resilience of the exposed populations. While road construction may be enhancing certain livelihood elements (for example, access to water, health care and education), leaving people vulnerable to landslide hazards can be seen to undermine development objectives. With many communities still isolated, the main objective of the Tenth Plan (National Planning Commission 2002) is to further expand the road network through the construction of national and regional highways and major roads at local level. It is therefore a logical step for future road design to take into account migration and roadside settlements.

Understanding what makes people vulnerable to landslides and how exposed communities and households perceive the risks they face are first steps towards effective disaster risk reduction. To achieve this we must step away from the top-down, technocratic approach to hazard and disaster management and consider the role of human agency and alternative framings of risk. For the exposed communities themselves these risks are largely concerned with human security, everyday needs and wellbeing. From the context of the outside scientist what may appear to be 'risky actions' are often, in fact, 'risk-averse' strategies. This does not mean that we should negate the management of landslides but rather that we should look towards devising interventions which reduce landslide risk whilst meeting the basic needs of the exposed populations.

At present, the level of understanding of the landslide risk system appears to be more advanced than society's ability to translate this information into risk reduction systems (Glade and Crozier 2004) particularly in the developing country context. Possible risk reduction strategies for resource poor rural areas identified by participants in a recent workshop on landslide risk reduction and resilience building in Nepal[1] include: improvements in risk communication; hazard zoning the road corridor to encourage settlements to develop in lower risk areas; the construction of feeder roads in 'safer' areas which enable communities to benefit from access to the road without being at risk from complete annihilation; the establishment of effective land-use policy which addresses landslide hazard and enhances livelihoods. However, these suggestions raise a series of questions regarding risk perception and the acceptability of risk, the targeting of already scarce resources and the governance of disaster risk reduction. Nepal has, after all, recently emerged from a decade long civil war characterised by political instability and poor governance.

7. Conclusion

Whilst landslide activity is strongly controlled by monsoon intensity, in recent years the number of fatalities has increased dramatically over and above the effects of the monsoon cycle. A number of suggestions have been postulated, including population growth, land use change and the development of transport infrastructure. However, with little evidence to support these causes a bottom-up approach has been undertaken to better understand social vulnerability in the Nepalese context.

Within the case study area of the Upper Bhote Koshi Valley, a clear transition has been seen over time in the settlement pattern, rural livelihoods and thus the occupation of landslide prone areas. Households were seen to occupy landslide prone sites through lack of choice as their fixed assets tied them to a particular location; or to take advantage of a roadside location. There was both scientific and supra-natural reasoning attributed as causes of landslide activity, with responses broadly reflecting Burton et al's (1993) behaviour patterns.

Building upon these findings, we now need to turn our attention towards policy and practice with a view to increasing the resilience of communities to landslide activity. This presents a significant challenge given the future uncertainty associated with climate change and the unknown impact this will have on monsoon intensity. In addition, with the continued investment into the expansion of the road network in Nepal, it is hoped that this research will help to target resources and improve the identification of areas and individuals at risk from the effects of landslides. In order to do this successfully we need to recognise alternative framings of risk and devise interventions which not only reduce landslide risk but also meet the basic needs of vulnerable populations. This will require the engagement of all stakeholders (including the vulnerable communities themselves) as set out in Nepal's National Strategy for Disaster Risk Management (UNDP Nepal 2008). Such an approach is essential to ensure the sustainable management of risk. Only then will we begin to reduce the vulnerability of rural communities to landslides in Central Nepal.

Acknowledgements

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[1] The workshop, organised by the International Landslide Centre, Durham University, involved five stakeholder groups working within the field of road construction, landslide mitigation and management and disaster risk reduction. These included: government ministries/departments; technical specialists (geologists/engineers), livelihood and development specialists, multilateral agencies and NGOs.

Giant Low-gradient Landslides in the Northern Periphery of the Crimean Mountains: Predisposition, Structure, Chronology and Links to Adjacent Regions

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Abstract. The Crimean Mountains (CM) are among the regions with the highest concentration of slope deformations within Europe. Geomorphic analysis (field mapping, study of remote sensing products and GIS analysis) of the CM has detected extraordinarily large landslides in the northern periphery of the mountains which are build by gently inclined Sarmatian limestones overlying weak, clay-rich Lower Neogene-Palaeogene substratum with a significant content of smectite.

Giant instabilities can be classified as fossil or almost stabilized features. Radiocarbon dating of deposits associated with the landslides has revealed at least two phases of increased landslide activity during the Late Glacial chronozone and Holocene epoch. The main landslide phase presumably took place some time between the Late Glacial and Atlantic chronozones (~11-6 ka BP). Minor reactivation of landslide toes occurred during the Subatlantic chronozone (1-2 ka BP) and some of them have been active up to recent times. Ongoing investigation in Southeastern Europe has revealed even larger fossil low-gradient megalandslides which originated in lithologically simmilar settings.

Keywords. Low-gradient landslides, cuesta topography, clay-rich substratum, Holocene

1. Problematics of giant low-gradient landslides

The problematics of extremely large slope deformations is nowadays among the most important branches of landslides investigation (Korup et al. 2007). A special group of extremely large slope deformations involves landslides occurring in “subcritical” relief on gently inclined slopes. Some of the well-known largest slope deformations in the world originated in relatively low-lying relief with gently inclined slopes (Philip and Ritz 1999). This category of slope instabilities belongs to the less explored, nonetheless, it usually brings great palaeoenvironmental and palaeogeomorphological record. Slope deformations evolving in non-typical topography usually indicate anomalies inside the rock mass or extraordinary intensity of triggering factors which have caused their genesis.

The term giant low-gradient landslide does not represent a genetic category and has not been delimited in any of commonly used classifications of slope processes (e.g. Dikau et al. 1996). Movement mechanism of these phenomena usually involves the whole spectrum of defined failures such as lateral spreading, toppling, rotational and translational landslides and even rapid flowslides. However, from the point of view of their size and specific topographic setting low-gradient landslides can be considered as an autonomous category of geodynamic events.

The presented article deals with extraordinarily large landslides that were identified in the northern periphery of the Crimean Mountains (Ukraine) (Pánek et al. 2008) (Fig. 1). The aim of the study is to contribute to the age, mechanism and palaeoenvironmental significance of these slope failures.

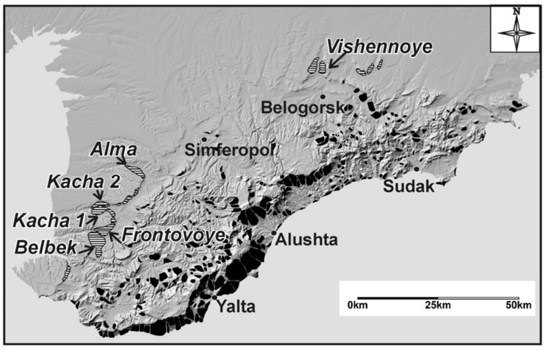

Fig. 1 Location of giant low-gradient landslides (hatched areas) and other landslides (black areas) in the Crimean Mountains (Ukraine)

2. Occurrence and preconditions of giant landslides

At least 5 large (mostly fossil) landslides (0.2 – 1.2 km^3 and 5.4-18.9 km^2) and several other smaller features have been detected by geomorphic mapping, GIS analysis and observation of satellite images in the northern domain of the CM (Fig. 1). This low-lying area is built by relatively weak tertiary sediments (claystones, sandstones and limestones) that have been neotectonically uplifted and northward-tilted to form cuesta-like ridges. Structural and mineralogical analysis revealed great predisposition of rocks to slope instabilities. Headscarp areas are associated with the presence of regionally important faults. Clay-rich sediments (claystones, marls and mudstones), forming substratum for landslides, contain up to ~40% of smectite, which is an important bedrock-weakening agent due to its swelling/shrinking mechanism nature.

3. Mechanism and age of landslides

Morphological analysis and observations of numerous outcrops within the landslide bodies revealed complex behaviour of sliding. Up to ~100 m high and several km (max. 6 km) long headscarps (Fig. 2) with slightly arcuate planform and undulating surface of landslide accumulations with < 50 m high blocks indicate predominantly rotational-translational sliding as the main landslide mechanism.

Some natural and artificial outcrops provided excellent opportunities for the study of the internal structure and age constraints of sliding activity. An abandoned quarry situated across the Alma landslide shows a section through elongated landslide elevation and adjacent flat depression infilled with post-landslide deposits that consist of redeposited colluvial-loess mixture (Fig. 3). The section reveals that the topography was more rugged after the landslide event. Buried steep front of the elevation within the landslide body has a well-developed colluvial wedge of angular limestone blocks (up to 0.5 m in a-axis), which points to rapid genesis of the landslide and subsequent dynamic processes acting on barren and rugged landslide body. Similar wedges of angular clasts of the thickness up to 0.5 m have been observed also in other outcrops cutting accumulations of landslides. Radiocarbon dating of organic remnants deposited directly above the colluvial wedges varies in the Alma landslide between 5-6 ka BP. This time period (Atlantic) is thus considered as minimal age of the landslide. Outcrops in the frontal parts of the landslides show contractional deformations with folded buried soils (Alma) and deformed loess and river terraces deposits (Belbek). Deformed soils in the frontal part of the Alma landslide have been dated to 1-2 ka BP, which is a clear proof of Neoholocene reactivation of the landslide toe.

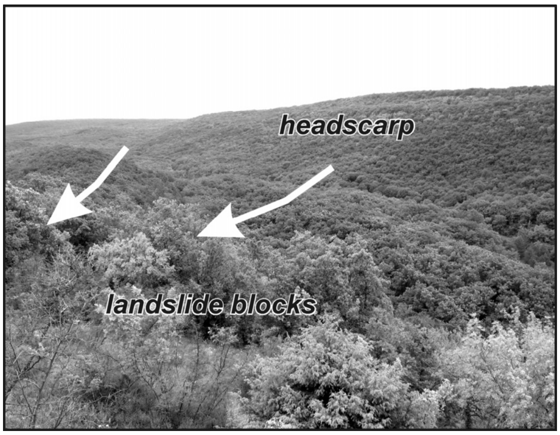

Fig. 2 An example of ~6 km long and 100 m high headscarp of the Belbek landslide

Beside sliding, we assume that part of the morphology of the studied slope deformations evolved as slow movements such as lateral spreading and toppling which are still contemporarily active (verified e.g. by tensional cracks on houses situated on landslide bodies).

4. Giant low-gradient landslides in adjacent areas

Preliminary recognition supported by GIS, DEM and remote sensing analyses revealed other locations of giant landslides in the peripheries of mountains in the eastern sector of European Alpides (namely Transylvanian Plateau in Romania, Stara Planina in Bulgaria and northern periphery of the Caucasus in Russia). All of them affect weak (usually Neogene) post-orogenic deposits which were tilted by Plio-Quaternary tectonics. The most extraordinary event is Armavir palaeolandslide (Russia), which is almost 100 km^2 in area and ~5-10 km^3 by volume and belongs to the largest recognized landslides in Europe.

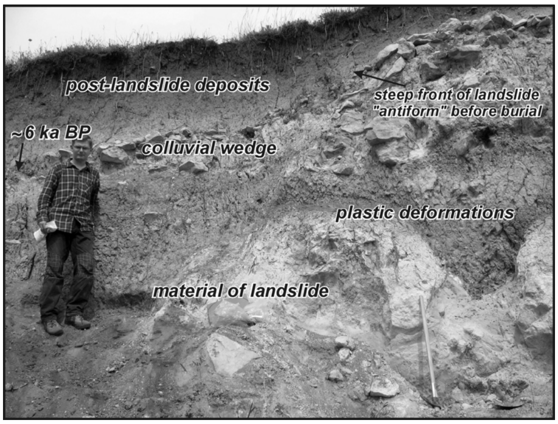

Fig. 3 Some elements of internal structure of Alma landslide

Conclusions

Giant landslides with gently inclined shear surfaces are common features in the margins of tectonically active mountains. They are result of the adjustment of generally weak post-orogenic (foredeep) deposits to topographic changes associated with neotectonic uplift and re-incision of valleys along margins of orogens. The studied deformations in the Crimean Mountains evolved likely in a more humid period between the Late Glacial and Atlantic chronozones and may indicate a major palaeoearthquake event. Fossil giant landslides in low-lying settings are important palaeoenvironmental indicators and their detailed study in Eastern and Southeastern Europe is contemporarily in the focus of the authors of this study.

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The Effects of Wildfires on Erosion and Debris-flow Generation in Mediterranean Climatic Areas: a First Database

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Wildfires are inevitable in many countries of the world, where burned watersheds are known as being among the more susceptible sites to flooding and debris flows. Fast-moving, highly destructive debris flows are particularly hazardous because they can occur with little warning, can damage structures and endanger human life (Iverson 1997).

Wildland fires are the most destructive disturbance of the natural lands in Mediterranean ecosystems. Mediterranean landscapes have always been subjected to fire, and burning has been part of their dynamic natural equilibrium (Figures 1 and 2). However, recent changes in land-use patterns in the Mediterranean basin have resulted in the reduction or abandonment of traditional activities such as grazing or agricultural practices which have kept fuel accumulations and the subsequent fire danger, and thus erosion, at a minimum. With these changes, the potential for significant erosion and debris flows has significantly increased. In southern California, expansion into fire-prone ecosystems has resulted in increased exposure to potential debris-flow hazards (Chourre and Wright 2005).

Wildfire can have profound effects on the hydrologic response of watersheds, and debris-flow activity is among the most destructive consequences of these effects (Figure 1), often causing extensive damage to human infrastructure (Cannon & Gartner, 2005). The effects produced by wildfires on hillslopes in terms of development of erosional processes (Fig. 2) and occurrence of debris flows have been object of studies for several decades, and this research experienced a strong impulse in the last 15 years.

These studies vary in scale, intensity, and frequency in very different natural settings, from alpine territories, to Mediterranean ecosystems, to semi-arid lands. The continued high likelihood of catastrophic wildfires in Mediterranean climates (Fig. 3) has created the need to develop methods to identify and quantify potential erosion and debris-flow hazards from burned watersheds. Following an analogous compilation of data related to the erosive response of recently burned basins in the Western United States by the United States Geological Survey (USGS; Gartner et al., 2005), we present here a first database dealing with the erosional effects of wildfires in the Mediterranean basin. To date, scientific literature on the topic in Europe has not been catalogued, and is dispersed in a number of different journals and in conference proceedings. Even though most of the literature available on the Mediterranean countries deals with studies on experimental plots rather than analysis of post-wildfire landsliding and erosional events (as it is common, on the other hand, in the US literature), nevertheless the catalogue and analysis of these studies may provide preliminary information about the responses of recently burned watersheds in typically Mediterranean climates and environmental settings.

Fig. 1 - Deposits left by debris flows following the Old and Grand Prix Fires in the fall of 2003 and rainstorm on December 25, 2003 in southern California.

Fig 2 - Cucamonga Canyon hillslopes (southern California) burned by the Old and Grand Prix Fires of November, 2003.

Studies made in the last decades have shown that the response of burned watersheds to rainfall may be extremely variable depending both on a number of on-site conditions as well as storm rainfall duration and intensity characteristics. The factors that have been found to most strongly affect the debris-flow response can be specific to different settings. For example, debris-flow triggering storms in intermountain west USA were exclusively convective thunderstorms, or short-duration, high-intensity rainfall (Cannon et al. 2008). In contrast, frontal storms of long duration, with relatively low intensities, have triggered debris flows in southern California. Further, the great majority of basins in the intermountain west had not burned, and thus not experienced a significant sediment-removal event, in hundreds of years. Southern California, on the other hand, experiences frequent fires and subsequent flood and debris-flow activity. These differences point to the need to develop models for debris-flow susceptibility specific to southern California, Mediterranean ecosystem conditions.

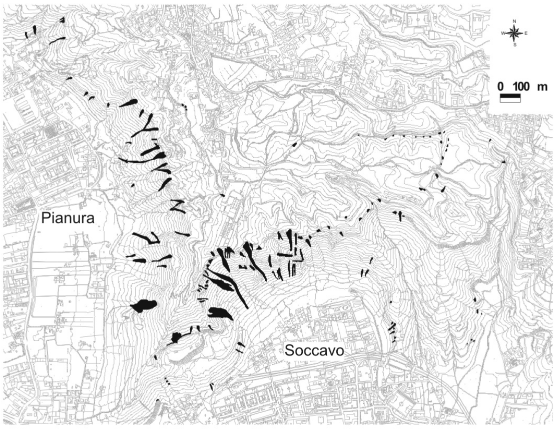

Fig. 3 - Location of landslides that occurred on the Camaldoli Hill (Naples, southern Italy) between 1996 and 2006. The Soccavo slope, in particular, was affected by wildfires several times during the last 10 years, the most severe event occurring on August 1, 2001 (after Calcaterra et al. 2007b).

The purpose of this paper is to assemble a database of known debris-flow events in Mediterranean ecosystems that will lead to the development of tools and methods that can be used for the prediction of post-wildfire debris-flow activity and hazard delineation. The database can be used to compare and contrast processes and conditions for debris-flow occurrence in different Mediterranean ecosystems. This will lead to a better identification of the processes that lead to post-fire debris flows and of the threshold rainfall intensity-duration conditions that indicate the potential for debris flows. In addition, the data will be used to identify those factors that most strongly affect the debris-flow response in different settings, and to develop stochastic models for debris-flow probability and volume as a function of basin morphology, material properties, burn severity distribution and event-triggering rainfall.

Debris flows following wildfires have been observed to initiate from three different processes: i) failure of discrete landslides on hillslopes (Meyer et al. 2001); ii) progressive bulking of runoff with sediment eroded from hillslopes and channels (Meyer & Wells 1997; Cannon et al. 2001); iii) a combination of the two processes above (Cannon 2001; Cannon et al. 2001). Runoff-dominated process, rather than infiltration-triggered landslides, has been shown to most frequently generate debris flows following wildfires (Cannon & Gartner 2005). Generation of debris flows from discrete landslide failures occurs, on the other hand, in response to prolonged periods of storm rainfall, usually of a day or more in duration, or prolonged rainfall in combination with rapid snowmelt.

This paper presents a compilation of data on the erosive response, debris-flow initiation processes, basin morphology, wildfire severity, rainfall characters, rock type in the Mediterranean basin. Data were compiled from the available scientific literature. Due to gaps in the information available, not all the above parameters are characterized for all sites. Differently from the analoguous compilation by Gartner and co-workers (2005) on 608 basins recently burned by 53 fires located throughout the Western United States of America, most of the data presented here were collected from experimental plots rather than wildfire-impacted watersheds. The examined literature reported data on about one hundred sites in the Mediterranean basin, distributed as shown in figure 4.

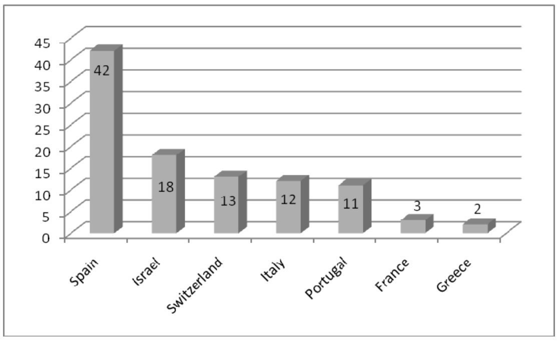

Fig. 4 - Geographical distribution of study sites on erosion and debris flows in recently burned areas in the Mediterranean basin (data from compilation from available literature).

Within the framework of projects devoted to evaluation of debris-flow hazards in recently burned areas carried out by the United States Geological Survey (USGS), with the co-operation of the Italian National Research Council (CNR), the main purpose of this compilation is to contribute in providing a single resource for future studies addressing problems associated with wildfire-related erosion and debris flows in the Mediterranean area. Further, this database, together with that one previously cited (Gartner et al. 2005) may allow comparison among the situations observed in the Mediterranean and in the Western United States of America, particularly for those areas with similar climatic settings, such as southern California.

In addition to providing a resource for researchers, land managers and civil protection departments interested in examining relations between the runoff response of recently burned basins and their morphology, burn severity, soils and rock type, and triggering rainfall, the database also illustrates the importance of erosional and debris-flow processes in areas affected by wildfires, a topic that only recently has gained attention in many Mediterranean countries.

Data reported in the database were extracted from the literature, without any additional analysis to ascertain or compute other parameters such as basin morphology characteristics. Thus, the database has to be considered as a preliminary data collection, subject to further updating and addition of more detailed information.

Studies on recently burned areas in the Mediterranean basin were generally carried out on small experimental plots, and often with simulated rainfall. This represents with no doubt a problem when trying to compare the outcomes from such studies with those from wide, intensely burned, areas. The problem of scale is definitely important, given the limited extesion of most of the experimental plots.

The geographical distribution shows a clear prevalence of research carried out in the western Mediterranean basin (Spain, essentially, but also Portugal), followed by the eastern Mediterranean area (Israel). Further studies developed in alpine environments, in Switzerland as well as in sectors of Italy and France. Some research was also published in southern Italy and Greece. In several cases, the same experimental plots, or other nearby along the same slopes, were analyzed over a period of several years and discussed in multiple articles.

Due to great variability in the study methods, in the scale, and depending upon the amount and type of analysis performed, the results shown in the database can be expressed in several ways, from erosion rate, to soil losses or sediment yield, to erosion threshold (in terms of rain, runoff yield, or sediment yield). Even though comparison of the results is not always immediate, the outcomes may offer a first idea of the amount of potential sediment removal after wildfires, and the overall susceptibility to erosional and debris-flow processes in burned areas.

Most reported sediment yields from the Mediterranean basin following wildfire were between 0.2 and 1172 g/sqm, and erosion rates between 0.7 and 1029.9 g/sqm/yr. Terry (1994) reports sediment yields of 3039 g/sqm and erosion rate of 4146.7 g/sqm/yr, by far the largest in the database. These hillslope- and plot-scale measurements are comparable to those reported in southern California studies (e.g. Doehring 1968; Neary et al. 2005). Very few debris flows or floods of significant magnitude were reported in the Mediterranean ecosystem, while widespread flooding and debris flows are the dominant response to rainfall on recently burned slopes in southern California. The different response may be due to occurrence of less severe fires in the Mediterranean basin, varying rainfall conditions, or possible differences in watershed morphology. Additional data is necessary to definitively evaluate this issue. .

The few reported cases of debris flows in the Mediterranean basin describe erosion of sediments from the hillslopes and the channels (sometimes down to bedrock), and, for a limited number of sites, failure of discrete landslides. This information indicates that debris-flow generation from recently burned areas in the Mediterranean basin appears to occur primarily through sediment bulking processes.

Most of the material in post-fire debris flows in southern California has been documented to be eroded from throughout the channel network (Santi et al. 2008), and channel yield rates are generally significantly higher than erosion rates reported from hillslope- or plot-scale measurements (D. Martin, U.S. Geological Survey, personal communication, 2008). However, no channel yield rates were reported for the Mediterranean basin.

Reported rainfall rates that lead to increased runoff and erosion from burned areas also vary between the Mediterranean basin and the western U.S. Conedera et al. (2003) report 91 mm of rain in 1 hour (rainfall record for the pluviometric station), that caused flooding and debris flows in the Riale Buffaga catchment in Switzerland. Such values are well above the threshold rainfall value defined by Moody & Martin (2001) as resulting in significant runoff response from recently burned basins (10 mm/h for 30 min), and the threshold value proposed by Cannon et al. (2003a, b) for increased sediment movement (20 mm/h for 30 min).

Acknowledgments

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Preliminary Approach for a Nation-wide Regional Landslide Early Warning System in South Korea

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Abstract. Many vulnerable steep slopes exist in South Korea causing continuous disasters and human casualties every year. The seriousness of steep-slope related natural disasters is increasing due to the urbanization and reckless development in and near hilly terrains. Also, scattered small size landslide disasters are attributed to the increased rainfall intensity due to climate change in Korea.

Therefore, it is necessary to provide a system that can be utilized for landslide disaster information collection and issuing early warnings to the local people. This paper describes a system, which is currently under development for landslide early warning and slope disaster information compilation in Korea.

Based on the relationship between rainfall data and previous landslides, the feasibility of early warning is examined for a test site. The system includes a pilot sub-system for landslide disaster inventory management and, to support local officials for early warning and evacuation practice, a real-time data display module for decision-making process is also included.

Finally, this paper reviews most suitable, applicable, and practical methods how to select and divide regions or areas for local governments' warning coverage considering administrational boundaries or river basins in Korea.

Keywords. Landslide, early warning, rainfall data, evacuation practice

1. Introduction

The frequency of landslide occurrence in Korea is increasing due to concentrated rainfalls during June and September every year. One of the governing factors triggering landslide is rainfall in Korea as in other areas in the world. The severity of slope-stability related disasters among other natural disasters is shown in Table 1. About 27% of the total deaths by various natural disasters are due to slope-stability related disasters such as steep slope failures in man-made cut slopes and landslides in natural terrain.

Since it is not always easy to find vulnerable slopes, an early warning system for landslide in local communities, which have previous landslide damage history, is found to be one of the practical countermeasures against landslide-related disasters.

In Korea, landslide disasters have been managed by general or other laws and regulations such as the Natural Disaster Countermeasures Act, the Mountain Area Management Act, etc. These laws and regulations, however, focus on specific purposes, not on landslide disasters. To cope with landslide disasters more efficiently and systematically, the Steep Slope Disaster Prevention Act has been proposed (Park et al., 2007a) and implemented since July 2008. To support this Act in the central government level, it is necessary to develop and provide various subsystems for geotechnical data compilation, slope inspection, early warning, and etc.

Table 1. Death by natural and landslide disasters in Korea from 1999 to September 2008

Year	by Natural Disaster	by Slope-stability related Disaster	Ratio (%)
Total	801	217	27.1
Average	89	21.7	
1999	89	32	36.0
2000	49	12	24.5
2001	82	9	11.0
2002	270	79	29.3
2003	148	37	25.0
2004	14	3	21.4
2005	52	11	21.2
2006	62	22	35.5
2007	23	4	17.4
2008	12	8	66.7

To minimize human loss using early warning systems for landslide disasters, quantification of stability of a target area followed by risk analysis will be needed. To analyze the landslide risks, classification and selection of basins based on the surface water behavior model is necessary for practical warning coverage.

This paper reviews feasibility of early warning system based on the relationship between landslide occurrence and rainfall data, proposes a method to issue a practical early warning, and introduces data management system currently under development for a test site.

2. Test Site for a Feasibility Study

A test site was selected for feasibility study in Inje County, Gangwon Province (Fig. 1), where a massive landslides disaster happened in 2006. There are several stages before issuing an early warning for landslide disasters. A regional mapping based on geomorphology and geology is necessary. Geo-statistical analysis is applied in the test site considering various affecting factors such as administrative boundaries and river basin as shown in Table 2.

To select proper warning boundaries, factors including shape of river basin, moisture index, fissures, bedrock type, etc. are compared with administrative boundaries. Based on the results proper warning boundaries selected and three tipping bucket rainfall stations in the test site were established. Real-time rainfall data are collected from the stations and analyzed to find characteristics of the rainfall and compared to previous landslide-triggering rainfalls.

Fig. 1 Landslide disaster warning system by the National Emergency Management Agency

Table 2. Factors for determination of early warning coverage for landslide disasters

Natural Factor	Geo-morphology	Mountain, River, Elevation, Gradation, Azimuth, Moisture, Area of Upper Slope, etc.
	Geology	Fissure, Petrology, Weathering Index and Direction, etc.
Social Factor	Regional and Local Administrative Boundaries	
Coverage	Regional	30m×30m, 200m×200m Precision
	Local	10m×10m Precision

3. Landslide Early Warning Coverage and Risk Analysis

In general, the spatial distribution of a rainfall is not uniform. It is important, therefore, to understand and predict rainfall characteristics for more meaningful landslide early warning. Three rainfall stations in the test site are equipped with tipping bucket rainfall gauges and they only represent point rainfalls. To predict spatial distribution using point data, upscale processes are required. Then, predicted spatial distribution of rainfall needs to be compared with actual rainfall distribution measured by radar or other weather stations.

Using inverse-distance squared method and kriging method, Curtis and Clyde (1999) compared point data to radar rainfall measurement, which is assumed to be the actual rainfall distribution. For the test site in Inje County measured rainfall data from three stations, which were established for the landslide early-warning feasibility study by the National Emergency Management Agency in 2008, were compared with those from nine other weather stations operated by the Korea Meteorological Administration to calculate relative precision using inverse-distance squared method (Smith, 1993) and kriging method (Kitanidis, 1997).

The relative precision of rainfall distribution for the test sites measured by three rainfall stations is shown in Fig. 2. It is found that, before issuing an early warning using point rainfall data, spatial uncertainty and variation need to be considered.

To analyze landslide risks and develop risk mapping method for the test site, five geomorphologic factors were used as shown in Fig. 3. The factors are moisture index, contributing area, curvature, gradation, and azimuth. Frequency analyses were performed on these factors to generate a masking map, where only important values for decision-making are displayed. Fig. 4 shows one of the examples with 30m grid.

The landslide risks for the test site are calculated with different combination of these factors. One of the promising outputs was generated by the combination of moisture index and contributing area added by the results of curvature multiplied by gradation and azimuth as shown in Fig. 5. The units of axes are kilometers and the vertical bar with range from 0 to 18 indicates relative instability. The green dots represent residential areas whereas red dots represent previous landslides in the test site.

It is found that most of previous landslides have occurred end of mountain slopes in this test site represented by blue dots or shades, even though this risk mapping process tends to exaggerate the landslide risks in general.

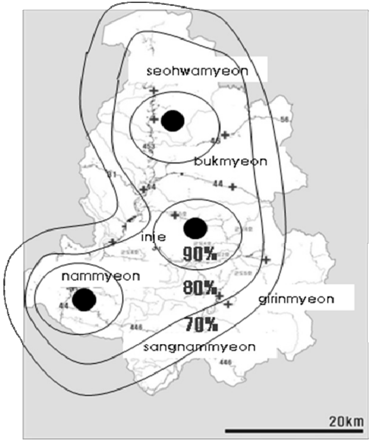


Fig. 2 Precision analysis on spatial distribution of rainfall in the test site

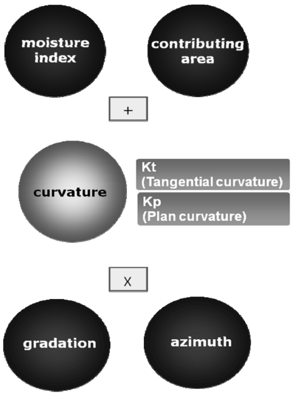


Fig. 3 Concept of risk mapping process for disasters in steep slopes

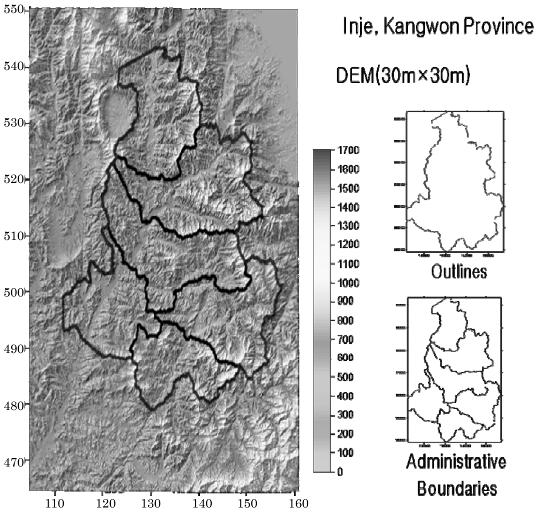


Fig. 4 DEM of a test site in Inje County, Gangwon Province in Korea

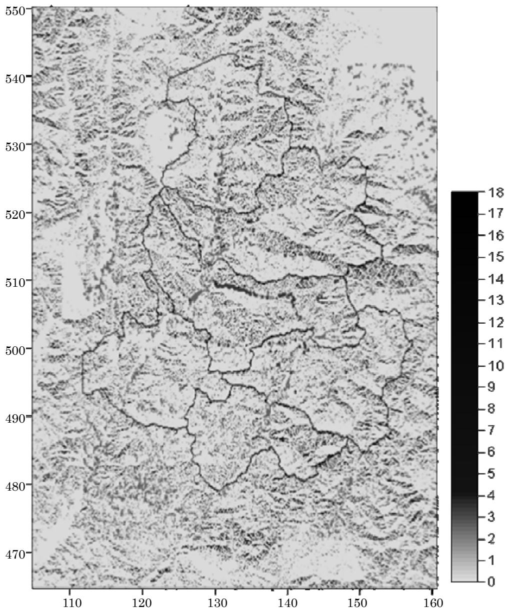


Fig. 5 Landslide risk mapping in a test site with residential area and previous landslides

The exaggerated displays are due to elimination of other affecting factors on landslide occurrence such as vegetation, geological setting, artificial or man-made structures, and etc. The general location of landslide risk areas determined in this analysis coincides with those of actual landslides.

4. Rainfall Data Compilation and Analysis System

For issuing an early warning against landslide disaster, it is crucial to develop a stable data management system with capacity of real-time data transmission capacity. The main system, which is being developed by the National Emergency Management Agency, is composed of three field loggers in the test site, data transmission devices, and a central database and analysis computer as shown in Fig. 6 schematically.

The analysis system is based on provincial-level index map of South Korea for the future expansion as shown in Fig. 1. Users can select various counties after selecting a specific province. In the county level real-time rainfall graphs are displayed, so that the serviceability of rain gauges and rainfall data during previous two weeks can be inspected.

Transmitted real-time rainfall data, as shown in Fig. 7, are saved and managed in the data files according to minutes, days, and months. The landslide warning and evacuation time can be determined based on the relationship of previous landslides and current rainfall characteristics. In general, rainfall intensity of 10 mm or higher and continuous rainfalls exceeding 40 mm are used for the analysis. The concept of half life can also be applied.

After presetting of critical boundary between landslide inducing and non-inducing rainfall characteristics, it is possible to monitoring current rainfall in real time to reach the critical boundary or not, and hence it is achievable to issue warning and evacuation message to local residents in advance (Park et al., 2007b). The leading time for warning and evacuation should be determined based on the local situation and accuracy of real-time rainfall data.

The local situation is critical to determine the evacuation moment and the number of population in target area and the location of shelters are important factor among other aspects.

Real-time rainfall tracking system for the test site is displayed in Fig. 8 for three rainfall stations. The ordinate and abscissa represent working rainfalls in millimeters with 1.5- and 72-hour half life, respectively. The tracking lines in this figure are generated by the calculation in the developed data analysis system using rainfall characteristics and did not reach the critical boundaries, which were selected beforehand prior to a rainfall event during July 23 to 25, 2008.

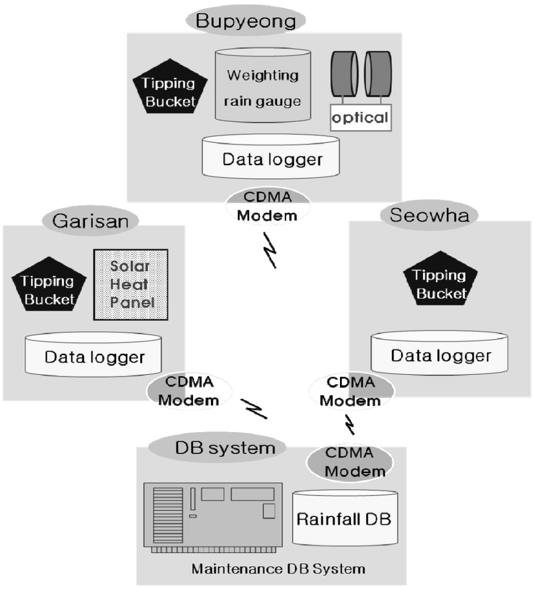
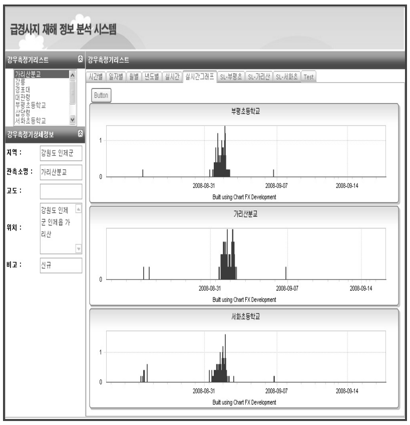


Fig. 6 Schematics of system operation for rainfall data analysis



지역 : 강원도 인제군

관측소명 : 가리산분교

고도 :

위치 : 강원도 인제군 인제읍 가리산

비고 : 신규

Fig. 7 Main screen of rainfall analysis system displaying real-time rainfall data

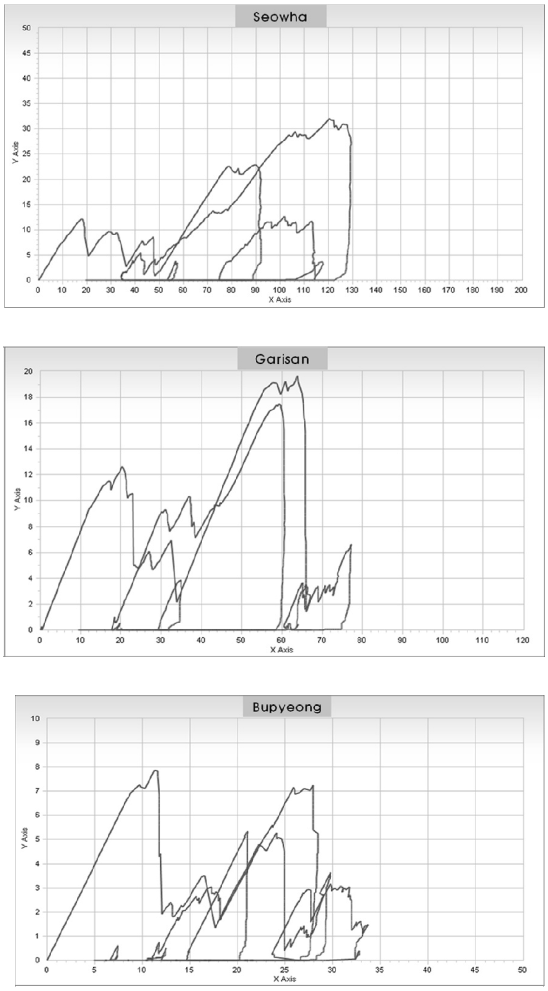


Fig. 8 Screen of real-time rainfall data display system for three rainfall stations in the test site

5. Conclusions

For the establishment of safer Korea against landslide disasters, feasibility of early warning system based on the relationship between landslide occurrence and rainfall data was reviewed. A method to issue a practical early warning and data management system currently under development for a test site were also proposed.

To support the Steep Slope Disaster Prevention Act in the central government level, it is necessary to develop, modify, and provide various subsystems for landslide-related data compilation and early warning practice.

Even though risk mapping process executed in this paper tends to embellish the landslide risks in general, it was found that the general location of landslide risk areas determined in this analysis agrees with those of actual landslides.

To set up precise critical boundaries and warning and evacuation lines it is necessary to collect historical landslide data considering local situation and rainfall characteristics. When the system for the test site works successfully, a nation-wide regional early warning system for landslide disasters will be developed by the National Emergency Management Agency of Korea.

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A Methodology for Community Based Disaster Risk Management

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Abstract. One of the lessons drawn from past disasters is that active involvement of the local people in the affected areas during disasters has been lacking and formed the weakest link in all risk management strategies. Despite the advances in science & technologies for disaster prevention, mitigation and management, the actual levels of successfully dealing with any disaster have been found to be low. This realization led the author to think for a workable methodology for community based disaster risk management which may be applied effectively by the rural communities in a part of Rudraprayag District, Uttarakhand State, India. The paper aims to discuss the methodology, its potential application in similar situations and the limitations therein.

The methodology has basically six distinct activities proposed in two phases: Hazard, Vulnerability, and Capacity Assessment in the first phase and Hazard Prevention / Mitigation, Vulnerability Reduction and Capacity Building are the subsequent activities for the second phase. The first phase requires informing people through awareness and sensitization campaigns about the impending risks due to disasters so that their self interests are aroused in this activity. Subsequently, inspire them to act against these risks and ensure them outside support to gain necessary knowledge, technologies, resources, and skills for managing these risks. Thereafter, the methodology explains how communities in rural areas can assess, plan and manage disaster risks by active participation / partnership of the public with support from professionals, administrators and other stakeholders.

Finally, a proactive continuum plan with necessary socio-economic, scientific and technical considerations as well as implementation, monitoring and review strategies for effective disaster risk management is available for deriving self initiatives and actions on the part of local communities to eliminate / reduce losses or threats from potential disasters.

Keywords: Hazard, Vulnerability, Capacity, Risk, Community, Management

1. Introduction

No part of the earth is free from natural hazards that adversely affect the life, economy and environment. But these hazardous events become catastrophic and termed as disasters when they strike any built environment & affect population that is not made safe to these hazards.

Despite all the scientific and technological innovations, it has been difficult to reduce the impacts of these disasters. Rather the frequency and intensity of disasters appears to have increased due to rise in population density, occupation of hazardous areas, unplanned developments, human interventions and hostile actions, and neglect of unforeseen hazards etc. Since most of these concerns are anthropocentric and relate to development of a sustainable environment for its survival, most hazards in remote and unpopulated areas are not cared for and all efforts focus towards disaster management of populated and built areas. India's most population lives in villages and hence, the present attempt is primarily oriented towards a rural community to build capacity and reduce disaster losses.

Disasters are linked not only to hazardous events but also to the vulnerabilities of the exposed elements and capacities within the society to cope with them. Thus, there are three major operating factors that influence the degree of disaster in any area i.e. hazard character (magnitude, frequency & duration), vulnerability of different elements (resident / mobile, degree of exposure, resistance to impacts and proximity to hazardous sources) and the capacities (techno-economic status & coping mechanisms). The paper focuses on possible methods of hazard identification and assessment by the community in its locality, by virtue of their natural experiences with these disasters in the past and present that affect their lives, livelihood, livestock, living shelters and environment. A history of past disasters and their impacts on community, its resources and environment are recorded through a community meeting and spatial assessment of all the hazards is depicted in a sketch called community based multi-hazard sketch of the village. The sketch shows not only the hazards but also the physiographic details, natural & social resources, infrastructure and community facilities. The second step in the approach relates to collection of information and data on different elements (physical, human, livestock, environment etc.) in a presentable form, thus, providing an idea of degree of vulnerabilities of different elements to all the hazards collectively as well as individually. In the third step, capacities within the community in terms of skills, resources, knowledge & information to face or cope with the disaster are evaluated. These three steps give a very good assessment of the potential risks due to future disasters in any locality and a plan is then prepared to prevent, mitigate or manage these potential disasters so that losses are reduced to a minimum possible.

The planning strategy again worked out on the basis of the aforementioned three steps. The fourth step (first in the planning strategy) makes an attempt towards hazard management i.e. to explore if the hazard can be avoided, prevented, mitigated, or monitored. The community looks for various options that can be applied using the local skills, resources, knowledge and techniques. The fifth step attempts to strengthen the existing elements or reduce vulnerabilities through the use of anti-disaster or disaster resistant technologies. The last step envisages that despite all the efforts, disaster may continue to inflict upon the society, ensures that the community is aware and prepared to face the residual risks in a planned way rather than being caught suddenly in a rash manner.

2. Why Community Based Disaster Risk Management?

The need for a Community Based Disaster Risk

Management (CBDRM) has been felt in the study area due to reasons given below.

Shortcomings in the present approach

a. Same plan regardless of the regional characteristics is implemented / imposed everywhere.

b. Local / indigenous knowledge, experience, skills, resources and techniques are not given due importance. Rather external resources and techniques are proposed to be utilized.

c. Negligence about local cultural instincts and heritage.

d. Prioritization is decided by an outsider and not the stakeholders or the community itself.

e. Local community does not have any information about the disaster management plans for their area and the role of different sectors in helping the community during disasters.

Advantages of CBDRM

a. Feelings of coordination and self belonging to the society are developed.

b. Local geo-climatic and socio-cultural characteristics get attention of the people in development and disaster management.

c. Local initiatives begin and community provides assistance to the executing agencies involved in disaster management.

d. There is exchange of knowledge, information, skills & techniques between the community and the experts.

e. Community comes forward to put its ideas and suggestions for selection of appropriate programs suitable to their locality and society.

f. Community can keep a watch / monitor the quality of works being done in its locality. It will also generate a sense of responsibility among the community.

g. It leads to capacity building of the community on issues of disaster safe developmental activities.

3. Development, Testing and Application of Methodology

Although several scientific and technological methodologies are available for hazard identification, assessment, monitoring and control; yet the community is barely benefited by their application. Therefore, an attempt has been made to use the community's experiences, information and knowledge in dealing with the issues of disaster assessment and management while applying scientific principles of disaster management along with it. Hence, a suitable methodology for use by the community was developed, tested and applied in an affected locality. Broadly, six steps were identified – three of which involve assessment of hazards, vulnerability and capacity within a community and the other three steps deal with action planning for modification or management of the first three issues. To make it practical and easier for the community to adopt, a tool called Participatory Learning and Action was applied during development of the said methodology. The raw methodology was taken to an interior village wherein the community was apprised about its objectives and usage. The village community took keen interest in the proposed activity and carried out the whole task without much difficulties in less than two days at a community gathering. The results of this test were quite encouraging and hence, it was planned to extend the methodology to the community in other villages through a training of master facilitators from the members of task forces for disaster management in these villages. The format of the methodology was designed in a way so that it can cover all the necessary steps for community based disaster planning and management yet kept in an open style so that the community should be able to add or alter any information necessary to make it more effective and applicable to any given locality. After drafting the plan, it was proposed that it should be presented before the community in a gathering of all the villagers and then tested and reviewed. The work plan and schedules of these plans should be available for public information. Further, the roles and responsibilities of the community members involved in planning, testing, review, implementation, monitoring and evaluation were also well defined.

4. Procedure for using methodology for CBDRM

The procedure for community based disaster risk assessment; planning and management has following steps.

At the onset of this process, some key actions are required to be taken by the community to initiate the work in an organized and systematic way. It involves formation of task forces and supporting groups, their affiliation with village development committee, community mobilization and disaster assessment.

A dedicated village level disaster risk management committee gathered necessary information about disasters and their impacts in their locality and sensitized people through awareness campaigns. They gained confidence among community and involve the community in drafting CBDRM plan, testing, review, monitoring, revision, implementation and evaluation of such a plan. The work plan and schedule involved the following actions.

Drafting the Plan: It involves following actions.

- Disaster Campaign and Community Mobilization
- Information about locality, community and the environment
- Multi-Hazard Identification & Assessment
- Vulnerability and Capacity Assessment
- Risk Identification & Classification (Determine the levels of risks and their prioritization)
- Existing Protection Systems (Identify what is already in place – What are we already doing?)
- Where are gaps in our protection? - Identify what is not being done
- What Action can be taken? – Brainstorming alternatives

Testing and Review: What is feasible? Evaluate Actions.

- Who else is doing this? – Coordinate with others
- How the implementation priorities will be set?

Implementation Strategy

During the process of plan preparation, community determines the WHY, WHAT and WHERE of the plan; WHY damages occur, WHAT is required to be done, and WHERE to implement the measures to reduce losses. To ensure that the plan will be implemented effectively, the additional questions like WHO, WHEN and HOW are also answered.

Decisions are made regarding requirements for permits / approvals, resources, sources of funding, time required and need for expert advice.

Initial implementation strategy is re-evaluated in the light of above-said factors for effective follow up of the plan.

5. Phase-wise Activities

As indicated earlier, the process for community based disaster risk management has been described in two phases in this methodology.

Phase 1: Hazard, Vulnerability & Capacity Assessment

It emphasized on collection, compilation and analysis of information, data, and maps for the purpose of assessing the hazards, vulnerabilities and capacities in a locality. Some of these activities are briefly described here.

Disaster Campaign and Community Mobilization

In order to involve the whole community in the process of disaster assessment and preparation of plan for disaster management, the people are made aware about the impacts of hazards and need for preparedness to reduce losses. Community mobilization or motivation has been done through street plays, skits, posters, meetings, interactions, campaigns etc.

Information on Locality, Community & Environment

It includes information population density / distribution, age distribution, mobility, vulnerable groups, and emergency resources etc. Environmental information includes water sources, climatic conditions, landforms, fauna and flora.

Community based Multi-hazard Assessment

Based on knowledge and experiences of local people, an attempt is made to depict the village boundaries, physiographic features, natural resources, social or individual resources, community facilities, infrastructure and hazards of all kinds. Such a sketch would be useful in displaying a very good picture of the resources, hazards and the development in the locality. Following steps are taken to achieve this goal.

List of Past, Existing and Potential Disasters

A list of the past, existing and potential disasters that have affected or may affect the life, economy and environment in the locality is prepared. The list would serve as a basis for indicating the affected or susceptible elements and collection of necessary information on these disasters and their impacts on the community which will ultimately help in planning and management.

Preparation of Multi-hazard Sketch of the Locality

Preparation of Community Based Multi Hazard Risk Assessment Sketch requires

- List of disasters (past, existing and potential)
- Village territory / boundaries and physiography (drainages, ridges, valleys, slopes, lake, ground cracks, landforms, rivers etc.)
- Natural Resources – Forests, Mines, Water sources such as falls, springs, lakes, medicinal plants
- Social / Individual Resources or properties – Human population, live-stocks, Agricultural fields, Cowsheds, Watermills, Open lands, Building sites, Houses, shops, factories
- Community Facilities – Panchayat Bhawan, Community Centre, Temples, Schools, Society or government offices, Police Station, Forest Post
- Infrastructure / Basic Amenities – Roads, Hospitals, Electric lines, telecommunication (phones, WLL, mobiles, wireless, Post office), Water pipelines
- Hazardous areas / Susceptible zones – indicate areas that are or may be affected by any hazardous event and put a symbol for that disaster e.g. landslide, earthquake, forest fires, hailstorms

Vulnerability & Capacity Assessment

Vulnerability assessment is done by determining the proportions of each group as part of the whole population, identifying any specific localities where there are concentrations of vulnerable people, e.g. schools, temples, in proximity to a hazard source. For each group identified, problems which might be expected under emergency conditions are noted. Community information also provides data on those groups in the community that have specialist skills or knowledge that may be useful in emergency management.

Risk Categorization & Prioritization

Based on the cumulative risk assessed on the basis of degree of severity of the hazards and the class of vulnerability of different elements, the various levels of risk can be defined as acceptable, tolerable, adaptable, and non-acceptable or intolerable risks. The categorization will help prioritizing the focus of disaster risk management plans.

Phase 2: Preparedness & Management Plan

Phase 2 of the procedure for use of CBDRM methodology involves application of the information and data obtained through the exercises in phase-1 for planning and management of disasters in the locality in a way so that impacts are minimized.

Hazard Prevention Plan – It may involve the following activities.

- Hazard Zonation – Incentive and Performance Zoning
- Regulating Development Controls / standards
- Enforcement of Building codes & Landuse Byelaws
- Promotion of Disaster Resistant Technologies
- Awareness and Dissemination of Safety Guidelines
- Sensitize about hazards impacts & build human capacity
- Structural Mitigation Measures
- Non-structural or Regulatory Measures

Hazard Mitigation & Vulnerability Reduction Plan

Disasters that can not be prevented are considered for mitigation and vulnerability reduction planning. Activities which aim to reduce the impact of a hazard on vulnerable communities, and address the related vulnerable conditions and their underlying causes are known as mitigation. Mitigation planning may include diversification of incomes / livelihood alternatives, food security, training for community in disaster planning and management, disaster resistant housing programmes, advocacy to government and community, building codes, and environmental protection. On the other hand, vulnerability reduction includes activities pertaining to strengthening of elements and reducing their weakness and exposure to hazards.

Disaster Preparedness Plan

The objective of disaster preparedness is to:

- Ensure that appropriate systems are in place to provide prompt and effective response during and post disaster.
- Prepare the community to handle the disaster in the first 48 hours or so when outside help has not reached.
- Establishment of Emergency Resources and Operations Centre with facilities and functions such as list of skilled and trained human resources, available emergency resources, information & data on past, existing and potential disasters; a copy of the community based disaster management plan, its schedules and progress with time; training materials for disaster management, facilities for collection and maintenance of disaster funds etc. It should also carry out activities like celebrating disaster reduction day and conducting mock drills or exercises.
- Action plan for warning and evacuation - Methods used for disseminating the warning may include media messages, door knocks, community networks, audible and/or visual

signals. Consideration should be given to warning special needs groups.

a. The stages of evacuation which are: warning; withdrawal; shelter; reunion; and return.

b. Identification of sites suitable as assembly areas; sites suitable as evacuation centres; evacuation routes between the above; organizations responsible for conducting and assisting with the evacuation; registration teams;

c. Organizations responsible for arranging and coordinating transport; and

d. Organizations responsible for operating evacuation centres.

Disaster Response Plan (with local capacities)

Response is the activation and implementation of operational systems which includes activating and staffing the Emergency Operations Centre, activating the communications system, collecting, processing, and disseminating information, alerting support organizations, preparing and disseminating warnings and other public information, activating liaison arrangements, coordinating and deploying resources and arranging outside assistance, and providing assistance to other areas. The response plan should include information on

- Reflex Action to disaster and information
- Emergency Communication and Transportation
- Search Rescue, Emergency Relief & First Aid
- Safe / alternate routes for evacuation
- Safe Accommodation, Temporary Shelters with basic amenities like food, water, light, ventilation (air), communication, health facilities (medicines), sanitation etc.
- Security of private properties and weaker sections particularly young women
- Carcass disposal, disinfectant spray and immunization
- Safe Drinking Water and Sanitation
- Consolation to the victims
- Damage Assessment and Relief Distribution
- Reconstruction, Resettlement, Rehabilitation, Recovery, Redevelopment

6. Limitations in implementation of CBDRM methodology

The experience of local community can help in developing a formally structured information infrastructure. Implementing such a process, however, will not be so simple. It will take time and commitment on the part of all those involved because there are some sources of frustration that will need to be addressed before it can become a reality.

A recurring view was expressed by the village community that they had ‘heard it all before’ at various times, but nothing practical had ever eventuated. They are looking for a worked-through example that they can follow and the resources to do it. That can not be achieved in any meeting, training or workshop; it can only be achieved on the ground in a real-world situation. The lack of communication reaching both down to, and up from, the village level was also seen as a major source of frustration, and consequently a major hurdle. For a process that is all about information and improving the effectiveness with which it may be disseminated and used, the sharing of information about the process is critical – and that depends on communication.

Another frustration revolves around a stated lack of coordination and cooperation between the people and agencies that should be working together to improve community safety. This was seen as part of the power and political processes that tend to build barriers, rather than bridges. Frustration also relates to the perceived lack of resources – human, financial and technical. This is probably a universal frustration for all disaster managers. Typically, they are allocated only limited resources because senior policy makers seem to hold the view that a disaster is unlikely to happen during their term in office, so why spend too much money on a disaster management system that does not bring significant votes with it. This may be a simplistic and cynical view, but it seems to correlate well with reality. These are not technical issues, they are human issues. Fortunately, frustrations can be overcome, even those as seemingly intractable as the ones identified here.

These established foundations are very sound indeed, and provide an excellent base on which to build an appropriate and sustainable information infrastructure that can address issues from the village level to the level of the district and beyond. There are undoubtedly frustrations and problems that will need to be addressed along the way; however, it is clear that the communities are committed to embarking on this journey. It is also clear that they will make a good job of it because they are committed to the task.

Another limitation of this hazard assessment approach lies in the fact that the local knowledge at the level of community can not always be sufficient to assess large scale phenomena especially if their origin lies away from the zone of perception of the community or if it results from an exceptional situation (e.g. flooding due to bursting of a landslide dam on upstream side of the community). Therefore, the logic of the concept should clearly indicate the possibility of integrating information received from outside the community (national / state / district level disaster warning centers), even if it is of scientific origin and not expressed in terms to which the community is used to, as another major contribution to the reassessment of a hazardous situation.

Conclusions

The successful application of this methodology in more than 50 villages by the community itself is evidently a good indicator of the acceptability of the approach as well as its outcome in the forms of large amounts of actual data and information generated through the process. If the methodology is applied in other areas in a similar fashion, the country will have, no doubt, a very large database on disasters and a culture of aware and prepared communities in all villages. The approach is open for further modifications to suit to specific requirements of any area as is permitted in any context specific approach. Technical and financial support from outsiders will further boost the efforts of these villagers in fully implementing their strategies for disaster risk management in their localities and communities.

Acknowledgments

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Environmental Consequences, Emerging Issues, and Management Options Associated with Landslide Disaster: Experiences from Nepal Himalaya

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Abstract. In this paper, an attempt is done to examine the consequences and emerging issues caused by landslides in the Nepal Himalaya. Along the Himalalayan chain of 2400 km., landslides (includes shallow, deep seated and debris flows) occur extensively, and in particular within Nepal. Substantial negative impacts particularly on human life, productive agricultural land, domestic animals, infrastructures, and world heritage sites are increasing. Since 1983 to 2006, human loss due to landslides and flood were 7200 numbers (equivalent to 300/year). Similarly the estimated properties loss between period of 1995-2006 was 32437466548 Nepali Rupees (equivalent to $ 499037947, @ of 65NRS. for 1 $). Recently nationally important watersheds of lakes, wetlands, hydropower station are degrading seriously due to debris deposition. Over 28% of the country's land area is believed to be in degraded condition. By annual rate of 1.6%, forest resources decreased by 24% (from 38-29% in between 1979 to 1994). In these contexts, associated issues amd management options are examined for a future management.

Keywords:
Landslide hazard, disaster management, Nepal Himalaya, Mitigation measures

1. Introduction

The loss due to landslides and related problems in the Himalayan region alone constitutes about 30% of the world's total landslide-related damage value (Li, 1990). Along the Himalayan chain of 2400 km, landslides (includes shallow, deep seated and debris flows) occur extensively (Owen et al. 1995; Sarkar et al. 1995), and in particular within Nepal (Petley et al. 2005). Environmental hazards, notably deforestation, surface erosion, landslides, flash floods and desertification are becoming major environmental problems (NPC, 1985). Substantial negative impacts particularly on human life, productive agricultural land, domestic animals, and infrastructures are increasing at local, regional, and national levels. For instance, the large failure at Krishnabhir in Dhading District led to the closure of Road for eleven days, Mugling Narayanghat road closed for more than 15 hours, a single landslide caused 26 people died, 88 members displaced and millions of properties damage in Baglung district, western Nepal (Paudel, 2007). So many similar incidents are experiencing across the nation. The watershed areas of nationally important lakes, major hydropower stations, wetland sites, world heritages sites are degrading due to frequent landsliding activities. Concern about the consequences of landslide hazards has been growing for the last couple of years, from international, national, and local levels. However; unavailability of adequate scientific information on disaster scale/effects, causes, mechanics, and other related site-specific details are hampering the progress on planning and implementation of landslide hazard management. Evaluation of economic loses, and poor quantification on long-term influence on National Gross Domestic Production (GDP) is hampering the progress to convince national level policy makers and to develop the concrete national action plan. Owing to increasing pressure on rural livelihood and realization on damaging effects caused by flood/landslides, recently Government of Nepal has approved the new concept on "Establishment of Flood/Landslide relief fund" under the Department of Soil Conservation and Watershed Management. Keeping due consideration on these facts, this paper makes an attempt to examine;

1) spatial socio-economic, and environmental impacts experiencing at national scale, particularly focusing on nationally important watershed areas (lakes, wetland, heritage sites),
2) linking major terrain characteristics and man made factors associated with slope instabilities, and
3) laws, policy, plan, and issues, related to landslide disaster management in Nepal Himalaya.

2. Data and methods

Different attempts like; direct field visit, consultation with respective district level soil conservation offices, news published in different national daily newspapers are utilized to obtain the data on landslide disaster. The information on loss of lives and estimated economic losses are obtained from the records maintained by Ministry of Home affairs. So as to assess the surface terrain characteristics of unstable mountain slopes, a typical Mid hill mountain watershed is examined using Digital Elevation Model (DEM), with the resolution of 20 m×20 m. prepared from topographic map.

3. Findings

Landslides occurrence, socio-economic, and environmental consequences

In fact, it is very difficult to mention clearly on how many landslides across the nation are occurring every year. However; in practice major sliding events (affecting human lives and large scale properties damage) are noting into account. Petley *et al*. 2006, have made an attempt to study on number of fatal landlides and fatalities, in which 397 fatal landslides, and 2179 fatalities was observed in between the period 1978–2005 (Figure 1). In Disaster data source, information on death casualties and estimated losses are maintained jointly for Flood/landslide hazards. Hence it is becoming difficult to segregate for an individual hazard. Since 1983 to 2006, human loss due to landslides and flood were 7200 numbers (equivalent to 300/year). Similarly the estimated properties loss between period of 1995-2006 was 32437466548 Nepali Rupees (equivalent to $ 499037947, @

of 65NRS. for 1 $). The annual trend is shown in Figure 2.

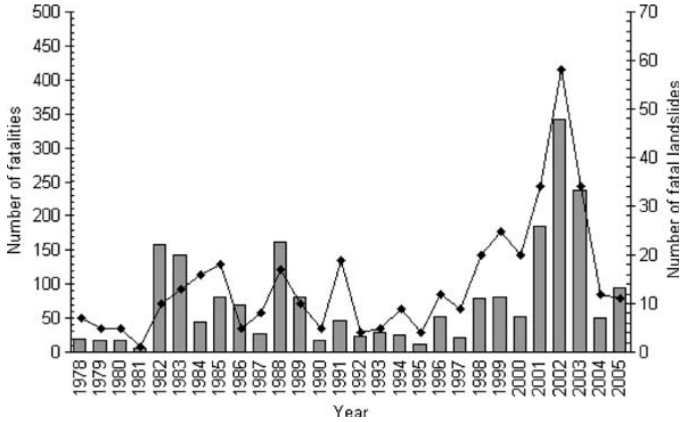


Fig. 1 Graph showing the number of landslide fatalities (bar graph, left hand scale) and the number of fatal landslides (line graph, right hand scale) each year for the period 1978–2005 (source: Petley et al. 2006).

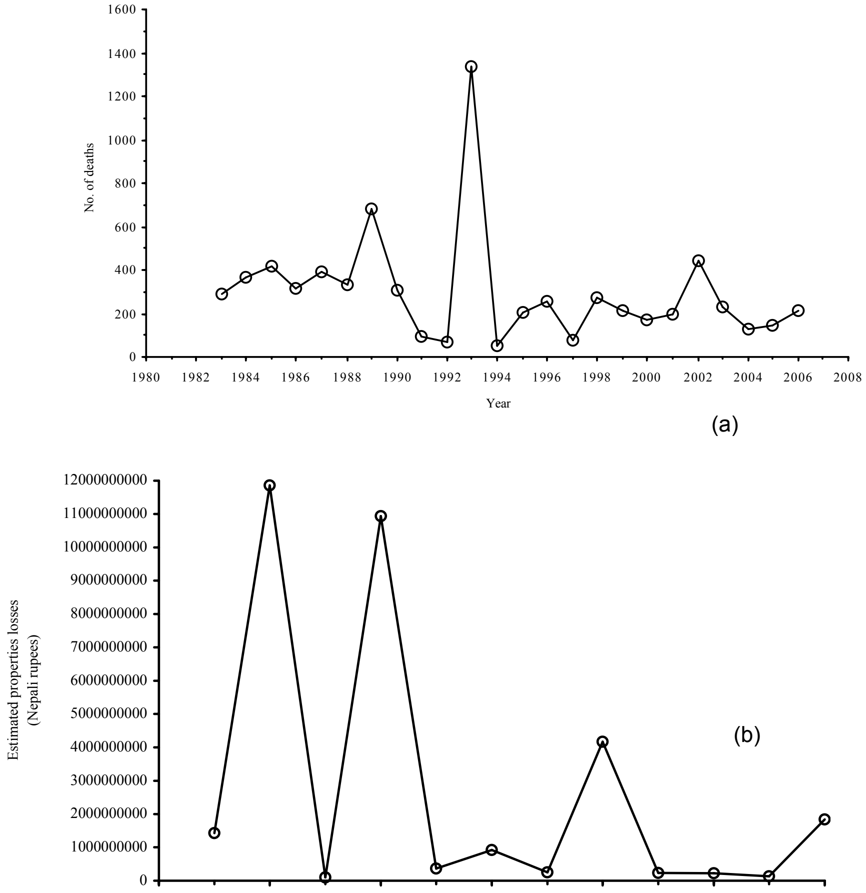
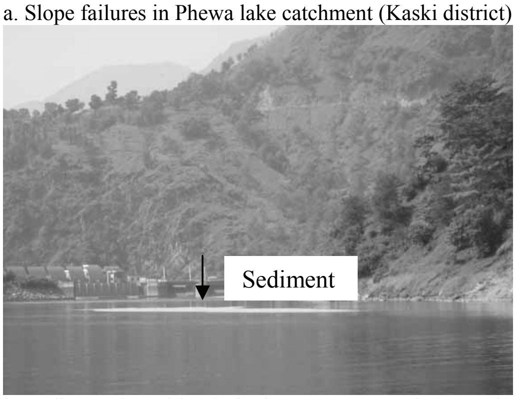


Fig. 2 Consequences of flood and landslides for different years, a) Number of annual death, b) estimated properties loss. (data are based on Disaster scenario report published by Ministry of Home affairs).

Recently nationally important watersheds of lakes, wetlands, hydropower station are degrading seriously due to debris deposition originated as a result of recurrent sliding (Photo 1). The Phewa lake, (surface area of 4.43 km^2), which has immense socio-economic, cultural and scientific values, is suffering from large siltation (at the rate of 175,000-225,000 m^3 in between 1990-'94), and excessive eutrophication (Photo 1 a). If this trend is continued, the lake might be "dead" by next 135-175 years, assuming loss of 80% water volume (DSCWM, 1994). Similarly, the reservoir of Kaligandaki-A hydropower station is facing siltation, debris deposition at the surface level (Photo 1 b). The electric poles (Photo 1 c) and biggest and important wet land (listed as Ramsar site) is also at risk due to sediment deposition derived from sliding activities at upstream (Photo 1 d).

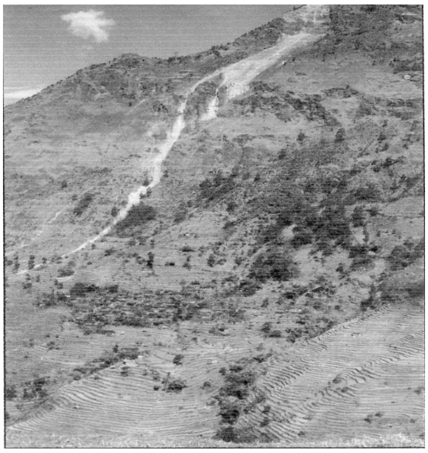
a. Slope failures in Phewa lake catchment (Kaski district)



b. Sediment deposition in hydropower reservoir (Syangja)

c. Electric pole at risk due to slide (Pyuthan district)

d. Sediment is depositing from upstream (Kailali district)



e. Whole village is under landslide threat (Myagdi)

Photo 1. Glimpse of different environmental consequences observed in different parts of Nepal.

Major issues

Although landslide hazard is representing serious environmental hazard and hindering the pace of development, yet the priority from Government for detail landslide hazard mapping is still inadequate. Some of the prominent issues can be noted as;

1. local/regional/central level landslide hazard mapping programmes are still lacking,
2. suitable/precise landslide hazard mapping techniques for a particular region is unavailable**,**
3. integration between research and development are lacking,
4. adoption of watershed/ ecosystem approach is lacking,
5. after landslide disaster only rescue, relief centered program are implemented but other associated technical issues like occurrence mechanism, rainfall threshold, disaster impacts for future lesson learn are poorly quantified,
6. inadequate institutional capacity,
7. land use practice is not managing through appropriate land use policy.

4. Discussion

Spatially, distribution of landslides is uneven and generally is concentrated more in Mid hill and mountain regions. Over 28% of the country's land area is believed to be in degraded condition. By annual rate of 1.6%, forest resources decreased by 24% (from 38-29% in between 1979 to 1994). From one typical Mid hill watershed analysis, it was revealed that maximum (38.8% of total watershed area) was under 20^o-30^o, while is it is 19% above 30^o. The cultivated terrace land with >30^o slope gradient have noticed with more slope failure activities. Improper land use practice (eg. paddy cultivation inside landslide zone) is common. As majority of sliding activities are reported during June and July, hence it is assumed that rainfall is the most triggering factor. Various acts like Soil Conservation and Watershed Management Act, Environmental Protection Act, Forest Act, Natural Calamity Relief Act and other so many associated laws are prevailing however; integrated actions are very weak. Hence in future management of landslide hazard should be integrated in a broader framework i.e. including technical, administrative and community based approach.

5. Conclusion

In this paper, few case illustrations on socio-economic and environmental consequences caused by spatially distributed landslides across the Nepal Himalaya are presented. Flood, landslide hazards are hampering national economy; but the realization and mitigation plan adopted at national level are inadequate. In some rural areas, still landslide victim people do not know to whom they have to contact in order to deal with problem. There is remarkable variation in geologic/topographic features across the nation and suitable landslide hazard mapping techniques are becoming essential. In addition, strong interagency coordination mechanism, establishment of apex body as landslide advisory committee at national level, linkages between research and development, extensive awareness programs are suggested for future actions.

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Distribution of Dangerous Rockmasses and High Steep Slopes in Three Gorges River Valley

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Abstract. The distribution features of high steep slope and dangerous rockmass in 63 Km-long valley of the Three Gorges is described on the basis of site investigation and geological mapping. Seven high, steep dangerous rocks and the respective monitoring situation is also described briefly. The high steep slope in the valley section is controlled by the stratum lithology, and the locality and damage of single dangerous rock is mainly subject to the combination of lithology, partial formation, and human activity.

Keywords: Valley section, Three Gorges, High-steep slope, dangerous rockmass, distributing features

1 Preface

The Three Gorges area is one of the places where geologic hazards occur frequently. Along with the impounding of the Three Gorge reservoir, the navigation condition in the waterway of the Three Gorges area improved greatly and in this area a ship passes every 3 to 6 minutes, but the threat to ships by rockfall or collapsed rock happens from time to time, increasing the risk to navigation. Currently, China Geological Survey conducted an investigation on high steep banks and slopes as well as the dangerous rock, which will be helpful to provide the related basis for the safe passage and pre-warning of dangerous rock and falling stone to sea- routes. This paper introduces some programs associated with the project.

An overall investigation was made in 2006 and 2007, and the authors will give a brief introduction for seven important dangerous rockmass (Fig. 1), such as Jianchuandong, but the Lianziya dangerous rockmass will not be covered here.

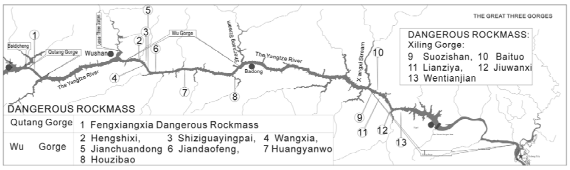

Fig.1 Regional distribution map of the important dangerous rockmass in the Three Gorges valley

2 Features of Rockmass structural plane

The growth of dangerous rockmass and the structural plane of rockmass have a close relationship, and in order to analyze these relationships between dangerous rockmass, high steep slope growth and structural plane, the authors made a statistical analysis for the structural planes of 7794 joint fissures in 150 river sections, gathered in the dangerous rock and high steep slope in the measurement area, such as Qu Tangxia and Wuxia. It was found that the advantageous structural plane is distributed parallel to or crossed with the tectonic line, X joint grows, and the unloading fracture keeps pressuring the structure, thus the structural joint grows. Under an advantageous free face condition, these structural planes blend with the surface fracture or landslip layer, and will be inclined to form dangerous a rockmass in the high and steep slope and bank of the reservoir area (Fig. 2).

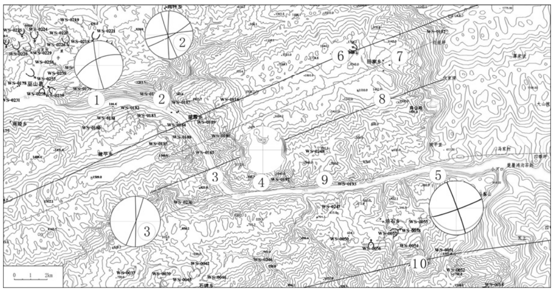

Fig. 2: The relationship between Stereo-net in Wu Gorges and the distribution of key dangerous rockmass and the regional geological tectonic line

1-5: Stereo-net of dangerous rockmass; 6 Hengshixi anticline; 7 Chuanjianxia syncline;8 Shengnvfeng anticline;9 Guandoukou-Shengnvxi syncline;10 Maozishan anticline.

3 Key dangerous rockmass

3.1Fengxiangxia Dangerous rockmass in Qutang Gorge

The Fengxiangxia dangerous rockmass is located in the SE wing of Qiyaoshan anticline in Qutang Gorges, which is also in the NW wing in the closed Qidaomou syncline. The dangerous rockmass consists of hard dolostone and limestone of Triassic Jialingjiang Formation, which dips towards the SW a little. The dangerous rockmass is 120 m long, 5~10 m wide and 10~30 m high, with the volume is almost 12000 m^3.

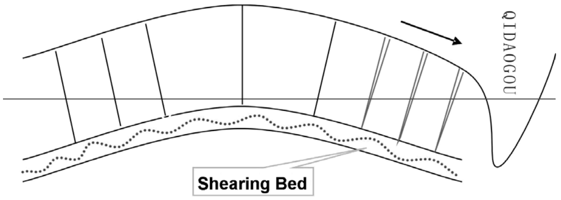

Fig.3 Sketch of the Dangerous rockmass in Qutang Gorge and its underlying large cutting belt occurring between layers

The reach of the Yangtze River is separated transversely into the Qidaomen anticline and the Fengxiangxia syncline respectively from the NW to the SE, which two belong to the NW wing of the Qiyaoshan anticline, with steep cliff stand at both banks. The Fengxiangxia dangerous rockmass is located in the north bank, which is dominated by weak dip at the bottom angle interlayer and the Qidaogou gulch on the east side, which developed with long and large fracture in the steep dip angle in the north east direction, and thus forms a dangerous rockmass(Fig.3). As to the uncertain feature which could be a threat to the Yangtze River sea-route, it is prudent to further study the development process.

3.2 Hengshixi Dangerous rockmass in Wu Gorge

The Hengshixi dangerous rockmass in Wuxia Gorge, located in the right bank of the entrance of Hengshixi brook at the north bank of the Wuxia Gorge, is configured in the north-west wing of the Hengshixi anticline, consists of the M1# dangerous rockmass on the top and the M2# dangerous rockmass at the bottom (Fig.4).

The M1# dangerous rockmass consists of hard limestone of Permian Qixia Formation. The M1# dangerous rockmass is 27.7 m long, 11.2 m wide, 76.8 m high, that is to say 23700 m^3 in total volume. Due to the activities of excavating coal in previous years, the coal-bearing Permian Ma'an Formation underneath the Qixia Formation deforms severely, which causes the rockmass to form an external-oriented, reverse and open breakage. In accordance with the investigation, it is found the root of dangerous rockmass has already formed a subsiding pit with a depth of 16 m that can be seen at the toe of the dangerous rockmass.

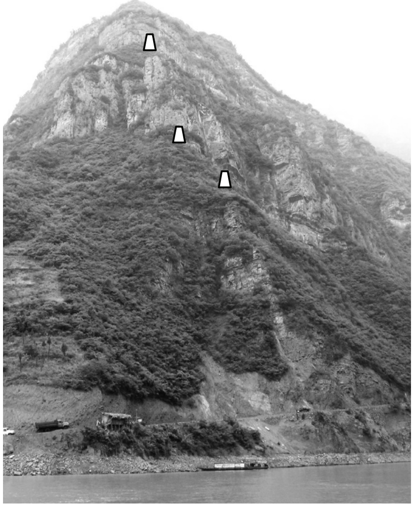

Fig. 4 The Hengshixi dangerous rockmass

The M2# dangerous rockmass is composed of the Silurian Shamao Formation sandstone, with limestone interbeded and weak sand shale underneath. The rock layer is oriented generally towards the NW with an dip angle between 25°～35°, and the rockmass is loose structure type. The M2# dangerous rockmass is 25m long, 12m wide, 117m high, and 31800 m^3 in total volume. Under the influence of cutting the slope to build a simple road, the right side of dangerous rockmass had already collapsed in this process, and a triangular free face was formed.

It causes a huge threat to the coal mine wharf and vessels in the surrounding area. Some rockfall happened as a result of the magnitude 12 May 2008 Sichuan Earthquake.

3.3 The Tongxincun Dangerous rockmass in Wu Gorges

The Tongxincun dangerous rockmass in Wangxia village, located on the left bank of the Yangtze River in Wushan County in the Great three Gorges area, is 11 km away from the new Wushan County site. The dangerous rockmass is in the core section of the Hengshixi anticline, where the stratum is flat with the configuration angle of 340°∠5°; the slope body is composed of Permian Gufeng Formation (Pg), Longtan Formation (Plt) and Wujiaping Formation (Pw). Among which the lithology of Pg is black lamina shale, lamina argillite and lamina dolostone, Plt is grey thick shale, lamina sandstone with coal within and the Pw is grey dark lamina silicon limestone, lamina shale. The flat section is mainly composed of shale, whereas the steep section is mainly composed of the mixed layer of argillite and limestone. The K2 coal bed (Plt coal bed) in the slope body has already been excavated; it is located at the bottom of Pw.

This dangerous rockmass is located on a slope with an elevation of between 1100 ~1250 m, the slope root is a flat slope within its 30 m, the slope gradient is 30°, but the top is almost a 90° cliff. In the last ten days of July, 1999, the dangerous rockmass in this slope happened to deform severely. There are 6 large fractures that exist in the slope, finally a dangerous rockmass cluster with the dimension of 230 m long, 50 wide and 115m high is formed, and its total volume is about 1,320,000 m^3; the fracture in the free face of the rockmass opened about 20 cm in one week in 1999. The dangerous rockmass that separates from the mother rock is around 8.6m long, 15 m wide, 75 m high with a total volume of 1000 m^3(Fig.5); there are subsiding pits on the top with diameters of roughly 10 m. After compiling the statistics on the crannies in the cliffs of several rockmass, it is found that two terms of advantageous joints in the rockmass, it's: 90～100°∠80～85°, 165～174°∠75～82°. The two groups of joints are vertical next to each other, and form a contour of steep cliff and dangerous rockmass. The dangerous rockmass triggering factor is the subsiding-level lifting mechanism along with human excavation. It constitutes a huge thread to the local residents, the mineral company and the sea-route.

3.4 Jianchuandong Dangerous rockmass in Wu Gorge

The Jianchuandong dangerous rockmass, located in the left bank of Yangtze River in Wu Gorges, is 12km away from Wushan County. The dangerous rockmass is composed of section 4 limestone of Triassic Daye Formation, For the configuration, the dangerous rockmass in Jianchuandong is located in the turning part of the core section in the SE wing of Fairy Mountain anticline. The core section in Fairy Mountain anticline is flat, in general, characterized by the joints developed in the whole.

The boundary of the Jianchuandong dangerous rockmass has obvious features, and looks like a bevel triangle with the head being heavier than the root. The elevation of the cliff top of the dangerous rockmass is 267 m, the base elevation is 153m, the dangerous rockmass is 114m high, 45m wide in the shoulder section, but only 14m wide at the base section. The overall volume of the rockmass is approximately 60,000 m^3. The barycenter elevation is 220 m, and it forms a height difference of 45~75 m with the river in 145~175m. The SE side shoulder section of the dangerous rockmass or above which goes after the lay and the joint cracks to form a slope in cascading shape. The SE side contour underneath the shoulder section of dangerous rockmass is wide unloading fracture, which makes the dangerous rockmass separate from the SE side of mountain. The NW side of dangerous rockmass in Jianchuandong is a vertical steep cliff roughly (Fig. 6).

Fig. 5 The Tongxincun dangerous rockmass

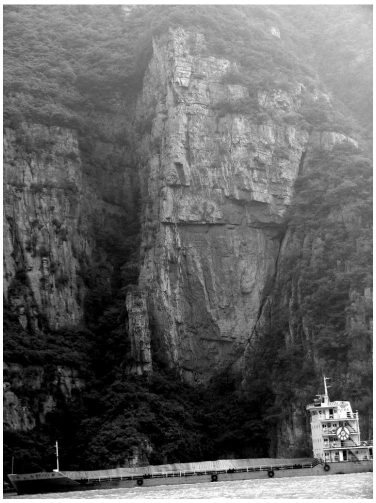

Fig. 6 The Jianchuandong dangerous rockmass

On the basis of the joint cracks being perpendicular to the Yangtze River, with an opening between 5~30 cm, and is filled with yellow clay. On the clay and interface of surrounding rock, it can be observed the mirror-like surface and scraping of slickenside activity, indicating the dangerous rockmass is displaced along the fracture towards The Yangtze River.

3.5 Jiandaofeng rockfall in Wu Gorge

After the deformation and instability feature of the primary high steep slope and bank investigating in 2006, the authors made a nonscheduled wide patrol, and found that sections between Jiandaofeng and Kongmingbei in the left Yangtze River bank in Wuxia Qingshi section unstable. This section happened to collapse along the high and steep bank and slope of configuration from time to time. Though it was less in volume, normally between 0.1~1.0 m^3, the height difference of this falling site was more than 400 m, with a huge amount of potential energy, and as a result, it constitutes a huge threat to ships. It is also found that two landslips happened in the area of Jiandaofeng Mountain in July, 2007 respectively, and the collapsed section looks like a 20 m- long plate measured from the east to the west, which is 0.35 m wide, 80 m high, and the total volume of which is 560 m^3 (Fig. 7).

In accordance with the interview with witnesses and ships, there were no ships around the area within 500 m when it collapsed on July 3^{rd}. The falling stone produced huge soot; and on July 23^{rd}, a second landslip happened at the same site, but luckily the falling stone did not hit any vessels even though there was a passenger ship moving towards the upper reaches, close to the cliff. At 50 m in the lower reaches, that passenger ship took more than 50 passengers. The falling stones boundary is unsteady joints along the section X (Fig.7). (1) and (2) is the vestige left by the landslip that happened on July 3rd and 23rd, 2007 respectively.

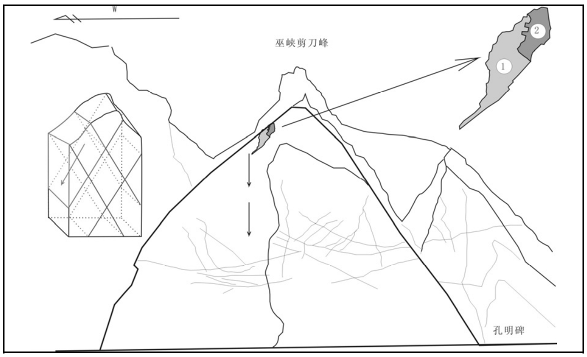

Fig. 7 Vestige of rockfall and mechanism of Jiandaofeng in Wu Gorge

3.6 Houzibao Dangerous rockmass in Wu Gorge

Houzibao dangerous rockmass is located in the right bank of the Lianzixi Brook, 3 km away from the west side of Badong county; it is located in the north wing of the Nanmuyuan anticline, is composed of limestone with firestone strip of Permian Wujiaping Formation, and underlies weak terrain of coal beared Longtan Formation and silicalite, mudstone of Permian Gufeng Formation, it grows the vertical fracture parallel to Yangtze River, it is possiblyeasily prone to failure. Since the coal excavation before years, lower part, has weakened and if Three Gorges impounds water, the large empty area in the bottom of the mountain will be submerged, the stability of dangerous rockmass will be worsened further, and deformation increases and will become more active.

The plane shape of dangerous rockmass in a 150 m vertical level is similar to a rectangle with a length of 82m and a thickness of 32m, roughly. The section plane constitutes a 2-step structure, is 180 m tall, and the top is narrow, the bottom wide, the top has a thickness of about 8.5m, and the bottom, around 34m; in a 3-dimensional view it looks like a ridge-table type column, with a total volume of 460000 m^3. The main body of the dangerous rockmass is composed of nodular limestone (Fig.8), with a shear zone layer at a height level of 160 m and 260 m, with the coal -bearing Longtan Formation. The shale of the Gufeng Formation is underlain, with the structure on top being harder and a weak bottom. The attitude of the rocks is 9～15 °∠16～25°, forming an angle of 15°~30° in slope direction, and the slope structure is a cataclined (inclined) slope.

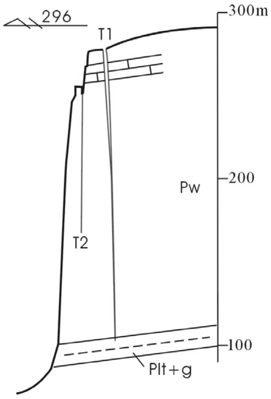

Fig. 8 Section plane of geology for Houzibao dangerous rockmass

3.7 The Wentianjian Dangerous rockmass in Xiling Gorge

The Wentianjian dangerous rockmass is located in the right bank of Yangtze River, is 1.5km away from the entrance of Jiuwanxi Brook. Overlaying the stratum, the middle-layer is limestone with shale, within the Cambrian Tianheban Formation. Below it is the middle-thin limestone with shale contained of Cambrian Shipai Formation (Fig. 9). The rockmass topside is rather complete, but on the downside, it is rather broken. The average distance between joints is 0.8 m, some of which are suspended. The geological mode of the dangerous rockmass is the typical one, with the top harder than the bottom. The locality is the anticline west wing of Huangling. In the W side, there are NNE-trending ruptures across the surface, toward the Jiuwanxi Brook at 1.5km; the stratum is a monocline structure, and the lay attitude is 270°∠20°.

The dangerous rockmass there has been cut into isolated rockmasses. The dangerous rockmass is 100 m high roughly, about 2~5m thick, appromixately 50 m long, the foundation of which is the broken Shipai group limestone with shale contained within, its cut borderline being 140°∠70°and 25°∠85°respectively; the two groups constitute an advantageous structural plane of a dangerous rockmass; there is one group of shale inside the dangerous rockmass at the top, it is heavily weathered, and it produces a severe influence on the stability of the dangerous rockmass. After a preliminary analysis, it can be found that there are two damage modes. One is, the rockmass bends from the middle shale; the other is the fracture located at the bottom of the dangerous rockmass keeps opening, and finally it collapses down from the fracture downside. The dangerous rockmass is a well-know landscape in the trunk stream of Yangtze River, called Wentianjian, but it brings a huge threat to the sea-route.

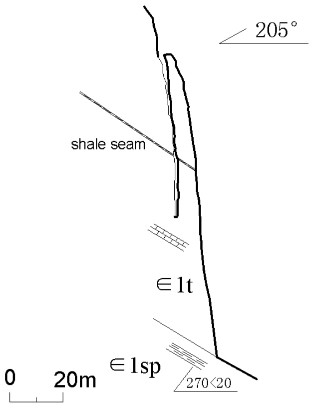

Fig.9 The section of Wentianjian Dangerous rockmass

4 Conclusion

(1)After making the related investigating and performing monitoring on the dangerous rockmass along both banks ,the paper concludes that constitutes directly the geological hazard of the safety of sea-routes is the landslip and falling stone.

(2)Through the investigation on the dangerous rockmass at both banks of the sea-route from Yichang to Fengjie, the spatial distribution situation of the dangerous rockmass that constitutes a direct threat to passing ships can be clearly seen.

(3)The high and steep slope in the river section is mainly under the control of stratum lithology and structure, the distribution of dangerous rockmass and damage is mainly under the influence of a lithologic combination, of structural plane, coal excavation, construction of roads, wharfs, and other human activities.

(4)After mapping the dangerous rockmass, it can be clearly seen that the borderline condition and geological structure of the dangerous rockmass, lays the solid foundation for evaluating the stability of dangerous rockmass and other related calculations.

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Does the Science about Landslides Need for Unified Classifications of Its Object?

Nikolay Petrov (Chuvash state university, Russia)

Abstract. The unified classification of landslides is submitted. It includes all their nature types with peculiarities of structure and displacement of landslides body for the first time. It based on own features of landslides, which was distinguish by system analyses.

Keywords:. Landslides studies, landslides bodies and systems, landslides taxonomy, structure and mechanism of landslides, level of organization of landslides bodies – block, cycle, storey, multistory, cinematic computation model.

1.The urgency of investigation

More than 30 years later, when the author begun his investigation of the landslides, he understood, that the main problem in the landslides studies is the absence the unified classification of landslides (UCL) and conventional apparatus of notions. The history of studies show that the appearance of science classification of objects usually preceded for transition from empirical to theoretical period of investigation. The landslides investigation has a lot of classification. We agree with G.I. Ter-Stepanyan (1984), he stated, that simultaneous coexistence the large numbers of classifications is equate to its absence. Therefore, during more than 100 years, since A. Baltzer (1875) the landslides studies exist without classification, on empirical period [1, 7]. So it will be interest to introduce with our version systematic of landslides, which was worked out in 1975-88 years [3, 4], and was verified by time. This version was based on critic analyses of exist schemes and now will be present as the doctoral dissertation [6].

2. The methodological principles of classification.

We propose to discuss about our UCL [1, 7]. Our classification is not the classification of slope movements or slope processes. We attempted to summarise all experience of landslides investigation. The main contribution to science made A.Heim (1882), D. Molitor (1894), A.P. Pavlov(1903), P.Almagia (1910), K.I. Bogdanovich (1913), D. Newland (1916), K.Terzagi (1929), F.P. Savarensky (1935), C. F. Sharp (1938), I.V. Popov (1946), G.S. Zolotaryov (1950), E.P. Emelyanova (1951), M.N. Goldstein (1952), N.N. Maslov (1955), G.I. Ter-Stepanyan (1958), D. Varnes (1958), K. Zaruba (1961), G.L. Fisenko (1965), M. Saito (1965), M.K. Rzayeva (1968), A.W. Skempton, J.N. Hutchinson (1969), K.A. Gulakyan and V.V. Cyuntsel (1970), A. Nemcok (1971), V.I. Presnuchin (1976), I.O. Tichvinsky (1978), etc. Some of them (Zolotaryov, Goldstein, Maslov in former USSR) made science school with own principles.

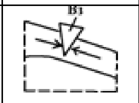
Leading, main elements				Inside dependence elements				Outer dependence elements (tongue)			
№	Name of the block	Index	Model	№	Name of the block	Index	Model	№	Name of the block	Index	Model
1	Subsi-dence	Ос		7	plastic compres sion	Сж		11	extruding	Вд	
2	Rotaion	Вр		8	plastic extension	Рс		12	protrusion	Вп	
3	flat sliding	ПС →		9	fragile compresion (thrust block, horst)	Вз		13	trust	Нд	
4	fault	СБ		10	fragile extension (graben)	Рс ↔		14	excrescence	Нп	
5	viscous flow	ВТ									
6	plastic flow	ПТ									

Fig. 1. The least structure elements of the landslides systems - landslides block

Proposed classification worked out by consecutive decision of the next three groups of methodological problems [3, 5]. The first group: 1) determination the object and subject of landslides investigation; 2) work out the principles (rules, aspects and aims) of system analyses of the landslides and their classification; 3) make out the indications of landslides systems for the aim of selecting the own features. The second group: 1) dividing the own indications on the groups by their role in structure and in functioning of the landslides systems; 2) ranking indications inside propose groups for the taxonomic aims; 3) setting up the nomenclature and diagnosis of the taxons of the landslides systems. The third grope:

working out the cinematic computation model, which allowed receiving optimal landslides stress and to offer the successive engineering protection measures.

1) dividing the simple and the complicate landslides; 2) the monographic description the taxons of the simple landslides by their mechanism; 3) the monographic description the taxons of the complicate landslides by the level of level of organization of landslides bodies – block (first level), cycle (second level), one-storey (third level) and multistory (fourth level).

With the decision of theoretical problems were decided the applied problems of landslides investigation: 1) mapping the landslides systems and their parts; 2) identifying the taxons of landslides in nature by their indications; 3)

3. The matter of classification in brief

For the construction of the landslides classification were investigate more than 150 features of the simple and complicate systems. Several of them are represented on figures 1-4.

The fig.1 shows the structure elements of landslides – leading and dependence, inside and outer by their role in functioning of landslides systems. The real landslides consist of these elements and their combinations and they may be the simple and the complicate landslides. The main indication of the simple landslides is the features of the displacement. The main indication of the complicate landslides is the features of structure. The fig.2 shows all the nature kinds of simple landslides. They represents by 12 types, which unites into 4 groups and then into 2 subclass and then into class of landslides. These types of simple landslides forms in nature a lot of number of combinations or complicate landslides of the different hierarchic level of organization.

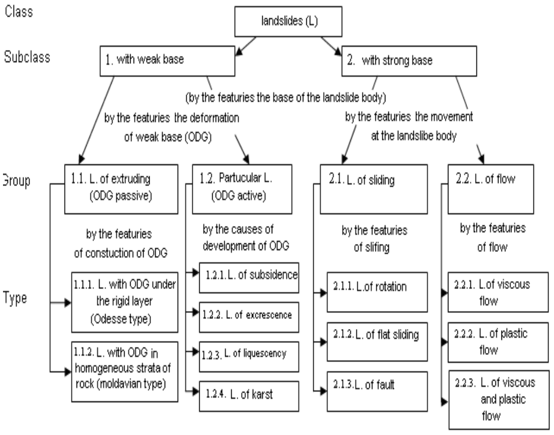


Fig. 2. Classification of simple landslides

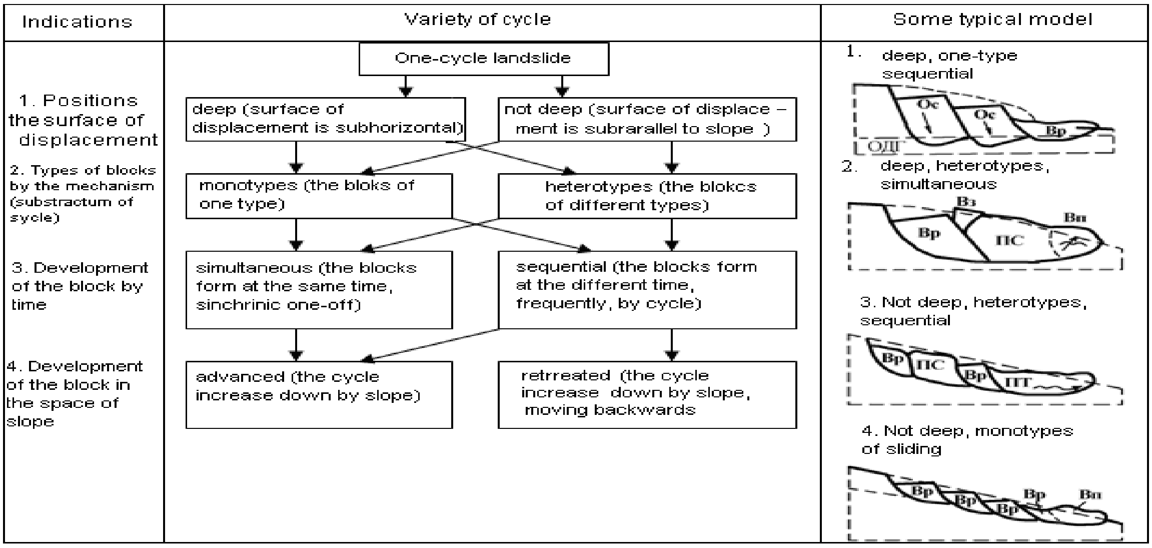


Fig.3. Classification of one-cycle landslides (the legend on fig. 1)

They divide into one-cycle landslides (fig.3) and multycycle. The multycycle landslides divide into one-storey and multistory landslides (fig.4).

Landslides are the slope occurrences which formatted by displacement the part of the massive with making the shear band and without the isolation from own bed.

For the first time landslides were classified by the features of the movement and the causes of deformation of the slope. This classification was made for the simple landslides. The main taxonomic role in classification plays the features of structure. So they divide into 4 hierarchic level from one-block to multistory landslides. All these classifications are complicated into unified classification of landslides - UCL. It will be present in full appearance during the Forum.

There are a lot of examples of the system description of all taxones in the authors publications [3-6].

The structure term "cycle landslides" is known in Russian scientist literature for a long time. But the term "multistory landslides" is appeared in1982, when G.S. Zolotaryov translated the book D. Varnes into Russian [2]. All these terms now are used in classification of the complicate landslides.

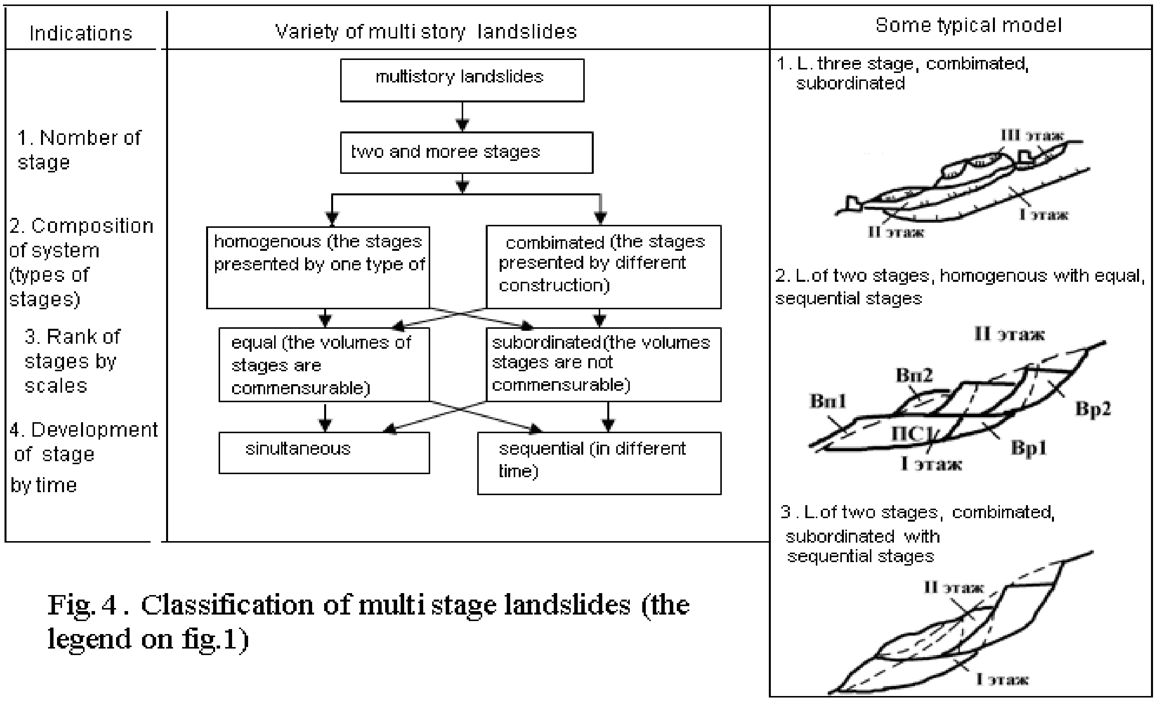


Fig. 4 . Classification of multi stage landslides (the legend on fig.1)

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The Flims Rock Slide Theatre, a Drama in Several Stages

Andreas von Poschinger (Bavarian Environment Agency, Germany)

Abstract. The Flims rock slide was an event in several stages, so a chronologic overview is helpful. In the last ten years there was a new impetus in the investigation of the Flims rock slide. The Flims slide in eastern Switzerland concerns about 9 km³ of rock mass and so it is known to be the largest in Europe and one of the biggest worldwide. Due to till and erratic blocks on top of the slide mass it was supposed to have a syn-glacial age.

The triggers of this new interest were the results of a radiocarbon dating, indicating instead a clear post-glacial age (Poschinger and Haas 1997). Even if only few new aspects about the slide event itself had been found in the last years, much new information about the main consequences of the rock slide could be shown up.

As a usual consequence for large rock slides several lakes were dammed. There extends and the lake level altitudes could be estimated. Obviously, the main lake, called Lake Ilanz, drained soon after the filling of the basin in a catastrophic flash flood, but it drained only partly. A relict lake at lower level is supposed to have survived for a longer time.

Another consequence of the Flims event, less common to large rock slides, was the extent and the mechanisms of the displacement of the alluvium on the valley floor. Several hundreds of thousand cubic meters must have been squeezed out. They were forced to flow upstream the valley of the river Hinterrhein. The rather characteristic sediments can be found now at a distance of about 13 km from the tongue of the rock slide deposits. The mobilised alluvial sediments must have reacted as a transport medium that was able to move large coherent components of loose rock with diameters of tens or even hundreds of metres on a distance of about 8 km. By this, the radius of the catastrophic consequences of the rock slide was more than doubled.

Keywords. Rock slide, rock slide dam, liquefaction of alluvium, hazard zone

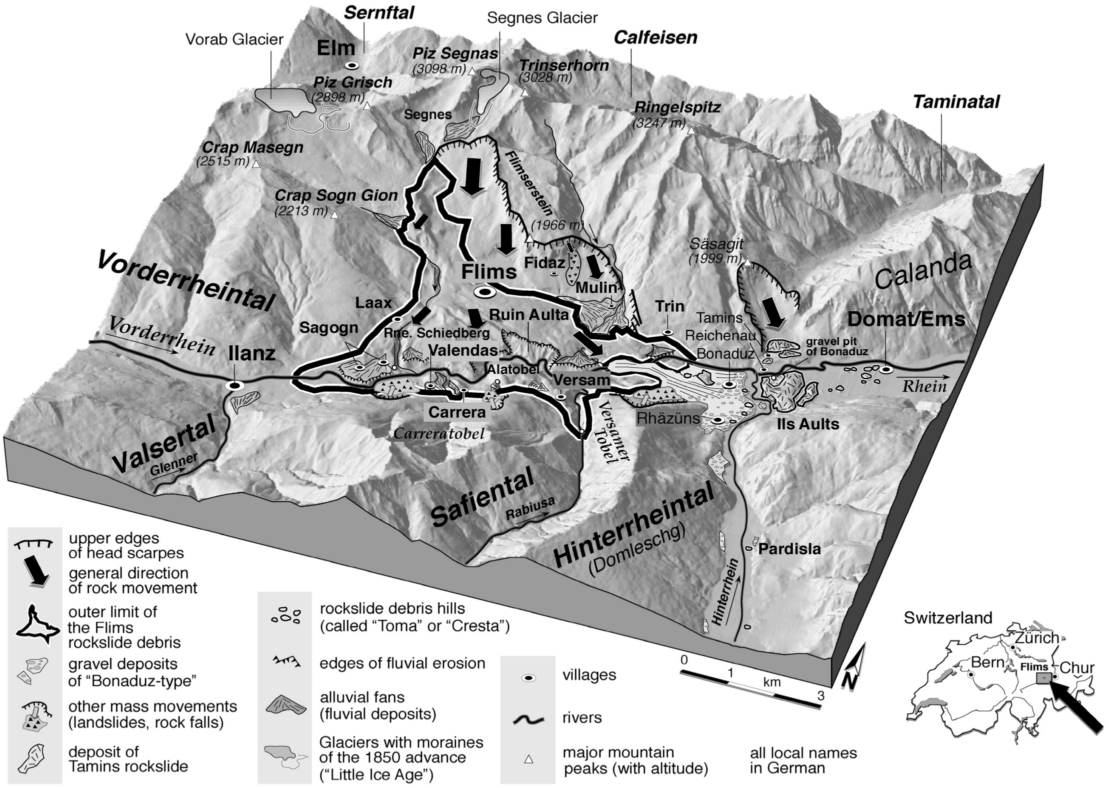

Fig. 1 3-D view of the surroundings of Flims. Block diagram reprinted with permission from Federal Office of Topography (BA024825), from: Poschinger at al. 2006.

1. The Tamins rock slide as a precursory event

Only several kilometers east of the Flims rockslide deposit, another large rock slide had occurred: The Tamins slide from the Säsagit Mountain (fig. 1). With a volume of about “only” 1.5 km³ (Abele 1974) it always remained in the shade of the neighboring Flims rock slide. That is probably the reason why no research work has been done concerning merely the Tamins slide. It has been dealt with only by researchers concerned mainly by other topics: either the Flims rock slide or some strange sediment in the adjacent Hinterrhein valley (s. below). The chrononologic classification of the Tamins event is crucial for the understanding of the whole very complex history of the Flims event in the larger sense.

In former literature (e.g. Abele 1974) the Tamins event had been classified to be overridden by the last Wurmian glaciers, so to be older than about 15.000 years. As a proof for glacial influence erratic pebbles on top of the slide mass were mentioned. Also some striation has been described that was attributed to the overriding glacier. More recent investigation instead showed in many examples that erratic boulders on top of a slide mass are not a stringent proof for a glacial influence (e.g. Heuberger 1966, Poschinger and Haas 1997). Consequently, also the former dating of the Tamins event came in doubt. A recent surface exposure dating (Ivy-Ochs et al. 2008) gave a clear postglacial age. It is within the range of uncertainty (several hundred years) similar to that of the Flims event (s. below).

Several geologic and morphologic hints indicate that the Tamins slide is older than the Flims event. The arguments are explained more in detail in Poschinger 2005. In short, it is mostly the fact that the special sediment of the Bonaduz gravel (s. below) is lying over Tamins rock slide material with a sharp contact, but is intercalated with Flims deposits. The Tamins deposits form a barrier, limiting the Bonaduz sediments to the area upstream of this obstacle. This can not be understood, if the Tamins rock slide barrier did not exist already before the deposition of the Bonaduz gravel. As the Bonaduz gravel are assumed to be mobilized by the Flims event (Poschinger and Kippel 2008), the Tamins rock slide must have happened already before the Flims event.

2. The Flims rock slide event

The Flims rock slide (fig. 2) had been described in detail in many publications. A synoptic overview showing the historic evolution of the knowledge is given in Poschinger et al. (2006). It is commonly accepted, that the whole mass had come down in one single event. The mass of Jurassic and Cretaceous limestone slid down on sedimentary layering structures more or less parallel to the slope. It preserved its structure but got entirely crushed during the transport and mostly at the impact on the opposite slope. The travel time is estimated to have taken about 10 minutes or even more.

Pollet and Schneider (2004) made a detailed investigation on the internal fabric. They proposed an idealized theoretic facies profile. In the field, instead, these types of facies hardly could be confirmed. As the mass reacted more as a block than as a flowing mass, also the term “sturzstrom” used by Pollet is not appropriate.

Due to the lack of clear indications about the thickness of the deposits, the volume is still under discussion. A recent reconstruction of the pre-rock slide morphology with GIS-tools by Caprez (2008) gave figures of 7-7.3 km³ for the volume of the detachment area and 8.6 to 9.3 km³ for the deposit. The latter figure has to be added by the erosional volume in the Rhine gorge (Ruin Aulta, fig. 1) of about 1.5 km³, resulting in a total volume of the deposition of about 10 to 11 km³. The difference between the volumes of the detachment and the accumulation areas is still to be discussed. The surface covered by clear rock slide deposits concerns 52 km².

Fig. 2 The cliff of the Flimserstein in the background represents the detachment area. The deposits of the rock slide in the foreground show secondary river erosion

A simple calculation about the energy released during the event had been done by the author (2006). Assuming a minimum volume of 8 km³ and a vertical displacement of the centre of gravity of about 1’100 m, a density of 2.2 x 10^3 kgm^{-3} gives an energy release of about 1.9 x 10^{17} Joule. It is clear, that an earthquake had been triggered by the event. Instead, if the event might have been triggered by an earthquake is mere speculation.

The Flims event first was dated to 8’200 – 8’300 yr BP (uncalibrated, about 9’300 cal yr BP) by Poschinger and Haas (1997) by radiocarbon on pieces of wood at the front of the slide mass. Surface exposure dating by Ivy-Ochs et al (2008) roughly confirmed these data. Deplazes et al. (2007) could precise this age by samples of wood in and just underneath small lakes on top of the deposits. They constrain the event to the period of 9’480 to 9’430 cal yr BP.

3. Liquefaction of alluvial deposits

Near the village of Bonaduz (fig. 1) a peculiar gravel and sand sediment is exposed, called Bonaduz gravel. The whole sediment pile of about 60 m shows about no sedimentary structure but a distinct fining upward. Within this sediment large components of rock slide debris are enclosed. These components with diameters of few to hundred meters (fig. 3) are entirely crushed, but preserve the former rock structure. Accordingly, during the transport over many kilometers they have not been subjected to great shear stress. The small hills, created by these components, are called Cresta and Toma hills. They can be found far upstream in the Hinterrhein valley, e.g. at Pardisla (fig.1, 3), up to about 8 km away from the tongue of the Flims deposits.

Fig. 3 Toma hill of Pardisla. The whole hill, consisting of crushed rock slide material, had been transported over more than 8 km upstream the Hinterrhein valley

Following a hypotheses given by Pavoni (1968) and as explained more in detail in Poschinger and Kippel (2008), the Bonaduz gravel is interpreted as the sediment of a fluidised material. The author suggests that the fluidisation occurred during the impact of the Flims rock slide mass on the Vorderrhein valley filled with water saturated alluvium. This caused a shock to the alluvium, made up of fluvial gravel and glacial lake sediments. The alluvium became very mobile and was squeezed out by the slide mass. It started to travel downstream in a stream like way. The special grain size produced by the crushing during the impact allowed a very high density of the flowing masses. Within this, single components could be transported without being exposed to great shear stress. Accordingly, the prevalent flow regime must have been laminar with little turbulence. During the flow, the larger components settled out and so the upper parts got relatively finer, creating the fining upward grading.

Sub vertical drainage pipes indicate an important amount of pore water in the Bonaduz gravel. It is quite possible that the former lake Bonaduz, dammed by the Tamins rockslide barrier, was still existent during the Flims event. So, the Bonaduz gravel may have been mobilised within the lake. On its way down the Vorderrhein valley the flowing masses arrived at the deposits of the already existing Tamins rock slide (Poschinger 2005). Its main barrier diverted great parts of the stream to the south into the Hinterrhein valley. Separate rock slide deposits of the Tamins slide were picked up, incorporated in the stream and transported further upstream.

At the point of diversion at Ils Ault (fig.1), the upstream surface of the Tamins deposits were polished and scratched by the debris stream. Parts of it, including large amounts of water of Lake Bonaduz, overflowed the rockslide barrier of Ils Ault, that became well rounded on its top and cleaned from almost all loose boulders. This part of the flow ran down the Rhine valley and caused an important sediment input to Lake Constance, 80 km downstream the Rhine valley (Wessels, 1998).

Probably it was also responsible for the transport and the deposition of the large “Toma” hills near Domat-Ems (fig. 1) and even at Chur, 8 km downstream from the Tamins barrier. There, rock slide hills have been interpreted until now as local rock slide deposits from the nearby Calanda Mountain (e.g. Abele 1974). Many features instead indicate the same origin than for the hills in the Hinterrhein valley.

4. The rock slide lakes

The Flims rock slide has dammed two large lakes as well as several small lateral ponds. The biggest lake was that of Ilanz (fig. 1) and only this will be discussed here. The maximum level of that lake is a crucial point of debate. A level of about 820 m a.s.l. is demonstrated by delta sediments, morphological traces and by lake sediments. This evidence marks the level at which the lake existed for some time. As important floodplain sediments also reach to that level, a first breach must have affected a higher level and the lake must have been dammed at that higher level for only a short time without leaving clear traces. This level might have been about 870 or even 900 m, but surely not more than 936 m. At that altitude a depression on the right bank indicates that no important overflow has ever taken place (Poschinger 2005).

The lack of any clear morphological hints or of sediments higher than 820 m indicates that this greater lake existed only for a short time and the first breach occurred very soon after the rock slide event, probably already in connection with the first overtopping. The filling of the lake up to 870 or even to 900 m, considering the actual mean discharge and neglecting seepage, took about 2-4 years.

In the literature there has been much speculation about the persistence of Lake Ilanz. The typical lake sediments beneath the actual Vorderrhein river-bed west of Ilanz and so right in the centre of the Lake Ilanz basin have a thickness of about 20 m. But also on the shoulders of the valley, near the documented lake level of about 820 m a.s.l., important outcrops of lake sediments are preserved (Poschinger 2006). The layering is almost horizontal and indicates that these sediments are not only lateral remnants of a partial filling, but that the basin was probably completely filled by those sediments. Thus, the lake must have persisted at this level for many years. Taking the large volume of the basin to be filled by sediments, a time span of 1000 and more years is reasonable. As already mentioned above, these sediments are only the witnesses of the longer lasting lake level at 820 m.

Several earlier authors (e.g. Abele 1974) assumed a complete and instantaneous break of the dam with catastrophic circumstances. All refer to a huge inclined erosion- and floodplain, stretching over more than 6 km. Probably already the first overtopping was responsible for the break. This might explain the observations of Wessels (1998) in the sediments of Lake Constance. He found two anomalies in the regular layering of the sediments, separated by several layers of normal sedimentation. According to the findings mentioned above it is realistic to link these two layers to the Flims rock slide with the generation of the Bonaduz gravel (first anomaly) and to the outbreak of Lake Ilanz (second anomaly).

Uncertainty still prevails about the structure of the former rock barrier. Probably the break started in the covering coarse upper facies. It must be assumed that subrosion as a consequence of heavy seepage within this facies played an important role for the first failure. The main part of the dam was built up by a dense three-dimensional jigsaw facies that is evidently more resistant. Erosion also has cut into this facies, but with the breach getting longer and longer, with the discharge reducing with the reduced lower lake surface and with the material harder to erode the breakage must have come to a stop.

Obviously the enduring barrier was stable until the remaining basin was filled, at least to a great part, with sediments. From then, the sediment load at the barrier increased and erosion became more active again. The further down cutting of the gorge from 820 m to the actual Vorderrhein level of 610 m NN, so additional 210 m, has not produced any important flood sediments. This indicates that it progressed slowly.

Conclusions

Due to its size without any doubt the Flims rock slide event was disastrous for the whole region. The investigations showed that it was not only the mere rock slide itself that devastated the valley. Secondary effects were responsible for exporting the effect to distant areas. Rather well known is the secondary effect of a giant flood after the break of the landslide dam, releasing large amounts of water in short time. Almost unknown instead is the process of mobilising the alluvium in the valley floor by the impact of the rock slide mass. In the case of the Flims rock slide obviously a volume of many hundreds of million m³ were fluidised. The resulting high density stream travelled over more than 13 km upstream the valley.

In case of future very large rock slides threatening these processes should be considered. This means that the area at risk might include a much larger area than it would be defined considering the rock slide only. Unfortunately, there is still too little knowledge about the specific conditions that are necessary to incite such an oversized debris stream. Any further research on the topic, as well in Flims as on other sites in the world, is most welcome.

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Indonesia Disaster Management Law: Challenges for Implementation

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The World Landslide Forum is a prestigious forum fitting to be a platform for Indonesia being one of the most disaster prone countries in the world to share its success and issues in disaster management. This presentation focuses on challenges that are confronting the implementation of a new disaster management policy paradigm in Indonesia. We maintain that the challenges to the policy implementation impinge upon the effectiveness of the management of landslide in Indonesia.

Masyarakat Penanggulangan Bencana Indonesia (MPBI) or Indonesian Society for Disaster Management was instituted on 03-03-03 by a group of professionals mostly working in various fields of disaster management as an avenue for promoting professional disaster management. Concurrently, the Society as one of the leaders in civil society has also been increasingly taking active role in promoting disaster management policy and practice.

Since early 2003, the MPBI advocated that a coherent policy was desperately needed in Indonesia to increase attention and to induce more favourable behaviour towards the overall disaster risk reduction to break the vicious circle of devastating disasters. One characteristic of effective policy is the size or magnitude of the change in behaviour targeted by the policy itself.

Charles Lindblom (1979), in his exploration of what he calls the "science" of muddling through, suggests that "incrementalism ... [or] political change by small steps" (p. 517) is the key to effective policy. Following the devastating Indian Ocean Tsunami at the end of 2004, however, MPBI seeing it even clearer that Indonesia needed radical policy change in disaster management. The nation can no longer afford to focus on emergency response and its energy must be re-allocated to reducing risks. This may entail, among others, a robust institutional arrangement, coherent end-to-end disaster intelligence system, sufficient resource allocation for disaster risk, and indeed change of life and disaster perspectives of the people and government of Indonesia.

Beginning 2005, MPBI led the policy advocacy shift to the Parliament. Together with other stakeholders Government agencies, NGO, INGO, the military, we supported the House of Representative of Republic of Indonesia in drafting a Disaster Management Bill. The MPBI as a member of civil society demanded that Government reckon with its constitutional duty to render protection to the motherland and its inhabitants and make disaster risk reduction and protection be part of each and every Indonesian people's basic rights. At the same time, the government should also perform as the duty bearer to deliver such protection, and be liable to contest when it fails to deliver adequate and sufficient protection and response to disasters.

After four arduous years of advocacy and struggle both within and without the parliament, Indonesian Disaster Management Law was ratified in mid-2007. It was and still is, a landmark legislation with a very progressive spirit. It is a comprehensive policy that calls for an overhauling of the disaster management institutions, resource allocation and mobilisation, and an integrated approach involving government, civil society and the private sector. It took bold decision to call for the full implementation of its provisions at national level within six month after the ratification, and one year at provincial and district levels.

A saying in the field of Public policy: "Everyone loves policy, but no one loves implementation" certainly rings true in the case of Disaster Management Policy in Indonesia. More than one year has passed and the Disaster Management Law has achieved little to changing the nation's behaviour regarding disaster management. The policy derivatives that are supposed to be in place are still partial and the institutional rearrangements achieved only in the "tinkering" the national agency. Resources required to mount a decent disaster management is more and more appear to remain to be diminutive comparative to the requirements.

The implementation of this ideal piece of Legislation was proven to be much more complex than it was contemplated. In this regard MPBI as a member of civil society and actively participating actor in the disaster management policy seeks, in this presentation, to examine why the Disaster Management Law falters at the implementation and propose how it should be addressed. This is being undertaken in the spirit of introspection to recommend way forward with the implementation. As doing so, MPBI continues to promote the principles and practice of disaster management and take active part in the dissemination of the Disaster Management Law and its derivatives to various sectors and the local levels.

Obviously some policies are more effective than others. This is an effort to examine the Disaster Management Law in changing target group behaviour in order to describe the characteristics of its effectiveness. Among the first lines of questions in this examination ought to ask if the Disaster Management Law is indeed an effective public policy. MPBI originally conceptualised the disaster management Law to successfully effect a change in target-group behaviour with a minimum of resistance. In reality while disaster management as a concept is generally acceptable, its translation into institutional and societal behaviour is contentious. In addition there is always the institutional reluctance and inertia to abide to the changes prescribed by the new law.

The Law attempted to be specific enough to clearly delineate expected behaviour without being so rigid that it does not allow local implementation flexibility. In practice the provisions of the new law are proven not to be specific enough and have too many loopholes that allow multiple interpretations. Ultimately this brings about disputes that prevent the implementation.

It must make sense within the context of other policies that are in effect, and it must be practical in terms of implement ability. Despite the extensive efforts de-conflict the law with other legislative products, there are collisions namely with a legislation on local governance that has provision on format and level of government agencies and officials. There is also a serious overlap with the legislation on coastal area management that also stipulate provisions and obligations for disaster mitigation. Obviously much more efforts must be exerted to prevent intra-institutional conflict by establishing a specific mandate and providing sufficient resources.

In addition there are also a host of other problems associated with the implementation of the Disaster Management Law. This may include but not limited to the following:

- Lack of capacity–the expertise, organisational routines and resources available to support disaster management planned change efforts are not readily available. In Indonesia this field is a budding discipline that emerged for less than a decade.
- Lack of will–there is insufficient will or motivation to embrace the disaster management policy objectives. In its effort to involve everybody the Law does not sufficiently assign anybody particular. In effect, may of the tasks for implementation are either disputed or being left unattended
- Lack of authority–against the backdrop of democratisation in the country, disaster management authority appears to be distributed, or at least perceived to be so, equally to various ministries and non-portfolio ministries. Case in point is the bitter dispute between the National Disaster Management Agency that sees itself to be the technical authority has been on logger head collision with the Ministry of Home Affairs that sees itself to be the authority in local governance. The net result is that local disaster management agencies cannot be established within a year as stipulated by the Law.
- Lack of credible leadership–the discourse of disaster management in Indonesia is lodged under the auspices of the Coordinating Ministry for People's Welfare whose leadership has been linked to a contentious disastrous volcanic mudflow. At the public sphere there is no single individual to provide the moral guidance to disaster management issues. There is not enough champions to conduct credible public debate to shed a light to disaster management given the public airspace that is very crowded with so many other issues.

Where are we heading with these issues?

At this rate it is going right now the Disaster Management Law will not be adequately implemented even within the next decade. As time goes by, there is increasing risk of the policy being diluted and fading into obscurity. In addition, disaster management would fall back into "business as usual" and other incremental policies may be formulated that further undermine the integrity of the policy. It is therefore imperative that measures being taken to address the stagnation. Some of these recommendations are as follow:

Exerting public pressure towards implementation: all possible avenues including various platforms must be mobilised to demand government to come up with more concrete deliverables against timeline of implementation. The emphasis must be given to promote buying in amongst government agencies and high officials as well as creating demand from local governments to produce a self-propelling energy within the national government.

Reinvigorating the public discourse: leaving such an important issue such as disaster management solely at the hand of the bureaucratic administration is simply too dangerous. The civil society must re-claim the discourse to re-attach importance to the issue. Disaster management discourse must be framed against the higher, global, and universal values and issues such as human rights values, good governance, MDGs, climate change, etc., and thus it is not simply pitted against the pragmatic and bureaucratic debates.

Reasserting legislative pressure: it is rather regrettable that the special committee of the parliament was dissolved after the Law was ratified.

This thrust the implementation issues squarely to the hand of the executive branch. MPBI will promote the convening of the parliament's special committee to promote accountability line both on the part of the policy maker and, more importantly on the part of the government against the stipulated time schedule.

Building stronger and broader powerbase: MPBI and other practitioner forums have the inevitable responsibility to establishing, strengthening and broadening the circles of professionals and practitioners. This is critical to sustain the momentum as well as to supply the necessary capacities that increasingly in demand as the policy are gearing towards implementation.

Linking with international support: international community both the United Nations and multilateral/bilateral donors must be called upon to extend support to Indonesian government particularly for activities that may require external supports. Forum such as this international conference is an ideal platform to expand network of supports to pursue the implementation of the policy.

In conclusion, the case of disaster management law in Indonesia demonstrate that a good policy is not in itself and by itself an effective means of changing social behaviour. Shortcomings and issues both internal to the policy itself as well as the politico-administrative environment place formidable hindrance to the implementation of the policy. Failure to implement such important policy will bring serious consequences for a disaster prone country such as Indonesia. In this regard there are various measures that must be brought forward to infuse credibility and accountability to the process. Against this background the civil society and international community have important role to hold Indonesian government accountable to their mandate and responsibility while, at all time, seek every opportunity to take active part and support the translation of the disaster management law into implementation.

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Deciphering Landslide Behavior Using Large-scale Flume Experiments

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Abstract. Landslides can be triggered by a variety of hydrologic events and they can exhibit a wide range of movement dynamics. Effective prediction requires understanding these diverse behaviors. Precise evaluation in the field is difficult; as an alternative we performed a series of landslide initiation experiments in the large-scale, USGS debris-flow flume. We systematically investigated the effects of three different hydrologic triggering mechanisms, including groundwater exfiltration from bedrock, prolonged rainfall infiltration, and intense bursts of rain. We also examined the effects of initial soil porosity (loose or dense) relative to the soil's critical-state porosity. Results show that all three hydrologic mechanisms can instigate landsliding, but water pathways, sensor response patterns, and times to failure differ. Initial soil porosity has a profound influence on landslide movement behavior. Experiments using loose soil show rapid soil contraction during failure, with elevated pore pressures liquefying the sediment and creating fast-moving debris flows. In contrast, dense soil dilated upon shearing, resulting in slow, gradual, and episodic motion. These results have fundamental implications for forecasting landslide behavior and developing effective warning systems.

Keywords. Landslide, experiment, failure behavior, hydrologic trigger, critical state, porosity

1. Introduction

Some landslides accelerate catastrophically with potentially lethal consequences, whereas others creep intermittently downslope, perhaps causing property damage but rarely fatalities. Rainfall patterns that initiate slide motion vary as well. Some slides require prolonged rainfall to instigate motion, yet others occur following short, intense rain bursts. Such profound differences in behavior have fundamental implications for designing mitigation strategies, implementing effective warning systems, and reducing risk.

Precise evaluation of the causes of diverse landslide behavior is difficult because controlling effects cannot be isolated in the field; this limits our understanding of landslide dynamics as well as our prediction capabilities. Previous studies have attempted to induce failure on natural hillslopes, with varying degrees of success (Harp et al. 1990; Cooper et al. 1998; Ochiai et al. 2004). Other studies have relied on small-scale laboratory tests or experiments to infer landslide behavior (Eckersley 1990; Wang and Sassa 2001; Okura et al. 2002; Take et al. 2004).

As an alternative to field investigations and small-scale experiments, we used the U.S. Geological Survey (USGS) debris-flow flume in Oregon, USA to perform controlled, large-scale landslide initiation experiments. This flume allows us to create landslides similar to small natural failures, but without the scale limitations of typical laboratory tests.

Our experiments focused on deciphering the influences of various hydrologic triggers and differing initial soil porosities on failure style, timing, and subsequent landslide acceleration. We examined three hydrologic conditions that can initiate landslide movement, including: groundwater exfiltration into soil from bedrock, prolonged rainfall infiltration, and bursts of intense rainfall (Reid et al. 1997). We also systematically investigated the effects of initial soil porosity (n) on landslide dynamics at a field scale. A well-established maxim of soil mechanics holds that failure behavior during shear depends on the initial soil porosity (or void ratio) relative to a specific critical-state porosity (Schofield and Wroth 1968). Saturated soils looser than critical state contract as they shear, thereby elevating pore pressures and inducing rapid flow. Soils denser than critical state dilate as they shear, temporarily reducing pore pressures and retarding motion.

Here, we briefly describe some of our landslide initiation experiments, document the effects of different hydrologic triggers, and illustrate landslide behavior derived from different initial soil porosities. We conclude by discussing some implications of these results for predicting landslide behavior and developing effective warning systems.

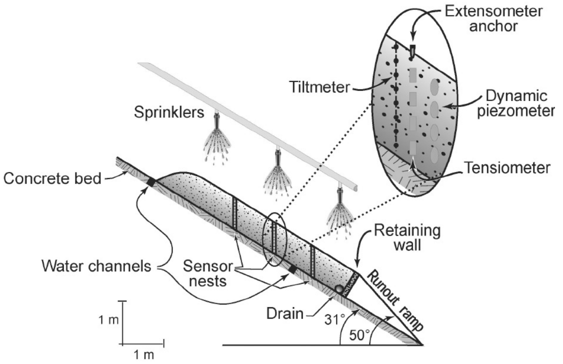


Fig. 1 Schematic longitudinal cross section of landslide experiments at the USGS debris-flow flume. The magnified ellipse depicts the positioning of sensors in vertical nests (from Iverson, et al. 2000).

2. Experiment Configurations

In each of six experiments, we induced failure in a 0.65m thick, 2m wide, 6m^3 prism of loamy sand placed behind a rigid retaining wall on the 31° flume bed (Fig. 1). We systematically investigated hydrologic triggering of sliding by either injecting water from channels in the bed (to simulate groundwater exfiltration), by overhead sprinkling (to simulate prolonged or intense rainfall), or a combination of these methods. We investigated differences in the failure behavior of dense and loose soils (relative to critical state) by varying initial soil porosity. To create loose soil, we dumped and raked the loamy sand without further disturbance. To create dense soil, we used controlled vibratory compaction on a sequence of 10cm thick soil layers of the same loamy sand. Further details of the USGS flume configuration can be found elsewhere (Iverson et al. 1997; Iverson et al. 2000).

About 50 sensors monitored at 20 Hz during each experiment included two nests of tiltmeters (total of 17 or 18 sensors) to measure subsurface deformation and slip-surface location, two surface extensometers to measure downslope displacement, three nests of tensiometers (12 total) and dynamic pore-pressure sensors (12 total) to record evolving pore-pressure fields, and three nests of TDR probes (12 total) to detect changes in soil moisture. We also extracted soil samples for laboratory measurements of porosity, shear strength, saturated hydraulic conductivity at various porosities, unsaturated moisture retention characteristics, compressibility, and, in a series of special triaxial and ring-shear tests, the soil’s critical-state porosity (n=0.44).

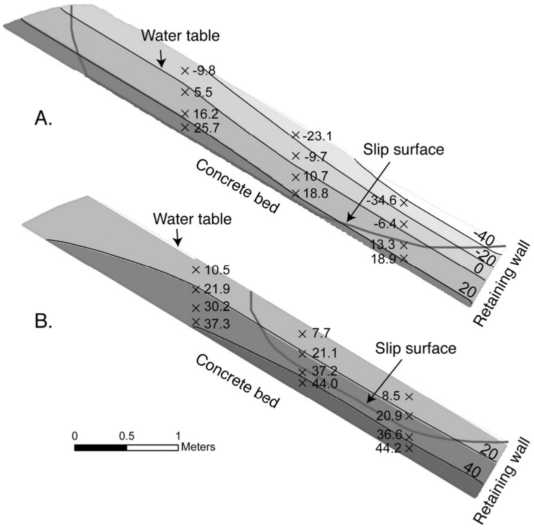
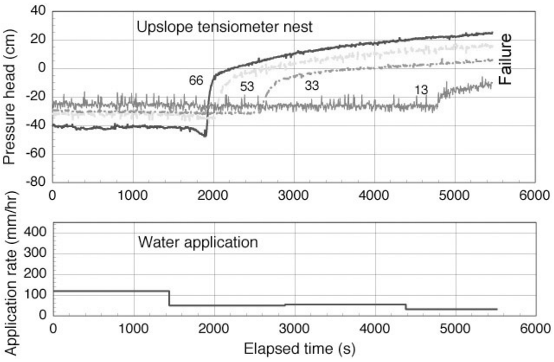


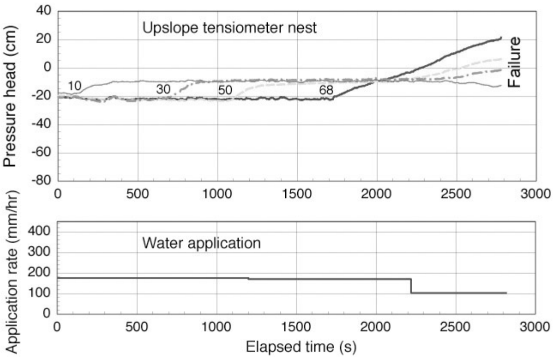
Fig. 2 Cross sections of experimental soil prisms showing slip surface locations, water table locations (zero contour), and pore-pressure heads (cm) at failure. A. Loose soil with groundwater injection. B. Dense soil with both groundwater injection and sprinkling.

3. Hydrologic Conditions Triggering Failure

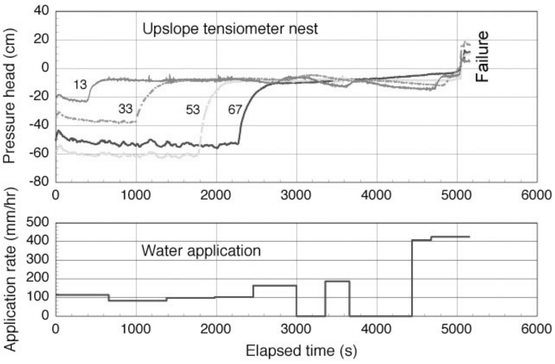
Both precursory and post-failure behavior varied dramatically depending on the initial porosity of the soil relative to its critical-state value. Controlled compaction used in the dense soil experiments resulted in lower hydraulic conductivities and greater shear strengths compared to those with looser soils. Failures in loose soil (n>0.44) typically occurred following about 50-90 minutes of water application, whereas failures in dense soil (n<0.44) usually required 4 to 5 hours of water application. Three experiments with loose soil resulted in nucleation of failure along the concrete flume bed with subsequent propagation of the slip surface upward through the soil prism to daylight near the retaining wall (Fig 2A). Failure often occurred with large parts of the soil partially saturated. In contrast, experiments with dense soil typically produced slip surfaces that nucleated within the soil prism, not along the bed, when positive pore pressures were measured throughout the soil (Figure 2B). With denser soil, both sprinkling and groundwater injection were needed to instigate failure in a timely manner.



A. Groundwater injection



B. Prolonged sprinkling



C. Initial wetting plus intense burst of sprinkling

Fig. 3 Pore-pressure head response and water application rate (normalized for area) for three failure experiments with loose soil. Vertical depths of tensiometers in cm indicated next to lines. A. Response during groundwater injection. B. Response during prolonged sprinkling. C. Response during initial wetting and subsequent intense burst of sprinkling.

In the loose-soil experiments, we were able to induce failure using three distinct water application methods: groundwater injection, prolonged moderate-intensity sprinkling, and initial wetting (without saturation) by moderate-intensity sprinkling followed by a high-intensity burst of sprinkling. Each of these methods resulted in different water pathways, different sensor response patterns prior to failure, and different pore-pressure fields at failure. For example, groundwater injection led to a water table that advanced upward, wetting over half the soil prism before pressures at the bed were sufficient to provoke collapse (Fig. 3A). With moderate-intensity surface sprinkling, an unsaturated wetting front propagated downward until reaching the flume bed, and then a mostly saturated zone built upward, with the highest pressures at the bed at the time of failure (Fig. 3B). With the third trigger using a high-intensity sprinkling burst, pore pressures remained near zero until a rapid rise at failure; this was likely due to a small pressure perturbation from the burst that traveled rapidly downward through tension-saturated soil (Fig. 3C). Failure occurred in the absence of widespread positive pressures after about 10 minutes of intense sprinkling.

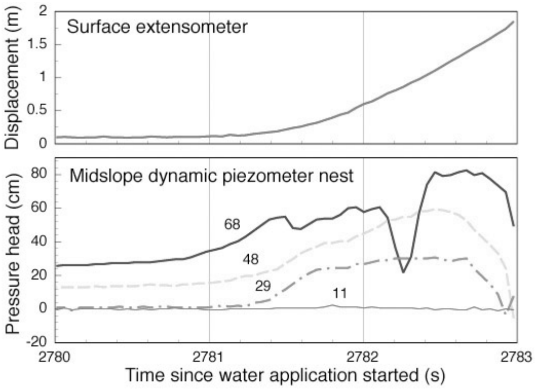
4. Landslide Behavior Following Failure

Our experiments demonstrated that a variety of water application methods and resulting pore-pressure distributions triggered failure, whereas the dynamic behavior following failure was primarily controlled by the initial porosity of the soil. In the loose-soil experiments (n>0.44), the dynamic behavior was remarkably consistent. Rapid soil contraction during shearing caused pore pressures to increase dramatically within 1 second as failure began; nearly complete liquefaction failure occurred within 2 seconds as the mass rapidly accelerated downslope (Fig. 4A). As a consequence, all of the loose-soil experiments produced fast-moving debris flows that traveled far downslope (Fig. 5A). Similar collapse behavior has been observed in other landslide initiation experiments using loose soils (Iverson et al. 1997; Reid et al. 1997; Wang and Sassa 2001; Okura et al. 2002; Moriwaki et al. 2004).

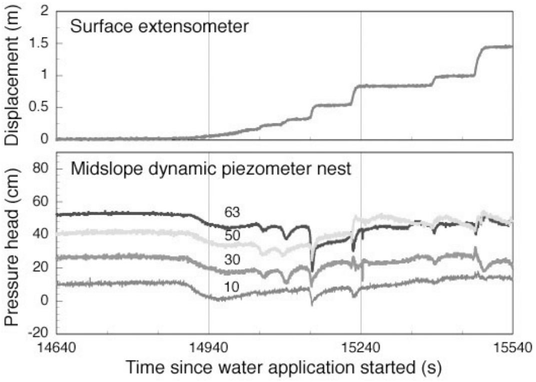
In marked contrast, our experiments with dense soil (n<0.44) produced slow-moving landslides. Dynamic behavior during failure in the densest soil consisted of repetitive cycles of slow (< 0.1 m/s) movement, each resulting in modest (< 0.3 m) displacement (Fig. 4B). Each movement cycle started with downslope displacement caused by elevated pore pressures. This displacement provoked soil dilation, a consequent decrease in pore pressures, and a temporary halt in slide movement. The cycle would then repeat, as pore pressures would slowly rebuild, triggering renewed slide displacement. Dilation of the dense soil during shear with concomitant pore pressure decline thereby regulated landslide motion (Iverson 2005). This regulation resulted in a slow-moving landslide with small secondary failures emanating from its toe (Fig. 5B). Video footage showing these dynamic behaviors during experiments conducted in June 1998 and June 1999 can be viewed at http://pubs.usgs.gov/of/2007/1315.

5. Discussion

We used the same loamy sand in each experiment. Our results demonstrate, however, that small variations in initial soil porosity can cause profound differences in landslide behavior, both in the hydrologic conditions triggering failure and in the post-failure dynamic response. Loose soils respond quickly to hydrologic triggering events, and mass failures in these soils can create rapid, potentially lethal debris flows. Dense soils respond more slowly and produce slow-moving landslides sometimes with episodic motion.



A. Loose soil

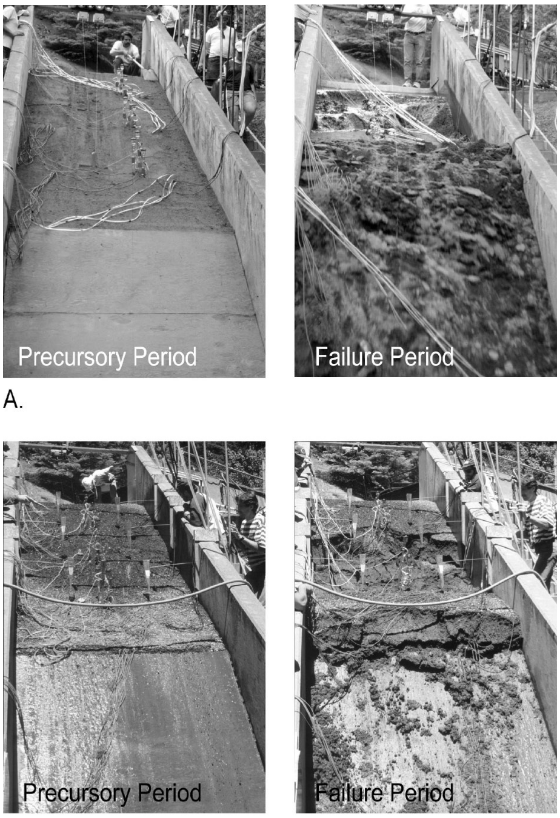


B. Dense soil

Fig. 4 Pore-pressure head response and surface displacement during two landslide initiation experiments. Note difference in time scales. Vertical depths of piezometers in cm indicated next to lines. A. Rapid failure in loose soil with dramatic rise in pore pressures. B. Slow failure in dense soil with episodic declines in pore pressures and concomitant deceleration.

Recognizing and understanding these differences is crucial for designing effective mitigation strategies and for better forecasting of landslide behavior. For example, differing hydrologic triggers can have strong implications for developing accurate landslide warning systems. Many regional warning systems rely on rainfall intensity/duration thresholds (Keefer et al. 1987). Our results illustrate that different hydrologic processes and different initial soil porosities lead to very different failure times. Thresholds developed for one hydrologic triggering process may not provide accurate warning when other processes instigate landsliding. Moreover, empirical thresholds based on data from multiple triggering processes may be unreliable.

Site-specific landslide monitoring systems often rely on ground-based sensors to detect destabilizing conditions (Reid et al. 2008). Here again, our experiments show that sensor responses leading up to failure can vary considerably (Fig. 3), and clear warning levels that span the gamut of triggering processes could be difficult to define. Our results emphasize that accurate warning systems need to be based on clearly identified landslide processes with appropriate thresholds developed explicitly for those processes. If multiple triggering processes exist, then multiple thresholds may be needed.



A.

B.

Fig. 5 Photographs illustrating landslide behavior during two controlled experiments. A. Behavior of loose soil (n = 0.52) prior to and during rapid failure triggered by groundwater injection. B. Behavior of dense soil (n = 0.41) prior to and during slow, episodic failure triggered by groundwater injection and overhead sprinkling.

Furthermore, effective mitigation strategies go beyond just forecasting when and where slides will occur. Fast-moving landslides are potentially lethal; mitigation strategies for these events are typically quite different than those for slow-moving landslides. Our results indicate that forecasting movement behavior cannot be based solely on material texture (i.e. clay or sand). A primary control is field porosity relative to the soil's critical-state porosity. These cautionary aspects reinforce the need to fully understand landslide processes and to not lump all landslides together when designing hazard mitigation strategies.

Acknowledgments

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Landslides, Natural Protected Areas and the Long-term Management of Mountainscapes: Emerging Challenges from the Study of the El Triunfo Biosphere Reserve, Chiapas, Mexico

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Abstract. In 1998 and 2005 two tropical storms triggered hundreds to thousands of landslides in the Sierra Madre de Chiapas of southwestern Mexico. A region that was particularly affected by these storms and associated landslides was the El Triunfo Biosphere Reserve (ETBR), an area of ~120,000 hectares that was set aside eighteen years ago to protect the elevated diversity of organisms and ecosystems of the Sierra Madre de Chiapas while promoting its sustainable development. Extensive landsliding in the ETBR raises numerous questions about the large-scale dynamics and conservation of these and other mountain ecosystems worldwide. Here we combine the classification of IRS and SPOT images with spatial analyses to examine the role of land cover/land use and reserve zonation on the distribution and extent of landsliding. We discuss the implications of our work for the management of the ETBR, including the role of protected areas in the conservation of landsliding as a key process driving the large-scale dynamics of mountainscapes.

Keywords. Landslides, protected areas, mountainscape dynamics, management and conservation, El Triunfo Biosphere Reserve, Mexico

1. Introduction

Setting aside areas for conservation has been a key strategy for the long-term protection of biodiversity, ecosystem functions, and cultural values worldwide. The establishment of most of these protected areas started in the early 80's and included lands settled, and influenced, by humans to various degrees. One consequence of this is that the short-term goals of people deriving directly and indirectly their livelihood from these areas and the long-term goals of conservationists and land mangers for the protection of these areas have often entered in conflict, a situation that persists to these days in many parts of the world. A variety of solutions have been proposed to ameliorate these conflicts and among these, the ecological-economic zoning of target areas for conservation proposed as early as 1970 gained wide acceptance (e.g., Unesco's Biosphere Reserves, Alves 2008). Not foreseen at the time was the threat of multiple drivers of change, of which climate change in interaction with a variety of ecological and social processes has the potential for large-scale transformations (Mehring and Stoll-Kleemann 2008, Schliep et al. 2008).

Landsliding has been a driver of change in mountainscapes throughout their history but only recently has it become a matter of concern for conservationists and land managers. The rapid an extensive loss of forest cover and soil due to landsliding in protected areas (Table 1) together with the delivery of large quantities of debris to the rivers, has been seen as a major environmental impact requiring due attention (Figueroa et al. 1987). On the other hand, it is known that the loss of forest cover and soil associated with the formation of landslides begins cycles of renewal that may explain the elevated levels of diversity and productivity observed in many mountainous regions worldwide. Therefore, the dual role of landsliding in mountainscapes poses numerous challenges for conservationists and land managers, in particular those involved in the management of biosphere reserves. First, the buffer areas in a biosphere reserve allow for the development of a variety of human activities that may be sustainable in terms of their effects on biodiversity (e.g., shaded coffee plantations of different kind and tree plantations) or ecosystem function (e.g., water cycle regulation). Yet landsliding is a complex process that interacts with a variety of human activities among which land-use change and road construction are the most studied ones and this can potentially modify natural cycles of landsliding. Second, the core areas in a biosphere reserve limit human activities in order to protect species, ecosystems, and natural processes. Yet, landsliding may strongly influence these areas challenging stakeholders' ideas about the need of protecting forest to reduce the risk of landsliding.

Here we focus on El Triunfo Biosphere Reserve (ETBR)-Polygon V to begin exploring the role of landsliding in protected areas. Specifically, we examine the distribution and extent of landsliding in relation to reserve zonation and land-cover/land-use change. The ETBR was established in the early 1990's in the Sierra Madre de Chiapas (SMDC) of southern Mexico to protect its enormous biological diversity that includes a mixture of species from temperate and tropical regions (Long and Heat 1991). In 1998 and 2005 tropical storms Javier and Stan, respectively, triggered hundreds to thousands of landslides in the Sierra Madre de Chiapas of southern Mexico. Storms of these magnitudes had been recorded in the early 1930's way before the biosphere reserve had been created (Waibel 1998).

Table 1. Protected areas in Central and South America affected in recent times by severe landsliding

Country, locality	Triggering event and name	Year
Mexico, El Triunfo Biosphere Reserve	ainfall, Storm San Javier and	1998, 2005
Guatemala, Sierra de las Minas Biosphere	Rainfall, Hurricane Mitch	1998
Costa Rica/Panama, La Amistad Biosphere	Earthquake	1993
Panama, Parque Nacional Darién	Earthquke, Darien	1976
Colombia, Parque Nacional del Huila	Earthquake, Paez	1994
Ecuador, Reserva Natural Cotacachi-Cayapas	Earthquake, Reventador	1987
Venezuela, Parque Nacional Avila	Rainfall	1999

2. Study Area

The SMDC (450 m – 2,450 m; 1,600 km^2) of Mexico is one of the several small, sub-parallel high ranges of Paleozoic age composing the Northern Sierras of Central America (Weyl 1980, Marshall 2007). It lies in a tectonically complex region, where the North American, Caribbean, Cocos, and Rivera plates converge. In addition to an elevated seismic activity, the SMDC is also subjected to seasonal severe rainstorms. Since the early 90's large tracts of land were set aside to create the El Triunfo Biosphere Reserve (ETBR), a status that allows the strict conservation of core, and sustainable development of buffer zones. Like in many other areas around the world, the establishment of this protected area occurred long-time after people had established a variety of activities that included timber production, coffee plantation, corn/bean production, and cattle ranching among others (Conanp 2007). Today the core area preserves needle and broad-leaved forests that vary greatly in species composition and structure, whereas the buffer area includes forests managed for timber production, different kinds of coffee plantations, and corn/bean plantations, and secondary forests. The SMDC has diverse climates, resulting from a combination of wide elevation gradients and precipitation shadows. The western flank of the SMDC draining into the Pacific Ocean is "wet" whereas the northern flank draining into the Grijalva watershed is "dry."

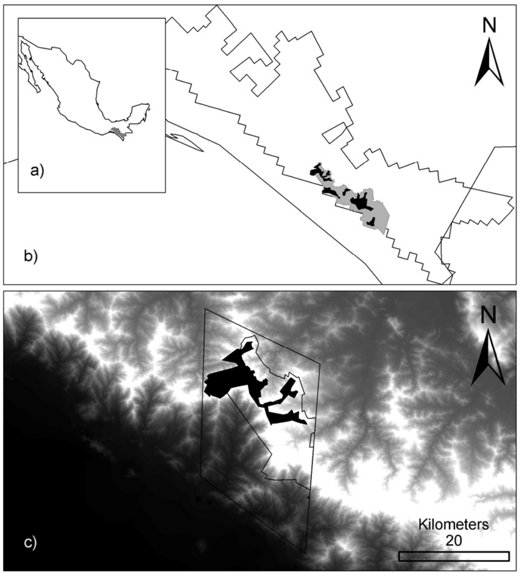

Fig. 1. (a) The Sierra Madre de Chiapas is located in southern Mexico. (b) The El Triunfo Biosphere Reserve includes an extensive buffer zone (gray) and five core areas (black). (c) In this study we focus on the western portion of the ETBR that includes the core area known as Polygon I (black) surrounded by its corresponding buffer zone within our study area.

3. Methods

To document the distribution and extent of landsliding we make use of various sources of remotely sensed data to map landslides and land cover within months of the occurrence of storms Javier [SPOT (multispectral-20 m) and IRS (panchromatic-5 m)] and Stan [SPOT (multispectral 10 m)]. The images were registered against a Landsat ETM+ mosaic (UTM15-wgs 84). We performed a supervised classification of the images to generate critical data to be used in a GIS for the analyses that we report.

4. Results and Discussion

The 1998 tropical storm Javier triggered landslides that denuded a total area of 406 ha in our study site within the SMDC. Landslides occurred in most zones and land covers but the total area stripped from vegetation and soil was highly variable among all possible combinations (Table 2). One possibility is that the land cover classes used in this study are not represented equally among the three zones (core, buffer, and remaining area) in which case additional calculations may allow to distinguish landslide "preferences" for certain land covers. If this is the case this may be indicative of conditions that favor the formation of landslides and this has two important consequences. First, if landsliding affects land covers corresponding to natural forest they may become natural candidates to investigate the influence of landsliding on biodiversity. Second, these land covers may become the target for conservation and management.

Table 2. Area covered by landslides according to zoning of the El Triunfo Biosphere Reserve and vegetation type around Polygon I

Zone	Selva alta perennifolia	Selva alta perennfilia with second growth	Broad-leaf forest	Pine forest with second growth	Pine forest	Fire-induced pasture	Cultivated pasture	Annual crops	Total landslides	Total area
Polygon V			48		1	34			83	6,837
Buffer	21	9	24	<1	<1	<1		2	56	18,872
Rest	29	38	11		2.4	153	21	16	270	41,863

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Space-borne SAR Analysis for Landslides Mapping in the Framework of the PREVIEW Project

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Abstract. Landslide inventory mapping by SAR interferometry is here described. Data from ERS and Envisat satellites, with temporal range from 1995 to 2008, were used to updated a landslide inventory map mainly concerning state of activity and geometry. A test site was chosen in Lombardia region (Italy) in the framework of the PREVIEW EU-GMES FP6 project. Results gave evidence that SAR interferometry is a powerful tool for landslides mapping due to its capability to measure ground displacements with millimetric accuracy.

Keywords. SAR interferometry, landslides mapping, ERS, Envisat.

1. Introduction

This work addresses the use of a multitemporal SAR interferometry technique for landslides mapping applications. The activities here described were carried out in the framework of an integrated project within the Sixth Framework Programme of the European Commission: Prevention, Information and Early Warning (PREVIEW). It proposes an end-to-end, integrated approach in close cooperation with all bodies involved in the risk chain in order to develop, on a European level, new or enhanced information services for risk management for the following types of hazards: Floods, Windstorms, Forest fires, Earthquake & Volcanoes, Landslides and Man-made hazards.

Deep seated, slow moving landslides on large areas were analyzed by spaceborne SAR interferometry: a test site in the Italian Alps of about 300 km2 was selected for updating pre-existing landslide inventory maps based on the advanced processing technique of Persistent Scatterers Pairs - Differential SAR Interferometry (PSP-DIFSAR), developed by Telespazio.

The stakeholders most interested, and therefore involved, in these activities were the Italian National Department of Civil Protection and the Office of Prevention of the Civil Protection of Regione Lombardia, who are in charge of landslide risk management at national, regional and local levels.

2. Study area

The test site is located in Valfurva, east of Bormio, in the Rhaetian Alps of the Lombardia Region, where significant rock-slides and deep-seated gravitational slope deformations were recognised; in this area Sackung type deformations affect pre-Permian metapelites, metabasites and marbles, as well as Late Pleistocene and Holocene glacial and rock glacier deposits. The deformation started after the Late-Wurmian age (15,000±11,000 years B.P.), and continued until few centuries ago, not excluding a present-day low-rate activity, Agliardi et al. (2001).

The evolution of fault systems, resulting in asymmetric trenches, led in some cases to the progressive failure of the slope during the last 10,000 years, as testified by large paleo landslide accumulations, and it is still in progress. Indeed, Lombardia Region is one of the most populated and urbanized region in Italy and it is also very prone to landsliding so the risk is high for human life and infrastructures. Local administrative authorities have a long experience in monitoring slope movements and recording historical data, measurements and investigations. One of the most hazardous phenomenon in the area is the 30 Mm^3 active "Ruinon" landslide, Crosta and Agliardi (2003). Such landslide is a typical rock slide with a slip surface depth of more than 90 m and characterized by a superficial debris flow almost 25 m thick.

2. Landslide inventory mapping by SAR interferometry

The PSP-DIFSAR technique jointly exploits spatial and temporal properties of the data, in order to improve the density and the accuracy of the measurements, Costantini and Rosen (1999), Costantini et. al (2002).

SAR images from ERS-1/2 satellites in the period April 1995 – January 2000 and from Envisat satellite in the time range August 2002 – March 2008, have been used, allowing the deferred-time analysis of past movements and the record of recent slope movements. The investigated area is 30 km x 30 km wide. The landslide inventory map, coming from end-user, was thus updated with the information from PSP-DIFSAR processing on ERS and Envisat satellites data, with measurements of mean velocities and displacement temporal evolutions of sparse points on the ground. From ERS images 26345 coherent points (Figure 1) were extracted (82.8 points/km^2) and the landslides characterized by the presence of points are 151 of the total 861 (27 km^2 of 62.75 km^2); instead, the coherent points extracted from Envisat images were 10624 (33.4 points/km^2).

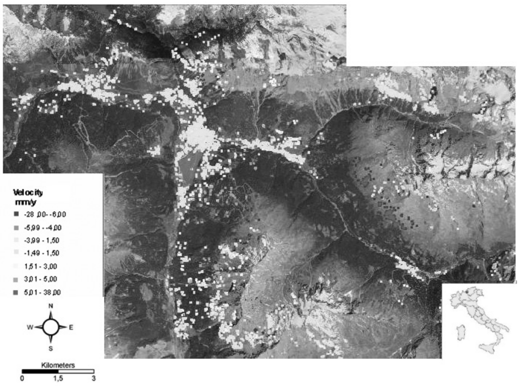

Fig. 1 Distribution of ERS1/2 points in the studied area

The results were examined in Geographical Information System (GIS) environment and were integrated with field surveys and in-situ measurements. The characteristics of the landslides were highlighted in the database: geometry, state of activity, typology, monitoring systems, interventions, source of information and the updating actions; furthermore, for each landslide area, the occurrence of points and the statistical description of their velocities were reported.

The main criteria used to define the state of activity were related to the mean velocities retrieved from the PSP-DIFSAR processing: e.g. if the velocity from Envisat data is above 2 mm per year then the landslide was classified as “active”. Main changes on the landslides concerned the state of activity and geometry while in some cases new landslides have been pointed out. An updated landslide inventory map was thus developed (Figure 2) in collaboration with end-users; field surveys have been carried out concerning some critical situation and validation activities with in-situ instrumentation are still going on.

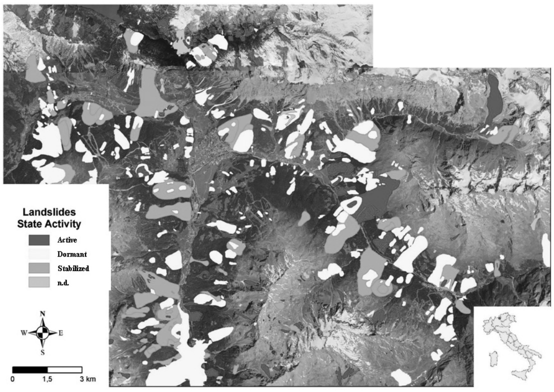

Fig. 2 Updated landslide inventory map

Conclusions

SAR images from ERS and ENVISAT satellites, with temporal range from 1995 to 2008, have been used for landslide inventory updating mainly concerning state of activity and geometry. PSP-DIFSAR technology has demonstrated its capabilities to map slow moving landslides for risk assessment and hazard zonation, even if the integration with traditional methods and field surveys is still necessary.

A system based on remote sensing techniques integrated in GIS with other traditional data can provide useful information to monitor the displacement of the land surface within landslide risk areas and can contribute to the mitigation of landslides hazards. both at national and local level.

Main limitations are due, of course, to the availability of radar satellite images and the processing of coherent points with good rate of reliability.

Acknowledgments

We thank the entire Preview Project team and especially acknowledge the Office of Prevention of the Civil Protection of Regione Lombardia and the Italian National Department of Civil Protection both of which were involved in the activities described in this work.

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Distribution and Classification of Landslides in Korean Peninsula (DPRK)

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Abstract. Geology and Distribution of landslides in the Democratic Peoples' Republic of Korea (DPRK) is presented. Types of landslides are classified (1) sliding surface condition, and (2) type of landslide body material. Rockfalls, shallow debris slides, and transitional landslides such as debris slides – debris flows are predominant. There are a lot of landslides in the volcanic deposits around Mt. Paektu which is located on the border of China. Deep retrogressive landslides of about 80-m-thickness are developed in the lahar deposits created by its 17th Century eruption.

Keywords. Classification, Case study, DPRK, geology, lahar

1. Geology and Distribution of Landslides

Most of the DPRK land is covered by Precambrian granite and crystalline schist, Precambrian Quartite and dolomite, Palaeozoic limestone and shale, as well as volcanic deposits around Mt. Paektu on the border of China. Major mountain ranges and plateaus are located along the eastern coast and along the northern border between China. Most of the landslides occur in northeastern Keima Plateau where the tectonic uplifting and inclining is active. However, Korean peninsula is less seismically active than adjacent Japanese islands and the triggering factor of landslide is heavy rains, rather than earthquakes.

There is no specific landslide prevention law has been made, however, Law for protection and increase of useful animals and plants (approved by the congress in late 1950's), Land Law (late 1960's), and National Land Environmental Protection Law (late 1970's) are regulating construction of houses and structures near the steep slopes. Ministry of Land and Environmental Protection is the relevant governmental entity for managing landslide prevention. The Geographic Institute of the National Academy of Science of DPRK has been engaged in landslide study as a part of erosion control engineering since 1955 for promoting agricultural and residential land conservation. Global environmental laboratory of the institute is the national center for landslide research in DPRK. Although this laboratory has investigated landslides over the territory for more than 50 years, however, almost no landslide statistics and inventory has been published. Distribution map of the investigated major landslide is shown in Fig. 1. Each landslide location is not precise and the plot density does not reflect the actual landslide density.

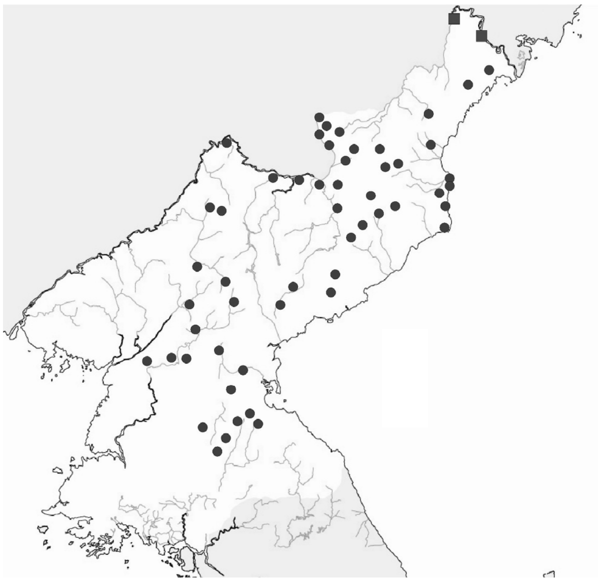

Fig. 1 Distribution of major landslides investigated by the National Geographical Institute of DPRK

Fig. 2 A typical rock debris slide near Pyongyang

2. Classification by Sliding Surface Condition

One of the authors (Rim) classified the landslides in DPRK by two keys. In this paper, his classifications of landslides in the Korean Peninsula (DPRK) are presented.

The key of the first classification is the sliding surface condition as; (1) hard and steep rock slope; (2) tectonic fault plane; (3) bedding plane; (4) boundary of lava – tuff layers; (5) lahar; (6) rock joints and schistosity planes; (7) eroded karstic voids/caves.

Among the type (1), rock falls and rock debris slides are most predominant. Highways are affected at many cut slope sites. Fig. 2 shows the typical rock debris slide site. Precambrian granite is very hard against weathering and deep slide is rarely observed. Often those falls and slides of rock or debris transitioned into debris flows. Fig. 3 shows typical transitional type landslide from debris slide into debris flow. It was triggered by a heavy rain storm in the summer of 2003 in the Jurassic granite on Mt. Onjin. This intense and localized rainstorm triggered numerous falls, slides, and debris flows around the site.

3.

Fig. 3 A debris slide – debris flow on Mt. Onjin.

Fig. 4 Fault cliff landslides on triangular facet along Chongchon river fault system.

Classification by Landslide Body Material

The second key for landslide classification is type of landslide body material as ; (a) Quaternary alluvial, colluvial, and deluvial deposits; (b) sedimentary rocks mostly sliding along the bedding plane; (c) lava; (d) pumice; (e) lahar. Landslides in the lahar deposits (e) are one of the most impressive landslides in the Mt. Paektu area. Fig. 5 shows the photo and schematic longitudinal section of the Daehyokok landslide, a typical lahar landslide. In the late 17th century, the volcano erupted and large amount of lahar was deposited on the flank and in the rivers. About 80-m-thick deposit has been eroded by the torrent and retrogressive landslides have been developed. These dynamic landscapes attract many tourists and the volcano is designated as natural heritage of the nation, however, active retrogressive landslide activities should raise environmental problems such as debris flows and landslide dam breach in the future.

Conclusions

Authors investigated landslides in DPRK and presented classification of landslides in the country. Shallow rock fall, debris falls, and debris slides are predominant. On the other hand, active retrogressive landslides in the old lahar deposits provides excellent touristic resources, however, those may cause serious landslide disaster in the future.

Acknowledgments

Authors appreciate the National Academy of Science of DPRK and National Institute of Geography for arranging the field investigation and joint research.

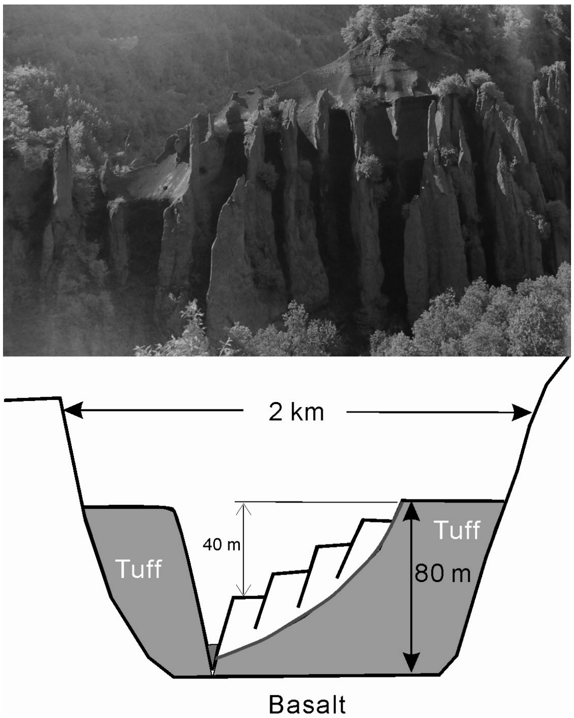

Fig. 5 Photo (above) and schematic longitudinal section (below) of the Daehyokok Landslide, a retrogressive landslide in the lahar deposits erupted in 17th Century. (copyright by DPRK National Press)

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Towards Landslides Risk Reduction in Sri Lanka

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Abstract. Landslides are the most recurrent and prominent disaster in Sri Lanka, well known for their crippling impacts on transportation, especially in the mountainous areas subjected to high intensity rains. A compressive program on landslide hazard mapping has been carried out with the support of UN to support landslide risk reduction strategies including land use planning. However, holistic programs on landslide risk reduction only started to emerge recently, as national responses to catastrophic landslide and tsunami disasters in the recent past.

Keywords. Risk evaluation, early warning, monitoring, rainfall forecasting, inter-agency cooperation

1. Characteristics of Landslides in Sri Lanka

Sri Lanka is an island in the northern Indian Ocean just south of southernmost part of India and extends in latitude form approximately 060 N to 100 E and in longitude from approximately 800 N to 820 E with an extent of about 65,000 km^2.

Sri Lanka has been subjected to a number of extreme landslide disasters that produced great loss of life, material damage, and distress. The experiences indicate that destruction is inversely proportional to the state of preparedness. The direct impacts suffered in Sri Lanka are the loss of life due to drowning, destruction of houses, road damages, etc., while indirect losses such as hunger, shelter, looting, breakdown of the infrastructure facilities, etc., are frequently experienced. The organizations related to disaster reduction are expected to respond immediately to disasters and reduce losses from direct impacts and reduce the indirect damages. While there is a remarkable sprit of solidarity and volunteerism in the aftermath of disasters, the potential is not adequately harnessed, trained, and directed. Moreover, much more attention should be directed towards preparedness and mitigation to reduce recurrent losses associated with landslides.

Adams(1929) was the first to draw attention to the existences of three well-marked plains of erosion cut in the precambrian rocks of Sri Lanka. These “three terraces” present three successive stages of denudation brought about by successive uplift of Island as a whole. On morphological grounds Wadia(1943) rejected this “erosion terrace theory” and postulated that the three peniplains are the result of successive bedrock uplifts. The recent detailed structural and tectonic mapping of central highlands indicates that in addition to the vertical epirogenic movements of the southerly drifting miniplate of Sri Lanka, there are horizontal thrust developed regionally and a series of strike slip faults along mega-lineaments (Vitanage, 1994). Some of the lineaments appear to be active and some of the older highly weathered lineaments are commonly associated with large destructive recurrent landslides. Since there are no simple mechanisms to foresee instabilities, monitoring is the most appropriate mechanism to understand their behavior.

Landslide becoming a frequent disaster category, with frequent disruption to transport sector in the central mountain areas, the government of Sri Lanka took serious note of the losses and initiated strategic plans for the reduction of landslide disaster during monsoon periods starting from year 1986. The report “ Landslide Hazard in Sri Lanka” published by the National Building Research Organisation in 1986, brought up the strategic requirement of disaster mitigation against landslides as a national issue. Subsequently the above requirements were adopted in a cabinet paper submitted by the Ministry of Policy Planning and Implementation, which supported the development and use of scientific methodologies in landslides mitigation. The beginning of the International Decade for Natural Disaster Reduction in 1990 provided a conducive environment and the Landslide Hazard Mapping Project was implemented by the government of Sri Lanka, executed by the United Nations Center for Human Settlement(Habitat), Nairobi, funded by the United Nation Development Programme. Due to the multi-disciplinary nature of the impact studies involved in landslide disaster evaluation aspects, the National Building Research Organisation was selected as the executing agency for the Landslide Hazard Mapping Programme and subsequently institutional capacity was upgraded by establishing a separate division for the Landslide Studies & Services at the NBRO, 1992. After couple of years, the first national Symposium of Landslide in Sri Lanka was held in Colombo generating a wealth of information on Sri Lankan Landslides covering a diverse range of landslide types.

Figure 1. Fifty Seven (57) people were buried in this Landslide in Alapatha, Sri Lanka in May 2003

2. Need for early warning

A case study of a recent flood disaster in Sri Lanka is presented here to describe landslide disaster mitigation needs in case of extreme rain events. From the May 11-19 of 2003, a tropical storm caused 247 deaths, the displacement of 200,000 persons, and heavy damage to the infrastructure, economy and livelihoods of the South-Western Sri Lanka. The main cause of the deaths was the landslides in the central and southern parts of Sri Lanka, triggered by the heavy rainfall. The storm first formed 700 km to the West of Sri Lanka on May 11 and then made its way North by about 500 km. It stalled for a week causing heavy rainfall 900 km away from the eye of the storm over the South-Western corner of Sri Lanka leading to the worst landslide disaster in recent history. The May is the month when the heavy monsoon rains start and the South-West of Country is expected to become wet. Indeed, there has been heavy rainfalls of order 600 mm in Sri Lanka in May during the period from 1920 to 1950 but not thereafter. According to the meteorological data this was the heaviest rain to hit the island since 1947. The track of the rainfall is shown in figure 2 and the observed rainfall from TRIMM satellite is shown in figure 3. In the past, there had not been a historical record of a cyclone in May in Sri Lanka. It was also rare that a cyclonic storm whose centre was 700-1500 km away and which was relatively weak could cause such damage. However, numerical simulation of the rain fields of this event carried out at UNU has confirmed the occurrence of such rainfalls due to the interception of anti-clock-wise winds by central hills of Sri Lanka. At the same time, due to steep hills, geology and frequent high intensity rainfalls the region is extremely vulnerable to landslides. While hazard zonations are carried out mainly guided by geotechnical considerations, it is well known that groundwater build up and surface soil saturation plays a critical role in triggering the landslides. The challenge is to develop mitigation measures when a vast area with potential for landslides is covered by a moving rain filed whose intensity varies according to the conditions dictated by atmospheric conditions over a region that is several magnitudes larger than the area covered by the whole country. As extreme rainfalls that that occur in a time frame of once in about half a century to a century trigger such catastrophic events, it is not feasible to implement stringent land use planning that deprive residents of the use of land. On the other hand, exorbitant resource requirements would make it impossible to strengthen all the potentially hazardous slopes in a place like Sri Lanka. What options does this leave? It is clear that we need to have better early warning systems in addition to the basic hazard zonation. Such early warning systems should be in place and go into operation when threat of prolonged high intensity rain is perceived. As a long-term solution this may prove to be the most effective way to reduce death and suffering from landslides.

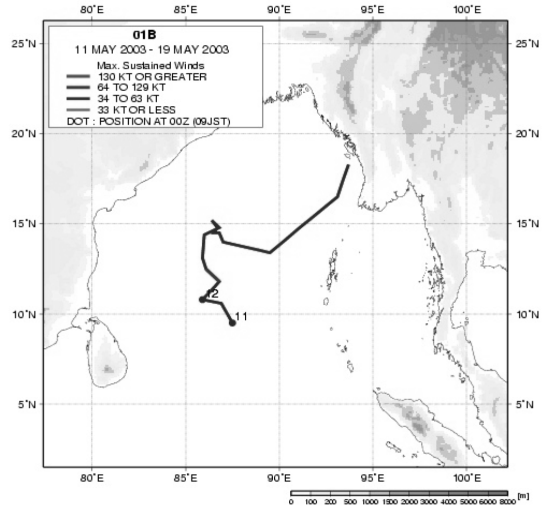

Figure 2 Path of the Cyclone

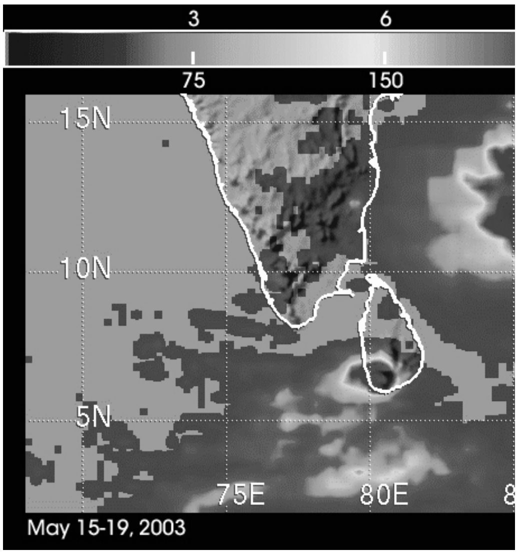

Figure 3 Rainfall patterns from TRIMM satellite observations

3. Rainfall forecasting through downscaling global forecasts through Local Area models

Atmospheric models that forecast the temporal and spatial distribution of rainfall is a useful alternative source of rainfall information, that is now increasingly being used in hydrological applications. Another very compelling reason to use atmospheric models is that it is they represent the only possible way to represent future climatic scenarios. It is often necessary for global model forecasts to undergo a process called 'downscaling' in order to re-introduce the variability like that is observed in real rainfall fields. Physically based atmospheric models, known as limited area models are able to reliably downscale global signals to scales comparable to those of hydrological/hydraulic studies. When accurate local data is given (e.g. static data like topography, land use, soils, etc. and dynamic information like local spot observations, weather balloon soundings, etc.) and run at high resolutions (often 5-4 km grids), they respond realistically to the local drivers of rainfall variability. While the atmospheric model output are much superior to rain gauges in terms of reproducing the variability of rainfall they show invariably

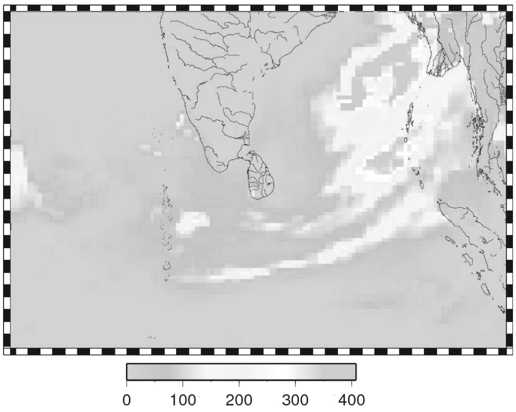

Figure 4 Forecasted rainfall (15-19 cumulative)

poor spot accuracy. In research applications that involve past data, often, best results can be obtained by assimilating both rain gauge data and spatial information provided by atmospheric models.

We used WRF (Weather Research and Forecast Model of NCAR, USA, NOAA 2007a and NOAA 2002) to downscale GSF global precipitation forecasts using a 3 stage nesting scheme and to make a local forecast of rainfall 24 hours to the future that include the extreme precipitation event period. The resulting rainfall field from the numerical simulations is shown in Figure 3 and as can be seen shows a good correlation with the satellite observations shown in Figure 2.

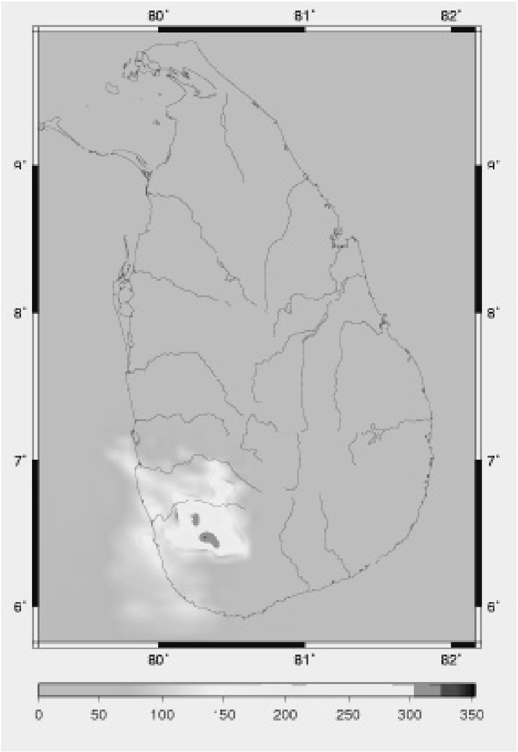

Figure 5 Forecasted rainfall for Sri Lanka

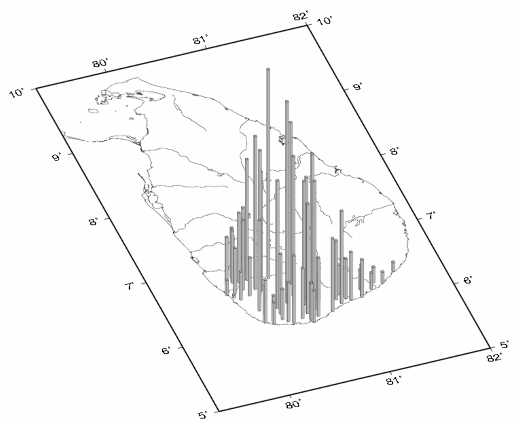

Figure 6 Observed rain gauge values

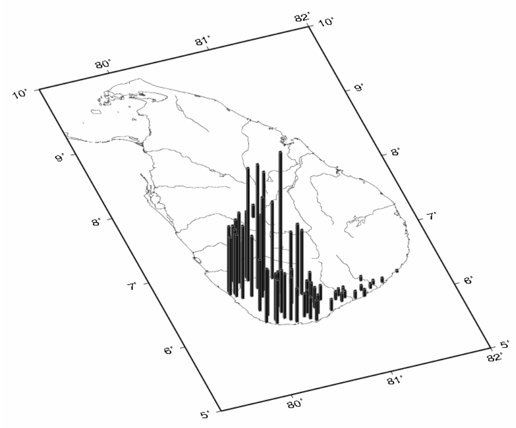

Figure 6 Forecasted rainfall

Large scale wind field induced by the storm is well described in figure 3. Figures 5 and 6 shows the observed rainfalls from gauges compared with predicted values at the nearest simulation grid. Again the forecasts compare well, but the forecasted rain values under estimate the observed cumulative rainfall. Furthermore, simulations also highlight a very important deficiency of current rainfall observations network. Most rain gauges currently operated in Sri Lanka are manually operated and only daily accumulated rainfall values are recorded. As numerical simulatons use aver short time step, it is possible to accumulate rainfall at desired intervals. The simulation results clearly show that the daily rainfall measurements cannot capture the triggering rain intensities as actual rain intensity distribution over the day is quite different from a constant rain of equal intensity. High-resolution temporal and spatial rain distributions are a pre-requisite input to carry out soil moisture estimations based on physically based distributed model. Even for establishing empirical thresholds for landslide warning, accurate rain intensity estimations are required. They are essential for understanding the mechanisms that lead to improved risk assessment and planning mitigation measures. Towards this end, there is an urgent need to improve meteorological observation network with high spatial and temporal resolution monitoring with an efficient dissemination system that could provide the necessary information to disaster management community.

4. Interagency cooperation

Landslide disaster risk reduction demands integration of a number of disciplines associated with various aspects of physical and hydro-meteorological characteristics of a region as well as social and cultural dimensions. Therefore, landslide disaster mitigation require collective and corporative efforts of all relevant R&D institutions lead by strong executing organizations of the country. One of the mechanisms that evolved during the disaster in May 2003 and implementation of Landslide Disaster Mitigation Works, was the establishment of a ad-hoc group named "Operation Professional Combine" established at Rathnapura, the most affected area. This was carried out in accordance with the action plan proposed by the Central Engineering Consultancy Bureau (CECB) at the council meeting at Disaster Management Committee held in Colombo, 28th May 2003. The "Operation Professional Combine" (OPC) consisted of hundreds of academics, professionals and volunteers from various backgrounds coming together for the first time in recent past. The objective of the exercise was to provide a comprehensive summary on destruction caused by landslides at Rathnapura district; propose recommendations to mitigate further losses and facilitate a basis for the next costly recovery phases in the disaster prone areas.

In addition to the above mentioned form of spontaneous developments, the Ministry of Disaster Relief Services was formed resulting from restructuring of the cabinet under the Gazette No. 1422/22, dated on 08th December 2005 in response to the 2004 Indian Ocean Tsunami Disaster and the national 'Disaster Management Centre' was established under the National Council for Disaster Management in accordance with the Sri Lanka Disaster Management Act No. 13 of 2005 passed by the Parliament of Sri Lanka on 13th May 2005. The respective authorities cover the general subject of Disasters addressing Preparation, Response and Recovery. An 'Emergency Operation' is proposed to be established at the Ministry providing efficient and immediate emergency services and coordinating activities, during the Post Disaster period.

The most recent development is the preparation of "Road Map for a Safer Sri Lanka" under the disaster Management Centre of the Ministry of Disaster Management and Human Rights. The proposals in this document adequately reflect the priority projects in the areas of natural as well as man-made disasters and human rights. The formulation of the Road Map represents a very significant achievement for the Disaster mitigation aspects of Sri Lanka since this clearly identifies the priority initiatives that need to be undertaken by various stakeholders-both the private sector and civil society- to lead to a Sri Lankan strategy that can pro-actively carry out landslide disaster mitigation.

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Landslide Tragedy of Bangladesh

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Abstract: Landslide is a regular geologic hazard in Bangladesh, especially in Chittagong, the South-eastern Part of the country. Landslides in Bangladesh and its associated causes were studied using multidisciplinary approach taking two recent landslides as reference. Landslide caused death to more than 300 peoples in Bangladesh since 2000, with a loss of hundred of houses and millions of dollars of properties. One single event, the landslide of 11 June 2007 caused death to 135 people, affecting 1.5 million people of the region. Most of the landslides happened after heavy rainfall. Heavy monsoon rainfall intensified by strong storm from the Bay of Bengal (BOB) caused an abnormal precipitation in the area caused the referred landslide. Combined effect of rainfall and hill cutting induced slope instability triggered landslide in Chittagong. Combined effect of hill cutting and climatic change induced erratic behaviour of the nature caused 11 June Tragedy. Detailed Area Planning, landslide vulnerability zoning, landslide database development, and a geophysical analysis of the area are recommended a complete understanding of the landslides of Chittagong. Influential peoples of the societies are involved with hill cutting in Bangladesh, violating existing rules and regulations. Legal instruments should be in place and the enforcement of existing rules should be ensured to avoid further 11 June Tragedy.

Key Words: Landslide, Chittagong, impacts, hill cutting, slope instability

1. Introduction

Landslide is becoming a concern of great priority because of its devastating nature worldwide (Evans et al. 2007; Havenith et al. 2007; Kyoji, Wang & Fukuoka 2004; Paudel et al. 2003). Landslide is an inveterate problem for south eastern part of Bangladesh and Chittagong city is particularly highly vulnerable to this hazard, with an increasing trend of frequency and damage. More than 300 people were dead in Bangladesh by landslide hazards since 2000. A total of 135 fatalities were recorded in one single event of 11 June 2008, with a repetition on 20 August 2008, adding 11 deaths in record. Slope instability caused by indiscriminate hill cutting activities and heavy rainfall are triggering factors of landslides of Chittagong. This paper focuses the hazards of landslide in Chittagong with a special referencing of two recent devastating landslides, and some potential recommendations are placed.

Chittagong city is the most important business centre of the country having a population of five million is situated at the right bank of the Karnafulli river with a geographic coverage of 22°14´N-22°24´30´´N latitude and 91°46´E-91°53´E Longitude. About half of the area of the city is plain land and the rest half is characterized by the presence of hillock and small hills. Surface run-off drains out to the Karnafulli River by a chain of small and medium canal that ultimately flows to the Bay of Bengal.

2. Flashback

a). 11 June 2007: At the very early morning of 11 June 2007, the city of Chittagong experienced a deadly landslide with huge number of casualties. The most affected areas are Motijharna of Lalkhan Bazaar, Power Colony, Kushumbagh Residential area, Taragate, Devpahar, Shaheed Minar area of Chittagong area, and Lebu Bagan of Chittagong Cantonment area. A total of 5,072 families were homeless with a death toll of 135 and 213 wounded. Extremely Heavy rainfall counting as long as 267 mm in 24 hours was observed on the day, causing water logging in the area, submerging ground floors of 500 buildings of city's commercial area Agrabad. Landslide and flush flood affected 1.5 million people of Chittagong region. Rice flour, sugar, pulse and other food grains stored in warehouses of Majheerghat, Sagorika road, Chaktai, and Patharghata were degraded because of water logging situation.

b). 18 August 2008: The landslide of 18 August 2008 took place at the very early in the morning killing 11 people of the city vanishing two whole families of Hossain Colony of Matijharna area of Lalkhan Bazaar. A total of 10 people were trapped to death by rubble of collapsed house, including six members of a same family, while one more was death in hospital. The devastating event completely bulldozed 13 cottages in a sudden moment. The night was full of shower of rain having a record of 142 mm in 24 hours till 12.00 noon of the 18th August, according to local weather department record (Hayat, 2008). Areas of Bakulia, Bahoddarhat, and Chandgaon were water logged because of heavy rainfall. Hossain Colony was built on an abundant property of Chittagong Water Supply and Sewerage Authority (WASA), state owned and the only water supply company of the city.

Another landslide was observed at Bhaditala village under Sadar sub-district of Cox's Bazaar, a neighbouring district of Chittagong. It was also a rain induced landslide that happened at around 4.00 am leading 3 deaths. The average rainfall of the city was 133mm in 24 hours of time (Hayat, 2008).

Rescue operation was participated by army, police, fire fighter, NGO activists and other volunteers. Rescuing the affected people was under challenge because of bad weather situation, especially heavy rainfall and flooding event with an additional drawback of inadequate rescue equipments. Rescue operation was observed very slow because of lack of technical knowledge, poor coordination, and absence of landslide contingency plan in place. Professional rescue coordination was not in place, even though the concerned authority experienced similar disaster event on 21 November 1997 when an earth quaque of Richter scale only 6.1 caused a death toll of 6 people (BBC,

1997) when ground floor of one four storied building was trapped under soil and it took three days for the rescue team to take out the trapped people.

3. Causes of Landslide in Chittagong

The steepness of a hill is the main factor for the movement of the materials that flow down towards the foot of the hill. Steep slope push down debris or mud converting gravitational energy into kinetic energy. A natural hill is a stable surface of the earth system having a balance of its components. Every natural hill is maintaining its stability by natural condition of the system that sometimes disturbed by improper interactions of human being and landslides of Chittagong are examples of human induced landslides where hill slopes are being steeped day by day by hill cutting activities and other associated factors those could be summarized as, but not limited to:

Slope instability by land degradation: Soils are extracted haphazardly from the hills of Chittagong region for the activities of housing, urbanization, industrialization, road construction, brick kiln construction or other commercial purposes. Practice of cutting hills is booming up with growing demand of home building. Quddusi (2007) mentioned that more than 100 hills of Chittagong city were demolished in last 30 years of times. Horizontal extension of Chittagong city, which is presently observed at a rate of 92 hectares per year by hill demolition (Biswas, 2007). Basement of a hill is the area where hill cutting is initiated by soil grabber decreasing base area of the hill leading to a steep slope and instable condition. The susceptibility of a hill is moderate and high at a slope of 20^0-30^0 and 40^0-60^0 respectively (Nagarajan et al. 2000), whereas hills of Chittagong are cut at 70^0 or greater slope (Islam, 2008). Hills are first deforested for soil extraction exposing the land surface of the hill increasing its vulnerability to erosion. Soils of open hill surface absorb rain water quickly that dissolve soil nutrient loosing its compaction and adding heavy weight to the basement of the hill. Slope instability turning by decreased base area, and loose muddy soil because of rainwater absorption can not hold the extra weight added by rain water, resulting downward soil movement or landslide.

A group of organized people including prominent political leaders of the city, leading real estate businessmen, truck owners, and brick-field owners are generally blamed for the senseless hill cutting activities in the region who are indirectly backed by Chittagong Development Authority (CDA), Chittagong City Corporation (CCC), and Department of Environment (DoE) by their silent role in controlling hill grabbing. More than a dozen of points of Chittagong including posh area of Khulshi, Nasirabad, Panchlaish, and Zakirhossain road, Shugandha residential area and other areas of Shantinagar, Oxygen, Polytechnic, Roufabad, Fatehabad, Shershah colony, Sholoshahar, Hamzerbag, Foy’s lake, Pahartoli, Kattoli, Motijharna, Devpahar, Rubigate, and Baizid Bostami (Biswas, 2007).

Heavy rainfall: A heavy rainfall during a shorter period of time can lead to a large scale landslide in a hill area. A study by Yalcin (2007) concluded that an intense rainfall of 70mm per hour or greater will create landslide favourable condition. Rainfall in Chittagong is second highest in the country with an annual average of approximately 3000mm per year, having maximum recorded rainfall in June (**Figure 1a**). The month of June and July shows most landslide frequency in Chittagong (**Figure 1b**) confirming strong relationship of heavy rainfall and landslides in the country.

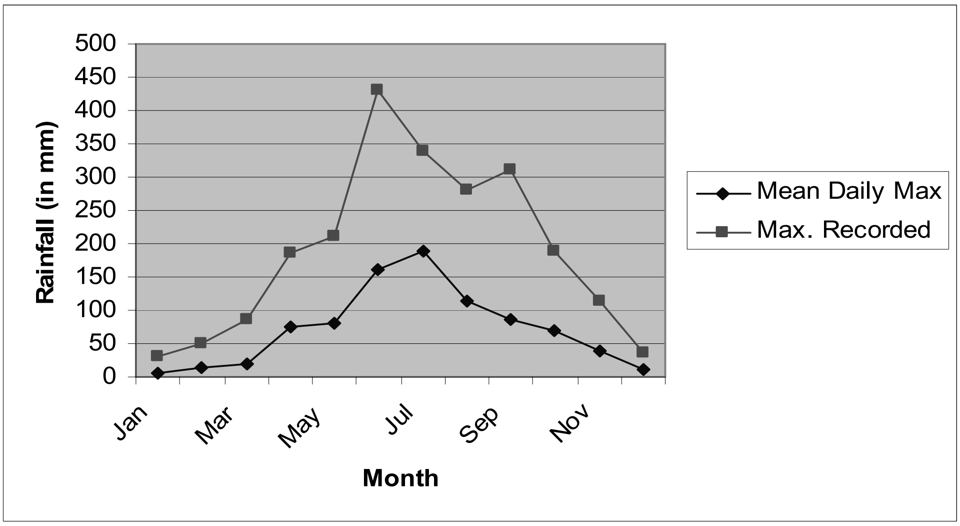

Fig 1a: Rainfall pattern of Chittagong in 2004

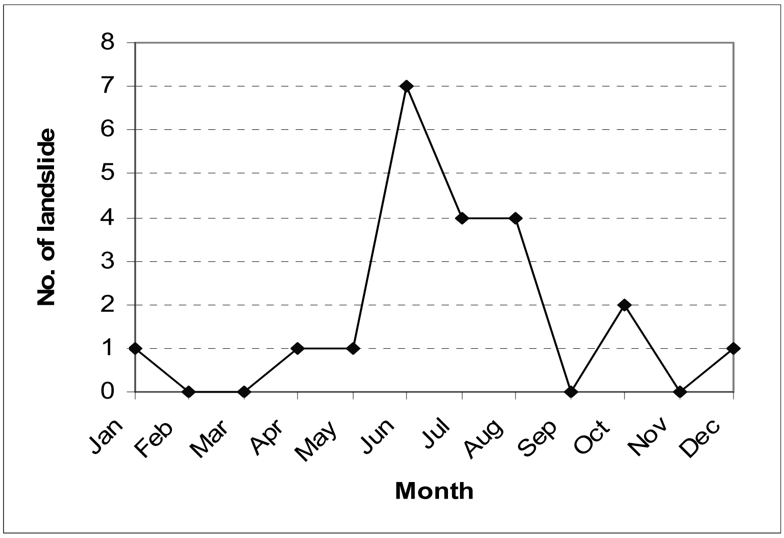

Fig 1b: Average landslide frequency in Chittagong by month.

Total rainfall of Chittagong in 24 hours before the event was 267 mm and this amount of heavy rain in such shorter period of time triggered landslide in unstable hills of the area where hills are formed by sandstones, siltstones and shales, which are rich in pyrites and lime. Excess rainwater dissolves these compounds breaking the strength of hill basement.

Deforestation, Seismic activity, and abnormal tidal flow in the city might have contributed to landslide in Chittagong, in addition to hill cutting and heavy rainfall. Deforested areas of hills are easily exposed and top soils are eroded by surface run-off or by wind erosion. Forest covered areas are less vulnerable to landslide than deforested area and debris stored areas are more in deforested area than a forest covered area. Vegetation protect earth surface from exposure and roots of a tree stabilize the strength of soil compaction acting as cementing material and reducing soil erosion. On the other hand, Seismic activities destabilize the soil structure of the region triggering landslide. Huge amount of strain energy is released by earthquake forwarding shear stress to slope destabilization system. Despite the fact that Chittagong is a city of small hill, its one third areas are covered by land of low elevation that experience abnormal tidal flow during spring tide of Monsoon season. Tidal water level was observed flowing at a higher level of one and a half to two meter higher than the season's average tidal height. Surface run-off could not find its way out but saturated the soils of hill base loosing its compaction.

4. Discussion

Landslide in Chittagong is influenced by heavy rainfall. A detailed scientific study is needed to understand the threshold of rainfall for landslide potentiality. It is not completely understood the exact role of rainfall for causing landslide in Chittagong. This component should be studied thoroughly for a better understanding of landslides in the region. At the same time, Detailed Area planning (DAP) of the city and a better management of government owned land are needed to minimize landslides and its hazards in Chittagong. Landslide vulnerability area need to be identified and highly vulnerable area should be declared as 'Red Zone' for housing or any other settlement activities. In addition to marking red zone, government land should be taken proper care by its respected owner organizations. Security fences should be built round the hill slope of the property of respective organization to prevent potential illegal settlement as because poor people will always try to find a cheaper housing option despite of risk of danger. Relocation of present inhabitants of dangerous hill slope is another issue to be considered. A high level working body should be formed to find out potential relocation site with financial support from emergency disaster fund or any other potential funding sources. After relocating people from the hill slope, afforestation should be done with plant species of medium height having long root to strengthen the soil stability of the area.

A landslide database is essential to have a better understanding of causes, impacts and trends of landslide in Bangladesh. It is will helpful to government and other organizations those are interested in working on the issue in work plan formulation and decision making process. A landslide database should be developed by government or by any other organization with due governmental support. In addition to the database, a landslide vulnerability mapping should be done using modern technic like Geographica Information System (GIS) and Remote Sensing (RS) technology that will be used as a strong tool for a better action plan. Furthermore, a geophysical analysis of the area is needed for a better understanding of geology and geomorphology of Chittagong region. Navigating access to the potential resources of international knowledge and expertise could be a good initiative for the understanding of the complex system.

The water drainage system of the city is very poor. Flash flood driven water stagnation is a common feature of

Chittagong city. There are 22 big canals in Chittagong to drain out the city's rainwater which have lost their water carrying capacity because of hill cutting induced siltation (Ashraf, 2007) and also of poor management. Drainage system of the city should be improved dramatically to drain out city's rainwater. Canal grabber should be removed and the flow of canals should be ensured for the improvement of water logging situation. In addition, landslide risk mitigation plan should be developed with efficient enforcement of existing legal instruments.

Rescue operations in recent landslides had an experience of poor coordination and inadequate rescue tools. Landslide disaster contingency plan at both government and community level should be formulated with definite coordination body and trained manpower equipped with necessary tools. Chittagong City Corporation should have plan in place to evacuate its residents in case of emergency situation.

5. Conclusion

Hill cutting and heavy rainfall are prime factors for landslides in Chittagong that causes death to hundreds people with a great property loss. This catastrophe could be checked by controlling the grabbing of government owned land and by understanding the rainfall pattern and its true relationship with landslide in the region. Detailed landuse planning of the city, a landslide database, landslide mapping and geophysical analysis of the city is essential to minimize landslides and its impacts in the region. In addition, a landslide contingency plan should be in place that would direct proper coordination of the needs of crisis period. Furthermore, incorporating international resources with total plan and actions will enhance the capacity of concerned organizations in dealing the hazard.

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The Forest City Landslide, South Dakota, USA

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Abstract. Following inundation of the Oahe Reservoir in the 1960s in South Dakota, USA, numerous landslides developed along the reservoir rim. A particularly large landslide reactivated at the location where U.S Highway 212 crosses the reservoir. The landslide is locally known as the Forest City landslide, after the former village that occupied the location prior to reservoir impoundment. Unbeknownst to the bridge designers, the bridge was located at the toe of an ancient landslide. Rising reservoir levels caused reactivation of the landslide; however it took many years before this was recognized. Water levels began rising in the early 1960s and the first bridge distress was noted in 1962. By 1965 an expansion device at the bridge abutment had closed. First recognition of geotechnical problems was in about 1968 and extensive monitoring of the landslide at the site began in 1972. Throughout the 1970s and 1980s intermittent monitoring and movements occurred, with occasional concerns for safety of the bridge. Hazard warning devices were installed at the bridge abutment in case of failure and loss of the traffic lanes. Continuing movements brought the need and realization for stabilization to the attention of political officials. Extensive remedial investigations began in 1988, with construction of several stabilization techniques during the 1990s, including stone columns, unloading of the driving force and installation of shear pins in the toe of the slide. Prior to the remedial measures the movements of the main slide and local slides ranged from 100 mm to 250 mm per year. The remedial measures have reduced the movements to less than 2 mm per year and have been performing well for nearly a decade.

Keywords. Back analysis, residual strength, shale, structural stabilization, reservoir slopes

1. Introduction

Landslides are a ubiquitous feature along the slopes of the Missouri River Trench and its tributary stream valleys, the landslides having developed primarily in the Pierre Shale Formation and overlying glacial materials. The slides are generally complex features consisting of graben blocks and slump zones in combination with rotational and translational failure masses. It is generally thought that the majority of the landsliding occurred in historic time with recent reactivation of ancient slide masses due to man's activities. The development of dams and transportation infrastructure along the Missouri River and in the Pierre Shale Formation has resulted in numerous instances of landslides impinging upon transportation structures. One such instance occurred along the Oahe Reservoir in South Dakota, USA, when a particularly large landslide reactivated at the location where U.S Highway 212 crosses the reservoir. The landslide is locally known as the Forest City landslide.

The U.S. Highway 212 Bridge was constructed prior to closure of the Oahe Dam, as a replacement to a bridge crossing the Missouri River some 10 km upstream. Unbeknownst to the bridge designers, the bridge was located at the toe of an ancient landslide. Rising reservoir levels caused reactivation of the landslide, leading to severe distress to the bridge. The local importance of the Highway 212 bridge structure stems from the fact that it is the only reservoir crossing for some 140 km upstream and downstream of the bridge. The Forest City landslide measures approximately 1.7 km wide, 1.25 km long from head to toe, and 125 meters high from head to toe. The depth of the sliding surface is from 60 to 120 meters below ground surface. It has been estimated that the landslide involves on the order of 60 million cubic meters of soil and rock debris and covers over three square kilometers of land area. Movements of the main slide and local slides ranged from 100 mm to 250 mm per year prior to stabilization. Due to the complexity and size of the landslide, stabilization measures were constructed over a number of years. The remedial measures have reduced the movements to less than 2 mm per year and have been performing well for nearly a decade.

2. Behavior of Pierre Shale

The Pierre Shale is a Cretaceous Age marine clay shale generally described as a weakly cemented compaction shale. A key aspect of its behavior is the change in strength from peak to residual as the overconsolidated materials are subjected to large strains due to stress relief and erosion. Beginning with Terzaghi's (1936) classical work and continuing with the pioneering studies by Skempton (1948, 1964, 1985) and Bjerrum (1967), an understanding developed of the behavior of overconsolidated clays and shales. It has been found that peak strengths could only be used in analysis of first-time slides and residual strengths must be used in cases where previous movement had occurred in a slope. A key to understanding the behavior of slopes in the Pierre Shale is its geologic history resulting in the formation of fissures and old landslide scars. Thus key to analysis of slopes in Pierre Shale is an understanding of the residual strength of the Pierre Shale. The residual strength of Pierre Shale is particularly important given the observation by Brooker and Peck (1993) that even extremely small disturbances to clay shales can cause historic slides to reactivate.

The Missouri River Trench formed in Sangamon time during Pleistocene glaciations 135,000 to 70,000 years ago, the result of meltwaters at the margin of the glaciers. Unloading of the Pierre Shale Formation due to melting of the glaciers east of the river and due to erosion of the clay shale materials west of the river provided a means for tremendous unloading of the near surface materials. This likely resulted in fracturing and the development of major planes of weakness. Along the Missouri River Trench and major tributaries, severe landsliding occurred. It has been postulated that the early landsliding occurred in Late Wisconsin time, 25,000 to 10,000 years ago, with continued landsliding during the Holocene of the last 10,000 years (Crandell (1958). With time the Missouri River Trench infilled with sediment leaving between 20 to 30 meters of alluvium in the present river valley. The alluvium consists of poorly sorted gravel, sand, silt and clay from erosion of both glacial materials and the underlying Pierre Shale bedrock.

The geologic history described above is thus responsible for the present day condition of slopes in Pierre Shale. The geologic history has left a formation covered with relict landslides and slope failures. The mineralogy of the Pierre Shale in terms of its high smectite content further serves to destabilize the slopes. The ancient landslide movements along valley slopes means that, at the least, peak strengths cannot be counted on for resistance to renewed movements. It is apparent that this geologic history means that for most slopes in Pierre Shale, both natural and man-made, residual strengths are operative relative to slope stability concerns.

For residual strength determinations it is well established that laboratory testing and back analysis of failed slopes offers two independent approaches to find the 'right' or 'operative' strength (Bromhead (1992). The construction of main stem dams on the Missouri River and development of transportation networks resulted in significant interest in the behavior of Pierre Shale by the U.S. Army Corps of Engineers and the South Dakota Department of Transportation. This interest has sparked several studies of the residual strength of Pierre Shale through the years. A compilation of available results for samples of Pierre Shale from South Dakota was reported by Schaefer (2002). A majority of tests were conducted using a direct shear device with precut failure surfaces and repeated shear until a residual condition is reached. Values of residual friction angle varied from a low of 3.1^o to a high of 9.7^o. It is of interest to note that Townsend and Gilbert (21) conducted tests with the three different testing apparatus and produced remarkably similar friction angles. With the exception of tests conducted by Schaefer and Lohnes (2001), all tests were conducted with distilled water. Schaefer and Lohnes (2001) found a nearly full degree higher residual friction angle using interstitial water compared to distilled water.

3. Project Timeline

The Oahe Dam and Reservoir was planned during the 1940s as part of the Pick-Sloan Plan for taming flooding along the Missouri River. Oahe Dam is one of six main-stem dams constructed on the upper reaches of the Missouri River; the dams have abated well over US$30 billion in downstream flood damages since the early 1950s. Oahe Dam and Reservoir is the fourth dam upstream with the dam located some 10 km upstream of Pierre, South Dakota. The reservoir is some 400 km in length and has a limited number of crossings.

One crossing is U.S. Highway 212, located some 100 km upstream of the dam. The next crossing is about another 100 km upstream. Hence, loss of this crossing would necessitate large detours for traffic.

The U.S. Highway 212 Bridge was constructed in 1958 and 1959 prior to closure of the Oahe Dam, as a replacement to a bridge crossing the Missouri River some 10 km upstream. Water levels began rising in the Oahe Reservoir in the early 1960s and the first bridge distress was noted in 1962. By 1965 an expansion device at the bridge abutment had closed. The first indication of geotechnical problems was in about 1968 and extensive monitoring of the landslide at the site began in 1972. In 1976 the end of the bridge was sufficiently distressed that a 60 foot extension was added to the bridge with expansion joints to accommodate movements due to the landslide.

Throughout the 1970s and 1980s intermittent monitoring and movements occurred, with occasional concerns for safety of the bridge. Hazard warning devices were installed at the bridge abutment in case of failure and loss of the traffic lanes (Bump 1988). Continuing movements brought the need and realization for stabilization to the attention of political officials. Extensive remedial investigations began in 1988, with the remedial measures constructed in three phases. The first phase completed in 1993 consisted of drilling large diameter stone columns into the toe of the slide to stabilize local slides near the bridge abutment. The second phase completed in 1995 and 1996 consisted of excavating a deep corridor through the center of the overall sliding mass to unload the driving forces. The corridor was approximately 185 meters wide, some 600 meters in length and was made some 40 meters into glacial till materials. Approximately 7 million cubic meters of material was removed from the cut. The third phase was completed in 1998 and consisted of the placement of 66 shear pins at the toe of the slide, to depths of 45 meters below ground surface to intersect deep shear planes in the overall sliding mass. The measures are described in more detail below.

4. Characterization of the Slide and Back Analysis

The stratigraphy at the site consists of firm and weathered Pierre Shale overlain by glacial till materials consisting of a heterogeneous clay matrix with sand, silt and clay and numerous gravel beds, likely the result of erosion in geological time. Fill was placed at the toe of the slope to provide an abutment for the bridge. A cross section of the landslide is shown in Figure 1. Landsliding was occurring in two parts. In the approach embankment area, where the bridge abutment was located, lateral spreading of the embankment fill materials was occurring on both sides of the fill. Additionally, the embankment toe area had a local wedge failure occurring towards the reservoir. Thus, the embankment fill soils were failing on three sides. An overall central corridor slide was also moving as a single unit towards the reservoir and impinging on the end of the bridge. The overall slide was approximately 1.7 km wide, 1.25 km long from head to toe, and 125 meters high from head to toe. The depth of the sliding surface is from 60 to 120 meters below ground surface. The overall landslide was estimated to involve on the order of 60 million cubic meters of soil and rock debris and covers over 3 square kilometers of land area.

Extensive instrumentation placed at the site allowed determination of the location of the failure plane and reasonable determination of water levels in the shale and overlying glacial till materials. A back analysis was performed using a failure surface along the "shear elevations" from inclinometer data from the 1970s and 1990s and water surface elevations in the slope in the early 1990s when significant movements were monitored by inclinometers and pinch tubes. The instrumentation showed that the movements were occurring at or just above the contact of the weathered shale and the firm shale. The slope stability analyses were conducted using the Spencer method. Initial analyses were conducted using a residual friction angle of 6^o for the weathered shale. This value was subsequently adjusted to produce a factor of safety of 1.00. The resulting residual friction angle was 7.3°. This value compares favorably with the range of 6.4° to 8.0° reported by Bump (1988). Fortuitously it corresponds almost directly with the value of 7.2° found by Schaefer and Lohnes (2001) who conducted tests on material directly from the failure surface.

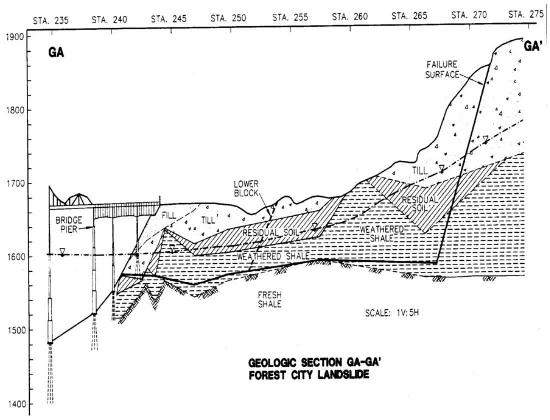

Fig. 1 Cross section of the Forest City landslide.

5. Remedial Measures

Numerous remedial measures were considered for dealing with the potential effects on the bridge including relocating the bridge and redesigning the bridge to accommodate the landslide movements. Options for stabilizing the landslides included various diversion methods whereby the moving material would be diverted around the end of the bridge, unloading of the driving forces, and structural measures for stabilizing the moving ground. In the end, a three phase stabilization program was adopted. In the first phase the slope failures around the bridge abutment fill embankment were stabilized. The second phase consisted of removing a portion of the central corridor material to unload the driving forces and increase the factor of safety of the slope. The third phase involved the structural reinforcement of the deep failure planes of the overall slide.

To stabilize the approach embankment, several alternatives were evaluated. Replacement of the embankment with light weight fill or anchoring the structure to materials below the failure surface provided only minimal improvement in slope factors of safety. Vertical reinforcing dowels or jet grouting on 1 to 2 meter spacing would increase factors of safety to about 1.2. Construction of counterberms around the approach embankment or placement of stone columns ($\phi = 40^o$ material) around the approach embankment both increased the factor of safety to 1.3. The stone column approach was selected and installed in 1993. Figure 2 shows installation of the stone columns. The embankment toe slide moving towards the reservoir was stabilized with 214 stone columns, 1.2 meters in diameter, and installed to depths of 10 to 12 meters. Twelve reinforced concrete dowels, 12 to 36 meters in length, were also installed to stabilize this slide. The lateral spreading slides were stabilized with stone columns, 13 on one side to depths of 21 m and ten on the other side to depths of 18 meters. Sixty tons of riprap was placed on the embankment toe to reduce erosion from wave action.

A number of alternatives were considered to stabilize the overall central corridor slide. Lowering of the groundwater in the slope would increase the factor of safety only four percent. A slurry wall was considered, but would have a factor of safety less than one during construction. Cutting into the slope escarpment and reducing the slope grade to seven percent would increase the factor of safety to 1.25, while decreasing the slope to five percent would provide a factor of safety of 1.36. Since these factors of safety were less than desired by government agencies, it was decided to stabilize the overall corridor by both removal of material and construction of structural pins at the toe of the slide.

Fig. 2 Installation of stone columns around approach embankment fill area.

During 1994 and 1995, a new roadway alignment was constructed for U.S. Highway 212 by cutting a five percent grade from the bridge abutment to the slope escarpment. The resulting cut is shown in Figure 3. The original location of the roadway can be seen on the left side of the picture. Approximately three million cubic meters of material was excavated to unload the slope. The cut took two construction seasons and difficulty was encountered in excavating glacial till materials due to the presence of large boulder layers and perched water on top of the underlying shale materials.

Fig. 3 Overview of central corridor cut to stabilize overall slope. Original road alignment to left in photo.

The third phase of the stabilization consisted of constructing structural Ts in the approach embankment area to stabilize the overall slope. These were installed in 1998. Sixty six structural Ts were installed. To stabilize various failure surfaces and intercept potential failure surfaces, one-half of the Ts were installed to 24 meters and one-half to 42 meters. The shear pins were one meter by three meter rectangular reinforced concrete members. Figure 4 shows construction of the shear pins.

(a)

(b)

Fig. 4 (a) Excavator used to construct the one meter by three meter shear pins, (b) reinforcing cage being lowered into the boring.

6. Results

The three phases of stabilization resulted in dramatically reduced movements in the slides. Some movement continued to occur in the approach embankment slides after placement of the stone columns, but it was dramatically reduced. Placement of the shear pins in the area of the approach embankment in phase 3 essentially stopped the local slides. The large cut made in the central corridor and the placement of the 66 structural Ts reduced movements of the overall slide from 100 to 250 mm per year to less than 10 mm per year. The combination of unloading the driving forces and strengthening the toe of the slide with structural elements has reduced the instability of the slopes, allowing use of the bridge and confidence in its safety.

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Short-term Weather Forecasting for Early Warning

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Abstract. During the first two years of research activity of the Euro-Mediterranean Centre for the Climate Change (C.M.C.C.), the work group two "Impacts on territory monitoring activity and hydrological risk prevention" in the Division "Impact on soil and coast" (I.S.C) has investigated the possibility to use short term weather forecast[1] to provide an early warning for landslides induced by intensive rainfall.

This goal wants to be obtained with "in chain "numerical simulations of the natural events causing the calamitous events beginning from the synoptic situation, to the mesoscale features and then to soil effects.

In this context, the development of numerical weather prediction model (NWP) is essential for the weather forecasting improvement and for hydrological calamities exact evaluation; is also important to provide a correct interface among the various simulations characterized by very different characteristics (horizontal resolution, time range).

All the numerical tools (simulation models and post processing tools), defined for this goal, are optimized to produce scenarios in less then half a day.

The instrument to produce these scenarios is the "numerical meteo-hydrogeological chain" (NMHC); it is specialized on simulations of extreme meteorological events and of their impacts on the soil, both at high resolutions.

A big preliminary research work has been necessary to define the NMHC features; after that it has been tested on some real test cases, producing heartening preliminary results.

Keywords. Numerical simulation models, landslides induced by intensive rainfall.

1. Motivation of the research project and innovative aspects

The CMCC is a structure of scientific research with the aims to deepen knowledge on the climate variability, its causes and its consequences, this is made providing models, simulations, middleware, application software and high quality personnel training both in the specific field of climate dynamics and computer technology. The CMCC uses these simulations directly to effect studies of climate change impact on the economy, on agriculture, on sea and earth ecosystems, on coastal zones and health. All these research activities are developed by its six divisions, each one devoted to specific issues relating to the themes of climate change.

The I.S.C. Division is the one studying the impact of climate changes on ecosystems (of earth and sea) and on the coastal zones, as well as to study the hydrogeological risk related to meteorological events.

The working group two of the I.S.C. division has as main goal the study and the development of models, algorithms and software for the analysis of hydrogeological phenomena (floods and landslides) related to extreme meteorological events. Interest in these events occurs, especially in recent years, for a gradual increase in hydro-geological phenomena of failure. As shown in several studies, the causes of such disasters must be sought both in the changes climate and in an increasingly intensive exploitation of the territory (urbanisation widespread, funnel of rivers, intensive agriculture and so on).

The hydrogeological phenomena of interest are, generally, circumscribed (basin and/or slope scale) and, so, the tools for prediction and prevention require not only the development and the optimization *ad hoc* numerical codes (accurate, robust, efficient), but also to couple the meteorological model with models evaluating impact of such phenomena on the soil (i.e. hydrological-hydrodynamic models. The main result expected in this framework is a numerical simulation instruments to permit an early warning for hydrological instabilities phenomena (landslide, flood) connected to meteorological events.

An innovative aspect of this activity is that the research work is developed by a multidisciplinary team; this permit to face the issues from different points of view and to introduce, through the integration and comparison between different skills, new methodologies resulting optimal for simulating phenomena of a different nature (as thunderstorm, landslide or floods). All these competences are essential for the NMHC definition.

The main motivation of this research project is to provide in the future a tool, available to the end users (civil protection and so on), to warn the people before the occurrence of the event permitting to save life and to diminish the damages.

2. The hydrometeorological simulation chain features

The first simulation models of the "chain" are represented by two different Numerical Weather Prediction (NWP) models: the first one is the global model, able to predict the synoptic situation all over the world. For this application has been used data from two different global models: the Global European Model (GME) developed at the German Weather Center (DWD, Offenbach, Germany) and the Integrated Forecast System (IFS) developed at European Centre for Medium-Range Weather Forecasts (ECMWF). Due to the great spatial area on which they forecast the weather, the global models don't have enough spatial and temporal resolution to solve some of the weather features that often are the main causes of the meteorological events providing intensive rain[2]; anyway they are necessary to provide the

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[1] NWP models with forecast range time from 12 hours to few days (1 or 2) produce "short term forecasts".

[2] The synoptic meteorology deals with analyzing and forecasting meteorological features of scales in excess of 2000 km. Features such as troughs, ridges, highs, lows and frontal boundaries are well understood. The mesoscale meteorology studies the weather systems smaller than synoptic scale systems but larger than microscale and storm-scale cumulus systems. Horizontal dimensions generally range from around 2 kilometers to several hundred kilometers. Examples of

initial and boundary condition for the limited area model (LAM) with higher spatial and temporal resolution.

The LAM model selected for this application is the Consortium for Small-Scale Modelling - Lokal Model (COSMO-LM), this non-hydrostatic limited-area atmospheric model is operatively used in Italy, and in many other European countries, to forecast mesoscale-phenomena. COSMO-LM is developed within an international collaboration among six national weather services of Germany, Greece, Italy, Poland, Romania and Switzerland with various research centres, regional and military services within the member states. COSMO-LM can provide different numerical schemes and physical parameterization in the same code and, depending for the application, different configurations can be defined. Two version of the model are available: one with 7 km of horizontal resolution and forecast range up to 72 hours, running operatively on all over the country, and a second one, pre-operative, with 2.8 km of horizontal resolution and up to 18 hours of forecast time range[3] with a smaller spatial domain. A big research activity, in our team, consists to find the optimal configuration of the two COSMO-LM versions (7 km and 2.8 km) for the simulations of extreme meteorological events on the Mediterranean area but also to improve the numerical scheme and the physical parameterization. This last topic requires, in particular, a detailed study of precipitation, soil-atmosphere interaction and soil infiltration, runoff, and transpiration/evaporation but also of the stability and convergence of the numerical schemes used to solve in time and space the descritized equation describing the atmosphere evolution. In the NMHC are used either COSMO-LM versions: the one with 2.8 km horizontal resolution is nested on the one with 7 km of horizontal resolution, covering a bigger spatial domain. This last one is nested on the global model (fig.1). This "two-step nesting" is necessary to guarantee the best quality of the forecast produced (in fact a resolution of 2.8 km is more able to take into account the effect produced by a complex orography) but also to permit a smaller resolution jump among the NWP models and the others cascade simulation models; nevertheless this configuration requires a very long computational time for this reason very efficient and powerful super computer area available to CMCC permitting to produce the scenarios for the different risks in less then one half a day.

Taking into account the very high resolution required for the landslide simulation models and the impossibility to use higher resolution then 2.8 km, for the limited NWP models, it has been investigated two different possibilities to interface the meteorological model at higher resolution and the landslide simulation models at areal level (the one with lower horizontal resolution compared to the one at punctual level). The first possibility is to use the direct output of the meteorological model as input of the simulation model for the stability analysis at areal level, the second one is to introduce some statistical downscaling techniques between the two models; this last technique permit to have a smaller spatial discontinuity and then more coherence in the results; on the other side using statistical procedures can be introduced additional errors. In first instance we decide to begin our evaluations using the direct meteorological model output because this option permits to spend less computational time; if the performances are not adequate for the scope is also possible to adopt the investigated downscaling techniques.

It is also important to emphasize that the coupling among the models is obtained, at this step of the work, through the precipitation field; this last one is a discontinuous meteorological variable, depending strongly from orography and soil properties then the downscaling algorithms have to consider also all these factors.

About landslide models, in order to produce risk scenarios on slopes, it has been decided that it is more useful to use a "one step nesting" technique; this means that precipitation information is used to initialize a stability simulation model working on area level; this first step permits a preliminary individuation of the critical slopes, then, this information is used to perform a more precise investigation only on these last slopes through a more complex simulation model for the stability analysis at punctual level. The outputs of this study are scenarios for the landslide risks on area interested by intense rainfall. The computational time required to run these stability models is very low; however a big a priori research activity is necessary to analyse the effects caused by meteorological phenomena in specific geomorphological contexts subject to instability, to establish the hydraulic and mechanical soil parameters governing the soil effects and to calibrate the numerical simulations through small scale physical modelling in order to simulate the slopes behaviour with particular stratigraphical and physical-mechanical characteristics.

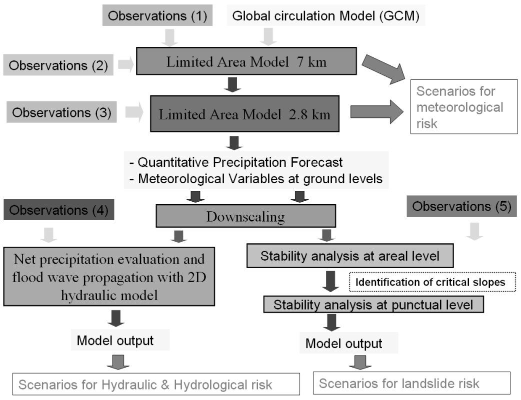

Fig. 1 the flow chart of the hydrometeorological simulation chain.

3. The performed test cases

The hydrometeorological simulation chain has been tested on some test cases occurred in the Campania region, located in the southern Italy. This area is frequently subject to landslides, sometimes initialized by precipitation; this special type of landslide will be investigated in this work. The first event, the one that is described, occurred at Nocera site, located about 30 km in south direction from Naples (the main Campania city). The others two test cases happened at the Camaldoli site, located near Naples respectively at the 18th of September 2005, after a thunderstorm in which was observed 70 mm of rain in 30 minutes, and at 13th of October 2004 after a rain of about 47.6 mm in 24 hours.

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mesoscale weather systems are small hurricanes, mesoscale convective complexes, thunderstorms and extremely large tornadoes.

3.1 The first test case (Nocera 4th March 2005).

The 4th March 2005 the Campania region was affected by a large Mediterranean perturbation caused by the contrast between the cold Arctic air and the milder one from the Atlantic Ocean; this situation establishes adverse weather conditions with heavy rainfall and locally intense showers. This meteorological situation triggered at the Nocera site a landslide around the 4 p.m. of the 4 March 2005, in the same area the precipitation event was characterized by a cumulative rainfall of about 80 mm (data from the meteorological stations located in the Campania Region) started at 00 of the same day.

The landslide experts classifies the landslide event as mixed “quick cast-creeping", it mobilized a land volume of 33000 m^3 (with thicknesses varying between 2 and 4 m), affecting an area of 24600 m^2 (with triangular shape: the summit and base seat respectively at140 and 390 m above sea level.), located along an opened side with average inclination of 36 degrees.

The first step in the application of the NMHC is to evaluate the meteorological models performances as input for stability analysis model at area level; for this goal is necessary to compare the precipitation forecast with the observed one. For this scope has been used data from three different sites located nearly the area in which was observed the landslide (fig.3):

- San Mauro pluviometric station
- Ponte Camerelle pluviometric station
- A3 railway pluviometric station.

For each station are available hourly precipitation data.

In first instance we show the comparison between hourly cumulated precipitations observed and forecasted data using a reference configuration of the two COSMO-LM versions, without using any optimized configuration (only the results obtained by the configuration with 2.8 km of resolution will be shown). Different comparison methods have been tested; the first one is to look only at the observation station and at the grid point nearest to landslide location but the results seem not good enough. This method doesn’t use a good experimental practice, because it doesn’t use all the available data (observation and forecast) because it assumes that the nearest point is also the most representative for the truth.

Fig. 3 the Google map of the area interested from the event. The F placeholder indicates the landslide place, the others placeholders the pluviometric station locations.

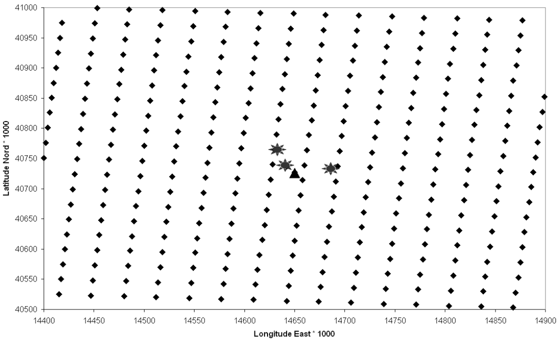

Fig.4 In the diagram is reported the 2.8 km COSMO-LM model grid points position (rhomb), pluviometric stations (star) and the landslide position (triangle).

Taking into account the particular nature of the precipitation variable and also the simulation model features seems that a better method, that is also the one with which are obtained the more realistic results for this test case, is to use a distance-weighted average of the available data. This assertion is not made looking also at the results of this test case, in fact, is known in the meteorological community that, at least at this stage of the NWP evolution ,these last ones are not yet able to "fit" the punctual observation, while their target is to predict what happens on an (time and spatial) area. That is the reason for which the punctual comparison, as verification methodology, has been passed in favour of the areal verification, at least for precipitation.

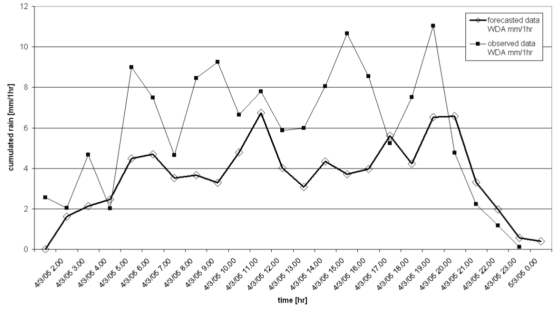

Fig.5 Comparison between weighted-distance average (WDA) forecasted and observed data (hourly cumulated rain)

To initialize the simulation model for the stability analysis at areal level can be is used the averaged values obtained. In this way is possible to identify a landslide risk scenario, which represents the more reliable scenario, but this scenario doesn’t extract from the weather forecast all the possible information. In the specific case of the ground impact, and for the events prediction that could have catastrophic effects, not is only important to identify the most likely scenario but also the most catastrophic one. The knowledge of these two scenarios provides more detailed information that can be used for the alerting. The most catastrophic scenario, based on the NWP models for landslide induced by intensive rain, can be obtained with the rain maximum hourly values identified among the points belonging to the area target.

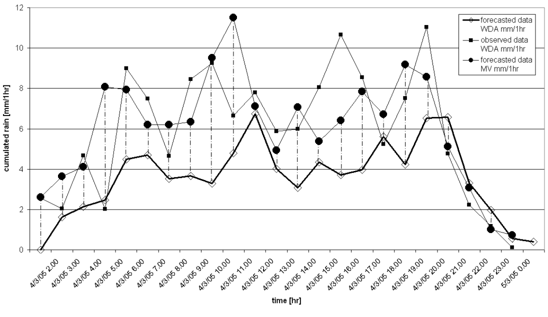

Fig.6 In the diagram are reported the forecasted rain using the distance-weighted average (WDA) and the maximum rain values (MV) and observed data

The area identified by dashed bars (fig.6) is the one between the weighted-distance average rainfall (from which will be obtained the scenario most reliable) and the maximum rain values (from which will be provided the most catastrophic one). Initializing with this pair of values the model for the stability analysis at areal level will get the two limits scenarios for the particular event. These two scenarios have 2 different risk factors associated. The two risk factors can be used by landslide specialists to take decisions. In this particular test case the 62.5% of the observed rainfall values are between the more reliable and the more catastrophic forecast. This result is fairly encouraging.

Remarks

Any optimization for the COSMO-LM model has been used to obtain the present results. This means that there is an ample possibility of improvement in terms of weather forecasting. The forecasted rain evaluated with the WDA and MV method will give two scenarios obtained from the NWP model. As a prediction, of course, there will always be an error respect to the real precipitation values, but, if the NWP models simulate "enough" well the rains observed, is possible to produce some warning one or two day before the event occurrence.

In this "enough" there are all the limitations that exist in trying to simulate reality with a simulation model. This limitation represents a bond that have to be accepted, taking into account that a big improvement is possible yet making better simulation models in the future.

The target area, is an area identified *a priori* as an area threatened by landslide that the specialists want to keep under observation, this is an area defined by the hypothesis to have "similar behavior in terms of landslide risk when it is affected by the same rain values"

Conclusions

In this work has been described the preliminary results obtained applying the NMHC tool. This numerical instrument has been defined by a multidisciplinary team working in the CMCC. The results regard the definition of the NMHC and its application on some test cases, occurred in southern Italy, in which the landslides were initialized by intense precipitation. The test cases permit to compare the results (risks scenarios) predicted by the numerical simulations and those that were observed during the events. This activity is necessary to assess the predictive power of the defined simulation chain and to understand its limits and then to make some new improvements

Acknowledgments

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Landslides, Forest Resources and Infrastructure in west central British Columbia Canada

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Abstract. The physical and biological diversity of northwest British Columbia Canada extends from a hyper maritime coastal environment through rugged mountain ranges to a drier, cooler climate of the interior plateau. Equally diverse are the types of landslides found throughout the region and their effects. These landslides include high frequency low magnitude debris slides, debris avalanches and debris flows dominant in coastal environments and large catastrophic rock slides, rock avalanches and debris flows found in the coastal mountains and the interior plateau. Landslides have long term economic impacts to forest resources through the destruction of second-growth forests, degraded site productivity, and reduced potential timber harvest volumes—impacts generally not considered beyond the direct cost attributed to clean-up or rebuilding of infrastructure. Along the east-west utility and transportation corridor of west central British Columbia, costs attached to the landslides are significant. Direct and indirect costs influence forest sites, timber values, and particularly local industry and businesses when utilities and roads are impacted. Examples of landslides that impact resources and infrastructure in the region are provided.

Keywords. Landslides, forest resources, infrastructure, direct and indirect economic costs, west central British Columbia.

1. Location and Physiography

West central British Columbia (BC) lies within the Canadian Cordillera (Fig. 1). The area was entirely covered by the ice during the Pleistocene (Clague 1984). The landscape exhibits features of post-glacial erosion and valleys are filled with moraine, glaciofluvial, glaciolacustrine and glaciomarine sediments. The physical and biological diversity of the region extends from hyper maritime coastal lowlands eastward through rugged glaciated mountain ranges to the cooler and drier interior plateau (Holland 1976; Mathews 1986). This distinctive combination of climate, physiography, vegetation and soil is reflected in the biogeoclimatic zones of the area (Meidinger and Pojar, 1991).

Equally as diverse as the landscapes are the landslide types and processes found in west central BC. On the BC north coast, including the Queen Charlotte Islands and coastal mountains, debris slides, debris avalanches and debris flows constitute the dominant processes although other large complex landslides also occur (rock avalanches, earth flows and flow-slides). In the interior portion of west central BC, landslides tend to be much larger, more complex and more destructive (Geertsema et al. 2006).

West central BC is sparsely populated with communities scattered along east to west and north to south transportation routes. The economic base for most of these communities is forestry with mining, agriculture and tourism also contributing. Landslides have only occasionally directly impacted communities within the region. However, in recent years, landslides have caused major disruption to utility services, such as, electricity and natural gas, and have closed major transportation routes for brief periods.

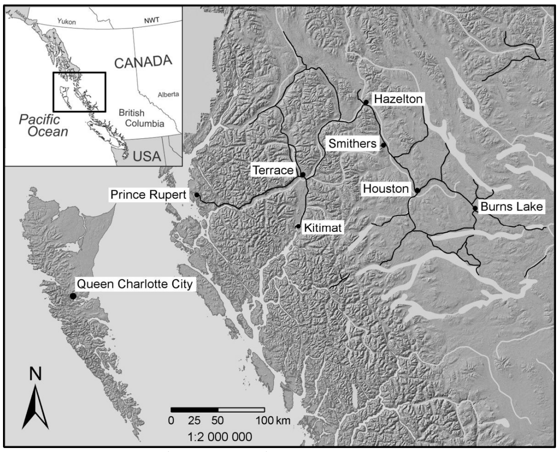

Fig. 1 West central BC Canada

The economic impact of landslides to resources and infrastructure is discussed in terms of dollar values. Lost value from timber lands is reported but consideration for other, unevaluated forest resources is also necessary. In BC forest resources are considered to include: water, soil, fish, wildlife, forage and associated plant communities, biodiversity, recreation, cultural heritage, and visual quality. Depending on the situation, their value may equal or exceed potential timber harvest values losses associated with landslides.

2. Debris Flows North Coastal BC

Many productive forest sites in north coastal BC owe their existence to a history of hydrogeomorphic processes; high frequency low magnitude debris slides-avalanches-flows and subsequent fluvial deposition (Gimbarzevsky 1988; Hogan and Schwab 1991; Schwab 1996). Natural events are generally widely distributed in both time and space and, therefore, do not cause widespread destruction (Fig. 2); rather, they serve to maintain soils capable of supporting productive forests (average coast timber volume, 660 m^3/ha). Forest harvesting on steep unstable hillslopes does, however, increase landslide rates (Fig. 3). Schwab (1983) in a study in the Rennell Sound area of the Queen Charlotte Islands showed on an area basis an increase of 36 times the natural rate during a single storm—an impact to approximately 4% of the steep, timber harvested land area. Rood (1984) in an aerial photograph inventory covering a larger land area on the Queen Charlotte Islands showed an increase of 34 times over a 7 yr period.

Landslides can have large-scale negative impacts to forest land productivity. The on-site impacts to forest stands and sites generally receive little emphasis compared to off site impacts (roads, personal property, and human life). However, there are both short and long-term direct and indirect consequences associated with landslides.

Smith et al. (1986) estimated productivity loss on debris avalanches of 70% in the first 60 yrs and in the order of 50% over an 80-yr rotation. A gradual productivity recovery is expected in subsequent forest rotations. Land areas intensively disturbed by landslides will likely require a doubling of the forest harvesting rotation to about 160 yrs as a result of the loss in productivity.

Fig. 2 Historic open slope debris flows, BC north coast.

On-site direct and indirect costs are realized when a debris avalanche or debris flow cuts a swath through a highly productive second-growth coastal forest (Fig. 3). A loss in present stand investment could include costs for plantation establishment, silvicultural surveys, brushing and weeding and juvenile spacing (Table 1). The loss of a second-growth forest stand is also viewed as extending the regeneration delay by the period of time equivalent to the age of the destroyed second-growth stand, and regeneration must establish on a degraded site. This loss is substantial on highly productive sites that could be managed for timber production on a 40-yr rotation (Mean Annual Increment 9-15 m^3/ha/yr).

Fig. 3 Destroyed 20 year old stand. The projected value loss in timber at rotation age is about $40,000/ ha.

Forest land timber productivity losses may hold a large future indirect cost. The extent of landslide disturbance in clearcuts was assessed by Schwab (1988) in an area encompassing Rennell Sound on the Queen Charlotte Islands. A landslide disturbance of 5.5 % (137 ha) of the clear cut area (2498 ha) projected as a non-recoverable land loss resulted in a loss in stumpage at rotation age of about one million dollars and a loss in economic activity of about 20 million dollars. Projections provided for the Queen Charlotte timber supply area that covers 45,000 ha of productive forest land, suggested a future loss in economic activity of 243 million dollars at rotation age (80 yrs). The gradual productivity recovery expected on landslides could offset this theoretical loss in timber yield and subsequent economic loss, but only if entry onto potentially unstable slopes during subsequent cutting rotations does not initiate more landslides.

The future cost of poor logging practices must be recognized when logging pushes on to potentially unstable terrain. Where stability problems were not recognized prior to logging, landslides affect up to 30 ha for every 100 ha logged upslope (Schwab 1988), thus justifying the removal of these unstable slopes from the net operable land area. Proven good forest management using sound road construction practices and silvicultural systems other than clear cutting, could make available large land areas for harvest that are presently excluded because of slope stability concerns.

Table 1. Silvicultural investments in second growth forests.

Silviculture Value	**Average cost[1] ($/ha)**
Plantation establishment	750
Silviculture surveys	100
Brushing and weeding[2]	1000
Juvenile spacing	2200
Total	4500

[1] North Coastal BC. Source: Pers. Comm. 2008 BC Forest Service, Kalum District and BC Timber Sales, Skeena.

[2] Brushing and weeding occurs on about 20% of sites.

3. Large Catastrophic Landslides, Coast and Interior

Large magnitude catastrophic rock slides-avalanches have increased over the past decade impacting forest lands and infrastructure in the west central BC coast and interior (Schwab et al. 2003; Geertsema et al. 2006, 2007). A documentation of landslides in west central BC that have impacted linear infrastructures including major resource roads, highways, natural gas pipelines, electricity transmission lines and rail lines is presented in Geertsema et al. (2008). Recent landslides of note include large rockslide–avalanches–flows, large debris flows and flow-slides in glacial marine sediments. On average, over the past decade two major (>0.5 M m^3) landslides have occurred per year within northwest BC. Table 2 provides a list of landslides easily viewed with Google Earth on images provide by the Province of BC.

4. Economic costs of large catastrophic landslides

A dollar value is often not commonly attached to landslides in remote mountain valleys unless there is a direct cost pertaining to lost production or infrastructure repair. (Documented costs are provided in Septer and Schwab, 1995) Landslides have however, resulted in the indirect loss of millions of dollars in timber from areas proposed for harvest. In addition, forest site productivity lost on the landslide track often equals an equivalent dollars loss in timber production over at least one forest rotation. Direct and indirect costs extend beyond the forest when landslides sever pipelines and close highways and major resource roads resulting in short-term industrial shutdowns. Direct and indirect costs are experienced by local industry and business. Direct costs pertain to lost production, lost revenue, and the repair to infrastructure. Indirect costs are related to delays in production. Costs are easily determined for large industrial energy users. However, with small business, costs are not recognized in dollars but as an inconvenience. It therefore becomes extremely difficult to determine/evaluate the costs.

Table 2. Catastrophic landsides impacting infrastructure.

Landslide name	Date	Latitude/ longitude	Values Impacted
Howson II[1]	1999	54°31'N;127°48'W	Pipeline/road/ forest[4]
Zymoetz[1]	2002	54°26'N;128°18'W	Pipeline/road/ Forest
Harold Price[1]	2002	55°04'N;126°57'W	Forest[4]
Bishop Bay[1]	2002	53°29'N:128°51W'	Forest[4]
NP Canery[2]	2002	53°10'N;130°10'W	Road/forest[4]
Porcher[2]	2002	54°00'N;130°20'W	Power line/ forest[4]
Port Simpson[2]	2002	54°29'N;130°21'W	Road/power line/forest[4]
Khyex[3]	2003	54°17'N;129°46'W	Pipeline/forest[4]
Twidledee[2]	2005	54°14'N;130°06'W	Highway/ forest[4]
Workchannel[2]	2005	54°17'N;129°59'W	Pipeline/forest[4]
Sutherland[1]	2005	54°22'N;124°56'W	Forest[4]
Legate I,II Legate III[2]	2004 2007	54°44'N;128°16'W	Highway/ forest[4]

[1] Landslide in rock and soil: Rock slide-debris avalanche-flow.

[2] landslides in soil: Debris slide-avalanche-flow.

[3] Flow slide in glaciomarine sediments.

[4] Forest includes: timber, forest site and aquatic values.

Fig. 4 Howson rock avalanche severed a natural gas pipeline. Arrows indicate: (1) the gas pipeline/access road; (2) a newly formed lake; and (3) the power transmission line.

Fig. 5 Harold Price rock slide-avalanche traveled 4km and destroyed 65 ha of timber in an area proposed for harvesting (Photo, M. Geertsema BC MOFR 2002).

General cost estimates attributed to large catastrophic landslides were obtained from the gas utility, large industrial users of natural gas and from the forest industry. Howson II landslide (Fig. 4) severed the gas pipeline resulting in a disruption to service for 5 days. Conservative estimates place the direct cost at $5 million and the indirect cost from lost production at $10.3 million. We estimate the direct costs connected to Zymoetz landslide (Boultbee et al. 2006) to be $5.9 million and indirect costs, $27.5 million. The landslide severed the gas pipeline disrupting service for 10 days, dammed the river and resulted in a forest road closure for one year. Two large plants were not in production at the time; otherwise, indirect costs could have been much higher.

The Harold Price landslide resulted in the indirect loss of $1.6 million of timber from an area proposed for harvest (Fig. 5). In addition, forest site productivity lost within the landslide track would represent an approximately equal loss in timber production over one forest rotation. Likewise, the Sutherland (Blais et al. 2006) and Bishop Bay landslides destroyed in the order of $0.65 million and $1.2 million of timber, respectively.

The Khyex River flow-slide occurred during the winter and left the port city of Prince Rupert and nearby community of Port Edward without natural gas service for 10 days (Schwab et al. 2004a; 2004b). The estimated cost to the city for emergency food and shelter for the period was about $0.3 million. A temporary gas line placed over the landslide to restore service cost in excess of $1 million. The cost for a permanent repair to the line was projected to exceed $5 million. A 45 yr old second growth forest was destroyed having an estimated future value of $1.6 to $2 million. The pipeline to the city was severed again two years later with the Work Channel debris avalanche. The city was left without gas service for 2.5 days and repairs to the pipeline line cost in the order of $0.5 million. These events were costly to repair and the indirect costs sustained by local business were not possible to accurately determine.

A large debris flow at Legate Creek closed the major highway link to the cities of Terrace and port cities of Kitimat and Prince Rupert for 2.5 days and opened to only single lane traffic for a week (Fig. 6). Disruption to transportation continued for up to one month. The direct cost to re-open and repair the highway was about $1.5 million. Indirect costs to the cities and port are not known.

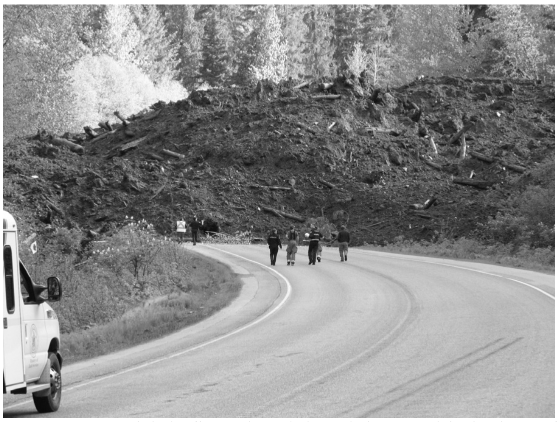

Fig. 6 Legate debris flow closed the Highway with the loss of two lives (Photo, G. Ross, BC MOTH 2007).

5. Summary

The mountainous terrain and climate conditions of west central BC have resulted in many landslides that have impacted communities, utilities, transportation routes, and forest resources. These landslides are costly in term of loss of life, emergency response, clean up, reconstruction of infrastructure, and lost productivity. Direct and indirect costs to utility providers and large industrial users are easily documented but indirect costs to communities and small business are not easily obtained. Indirect costs to forest resources are often overlooked but are substantial in terms of losses in timber volume, silviculture investments and degradation in forest soils and sites productivity. Landslide risk management is necessary to prevent ongoing devastating impacts from landslides in west central BC.

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Integration of Bio-engineering Techniques in Slope Stabilization Works: a Cost Effective Approach for Developing Countries

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Abstract:
Nepal is predominantly a mountainous country where road transport is the backbone of development. The geography of Nepal presents a fragile and rugged landscape but it will not be an exaggeration that the country’s progress largely hinges on the expansion of the road networks. Several road agencies including the Department of Roads (DoR) speeding up road building in Nepal at a great pace therefore, Nepal has now been experiencing highest road networks growth rate in the history of Nepal’s development. This resulted in disturbance of the marginally stabilized, long, steep and geologically weak slopes. Heavy monsoon rainfalls is causing triggering of slope failures such as slides, debris flow, rock falls, erosions etc. on those marginally stable slopes. Nepal being one of the least developed countries in the world where most of the people live below the poverty line, may not be able to manage these slope problems with sophisticated and costly civil engineering structures alone. Bio-engineering, a low cost technology, if applied in conjunction with civil engineering technology, could give a cheap yet, effective solutions to a range of slope stability problems. This paper highlights on how bio-engineering can be integrated with civil engineering techniques successfully.

Background:

Nepal is predominantly a mountainous country where road transport is the backbone of development. The geography of Nepal presents a fragile and rugged landscape but it will not be an exaggeration that the country’s progress largely hinges on the expansion of the road networks. Road network is one of the basic infrastructures that need to be developed as a first step towards sustainable development. Therefore, road network development has been in the priority list for both central and local governmental organization from last couple of decades. Consequently, Nepal has been experiencing the highest growth rate in road network development in this period.

Department of Roads, Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR), Municipalities, District Development Committees, Village Development Committees are the main agencies that are building roads in Nepal. Road building in such a great pace has been causing considerable disturbances to marginally stabilized slopes. Poor engineering in road design, construction and maintenance practices with limited budget leading to increased numbers of slope disasters in geologically weak, steep and long slopes of Nepal.

Excessive and typical rainfall pattern with 80% of the total average annual rainfall occurring in four months period of monsoon from June to September causes drastic rise in ground water table, excessive sub-surface and overland flows in short period of time. These are the main triggering factors for the initiation of landslides, slumping, debris flow and erosions on the slopes disturbed by the road constructions. Nepal being one of the poorest countries of the world can not afford to stabilize these slopes by constructing expensive civil engineering structures alone. Poor founding conditions, difficulty in deep excavation for the foundation and toe cuttings by about 6000 numbers of streams and rivers further contributing in destabilization of slopes. Research carried out by experts in Nepal and countries having similar geological and topographical conditions revealed that slope stabilization by supporting the slope with massive retaining wall improves the factor of safety of the slope in the order of 0.05 to 0.1 only (Howell et. al., 2003).

Inclusion of bio-engineering structures with civil structures have proven to be very successful, cost effective and sustainable technique in solving a range of slope instability problems ranging from simple to complex like Krishnabhir in Nepal. Although this paper's discussions and conclusions are drawn on the basis of case studies in Nepal, it shall be equally useful to Hindu Kush-Karakoram region and other south-east Asian regions as well.

Road Development Scenario in Nepal:

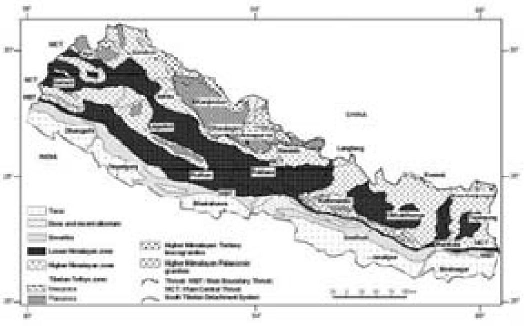
The history of roads development in Nepal is not very long. The first motorable road was constructed in Kathmandu, the capital city of Nepal in 1924 but the first long distance road (115 kilometers) connecting Kathmandu valley with Bhainse towards the border with India in south, was constructed in 1950s only. After that, the Department of Roads, which was the only road building agency till mid nineties, has contributed directly or indirectly in construction of about 17,200 kilometers of road network with assistance from bi-lateral and multi-lateral agencies.

From mid nineties, Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) and other local government agencies such as Municipalities, District Development Committees, Village Development Committees are also emerged out in road development scenario. DoLIDAR has constructed 3500 kilometers of agricultural roads from 1995 to date and by next 7 years, they have target to construct another 2700 kilometers of agricultural roads. Municipalities and District Development Committees are building urban and district roads respectively whereas, Village Development Committees too building thousands of kilometers of local roads without following the road standard set for the local and village roads. These rapid road building activities are causing considerable disturbances to marginally stabilized slopes. The village roads in particular, constructed by VDCs, are non-engineered roads and hence the maximum contributor to slope failures. Most of these village roads are non-functional after few years.

Geology of Nepal

The fold mountains of Nepal evolved through collision of the Indian and Eurasian continental plates, compressing a deep basin of sediments that lay between them and thrusting these sediments up into a series of great folds (TRL, 1997). This thrusting resulted in formation of continuous northwest-southeast lineations which have been controlling the distribution of the uplift and elevation, differential weathering and drainage pattern.

Nepal can be divided into the five physiographic zones as shown in the fig. 1. These zones extend essentially parallel to each other and separated by major thrusts. The Terai which is located south to the Major Frontal Thrust (MFT), is comprised of unconsolidated sediments like gravel, sand and mud. The Siwaliks bordered by Major Frontal Thrust (MFT) at south and Major Boundary Thrust (MBT) at north, consist of soft sedimentary rocks (such as mudstones, sandstones and conglomerates). The Lesser Himalaya zone sandwiched by MBT at south and Main Central Thrust (MCT) at north, contains the indurate sedimentary rocks as well as low grade metamorphic rocks like slates, limestones, dolomites, phyllites and quartzites. The Higher Himalaya to the north of MCT, comprised of medium to high-grade metamorphic rocks such as schists, gneisses and migmatites with granite intrusions; and the Tibetan Tethys zone of sedimentary rocks such as shales, limestones and sandstones with granite intrusions.



Source: M R Dhital, 2003

Fig 1: Generalized geological map of Nepal

Engineering Measures of Slope Stabilization:

A range of civil engineering techniques are available in DoR publication "Guide to Road Slope Protection, 2003". TRL, 1997 also contains some very practical low cost solutions to a range of slope stability problems. The budgetary constraint and the available technical capacity within the country often dictate the final selection of the remedial measures.

Majority of slopes failures of Nepal are shallow seated translational failures. The slip plane tends to follows the interface between rock and overlying soil material (fig. 2) or the interface between loose soil mass and relatively compact mass underneath (fig. 3). Deep seated failures which occurs in the thick soil, is quite few in numbers but where it occurs, it is very difficult to stabilize. Chalnakhel landslide along the Kathmandu-Dakshinkali road is of deep seated nature and attempts are being made for stabilization from few years but without satisfactory results.

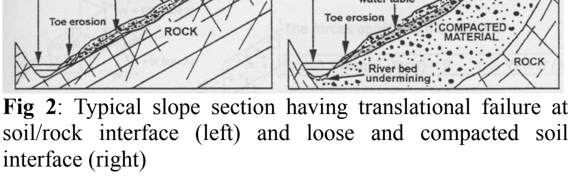


Fig 2: Typical slope section having translational failure at soil/rock interface (left) and loose and compacted soil interface (right)

Inadequate attention to geo-technical study in road constructions leading to inappropriate design of cut slope angles, support walls, drainage measures etc. Consequently, slope failures in cuttings are by far the most frequent of instability problems observed along mountain roads, and the standard approach to their rectification is breast wall construction, either in gabion or in masonry (Howell et. al., 2003). In mountainous terrain, steep slope prevents deep excavations in search for a stable ground, which is often required to support the potential moving mass of long slopes. Providing required foundation width is another major problem in mountainous terrain. There is tendency among the engineers to stabilize the slope by providing high walls following the standard design. This adds huge mass on the geologically weak slope, thus, in stead of solving a problem, it contributes to failure by increasing disturbing force on the slope. Study carried out by the author in Nepal and Bhutan showed that the provision of huge mass as retaining structures in the steep and long slopes have increased the factor of safety of the slope against instability in the order of 0.05 to 0.1 only. Similar results have been obtained by some foreign experts as well (Howell et. al., 2003). This reckons the need of other measures as well to attain the required safety level in steep and long slopes of mountain regions. Infiltration control measures such as slope revetments or pitching with masonry or gabion would help in checking the shear strength from lowering along the potential slip plane. Covering the slope with such material would have adverse effect upon the environment and the cost would also be significantly high. Maintenance will be another major issue and sustainability could be a major concern.

Water management with construction of slope drainage, road side drains, check dams, cascade drains and culverts, is probably the most important aspect that needs to be addressed in controlling slope instabilities in this mountain and hilly terrain where rain falls of magnitude over 100 mm in 24 hours is quite common. Occasional cloud bursts with rainfalls around 500 mm in 24 hours is also a common phenomenon. This fact is well realized by the engineers of Nepal but yet, adequate drainage networks on the slope is rarely provided due to cost factor. Maintenance of catch / cut off drains located high up in the slope from the road, tends to get less attention of the road engineers. Choking of such drains creates more problems due to concentrated flow of water from breached or cracked drains.

Integration of Bio-engineering:

Bio-engineering is the use of living plants to reduce erosion and shallow seated planar failures and slumpings. The effectiveness of vegetative structures is limited to 0.5 to 1.0 meters in general and complements the conventional civil engineering structures. For deep seated failures, bio-engineering structures can not stabilize directly but can contribute indirectly to civil engineering structures by protecting the soil surface. It functions in the similar way as civil engineering structures. Six major engineering functions that a bio-engineering structures are :

Catch (Holding / stopping of falling soil particles over the surface), Armour (armouring the slope surface against rain splash and erosion), Support (supporting the soil mass from below), Anchor (anchoring the loose particle down to a firm ground), Reinforce (reinforce the soil by increasing its shear strength) and Drain (improving drainage capacity of the poorly draining soil).

The plants that are used for the bio-engineering purposes are various grasses, shrubs, small and large trees. It is appropriate to use local species rather than imported materials because native plants are more likely to be adapted to grow in the hostile conditions found on the bare sites and are resistant to local diseases (TRL, 1997).

The main advantages of vegetative structures are:

- it protects soil surface against erosion and prevents the

movement of soil particles down slope under the action of gravity
- it increases the soil infiltration capacity which helps to reduce volume of overland flow
- plant roots bind the soil particles thereby improving the shear strength of the soil mass
- transpire considerable volume of water, reducing soil moisture and increasing soil suction
- it uses locally available knowledge, skill and materials, therefore, it is a cheap and sustainable technology.

These vegetative structures however, can not be designed or build to achieve quantifiable factor of safety of slope against failures as in the conventional civil engineering structures. It can be monitored whether the desired engineering functions have been fulfilled or not by visual inspections and instrumentation.

Generally, a mixture of plant types shall be selected so that the plant community will be formed and propagate. The characteristics of the plants required for bio-engineering are:

- should be adapted to the growing conditions of the general environment
- rapid growth
- long living
- substantial root system
- easy to propagate
- should not be invasive or poisonous to livestock

Bio-engineering structures when provided with civil engineering structures give best results in slope stabilization and protections economically and effectively. Vegetative structures can be integrated with civil structures either serving the same or complementary functions. The vegetative structures need few years to serve engineering functions whereas the civil structures start serving engineering functions immediately after its placement.

If these technologies are integrated to serve complementary functions, the use of civil or bio-engineering structures should be decided based on the particular engineering function that can be better addressed by each technologies. Bio-engineering structures were provided particularly in slope protection works against erosion, shallow planar sliding and slumping and improve drainage conditions of the semi-pervious slope materials whereas, civil engineering structures were provided in the places where

- mass movement is required to be stopped
- need to provide strong barrier against impact forces of flowing/falling debris such as check dams
- the structure/s need to fulfill the required engineering functions immediately after its placement since,
- use of bio-engineering structures are practically ineffective.

Integration of bio-engineering with conventional civil engineering techniques, is now an established approach and used in almost every attempts of slope stabilization in Nepal. Nepal has stabilized some of the very complex and big slope instability problems like Krishnabhir, Mugling-Narayanghat slope disasters and many others. Some of the cases which were solved by this approach have been described in the subsequent paragraphs.

Stabilization of Krishnabhir Landslide:
This is one of the worst slope disasters Nepal has ever had along the highway corridor. This site is situated at 82.50 kilometers west from the capital city Kathmandu in the Prithvi Highway which is the only supply route to capital city Kathmandu from southern Terai. Closure of this road for even an hour hits the headlines of all forms of media. When this road was closed for 11 consecutive days from 11 August 2000, the havoc faced by the nation was unforgettable.

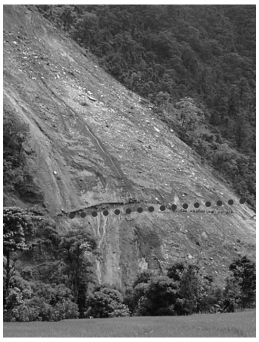


Fig 3: Krishnabhir slide. Photo taken in 2000 August

It was a translational failure with failure surface roughly at 10 m depth from the ground surface. The failure stretched 240 meters (vertical height) above the road level and 200 meters wide along the road. The failed mass deposited further 90 meters (inclined length) down the slope to the river Trishuli. The huge mass of debris was too mobile and very dangerous to even walk along the newly cut track for opening the road for vehicular movement. After this slide, the road was closed quite frequently even at minor drizzle or wind.

The problems for stabilization of this site were unavailability of sound rock even at 18 to 20 m. depth from the surface, covering of the surface with very loose debris which was very mobile and the overland flow causing severe debris flow closing the road frequently.

Water management did appear to be one of the significant measures to be designed in order to control the overland and sub-surface flow. Construction of drainage system on this loose debris was a great challenge as the whole drainage system could be washed off in the event of torrential rain fall. So, civil engineering measures such as check dams, cascade drains and culverts were provided to withstand against great force of impact from the flowing water/debris. There was no firm ground on the sides of check dams and cascade drains, so, vegetative structures were provided at the keys of check dams and other structure/soil interface. Main functions of civil structures were to support and drain whereas the functions of vegetative structures were to armour and reinforce the soil. At the toe of the slope, 6 meters high concrete toe wall was provided. 3-4 meters high gabion retaining walls were provided at the road level. At hill side of road, 6 meters high gabion breast wall was provided to support moving upslope. The ends of check dams were extended sideways to partly function as slope support wall as well. Surface drains of gabion bolster tubes in the herring bone pattern were provided at the mid part of the slope to drain the slope surface. In between the slope support walls and branch drains of herring bone drains, vegetative structures mainly of grass and shrubs in the diagonal pattern were provided. Armour, reinforce and drainage improvement were the main engineering functions that were expected with these vegetative structures. On the steep up slope where the thickness of debris was relatively thin, random grass plantation with the support of wiremesh nets or ROFA (planting board) were provided to armour and reinforce the slope surface.


Fig 4 (left): Before execution of mitigating measures at

Krishnabhir in 2000 A.D. **Fig 5 (right):** Stabilized Krishnabhir.

With such structures, the huge slope instability problems of Krishnabhir was stabilized with a total cost of 55 million Nepalese Rupees which was about 2% of the total cost proposed by a foreign consultant to solve the same problem with civil engineering structures alone.

Stabilization of Simaltal Landslide:

Simaltal landslide is located at 95 kilometers west from Kathmandu on the Mugling-Narayanghat Highway. The slope disaster due to cloud burst in July 29-30, 2003 closed this highway for a week as there was landslide and debris flows at 118 locations in this 36 kilometers long highway. Since, this highway is also a part of the main supply route to the capital city Kathmandu, this slope disaster became one of the major concerns of the government at that time.

The rain gauge at Bharatpur recorded 364 mm of precipitation in 24 hours whereas, that of Devghat which is 5 km north to Bharatpur recorded 446 mm. Heavy rainfall on Aug 17, further worsened the stability conditions and since then, there was no single day passed without having a road closure in monsoon of 2003.

Simaltal was one of the worst hit sections of that disaster. About 75 meters of road segment subsided more than 5 meters at this location. The failure was resulted because of the toe cutting by the river Trisuli flowing almost 50 meters below the road surface. A thick slope mass was moved and therefore, a stable foundation could not be expected at workable depth. No stable rock outcropped at toe as well, so, it was a great challenge to protect the toe against thundering Trisuli. A massive concrete toe wall was constructed with concrete launching apron of 5 meters width. This provided limited support to moved slope as well. Stability analysis showed that the expected slip plane would be at considerable depth and hence, an RCC retaining wall at valley side with 66 numbers of rock anchors having length greater that 15 meters were provided. The colluvium slope above the road was supported by 4 meters high gabion wall at hill side since, a stable foundation at hillside can not be expected and the ground water table was fairly high at hill side. The slope above gabion breast wall and the loose slope mass between road retaining wall and toe wall was protected by providing vegetative structures such as Kans (Saccharum spontaneum), Babiyo (Eulaliopsis binata), Amliso (Thysanolaena maxima), Bhujetro (Butea minor), Simali (Vitexnegundo) etc. This vegetative structures protected the slope by armouring and improved the shear strength of the slope by reinforcing function. This combination of civil and vegetative structures are giving quite a satisfactory results as there was no slope movement observed after completion of these structures.

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Conclusion:

Developing agencies focusing their attention in expanding road network since the roads are the basic infrastructure for a sustainable development. So, road building has now been experiencing the highest growth rate in Nepal. Difficult geological, climatical, topographical and poor engineering practices are causing a number of slope instabilities along the road corridors. Poor economic conditions of Nepal do not allow the use of sophisticated civil engineering techniques alone to stabilize those slope instabilities. Bio-engineering is a well established technique in Nepal by now and does not demand heavy cost and skills for its implementation. Integration of bio-engineering techniques with conventional civil engineering, has been proved to be very effective and cheap techniques in stabilizing a range of slope instability problems. However, clear understanding of the ground conditions, failure modes and engineering functions of vegetative and civil structures are prime requirement for its success. This approach can be used in other developing countries having similar geologic and topographical conditions.

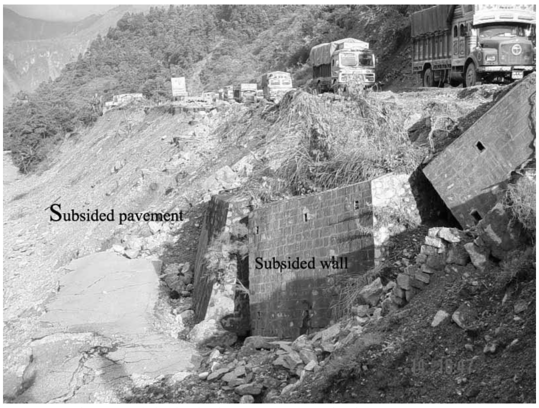

Fig 6: Photo of failed slope at Simaltal in 2003.

Fig 7: Photo of stabilized slope at Simaltal in 2008.

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Cause Analysis on the Shallow Landslide of Highway Soil Cutting Slopes in Seasonally Frozen-Ground

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Abstract. The paper studies the landslide phenomenon by way of combined field tests and lab tests, mainly studies the change of moisture of the soil body of the slopes with seasonal temperature and the effect of moisture of the soil body on the slope stability. It is proved by the study that: during freezing of the soil body of the slopes, moisture moves towards the frozen zone, resulting in higher water content in the frozen zone; with deeper depth of freezing, change of water content tends to take place at deeper depth too; the herbaceous plants has better moisture absorption function than the grass family on slope surface; the strength of the soil body is affected by variation of water content of the slope and temperature of the soil body. When the temperature of the soil body of the slopes is above 0℃, the strength of the soil body is mainly affected by its water content. When the temperature of the soil body of the slopes is below 0℃, the strength is mainly affected by temperature. It is proved by triaxial test that: cohesion of the soil body of the slopes increases with increase of water content in the beginning, but starts to decrease with increase of water content when the water content reached a peak of 15%. The internal friction angle of the soil body of the slopes generally decreases with increase of water content. This study can provide basis for prevention and treatment of freeze-thaw destabilization of soil road cutting slopes of high-grade highways in seasonally frozen-ground region.

Keywords. Seasonally frozen-ground region, Soil cutting slope, Water content, Strength of the soil body, Slope protected by plants

Introduction

When a high-rank highway is built in seasonally frozen regions, it is inevitable to excavate the mountain slope in order to meet the route requirement of the highway grade. During highway construction, a mass of extraction damage the surface vegetation and cut off the runoff passage of groundwater, cause the outcrop of underground water on the cutting slope and affect the intrinsic ground stress equilibrium of the slope body, lead to the redistribution of ground stress and the heat balance change in the near-surface of the cut slope (Chen et al.2006, Song et al 2005). Under influence of rainfall in autumn and the cold climate in winter, the moisture transfer to frozen zone of cutting slope and lead to the frost heave in the shallow depth of the slope (Liu and Wang 2006). During the thawing period in spring, with effect of integrated factors including rainfall and increasing temperature, ice kernels on both the surface and the near-surface of cut slope thaw quickly. The water melting from frozen soil，will hampered by frozen layer in process of infiltration. As a result, the water content of the intersection between the freezing and melting layer is high enough to cause saturation or even over-saturation, and accordingly the intrinsic effective stress on the slope body decrease. For the reason of gravity, the near-surface of slope collapses partially or entirely and slides downwards along the intersection of the freezing and melting layer (Niu et al 2004). As shown in Fig. 1. The study for the stability of frozen soil appears early (Tarr 1897) (McRoberts and Morgenstern 1974, Clark 1988, Zhou and Guo 1982), but the research results mainly related to the permafrost region on plateaus, there is lots of different on the instability theory between seasonally frozen region and permafrost region. Therefore, the theme of this article has important significance in judging the instability of the slope.

Fig. 1 Sandwich ice and freeze-thaw destabilization on the surface produced in the road cutting slopes of Jiamusi-Harbin section of Tong-San Highway

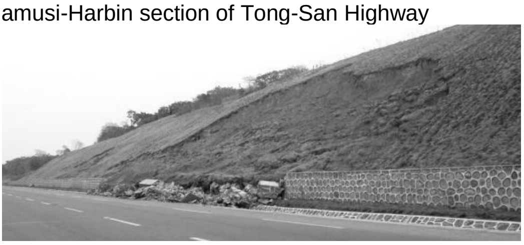

Fig. 2 Freeze-thaw destabilization of the road cutting slopes of Jiamusi-Harbin section of Tong-San Highway

Study Area Overview

On Tong-San Highway from Jiamusi-Harbin section K562+500-K563+900, we selected three sections for our study which is on the stability of cutting slope and area environment around the highway.

The region of test sections belongs to continental seasonal climate. It is very cold and dry in winter under the control of the continental air mass from the polar region, is hot and rainy in summer for influence of the ocean air mass from the subtropical zone, and is very changeable in spring and autumn due to taking-over of summer monsoon and winter monsoon. In spring, it is windy with low rainfall and fast evaporation, and is liable to drought. In autumn, there is more cold wave invasion occurrence. The average annual temperature is 3.2℃, with a record high of 36.4℃ and record low of -41.1℃. The average annual rainfall is 542.6 mm. Rainfall concentrates in June, July and August, accounting for about 62.5% of the total rainfall of the year. The maximum thickness of snow accumulation is 50 cm and the maximum depth of frozen soil is 2.2 m. The stable ground freeze date is November 24 and the stable ground unfreeze date is April 15 of the next year. The prevailing wind is southwest wind, with maximum wind speed at 30 m/s and average wind speed at 4.3 m/s.

Formation structure along the road mainly is khaddar: the upper is yellow loam, sandy loam, silt-mild clay, its thickness is between 3 m and 20m, and partially as high as 30m, they mostly are middle-lower consolidated clay; the lower is yellow gravel and grey gravel, its thickness is between 5m and 15 m, partly of them has clay lenticels. The soil slope body belongs to silty clay type. In the process of freezing, the water easily form the accumulation of water-ice-belt which melt slowly in spring and block the water down infiltrate, under this situation, frost heaving, frost boiling, slope thawed slumping will happen.

Contents and Methods of Study

To make a detailed study on the changing rule of water content in soil cutting slope varying with seasonal temperature, slope depth, plant species and different locations on the slope, three typical road sections are selected, which has different kinds of plant to reinforce slope, they are turf, lespedeza, and amorphous fruticosa respectively. We puts focus on water content observation to different depth of the soil cutting slopes, especially in winter and in spring. In order to reflect the regularity of water content in a more objective way, our test method is to dig holes to get samples at different depths, and meanwhile on the pit wall, to measure the strength and temperature of the soil body.

Triaxial test indoor is used to study the changing rule, which is regularity of slope soil shear strength varying with soil water contents and soil dry density. Five different water contents and five different dry densities of soil body are designed on basis of the measurement of water contents and dry density of the soil body. The water content is 8%, 14%, 18%, 22% and 25% respectively and the dry density is 1.5 g/cm^3, 1.6 g/cm^3, 1.7 g/cm^3, 1.8 g/cm^3 and 1.9 g/cm^3 respectively.

Analyses on Study Results

1. Study on the Regularity of Variation of Water Contents Varying with Seasonal Temperature

In this region, the land usually has temperature below zero degree in November and begins thawing in March. It can be seen from the pattern of the curves in Fig. 3 that during the course of freezing of the soil body, moisture moves towards the frozen zone, resulting in higher water content in the frozen zone either with Lespedeza or with Amorpha fruticosa for slope reinforcement. With deeper depth of freezing, higher moisture tends to take place at deeper depth too. But little change will take place in the already frozen soil body with temperature drop. During the process of freezing, the soil body protected with Lespedeza, whose water content can increase max to 5%, while with Amorpha fruticosa the increase is max to 2% or so.

Within the depth of 180 cm below the slope surface, the water content of the soil body shows a gradual increase with depth except several exceptional cases as bellow: On April 13, there is obviously increase of water content observed by us, which was due to seepage of rainwater; On April 26, there is obviously decrease of water content in melting layer especially on the surface of the slopes, which was due to evaporation of moisture and water absorption of plant root.

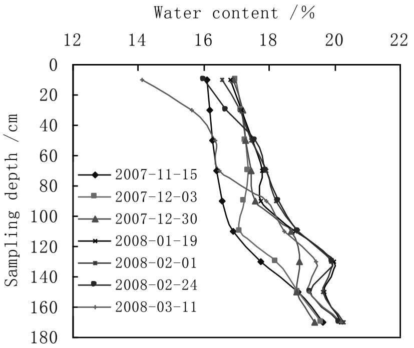

Fig. 3 Regularity of change of water content of slopes protected with Amorpha fruticosa

Study on the Influence of Plant Distribution on Soil Water Content

In the spring melting period, we carried out survey on water contents of the soil body with different slope protecting plants. The results of the survey are shown in Fig. 4 and Fig. 5. The curve shown in Fig. 4 is the contrast curve of water content of the soil body for with turf protected and with Lespedeza protected. The curve shown in Fig. 5 is the contrast curve of water content of the soil body for with turf protected and with Amorpha fruticosa protected. It is obvious to see that moisture absorption with woody plant protected slopes is better than with turf, and the performance of Amorpha fruticosa is good. The water content can be cut by about 2% with Lespedeza as the protecting plant than with turf. The water content can be cut by up to about 12% with Amorpha fruticosa as the protecting plant than with turf, the effect is the most obvious at depth of about 80 cm.

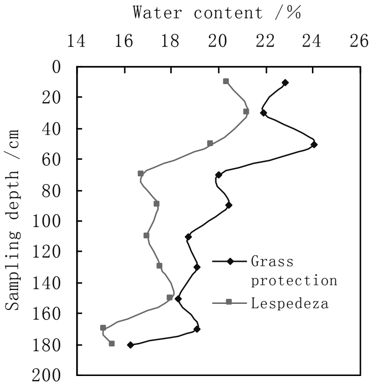

Fig. 4 The contrast curve of water content of the soil body for with turf protected and with Lespedeza protected

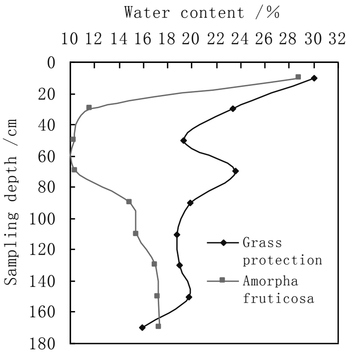

Fig. 5 The contrast curve of water content of the soil body for with turf protected and with Amorpha fruticosa protected

Study on the Regularity of Vertical Distribution of Water content of the Slope

The curve shown in Fig.6 is the contrast curve of water contents of the soil body for on top of the slope, in the middle of the slope and by the toe of the slope, which is protected by turf and in thawing season. It can be seen from the location and spreading feature of the curve that the water content on top of the slope is the highest, especially significant at depth of 60~100 cm. The water content in the middle of the slope is relatively low. The water content within depth of 20 cm varies very little or shows no regularity, whose main reason is that the change of water content in this range of depth is more influenced by climate.

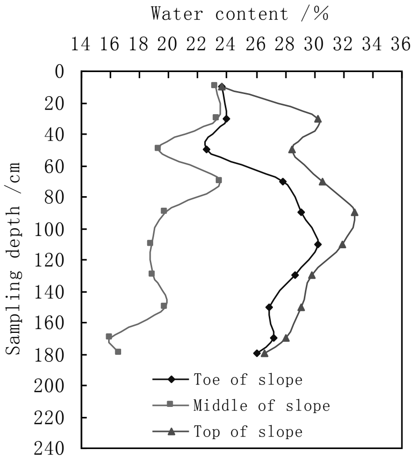

Fig. 6 Curves for comparison of water contents on top of slope, in middle of slope and by toe of slope protected with turf

Study on Relation of Water content, Land Temperature and Soil Body Strength

On April 26, 2008, on the slopes protected with Lespedeza and turf, we dug holes and collected samples from different depths, and meanwhile on the pit wall, measured the strength and temperature of the soil body. The results of measurements are shown in Fig.7.

The strength of the soil body is affected by water content and temperature of the soil body. When the temperature of the soil body of slope is above 0℃, the strength of the soil body is mainly affected by its water content and tends to increase with decrease of water content. In case of slope protection with Lespedeza, when water content decreases from 18.2% to 13.7%, the soil body strength increases from 2.5 kPa to 12.0 kPa. In case of slope protection with turf, when water content decreases from 23.5% to 19.0%, the soil body strength increases from 3.0 kPa to 10.8 kPa. When the temperature of the soil body of the slopes is below 0℃, the strength is mainly affected by temperature. When temperature at depth of about 80 cm decreases to under zero degree, the soil body strength increases rapidly. In case of slope protection with Lespedeza, the soil body strength increases from 12.0 kPa to 25.3 kPa. In case of slope protection with turf, the soil body strength increases from 10.8 kPa to 29.9 kPa. At negative temperature, the soil body strength is more or less affected by water content, but the change is very limited.

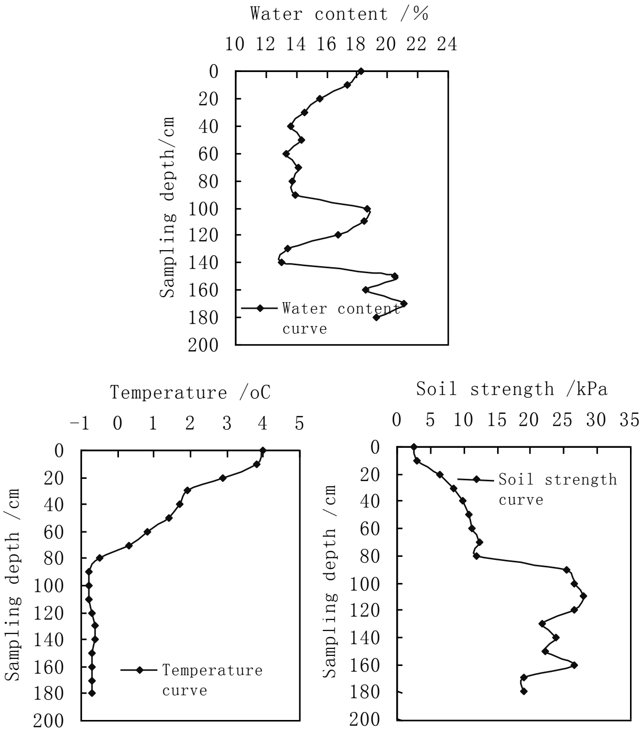

Fig. 7 Curves for comparison of soil body strength with change of moisture and land temperature of soil body of slope protected with Lespedeza

Study on Influence of Water content and Dry Density of Soil Body on Soil Body Strength

Water content and dry density are two major factors that affect shear strength of soil body. The shear strength of soil body is mainly represented by two shear strength indexes, i.e. cohesion c and internal friction angle φ. The two parameters c and φ are important in quantitative analysis on stability of slopes and can provide basis for calculation of freeze-thaw destabilization of slopes. Triaxial test is carried out to study the regularity for c, φ varying with soil water content and density. The results of the study are shown in Fig.8 and Fig.9.

It can be seen from Fig. 8 that whether the dry density is high or low, the cohesion of the soil body of slopes increases with increase of water content in the beginning, but after the water content has reached 15%, the cohesion of the soil body of slopes begins to decrease with increase of water content. Such regularity is more obvious for higher dry density. Under a fixed water content, the cohesion increases with increase of dry density. The increase of cohesion is more obvious at lower dry density. When the dry density is 1.8 g/cm^3 and 1.9 g/cm^3, the influence on cohesion by water content is similar.

It can be seen from Fig. 9 that whether the dry density is high or low, the internal friction angle of the soil body of slopes generally decreases with increase of water content. Such regularity is more obvious for lower water content. The main reason is that when water content increases, the lubrication function by water is strengthened in soil body, causing decreased internal friction angle with increased water content. At low water content, higher soil body density helps to increase the internal friction angle of soil, but at high water content, the influence of higher soil body density on the internal friction angle is very limited.

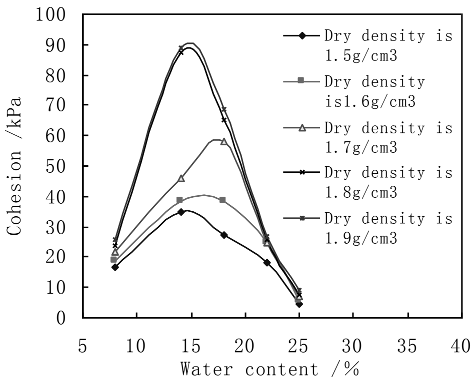

Fig. 8 Regularity of change of cohesion of soil body of slopes with water content and dry density

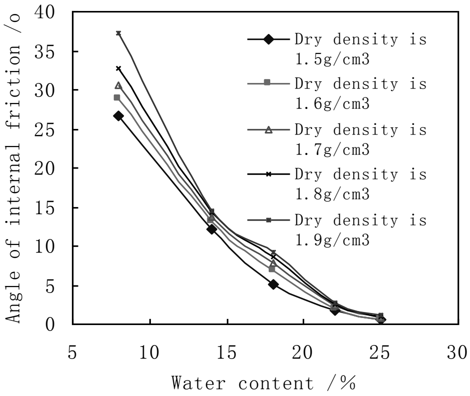

Fig. 9 Regularity of change of internal friction angle of soil body of slopes with water content and dry density

Conclusions

1. During freezing of the soil body of the slopes, moisture moves towards the frozen zone, resulting in higher water content in the frozen zone. With deeper depth of freezing, change of water content tends to take place at deeper depth too. It is known from comparison that for the slopes protected with Lespedeza; the water content of slope body can increase by up to 5% during the process of freezing, while with Amorpha fruticosa the increase is up to 2% or so.
2. Woody plant used to protecting slope is better than turf in moisture absorption and the performance of Amorpha fruticosa is good. The water content can be cut by about 2% with Lespedeza as the reinforcing plant than with turf. The water content can be cut by up to about 12% with Amorpha fruticosa as the reinforcing plant than with turf. The effect is the most obvious at depth of about 80 cm.
3. The water content on top of the slope is the highest, especially significant at depth of 60~100cm. The water content in the middle of the slope is relatively low. According to such analysis, freeze-thaw destabilization, if any, will take place most probably on the upper part of the slope. This is proved by the actual circumstance as Fig. 2.
4. The strength of the soil body is affected by variation of water content and temperature of the soil body. When the temperature of the soil body is above 0℃, the strength of the soil body is mainly affected by its water content. When the temperature of the soil body is below 0℃, the strength is mainly affected by temperature. At negative temperature, the soil body strength is more or less affected by water content, but the change is very limited.
5. The cohesion of the soil body of slopes increases with increase of water content in the beginning, but after the water content has reached a peak and after that, the cohesion of the soil body of slopes begins to decrease with increase of water content. Under a fixed water content, the cohesion increases with increase of dry density. The internal friction angle of the soil body of slopes generally decreases with increase of water content.

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Sustainable Community Disaster Education in Saijo City and its Effectiveness in Landslide Risk Reduction

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Abstract. Many of the Japanese small and medium size cities are located in the coast, and become vulnerable to both coastal and mountain hazards. The vulnerability is increased due to increasing aged population, low resources and lack of capacity in the local governments. In this scenario, it is important that the community's potential should be utilized in its fullest form through proper awareness raising and capacity building. Town watching and mountain watching are considered as useful tools to reduce urban risk in small and medium sized cities, where participation of local schools, its students, teachers, parents, resident associations and local government members collective watch both good and bad (vulnerable) parts of their cities. This collective watching and participatory mapping helps the engagement of school children and communities in risk reduction activities. This type of neighborhood watching is a process, and it is important to continue the initiative for effective risk reduction at community levels. Through sustainable community disaster education, it is possible to reduce the risk of landslide, and thereby making the small and medium size mountain cities safer to both geological and hydro-meteorological hazards.

Keywords: Community education, Town watching, Mountain watching, Small and medium size cities, Saijo

1. Background

1.1 Small and medium sized cities in Japan

In Japan, there are a lot of small and medium sized cities. Two thirds of all cities in Japan have less than 100,000 people as population. Recently, such local cities had many problems, for example, faltering local economy, sagging and hollowing local industry, tight local finance, functional decline of urban area, and so on. These problems are closely related to each other. This study belongs to the Master Thesis in the GSGES, Kyoto University[i].

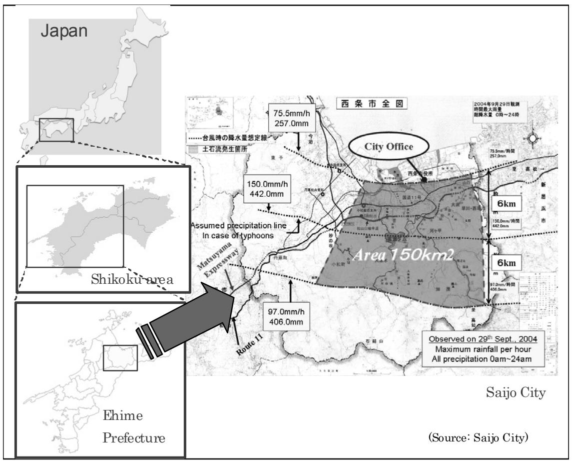
All over the country, declining birth rate and aging is proceeding, and population decrease in coming thirty years is quite certain. In 2030, it is estimated that the population would be about 112 million and aging rate is about 32.4%. Especially, local cities have the pronounced tendency because young people are going out of the area. The main reason is educational advancement and getting employment. At the same time, old people prefer staying back in the place where they have lived for a long time. So, the living base and economic base will become poor.

Aging in local cities affects not only financial problems, but also disaster prevention. In case of a disaster, young people's help is essential. According to the proposal of MLIT (Ministry of Land Infrastructure and Transport), characteristic of recent heavy rain disaster is that, many people who need help in case of a disaster are affected, system of mutual assistance in case of a disaster is poor, risk awareness is low, and so on. So, it is important for community people to work together for disaster prevention. But the relationship between urban area and mountainous area becomes poor. Many people living in urban area have never been to mountainous area and don't know about the area. Saijo City in Ehime Prefecture is one of such cities.

1.2 Background of Saijo City

Saijo city is located in the eastern part of Ehime prefecture. It has an area of 509.04 square kilo meters, with a population of 116,059 (2006.10). On the 1st of November, 2004, Saijo City, Toyo City, Tanbara Town and Komatsu Town from Shuso County merged to form the new "Saijo City" (Figure 1).

The geography of the city is classified broadly into four parts; plain area along the coast, hilly area between Saijo City and Nihama City, hilly terrain ranging in the north side of median tectonic line along the south side of the plain, and precipitous mountains in the southern side of median tectonic line. There is Mt. Ishiduchi, the highest mountain in the western part of Japan. Two big rivers, Kamo River and Nakayama River, flow in the center of the city.



(Source: Saijo City)

Figure 1. Location of Saijo city and it's the rainfall contour of 2004 Typhoon 21.

Saijo city is famous for its spring water called "Uchinuki". The river water soaks into underground and pools, then spouts above ground under pressure. Just by driving a pipe into underground, water comes out. The amount of the flowing water is about 90,000m^3 per day. Due to the little temperature change through all seasons, it is used as daily life water, agricultural water and industrial water. "Uchinuki" is one of the 100 best waters in Japan.

There is a traditional annual festival called "Saijo Matsuri" in October, when almost all people, the young and the old, get wildly excited. Each Jichikai (neighborhood association) has their own "Danjiri" (floats) and relationships among people in the communities are strong. "Jichikai" is neighborhood association which is organized in each area within municipality at their own initiative. There are 540 Jichikai in Saijo city and they make 28 Jichikai union.

2. Saijo's Emerging Disaster Issues

In summer and autumn in 2004, 6 typhoons (no.4, 6, 10, 11, 21, 23) at record high hit Shikoku area. (In Shikoku area, 2 was the most since 1995 and 1.5 is average.) In Seto Island Sea area where they have little heavy rain damage basically, there were many concentrated downpours and landslides, high tide and they cost much precious possession like 61 people's valuable lives and houses. Especially, typhoon no.15, 16, 18, 21, 22, 23, numbering 6 typhoons caused damages to Saijo City and no.21 and 23 caused larger damages.

On 29th September, 2004, typhoon no.21 moved across Shikoku area. Because of this, in Saijo City, they had record concentrated heavy rain, 75.5~150mm rainfall per hour. Avalanche of rocks, earth and driftwood surged which seemed to have occurred due to slope destruction of intermediate and mountainous area and forming destruction of natural dam. A lot of driftwood got stuck with bridge pier and water was held back and overflowed. As the water level rose suddenly, surrounding houses were flooded. In the flat part, each area was flooded above or below floor level. In the mountainous area, landslide disaster occurred frequently, roads were severed, many villages were isolated and house destruction and human suffering were caused. The dead in Ehime prefecture by typhoon no.21 numbered 14 people and this was the worst record in human suffering caused by typhoon.

Emerging problems due to the typhoon are as follows.

(1) Ill-maintained forest and thinned wood in the mountains

Frequent small slope failure by the concentrated heavy rain of typhoon no.21 added to the damage. While "deep-seated landslide" which each ground slides is not related to the form of forest, "shallow landslide" which surface soil slides directly results from the extent of maintenance. In addition, in artificial forests which are not thinned for a long time, sunlight doesn't reach ground and bottom weed and young trees are difficult to grow. When it rains there, surface soil is hit directly by raindrops and clogged, and rain water which cannot soak through the ground runs on the surface. The "water road" caused by the erosion forms valley and finally draws mudslides involving surface soil and fallen trees. Abandoned thinned wood were also the problem. They flew into the river by the heavy rain, got stuck with bridge pier and water was overflowed downstream (Figure 2).

(2) Concentration of elderly people in mountainous area

According to the rate of aging in each area of Saijo City, the first to forth areas are mountainous areas and it means there are many elderly people there. In the typhoons of 2004, especially mountainous area was seriously affected. Some areas were isolated because the roads were blocked. In such areas, young people's help is needed for elderly people to evacuate.

Figure 2. Disaster issues in Saijo: from top left clockwise: Landslide in the mountain areas, uprooted trees block the river, and causing damages to buildings in the downstream.

(3)Dangerous shelter

Some designated shelters turned out to be dangerous. For example, in Ofuki area, the mountainous area, some people evacuated to the community center which was a designated shelter. But one person noticed that the river nearby the center suddenly changed muddy, so they escaped to a different building. One minute after they evacuated, the center was buried in the mud. In Funakata area, mid-mountainous area, the designated shelter was at the head of the hill and difficult to get there. So residents evacuated to near meeting house. Therefore, the designated shelters built by the municipality should be reexamined and residents should know better about the area.

(4) Low awareness for disaster prevention

Referring to disaster history of Saijo City, there had been no such large typhoons in these days. These typhoons caused first dead since 1976 in old Saijo City. Fading memory of disasters leads declining awareness for disaster prevention. Also, judging with one's own experience is dangerous. According to the questionnaire survey in Ofuki area (OYO, 2005)[ii], many people didn't evacuate for the reason that they just thought it was not dangerous or judged from their long experience and thought it was not so dangerous as to evacuate.

3. Education as a tool to enhance participation

3.1 Participatory Learning

Yamori [iii] (2006) states that it is necessary for disaster education in the future to focus on the process of restructuring "communities of practice" (J.Lave 1993), and not only just transfer of knowledge and skill between individuals. That is, it should be an important goal of education or learning to establish community in which educator and learner can "participate" together. For example in school, it will be all right just to involve pupils, teachers or school system itself to network with those who teach what one doesn't know and organization or group to work with on disaster prevention. Teachers or school itself don't need to have all things about disaster prevention. One of such learning tools will be "town watching".

3.2 Town Watching

Town watching is a participatory technique used in community or neighborhood planning in the context of a larger administrative unit (such as municipality or city) in order for residents to recognize problems as a group and put forward solutions together. The problem solving process is guided by at least one expert or professional trained in one or more aspects of planning[iv] (Ogawa, 2005). Town watching which has been developed as a technique practiced by Japanese urban planners from the 1970s, has become popular as a participatory tool in machizukuri [v] (Setagaya Machizukuri Center 1993). "Machizukuri" has been translated as "community planning" by Evans[vi] (2001), and as "town making" participatory community building [vii] (Yamda 2001). "Machi" means town, district, community and "zukuri" means making or building. The origins of "machizukuri" can be traced as a movement associated with organized citizen actions to fight against pollution in the 1960s in Japan; local authorities needed to adapt to include consultation with its citizens. Lately, machizukuri in some localities evolved into partnerships[viii] (Yoshimura 2002). In recent years, the "machizukuri" movement emerged from Japanese planning practice with a predominant focus on urban design that encourages citizen involvement. Concerns in machizukuri such as access to public road, open space, land use, etc. are well taken into account by town watching. The use of town watching has been extended to dealing with disaster and safety related physical issues such as safe or unsafe places and evacuation routes; we shall call this disaster town watching.

4. Participatory disaster education as a risk reduction measure

4.1 Relevance of Town/Mountain Watching in Saijo City

At the time of the typhoon no.21&23 in 2004, mountainous area of Saijo City was especially damaged. Land condition and concentrated heavy rain are major factors, but there are other reasons concerning so-called software. In the mountainous area, there live many elderly people and few young people. So some elderly people had difficulty in evacuating and needed help of young people. Low awareness of disaster prevention is also a problem. According to the research of OYO cooperation[ix], not a few people didn't evacuate at the time of typhoon. The same problem is faced in the plain area.

Plain area is rather urban and there are many young people. So, it is necessary to make "disaster prevention network" (see figure 3) between the plain area and the mountainous area, so as to help elderly people in the mountainous area in case of a disaster. As the driftwood stuck with bridge pier caused flood to the plain area, disaster in the mountainous area have bearings with that in the plain area. Both residents have to know each other about the circumstances.

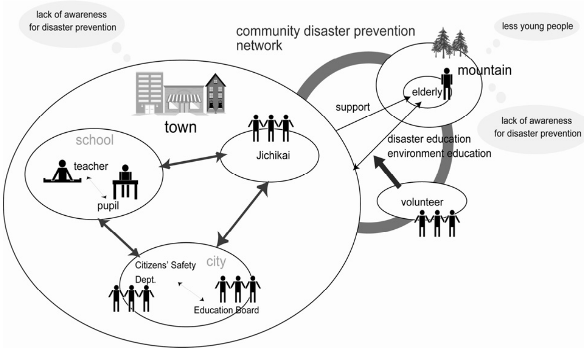


Figure 3. Conceptual framework of town and mountain watching

For these reasons, mountain watching is proposed to be implemented in Saijo City. Mountain watching is just like town watching and it is conducted in the mountainous area. Main target is children, and also residents in the mountain, teachers, municipal officials and forest workers are involved. The working field is upper area of a river along school. Participants watch the site damaged by the typhoon in 2004 and hear the story from victims (Figure 4)

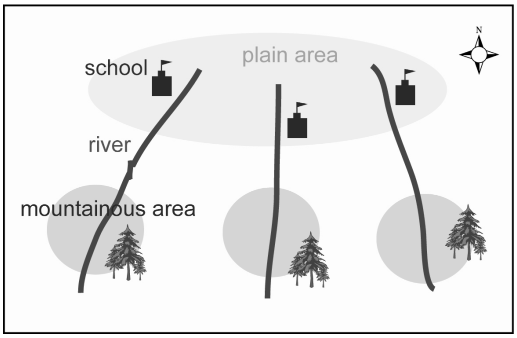


Figure 4. Areas of mountain watching.

At the same time, town watching is proposed to be implemented in the plain area. The main target is pupils and teachers, parents, Jichikai and municipal officers. They walk around the school zone and search for dangerous places, useful facilities in case of disasters and favorite places which they don't notice otherwise in daily life. This time, town watching is to be implemented in five elementary schools and mountain watching in three junior high schools as "disaster education program", which is an activity of 12-year-old education project.

4.2 Outline of Questionnaire Survey

The questionnaire survey is conducted to evaluate the impact of town/mountain watching. Target is all participants; pupils, teachers, municipal officers, parents, Jichikai, residents in mountain and forest workers. The questionnaire survey was conducted both before going to field and after the whole process on the implementing day. It took about 20 minutes each, and was not read out. For two elementary schools, another questionnaire was conducted in November to evaluate pupils' awareness a while after town watching.

Pupils are to describe what they know about the typhoon in 2004. The answers are categorized in 4 groups; a) impact on typhoon itself (e.g., it rained heavily, it caused great damage, etc.), b) impact on land and infrastructure (e.g., the river was overflowed, there were lots of mudslide in mountains, etc.), c) impact on houses and properties (e.g., the houses were flooded over the floor level, rice fields were flooded, etc.), d) impact on human beings (e.g., people evacuated to the school gym, there were a few dead, etc.).

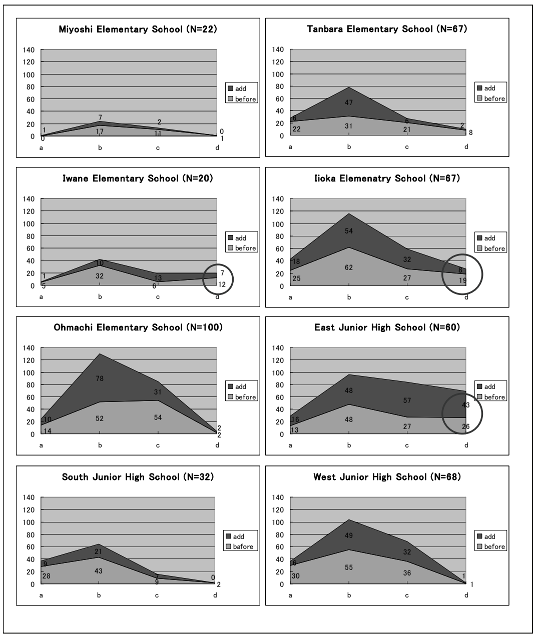


Figure 5. Impact of town watching and mountain watching

Figure 5 shows the number of the answers in each school. "Add" area shows the post-answer, excluding the same answer as pre-answer. So, it will be the impact of town/mountain watching. Each school has characteristics and it is considered to have resulted from the background of the area.

5. Conclusion

Local cities in Japan have some common problems. Young people leave mountainous areas and go to towns, so declining population and aging become serious problems in mountains. Also declination of forestry increases ill-maintained forests. When a disaster happens in such areas, the damage would be serious. Landslides are easy to occur because of the weak ground condition and some elderly people have difficulty in evacuation without the help of the young people. In such cases, help of people in the town would be great. But there is often little relationship between mountainous area and town. It is important for community to work together on disaster reduction.

In the meantime, the importance of disaster education becomes well-recognized and the number of schools which adopt it increases. But there are some problems in current disaster education, for example, lack of teachers' training, time pressure in school curriculum, lack of involvements of parents and family, lack of linkage of scientific studies with social issues, in-school education and events-oriented education.

Town watching or mountain watching is a suitable tool to resolve these problems. It involves many stakeholders, such as pupils in elementary schools and junior high schools, teachers, parents, Jichikai, residents in mountains, forest worker, Citizens' Safety Dept. and Education Board. So, it provides a good opportunity to them to communicate with each other. In case of a disaster, such relationship is very important. Through town watching, participants get interested in the local area and also get knowledge about disaster prevention.

But town/mountain watching should not end up with only one time event. Through a series of continuous actions, it will become better and develop disaster resilient area. So, clear implementing body and guideline is necessary for continuing town/mountain watching.

In Saijo City, a "teachers' association of disaster education" has been set up. This association consists of teachers who have incentive to promote disaster education. They study on the way of disaster education and share information. Now they have several meetings and make a guideline of town/mountain watching, making use of the past experience.

In addition, "Kids Disaster Prevention Club" is proposed to be set up here. It is different from boys and girls fire club. It consists of students, teachers, parents, community people, and so on who get interested in disaster prevention through town/mountain watching. Students suggest what they want to know more about or questions arise in their minds through town/mountain watching in the club activity.

Also with daily learning, they study about disaster prevention. A forum of disaster prevention such as Kids Summit is held once or twice in a year and students from each school in Saijo City make presentations about what they have learnt.

In this way, sustainable disaster prevention will start from school and involve the entire city.

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Capacity Building of Local NGO as Community Leader in the Affected Area of Pakistan Earthquake of 2005

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Abstract. Kashmir area is the affected area of Pakistan Earthquake of 2005. But Kashmir is located in mountain area. Kashmir has landslide risk as well as earthquake. Actually, Kashmir had landslide caused by the earthquake. ADRRN (Asian Disaster Reduction and Response Network) conducted the reconstruction project named as "Training and Capacity Enhancement of Local Governments in the Earthquake Affected Areas of Pakistan" in Bagh District in Kashmir from August 2006 to April 2007.

Main purposes of the project are to provide training program to local people including local government and to establish knowledge centre. Finally, 3 Village Knowledge Centres (VKC) and District Knowledge Centre (DKC).

The author was a member of SEEDS Asia (NGO based in Japan and one of the member organizations of ADRRN) and the project manager to complete the project. At that time, a local staff was employed as assistant.

The assistant of ADRRN project established his own NGO named as STAR Foundation after the project although he was just college student before and during the project. STAR Foundation is working in DKC established in ADRRN project, providing school safety drills and disaster risk reduction training to local community, and contributing community development activities. It means that the assistant was motivated through the project and realize disaster management is important for his community.

It is successful case of awareness rasing and capacity building of local NGO although he was just one of affected persons when the project started. This paper identifies roles of actors in capacity building and proposes effective capacity building process. In capacity building process, motivation, confidence building, and making connection are necessary and close discussion between trainer and trainee are important factors in capacity building.

Keywords. Capacity building, NGOs, Reconstruction, Pakistan

1. Background

The devastated earthquake attacked Kashmir area of Pakistan on 5th October in 2006. According to UN ISDR (2008), more than seventy thousands people were dead and more than three million people were affected. Six hundred thousands house, more than seven thousands school building, and five hundreds medical institutions were attacked (National Disaster Management Authority of Pakistan, 2008). The earthquake gave devastated impacts to human being in Pakistan.

In addition to direct impacts of the earthquake, landslides were also occurred in many places because of the earthquake. Landslide covered roads and people could not pass roads. Some people lost land because of landslides. They could not remove rocks or slid land by themselves lack of equipments or fund. Such people had to move for new house reconstruction.

The author, who was a member of NGO based in Kobe, Japan, conducted the reconstruction project from August 2006 to January 2007 in Bagh, Pakistan as a project manager. The project was named as "Training and Capacity Enhancement of Local Governments in the Earthquake Affected Areas of Pakistan". The project was one of projects by ADRRN (Asian Disaster Reduction and Response Network) and was funded by UN ISDR.

During the project, the author employed one of college students as project assistant. He was not eager to be involved in the project. But he established his own NGO after the project. The NGO is working for disaster reduction and community development in the earthquake affected area including villages attacked by landslides. His mental change and his and his NGO activities in local level can be regarded as one of good practices of capacity building process.

This paper identifies roles of actors in capacity building and proposes effective capacity building process.

2. Case of the Reconstruction Project

2.1. Overview of the Project

Main purposes of the project are to provide training program to local people including local government and to establish knowledge centre. The roles of knowledge center were to provide information of disaster management and to collect and transfer village information. It means knowledge center is community center for disaster management. In the project, three Village Knowledge Centres (VKC) and District Knowledge Centre (DKC). VKC is managed by VKC committee and local NGO. DKC is managed by local government and project assistant (refer to Fig. 1). In the project, three training programs (community based disaster management, safer construction, and disaster education) were provided through involving local government, local NGOs,

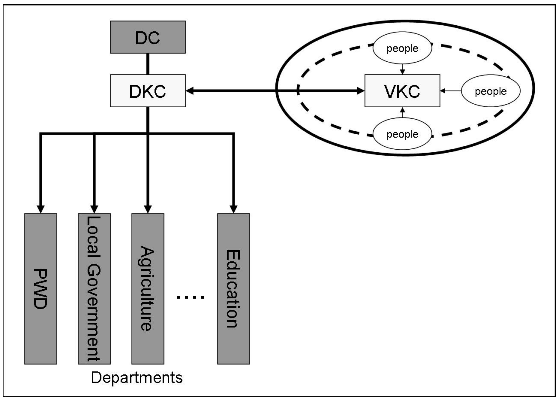

Fig. 1 Linking among local government, DKC, and VKC

and local people.

The implementation process of the project includes main five activities as below (UN ISDR et al., 2007);

- Meeting with local government
- Need assessment survey/Focus group discussion
- Site selection of VKC
- Implementation of training
- Establishment of DKC and VKC

Main achievements are following;

- Awareness raising of local government, local NGOs, and local people for disaster management
- Establishment of VKC and DKC
- Communication among stakeholders

2.2. Role of Actors

Table 1 shows the detail activities done by the author (project manager) and the assistant of the project. The project was implemented through continuous discussion with local government and local people and information transmission to them. The project was completed by project manager and assistant. Therefore, it was necessary to share works among them and communicate with each other to have same intention to success the project. But it was difficult in the beginning of the project because the assistant did not have any knowledge on disaster management and have any experiences to be involved in such projects. In the beginning of the project, assistant's work was mainly interpretation between English and Urdu so that local people understand of the project. Through working with project manager closely, the assistant had deep understanding the project and realized importance of disaster management. He became active and could work independently. In the beginning, negotiation or discussion with local government or local people was responsibility of project manager. But a part of such works could be done by assistant at the end of project.

3. Activities of Local NGO

At the end of the project, the assistant established his own NGO named as STAR Foundation (Sustainable Development

Table 1 Role of project manager and assistant to implement the project

Activity	Project manager	Assistant
	・ Discussion with college professor to find project assistant	
Meeting with local government	Before activity ・ Explanation of the project to local government ・ Negotiation with local government ・ Participants arrangement ・ Arrangement of meeting venue During activity ・ Discussion with local government ・ Fixing project sites with local government	Before activity During activity ・ Taking photos
Need assessment survey/Focus group discussion	Before activity ・ Visiting proposed sites and selection of sites for survey ・ Preparing survey sheets ・ Negotiation with village leader ・ Training of surveyors During activity ・ Discussion with village leader	Before activity ・ Taking training as surveyors During activity ・ Conducting survey as surveyor ・ Interpreting during discussion with village leader ・ Participants arrangement with village leader for core village meeting ・ Date entering
Site selection of VKC	・ Discussion with the assistant ・ Selection of three sites based on discussion and the results of survey ・ Making VKC committee	・ Discussion with Project manager ・ Discussion and arrangement with key persons in each villages
Implementation of training	Before activity ・ Finding resource persons ・ Negotiation with resource persons ・ Developing training module During activity ・ Conducting one of training programs as resource persons ・ Presiding during training	Before activity ・ Participants arrangement During activity ・ Helping training program as staff
Establishment of DKC and VKC	Before activity ・ Discussion with local government to select local NGOs ・ Discussion with committee members to select location of VKC During activity ・ Providing education materials, poster, and brochure	Before activity ・ Discussion with local government to select local NGOs ・ Discussion with committee members to select location of VKC During activity ・ Establishment of VKC ・ Negotiation with international organization to get container for utilization as DKC

and Response) (hereinafter, STAR) and he became president of STAR. Currently, STAR has more than 30 members and 9-10 members out of them are contributing STAR's activities. After establishment, the NGO started their own programs including management of DKC and distribution of brochure developed during the project. Following are parts of their programs;

- Training for safer construction: This program was held in one of VKC. Local NGO and the president of STAR acquired knowledge of safer construction through the training during the project. Training module during the project was used. Based on the training module, both NGO trained local masons and community people to provide knowledge of importance of safer construction and skills of construction.
- Disaster education to school students: During the project, the author provided education materials developed by NIED for DKC and VKCs. STAR utilized one of materials as school disaster education (refer to Fig. 2).
- Training on school safety: The president got knowledge of school safety drill from other organization and provided this program. STAR provided lecture on disaster management and exercise of first aid, evacuation, and rescue (refer to Fig. 3). In addition, STAR helped to establish school safety council including community people and school teachers.
- Making community organization: Local government has promoted to establish community organization (CO) under CDP (Community Development Project). It is not difficult for STAR to know the project of local government because STAR is in charge of DKC located in local government. STAR had established CO with close interaction with community key persons.
- Disaster management event: This program was held in October 2007 to remember the earthquake of 2005. STAR invited 12 schools and organized speech competition.

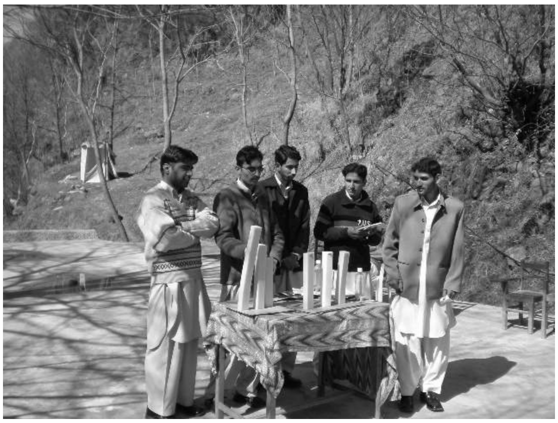

Fig 2 School disaster education on buildings and their proper period (copyright: STAR Foundation)

Fig 3 First aid in the training on school safety drill (copyright: STAR Foundation)

The activities of STAR are divided into two types. One is activities based on the project which the president was involved as assistant. The other type is activities which STAR developed or local government requests. The roles of the NGO can be regarded as trainers and coordinators among community. UNCRD (2004) was considered Policy makers, national disaster managers, local disaster managers, trainers, and community worker as main actors for community based disaster management. The activities of STAR play roles of trainers and community worker. Bagh is the remote and mountain area and the local government does not high awareness on disaster management. In such situation, activities of STAR is very important for communities.

4. Capacity Building Process

4.1. Proposed Capacity Building Process

The important point is that the president of STAR was just a college student in the affected area when the project started but that he established his own NGO and has continued NGO's activities. He did not have any knowledge on disaster management and know importance of disaster management (personal communication, 2008). He became project assistant because a college professor appointed him as the assistant. It does not means that he is motivated person. Becoming assistant is one of opportunities to earn money for him. In his comments as followed, there are important points to consider capacity building;

1. *After starting working, I realized importance of working. Therefore, I can work hard even if work is much.*
2. *When I started working in the project, I did not have any confidences. I had not thought I can do anything. I had not thought I have any abilities.*
3. *Through working, I could meet many persons and great persons who I could meet if I had not working in the project. It is great pleasure to meet such person while I am working now.*

The first comment was showed after several month working (around October 2006). The second comment was showed at the end of the project (December 2006). The third comment was showed in 2008.

In this paper, his mental changing and activities of STAR is regarded as one of good practices of capacity building for disaster reduction. Based on his comments, capacity building process can be proposed as below

1. Motivation for disaster reduction
2. Confidence building
3. Connection making

Next, the effective factors which can achieve each stage mentioned above are examined and discussed.

1. Motivation for disaster management: Through the activities mentioned in Table 1, he could get knowledge on the project and disaster management. At the beginning of the project, his main task was interpreter between the project manager and government or villagers. He was required to get concrete knowledge not only to translate but also to explain. Discussion was always done between project manager and him. Discussion was effective to transfer knowledge and to let him consider disaster management. Discussion was good opportunities to consider what is useful or advantage for local people. Shiwaku and Shaw emphasized discussion in a process of disaster education (in press). Capacity building can be regarded as a kind of education. He realized importance of disaster management because of close discussion.
2. Confidence building: From the middle of the project duration, his tasks were increased and his responsibility was also increased. He had opportunities to negotiate with local government or local villagers. These opportunities required him to have more concrete knowledge and negotiation skills. Through the negotiation by himself, he could make strong connection with local government, local NGOs, and local people. In addition, his work succeeded for the project. Through his activities, he could build confidence by himself. It is important not only to transfer knowledge but also to let person have responsibility in the field.
3. Connection making: Through the working, he negotiated and discussed with the highest person or person in UN ISDR. Even if he was not involved in the project, he could not meet such people. It is great opportunities for him to meet them and can motivate him to be involved in disaster management. In addition, he could make connection with various people. He could conduct many activities, utilizing connection with stakeholders. To continue NGO activities, help or cooperation from stakeholders is necessary. Additionally, making good relationship or meeting with persons who it is difficult to meet in daily life is great opportunities for the president. Such opportunities are pleasure for him and motivate him more.

4.2. Role of Outside Organization

When outside organization conducts project, it is necessary to consider sustainability of project. As for sustainability, key persons are community involved in project and local staffs. Therefore, it is necessary that they realize usefulness and importance of sustainability. It means that outside organizations should play role of trainer for local people. In the project conducted by the author, the assistant realized it and is doing various types of works for disaster reduction and community development. Currently, EDM-NIED and STAR are doing two research projects. EDM-NIED is providing small fund to STAR.

STAR is a new NGO. It is difficult for new NGOs to acquire project fund by themselves. Even if NGO has good skills or abilities, NGO has difficulties to survive. It is important for NGO to continue work and increase their experience and knowledge. Therefore, the roles of outside organizations can be proposed as below;

- Motivate local person
- Give responsibility
- Discuss closely to understand each other
- Work (Support) continuously
- Bridge with related persons

Close discussion is necessary to make good relationship among stakeholders, for example, between project manager and assistant or between practitioner and community. Good relationship is necessary to conduct projects (Center for Disaster Mitigation, Instituit Teknologi Bandung, 2008). But it is necessary for capacity building process as well as implementation of project.

5. Conclusion

Onda (2001) mentioned that capacity building includes conscientization and self-empowerment. According to his description, self-empowerment is in the basis of self-reliance, self-help, and self-determination. Three steps proposed as capacity building process in this paper has similar parts of conscientization and self-empowerment. Motivated for disaster management is conscientization. Confidence building is self-reliance. Through making connection, the NGO could conduct their activities. This process is self-help and self-determination. Therefore, capacity building process for STAR can be regarded as good practices.

This paper propose motivation, confidence building, and connection making as capacity building process and close discussion is effective factors. In the future, monitoring of capacity building of STAR is required. The process is useful for development of NGO activities for future research.

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The Role of Forest and Trees in Landslide Risk Mitigation

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Abstract: Considerable number of landslides and debris flow events has originated from Alborz Ranges in the southern parts of Caspian Sea basin with west to east orientation. Due to the expansion of human activities towards higher marginal lands and forest areas and also land use changes, the number of landslide events has increased rapidly during recent decades. The landslide mass movement poses high risk to both the lives and properties of inhabitants at the lower part of the basins. Some of these events are disastrously fast-moving with highly destructive debris flows that mainly occur some years after deforestation and that are triggered by high intensity rainfall. Landslide and debris flow events which have occurred over longer time periods are related to forest destruction.

According to Iran's Forest and Rangeland Organization, the area of northern forest has decreased from 3.6 million ha in 1940 to 1.9 million ha in 1970 for activities such as wood industry and cultivation. This is due to both inadequate management of forests and lack of proper legislation for forest protection.

The effects of forest management on slope stability are investigated through some research programs performed in relevant sectors of Iran. The results have been used for clarifying the mechanisms of the deforestation-induced landslides and debris flows in order to plan for the extension and education of the issues to the local authorities and residents. This paper is aimed to present a summary of these research activities.

Introduction

Forests of Iran cover about 12.4 million hectares. Approximately 8000 plant species have been identified. The climatic diversity is high and geographers have called Iran the global climates' bridge. Most forests of the country belong to the low forest cover type. Special climatic diversity has given rise to at least five distinct forest zones. The most dense and unique forest, the so called Hyrcanian forest zone, encompasses the Caspian Seaside and is considered as commercial and industrial forests. Most forests are located in the upper reaches of the basins (Figure 1). In general, the Hyrcanian climate is warm Mediterranean in the east and temperate and semi temperate Mediterranean in the central and western parts. The Hyrcanian forest zone is humid with average annual rainfall between 530 mm in the east and 1350 mm in the west. Occasional record values can even reach 2000 mm in the west. Based on the climatic data from meteorological stations, the maximum annual rainfall is experienced during spring, late fall and winter.

In the past 50 years, because of expansion of human activities towards higher marginal lands and forest areas, aggressive logging and development have destroyed over 50% of the original forests. The total area of these forests that covered elevations up to 2700m, was reduced from 3.6 million ha in 1940 to 3.4 million ha in 1958, to 1.9 million ha in 1970 and to approximately 1.8 million ha today comprising 15% of the total Iranian forests and 7.5% of the country's area (FRRI, 2007).

Rapid urbanization and industrialization, intensive grazing, over-utilization of forests for firewood production and farming in wooded areas are amongst the main causes of deforestation in this area. Over the last few decades, forest degradation has brought about a number of environmental, social and economical impacts including soil erosion, floods, degradation of farmlands and habitats, reduction of biodiversity and natural resources and air and water pollution. Clearcut areas do not absorb water. Instead, when heavy rains come, clearcut areas allow for rapid runoff, causing flooding and erosion. The floodwater transports tons of silt which leads to the clogging of waterways. In steep areas, the earth can no longer resist the pull of gravity and pulls away in a landslide. In Alborz forests it is found that clearcutting is the most significant factor contributing to an increase in landslide events. Most landslide events in the Caspian Sea basin originated in the Alborz Ranges in the southern parts of the basin with west to east orientation (Figure 1).

It was reported that flood and landslide events in the northern forest of Iran have been increasing by 25% and 80% in the last 20 years.

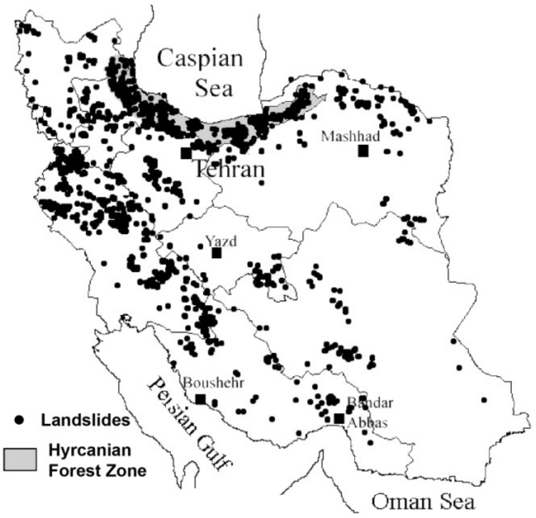

Figure 1 Hyrcanian province along Caspian Sea side and distribution of Landslides.

Landslide and debris flow events which have occurred over longer time periods are accompanied by root decay and loss of soil strength. This is due to both inadequate forest management and lack of proper legislation for forest protection. Most clearcutting of forest in two provinces along the Caspian Seaside (Gilan and Mazandran Province) was for the purpose of agricultural and rural developments. The effects of deforestation on slope stability was investigated through some research programs carried out in the Watershed Management Institute of the Ministry of Agriculture and in other relevant sectors.

Landslide in forests

It was reported (Nikandish, 1995) that seventy landslides were triggered after intensive rainfall in October 1994 (total 530mm/2months) in the Caspian Seaside provinces. All these landslides were located on slopes of 30 to 50 degree. 100 ha of tea orchards were completely, about 553 ha partially damaged. A case study showed that the total area of tea orchard in these two provinces has increased by 44% from 1996 to 2006 (Shakuri, 1995). The study also confirmed that most of the landslides occurred in the newly developed tea orchards.

The review of published papers in Iran showed that the slope angle of 10 degrees had been recommended for tea orchard development. However, due to land limitation and rapid food requirement, most of the development was done on slopes of 30 to 50 degree. On the other hand, research work in Iran evidenced that 47.4% of slope instabilities were observed on slope angles of 26-50 degrees and 30.5% on slop angles between 16 and 25 degrees (Ghayoumian, 1997). Relating these figures to the fact that 82.6% of landslides in this region have occurred in forest areas indicates that the development in the forest areas and on the most critical slopes was probably the most important factor for the increase of the landslide occurrence.

The review of papers from other countries (Nikandish, 1995) shows that amongst the landslides that have occurred in the forest area of Tanzania, 47% were triggered by land-use changes and disturbances as a result of human activities. In New Zealand it was reported that 10 years after clearcutting, a rainfall event of 30 years return period triggered many landslides that normally are expected to be triggered by rain intensities of 100 years return period. These landslides occurred as a result of the root decay and loss of soil reinforcement.

Recent studies showed that in the northern forest of Iran, many landslides were triggered in years with 500 mm of rainfall. The historical records indicate that in the past such degree of landsliding occurred in wet years with more than 1000 mm of rain (Nikandish, 1995). Changes in forest density by clear or partial cutting are most likely the main reason for this high landslide occurrence with lower rainfall.

Effect of trees on slope stability

It is generally accepted that additional strength is provided by roots to the soil that is considered to be a cohesion strength which may range in magnitude of 1 to 20kpa. Soil reinforcement by root was examined by many studies. Davoodi (Davoodi, 2002) reported that willow is a suitable tree for slope stabilization. He concluded that the peak and residual shear strength of rooted soils are higher than those of rootless soils. The increase in shear strength of soils by roots is proportional to the ratio of root area. The influence of willow roots may rise to 30% for root area ratio of 28% at a depth of about 3m. A high density or concentration of small diameter roots is also more effective than a few large diameter roots. Deeply penetrating vertical taproots provide the main contribution to the stability of slopes.

Reinforcement of soil only extends as far as the depth of root penetration. The best condition of soil reinforcement by roots is the penetration of the roots across the failure surfaces. For oxygen exchanges, the roots normally reach to a depth of about 5 meters. Thus the reinforcing or restraining influence of roots on a slope is probably limited to a zone of about 5 meters depth. Sixty four percent of recognized landslides in Iran have the depth of sliding surface of about 1-1,5 m. Shafaei (Shafaei, 2002) has reported that tree roots may increase the shear strength of soil from 37% to 66% depending on both root depth and density (Figure 2).

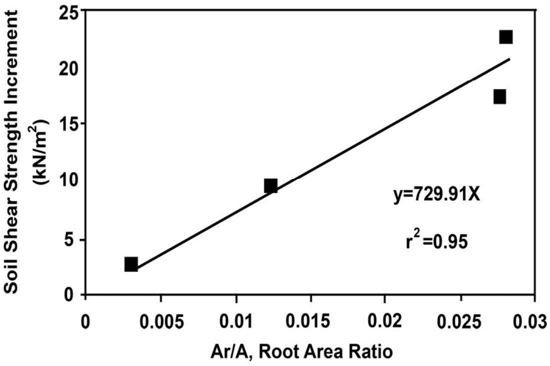

Figure 2 The effect of tree roots area on the increment shear strength of soil.

Decrease of soil strength due to the decay of roots is different for various types and densities of roots. Also the depth and distribution of roots vary for different tree species. While root depth of some grass species is a few tens of centimeters it reaches 2 to 30 meters for different tree species. Thus, changing vegetation cover from thin and shallow distributed roots to species with deep and well distributed roots will increase the stability of slopes. Conversely, the change of landuse from forest with deep root species to orchards and farmlands will increase slope instability and landslide risk. This is clearly evidenced in northern Iran, where the farmers cut the dense forests to develop their farmland and tea orchards. In this area the replacement of species such as *Acer* and *lotus,* which are characterized by root depths of about 20 to 25 meters, with tea or citrus species with maximum root depths of 5 meters, is resulting in slope failures in many newly established orchards (Figure 3 and 4). The lag time between clearcutting and slope instability is different for different species. In Iran, the slope instability in tea orchard occurs about 8-10 years after clearcutting.

Many detailed studies about the effects of land-use changes on slope stability in forest area have been implemented. Their findings can be summarized as follows:

Depending on the capacity of evapotranspiration, the infiltrated water can be absorbed and transpired by trees and the amount of infiltrated water to the underground zone is controlled. The amount of evapotranspiration varies a lot for different tree species. It is 500lit/m^2 for *Eucalyptus*, 250lit/m^2 for *Lucust Acasia* and 1 lit/m^2 for grass fields.

The canopy of different plant species is very important in controlling precipitation on slopes. It was found that land cover change from dense forest of *Oak*, *Taxus* and *Juniprus* to tea orchards can decrease the canopy from 100% to 50 %. As a result, the infiltration of direct precipitation on the orchards will increase considerably. It was estimated that in natural forest 25% of rain can be absorbed and evaporated by tree leaves and trunks during intensive and long precipitation.

Figure 3 Initiation of landslides due to the change of land cover from dense forest to tea orchards, north of Iran, along Alborz Ranges, southern parts of Caspian Sea basin (elevation of photo: 1800m).

In some specific cases, close to 100% of precipitation can be absorbed by trees. Accordingly, the control of infiltration of rain water can control the stability of slopes by drying the surface zone and controlling the groundwater table. Drying out of surface layers has a very positive effect on superficial landslides. The high differences between wet and dry clay bearing soil was reported in some works (Shoaei, 1990). It was reported that 10% of moisture will make appreciable changes on friction angle of clayey soils.

Discussion and conclusion

Landslide mass movements pose high risks on both the lives and properties of inhabitant at the lower part of the basins. Some of these events are disastrously fast-moving with highly destructive debris flows, that mainly occur some years after deforestation and that are triggered by high intensity rainfall. The effects of trees on slope stability can be summarized as follows:

1- Increase in soil strength due to reinforcement by tree roots in soil or rock bodies on slopes.
2- Absorption of precipitation water by trees.
3- Control of the moisture in the root zone through the evapotranspiration capacity of trees.
4- Control of the level of ground water and hydrostatic pore-pressure inside slope bodies.
5- Change of the rate of erosion by different kind of trees.

Landslides not only cause serious damage to the denudation area but also destroy all natural resources and human properties along their paths and deposition areas. Forest management services are very important to protect valuable forest and to prevent damages to people's properties.

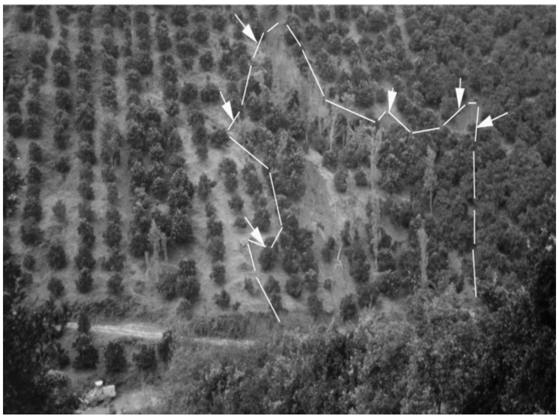

Figure 4 Initiation of landslides due to the changes of dense forest cover to citrus orchard, north of Iran.

In Iran, serious attention has been paid since 1980 to the protection of the northern forest. At present, 914000 ha amounting to 45% of the Northern forests are managed by governmental, private sector and cooperative contractors in 392 districts. Over the past decade, considerable changes have been made in forest management plan selection criteria due to the reinforcement of ecosystemic considerations. Even-aged high stands have been changed to uneven-aged high forests, clear cutting in restoration areas has been stopped, spot cutting in limited areas has attracted attention and harvesting rates have been diminished (Table 1). This means a 32% reduction in forest utilization versus 47% increase in forest planned areas.

Landslides in forests due to clear or partial cutting were observed on slope angles of 26-50 degrees. However, some landslides in newly developed tea orchard occurred in slope angles of only 10 to 20 degrees. Accordingly it is not possible to recommend a range of slope angle on which the occurrence of landslides is not to be expected. In order to recommend the proper slope angle for development projects, all effective parameters such as geology, earthquake, hydrology and hydrogeology as well as geotechnical characteristics of each site should be taken into consideration. It should be emphasized that slopes with slope angles of 25 to 35 degrees are very sensitive and that any changes of vegetation cover in such zones should be avoided or even prohibited.

Table 1 Iranian Northern Forests harvest variations over the last decade.

Year	Area of functioning forest plans (ha)	Harvest (m^3)	Average harvest (m^3/ha)
1989	659000	2015000	3.05
1998	914000	1342000	1.46

Small and shallow mass movements will impede drainage and will result in large scale landslides and debris flows. Therefore, small scale retaining walls or similar structures with drainage systems can control the initiation of small landslides and prevent subsequent larger events.

The proper legislation and regulation for any development on slopes is necessary. Some remedial works such as construction of retaining walls, proper drainage systems and protection of the remaining part of the natural vegetation cover should be compulsory before any slope modification. A combination of different tree species for the rehabilitation of damaged forests is recommended. It was also found that the best density of deep rooted species should be more than 4000 per hectare. Specific studies should be implemented in steep slopes of forest for preparing a zonation map of landslide hazard and risk for local and regional planning purposes in these areas. Finally, a regional plan for increasing land productivity will be very effective to satisfy people's income and enable the governor to prevent any further land development.

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Geomorphic Evidence of Debris Flows in Culmination Parts of the Czech Flysch Carpathians

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Abstract. The Czech Flysch Carpathians are built by a nappe structure, the Moravskoslezské Beskydy Mts, which originated in the Upper Neogene. Long steep slopes, a huge diluvium layer of flysch rocks, heavy precipitation and extensive deforestation of potential debris triggering zones represent dominant predisposing factors of debris flow genesis. Two main types of debris flow accumulations on the ground can be distinguished. They differ in magnitude, localization on slopes, sedimentological properties, present morphology and age. The first type of accumulations is represented by large fans localized at the gully mouth on high terraces of the valley floor as erosion relicts of ancient debris flows which filled the valley bed. The height of the terraces often exceeds 10 meters, but the debris flow fans are even higher, estimated by a geophysical ERT method (Electrical Resistivity Tomography) at over 20 meters. This method also proves the multigenerational character of debris flow fans which originated in successive storage of individual debris flows. Granulometric analysis of debris flows material proves a high content of mud-clay fraction (more than 30 %). Absolute dating of debris flows total organic sterility by the ^{14}C method was not possible. The other type of debris flow accumulations differs in almost all properties. This type is represented by low mounds (up to 3 meters high) which often cover the first type of accumulations. The content of mud-clay fraction in this material does not exceed 20 %, which corresponds to granulometric properties of diluvium on slopes. Debris flow triggering zones have been localized not only on slopes, but on the surface of old accumulations as well. We also suppose that the old accumulations have been reactivated as a result of "firehose effect". This fact confirms the origin of some smaller debris flows after extreme precipitation in 1996, 1997 and 2005. Dendrochronological methods were used to exactly determine the youngest debris flows. The dating included mainly old accumulations reactivations as a result of "firehose effect". Individual phases closely correlate with the occurrence of extreme precipitation in a given year. However, in comparison with the past, far fewer debris flows occur at present. There is evidence of large old debris flows in the form of high terraces and large debris flow fans.

Keywords. Moravskoslezské Beskydy Mts, debris flow, chronology, sedimentology

1. Introduction

The research of debris flows in the Moravskoslezské Beskydy Mts has only been under way for a short time now. It was works of Šilhán and Pánek (2006) that started to give greater attention to this research. By that time the origin of the debris flows accumulations had been attributed to solifluction or glacier action (Pelíšek 1953). Nevertheless, they occur profusely in this locality; so far more than 60 slope deformations of this type have been discovered. The main predisposing factors include distinct morphometry of the mountain range with long steep slopes, thick layers of weathered material on slopes and high amount of precipitation (the highest peak, Mt. Lysá hora, is the place with the highest amount of precipitation in the CR).

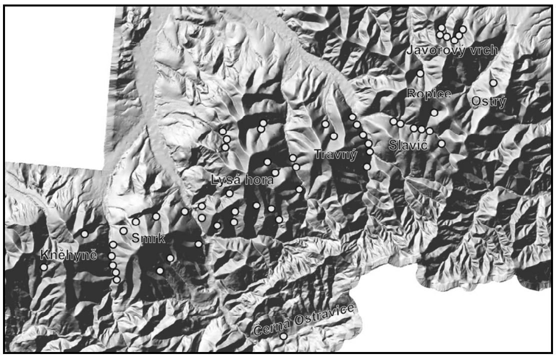

Fig. 1 Localization of debris flows (grey points) in the Moravskoslezské Beskydy Mts.

Debris flows accumulations are found almost exclusively in the culmination part of the range in the massifs of Mt. Smrk (1 276 m), Mt. Lysá hora (1 323 m), Mt. Travný (1 032 m), Mt. Slavíč (1 054 m) and Mt. Javorový vrch (1 203 m) (Fig. 1).

2. Types of debris flows

The debris flows accumulations in the area of interest occur in various forms. However, on the base of a simple classification we can distinguish two basic types of accumulations that further differ in a few aspects (morphology, morphometry, granulometry, age, and location). The first type (Fig. 2B) of accumulations is represented by elongated mounds in river beds the height of which does not generally exceed 3 m. The width ranges from 2 m to more than 15 m. Yet, the accumulations are the longest and can reach the length of a few hundreds of meters. They often occur as low as the bottom part of the transport zone. In the accumulation zone they partially or completely bury the original river bed. The original stream not infrequently flows on the accumulation base washing out the finest material. The accumulations can thus be characterized by very coarse-grained granulometry. Estimated thickness does not prevailingly exceed 4 m.

The other type of accumulations is represented by high terraces in the vicinity of the valley bottom (Fig. 2A). These forms are relicts of originally larger accumulations. They can be more than 15 m high and the length occasionally exceeds 200 m. The accumulations rather occur in lower parts of the valley profile, however, they also line lower parts of transport zones. Generally, they show signs of significant age and their material is clayey and heavily weathered. The accumulations also include fans at the mouth of gullies or smaller valleys. They can reach various dimensions, from 10 to 300 m in length. At the same time, they represent the most complex type, not only from the point of view of morphology but also sedimentology. They mostly originated as a result of a few recurring processes, not during a single event. The processes of material accumulation are both slope processes (debris flows) and fluvial processes. Therefore, the material shows very varied sedimentological characteristics. The study of the relation between fan area and basin area helps to identify fans that originated by debris flows processes since the relation shows a high degree of dependence (Scally and Owens 2004). This assumption partially proved true in the case of the studied fans (r = 0.41). Another important relation is expressed by Melton's index and fan area that normally also show a higher degree of dependence in connection with these fans. However, this assumption could not be acknowledged (r = –0.11). The last studied relation is between Melton's index and the fan inclination which, however, does not show any dependence. This assumption proved true in connection with the analyzed fans (r = 0.01). On the basis of the above analysis we can thus assume dominant influence of debris flows on the formation of fans; nevertheless, with the assistance of fluvial processes.

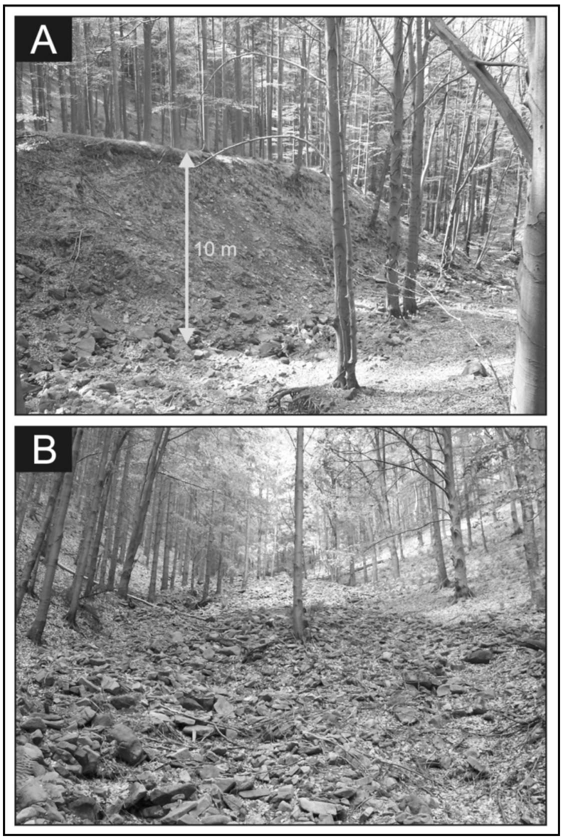

Fig. 2 Basic types of debris flows accumulations, A – old accumulations (Pleistocene?), B – young accumulations (LIA?)

The thickness and inner structure of the fans was studied by a geophysical, geoelectric ERT method (Electrical Resistivity Tomography). Two ERT profiles were performed on a 200-m-wide fan on the western slope of the Mt. Smrk. Profile in the lower part of the fan (Fig. 3) shows relatively low resistivity values within the whole fan (< 1 000 Ω.m). No flow is observed over this fan, thus, we can assume subsurface run-off, through the body of the fan. Although absolute material depth cannot be precisely specified, the thickness of up to 30 m can be expected. Near-surface parts reveal a few zones of considerably increased resistivity (> 4 000 Ω.m), corresponding with elevations on the fan surface. The zones can concern flows of course-grained material on the fan surface. Underneath them there are areas with locally lowered resistivity, the geometry of which resembles debris flow river bed that was afterwards filled with sediments.

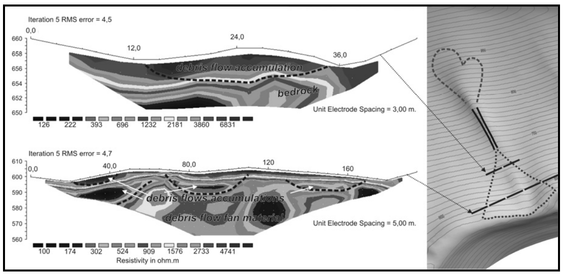

Fig. 3 ERT profiles on debris flow fan

A profile across a mound in the upper part of the fan shows high resistivity values in the place of the debris flow material (> 5 000 Ω.m). Its thickness reaches ~4 m. It is obvious that the debris flow material displayed itself here as a zone of increased resistivity. ERT method proved the occurrence of a few generations of debris flows building the fan body, while older flows display themselves as zones of decreased resistivity values and younger flows as zones of considerably decreased resistivity values.

3. Sedimentology of debris flows

From the sedimentological point of view, the two above-mentioned types of accumulations have been compared by means of cumulative granulometric curves (Fig. 4).

The curves clearly reveal sings in which the two groups of accumulations differ. An important aspect is represented by different content of the finest fractions. Small debris flows are characterized by low content of clay-silt (aleuritic-pelitic) fraction (< 63 μm) which hardly ever exceeds 20 %. On the contrary, older debris flow samples brought higher content of this fraction; more than half the samples reached even more than 30 %.

Increased content of this fraction in older accumulations is probably caused (apart from the source material character) by long weathering of clay clasts inside the accumulation, while younger accumulations rather reflect grain characteristics of source material or had their finest fraction washed out by neighbouring streams as it can practically be found exclusively in their beds.

However, old accumulations further record significant jump increase in particles larger than 63 μm (beside high content of smaller particles). This can potentially be explained by long-term weathering of sandstone clasts, which do not weather into the finest particles as clay clasts.

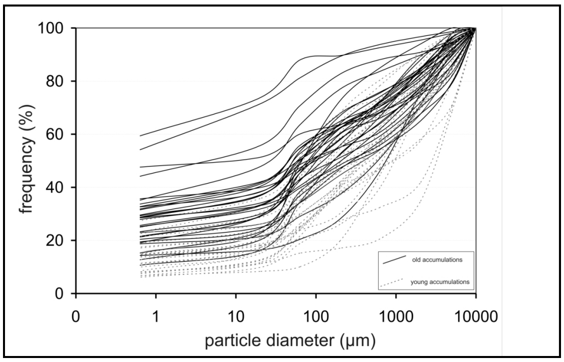

Fig. 4 Grain size analysis of debris flow material

Sorting coefficient (σ_I) for the quantification of debris flows material sorting was calculated in GRADISTAT software ver. 4.0 according to the formula (Folk and Ward 1957):

$$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6},$$

where ϕ_x are individual grain-size percentiles. Average coefficient value of all the samples is 3.88. This value comes within the interval 2 - 4 by which the above-mentioned authors mark very badly sorted sediment. The category does not encompass only average values but most of the values of individual samples as well. Some of the samples even fall within the category $\sigma_I > 4$ that represents extremely badly sorted material.

4. Chronology of debris flows

Accumulations of debris flows in the Moravskoslezské Beskydy Mts. have not been dated so far. This results from the absence of broader interest in the forms and difficulties related to the absolute dating itself. The very accumulation material is organically absolutely sterile, nevertheless, in exceptional cases, the debris flows covered organic matter on their base (lacustrine, organic or peat sediments) or caused valley blockage creating sedimentation environment of organic material. Therefore, ^{14}C dating could be performed in one locality only; dating of the youngest debris flows (max 80 A BP) was carried out by means of dendrochronological methods.

The species of *Picea abies* and *Fagus sylvatica* were dated. The dating of debris flow displays on trees included trunk burying and trunk or root scars.

On the basis of the above analyses and information on 2 more debris flows from historical records, 33 debris flows were dated altogether, the oldest of which dates back to 1939. (Fig. 5). Increased activity of debris flows was recorded in the 1970s; eight debris flows occurred from 1972 to 1979. The most intensive activity could then be observed in the second half of the 1990s; 18 new debris flows originated from 1996 to 1999. Another increased occurrence of debris flows was also dated from 2002 to 2005 (5 events). Apart from that, there was an isolated in 1988. In total, there were 10 years of debris flow activity. A majority of the dated debris flows occurred in a year of extreme precipitation totals (more than 100 mm/day).

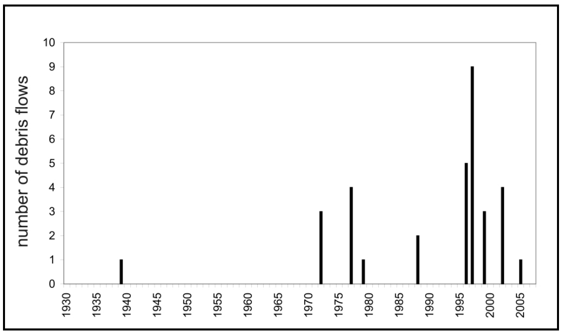

Fig. 5 Historical activity of debris flows

Conclusions

Debris flows in the Moravskoslezské Beskydy Mts. occur in the upper-most parts that are characterized by the highest values of slope inclination, big relief energy, long slopes and high values of Melton's index (more than 0.25, which is a boundary value for the emergence of debris flows in basins). It is particularly the massif of Mt. Smrk that records the concentration and features of debris flow accumulations that approximate the situation in alpine regions. There is very close coupling between the occurrence of debris flows and areas of deep slope deformations that very often represent the source of material running down the slopes. Although debris flows processes can be observed at the present time, their activity and magnitude was supposedly higher in the Pleistocene and some periods of Holocene.

Acknowledgements

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Impact on Livelihoods of Landslide Affected Communities due to Resettlement Programmes

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Abstract

Landslides occur due to various reasons. Most of them are man-made causes. If the human settlements are located in the landslide prone areas, the risk levels will be high. Further if the locations that are susceptible to landslides are identified, introduction of mitigatary measures are inevitable. Therefore, in this kind of situation, the communities with the highest risk level, sometimes needs to be relocated. This is considered after careful investigation into different variables such as; landslide hazard level, awareness, housing and structural condition, and livelihood. Affected communities are 'put into' two types of resettlement programmes after identification of different risk level (high) and after a disaster event. In this connection, the resettlement becomes an inevitable solution than an option. In most cases the resettlement becomes necessary in the latter type mentioned above. One of the main concerns among others, in this kind of resettlement is the impact on the livelihood.

People with the location specific livelihoods are more vulnerable on this kind of resettlement programmes and therefore, it is very relevant to identify the socio-economic background including livelihood, occupation etc. in this situations.

When affected communities are categorised, it is also important to look into the issues, such as why they are settled in this particular location. In Sri Lanka one of the notable issues that we are considering is the background of affected communities that we earmarked for resettlement. The affected communities surveyed for their socio economic background including livelihoods and educational/skill level among the other things. Main objective of this back study is to determine the socio cultural background which allow to determine inter and intra community linkages. Also, the location specificness of livelihood and the will determine the possibility of changes in type of livelihood if resettlement is inevitable.

Further, this paper discusses the issues related to landslide affected communities and the options available to reduce the impact with special reference to landslide/subsidence affected communities in Matale and Nuwara Eliya districts of Sri Lanka as per the recent studies.

Introduction/Background

In Sri Lanka, in the recent past, NBRO has actively participated in number of rehabilitation programmes for people affected by natural disasters. Floods, landslides, tsunami, droughts, strong winds and lightning strikes are the prominent natural disasters. Until the mid 90's the government approach was to provide the affected community with a relief package. However, since mid 90's, government policy has changed especially after the great Asian Tsunami 2004, where a clear policy of mitigation of vulnerable communities was adopted including the landslide prone areas. Present policy on rehabilitation are of two folds; most vulnerable to be resettled and others are to be put into retrofication programmes.

This paper discusses the landslide studies carried out in Sri Lanka and its evolution, socio economic context of affected communities, recent disaster events and experiences, resettlement and rehabilitation programmes with note worthy experience and conclusions.

Landslide Studies and Scio Economic Conditions

In the recent history, since 1980's, scientifically structured landslide studies were conducted by Sri Lanka. The study originated with the increasing number of landslides events with significant impact on the population occurred during the 1980's. The United Nations Development Programme (UNDP) came forward to assist Sri Lanka to initiate this scientific study on Landslides. This Study began with a geotechnical and geological approach but sooner it was realised that the importance of human settlement aspects in the overall study. Then the multidisciplinary approach was preferred and different professional got involved in the study. Professionals such as human settlements planners, environmentalist, meteorologist civil engineers, land surveys and botanists were involved apart from the geologist and geotechnical engineers. Main task of the project was to formulate a strategy to study the landslides with a view to reduce the impacts on human settlements.

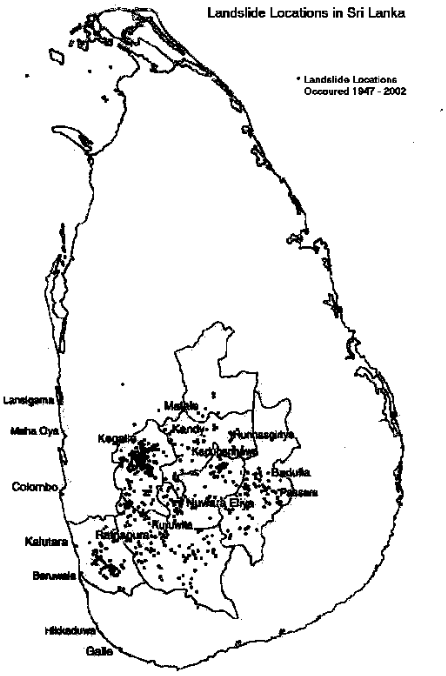
Project initially focused on a mapping system to identify the landslide prone areas. After a number of studies, project team was able to develop a methodology for the preparation of Landslide Hazard Maps in 1992. In the early stages, in recognising the importance of socio economic context, a separate section was created to look after the human settlement aspects.

Methodology of landslide hazard mapping includes the study of six deferent essentials that considered recognise hilly regions which are landslide prone. These six essentials are geology, hydrology, colluvium deposit, landuse patterns, landform and human settlements. For each of these essentials, separate factor maps were prepared to develop the final landslide hazard zonation map. Landslide hazard mapping programme in Sri Lanka is one of the early interventions to landslides arena in this region. Out of 24 districts in Sri Lanka, 11 districts are identified as landslide prone districts and they are taken up for the landslide hazard mapping (Refer map 1)

Locations of Landslides in Sri Lanka and the Area Covered by the landslide Hazard Mapping Project.

By using these landslide hazard maps, policy makers in the country presently decide on the future human settlement patterns and the development scenarios. One good example is the recently adopted national physical plan of Sri Lanka. This is one of the few such initiatives of the region. This plan directs the current development trends at macro level. In short, the national physical plan is mainly formulated by considering the natural disasters, environmental sensitiveness, topography and the climatic conditions of the country.

One key question that we are still posing is, why Sri Lanka has diverted our human settlements from generally safe ancient settlements in dry zone to environmentally fragile and geographically sensitive (for natural disasters) wet zone. One of the major reasons may be the, change of economy to agricultural base to plantations in 19th Century. This change created the landslide prone area in the high land of the country. It disturbed the landuse in the fragile hilly areas that was intervened. Earlier days landslides were occurring, but the impact was not that significant. However, present national physical plan adopted by the government is not encouraging communities to settle down in these areas, but promotes settlements in the irrigated dry zone areas with less confrontation with the natural systems.



With the changes in the system with invited natural disasters to the human settlements, it was inevitable that number of factors contributing people to locate themselves in the disaster prone areas. It is well documented that, livelihoods are directly connected to the inadequately earned communities to locate them in the disaster prone areas. In 1999, National Building Research Organisation (NBRO) conducted a research study on 'Livelihood Options for Disaster Risk Reduction' with Intermediate Technology Development Group in South East Asia (ITDG-South Asia) to find out the connection between livelihood and the vulnerability. Project findings highlighted a strong relationship between the livelihood and the location of settlement.

People try to settle closer to their livelihood. In turn, income levels decide the selection of land for their housing. Mostly, inadequately earned families are forced to locate themselves in hazard prone areas due to the land sacristy and land values in specific locations. Countries like Sri Lanka carry a very different landuse pattern when compared with other countries in the region. Sri Lanka is a small country compared with Australia been 60 times larger (Japan is more than 5 times larger). Current population in Sri Lanka has a gross land-man ratio of less than one acre or 0.4 ha per person and still people can have a manageable acceptable ratio leaving the fragile areas away from settlements. While Table below shows the population distribution in hilly Areas the map above shows the distribution of landslides events.

Population Distribution in Landslide Prone Areas

District	**Popn. (mn)**	**Density (per sq km)**	**District**	**Popn.**	**Density (per sq km)**
Kalutara	1.07	677	**Galle**	0.99	613
Kandy	1.28	667	**Matara**	0.76	600
Nuwara Eliya	0.70	412	**Hambantota**	0.53	211
Matale	0.44	226	**Badulla**	0.78	276
Ratnapura	1.02	314	**Kegalle**	0.79	466
SRI LANKA				**18.80**	**300**

Source: Based on the National Census data 2001

Also, Sri Lankan culture is such that people decide on their location for living bases on the livelihood, their origin and facilities available. Another important factor that is considered by our majority of middle income families is to build a house (which is a life time achievement) as a single separate house. Still Sri Lankans are not adapted to mass scale condominium housing. This puts further pressure on the already strained land for housing. This situation leads the inadequately earned families in land logged areas to settle in hazard prone areas. This is mainly due to the reason that poor accessibility to good residential land for inadequately earned families. Hence, one of the key things that need to be addressed at the policy making level is the use residential land rationally and to create access to all segment of population for good residential land. So far, government has failed in this respect, people are provided only with marginal land for housing. Study by NBRO showed that, in the recently concluded large scale housing programmes by the government, has provided with the poor with marginal land which is not adhering any of the basic criteria and now they have become disaster prone with the intervention in landuse.

Presently, in many instances, the main cause of high impacts on human settlements by natural disasters is the incorrect locations of activities or incorrect landuse practises. Reasons behind this is, the level of socio economic condition prevailing in the hazard prone areas. This leads to an important conclusion; there is a need to understand the location of human settlements and their socio economic status, livelihood etc, with the same level of understanding the scientific processes of disasters.

Now having this experience for several years with landslide studies, the recent disaster experiences and approaches taken to mitigate or recover are discussed in the next sections of the paper.

Recent Disaster Experiences and Recovery

This section discusses and analyses the landslide events in Nuwara Eliya, ground subsidence event in Matale.

One of the early mapping exercises was taken up in Nuwara Eliya district. Landslide hazard maps finalised in 90's of Hanguranketha and Walapone show a high hazardous area. These two areas have an agriculture based economy. Mostly they are vegetable farmers, who were engaged in the tobacco cultivation until recently. The landslide studies revealed that tobacco cultivation disturbs the land and in turn helps to trigger the landslides. In January 2007, with the onset of North-East monsoon (this area receive more than 125 mm in one day) number of landslides occurred. It was reported that nearly 250 landslides in area, with 15 large landslides affecting nearly 5000 people. Directly, 2300 families were affected out of which 1450 to be in the high risk category.

Families identified for resettlement were mainly of middle income and low income segment and out of which 75% had a location specific livelihood. Most of them were farmers and the government without knowing the landslide risk has provided them with land in early 70's for cultivation. Most importantly, due to the livelihood specific nature of the settlement the resettlement programme implemented at a slow pace for identified families. It was only implemented for the most critical or families with totally damaged houses. One good lesson learnt from this exercise is that when resettlement plans are made options should be given. For these reasons, and lack of suitable lands in the areas, still the resettlement programme is being implemented. Because of this, for example, resettlement plan needs to address different categories of affected people. Most critical affected to be given a package to relocate (in the same area or outside), housing, livelihood support, relocation allowance etc and the others will be given the option of retrofication if voluntary resettlement is not preferred. This option now been implemented in the rehabilitation work in Matale district.

In Matale district, due to an unusual appearing of cracks in the large number of houses, some changes in the hydrology etc. a study was initiated by NBRO in 2006. The geological studies were conducted initially and it was evident of a strange geological phenomenon in the area. It is described as a 'ground subsidence due to underground erosion of silt material of soil to the cavities inside the marble rock'. Two ways of ground subsidence were reported from nearly 3000 affected families. Detail studies consisting geological, geotechnical, human settlements and environmental were carried out in order to formulate the rehabilitation plan.

The studies concluded that, existence of a weak geological zone area which needs to be monitored and to guide human settlements accordingly. Hence, the planning approach that was taken is of three folds; most critical and voluntary resettles' (nearly 15%) to move into areas that are identified in the National Physical Plan as mentioned earlier. People who need to resettle but refuse to move away voluntary (nearly 35%), were given the option of relocating themselves in the same area with strengthen houses. Balance families (50% were given the option of retrofitting the existing houses to suit the unstable ground condition.

A community base rehabilitation programme was initiated and as the first step a capacity building programme was carried out fro the construction workers in the area. Then, a set of guidelines was developed to strengthen the civil works of the new houses and existing houses. Survey revealed that the construction capabilities and techniques prevailing in the area are poor and not adequate to face this kind of phenomena. This is revealed as, nearly 70% of the affected households non use of appropriate construction techniques suitable for poor ground conditions. This is evident from the fact that, most of the not affected houses had used better construction techniques. In other words, this is a classic example to show the socio economic condition against the impact on disaster prone community.

Other disaster experience that discussed in this section is the 2004 tsunami. This disaster was impacted on 75% of the coastal belt of Sri Lanka with nearly a million population affected. About 100,000 houses were affected and were earmarked for rehabilitation. Soon after the tsunami government introduce a buffer zone with the no-built zone. This gave the population no option but to resettle (houses outside the buffer zone were allowed to reconstruct). In this programme with an artificially demarcated line communities were disintegrate into two. Families within 100m buffer zone were given no option but to resettle. Now, 3 years after implementing the resettlement programme it was reported that only 70% of the houses are occupied by the original recipients. Main reason for their return to original place is recorded as 'location of the livelihood'. This programme is mentioned in the paper mainly to describe one of approaches taken and the repercussions on the communities. Same situation applies to the other disaster prone communities.

This section mainly describes and analyse the disaster events and the socio economic background of the affected families and the rehabilitation approaches considered.

Conclusions

In a country like Sri Lanka, where the ancient settlements were located considering the three basics; topography, climate and economic base and it was able to stay away from the natural disasters. This approach has completely lost during the development process mainly due to 'incorrect beliefs' of need for more land with population increase. This perception has been incorrectly interpreted and in the process, we have invaded into much preserved fragile. Other main reason for settlements been diverted into fragile areas is changes in the economy. All these factors have created settlements which are vulnerable to natural disasters.

Now, disaster management should be combined into number of settlements created with different economic backgrounds. For example some of these farmer settlements are later created in hilly areas as home gardens without considering the carrying capacities of the hilly areas. This has led to settlements becoming vulnerable to landslide hazards.

Finally, one key factor that is to be considered is the carrying capacity of hilly areas, and the national development policies. It is important utilise the national physical plan prepared incorporating the landslide hazard maps prepared by NBRO which identifies the long term mitigation proposals of in voluntary relocation of population to safer areas. This will not put 'pressure' on the community since the policy is only to direct or guide the population. Structural and non structural mitigation methods including, mapping, guidelines, awareness etc. can be put forward as mid term solutions. Short term answer is the retrofication and building of physical structures.

The lessons learnt from the resettlement programmes include the important of supporting the location specific livelihoods in resettlement. Also, rather than involuntary resettlements the voluntary long term resettlements are opted for implementation.

Acknowledgement

Various research projects conducted at NBRO, enable the author to develop this paper. Also, experience gained by working in the tsunami rehabilitation programme is also allowed to discuss the policy issues of resettlement. However, contribution by Dr Udeni Nawagamuwa, Senior Lecture in Geotechnical Engineering and Mr NMSI Arambepola Director ADPC is worthwhile mentioning in preparation of this paper. Information shared by the Landslide Studies team is also acknowledged. Finally my gratitude is for the staffs of NBRO including the Director General who allow me to develop this paper.

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Composite Geotextile Reinforced Gabion Structure for River Side Slope of a Factory in Bali - Indonesia

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ABSTRACT: Low quality performance and the pressure of ground water as consequence of overflow from river in front of the structure had caused failure of soldier pile structure that was designed as retaining wall for 12m of slope.

This failure caused landslide behind the wall and was also threatening the stability of the building above.

Considering that this landslide on February 2006 was the second occasion after the earlier failure of the slope stabilized by gravity wall, the rehabilitation had to be analyzed thoroughly, and to accommodate many aspects, including engineering and economic aspect.

Through engineering analysis applying the latest data, including soil investigation and laboratory testing, it was decided to adopt geosynthetic reinforced earth as retaining structure.

This paper was to present the landslides; including landslide analysis, engineering consideration aspects, estimation and design analysis of geosynthetic material – in this project using composite Geotextile - with computer program, and also project execution on site.

KEYWORDS: Geosynthetic, composite geotextile, landslide, computer program

1. PROJECT BRIEF INFORMATION

Introduction

To support the production and also to cut short its distribution line, a beverage manufacturer planned to build a factory in Bali at 2004.

After considering several factors like the strategic approaches and "luck" factor, it was decided to build the factory at certain elevation of riverside.

For the choice, the consequence was to construct a 12m of retaining earth structure to overcome the landslide potential of slope.

At the beginning of factory construction, a conventional structure – massive gravity wall was chosen as retaining structure.

But unfortunately, this conventional structure was failed. As replacement, soldier pile structure was adopted. The piles used were 60cm in diameter and penetrated 2m into the subsoil (base on the data from soil investigation later, it was found that they could not install the soldier pile deeper than 2m into subsoil due to the soil layer was too hard to be penetrated by soldier pile).

Triggered by rapid draw down of river water after a flood of 3m high, the failure was inevitably due to the low quality

Fig. 1 The landslide threaten the factory building

Fig. 2 The piles were broken and pulled out

performance of structure and also the anchorage length of soldier piles were too short.

The pictures on the next page show the condition of project several days after landslide.

Although some parts of soldier pile are still intact, it was decided to strengthen it using some additional structure such as ground anchored geosynthetic reinforcement.

After considering several factors, the reinforcement using geosynthetic material and the gabion structure as facing was chosen.

Project Location and Data

The project is located at Samsam Village, Tabanan – Bali (one of beautiful island in Indonesia), 1-hour journey from Denpasar - the capital city of Bali Province.

The original soil is described as segmented sandy silt with N-SPT value more than 30 blows/ft.

The climate of this area is classified as Tropical wet and dry.

The slope height should be reinforced are 12 m with length 120m and facing using gabion structure.

The project was planned to be started at October 2006 and finished in 2 months.

Fig. 3 The project location

2. PROPOSED EARTH REINFORCED SYSTEM AND DESIGN

The earth reinforced system is proposed by the contractor was a geosynthetic reinforced wall system, selected for a variety reasons which included the economics consideration, the ease of construction, aesthetics, etc.

Facing

The facing type proposed in this project is gabion structure.

The gabion boxes have a dimension of 200cm x 100cm with 50cm height.

These facing were assumed as non-structural structure, which did not have any contribution to structural stability against overall landslide.

Geosynthetic Material

The geosynthetic material used in the construction of the earth reinforced system for this project is a composite geotextile. Composite geotextile is a geosynthetic material, consists of nonwoven geotextile and reinforcing filament. Two different grades of tensile strength were used for the design of the retaining walls of this project. Table 1 shows the derived allowable long-term design strength of the composite geotextile used for the design. The design life was 120 years at average ambient soil temperature of 30^{o}C.

The composite geotextile was laid between gabion boxes without wrapped back.

A total of 17,160 m^2 of composite geotextile were used as reinforcement in the construction of retaining walls for this project.

Backfill Soil

The backfill material was obtained from a nearby borrow area. Soil tests were done at the soil mechanic laboratory of Udayana University – Bali. Table 2 shows the test properties. The internal friction and cohesion were obtained from direct shear test in the laboratory.

Table 2 Properties of backfill soil

Properties	Tested	Design
Bulk density (kN/m^3)	18.88	19
Cohesion (kg/cm^2)	0.06	0
Internal friction (^{o})	27.98	25
MDD[1] (g/cm^3)	15.40	-
OMC[2] (%)	22.60	-

[1] MDD = Maximum dry density (Standard Proctor)

[2] OMC = Optimum moisture content (Standard Proctor)

Drainage material

Clean sand was placed behind the facing unit with minimum width of 300mm, which was put in the bag of nonwoven geotextile.

To facilitate the dissipation of ground water -if any- behind the reinforced earth structure, a drainage synthetic material was proposed too.

Table 1 Allowable long-term design strength of composite geotextile

Property of composite geotextile	Strength of material	Partial factor	Type 1	Type 2
Ultimate tensile strength	T_u (kN/m)		75	100
Creep rupture		f_c	1.55	1.55
Creep limited strength $T_c = T_u / f_c$	T_c (kN/m)		48.4	64.5
Construction damage		f_d	1.00	1.00
Environmental effects		f_e	1.10	1.10
Allowable long term design strength $T_a = T_c / (f_d \times f_e)$	T_a (kN/m)		44.0	58.7

Design and Detailing

The design follows the code of practice for strengthened/reinforced soils and other fills; British Standard BS 8006; 1995 and the analyses would be carried out using the commercially available software Plaxis version 7.2.
The design surcharge load was 20 kN/m^2 of live load.

For stability of reinforced slope, British Standard recommends to check both internal and external stability of reinforced slope in two types of limit state:

1. Ultimate Limit State
2. Serviceability Limit State

Limit States

The ultimate limit state should consider the following stability:

a. External Stability
  - Bearing and tilt failure
  - Forward sliding
  - Slip failure around the reinforced soil block

b. Internal Stability
  - Tensile failure of the individual reinforcement elements
  - Bond failure of the individual reinforcement elements

c. Compound Stability
  - Tensile failure of the individual reinforcement elements
  - Bond failure of the individual reinforcement elements

The serviceability limit states, which should be considered, are:

a. External stability
  - Settlement of the slope foundation

b. Internal stability
  - Post construction strain in the reinforcement
  - Post construction creep strain of saturated grained soils used with reinforced soil.

External Stability

The external stability is normally analyzed using the slip circle techniques such
as Bishop analysis, Janbu, Morgenstein etc.
In this project, the external stability would be analyzed using Plaxis version 7.2.

Internal Stability

The internal stability of reinforced slope depends on the ability of reinforcement elements to resist the loads imposed upon them.

There are several methods available for this internal stability analyze, such as two-part wedge analyses, circular or non-circular analyses etc.

Two-part wedge analysis

The two-part wedge analysis assumes a bilinear failure surface.
Two criteria would be analyzed are:

- Vertical reinforcement spacing, S_{vj}

$$S_{vj} \leq \frac{T_j}{K\left(f_{fs}.\gamma.h_j + f_q.w_s\right)}$$

- Reinforcement bond length, L_{ej}

$$L_{ej} \geq \frac{f_p.f_n.T_j}{2\left[\left(\gamma.h_j + w_s'\right)\frac{\alpha'.\tan\varphi'_p}{f_{ms}} + \frac{\alpha_{bc}'.c'}{f_{ms}}\right]}$$

Where:

S_{vj} : vertical reinforcement spacing at level j in the slope

T_j : maximum reinforcement tensile load at level j in the slope

f_{fs} : partial load factor applied to soil unit weight

h_j : fill height above level j in the slope

f_q : partial load factor applied to external surcharge loads

w_s : external surcharge due to the dead load and live load

L_{ej} : minimum calculated reinforcement bond length at level j in the slope

f_p : partial factor governing reinforcement pull-out

f_n : partial factor governing economic ramifications of failure

f_{ms} : partial factor applied to tan φ'_p and c'

w_s' : external surcharge due to dead load only

α' : coefficient of interaction relating soil/ reinforcement bond angle with tan φ'_p

φ'_p : peak angle of shearing resistance of the fill

α_{bc}' : adhesion coef. relating soil/reinforcement bond to c'

c' : effective cohesion of the fill

Analysis Results

The following figures show the analysis result from the computer software, include the condition of rapid draw down after 3m flooding.

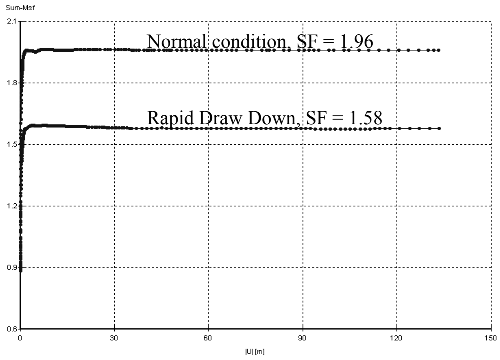

Fig. 4 Safety factor of structure

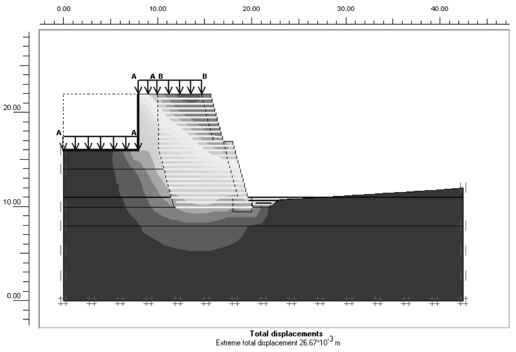

Fig. 5 Displacement pattern (normal condition)

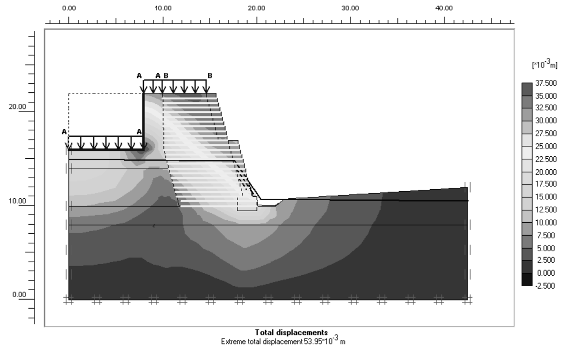

Fig. 6 Displacement pattern (after rapid draw down)

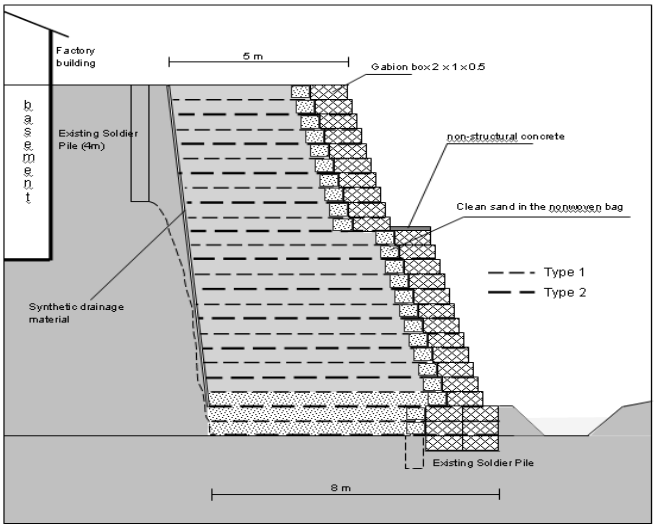

Fig. 7 Reinforcement details

Fig. 8 Laying of composite geotextile

Fig. 9 Backfilling process

Fig. 10 Soil compaction

Fig. 11 Quality control of compacted soil

3. CONSTRUCTION

Before the commencement of gabion structure and composite geotextile lay, the subgrade condition was checked along the alignment. Any soft material, debris encountered was removed. A 100cm wide trench was excavated along 120m. The depth of trench was such that the designed gabion structure embedment will sit on a minimum of 1m.

The initial layer of gabion unit was then placed over the subgrade. The initial layer of gabion unit was carefully checked for proper leveling.

The next sequent of installation was composite geotextile laid. The composite geotextile was laid with the machine direction perpendicular to the wall face alignment, from the front of wall face extending to the back of reinforced soil zone. The composite geotextile should be laid flat and free of wrinkles.

Backfilling was carried out in lifts of 150mm – 200mm, then compacted to a minimum of 90% of the maximum dry density and plus or minus 2% of the optimum moisture content, according to Standard Proctor laboratory test result.

At the designed level the designated composite geotextile was laid over the compacted backfill with facing of gabion structure and drainage bag.

4. CONCLUSION

The application of composite geotextile as a reinforcement material against landslide of riverside slope was success complete and to date is performing satisfactorily. The factory already opened and running well without any anxious about the landslide problem.

ACKNOWLEDGEMENTS

I would like to most sincerely appreciate and thank you to Prof. Chaidir Anwar Makarim, PhD (senior geotechnical consultant) and Andry Setiawan (main contractor) for their support and contribution in this project.

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Risk Management Strategies in Megacities: Delhi Experience

Akhilesh Surjan (Environment and Sustainable Development Programme, United Nations University, Japan)

Abstract: Delhi is not only capital city of one of the world's largest populated country but also vulnerable to variety of natural and manmade disasters. River Yamuna pass through the city and a long stretch of the city's settlements located around the riverbank experiences flooding at intervals. Some of these settlements houses most poor and thus vulnerable population as well. Due to variety of socio-economic processes, poor communities are forced to live in riverside slopes, and flood plains. Many of them also found resort in landfills near riverbed. Urban risk of Delhi although recognized for long time, started being systematically addressed through a major intervention jointly initiated by Government of India and United Nations Development Program. This paper presents some of the risk reduction measures taken in Delhi and shows possibility as how these efforts can be further elaborated to address integrated risks including flood induced landslide risk in some areas of this megacity. Although, examples in this case are confined to Delhi, it is expected them to reflect on the issues which are similar in nature in some of the Asian megacities.

Key words: Urban risk, megacities, community partnership, cooperation

Introduction

Delhi, the capital of India, is extremely vulnerable to natural hazards. 'Vulnerability Atlas of India' is prepared by an expert group formed by urban development ministry of the Indian government. The group collected, collated, analysed and presented only available authentic information/data and says that Delhi can experience earthquakes of 5.5 to 6.7 on Richter scale (MSK intensity VIII) which may induce landslide as well. Its densely populated areas with large amounts of unsafe building stock, non-engineered structures, the sizeable number of unauthorized colonies and urban slums compound vulnerabilities in this thickly populated megacity. The safety of Delhi is prime as the national capital, the hub of national government business, multiplying many-fold the implications of a major earthquake, not only on the population of Delhi and its infrastructure but also on the functioning of the country (India) itself. Delhi is also prone to flooding and heavy rainfall induced landslide is also a possibility in the city.

Addressing Delhi's risk

Keeping in mind the hazard exposure of india, Government of India and UNDP initiated Disaster Risk Management (DRM) Programme, which aims to contribute to the socio-economic development goals of the city by enabling communities to minimize losses to development gains and to reduce their vulnerabilities to disasters. Disaster Risk Management Program (2002-2007) is a nationwide program which is initially planned to implement in 125 most-hazard prone districts of 12 states across the country with a massive investment of approx USD 27 million. The program was later expanded to cover 169 districts of 17 states in the country. Delhi is one of the program state and all nine districts of Delhi were included in the program. Although Delhi is considered a state in Indian legislature, in real terms it is a city-state having population over 15 million residing in its 1584 square kilometers of area.

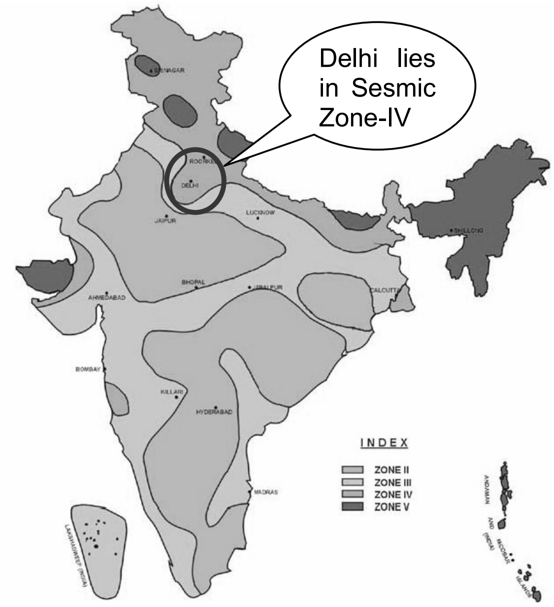
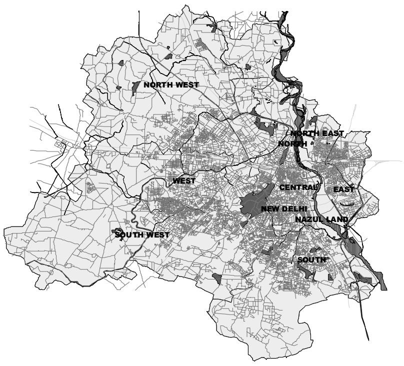


Figure: The seismic zonation map of India
(currently based on 200 year history of specific events)
Source: http://www.quakesafedelhi.net/rollout/Bilham.pdf.

The DRM program takes community based approach to disaster management hence seeks to build capacities of communities, government functionaries and other stake holders at all levels. 'Community Based Disaster Reduction and Recovery through Participation of Communities and Local Self Governments'[i] is the underlying principle around which various activities of the program revolve around. In Delhi, the DRM program effectively started making progress from the later half of the year 2003. Due to highly complex community structure in an urban area, the biggest challenge was how to engage urban communities in disaster risk reduction activities in Delhi. However, with innovative, sensitive to community needs, target based, user oriented community based disaster preparedness approach, the overall climate for vulnerability reduction and risk mitigation is changing positively. The main initiatives of the programme are as follows:-



Map: Delhi and its nine district, also shown river Yamuna flowing across the city

Awareness Generation: among government functionaries, technical institutions, NGOs, CBOs and communities about earthquake vulnerability and possible preventive actions.

Development of a Techno-Legal Framework: To promote safe construction and systems to ensure compliance.

Disaster Management Plans: Development and Institutionalizing of natural hazard Preparedness and Response Plans and practice these through mock drills.

Capacity Building: For certification by Government functionaries and engineers and architects.

Making communities aware

This was taken up as the most important tool recognizing the fact the in a city of such a mammoth scale, community will be first not only to respond but also to mitigate the disasters. Context specific Information, Education and Communication (IEC) Material were developed in local languages and distributed to all districts, schools, communities, markets, RWAs, offices etc. In addition to this, Disaster Preparedness Months have been celebrated in various districts to further intensify the awareness upto the grass root level. Disaster education was also mainstreamed with the formal school curriculum and Disaster Management included in curriculum for junior high school grades.

Developing technical skills

Technical knowhow is very important in especially an urban setting to safeguard the sophisticated built environment including lifelines and crucial facilities. Technical capacity development in Delhi was addressed through setting up of Hazard Safety Cell where various line departments were requested to nominate experienced engineers to constitute a hazard safety cell within the department. Development authority and municipal corporations are the major government bodies who cooperated in this task and formed the Cell. Central government also urged all the states to make appropriate amendment in Urban Development Legislations / Regulations / Bye-laws for incorporating "multi-hazard safety" provisions. Towards this, series of meetings were held with planning, construction and legislative agencies and suitable risk reduction measures are taken up at different levels. Delhi Development Authority, which is the apex organization for spatial development of Delhi reviewed the existing provisions and prepared text incorporating Multi Hazard Safety provisions in the Master Plan for Delhi -2021. Municipal Corporation of Delhi has also developed a draft of the new building byelaws, in which amendments as per the recommendations made by the National Expert Committee, have been incorporated.

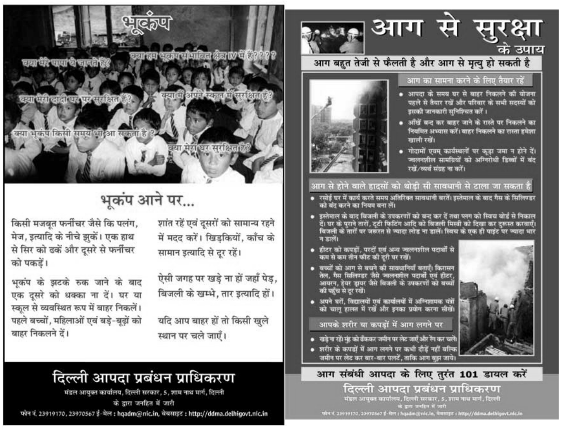


Figure: IEC for community awareness in local language

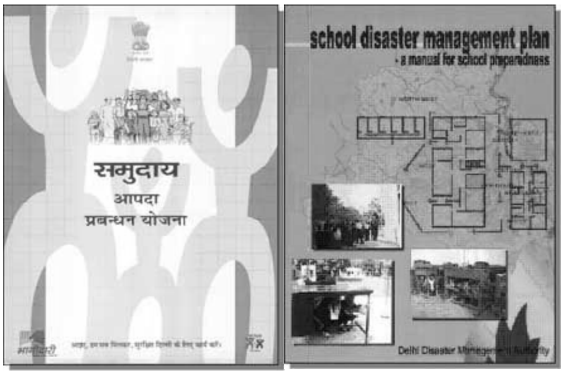


Figure: Community and School Disaster Management Plans in Delhi

Plan before the disaster

Disaster management plans of most Indian cities used to resemble an un-updated telephone directory. To change this trend and to incorporate methodological approach to this, number of meetings and discussions involving wide range of stakeholders were organized. It was also felt that state or district level disaster management plan should also guide and incorporate similar plans prepared at neighborhood and community levels. This was a difficult task which required both top-down as well as bottom-up synergies. With the help of community based organizations and NGOs, United Nations Volunteers inspired schools and residential units to take this initiatives.

Building the capacities for safer Delhi

Disaster management, being a new concept both in government as well as non-government spheres in Delhi, capacity development was taken up across hierarchies and disciplines to equip the decision makers, and common people with the right kind of tools and information. Training was offered to engineers, architects and masons from various Government, Public Sector and private departments in specific skill sets. A different training package was developed to offer policy and decision making help to senior administrators and politicians. Incident Command System was also followed on the lines of FEMA and various line departments and key officials were made aware of their roles and responsibilities along with resource inventory to make them optimize on the available resources. Teachers were separately trained to help children learn basics of disaster management right at the primary education.

Conclusion

The successful initiatives of DRM program resulted in remarkable change in community perceptions and preferences towards a disaster resilient built environment in Delhi. The master plan of Delhi which is a legal tool to guide spatial development of Delhi is also first time considering natural disaster proneness of Delhi and incorporating various land-use planning, zoning regulations etc. With some external support, now the building bye-laws are also under revision. At the national level, building codes and zoning regulation guidelines along with landslide hazard atlas of India is developed in the year 2004, but its application at city level is still need better scientific understanding and further research.

Due to the pressure of urbanization, many earlier low lying area in the city are now been filled-up and have unstable slopes where the development is taking place. These areas need special care while development activities are taking place.

It may be concluded that although disaster risk management program follows multi-hazard approach where urban landslide is also one of its components which is being addressed in a holistic manner. However, better scientific understanding of the geology and topography due to improved technology, micro-zonation, and other field verification methodologies are helping at regional or provincial level and their distillation to ground level still need more work for urban areas. Nonetheless, such community based approached supplemented by increasingly informative technological tools are expected to reduce urban risk in the megacity Delhi in near future.

Acknowledgments

The author would like to sincerely thank his advisors, and colleagues who worked with him in during 2003-05 on Delhi’s Disaster Risk Management Program. The author would also like to highly acknowledge the support provided by local communities, government officials and support staff to perform his duties.

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[i] DRM Program brochure is available at http://www.ndmindia.nic.in/EQProjects/goiundp2.0.pdf.

Role of Theme Based Regional Task Forces in Enhancing International Cooperation and Reducing Disaster Risk

Akhilesh Surjan (Environment and Sustainable Development Programme, United Nations University, Japan)

Abstract

Some of the recently established partnerships among the international agencies in the pre-disaster phase are the key discussion point of this paper. This is due to the recognition of the fact that addressing the root causes of vulnerabilities and disasters are more important and is also pointed out in the Hyogo Framework of Action. One of such initiative is promoted under the umbrella of UN/ISDR through establishment of regional thematic coordination and cooperation mechanisms. An examination of some of the past disasters revealed that it takes considerable amount of time to even figure out who is doing what in a disaster struck area even amongst the international agencies, donor agencies and humanitarian agencies. This paper will cover how such partnerships can be made more effective, and inclusive to benefit various levels of at risk communities, governments, civil societies and also existing systems of addressing disaster risk.

Key words:

disaster risk, international cooperation, partnership

1. Introduction

International cooperation initiatives are not new to development regime. Disaster management is one of the most gigantic task humanity is repetitively facing and multiple number of organizations work individually or collectively to address the sufferings of communities and / or enabling the governments. Mostly, these partnerships prominently emerge in the post-disaster phase. Indian Ocean Tsunami and Kashmir Earthquake are two most recent examples clearly illustrate how newer horizons of partnerships emerge in response to a large-scale calamity. It is very obvious for the international agencies to come forward in response to disasters and support mutual initiatives, however at times this also leads to overlapping of numerous tasks and also result in creating a misleading picture. Examination of some of the past disasters reveals that it takes considerable amount of time to even figure out who is doing what in a disaster struck area even amongst the international agencies, donor agencies and humanitarian agencies barring clarity of cooperation among local stakeholders.

Nonetheless, some of the recently established partnerships between the international agencies in the pre-disaster phase are the key discussion point of this paper. This is due to the recognition of the fact that addressing the root causes of vulnerabilities and disasters are more important which is figuratively pointed out in the Hyogo Framework of Action – an outcome of World Conference on Disaster Reduction held in Japan in 2005. One of such initiative is promoted under the umbrella of UN/ISDR through establishment of regional thematic coordination and cooperation mechanisms known as Regional Task Force.

2. Global Platform and Thematic Clusters

“In the past the ISDR system has been structured at the global level through the IATF/DR and associated thematic Working Groups, with only limited representation and outreach”i. Over the period of time and with increased exposure to disasters, a number of countries have created National Platforms (or nodal ministries) to promote disaster risk reduction. This necessitates the multilayered empowerment of ISDR system especially at the regional and sub-regional levels to co-ordinate disaster risk reduction initiatives.

Multi-stakeholder based ‘Global Platform for Disaster Risk Reduction’ which took birth through a consultative process launched in 2006 by the United Nations, is foreseen to become the main global forum for all parties involved in disaster risk reduction, namely Governments, United Nations agencies, international financial institutions, regional bodies, civil society, the private sector, and the scientific and academic communities. It was envisaged that the Global Platform will be instrumental in “addressing gaps, providing guidance and coherent support to countries for the implementation of the Hyogo Framework”. While drawing the strength of existing networks, Global Platform’s thematic clusters, groups and platforms works on specific topics, such as: climate change, education, urban risk, early warning, recovery and training. With a global or regional scope, the theme based current approach attempts to arrest the multidisciplinary nature of disaster risk related issues across the mandated geographical area.

3. Partnership for Urban Risk Reduction

Urban risk is one of the very fast emerging threats in developing countries and Asian cities are particularly vulnerable. Fast pace of urbanization coupled with various social-economic processes have lead to concentration of dense urban development activities in and around existing cities which often result in development taking place in the hazard prone areas as well. No single agency can look into the matter of urban complexities and so do the international agencies. Recognizing this, to facilitate interaction among different stakeholders, the Asia Regional Task Force on Urban Risk Reduction[ii] was established in January 2008. The Task Force is represented by 14 founding member organizations and is open for expansion. The Task Force is coordinated by UN/ISDR’s Japan Office. The founding member organizations includes following:

UN bodies	such as UNEP, UNCRD, UNU, UN-Habitat, UN/ISDR, WHO, IRP;
International expert organizations in the region	Such as ADPC, ADRC, DRI, EMI;
International donor agencies	such as JICA
Renowned academic institutions	such as Kobe and Kyoto Universities.

Source: http://www.adrc.or.jp/events/RTFmeeting20080130/top.html

The Task Force is envisaged to act as an advocacy vehicle to major urban policy bodies, and expected to provide a platform for collective information and knowledge development and sharing, facilitate interaction and cooperation among related organizations and stakeholders.

4. Capitalizing on existing cooperative efforts

It is important to note that some of the agencies listed above in forming the Task Force were already cooperating with each other on various occasions and their respective programs or projects to maximize benefits arising from cooperative efforts. For example – ADPC holds annual regional consultation in which a number of decision makers from the countries of Asia-Pacific participate. This summit is also joined and supported by a number of interested bilateral/multilateral agencies and donor agencies to further buttress experiencing sharing. Many other founding organizations also act as focal point to nurture partnerships in various specializations. For example United Nations University is instrumental in managing and developing Mekong Basin Research Network (MekongNet). This Network is designed to provide science-based knowledge for cooperative/collaborative development and management of water resources in the Mekong River Basin through the creation of an international research network and provides knowledge and tools to assist policy making in the countries of Mekong Basin. This network addresses the issues relevant to the sustainable water resources management of the basin promoting basin-wide cooperation towards poverty alleviation ensuring environment security. In addition to addressing disaster risk issues, this network also encompasses water and eco-security issues and hence provides a holistic and inclusive approach to address regional risks.

It may be noted that not all the partnerships are very effective in all phases. In fact, some of such partnerships did well in the past but diminished their efficacy in recent times. This paper is purposefully not pointing at those not-so-successful cases in the interest of space limitation. After the cyclone SIDR in Bangladesh last year, an official from leading donor agency opined that many namesake partnerships on flimsy ground contributed more to existing chaos in Bangladesh during cyclone response. Initiating and furthering networks and partnerships needs great amount of homework and considerable time needs to be spent on developing common reference points, matching of interest areas and calibrating interests of particular organizations to work collectively. This is amply demonstrated by networks nurtured by ADPC and UNU. Kyoto University recently promoted ‘Asian University Network of Environment and Disaster Management’. In near future, UNU is promulgating the idea of joint degree programs to offer international academic expertise to local level. These initiatives are intensely focused and addressing a particular sector or stakeholder to remain effective and relevant.

5. Possibility of realigning focus on landslide risk

Since last few years, UNU is playing key role in creating awareness about landslide risk in the region. Projects on water cycling and flood modeling have directly addressed landslide issues in project areas and also is an adviser to the management committee on ‘International Program on Landslides (IPL)’ and is an active member in the promotion of IPL though the International Consortium on Landslides. Tokyo Action Plan which is an outcome of UNU facilitated Tokyo Roundtable Discussion is one of the major achievements in this direction. International Environmental Technology Centre (IETC) of UNEP [iii] pays specific attention to urban environmental problems such as water supply, sewage, solid waste, energy, loss of green and natural spaces, urban sprawl, land contamination, traffic, transport, air pollution and noise with an aim to reduce urban vulnerabilities.

Regional Task Force on Urban Risk in which is founded by important players including UNU and UNEP is also unique. Interestingly, this partnership of a multiple number of global and regional organizations will not act as an implementing body rather will promote the collective activities of its member organizations. Mapping of urban risk resilience is taken up as one of the first major activities of the Task Force. Landslide risk community is relatively a small community among disaster professionals mainly dominated by engineers and geologists (or soil scientists). However, the multifaceted risks are likely to get associated in the event of a landslide. Hence, landslide risk reduction can derive strengths from and build upon available expertise and knowledge with disaster risk reduction community and organizations.

6. Epilogue

International cooperation initiatives in addressing community’s vulnerabilities through multi-stakeholder partnership is an encouraging development and started focusing not just on large scale disasters or ‘shocks’ but on small scale incremental disasters or ‘stresses’ as well. Such partnerships are expected to usher in new culture of pro-active stance in reducing risks including landslide risks various settings across geographical areas and countries. It is important to draw lessons as how such partnerships can be made more effective and inclusive to benefit various levels of at risk communities, governments, civil societies and also existing systems of addressing disaster risk including landslide risk. This paper recognizes that landslide risk is growing and with environmental degradation and climate change, it is bound to alter some existing notions of risk and vulnerability. However, it is also important for the emerging international landslide initiatives and other parallely growing thematic groups to look back at the existing partnerships and expertise to carefully synergize the efforts with them rather than reinventing the wheel to start afresh.

Acknowledgments

The author would like to sincerely thank IEDM Laboratory of Graduate School of Global Environment Management of Kyoto University, Japan for providing opportunity to attend formative meetings of the Asia regional Task Force on Urban Risk Reduction. The author would also like to highly acknowledge the support provided by Asian Disaster Reduction Center, Kobe, Japan to attend meeting in Thailand.

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[i] For more information about Global Platform, please refer to http://www.preventionweb.net/globalplatform/gp-abouth.html

[ii] More information on Asia Regional task force on Urban Risk reduction is available at http://www.adrc.or.jp/events/RTFmeeting20080130/top.html

[iii] Detailed information of UNEP/IETc's focal areas is available at http://www.unep.or.jp/ietc/background/Index.asp

High Resolution SAR Images of Landslides Triggered by Sichuan and Iwate-Miyagi Earthquakes

Takashi SUZUKI ・ Takashi SHIBAYAMA ・ Toshiaki UDONO (Pasco Corp., Japan)

Abstract.

There were massive landslides in Sichuan Earthquake of May 12, 2008, and The Iwate-Miyagi Nairiku Earthquake of June 14, 2008. All of them arose in intermountain areas, and the bad weather condition also made it difficult to capture the whole figure of the landslide areas. TerraSAR-X, a high-resolution SAR satellite launched last year, is capable of acquiring images independent of weather conditions, and that characteristic of the SAR satellite made it possible to conduct an emergency data acquiring session. About after 1 month of the earthquake, another session was conducted, too. Authors of this paper, attempted to analyze the topographic characteristics of the landslides caused by these earthquakes and detect the changes of the event over time.

Keywords.
high-resolution SAR satellite, landslide dam, landslide dammed lake

1. TerraSAR-X description

TerraSAR-X is a satellite with a right-side-looking X-band synthetic aperture radar (SAR) based on active phased array antenna technology. Table 1-1 summarizes the characteristic values of the orbit and altitude parameters, while Table 1-2 summarizes the system parameters (Herrmann and Bottero, 2007).

Table 1-1 Orbit and System Parameters

Orbit height at the equator	514 km
Orbits / day	15.2
Revisit time	11 days
Inclination	97.44°
Equatorial crossing time	(ascending) 18:00 ± 0.25 h (local time) (descending) 6:00 ± 0.25 h (local time)

Table 1-2: TerraSAR-X System Parameters

Radar carrier frequency	9.65 GHz
Band	X-band
Wavelength	3.11 cm
Polarizations	HH, VH, HV, VV
Nominal antenna look direction	right
Incidence angle range for StripMap/ScanSAR modes	20° - 45° full performance
Incidence angle range for SpotLight mode	20° - 55° full performance
Maximum achievable resolution (in range)	0.65 m – 1.5 m @ 300 MHz (advanced mode)
Azimuth resolution	1 m – 16 m depending on imaging mode, incidence angle, and number of polarizations

The following imaging modes are defined for the generation of basic image products:

- StripMap mode (SM) in single or dual polarization
- High Resolution SpotLight mode (HS) in single or dual polarization
- Spotlight mode (SL) in single or dual polarization
- ScanSAR mode (SC) in single polarization

The characteristic parameters of these modes are listed in Table 1-3(Herrmann and Bottero, 2007).

Table 1-3. Characteristic parameters

Imaging modes	StripMap	SpotLight	ScanSAR
Scene Extension (azimuth)	50km tandard	5km-10km	150km
Swath width (ground range)	30km (single polarization) 15km (double polarization)	10km	100 km
Full performance incidence angle range	20°- 45°	20° - 55°	20° - 45°
Azimuth resolution	3m at 150 and 300 MHz	1m and 2m (single pol) 2m and 4m (dual pol)	16 m
Ground range resolution	1.55 – 3.21 m @ 45°-20° incidence angle	1.34m - 3.21m	1.55m - 3.21m @ 45°-20° incidence angle
Polarization	Single pol (HH, VV), Dual pol (HH/VV, HH/HV, VV/VH)	Single pol (HH, VV); Dual pol (HH/VV)	Single pol (HH, VV)

2. SAR image interpretation

SAR images are suitable for interpretations of terrains due to its shadowing effect. Detailed geomorphic change caused by landslides can be interpreted with high spatial resolution SAR images. Roads and open waters are easily identified by the area of low backscatter in SAR images.

On the other hand, any information could not be derived from radar shadow area on the slope of opposite side to the SAR sensor and, as the disadvantage of SAR, fore-shortening effect makes it difficult to interpret land features from SAR images.

It should be strongly emphasized to understand these characteristics of SAR image well to avoid interpretation errors.

Landslides are often accompanied by specific land features like scarps or moving bodies, we used these characteristics as interpretation keys. Landslides in a mountainous region could cause a natural damming of rivers, the inundated areas associated with the landslide dam are also used as a key to indentify landslides in SAR images.

3. Landslides triggered by the 2008 Sichuan earthquake

A huge earthquake measured at 8.0 Ms by Chinese Earthquake Administration (CEA) occurred in the western part of Sichuan province of China on May 12th, 2008 and the earthquake triggered a large number of landslides in Beichuan county, Sichuan, China and its vicinity.

3.1 Description of TerraSAR-X data utilized

The TerraSAR-X data were acquired in May (shortly after the earthquake), June (about one month after the earthquake) and August (about three months after the earthquake).

Table.3-1 shows the detailed information of the data for landslide interpretation of the Beichuan earthquake.

Table.3-1 Description of TerraSAR-X data used in this study

	1st	2nd	3rd
Date	May.16,2008	Jun.18,2008	Aug.11,2008
Orbit Direction	Descending	Descending	Descending
Incidence Angle	41.6	41.6	41.6
Mode	Strip Map	Strip Map	Strip Map
Resolution	3.0m	3.0m	3.0m

3.2 The coverage of TerraSAR-X images

The TerraSAR-X coverage areas over Beichuan, China are shown in Fig.3-1.

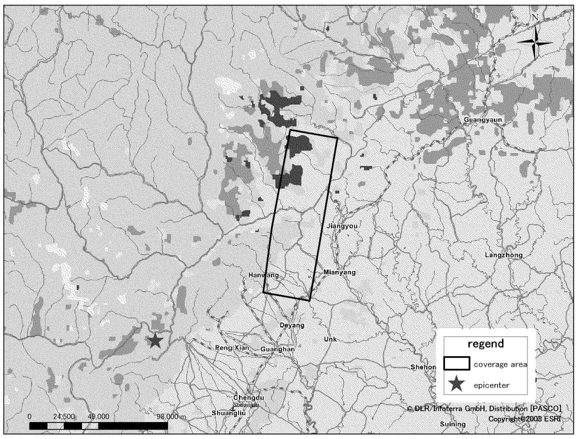

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Fig.3-1 The TerraSAR-X coverage area over Beichuan, China

3.3 Interpretation results

It was ascertained that there are three types of methodology to identify landslides displayed on the SAR images:

1) identifying landslide only by a single (first) image
2) identifying landslide by a single image and confirming it by the existence of the landslide dammed lake
3) identifying landslide by the existence of the landslide dammed lake though it could not be found on the first image

1) Example1: identifying landslide only a single image

Fig.3-2, 3-3 are images of Tangjiashan Lake , one of the largest landslide-dammed lake caused by this earthquake.

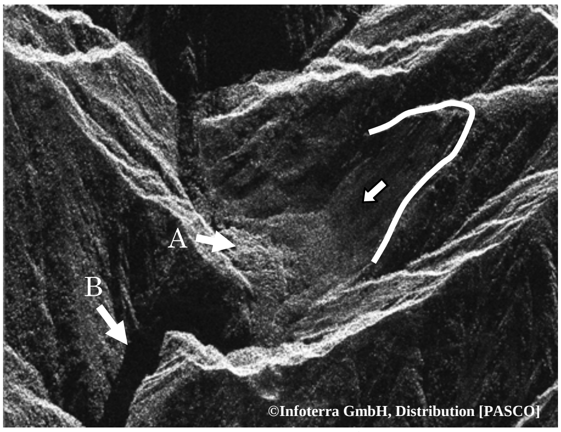

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Fig.3-2 Tangjiashan lake, just after the earthquake

A huge landslide occurred on the slope at the right side of the river and the moving body filled the river channel (A) and water level in the upstream of the dam had been already rising (B).

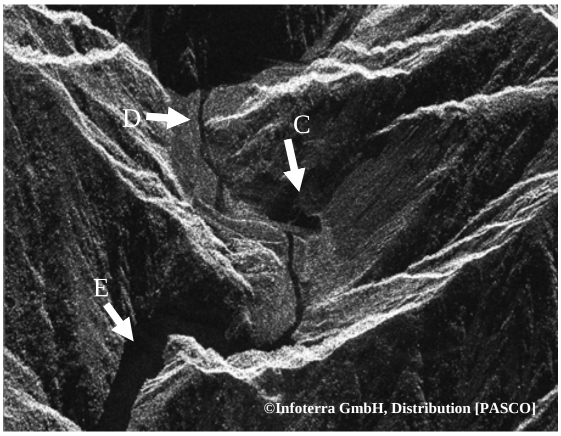

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Fig.3-3 Tangjiashan lake, one month later the earthquake

The spillway was built up. Sediments on the right bank slope seem to be being eroded by the strong flow of discharged water(C). Also, a large amount of sediment had deposited in the downstream of the dam (D) and was forming terraces.

Although it may not be clearly distinguished on the image shown here, the dammed lake are still spread larger than in May. Even though the increase of discharge of drainage, the dammed lake were larger than that in May.(E)

2) Example2: identifying landslide by a single image and confirming it by the existence of the landslide dammed lake

It seems that a slope failure occurred at the left bank and the moving body dammed up the river.(Fig.3-4,F,G)

There had not been any water surface in the upstream of the slope failure. We judged that this landslide dam was formed at the time of this earthquake due to its freshness of shape.

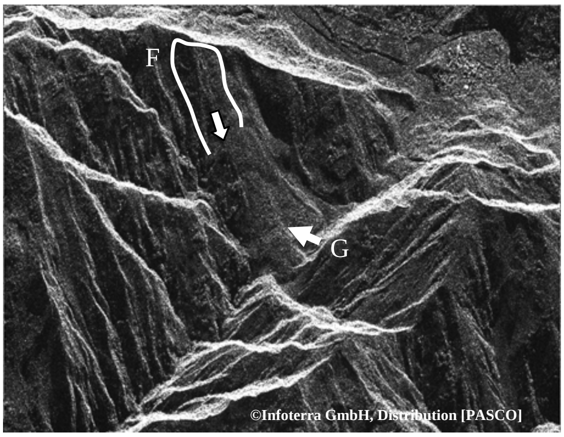

Fig.3-4 Another landslide and its damming

There were two dammed lake and this fact indicates that this landslide was triggered by this earthquake.(Fig.3-5)

Fig.3-5 Landslide dammed lakes on the second image

3) Example3: identifying landslide by the existence of the landslide dammed lake though it could not be found on the first image

Although we could not identify landslides on the first image, we later recognized two landslips and small ponds related to the landslides based on the second and third images.

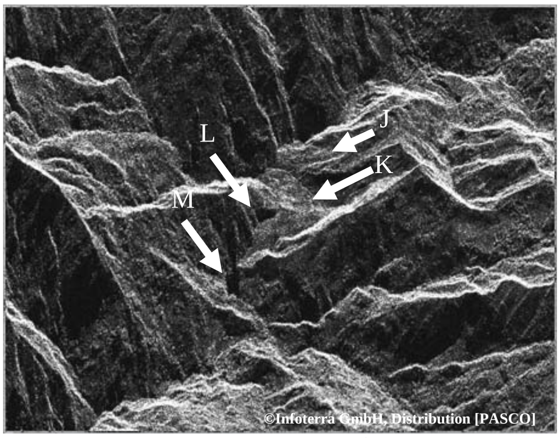

Fig.3-6 Small ponds on the first image

These small ponds (J, K, L and M) gathered to be larger, and new ponds (N and O) appeared at the upstream of the landslide.

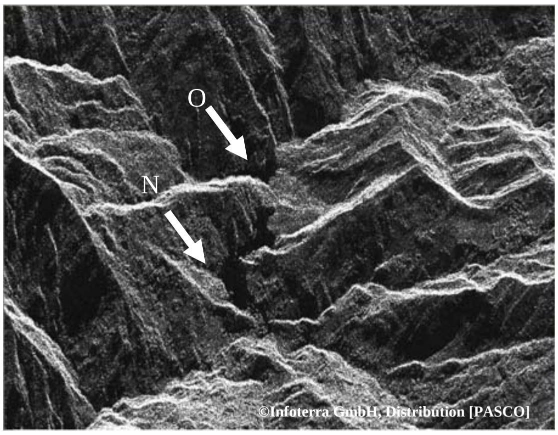

Fig.3-7 Larger ponds on the second image

4. Landslides triggered by the Iwate-Miyagi Nairiku Earthquake in 2008

On 14th June, 2008, a 7.2-magnitude earthquake centered in the border between Iwate and Miyagi prefectures triggered a large number of landslides.

A particularly-large landslide with approximately 700 m width and 1,500 m length occurred in the vicinity of Aratozawa dam.

4.1 Description of TerraSAR-X data utilized

Table.4-1 shows the detailed information of the data for landslide interpretation of the Iwate-Miyagi Nairiku earthquake.

Table.4-1. Description of TerraSAR-X data used in this study

	1st	2nd	3rd
Date	17:37,Jun.16,2008	17:37,Jul.08,2008	17:37,Jul.30,2008
Orbit Direction	ASCENDING	ASCENDING	ASCENDING
Incidence Angle	49.4	49.3	49.4
Mode	Spot Light	Spot Light	Spot Light
Resolution	1.6m	1.7m	1.7m

4.2 The coverage of TerraSAR-X images

The TerraSAR-X coverage areas over Aratozawa are shown in Fig. 4-1.

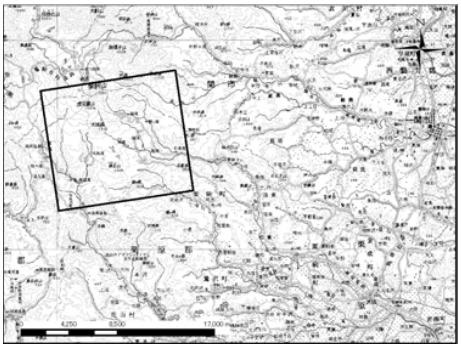

Fig. 4-1. TerraSAR-X coverage area over Aaratozawa area

4.3 Interpretation results

In comparison with the Sichuan earthquake, the scale of the change is much smaller, so it is not easy to extract any change by comparing the images of before and after the earthquake.

However, it is easier to extract changes between multi-temporal images from a color composite image.

A new crack appeared on the image(A). The height of the cliff could be calculated by the length of the radar shadow. The length of the shadow is approximately 10 meters so that the height is estimated about 8.5 meters. Recession of shadow can be interpreted the influence of the slumped cliff(B). Shadows accompanied with logging operation and earth excavation by road repairments(C).

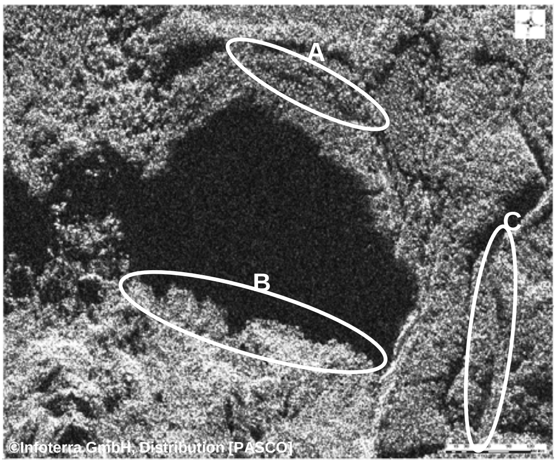

Fig.4-2 Cracks and other features interpreted by the images

The widths of crack at third acquisition are larger than that of the time of second acquisition.

The length of the shadow became longer and the cliff height can be calculated to be 11 meters.

Shadow has been rolled back further on the second image.

A new crack cliff with 10 meters height was observed in the field.(fig.4-3)

Fig.4-3 Photograph taken at the cliff

5. Applicability of SAR image interpretation for landslide monitoring

High-spatial resolution SAR image emphasizes topographical relief as if it were shaded-relief map. Specific features accompanied with landslide and asynechia of river channels or roads can be interpretation keys for landslides.

Dammed lake associated with landslide dam assures the existence of the landslide.

Under favorable conditions, the height of head cliff of the landslide can be calculated by the length of radar shadow.

The direction of image should be taken into consideration because the difficulty of image interpretation depends on the direction of the slope and valley.

6.Summary

Specific land features associated with landslide (e.g. scarp and moving body) could be detected and identified by high-resolution SAR image.

With multi-temporal SAR images, cracks which drop from great heights and reduction and expansion of dammed lake area were obviously identified in the SAR images.

Especially, a simple temporal color-composite SAR image is valuable to detect changes between two different acquisition time in short time.

Satellite SAR imaging has characteristics such as the wide area coverage and weather independency. So, SAR images are suitable for the monitoring of landslide compared with aerial photographs and optical satellite images.

Advances in accumulation of SAR data will make it easier to compare images before and after the disaster, and it will strongly contribute to detect landslide features more efficiently. Our activity of disaster monitoring using TerraSAR is now in progress, and our advance will be shown elsewhere.

Acknowledgement

Authors are thankful to Landslide Research Team of Public Works Research Institute (PWRI), Japan for providing *in-situ* information.

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Study on Early Warning System for Debris Flow and Landslide in the Citarum River Basin, Indonesia

Kaoru Takara (Kyoto University, Japan) · Apip (Kyoto University, Japan) · Agung Bagiawan (Ministry of Public Works, Indonesia)

Abstract. This paper presents three possible approaches for early warning systems. The first approach based on map of the susceptibility of debris flows and landslides is developed on slope stability, soil characteristics, land cover, geological formation, and the rainfall intensity duration thresholds. This early warning is qualitative and only informs people the areas of high susceptibility of landslides and the amount rainfall thresholds people should be aware of. The second approach based on prediction of debris flow and landslide from the distributed sediment yield transport model. This approach is quantitative, but still cannot answer the question when debris flow will occur. The third approach based on real-time monitoring of hydrological network and soil/ground movement monitoring in areas of high susceptibility of debris flow/landslide and real-time predicting of debris flows and landslides based on sediment yield transport model. This approach is quantitative and warning can be informed to the people a few hours ahead.

Keywords: susceptibility map, prediction, monitoring, distributed sediment runoff model

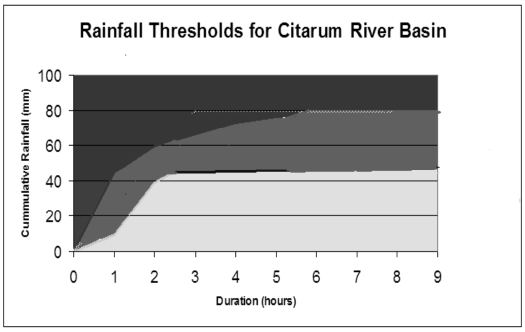

Fig. 1 Rainfall Thresholds for the Citarum River Basin Indicating Danger (red), Watch (blue) and Safe (light blue) zones.

1. Introduction

The annual reoccurrence of floods, debris flows and landslides in the Citarum River basin has caused the major property damage and the life loss of hundreds of people. The catchment characteristics (soil, geology and land cover) are prone to landslides. Debris flow warning system studies at the Citarum River basin are beneficial for developing a methodology for monitoring and predicting debris flows, understanding linkages between rainfall intensity, area of high susceptibility of landslides and debris flow occurrences. Indicators such as forest area of less than 15%, loose soil more than 50%, intermediary igneous rock more than 60% and the sedimentation rates at Nanjung, show that the upper Citarum River basin has a high susceptibility of debris flow

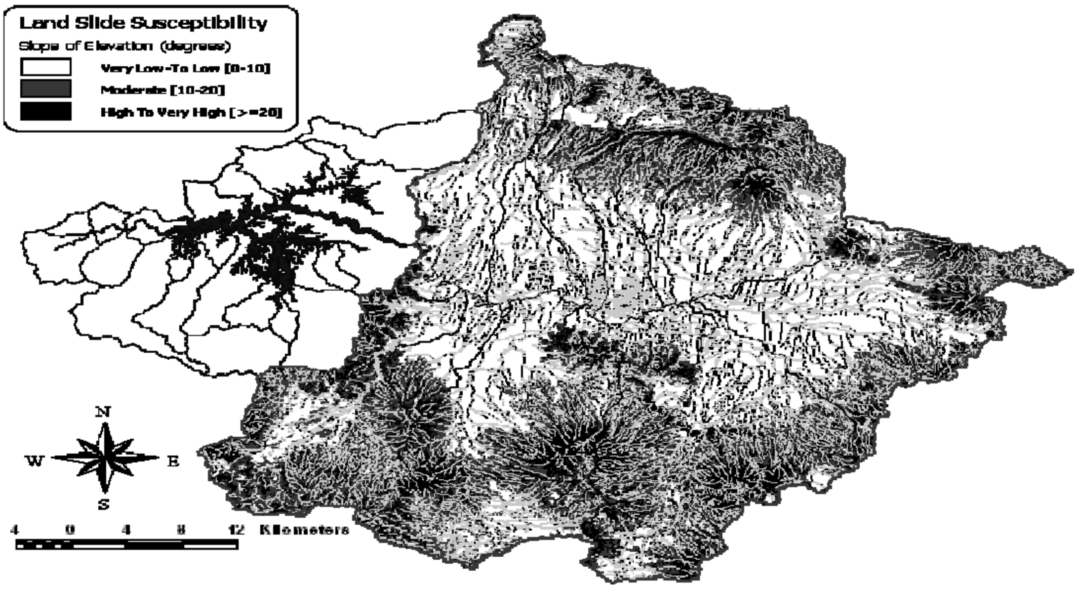

Fig. 2 Landslide susceptibility map for the upper Citarum river basin

and landslides.

This paper deals with four steps that have been prepared for developing early warning system in the Citarum River basin.

2. Storm rainfall intensity-duration threthpld

The first step is to develop storm rainfall intensity-duration thresholds by using rainfall data from the stations closest to landslide locations. These rainfall thresholds can be used to indicate different levels of potential hazards. The Rainfall Threshold for Citarum River Basin can be seen in **Figure 1.**

3. Susceptibility map

Second, a map of susceptibility for the upper Citarum River basin has been created from the inventories of some aspects such as geological condition, land use, soil, slope, and rainfall. These maps empirically showed the part of areas of debris flows and landslides will potentially occur. **Figure 2** shows a landslide susceptibility map based on slope angle. According to this, the area of 355.25 km^2 is high to very high susceptibility (**Figure 3**).

4. Distributed sediment runoff model

Third, a physical distributed runoff and erosion model has been developed to determine the runoff hydrograph and sedimentation graph. Apip et al. (2008) developed a physically-based distributed sediment runoff model and its lumping for the upper Citarum River basin, Indonesia. Its basic concepts are expressed as follows.

The physically-based distributed sediment runoff model has been developed to determine the runoff hydrograph, sedimentgraph, and total sediment runoff generated from any temporally-spatially varied rainfall event and continuous rainfall data input. The modeling approach is deterministic, physically-based, empirical, spatially distributed and dynamical in time. Dynamic spatial of water movements, erosion patterns and sediment rates can be predicted at any location inside the catchment as well. The concept of physically-based distributed sediment runoff modeling is shown in **Figure 4**. A sediment transport algorithm is newly added to the rainfall runoff model. Sediment runoff simulation can be divided in two parallel phases: runoff generation and soil detachment.

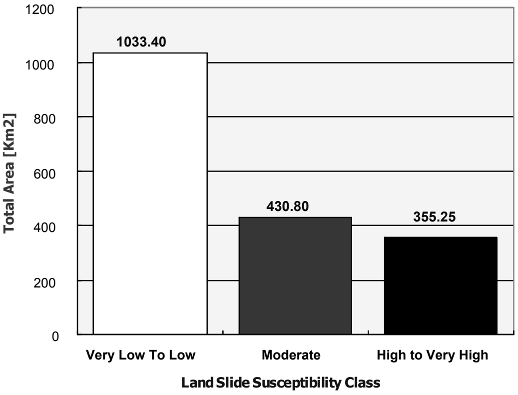

Fig. 3 Areas of landslide susceptibility classes

For a given rainfall event, once the rainfall is directly added to subsurface or surface flow according to the water depth on the rainfall dropping grid-cell. The model does not consider the initial rainfall losses due to vertical water flow directly, such as infiltration effects. Rainfall runoff model effectively simulates lagged subsurface flow with calibrated hydraulic conductivities and soil layers depth.

The hydrological model considers three principal water flux pathways within a catchment: subsurface flow through unsaturated flow (capillary pore), subsurface flow through saturated flow (non-capillary pore), and surface overland flow. Using a stage-discharge relationship, after the water depth is greater than the surface soil layer, the net rainfall will accumulate as surface water and begin to flow as overland flow. Subsurface and surface flows in both land surface and river channel networks are computed as kinematic wave. The eroded sediment is transported by overland flow to river channels.

The sediment transport algorithm includes multiple sources of sediment transport, which are soil detachment by raindrop (*DR*) and hydraulic detachment or deposition driven by overland flow (*DF*). Soil detachment for interrill and rill implicitly are simulated respectively, rain splash and flow detachment. The erosion or deposition rates are calculated as a function of the hydraulic properties of the flow, the physical properties of the soil and the surface characteristics. The detachment of soil particles by raindrop impact is function of the energy imparted to the soil surface by the

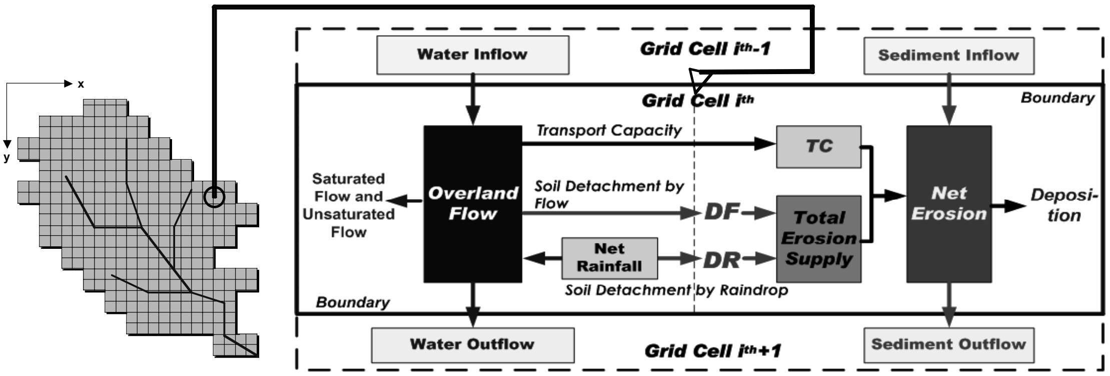

Fig. 4 Schematic diagram of the physically-based distributed sediment runoff model within grid-cell scale.

individual drops.

The basic assumption of this model is that the sediment is transported and yielded when overland flow occurs. The transport capacity of the overland flow also needs to be specified, in which suspended sediment flow is calculated using the transport capacity approach, as it acts as an upper limit to the potential contribution of each grid-cell to sediment concentrations in saturated areas. Soil detachment and transport is handled with the continuity equation representing *DR* and *DF* as:

$$\frac{\partial h_S c}{\partial t} + \frac{\partial q_S c}{\partial x} = e(x, t) \qquad (1)$$

where $e(x,c)=DR+DF$, C is the sediment concentration in the overland flow (kg/m^3); h_s is the depth of overland flow (m); q_s is the discharge of overland flow (m^3/s); and e is the net erosion (kg/m^2/hr).

Soil detachment by raindrop is given by an empirical equation in which the rate is proportional to the kinetic energy of effective rainfall and decreases with increasing h_s. From the observation of rainfall characteristic in the study area and dampening soil detachment rate by h_s (Morgan et al., 1998) the empirical equation for *DR* for the i^{th} grid-cell is expressed as:

$$DR_i = k\,KE\,e^{-b*h_{si}} = k\;56.48\;r_i\;\mathrm{e}^{-b*h_{si}} \qquad (2)$$

where k is the soil detachability (kg/J); *KE* is the total kinetic energy of the net rainfall (J/m^2); and b is an exponent to be tuned.

Following the theoretical work of EUROSEM (Morgan et al., 1998), the concept of transport capacity (*TC*) is used to determine sediment transport rates in overland flow. Sediment transport capacity of overland flow is defined as the maximum value of sediment concentration to transport, which is estimated for each grid-cell. Then for the i^{th} grid-cell, *DF* is simulated as a result of overland flow and function of *TC* as follows:

$$DF_i = \alpha\,(TC_i/1000 - C_i)h_{s_i} \qquad (3)$$

where α is the detachment/deposition efficiency factor. Detachment or deposition by flow is assumed to be proportional to the *TC* deficit. Following the *TC* approach; if actual suspended sediment from upper grid-cells is lower than this capacity, detachment or erosion occurs, otherwise soil deposition excess.

The simulation area is divided into an orthogonal matrix of square cells (250 m x 250 m), assumed to represent homogenous conditions according to the digital elevation model (DEM). This allows the use of DEM to derive flow direction map to define the interaction between the objects that simulate sediment runoff at each grid-cell. Runoff generation, soil erosion or deposition are computed for each grid-cell and are routed between grid-cells using the kinematic wave model following water flow direction, which defines the routine order for the water flow and sediment transport propagation. The model uses the one-dimensional kinematic wave equation for both subsurface and surface flow.

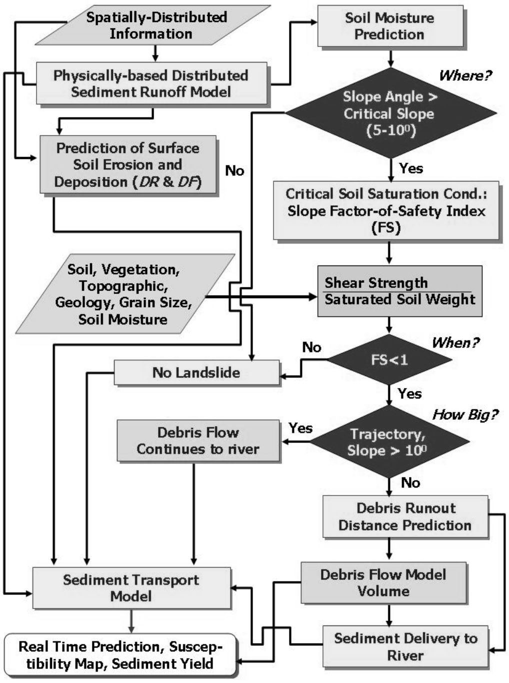

Fig. 5 Hydrologic-shallow landslide conceptual model

Integrating this model with the debris flow information (spatial water, sediment, and rock movements) will allow us to predict the sediment yield and landslide development map (see **Figure 5**). The fourth step involves relocating some of the hydrological stations and upgrading the equipments. Based on susceptibility map, the real time network stations will need to have 17 rainfall stations, 11 water level stations, extensometers geophones, water pressure monitoring stations and a computerized database system for hydro-meteorological data storage/retrieval.

The model has been applied and successfully in some river basins in Indonesia. The model is used for predicting erosion and sedimentation in the Cisangkuy River basin in West Java. Daily data from 1995 up to 2005 and distribution of rainfall pattern for the Cisangkuy have been prepared to calibrate and verify the model parameter. Digital map of Citarum River basin is processed to be a TIN map and then is changed to Digital Elevation Model. From this information, as can be seen in **Figure 6**, the flow direction (left-bottom) and slope raster (right-bottom with land use) can be mapped.

5. Susceptibility map

Fourth, in the case a real-time warning system will be used, some of the hydrological stations at the upper Citarum Basin have to be relocated and upgraded. Based on the high susceptibility map, real time network stations have to consist of 17 rainfall stations, 11 water level stations, extensometers geophones, water pressure monitoring stations and a computerized database system.

A comparison study on data transmission showed that SMS (Short text Messaging Service) and GPRS (General Packet Radio Services) are the optimal solution for data transmission on the GSM (Global System for Mobile) network. Information and education on early warning system of debris flows and landslides and evacuation procedure have

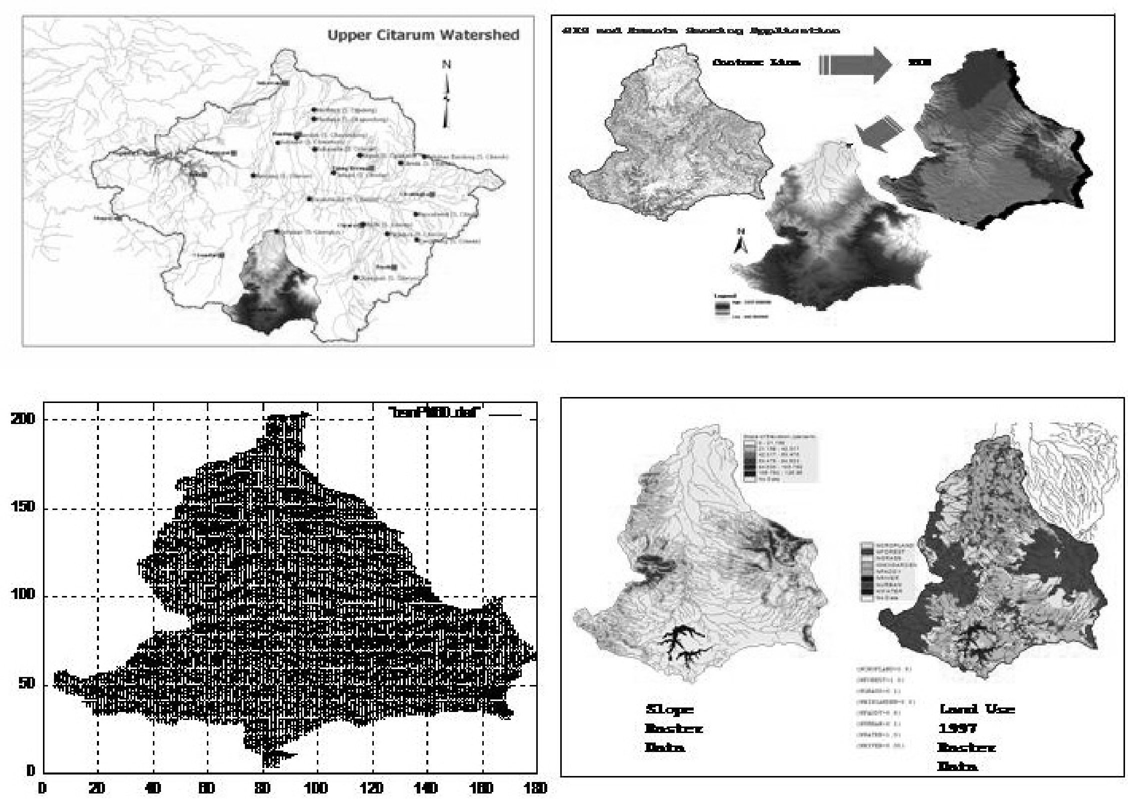

Fig. 6 Maps for Prediction of Debris Flow and Sediment Yield

been prepared to help the local people avoid the disaster.

The results of this study show that landslides are likely to occur in areas that have high to medium susceptibility. These landslides are usually triggered by heavy rainfall intensity above 70 mm within 5 hours or more in duration. The distributed model, which incorporates flow and sediment yields movement, soil hydraulic properties, root factor and slope stability, is capable to predict debris flow and landslides.

6. Conclusions

(1) Debris flows and landslides occur in the upper Citarum River Basin every year.
(2) Landslides occurred in areas with have high to medium susceptibility triggered by heavy rainfall above 70 mm with rainfall duration of 5 hours.
(3) The percentage area of forest less than 15 percent and the increasing of sedimentation rates at Nanjung, showed that the upper Citarum River Basin has a high susceptibility of debris flow and landslides may occur.
(4) Maps of susceptibility and rainfall thresholds have to be modified regularly if any significant changes in catchment or climate characteristics.
(5) The distributed model, which incorporates flow and sediment yield movement, soil hydraulic properties, root factor and slope stability, is capable for predicting debris flow and landslides.
(6) It is required to develop continuous early warning system in the upper Citarum River Basin.

The authors believe that the sharing of data among Asian countries is very beneficial for developing the most appropriate approaches and debris flow and landslide models, which can contribute to landslide disaster reduction.

Acknowledgments

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The Education of Sediment Disaster Generation Process Including Sediment Transport to Resident's Action in Hiroshima City

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Abstract. Every year sediment disaster occurs in the mountain areas trigger of heavy rainfall or typhoon. As for sediment disaster, condition of geological characteristic and rainfall etc. being the almost same, generation property of the mass movement differs in each geological characteristic. It is difficult to announce officially evacuation advice for each property. It is necessary for the resident to judge the information without waiting for the official evacuation advice; they have to judge the information comprehensively using forerunning phenomenon that is sound and vibration etc. and the weather forecast, for the independent evacuation. In the recent researches, recognition for the sediment disaster of the local resident to be low and tendencies are pointed out that evacuation starts after the danger approached. Diversification and complication of the disaster with the climate change of recent years, construction of the resident entity disasters software measure for synthetically disaster prevention system is urgent.

This paper is the report of disaster education at Hiroshima city. Hiroshima city experienced the damage of sediment disaster on 1999 June 29th. The author made disaster education textbook in this area and analyzed about it. As the result, people can easy understand about local risk information. For early evacuation, education is important issue. This textbook will support tool in this area.

Keywords: Disaster education, Resident's action, Hazard map, education tool, Hiroshima-city

1. Introduction

Many sediment disasters happened in every year by Typhoon, heavy rainfall and heavy rainfall caused by depression. Sediment disaster's characteristic is different activity of each valley. Therefore, it is not possibly perfect defense by government prevention. For that, the people have to prepare by themselves; check risk area, get some information, understand environment condition, etc. People were informed about government activities and residents action after the Nagasaki Disaster in 1982. The government made hazard map to help understand disaster information. After Hiroshima Disaster (1999) and Tokai heavy rainfall disaster (2000), government is looking for intense resident activities to protect loss of lives. For those reasons, people have to understand disaster and how to prevent that.

2. Soft measures of disaster prevention

Disaster prevention's key stakeholder is residents and government. Main countermeasure is hard type by engineering activities and soft type by evacuation and education. Soft type countermeasure is important for residents. For early evacuation and safety life, people have to do something for prevention. 1st step is getting some information about hazard and vulnerability from governments. Second is to understand that information. Third is to prepare action plan by them, and the final is to do some action.

Risk information is of three types. One is for usual time information, second is emergency time information, and third is recovery information. But, Sediment disaster's one characteristic is different activity of each valley. People have to get some information by themselves and decide some action by themselves. To make decisive actions, people have to learn some information and make action plan.

However, some people could not get some information in usual time and if they catch some information, they did not understand information means. As the result, people did not evacuate in emergency time. It is a crucial problem about soft type countermeasure of disaster prevention.

For the evacuation, people have to get right information and understand it. This is only possible through appropriate disaster education.

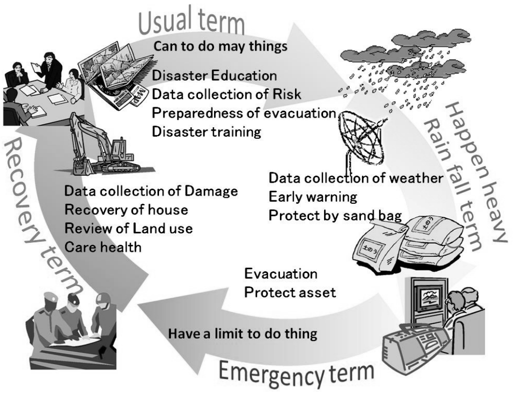


Fig. 1 Disaster cycle and prevention action of Rainfall Disaster

3. Outline about Hiroshima city

Hiroshima city is large city, but like other coastal cities in Japan, the city also lacks enough flat area. From 1970s, there has been a steady population growth till mid 1990s, and people from different places gathered in the city. As the result, the city was spread over to mountain area. Therefore, Hiroshima city has the highest sediment disaster risk area in Japan. Old resident's knew which part and when the disaster may happen through the experiences and legacy. But, new residents did not know that information. In the new resident's area, people's average living years is 15 years. Old resident's people's average is 60 years (Takeuchi, 2004). The other issue is the geology of the areas, which is full of granite, vulnerable to erosion and one of the main causes for the sediment disaster.

On 29th June 1999, heavy rain fall (over 150mm/3 hours) happened in Hiroshima city due to depression. Before this rain fall, similar heavy rain fall occurred in the same region two times (23-24th June and 26-27th June). Several debris flows occurred in the region due to heavy rainfall. This disaster damage was as follow: debris flow occurred in 139 sites, collapse was 186, death toll was 31 persons, the missing people was 1 person and house damage was 154 (Fujiwara, 2000). After the disaster, Hiroshima prefecture and Hiroshima city performed many various soft and hard countermeasures.

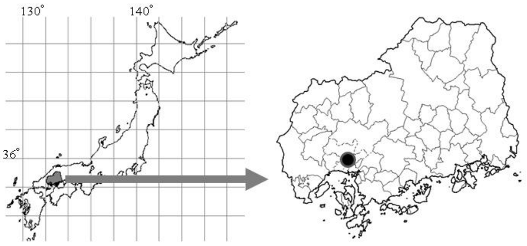
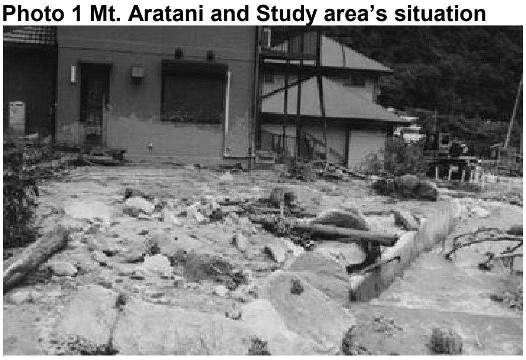


Fig. 2 Study area

(Photo by Kotake)

Photo 1 Mt. Aratani and Study area's situation



(Photo by Ootani)

Photo 2 Situation of sediment disaster at Hiroshima, 1999

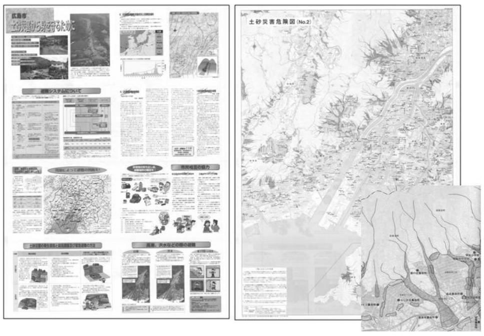


Fig. 3 Hazard map by Hiroshima city (2000)

4. Disaster education of Hiroshima city

For early and safety evacuation, people have to get some risk information and understand those information. Therefore people need some support tool and system. The author made disaster education textbook and analyzed those effects in Hiroshima city.

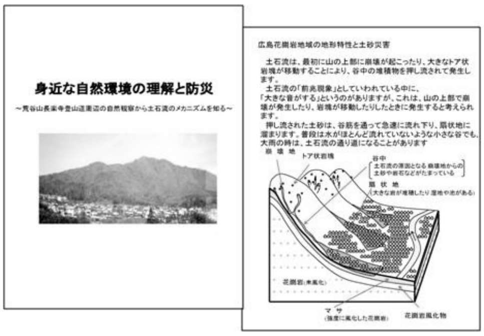
4.1 Textbook development

Target area is Aratani Mountain (631.3m) at Asa-minami word on Hiroshima city. There are three specific aims of the textbook: One is to understand about near environment forces to characteristic of Granite Mountain. Second is to focus on how the debris flow happened. The third is how to prepare for the disaster.

The author selected one climbing road at Mt. Aratani. Climbing road is easy access part for resident's people, and made research at Mt. Aratani at August and October 2002. Figure 4 and 5 were prepared through the research. We can see one pond and two check dams near climbing road entrance. Climbed 500m, we can check weathering Granit and bed rock. Some bolder size (3-4m/ ϕ) rocks appear around 300m above sea level. We can see old land slide at same area. Fudou-temple is position at 364.1m above sea level. This point is critical point to steep slope and appear Tor type rock (7-8m/ ϕ). Peak of south part to Top area is gentle slope.

The textbook is the result of these investigations (Figure 4). This textbook's table of contents is as follow:

- About debris flow
- Debris flow is where happen
- Characteristic of Granite as the bed-rock
- Characteristic of geomorphology at Hiroshima
- Watch map
- Observation of Granit mountain
- Countermeasures of disaster



身近な自然環境の理解と防災

～荒谷山長楽寺登山道周辺の自然観察から土石流のメカニズムを知る～

広島花崗岩地域の地形特性と土砂災害

土石流は、最初に山の上部に崩壊が起こったり、大きなトア状岩塊が移動することにより、谷中の堆積物を押し流されて発生します。

土石流の「前兆現象」としていわれている中に、「大きな音がする」というのがありますが、これは、山の上部で崩壊が発生したり、岩塊が移動したりしたときに発生すると考えられます。

押し流された土砂は、谷筋を通って急速に流れ下り、扇状地に溜まります。普段は水がほとんど流れていないような小さな谷でも、大雨の時は、土石流の通り道になることがあります

Fig.4 Textbook and its outline

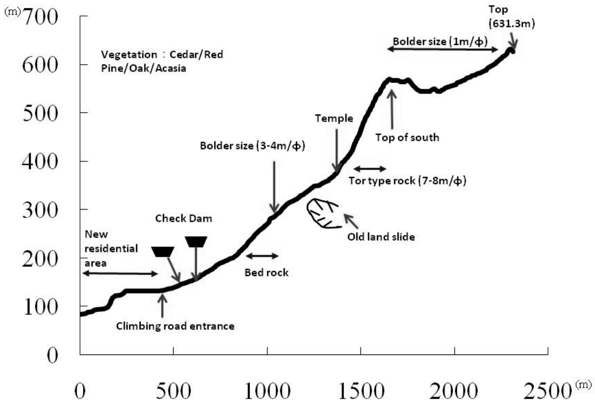


Fig. 5 Characteristics of climbing road at Mt. Aratani

4.2 Outline of disaster education to residents

This disaster education take part in 30th August 2003 includes disaster training by local disaster organization (*Jishu Bousai kai*). The author explained debris flow used by the textbook. Participants known that characteristic of Granite Mountain and new residential area are high vulnerable area of debris flow. Hiroshima city published landslide hazard map at 2000. Participants checked them house on the hazard map.

Disaster training's participants was about 700 people. Disaster education's participants were 200 people. After the education, the author undertook a questionnaire to participant. Answer was 103 people.

4.3 Questionnaire result

Questionnaire's total sample is 103 (Male 94%, Female 6%). Majority of age is 30-39 years old and 60-69 years old (each 27%). 42% people are live in this area under five years and 63% people are live in this area under ten years. Figure 6 shows the attribute of the questionnaire results, and Figure 7 is opinion and contents about disaster education.

As the result of questionnaire, people accepted this textbook and understand those needs and information. Some people suggested that they want use some animation and figure than character. Fig 8 is request for textbook. In the future, we can make the education textbook which are easy to be understood more by adopting the thing which is easy to be understood visually.

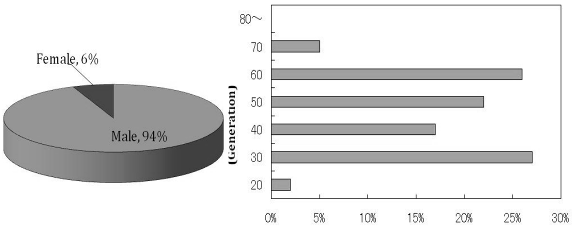


Fig. 6 Attribute of questionnaire result

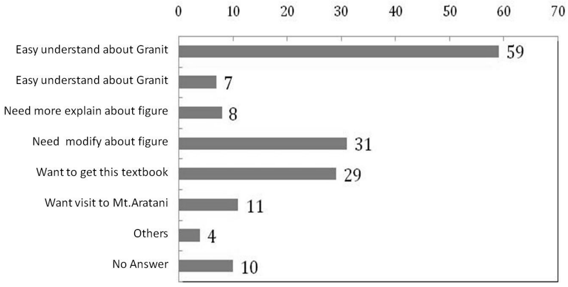
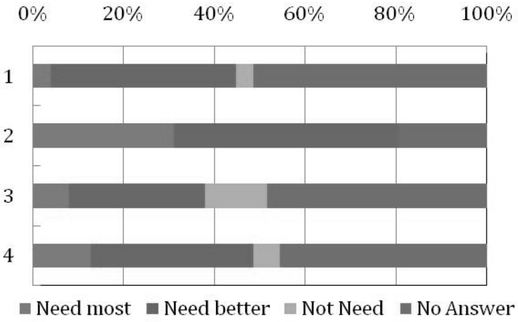


Fig. 7 Opinion of textbook



1: Many writing type
2: Use some numerical formula type
3: Use many picture and figure type
4: Use detail simulation type

Fig. 8 Request for textbook

5. Proposal of Disaster Education at local community

As the result of this action research, the author proposed flow of disaster education for local community.

1. Local government and local people have to grasp the local issue, local disaster characteristic and local activity. Local means is like elementary school area.

2. Local government and local people have to divide those issues to government, local and personal.

3. Local disaster education's target is mulch stakeholder (local people, local disaster organization, NPO/NGO, local government and university etc). Disaster education's contents caver disaster mechanism, countermeasure, role of preparedness and understanding about risk information etc.

4. Important things is local disaster education include some local event. Continue is important and multi stakeholder.

Disaster education has to make a balance of "grown local leader" and "understanding risk information". Target of "grown local leader" is local leader and person having interest about disaster prevention and mitigation. Those education's contents is support to grown decision thinking at emergency situation. Target of "understanding risk information" is person who stays in the home for a long time and person who care handicap people. As the result of questionnaire, best target person is male of 50-70 years old and female of 30-60 years old.

6. Conclusions

Divers flow disaster happen the meeting point soil sediment area and human society. Many hard type countermeasures were made by government. But, sediment disaster's activity is different each valley. Resident's people have to prepare by themselves. Disaster education is important process to understand some risk information and support early evacuation. For good disaster education, we have to make some easy understand tool and local reader who understand disaster.

Acknowledgments

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Kenzou Fujiwara, 2000, Analysis of sediment disaster at Hiroshima city on June 1999, Hiroshima University of economics, Vol.22, No.4, 3-37.

Intelligence Explanation System on Landslide Dissemination: A Case Study in Malaysia

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Abstract. The objective of this paper is to study how the Intelligence Explanation System can provide better understanding about the mechanism of landslide. Landslide has caused serious casualties of life, injuries and great economics loss due to the low awareness of the landslide hazard in Malaysia. At the present time, the landslide information could be obtained easily from the Internet and book resources. However they are not so interactive and lack the information of landslide hazard sites and landslide management particularly in the tropical rainfall countries, for example Malaysia. With our Intelligence Explanation System and the utilization of IT technology, knowledge on how and why landslide occurs could be easily disseminated to public to reduce the unnecessary human casualties. In addition to the predefined dictionary database, explanation will also be provided from the searches among the websites through the Internet to obtain a more comprehensive explanation.

Keywords. Landslide, landslide dissemination, explanation system

1. Introduction

Malaysia is an equatorial country, abundant with sunshine and rainfall. Rainfall intensity is one of the main factors in triggering landslide. The following are major cases of landslides in Malaysia:

- Highland Tower Luxury Condominium (11 Dec 1993, Taman Hillview, Ulu Klang, Selangor) killed 49 lives.
- Pos Dipang Landslide (29 Aug 1996, Perkampungan Orang Asli, Kampar, Perak) killed 44 lives, damaged 30 houses.
- Ribut Greh(26 Dec 1996, Keningau Sabah) killed 230 lives, damaged 4925 houses.
- Landslide in Kampung Pasir, Ulu Klang, Selangor (31 May 2006, Kampung Pasir, Ulu Klang) killed 4 lives.

As we know that landslides caused many injuries, deaths and economic loss, increasing the public awareness on landslide issues is very important. Here, we propose the Intelligence Explanation System (IES) to present and disseminate landslide knowledge and information in a smarter, more resourceful and effective way.

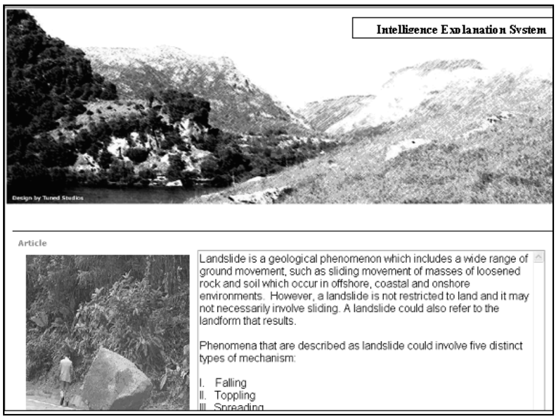
Interactive materials such as landslides animations are added in order to attract the readers' interest and also providing better understanding on landslide. Daily news on landslide issues from newspaper website is collected and presented, in IES, in easy readable way. So readers can easily trace back the history of landslide in this world.

A simple public awareness survey on landslide knowledge has been conducted to collect the statistic of public understanding on this natural phenomenon and to evaluate the effectiveness of the IES on landslide dissemination.

2. IES on landslide dissemination

Landslide, one of the natural hazards, has noticeably increased in its number of occurrence and caused some serious civilians and economic casualties. In most cases, the damages inflicted could be mitigated if proper measurements are taken. In this case, the IES provides better understanding on the mechanism of landslide as well as the preventive measurements on landslide.

The IES has two main modules, namely explanation module and content setting module. Fig. 1 is the main interface design of IES for Internet user.



Landslide is a geological phenomenon which includes a wide range of ground movement, such as sliding movement of masses of loosened rock and soil which occur in offshore, coastal and onshore environments. However, a landslide is not restricted to land and it may not necessarily involve sliding. A landslide could also refer to the landform that results.

Phenomena that are described as landslide could involve five distinct types of mechanism:

I. Falling
II. Toppling
III. Spreading

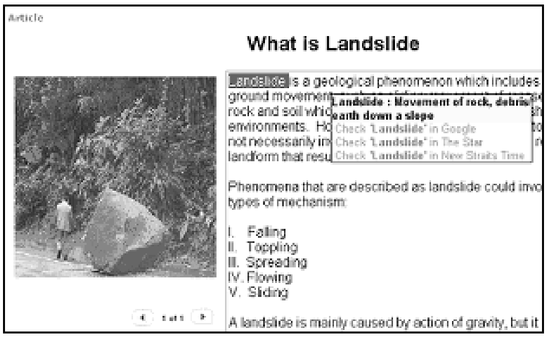
Fig.1 IES main interface design. Referenced Tuned Studios Sound Vision Design.

2.1 Explanation module

The function of Explanation Module is to provide landslide explanation to readers. Menu "Explanation" will be shown when user highlights and right clicks on the word.

In Fig. 2, the system shows explanation/definition of the indicated term. Reader can obtain further explanation on the indicated term from Menu "Explanation". In addition, the system also provides searching function where a user could be conveniently linked to the searching result by one click. A photo box in Fig. 2 displays a series of pictures corresponding to the article.

Fig. 3 is an example of Menu "Explanation", its functions are providing predefined explanation and checking definition from search engine and newspapers website. Likewise, Fig. 4 shows available landslide-related articles in Menu "Article". Item "News" from Menu "Article" serves to disseminate the landslide-related news. System will automatically run a daily collection for the related information on the online newspaper sources. Any landslide web pages and URL related to the title will then be saved. Under item "News", reader will request to select a date to order the system to display the indicated date's news.



What is Landslide

Landslide is a geological phenomenon which includes
ground movemen
rock and soil whic
environments. Ho
not necessarily in
landform that resu

Landslide : Movement of rock, debris earth down a slope
Check 'Landslide' in Google
Check 'Landslide' in The Star
Check 'Landslide' in New Straits Time

Phenomena that are described as landslide could invo
types of mechanism:

I. Falling
II. Toppling
III. Spreading
IV. Flowing
V. Sliding

A landslide is mainly caused by action of gravity, but it

Fig.2 With the IES, landslide knowledge can be disseminated in smarter way.

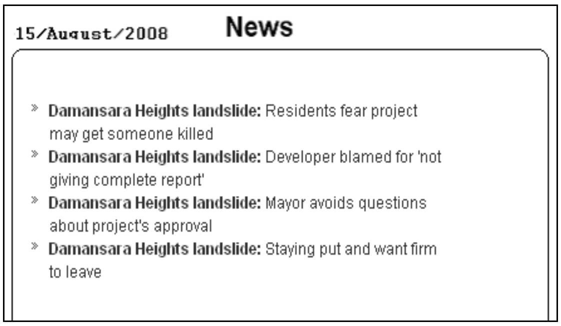
Fig.3: Example of Menu "Explanation".

Fig.4 Example of landslide related titles.

The dissemination of landslide news will help to instill awareness among public. Fig. 5 is an example of news collection dated on 15th August 2008. Reader can be linked to the related article by a simple click.

Nowadays, much landslide information and knowledge can be easily obtained from Internet, but all the landslide-related knowledge and news are presented separately. Landslide related news are only available from newspaper, while landslide knowledge are disseminated through academic website. Thus we propose to present all the related news, information and knowledge in a single web site. This will help to convenient reader to become more focus on the landslide title.

In addition, IES also focuses on information improvement. Surveys had been done on some landslide websites and found that those available landslide web sites are only providing details about the mechanism of landslide. They lack details in providing landslide hazard sites especially tropical rainforest country like Malaysia. In the IES we have also included a map of Malaysia landslide hazard sites and the locations of potential landslides.



15/August/2008 News

- **Damansara Heights landslide:** Residents fear project may get someone killed
- **Damansara Heights landslide:** Developer blamed for 'not giving complete report'
- **Damansara Heights landslide:** Mayor avoids questions about project's approval
- **Damansara Heights landslide:** Staying put and want firm to leave

Fig.5 Example of collection news taken from newspaper "New Straits Time" on 15th August 2008.

The content of IES will focus on how the landslide knowledge can be easily accessed by the public so that the public can make the necessary preparation in case landslide should occur. Fig. 6 is an example of landslide video. With the landslide animation, readers can understand better the mechanism of landslide.

Fig.6 Landslide video.

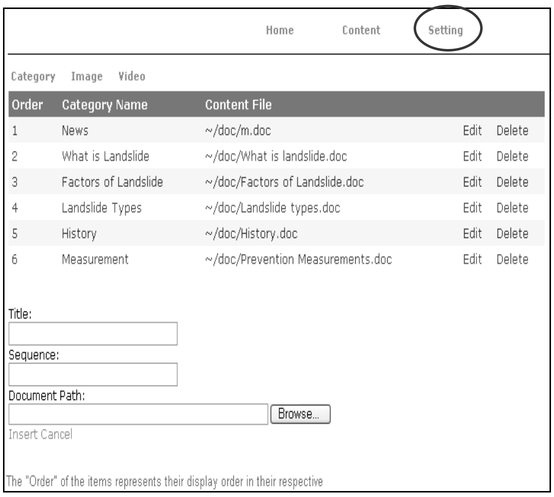
2.2 Setting module

By using Setting Module, system admin can upload landslide-related articles, images and videos. The contents of IES focused on the types and mechanisms of landslide, warning signs of landslide, preventive measurements of landslide and landslide hazard site. By providing such information, public will be more alert of the steps to protect themselves from landslide when landslide occurs, or even better, to avoid landslide by staying out of the landslide-suspected area.

The "Setting" button from Fig. 7 is used to prepare IES's content and only the system admin is allowed to access it. "Category" button is used for processing articles. System admin can insert, update and delete articles. The "Image" button is used for processing images, which the "Video" button is for processing videos.

Multimedia files such as images and videos play significant roles to attract readers' interest and improve the articles to be readily understandable.

With the Setting Module, key word and its definition/explanation for the articles can be defined. Usually, readers will get confused easily when faced with those terms have multi-meaning. Therefore, providing explanation to the landslide article is essential to increase public awareness.



Order	Category Name	Content File		
1	News	~/doc/m.doc	Edit	Delete
2	What is Landslide	~/doc/What is landslide.doc	Edit	Delete
3	Factors of Landslide	~/doc/Factors of Landslide.doc	Edit	Delete
4	Landslide Types	~/doc/Landslide types.doc	Edit	Delete
5	History	~/doc/History.doc	Edit	Delete
6	Measurement	~/doc/Prevention Measurements.doc	Edit	Delete

The "Order" of the items represents their display order in their respective

Fig.7 Setting Module is created for system admin to upload, update or delete any articles, photos and videos. Thus, the content of IES will be highly dynamic and is always up to date.

Order	Image	Image Name		
1		Landslide	Edit	Delete

The "Order" of the items represents their display order in their respective pages. Any item with an order of 0 will not be displayed.

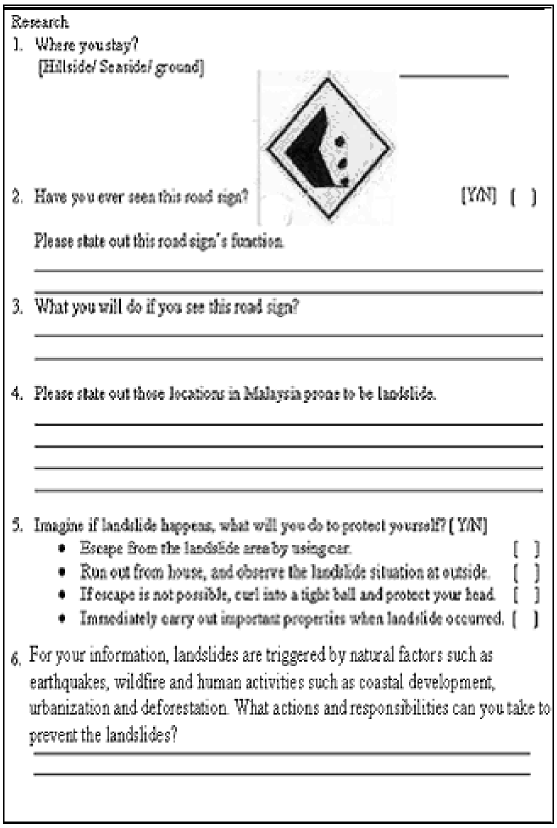
Fig.8 Example of image upload process.

3. Pilot survey of public awareness on landslide

3.1 Before visiting IES

Although the knowledge and information of landslides are readily available throughout all sorts of media (especially the web), the public awareness and understanding of the landslides are very weak. Landslides, unlike earthquakes, sometimes provide warning signs that, if heeded in time, can help saving such lives and properties. For this very reason, we have to disseminate the landslide knowledge to the public, encourage people to practice the safety plans to protect themselves and the others.

15 people from different part of the city have been selected to join the pilot study. Fig. 9 is the study questions used to collect information about understanding, and public awareness on landslide. Based on the study answers collected from the participants, we realized the information that is needed to disseminate to public.



Research

1. Where you stay?
[Hillside/ Seaside/ ground] ____________

2. Have you ever seen this road sign? [Y/N] [ ]
Please state out this road sign's function.
____
____

3. What you will do if you see this road sign?
____
____

4. Please state out those locations in Malaysia prone to be landslide.
____
____
____
____

5. Imagine if landslide happens, what will you do to protect yourself? [Y/N]
- Escape from the landslide area by using car. [ ]
- Run out from house, and observe the landslide situation at outside. [ ]
- If escape is not possible, curl into a tight ball and protect your head. [ ]
- Immediately carry out important properties when landslide occurred. [ ]

6. For your information, landslides are triggered by natural factors such as earthquakes, wildfire and human activities such as coastal development, urbanization and deforestation. What actions and responsibilities can you take to prevent the landslides?
____
____

Fig.9 Survey form.

Table 1 shows the summary of participants answer. Based on the survey, we can conclude that:

- Only 20% (3 of 15 participants) participants saw landslide road sign and understand its warning. Those staying near seaside and ground never saw it and don't understand the message of road sign.
- Landslide can happen anytime, anywhere, not only on highland and hilly city, but also on express highway. Road widening projects and building express highways are examples of human activities that may cause cut slope failure.
- Nowadays, the publics are too dependent on car; especially those participants that come from city.
- Most of the participants who stay at ground assume that observing landslide from outside of a shaking building is safe. The safest place should be on relatively flat-lying areas away from slopes and steep riverbanks.
- Curling your body into a tight ball and protecting your head is a correct way to be safe and protected, but all of the participants failed to do that.
- Almost 95% participants realized that life is more precious than properties.

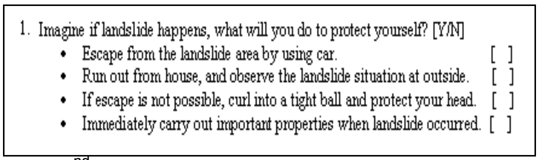
Table 1 Summary of participants' answers from the study form before using IES.

Question	Answer		
House location	Hillside = 5	Seaside=5	Flat ground=5
Road Sign	Yes=2 No=3	Yes=0 No=5	Yes=1 No=4
Landslide location	Cameron Highland, Balik Pulau, Penang Island (date 25/8/08, a small landslide case) Hilly city, Cave		
Escape from landslide area by using car	Yes=0 No=5	Yes=0 No=5	Yes=5 No=0
Observe landslide at outside	Yes=0 No=5	Yes=0 No=5	Yes=4 o=1
Curl into a tight ball	No=5	No=5	No=5
Carry properties	No=5	Yes=1 No=4	No=5
Landslide Prevention	1. Vegetation 2. Reduce usage of paper. 3. Don't stay around hillside. Discourage housing development around hillside. 4. Encourage involvement on activities related to deforestation.		

3.2 After accessing IES

A second survey form is being used to test on their understanding about landslide self rescue after viewing IES.

- Participants have provided 100% correct answer.



1. Imagine if landslide happens, what will you do to protect yourself? [Y/N]
    - Escape from the landslide area by using car. [ ]
    - Run out from house, and observe the landslide situation at outside. [ ]
    - If escape is not possible, curl into a tight ball and protect your head. [ ]
    - Immediately carry out important properties when landslide occurred. [ ]

Fig.9 2nd set landslide survey form.

4. Comparison between existed landslide web pages and IES

Three main advance functions/characters in IES are real time explanation, daily news collection and map of landslide hazard sites. Quick response explanation facility is very helpful to improve readers' comprehension and knowledgeable lecturer will define the explanation, but none of the existed landslide system is able to provide that function. To make the system more advanced, maybe the explanation can be presented in multilanguage form.

Daily news collection facility has integrated newspaper resources into IES. Thus readers can easily trace back landslide history by simply selecting a landslide date and the selected landslide history will be displayed. Almost every existing landslide web site is only able to display static content or may need system admin to manually update it, so it is very time consuming. The map of Malaysia landslide hazard site will be presented in the system but not on the existed landslide web sites.

5. Discussion

The landslide risk reduction projects -- landslide prediction and warning system in our country are still unable to accurately predict the occurrence of landslides, thus the public awareness of the landslides is vital in reducing the landslide hazards. Good landslide knowledge would certainly prevent the residents from becoming the next landslide victim.

As analysis to survey result has found that only 20% of the participants saw landslide road sign and understand its warning, it is essential to include more landslide road sign at hill side. Landslide can occur on any terrain when given the right conditions of soil, moisture, and the angle of slope, and not only on location where landslide had previously occurred.

In Malaysia, most of landslide cases took place at North-South express highway, especially near "Gua Tempurang" and "Bukit Lanjan" so we have to pay special attention when passing by these locations and try to avoid using the road if possible. Therefore we have provided a map of landslide hazard sites for public convenience. People should always access to intelligence explanation system to obtain the latest information about landslide cases.

The existing landslide web pages are more suitable for academic usage as it provides more knowledge on the mechanism of landslide, but has disregarded the public awareness on landslide. Some of the simple steps on how to escape if landslide occurs should be disseminated, for example observing landslide from outside of a building without escaping to safety ground is a very dangerous action and should be avoided. Public awareness on the seriousness of landslide hazard is still very poor. Thus intensive promotions to encourage people to visit IES are very important in order to decrease unnecessary casualties.

6. Conclusion

Generally, Malaysians have poor landslide-awareness. Thus, promoting landslide awareness program to prepare the public for any landslide event is essential in order to avoid casualties. Public awareness is more effective than landslide prevention on reducing casualties.

By having an intelligence and enhanced explanation system will help in public awareness on landslide.

Acknowledgements

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Tuned Studios, Sound. Vision. Design. http://www.tunedstudios.com/comments/template/0/9/

Quantitative Landslide Risk Assessment at the River Basin Scale

Veronica Tofani, Nicola Casagli, Filippo Catani (University of Florence, Italy)

Abtsract. Landslides and mass movements in general are very common in Italy, especially along the main mountain chains such as the Alps and the Apennines. The study area is no exception to this rule, as it is strongly subjected to mass movements.

The study area is the Arno river basin, which is located in northern Apennines, Italy, and has an extension of 9116 km^2. A new landslide inventory of the whole area was carried out using conventional (aerial-photo interpretation and field surveys) and non-conventional methods such as remote sensing techniques including DInSAR and PS-InSAR, (Farina et al. 2006). The great majority of the mapped mass movements are rotational slides (75%), solifluctions and other shallow slow movements (17%) and flows (5%), while rapid flows and falls seem less frequent everywhere within the basin.

This research is aimed at assessing landslide hazard and risk at basin scale. The final goal is to create a dynamic tool, managed in a GIS environment, useful for landslide risk pre-disaster planning and management.

The assessment of landslide hazard in terms of probability of occurrence in a given time, based for mapped landslides on direct and indirect observations of the state of activity and recurrence time, has been extended to landslide-free areas through the application of statistical methods implemented in an artificial neural network (ANN). On the basis of the more common landslides in the Arno river basin and the results of the univariate statistical analysis five preparatory factors were selected: slope angle, lithology, profile curvature, land cover and upslope contributing area.

The definition of position, typology and characteristics of the elements at risk has been carried out with two different methodologies: i) buildings and infrastructures were directly extracted from digital terrain cartography at the 1:10,000 scale, whilst ii) non-urban land use was identified and mapped based on an updated and improved CORINE land cover map at the 1:50,000 scale.

The definition of the exposure for each type of element at risk was based on their presumed asset and income values. Landslide vulnerability, defined as the degree of lost of elements at risk due to a landslide of a settled intensity, usually expressed as a value ranging from 0 to 1, was estimated on the basis of the typology and economic and social relevance of the elements at risk. Landslide intensity, usually defined as proportional to kinetic energy, was obtained considering landslide typology as a proxy for expected velocity.

The landslide risk was assessed both in a qualitative and quantitative way. In the former case contingency matrices were used to intersect hazard classes with vulnerability and exposure classes, while in the second case quantitative assessment of risk was carried out through the application of the risk equation, therefore applying the product of the numerical values of hazard, vulnerability and exposure (Cruden and Fell 1997).

Keywords. hazard analysis, risk analysis, Arno river basin, Artificial Neural Networks

1. Study area and landslide inventory map

The study area is strongly subjected to mass movements that have accumulated a large number of recorded cases (more than 27,500) and a huge total damage, both in properties and life losses.

The Arno River basin extends for about 9100 km^2 across the Northern Apennine chain in Central Italy.

This orogen is a complex thrust-belt system made up by the juxtaposition of several tectonic units, built up during the Tertiary under a compressive regime that was followed by extensional tectonics from the Upper Tortonian (Catani et al. 2005).

The extensional phase produced a sequence of horst-graben structures with a NW-SE alignment which have been filled with marine (to the West) and fluvio-lacustrine (to the East) sediments (Martini and Vai 2001) set down from Upper Tortonian to Quaternary.

From a geomorphological point of view the Arno river basin is mainly hilly, with four chains: Monti Pisani-Montagnola Senese, Monte Albano-Chianti, Calvana-Monte Morello and Pratomagno, Monte Falterona-Mandrioli-Alpe di Catenaia, which are mainly made of flysch rocks. Cohesive and granular fluvio-lacustrine sediments outcrop in the plains.

The area is characterized by a temperate climate with a dry summer. The general annual rainfall pattern is characterised by a summer minimum in July, and two maxima, one in November and the other at the end of the winter. Mean values of yearly rainfall vary in relation to relief and location, ranging from 800 mm on the Chiana valley to about 1800 mm on the Apenninic ridges.

It is widely known and agreed that slides affecting the Arno River basin and generally the Northern Apennines mainly move by reactivation of dormant slides, which were probably initiated during the early phases of the Holocene as a consequence of ice retreat at the end of the last glaciation (Bertolini et al. 2001).

The landslide inventory of the Arno river basin, carried out between 2003 and 2005, counts more than 27,500 events. The inventory has been organized following the approach proposed by Soeters and van Westen (1996) which consists in i) Acquisition of literature and ancillary data such as existent inventories, ii) mapping from aerial photographs at 1:13,000 and 1:33,000 scale (years from 1993 to 2000), iii) field survey and validation, which represented a key source especially for assessment of state of activity and validation of hazard. The inventory was then updated with the Persistent Scatterers technique which allowed to redefine the state of activity and the perimeter of the former landslides, and detect new movements (Farina et al. 2006).

For each landslide, information regarding the typology, state of activity, perimeter and area has been recorded. Detachment and deposition zones were mapped together.

Statistics on landslide types show that the most represented surface processes are slides (74.8%) and solifluctions (17.4%), followed by shallow landslides (6,6%) and flows (4.5%). Regarding the state of activity 60% of the phenomena are in a dormant state, 38% in an active state and just 2% are in inactive, stabilized state (Fig. 1). The single landslide surface area ranges from 100 m^2 to 5 10^6 m^2.

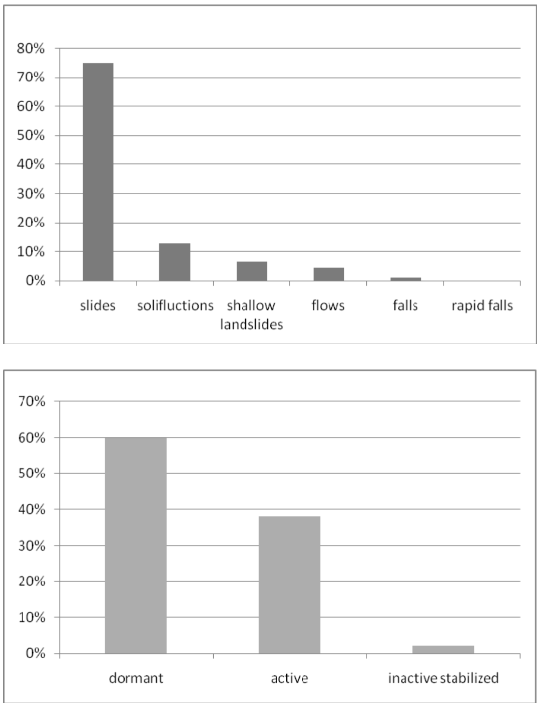

Fig. 1 Typology and state of activity of landslides mapped in the Arno river basin.

2. Hazard analysis

The method adopted for the susceptibility analysis in the study area has been the setting up of suitable statistical estimators defined with the help of a set of artificial neural networks (ANN). Neural networks were chosen because they require loose hypotheses on the variable distribution and allow for the use of mixed-type parameters (e.g. categorical and cardinal units) (Ermini et al. 2005; Gomez and Kavzoglu 2005). The computation was carried out through a discrete pixel basis analysis followed by the definition of unique condition units (Bonham-Carter 1994; Chung et al. 1995) for the application of statistical analysis within a GIS environment.

On the basis of the most common landslides in the Arno river basin and the results of the univariate statistical analysis five preparatory factors were selected: slope angle, lithology, profile curvature, land cover and upslope contributing area. All the morphometrical parameters have been derived from a DTM of the Arno basin, produced by the cartographic service of the Tuscany Region Administration and released in 2002, with a resolution of 10 m × 10 m.

Temporal prediction was obtained through the combination of the model results with the information regarding the state of activity for the mapped landslides.

The state of activity has been used to assign average recurrence intervals to the susceptibility classes and to active landslides. In such a way, five classes of recurrence time were selected and associated to five classes of temporal hazard (10,000 years for H0; 1000 years for H1; 100 years for H2; 10 years for H3 and 1 year for H4), the latter directly assigned only to active mapped mass movements (Catani et al. 2005). Recurrence time was then translated into probability by the computation of the absolute hazard H(N) in a given time span N using the binomial distribution so that $H(N) = 1 - (1 - 1/T)N$ (see e.g. Canuti and Casagli 1996). Computations were carried out for N=2, 5, 10, 20 and 30 years, respectively. Absolute hazard is thus characterized by five classes (from H0 to H4) with probabilities ranging from 0 (class H0) to 1 (class H4) for each time span.

3. Risk analysis

Risk was computed on the basis of the combination of hazard, vulnerability and exposure as suggested by Varnes and IAEG (1984):

$$R = H\ V\ E$$

Where R is risk, H is hazard, V is vulnerability and E is exposure.

Vulnerability is a function of intensity, which can be defined as a measure of the severity of the phenomenon in terms of potential destructive power. Intensity is essentially considered as depending upon kinetic energy, hence, mass and velocity (Hungr 1995).

In the case of the Arno River basin the definition of intensity and run-out is influenced by the fact that mass movements are deep-seated reactivated slides sometimes evolving into flows. Restricting the analysis to this type of movement introduces a notable simplification, since a limited range of velocities can be adopted for the intensity computation and the expected mobilized volume can be reasonably deemed as equal to the present estimated landslide volume (Catani et al. 2005; DRM 1990; Cruden and Varnes 1996). Two main cases were thus considered: deep-seated rotational slides and shallow flows or planar slides with virtually constant depth. In the latter case, intensity as a function of volume was set proportional to the area of the mapped phenomenon. In the former case, a geometric model was used to compute the volumes. The volumes range from 10^2 m^3 to 10^8 m^3. Four classes of intensity have been defined on the basis of the statistical distribution and literature values (Fell 1994).

The vulnerability is usually considered as a function of a given intensity and it is defined as the expected degree of loss for an element at risk as a consequence of a certain event (Varnes and IAEG 1984; Fell 1994). The vulnerability value ranges generally between 0 (no damage) to 1 (complete destruction). Exposure, defined as the number of lives or the value of properties exposed at risk, is often strictly connected to vulnerability in its practical assessment (Schuster and Fleming 1986; Turner and Schuster 1996).

The assessment of vulnerability and exposure is based on the selection of the relevant information present in digital topographic maps at the scale of 1:10,000 as well as in the updated land cover map at the 1:50,000 scale. For every single object a value of vulnerability and exposure has been given on the basis of typology and main utilization. Vulnerability values are given in percentage of loss for each different class of intensity and for each type of element at risk, while exposure has been given in euro/m^2 and estimated on the basis of the presumed asset and income values.

The landslide risk was assessed both in a qualitative and quantitative way. In the former case contingency matrices were used to intersect hazard classes with vulnerability and exposure classes, thereby classifying the territory of the Arno river basin in five classes of landslide risk (R0, R1, R2, R3, R4).

The quantitative assessment of risk was carried out through the application of the risk equation, therefore applying the product of the numerical values of hazard, vulnerability and exposure (Cruden and Fell 1997). The procedure lead to the definition of risk values expressed as economic losses for each terrain units and for different periods of time in the future (2, 5, 10, 20 and 30 years) (Fig. 2).

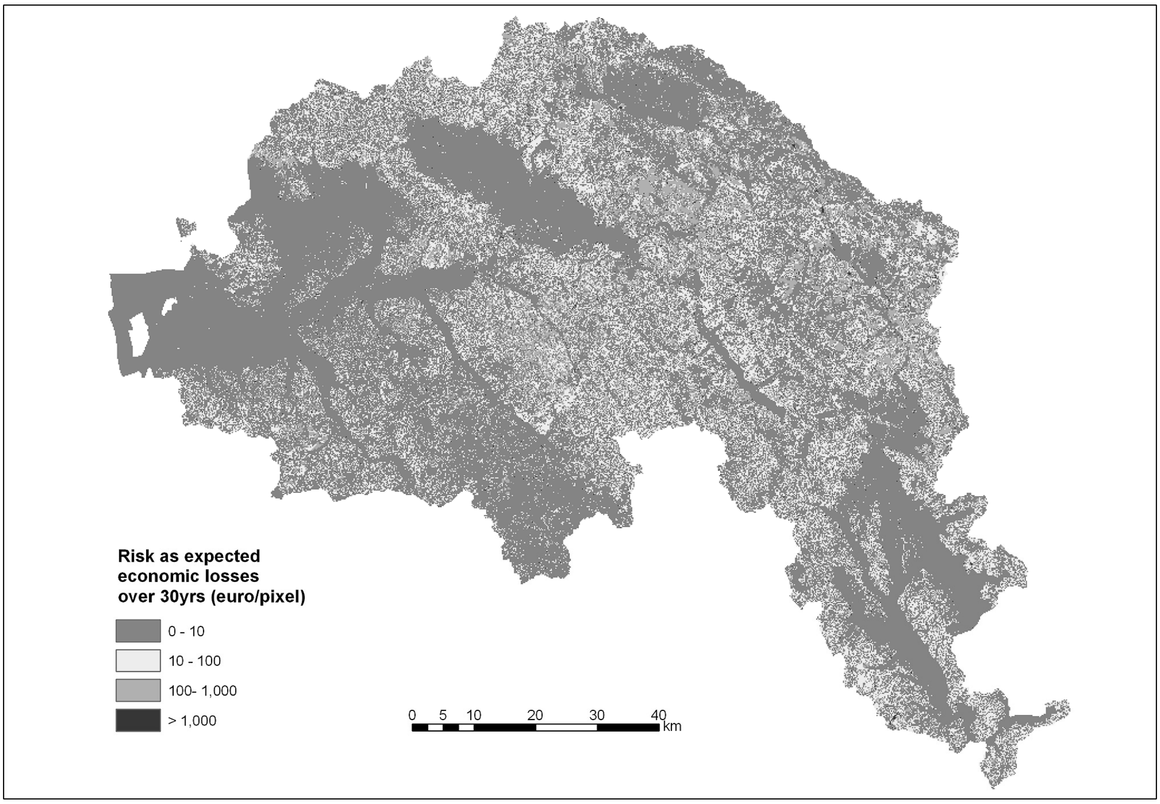

Fig. 2 Landslide risk map of the Arno river basin over a period of 30 years. The risk is expressed as economic losses due to landslides for each terrain unit (from Catani et al. 2005)

4. Results and conclusions

In this research an analysis of landslide risk at the basin scale has been carried out. The study area is the Arno river basin, located in the northern Apennines.

For the landslide susceptibility assessment a statistical approach, through the implementation of artificial neural networks, has been used. The Arno river basin has been classified in four classes of susceptibility: S0, S1, S2 and S3. The results show that the 41.6 % of the territory is in the lower class of susceptibility S0, 25.5% in S1, 20.3% in S2 and 12.6% in S3.

Model validation, carried out comparing susceptibility statistics with mapped landslides, confirms that prediction results are very good, with an average percentage of correctly recognized mass movements of about 90%. The analysis also revealed the existence of a large number of unmapped mass movements, thus contributing to the completeness of the final inventory.

The qualitative landslide risk assessment carried out by means of contingency matrices allowed to classify the whole territory of the basin into five classes of risk. The results show that just 0.1% (about 9.17 km^2) of the territory is classified in higher class of risk (R4). The most risky areas are located in the SE portion of the basin, where particular geological conditions cause many landslides and pose high risk to buildings and infrastructures.

The quantitative risk has been computed through the direct application of the risk equation, therefore applying the product of the numerical values of hazard, vulnerability and exposure (Cruden and Fell 1997). The procedure lead to the definition of risk values expressed as economic losses for each terrain unit and for different periods of time in the future (2, 5, 10, 20 and 30 years). It is worth noting that these figures represent the cost of direct and indirect damages due to landslides in absence of mitigation measures (Table 1).

In the next five years, around 2.5 billion of euros should be expected as economic losses due to landslides. This value agrees with the data regarding the costs for landslide mitigation measures spent in the Arno river basin in the last five years.

Table 1 Risk values computed as expected economic losses cumulated for five time intervals

Cumulated time (years)	Expected economic losses (euro)
2	€ 1,497,099,000
5	€ 2,498,767,000
10	€ 3,662,134,000
20	€ 4,930,778,000
30	€ 5,586,896,000

Acknowledgments
The work was carried out by the Department of Earth Sciences of the University of Firenze and the Basin Authority of the Arno River in the framework of a co-operative project for the landslide risk mapping of the Arno river basin. G. Menduni e M. Brugioni are acknowledged for their support during the project.

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Instability Conditions of the Landslides Triggered by the 2006 Rainfall Event in Ischia Island, Italy

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Abstract. Ischia is an active volcanic island located in the Tyrrhenian Sea, approximately 30 km WSW from the city of Naples in Southern Italy. On 29-30 April 2006 Ischia was hit by an intense rainfall which triggering in the Mt. Vezzi area, in the SE portion of the island, four soil slips-debris flows. The flows caused the deaths of 4 people, forced the evacuation of another 250 inhabitants and destroyed several buildings.

The debris flows initiated as soil slips at the soil – fallout interface, in hollows with slope gradients ranging between 35° - 40°, and quickly transformed into flows that reached the floodplain at the base of the hill, finally coming to a stop in a low gradient road.

A geotechnical characterization of the site was carried out by means of laboratory test (grain size analysis, measurement of Atterberg limits, phase relationship analysis and ring shear box) and in-situ tests (Borehole Shear Test, Constant Head Permeameter and tensiometers).

In order to identify the triggering conditions of the landslides Seepage-Stability analysis and Ring Shear Test were carried out. The ring shear test is an instrumentation developed within DPRI (Disaster Prevention Research Institute) of Kyoto University with the aim of simulating the process of failure in a sample soil.

Keywords. Ischia island, modeling, ring-shear test, triggering conditions

1. Study area and landslide description

Ischia island is located in the northwestern corner of the Gulf of Naples and represents the emerged top of a large volcanic complex, the Phlegran Volcanic District. The island has an extent of about 42 km^2 and from a morphological point of view is dominated by Mt. Epomeo (786 m a.s.l.) located in its central part. Ischia is composed of volcanic rocks, landslide deposits and subordinate terrigeneous sediments, reflecting a complex history of alternating constructive and destructive phases due to the interplay among tectonism, volcanism, volcano-tectonism, erosion and sedimentation (Vezzoli, 1998; Orsi et al., 1991, 2003; De Vita et al., 2006). Volcanism began prior to 150 ka B.C. and continued, with centuries to millennia of quiescence, until the last eruption occurred in 1302 A.D. The record of past slope instabilities highlights that, although the oldest landslides have been associated with volcanic eruptions, the ones that occurred in recent times are related to seismic activity and exceptionally heavy rains (De Vita et al., 2006).

On 30 April 2006, following several hours of rainfall, four small soil slips-debris flows were triggered on the slopes of Mt. Vezzi (ca. 400 m a.s.l.), in the SE portion of the island. The flows caused the deaths of 4 people, forced the evacuation of another 250 inhabitants and destroyed several buildings.

Mt. Vezzi is characterized by volcanic deposits younger than 10 ka; a typical schematic stratigraphy of the upper section of the slopes where the landslides initiated comprises a layer of colluvial soil of 1-1.5 m overlying the pyroclastic rocks.

The landslides occurred in the highest portion of Mt. Vezzi area, at elevations ranging from 310 to 350 m a.s.l and stopped at approximately 80 m, corresponding to a travel angle of 20°-24°. Slope gradients in triggering area are around 35° and the landslides involve the colluvial soil overlying the pyroclastic rock. The volumes of the single events ranged from 2000-5000 m^3.

The landslides triggered as soil slips evolved afterwards into debris flows. Following the Cruden and Varnes (1996) nomenclature, all the phenomena can classified as complex, extremely rapid, very wet, slide-debris-flow. Following the Hungr et al. (2001) classification, landslides (1, 2, 3a) can be classified as debris avalanches whilst the landslide 3b, which is almost totally channelized, can be classified as debris flow (Figure 1).

2. Geotechnical characterization

Two field campaigns carried out immediately following the events were focused on collecting geotechnical data in the source area (angle of internal friction, unit weight, water content, grain size, etc.). Laboratory tests as grain size analysis, measurement of Atterberg limits, phase relationship analysis were carried out on the soil sampled in proximity of the exposed slip surface of the landslides. The samples are mainly sandy soils and classify following the USCS Unified Soil Classification System (Wagner, 1957) classification as SM and SC.

Material shear strength was determined both in the laboratory on reconstituted samples and in-situ by means of Borehole Shear Tests (BST) coupled with a tensiometer for the measurement of matric suction. Soil strength was assessed both in partially and totally saturated conditions. The friction angles of the samples range between 37° and 40°.

Soil hydraulic conductivity was quantified by means of in-situ constant head permeameter tests. These highlighted a marked contrast in permeability between the soil and the underlying pumice layer. Saturated hydraulic conductivity values ranged from 1.2 x 10-5 m/s in the former to 6.2 x 10-8 m/s in the latter.

3. Analysis of the landslide triggering mechanism

Soil slip triggering conditions were analyzed on the basis of precipitation data related to the 24 hour period prior to the event using two different approaches: a coupled seepage-stability analysis and a geotechnical modeling by means of the ring shear apparatus DPRI-No.7.

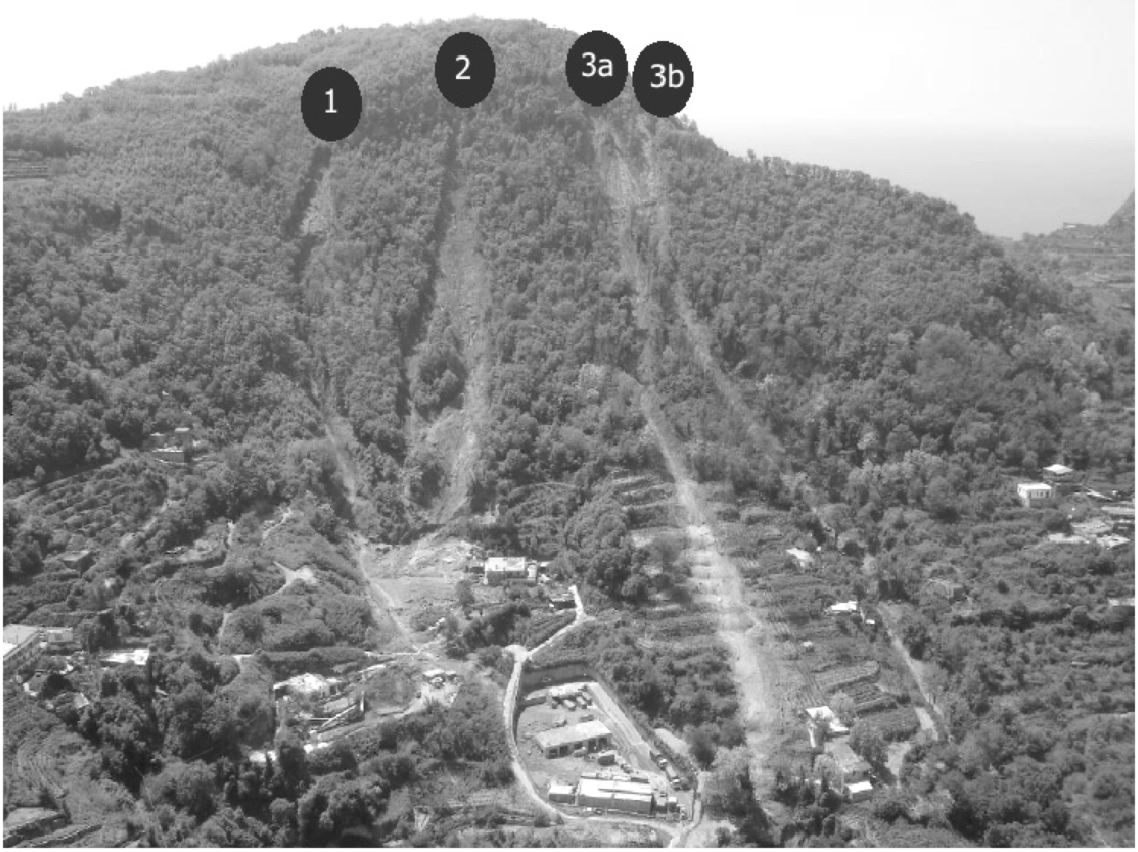

Figure 1: Picture of landslides that occurred in Mt. Vezzi area on 30 April 2006.

The former approach consists in the modeling of changes in positive and negative pore pressures during the event by a finite element analysis in transient conditions, using the software SEEP/W (Geo-Slope Int.). The code utilized within this software is based upon the equations of motion and mass conservation. Both saturated and unsaturated flows are simulated using a modified version of Darcy's law. For unsaturated conditions, the hydraulic conductivity function (k-curve) is described by the relationship between water content and pore water pressure (Brooks and Corey 1964; Fredlund and Rahardjo 1993). The mass conservation equation governs the model, which has been extended to incorporate unsaturated conditions (Richards 1931; Fredlund and Rahardjo 1993)

Positive and negative pore pressure distributions obtained from the seepage analysis were used as input data for the stability analysis. This was performed with SLOPE/W, applying the limit equilibrium method (Morgenstern-Price) for each of the time steps used in the seepage analysis. The Mohr-Coulomb criterion in terms of effective stress was used in the case of positive pore pressures, while the Fredlund et al. (1978) criterion was applied in the case of negative pore pressures.

The results show that the distribution of pore pressure conditions are largely influenced by the high permeability contrast between the soil pyroclastic cover and the underlying pumice layer, by the soil type and by the limited thickness of the cover.

As seen in Figure 2 the Factor of Safety goes below 1 around 5:30am of 30 April 2006. This means that the instability condition are reached 10 hours after the beginning of the rainfall event with a value of pore water pressure over the shear surface of about 7 kPa and a complete saturation of the soil layer. This result is in agreement with the real time failure as reported by witnesses of the event.

The ring shear apparatus DPRI-No.7 is a geotechnical instrumentation developed at the Disaster Prevention Research Institute at Kyoto University. The purpose of the DPRI ring-hear testing program is to design an apparatus that can quantitatively simulate the entire process of failure of a soil sample, from initial static or dynamic loading, through shear failure, pore-pressure changes and possible liquefaction, to large displacement steady-state shear movement (Sassa et al., 2004).

The shear apparatus has an inner diameter of 27 cm and an outer diameter of 35 cm, the maximum sample height is 11.5 cm. The apparatus has two kinds of shearing controlling modes: shear speed-controlled mode and shear stress-controlled mode. By means of a gap-controlling system with a precision of 0.001 mm, the shear box can be kept in fully undrained condition.

Seven tests have been conducted on Ischia samples: 5

stress-controlled tests at naturally drained conditions and 2 speed-controlled tests at undrained conditions. The test procedure is composed of five steps: sample setting, sample saturation, saturation checking, sample consolidation and sample shearing.

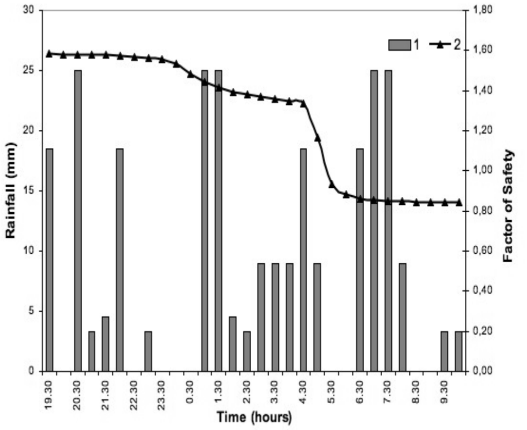

Figure 2: Variation of Factor of Safety, obtained with the SEEP/SLOPE modeling, during the rainfall event.

The normal stress and the shear stress are computed on the basis of the unit weight (γ) of material, the slope gradient and the thickness of the colluvial soils, considered as in average 1.5 m thick.

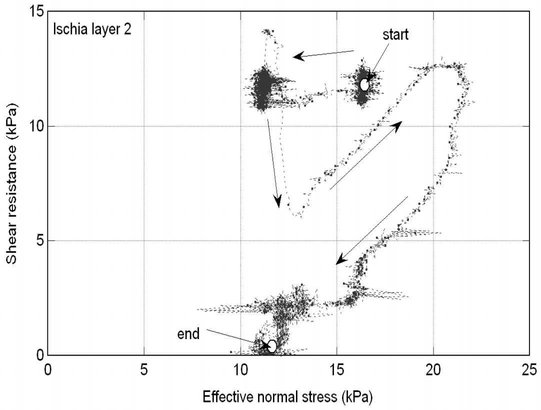

Figure 3: Results of the naturally drained ring-shear tests showing effective stress path (ESP).

After this fast drop the shear resistance increases and soon after again decreases following the failure line of the material until it reaches the value of zero. This process of dilatancy is probably due to the very low stress conditions used during the test which are around 21 kPa for normal stress and 15 kPa for shear stress. This is also confirmed by the tests performed by the tests performed for comparison on the underlying pumice layer. The test shows that an increase of the stress condition doesn't cause the process of dilatancy recorded during the test of colluvial soil.

In the stress-controlled test, carried out in naturally drained conditions, after the consolidation process is finished the shear stress has been applied until it reaches the field value. Afterward the back pressure is supplied in order to recreate the pore water pressure increase due to the rainfall event. During the test the shear displacement, shear resistance and pore water pressure were measured.

The results of the naturally drained test are reported in figures 3 and 4. Figure 3 represents the ESP (Effective stress path) while figure 4 represents the variation of the normal stress, the effective normal stress and the pore water pressure versus the displacement rate. The two figures show that there is a drop of shear resistance shortly after the increase of the pore water pressure. The value of pore pressure at the failure condition is around 6.5/7 kPa while the shear resistance is around 12 kPa. During the failure grain crashing occurred causing the liquifaction of the material.

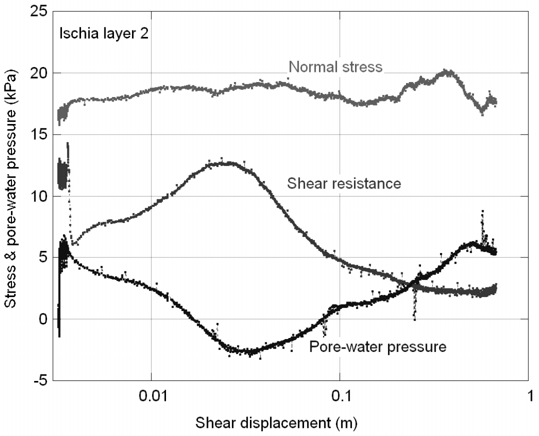

Figure 4: Results of the naturally drained ring-shear tests. Variations of the normal stress, shear resistance and pore-water pressure.

4. Conclusion

On 30 April 2006, following several hours of rainfall, four small soil slips-debris flows were triggered on the slopes of Mt. Vezzi (ca. 400 m a.s.l.), in the SE portion of the island. The debris flows initiated as soil slips at the soil – fallout interface, in hollows with slope gradients ranging between 35° - 40°, and quickly transformed into flows. The landslides initiated in colluvial soil with a thickness of an average 1.5 m.

Geotechnical characterization of the material was carried out by means of laboratory tests and in-situ tests. The results show that the material involved in the landslides is mainly sandy soil with friction angles ranging from 37° to 40° and high permeability (1,2 10^{-5} m/s).

The analysis of the triggering conditions was carried out by means of seepage-stability analysis and by means of the ring shear apparatus.

The results highlight that the distribution of pore pressure conditions are largely influenced by the high permeability contrast between the soil pyroclastic cover and the underlying pumice layer, by the soil type and by the limited thickness of the cover. In the modeling the instability condition are reached 10 hours after the beginning of the rainfall event with a value of pore water pressure along the shear surface of about 7 kPa. In the ring shear test the simulation of the triggering conditions on Ischia samples highlights that the drop of shear resistance occurs when the pore water pressure on the failure surface reaches a value of about, in good agreement with SEEP/SLOPE modeling.

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Remote Sensing Based Investigation of Landslides in Himalaya Mountains

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Abstract. Based on remote sensing and MAPGIS, the landslides developed in Himalaya mountains are investigated. The images of ETM, SPOT and ALOS are used to interpret landslides. The image parameters include area, slide orientation and slope angle with 3D visualization technology. The developed regulation and geological background of the landslides are comprehensively studied under the support of geology of disasters and GIS. The investigation indicates that there are 151 large scale_landslides in total and they are mainly developed in Langxian County, Longzi County, Cuomei County and Zhada County.

Statistics results indicate that the slope angle of the most of slides is in the range of 10-30°, and there is few slide occurred with slope over 40° or below 10°. Meanwhile, the landslides are mainly developed in seven types strata as lists below: (a) pseudo-consolidated variedness sandy gravel and clay stone with river and lake face of Zhada group of Tertiary system to Quaternary system (N_2-Q_{p1Z}), (b) gray silt sandy sericite slate interbedded gray thin layer metamorphic silt sandstone of Weimei formation of Jurassic system (J_{3w}), (c) gray to dark gray carbonaceous silt sandy calcareous shale interbedded with silt sandstone and limestone of Menkadun formation of Jurassic system ($J_{2\text{-}3m}$), (d) gray to dark gray limestone, sandy shale and sandstone of Nieniexiongla group of Jurassic system ($J_{1\text{-}2N}$), (e) dark gray, gray brown, gray green, purple red silt sandy sericite slate interbedded with gray thin layer metamorphic silt sandstone of Ridang formation of Jurassic system (J_{1r}); (f) variedness shale, slate, metamorphic sandstone, quartz sandstone of Xiukang group of Tertiary (T_{3x}), and (g) gneiss, schist, slate and phyllite of Precambrian.

The landslides occurred in strata of Zhada group, Xiukang group and Precambrian mainly show that the fore section of the landslides failure at first and then tow the behind, and the only part of the landslides occurred in the Jurassic system show that feature.

Keywords. Landslide, Remote sensing, GIS, Himalaya Mountain.

1. Geological setting

Investigation into landslides occurring in the Himalayas by remote sensing is one task of major investigation on land resources of "Investigation into great geological hazard in the Chinese Himalayas by remote sensing". Its overall target is to investigate great geological hazard by remote sensing, find out distribution of great geological hazards and hidden dangers, preliminarily discuss its stability and geologic environment, provide fundamentally geologic reference for Himalayas to reduce and prevent hazard, by use of satellite data.

Investigation work area of this project starts from Ali Area in the west to the large River Bend (Mt. Namjagbarwa) of Brahmaputra, to the Brahmaputra major fracture in the north, to the border between China and India, Nepal, Bhutan, Sikkim and some other countries in the south, and it is situated between 78° and 95°30′ East Longitude and between 26° and 33° North Latitude. It is 1700 km long from east to west, and 60-250 km wide from south to north.

Himalayas region is situated in the south of Qinghai-Tibet Plateau, also is national boundary between China and Nepal, India, Bhutan, Sikkim, and some other countries. It extends 2450 km from east to west, and not only has Everest titled "first peak of the world", but also has notable grand Brahmaputra canyon with great drop in topography, great change in climate, and frequently geological hazards. In particular, along with further exacerbation of ecological environment in recent years, increase of local precipitation, rise of air temperature, and melting of glacier, geological hazards in the Himalayas region, such as landslide, mudflow, dilapidation, burst of ice lakes, etc., occur more frequently.

2. Working content and method

Working content of this project is to use satellite data to interpret scope, scale and structural features of landslides in the investigation area, and integrate geology, theory of the catastrophology and geographical spatial information techniques to analyze influencing factors and inducing factors of landslides and appraise hidden dangers, etc.

First of all, use data and image of American landsat ATM to carry out general investigation on regional landslide hazard; then use high-resolution images of French satellite SPOT-5 (see Fig.1-a), Japanese ALOS (see Fig.1-b) satellite and ASTER satellite to carry out detailed interpretation on landslides and typical sites which potential danger, according to outcome of general investigation.

Interpretation of remote sensing is divided into somestages, i.e., (1) preliminary interpretation stage: comprehensively analyze the collected geological data and remote sensing images, comprehend tectonic framework, quaternary geology and formation lithology, give more emphasis on analyzing image characteristics of known geological hazards, and establish interpretation key of geological hazards in the work area; (2) particular interpretation stage: on the foundation of interpretation key of geological hazards established in the preliminary interpretation stage, interpret landslide body particularly; (3) field verification and synchronous interpretation stage: carry out field survey based on interpretation achievement, and carry out amendment and re-interpretation on landslide interpreting key; (4) reinterpret and check stage: after finishing field verification, amend the interpretation key overall, perfect interpretation results, interpret the amended achievement, and finish the investigation map of landslide hazard by remote sensing.

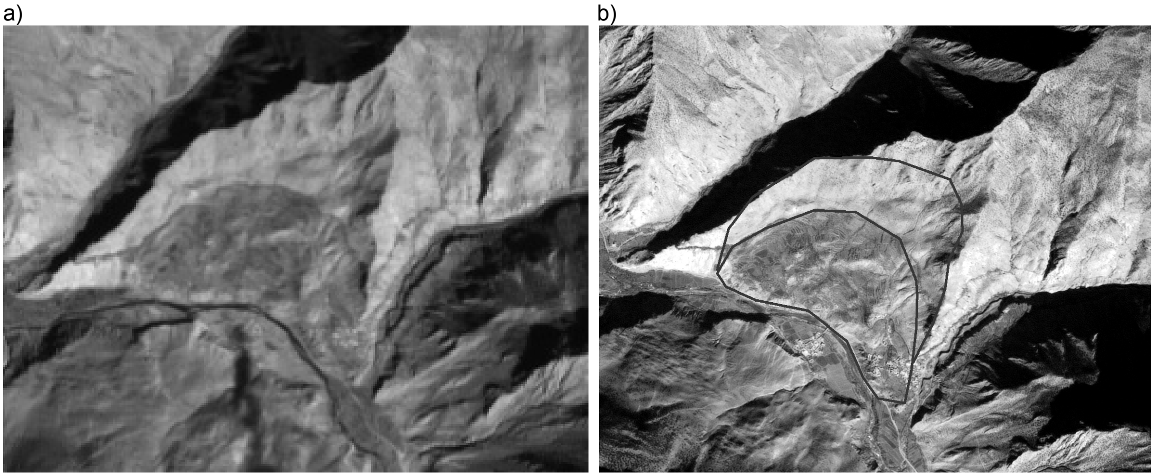

Fig. 1 The Saiji landslide case in Longzi County. a) Alos image; b) Spot-5 image.

Conclusions

Remote sensing investigation shows that there are 151 large-scale (more than) landslides in the Chinese Himalayas region, which are principally located in the Lang County, Longzi, Cuomei, Zhada and some other counties. There are 10 concentrated distribution areas in the Chinese Himalayas region: Lang Town, Laduo Village and Jindong Village of Lang County; Liemai Village and Jiayu Village of Longzi County; neighborhood of Douyu Village of Longzi County; Bubula Mountain of Motuo County; north shore of Xubuqu in Cuomei Town of Cuomei County; Naixi Village of Cuomei County; Cuomulong Mountain-Kala Village of Zongga Town of Jilong County; south margin of Zhada Basin of Zhada County.

Average slope of landslides varies from 8.4° to 48.6°, and slope of most landslides varies from 10° to 30°. There are 6 landslides with slope more than 40°, 21 landslides with slope 30° to 40°, 63 landslides with slope 20° to 30°, 54 landslides with slope 10° to 20°, and 6 landslides with slope 8.4° to 10°. It indicates by statistics that landslides with slope 10° to 30° occur most easily, landslides with slope more than 40° or less than 10° occur infrequently.

Landslides of Himalayas are principally distributed in the river and lake facies half-consolidated varicoloured sandy conglomerate and clay rock of Zhada Group (N_2-Q_{p1Z}), grey silty sericite slate bearing grey thinly laminated metamorphic siltstone in the Jurassic Weimei Formation (J_{3w}), grey to charcoal grey carbonaceous, silty and calcareous shale bearing siltstone and limestone in the Jurassic Menkadun Formation ($J_{2\text{-}3m}$), grey to charcoal grey limestone, sandy shale and sandstone in the Jurassic Nieniexiongla Group ($J_{1\text{-}2N}$), charcoal grey, taupe, celadon, amaranth silty sericite slate bearing grey thinly laminated metamorphic siltstone in the Jurassic Ridang Formation (J_{1r}), varicolored shale, slate, metamorphic sandstone and quartz sandstone in the Triassic Xiukang Group (T_{3x}), and gneiss, schist, slate and phyllite in the Precambrian.

Landslides in the Zhada Group, triassic Xiukang Group and Precambrian strata are pull-type landslides mostly, and their formation condition are principally controlled by regional geologic structure and intense cut of water system, where steep landform and highly fissured rock mass and loose sediments with thin surface layer are formed. Reasons inducing landslides have close relation with lateral erosion of bank slope by rivers.

Landslides in the Jurassic strata have characteristics of pull-type landslides and have characteristics of push-type landslides at the same time, and their formation condition are principally controlled by steep landform and stratigraphic structure with weak intercalation, and their inducing reasons have relation with groundwater and weak intercalation, or have relation with the erosive action of slope foot by rivers.

Landslide Disasters in Sabah, Malaysia: Issues and Challenges

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Abstract: Landslide hazards associated with steep slopes and heavy rain are quite common in Sabah. Seven significant landslides that involved loss of lives and properties occurred in Kundasang, Sandakan and Kota Kinabalu areas during the last 20 years. In Kundasang area, two people died, one reported missing and one seriously injured in a landslide in 1989. In Sandakan area, four people were killed and nine others injured when tons of earth partially buried a house in Batu Sapi in 1996. In a nearby area, 17 people died and two injured when four houses were buried under tons of rubbles during a pre-dawn landslide in 1999. In 2006, three people were buried alive and two injured when a landslide swept through several houses not far from the previous landslide sites. In 2007 one died and two injured when trees fell on them during a landslide. In Kota Kinabalu area, one person was killed when a road embankment failure buried three houses in June 2006. Not far from this site, a huge landslide destroyed 15 squatter houses in October 2006. At this same site, three people died due to an earlier landslide in 2001. The landslide disasters in Sabah were associated with unfavorable geological and geographical setting and unsustainable human activities. The lack of policy on development in landslide prone areas poses a major challenge to the State Government in addressing this problem.

Keywords: Case studies, capacity building, education, land use policy.

1. Introduction

Sabah, one of the eastern State of Malaysia on Borneo Island comprised largely of mountainous areas (46%). The Crocker Range, which is more than 40 km wide, having an average altitude of about 2000 m and stretching for about 200 km along the west coast of Sabah is the most prominent mountain belt (Fig. 1). Mt Kinabalu (4093m), the highest peak, rises from the Crocker Range. Heavy rain and steep slopes contribute to the widespread occurrence of landslides in Sabah. Most of these landslides however occur in remote areas away from major settlements. The construction of highways across the mountainous region, which involved cutting steep slopes have to a certain extent made the occurrence of landslides more frequent and visible. For the past 20 years several landslides of various dimensions have resulted in the temporary closure of these highways. The rapid development activities on hilly slopes within town areas have also contributed to the frequent occurrence of landslides. However most of these landslides are not fatal except for a few that occurred in areas around Kundasang, Sandakan and Kota Kinabalu. This paper provides some description of these landslides and highlights some of the issues and challenges in managing landslide risk in Sabah.

Figure 1. Location of Kundasang, Sandakan and Kota Kinabalu areas.

2. Kundasang Landslides

Kundasang area, located in the District of Ranau lies at the foot of Mt Kinabalu. The mountainous area located about 1200-1400 m is underlain mostly by a highly deformed argillaceous sedimentary unit, referred to as the Trusmadi Formation. These Paleogene argillaceous rock easily expands when wet and provide an ideal slip plane for landslides to occur. According to a recent finding by Ibrahim Komoo & Hood Salleh (2003), the whole Kundasang area is affected by several large active landslide complexes (Fig. 2). Movements within these landslide complexes have severely damaged houses, shop houses, school buildings and roads. Except for one incident in 1989, no reported deaths have been attributed to these landslides. Due to the severity of the landslide hazards the local authority has put on hold new development in Kundasang area, especially heavy structures.

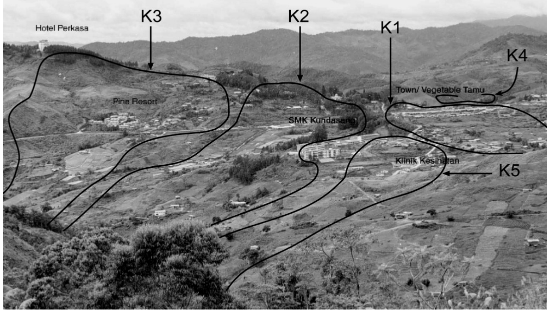

Figure 2. Approximate boundaries of Kundasang landslide complexes (K1, K2, K3 & K4).

On 25 February 1989, a torrent of mud, boulders and logs crashed down a steep ravine at Kundasang Lama Village during a heavy downpour at 3.15 pm killing a woman and a boy while another boy went missing. A man suffered a broken leg during the tragedy. The woman was killed when her house was crushed after being swept about 30 metres down steep terrains, while the boys and the man happened to be hunting for crabs at the stream near the woman's house. The landslide occurred on a steep slope about a hundred metres below the Perkasa Hotel. Despite the near vertical gradients in many of the slopes where the landslide occurred, the site have been nearly "shaved" of its trees and planted with vegetables (Kan Yaw Chong, 1989).

3. Sandakan Landslides

Sandakan area, although not located in a mountainous area is also prone to landslide occurrence. The area is underlain by a Miocene sedimentary unit comprising of thick sandstone and thick mudstone sequences, referred to as the Sandakan Formation. The Sandakan sedimentary rocks have been tilted gently towards the northwest and cut through by a series of NE-SW trending major normal faults, producing half-graben structures. Along these normal faults, steep to nearly vertical slopes (between 50-200 meters in height) have developed. Most of the recent disastrous landslides which claimed lives have occurred along these slopes.

On 6 January 1996 a hill slope which collapsed due to heavy rain partially buried a terrace house at Taman Po Hing housing estate, in Batu Sapi killing three people and injuring three others (Fig. 3). The tragedy occurred at 1.30 in the morning (Tam, 1996).

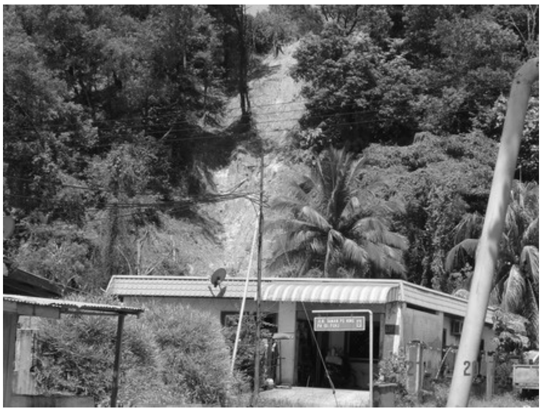

Figure 3. Landslide-prone area at Taman Po Hing housing estate.

On 2 February 1996 at 3.30 in the morning another landslide at Taman Nam Tung housing estate, near Sandakan town hit a double-storey house and killed a woman, while six others were injured.

On 7 February 1999, 17 lives were loss and two injured following a pre-dawn landslide which buried four squatter houses under tonnes of mud and debris in Gelam Village, near Sandakan town (Fig. 4). The village, which has about 20 houses, is sandwiched between two hills. Most of the 17 who perished are boys and girls and they were asleep when the landslide occurred. Nine days of continuous rain was the main cause of the landslide (Jaswinder Kaur, 1999).

Figure 4. Rescue team searching for those missing after the Gelam landslide (Jaswinder Kaur, 1999).

On 7 February 2006 a mother and her two daughters were killed in a landslide that swept through Sundang Village, along Batu Sapi Road. They were buried alive in the mud and debris that came down on almost 20 houses on a hillside around 8 pm. Continuous downpour for two days have been blamed for the tragedy (Julia Chan, 2006).

On 9 January 2007 a 13-year-old female student died while two of her friends were seriously injured when trees fell on them during a landslide. They were on their way to school (Ching Ming Secondary School) when the landslide occurred.

4. Kota Kinabalu Landslides

Kota Kinabalu area, located on the western foothills of the Crocker Range is characterized by linear belts of hills and valleys trending NE-SW. The hills ranges from 100-500 m; rising to over 700 m towards the east at the foot of the Crocker Range. The area is underlain by a Paleogene sedimentary rock unit called the Crocker Formation. This formation is tightly folded, intensely faulted and fractured. These rocks, once exposed to weathering are quite unstable. The widespread cutting of hill slopes for infrastructural development has contributed to the common occurrence of landslides in the Kota Kinabalu area.

On 27 June 2006, an eight-year-old child died crushed under wooden beams and rubble when her house in Bundu Village, Karambunai, collapsed after it was hit by a landslide about 11.15pm. The landslide was associated with a failed road embankment (Fig. 5).

About a Kilometer away from the previous site, on 12 October 2006 about 8.15 in the morning a landslide occurred in Lok Bunuk Village, Sepanggar, destroying 17 houses and a mosque (Fig. 6). The incident involved 96 residents of the area but there were no major injuries. The landslide at the settlement of about 70 houses occupied by 107 families was the second in five years. The first in 2001 claimed three lives.

Figure 5. Road embankment failure buried a house at Bundu Village.

Figure 6. Houses buried during the Lok Bunuk 2006 landslide.

5. Issues and Challenges

As pointed earlier the occurrence of landslides in Sabah, apart from the presence of unfavorable geological and geographical setting (e.g. weak rocks and heavy rainfall) is associated with unsustainable human activities (e.g. uncontrolled agriculture and construction). In Kundasang area, despite the known occurrence of major landslide complexes here, many of the steep slopes continue to be cleared of its vegetation for intensive planting of vegetables making the area more susceptible to slope failures. In Sandakan area, many houses continue to be constructed right under steep slopes disregarding the danger of impending landslide. Several squatter villages located right at the edge of foothills have not been moved and are waiting for another landslide disaster to happen. Similarly in Kota Kinabalu area, houses built on hill slopes are a common sight. Squatter houses are also occupying landslide-prone areas, even on old landslide site.

Based on these observations it appears that the general awareness of the public on landslide hazards is still low, especially among squatters. The Gelam landslide disaster in Sandakan area could have been avoided if the squatters had complied with the local authority's directive to vacate the area several years before the incident. Similarly, the Lok Bunuk landslide disaster in Kota Kinabalu would not have happened if the squatters stayed away from the old landslide site. The local authorities also appear to lack the necessary tools and capacity to manage the landslide hazards effectively. For example, while the local authorities are aware of the potential landslide hazards associated with steep slopes they are not able to prevent people from settling in these areas as there is no specific law or policy on land utilization in these landslide-prone areas. The existing policy on Hill Slope Development formulated in 2001 by the State Government is too general in nature and do not specifically address landslide-prone areas. The lack of detailed landslide hazard maps makes it difficult for the local authorities to plan appropriate development activities in their areas.

6. Concluding Remarks

The landslide hazards in Sabah could have been better managed if the locations of landslide-prone areas are clearly delineated on large scale maps for easy reference by decision makers and a clear policy on how these areas ought to be developed are available. There is therefore a need for the relevant authorities to allocate appropriate resources for landslide reduction programs in Sabah. Clearly, landslide disasters are increasingly caused, or aggravated, by environmental changes brought about by uncontrolled human activity. There is also a need to increase public awareness and public participation on how to reduce vulnerability to landslide hazards.

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Environmental Effects of Possible Landslide Catastrophes in the Areas of Radioactive Waste Warehousing in Kyrgyzstan (Central Asia)

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Abstract. Kyrgyzstan is an Alpine country located in the Central and Western part of the mountainous system in Tien-Shan (Fig. 1). The new and developing Tien-Shan Mountains are characterized by high topography energy, therefore in mountain areas of Kyrgyzstan the gravitational mass movements are actively generated and widely propagated, as the following: landslides, avalanches, rockfalls, mudflows, snow avalanches and glacial shearing. The most troublesome are the landslides, which occurred on mountain slopes and in narrow canyons. Presently within the Kyrgyz part of Tien-Shan more than 5 thousand new landslides have been registered, vast majority of which is developed in Loess Belt of submountain areas of Fergana Valley (Fig. 1). During the last 20 years against a background of noticeable climate changes a great increase of landslide activity is registered. Within the 1993-2008 period more than 300 large-sized ($V \geq n \cdot 10^5 m^3$) landslides have occurred taking lives of 240 people. The volumes of rocks and soils moving in the time of landsliding run up to many millions of cubic meters. Landslides destroy inhabited localities and objects of infrastructure, exert destructive influence on local economy and subsistence of Highlanders, and hamper the expansion of mountain areas.

According to statistical data, in Kyrgyzstan up to 70% of present landslides is the result of unreasonable man-caused (anthropogenic) activities in mountain areas, mainly it is related to mining and processing operations. The distinctive features of "man-caused" landslides are the following: their greatly more extended volumes and striking effects in comparison with natural-origin (genesis) landslides; concentration of man-caused landslides in small-volume mining areas; continuous and undamped mode of their expansion. Most hazardous are the landslides appearing in the areas of warehousing and storing of radioactive and toxic wastes of mining industry. In most cases in Kyrgyzstan these tailings are located on weakly stable rocks, and/or close to landslide-hazardous slopes, in valleys of narrow mountain rivers. Therefore, landslides and secondary effects in a form of floods and mudflows triggered by them, may lead to radioactive contamination of vast territories in down-stream rivers flowing into the densely populated valley areas of Kyrgyzstan and neighboring countries. This hazard poses a great problem in northeastern part of Fergana Valley, in Mailuu-Suu river basin, as well as in a vicinity of Min-Kush settlement, and in Naryn (Syrdarya) river basin. The present paper discusses environmental risks on the territory of above-mentioned areas related to direct and/or indirect influence of landslides on tailing dumps of uranium ore mining and processing.

Keywords. landslides, radioactive waste tailings, hydrodynamic and environmental risks.

1. Landslide geoenvironmental hazards in Mailuu-Suu

Mailuu-Suu area is a territory of the former large-sized industrial mining complex located in north-eastern foothills of Fergana depression (Fig. 1). A strong man-caused pressure upon weakly stable geological environment of this area, related to mining operations (uranium, coal, oil) and associated infrastructure development appeared as a distinctive trigger mechanism, which apparently stimulated to intensive growth of landslide processes.

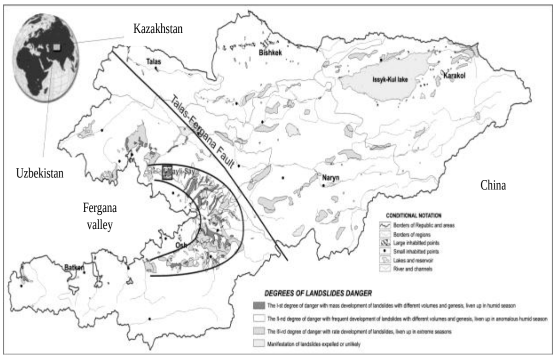

Fig. 1 The map of landslide susceptibility of Kyrgyzstan

Landslide processes most frequently (98%) occur in a mid-stream of Mailuu-Suu River (Fig. 2), in a band of midmountain (900-1600 m) topography development, on a propagation zone of Meso-Neozoic sediments strongly crushed in folds, which due to their lithologic (presence of loess-like loams and clays) and stratigraphic (alternation of water-permeable and waterproof soils) features are predisposed to slumping. Hence, presence within the study area of the both ancient and the newest folded and disjunctive structures of various kinds, high geodynamic regional activity conditioned by meridional compression of Tien-Shan, and wide propagation of ancient landslides caused to active development of new landslides, from which 50% confined to slopes of ancient-slope genesis.

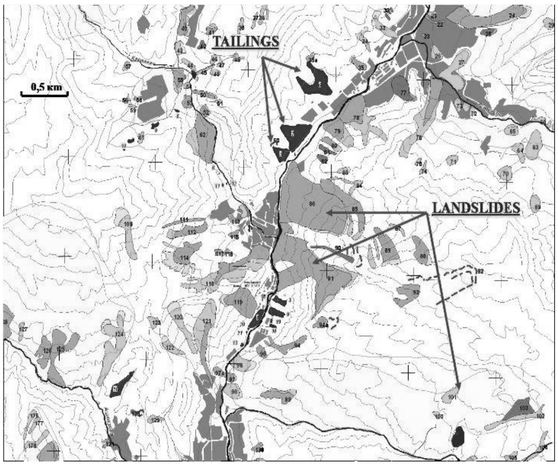

Fig. 2 Landslides and tailings in Mailuu-Suu valley

Presently, in this area more than 200 new landslides of various scale (volume is up to 8 min.m^3), genetic age, and development stages have been registered. Based on the situation at the beginning of 2008, the whole area affected by landslides estimated to 6.37 km^2, and the total volume of landslide masses moved during 1950-2005 - 260 mln.m^3. More than 30 landslides are in a preparation stage for the main movement, and they pose a direct danger to the population, objects of economy and infrastructure, as well as to radioactive waste tailings.

In terms of a complex mountain topography due to a deficit of balanced and available areas the housing estates, communications, industrial objects, including radioactive waste tailings (tailing dumps and stockpiles) were placed along riverbeds, in floodplains and over-floodplain terraces of Mailuu-Suu river and its tributaries, at mountain foothills and/or on slopes themselves, as well as on weakly stable ancient-landslide sites (Fig. 2). In such a situation characterized by high susceptibility of the area to landslide processes and their phenomena, including their frequency, landslides appear as a source of great risk for life activity in Mailuu-Suu town.

Most hazardous are the landslides, which are formed on edges of river valley and its tributaries (Fig. 2) since, their development, and, particularly their final stage - mixture, often has a synergetic character (domino effect).

Synergetic character of landslide movements in mountain river basins proves that landslide event in a narrow river valley is triggering a series of other hazardous phenomena by the following scenario: landslide - rockslide-landslide blockage of riverbed or river valley - landslide dam upstream submergence - breach of this dam - downstream flood or mudflow.

Quite often these hazardous phenomena triggered by a landslide, cannot yield, but sometimes even prevail by their destructive force and causing damage over the initiating event, i.e. the landslide. During the latest 17 years in Mailuu-Suu area more than 10 landslide movement episodes with a blockage of a river and its tributaries have been registered. The most destructive of them was a river blockage on Tektonik landslide zone in June 1992, when as a result of landslide mass movement about 2 min. m the dam with 15 m height and 800 m length was formed, and simultaneously a small-sized tailing No 17 was blown into the river.

A special hazard development of such synergetic scenarios is related to that in transit zones of landslide masses, submergence, or in a spread zone of breach flows can be not only housing estates, but tailings and dumps of radioactive wastes (RAW) located along riverbeds of Maily-Suu, Karagach and Kulmen-Sai (Fig. 2). In case of possible destruction of these tailings the propagation areal of radioactive materials stored in them may be substantially expanded owing to their propagation through the drainage network of Mailu-Suu river inhered in Syrdarya river basin.

We have explicitly studied environmental risks related to destruction of tailings as a result of direct fall of landslide masses in the articles (Torgoev et al. 2004). Risks concerned with tailing submergence with breach and mud- flow effect on them are highly probable and sound, if taking into account a series of previous incidents having place in the study area (Torgoev et al. 2006). Therefore, in April 1958 following a No 7 tailing dam destruction triggered by extremely heavy rainfall and increased seismic activity in the nearest zone (R < 100 km), the mass of radioactive tails with a volume of 400-600 thousand m^3 bursting from this tailing dump, propagated as a mudflow with 250m^3/s water discharge downstream Maily-Suu river, causing to men depth, destruction of some industrial-civil objects and radioactive contamination of a bed, a floodplain and a valley train of the river including Uzbekistan areas.

Presently the largest risk of tailing submergence with their subsequent destruction and catastrophic environmental effects in a form of radioactive contamination of a valley and a valley train of Mailuu-Suu river is registered on the site of a vast (V > 5-7 mm. m^3) Koitash landslide (Fig. 2). In case of a river valley blockage during simultaneous unloading of this landslide the dam with 15-25 m in height may be formed, and weakly stable tailings No 5, 7 (Fig. 3) with total RAW volume about 800 thousand m^3 may be in this submergence zone. The largest submergence risk is in spring season and at the beginning of summer, when water discharge in Mailuu-Suu river at crest segment may reach to 100 m^3/s. Totally the computation shows that based on the most pessimistic scenario - absolute destruction of tailings No 3, 5, 7, 8, 18 (Fig. 2) through a direct or indirect influence ofTektonik and Koitash landslides, the total volume of radioactive "tails", which may be dispersed in a flood-plain and on debris cone of a river, may be approximately 1 min. m^3 (total activity is about 10 thousand Ku), and the total volume of radioactive contamination - about 100 km^2.

Aiming to reduce a risk of uranium tailing landslide destruction in Mailuu-Suu at present time it is planned during the nearest 2-3 years to provide a series of preventive measures and projects including the southern flank unloading of Tektonik landslide, transportation of No 3, 8 tailings to a safer zone, bypass tunnel construction on a site of possible river blockage by Koitash landslide, as well as monitoring and early warning of landslide process hazard in the area of uranium tailings.

2. Geoenvironmental risks in Min-Kush settlement

Within the last years alarm condition has arisen in the area ofTuyuk-Syy uranium tailing located directly in analogous river-bed (Fig. 3) related to Naryn river basin (Syrdarya). This tailing is placed at a height of more than 2000 m above sea level, and it occupies 5 hectare volume zone, where 640 thousand m^3 of Kavak uranium tailing wastes including 450 thousand m^3 of radioactive tails have been concentrated.

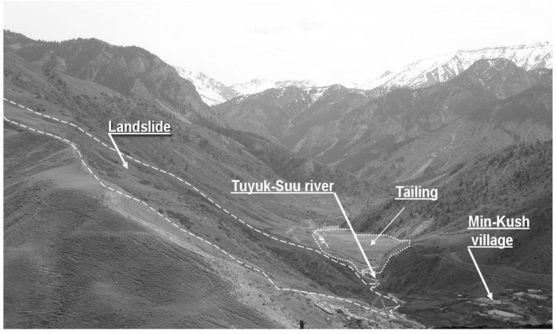

Fig. 3 The common view of the tailing and landslide in valley of river Tuyuk-Suu.

Based on the results of comparative risk analysis connected to the Tuyk-Syy tailing it is determined that at present time the most hazardous risk is the destruction of supporting dam and by-pass channel, that can happen following mudflows passing through it, and landslide event with a volume of more than 1.2 mln. m^3. This landslide began to develop during moisture-abundant springs in 2004 on a right side of narrow valley 120-150 m lower than the study tailing area (Fig 3).

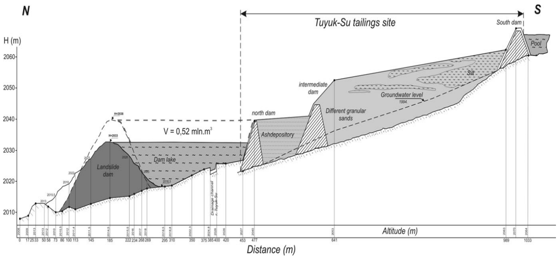

Fig. 4 The modeling results of landslide blockage of river in lower part of tailing Tuyuk-Su.

The phase of this landslide general movements predicted to occur during a spring 2009, is fraught with this narrow valley blockage by a landslide dam, which height, according to calculations, may be more than 30 m over the Tuyuk-Suu river bottom (Fig.4).

It is inevitable that under-pond lake creation with a volume of more than 500 thousand m^3 will lead to a tailing submergence. The results of stability assessment of lower supporting RAW storehouse dam showed that due to a great water-saturation of this tailing body the stability factor is rather low even without taking into consideration a submergence and/or dynamic forces from possible earthquakes. In case of landslide dam unexpected outburst, which usually coincides with water overflow, the outburst flow (wave) with initial water discharge up to 600 m^3/s with capturing and entraining radioactive tails into this movement, can be formed. In the final analysis there is a high probability of not only the destruction of Min-Kush settlement apartment buildings located in the adjoining zone of Tuyuk-Suu river outfall (hydrodynamic breakdown), but of the subsequent extensive contamination of Min-Kush, Kokomeren, Naryn riverbeds and flood-plains by radioactive wastes.

As the preventive measures presently landslide movement monitoring is carried out, moreover, special arrangements for controlled and maintained water discharge in case of river blockage by landslide masses have been worked out. Besides, the fundamental plan is to transfer Tyuk-Suu tailing onto the safer zone adjoining the Min-Kush settlement.

Conclusions

The increased probability of hydrodynamic accidents and environmental catastrophes of both regional and transboundary character in warehousing areas of radioactive and toxic mining wastes in Mailuu-Suu, Min-Kush, and other areas of Central Asia is conditioned by that these waste storehouses are located in the influence zone of hazardous geological processes (earthquakes, landslides, avalanches, mudflows), which are typical for geodynamic active mountain areas of Tien-Shan.

Recently one of the major triggering factors of great number of failures in tailings and dumps, negative impacts of these tailings on the environment, as well as the increasing probability of environmental catastrophes appearing on the mentioned objects, consists in the following. During designing and building of these objects "flat reasoning and experience" of planners prevailed upon without taking into consideration mountain region specificity; increased geodynamic activity of new mountain-folded zones; weak geomechanic stability of mountain slopes in terms of intensive man-caused effects; all-round propagation of hazardous natural processes and phenomena in mountain areas; high environmental vulnerability of mountain zones to anthropogenic pressing and climate changes. Short-sighted engineering decisions made during warehousing of radioactive and toxic wastes in catchment areas in narrow river valleys and on landslide-hazard slopes after 40-50 years have led to transformation of local landslide hazards into environmental risks of radioactive regional and/or transboundary contamination.

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IFFI Project (Italian Landslide Inventory) and Risk Assessment

Alessandro Trigila, Carla Iadanza, Daniele Spizzichino (APAT, Italy)

Abstract. Landslides represent one of the most relevant natural hazards in Italy. The main scope of the IFFI project is the identification and mapping of landslides over the entire Italian territory according to rigorous and shared standardized criteria. Developed by APAT/Geological Survey of Italy and by the Regions and Autonomous Provinces, the project was financed in 1997 with 4.1 mil. euro by the Italian Government. The present work provides an overview of the IFFI Project and gives a preliminary landslide risk assessment at the national level. This analysis estimates the impact of landslides on the urban areas, the population at risk and the critical points along highways, railways and road network.

Keywords. Italy, inventory, landslide, risk

1. IFFI Project methodology

The methodology applied to produce the national landslide inventory is based upon the collection of historical documents and archive data, aerial photo-interpretation, field surveys, a landslide data sheet and a detailed cartographic representation (Fig. 1).

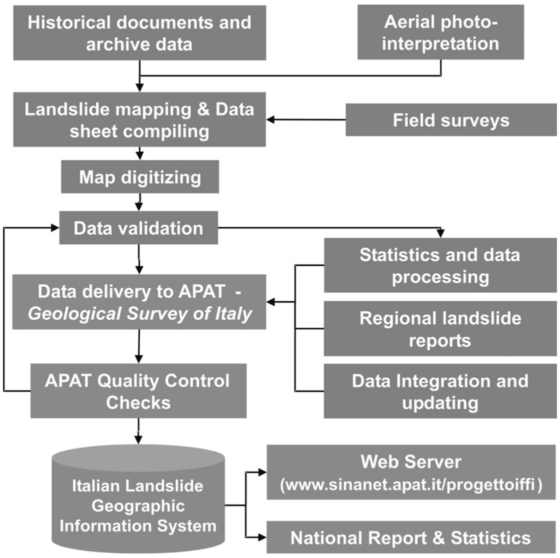


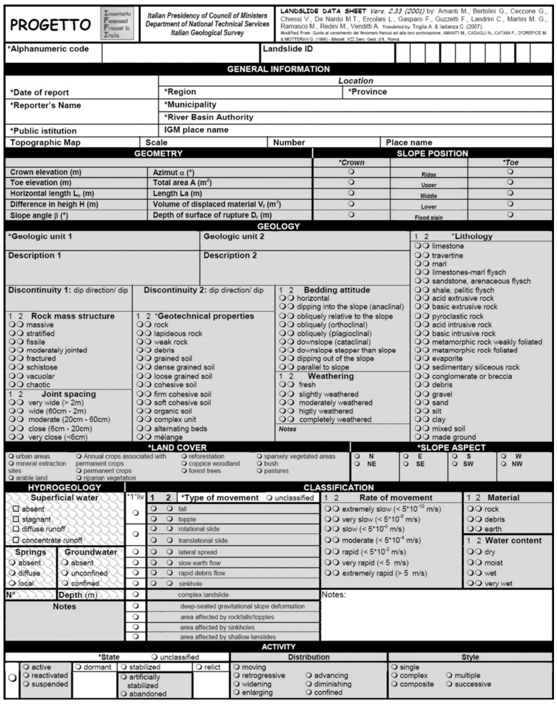
Fig. 1 IFFI Project work flow diagram

The research of historical sources is fundamental in order to assess return period, magnitude and intensity of a landslide phenomenon through the reconstruction of past events. The main information sources used to compile the IFFI database are: a) National projects (AVI - Inventory of information on sites historically affected by landslides and floods in Italy for the period 1918/2000; SCAI - Special project for the study of unstable towns; CARG - Geological map of Italy, scale 1:50,000); b) Landslide inventories by Regions, River Basin Authorities, research institutes and universities; c) River Basin plans (PAI - Law 267/98); d) Emergency Declarations (Law 225/92); e) National and local public archives; and f) Scientific and technical papers and reports.

Aerial photo-interpretation has been a fast and efficient way to perform geomorphological surveys over a large portion of the territory. Field surveys have been used to verify and integrate the data collected in the aerial photointerpretation phase and to update the archive.

With the aim of homogenizing the classification and glossary (i.e. type of movement, state of activity, intensity, velocity, distribution), the following international classification standards have been adopted: Cruden and Varnes (1996), Recommendations of the International Association of Engineering Geology (IAEG 1990), International Geotechnical Societies UNESCO Working Party on World Landslide Inventory (WP/WLI 1993a), Multilingual Landslide Glossary (WP/WLI 1993b), and International Union of Geological Sciences Working Group on Landslides (IUGS/WGL 1995).

The IFFI data sheet, organized in three different levels of increasing detail, has been compiled for every single mapped landslide (Amanti et al. 1996) (Fig. 2).



PROGETTO Inventario Fenomeni Franosi in Italia

Italian Presidency of Council of Ministers
Department of National Technical Services
Italian Geological Survey

LANDSLIDE DATA SHEET *Vers. 2.33 (2001)* by: Amanti M., Bertolini G., Ceccone G., Chiessi V., De Nardo M.T., Ercolani L., Gasparo F., Guzzetti F., Landrini C., Martini M. G., Ramasco M., Redini M., Venditti A. Translated by: Trigila A. & Iadanza C. (2007).
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*Alphanumeric code
Landslide ID

GENERAL INFORMATION

*Date of report
*Reporter's Name
*Public istitution

Location
*Region
*Province
*Municipality
*River Basin Authority
IGM place name

Topographic Map
Scale
Number
Place name

GEOMETRY

Crown elevation (m)	Azimut α (°)
Toe elevation (m)	Total area A (m^2)
Horizontal length L_o (m)	Length La (m)
Difference in heigh H (m)	Volume of displaced material V_f (m^3)
Slope angle β (°)	Depth of surface of rupture D_r (m)

SLOPE POSITION

*Crown		*Toe
○	Ridge	○
○	Upper	○
○	Middle	○
○	Lower	○
○	Flood plain	○

GEOLOGY

*Geologic unit 1
Geologic unit 2
Description 1
Description 2
Discontinuity 1: dip direction/ dip
Discontinuity 2: dip direction/ dip

1 2 Rock mass structure
○○ massive
○○ stratified
○○ fissile
○○ moderately jointed
○○ fractured
○○ schistose
○○ vacuolar
○○ chaotic

1 2 Joint spacing
○○ very wide (> 2m)
○○ wide (60cm - 2m)
○○ moderate (20cm - 60cm)
○○ close (6cm - 20cm)
○○ very close (<6cm)

1 2 *Geotechnical properties
○○ rock
○○ lapideous rock
○○ weak rock
○○ debris
○○ grained soil
○○ dense grained soil
○○ loose grained soil
○○ cohesive soil
○○ firm cohesive soil
○○ soft cohesive soil
○○ organic soil
○○ complex unit
○○ alternating beds
○○ mélange

1 2 Bedding attitude
○○ horizontal
○○ dipping into the slope (anaclinal)
○○ obliquely relative to the slope
○○ obliquely (orthoclinal)
○○ obliquely (plagioclinal)
○○ downslope (cataclinal)
○○ downslope stepper than slope
○○ dipping out of the slope
○○ parallel to slope

1 2 Weathering
○○ fresh
○○ slightly weathered
○○ moderately weathered
○○ higtly weathered
○○ completely weathered

Notes

1 2 *Lithology
○○ limestone
○○ travertine
○○ marl
○○ limestones-marl flysch
○○ sandstone, arenaceous flysch
○○ shale, pelitic flysch
○○ acid extrusive rock
○○ basic extrusive rock
○○ pyroclastic rock
○○ acid intrusive rock
○○ basic intrusive rock
○○ metamorphic rock weakly foliated
○○ metamorphic rock foliated
○○ evaporite
○○ sedimentary siliceous rock
○○ conglomerate or breccia
○○ debris
○○ gravel
○○ sand
○○ silt
○○ clay
○○ mixed soil
○○ made ground

***LAND COVER**

○ urban areas
○ mineral extraction sites
○ arable land
○ Annual crops associated with permanent crops
○ permanent crops
○ riparian vegetation
○ reforestation
○ coppice woodland
○ forest trees
○ sparsely vegetated areas
○ bush
○ pastures

***SLOPE ASPECT**

○ N ○ NE ○ E ○ SE ○ S ○ SW ○ W ○ NW

HYDROGEOLOGY

Superficial water
☐ absent
☐ stagnant
☐ diffuse runoff
☐ concentrate runoff

Springs
○ absent
○ diffuse
○ local

Groundwater
○ absent
○ unconfined
○ confined

N°
Depth (m)
Notes

CLASSIFICATION

*1°liv	1	2	*Type of movement ○ unclassified
○	○	○	fall
	○	○	topple
○	○	○	rotational slide
	○	○	translational slide
○	○	○	lateral spread
○	○	○	slow earth flow
○	○	○	rapid debris flow
○	○	○	sinkhole
○			complex landslide
○			deep-seated gravitational slope deformation
○			area affected by rockfalls/topples
○			area affected by sinkholes
○			area affected by shallow lanslides

1 2 Rate of movement
○○ extremely slow (< 5*10^{-10} m/s)
○○ very slow (< 5*10^{-8} m/s)
○○ slow (< 5*10^{-6} m/s)
○○ moderate (< 5*10^{-4} m/s)
○○ rapid (< 5*10^{-2} m/s)
○○ very rapid (< 5 m/s)
○○ extremely rapid (> 5 m/s)

1 2 Material
○○ rock
○○ debris
○○ earth

1 2 Water content
○○ dry
○○ moist
○○ wet
○○ very wet

Notes:

ACTIVITY

*State ○ unclassified
○ active
○ reactivated
○ suspended
○ dormant
○ stabilized
○ artificially stabilized
○ abandoned
○ relict

Distribution
○ moving
○ retrogressive
○ widening
○ enlarging
○ advancing
○ diminishing
○ confined

Style
○ single
○ complex
○ composite
○ multiple
○ successive

Fig. 2 Section of the IFFI Project landslide data sheet

The first level contains basic data on landslide location, type of movement and state of activity and it is mandatory for each landslide; the second level provides data on morphometry, geologic units, discontinuities, lithology, geotechnical properties, land use, causes and dates of activation; the third level gives detailed information on damages, investigation processes and remedial measures for risk mitigation.

The scale of representation is 1:10,000; a smaller scale has been adopted in uninhabited or high mountain areas. Every landslide is represented by: a geo-referenced point located, as it is customary, at the highest point of the crown area; a polygon, if it is possible to map the landslide in respect to the scale of representation; and a line when the phenomenon is too narrow to be appreciated (debris flows case).

The IFFI database has been validated by performing spatial, relational and completeness quality control checks.

2. Landslide data

Presently, the Italian Landslide Inventory contains about 470,000 landslides occupying an area of about 20,000 km^2, corresponding to 6.6% of the entire national territory (Trigila 2007) (Fig. 3).

Fig. 3 Landslides distribution in Italy

The most frequent types of movement are rotational and translational slides (33%), slow earth flows (15.5%) and rapid debris flows (15%).

Such a substantial number of landslides should be considered in association with the peculiar morphological, lithological and structural setting of the Italian territory. On a surface which is scarcely above 300,000 km^2, the mountainous-hilly terrain represents 2/3rds of the total – 31% mountains and 43% hills, respectively. Fig. 4 shows a simplified orographic model obtained through a 20 m x 20 m DEM (Fig. 4). Plains include areas with <300 m elevation and <3° slope; hills comprise landforms with >3° slope and 300 to 600 m elevation, while landforms that extend above the surrounding terrain at an elevation >600 m are identified as mountains. A study conducted over large portions of the peninsula has proven these threshold values to be optimal.

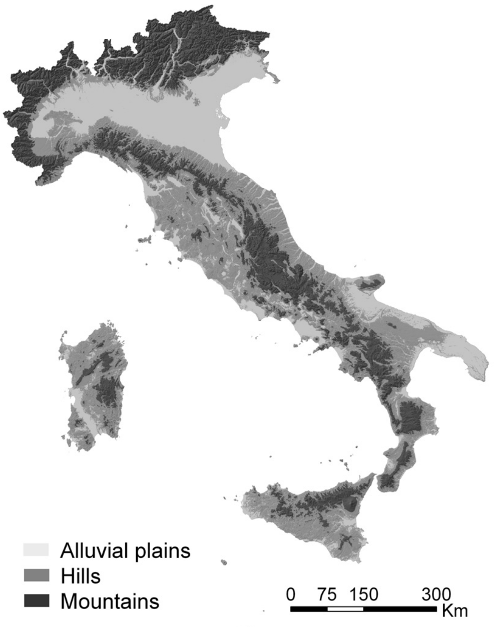

Fig. 4 Digital Terrain Model of Italy

The IFFI landslide maps are accessible on the Internet by means of a WebGIS application (www.sinanet.apat.it/progettoiffi). The application allows, through a simple and clear navigation, to visualize landslides, query the database, promote geographical investigation and consult documents, photos and videos (Trigila et al. 2008). The WMS (Web Map Service) service guarantees interoperability and data sharing in compliance with the European Directive INSPIRE 2007/2/CE. Since 2005 the website has recorded over 300,000 hits.

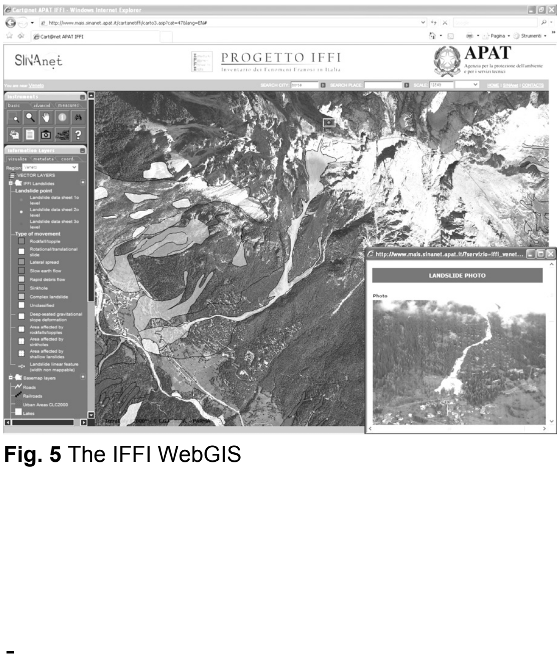

Fig. 5 The IFFI WebGIS

3. Risk assessment

This study presents the results of a preliminary landslide risk assessment analysis carried out in urban areas, their inhabitants and linear communication infrastructures.

The input data used are: the IFFI Landslide Inventory, the urban areas database of Italy, the 2001 Population Census data and the Italian transportation networks database.

- *Landslides and urban areas*

In the past 50 years, Italy has experienced a substantial increase in the size of urban areas, whose surface area has more than doubled. However, the increase has not always been matched with proper urban planning. Frequently new urban settlements have developed either on unstable sites or areas with a high landslide susceptibility.

The overlapping of the IFFI landslide polygon layer on the layer of Italy's Urban Areas (Intesa GIS- 1:10,000 scale) has made it possible to assess the impact of landslides on urban areas. Out of 17,929 km^2 of urban area, 2.13% is subject to landsliding – 381.32 km^2.

Fig. 6 shows the impact of the extremely rapid mud-debris flows in the urban areas of the Sarno and Quindici municipalities that caused 160 casualties on May 5/6 1998.

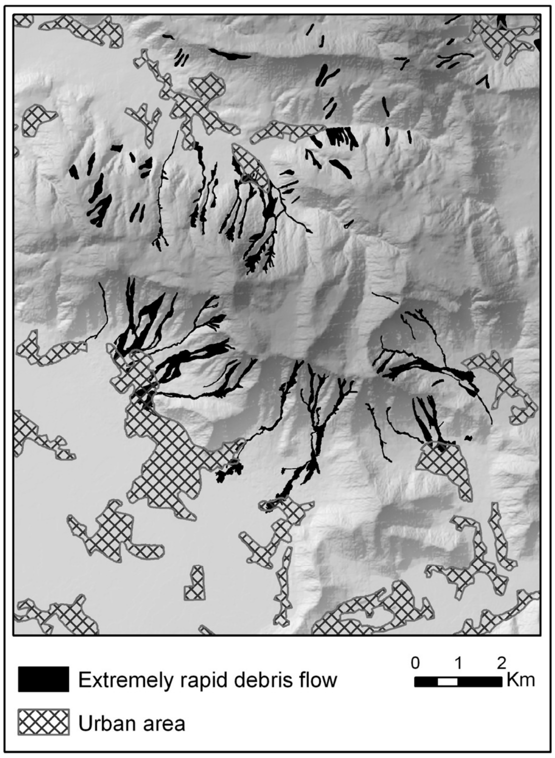

Fig. 6 Landslides and urban areas (Sarno and Quindici municipalities, Campania Region)

- *Population at risk*

People residing in Italy total 56,995,744 individuals according to ISTAT 2001 Census (Population Census Data, ISTAT – Italian National Institute of Statistics).

By intersecting the landslides recorded in the IFFI Inventory with the 382,534 census sections in Italy, we have calculated the area affected by landslides as a percentage value within each census section. Knowing the number of residents per each section, the number of people exposed to landslide risk has been estimated (Guzzetti et al. 2003). The result indicates that some 992,000 people are exposed, i.e. 1.74% of the overall residing population.

Fig. 7 shows the aggregate data of risk-exposed population for the nation's 8101 municipalities (NUTS 5 – according to the EU Nomenclature of Territorial Units for Statistics). Over 3000 people are at risk in 14 municipalities, whereas the figure ranges between 1000 and 3000 in 154 municipalities. The residents exposed to landslide risk are between 250 and 1000 in 909 municipalities, and that figure falls between 1 and 250 in another 3924 municipalities. Finally, 3100 municipalities do not record any of their inhabitants as exposed to landslide risk.

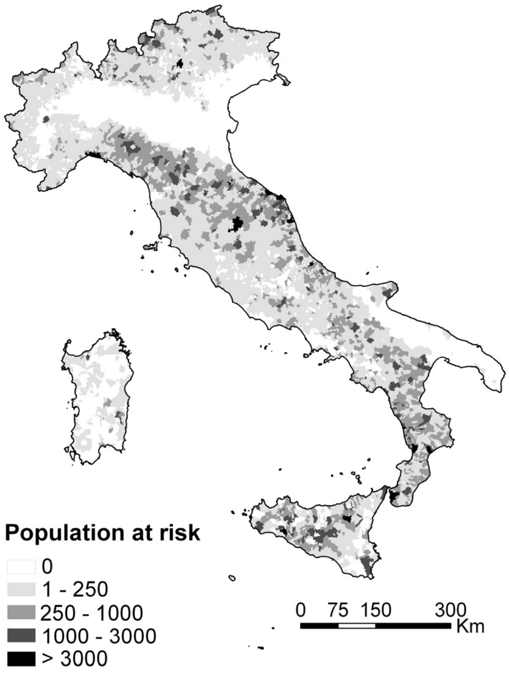

Fig. 7 People exposed to landslide risk in Italy per municipality

- *Critical points along highways, railways and road network*

The IFFI layer has been combined with the main Italian transportation networks (Tele Atlas) as digitized from topographic maps at 1:10,000 scale. The 706 critical points along highways (total length 6487 km), 1806 along railways (16,000 km) (Fig 8) and 41,109 along road network (172.420 km) have been pointed out. Fig. 9 shows a segment of State road n. 51 exposed to landslide risk (Fiames, Cortina municipality, Dolomites, Veneto Region).

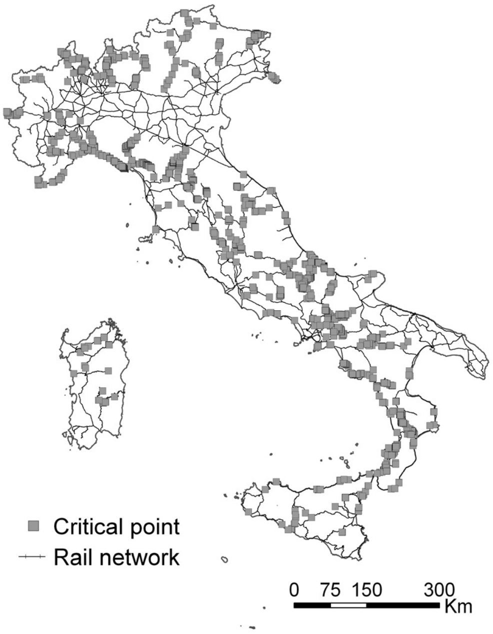

Fig. 8 Critical points along the railway network

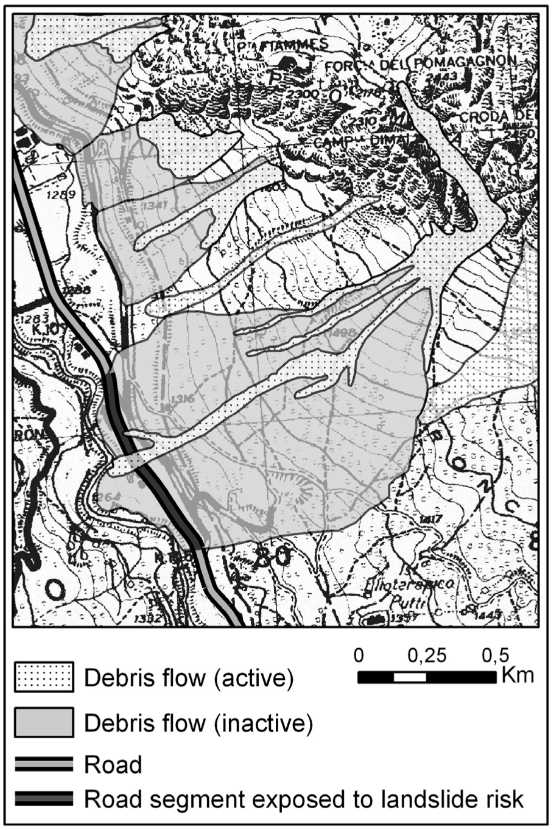

Fig. 9 Road segments exposed to landslide risk (Cortina municipality, Veneto Region)

4. Conclusions

The Italian Landslide Inventory represents a point of excellence among the geothematic databases at the national, European and international level because of several considerations: its methodology; its working standards which govern the collection and processing of data; its total coverage of the territory; the level of detail of the landslide cartography; and the thoroughness of the Landslide Data Sheet.

The preliminary analysis conducted by implementing the IFFI database shows that 2.13% of urbanised areas are susceptible to landslides, 992,403 inhabitants are exposed to landslide risk and 43,621 critical points have been identified along the linear communication infrastructures.

This kind of analysis is addressed to policy makers, professionals, and stakeholders. It provides a DSS – Decision Support System to establish priorities and planning actions in order to minimise the landslide risk.

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Capacity Building and Awareness Raising for Disaster Reduction through Formal Education
- Lessons learned from the Indian Ocean Tsunami -

Etsuko Tsunozaki (Asian Disaster Reduction Center)

Abstract. The unprecedented tsunami disaster occurred on 26 December 2004 was attributed to the absence of tsunami early warning system in the Indian Ocean as well as lack of knowledge about tsunami among the people. However, the latter had not been proved with evidence prior to the Tsunami. Therefore, the Asian Disaster Reduction Center (ADRC) conducted a survey on tsunami awareness in 2005, first in Sri Lanka, then in Maldives, and lastly in Indonesia, targeting at residents, school children, teachers and government officials.

The results of the survey showed that in Sri Lanka, for example, 93.5% of residents did not know about tsunami before the disaster event, and 90% of them answered that they could have reduced the loss and damage if they had known more about it. 49% of school children answered that they had never learned about tsunami at school and 90% of them wished to study about natural disasters at school. Further, 94% of children answered that they discuss what they have learned at school with their family. 77% of residents in Sri Lanka answered that the most effective way to utilize for preventing a future tragedy was the integration of disaster study into school curriculum.

Based on the findings of the survey and as the first step towards the promotion of disaster education at school, ADRC carried out school education projects in Thailand, Sri Lanka and Indonesia. The activities included developing tools (educational materials for school children and manuals for teachers in the local languages), organizing workshops, drills and seminars for capacity building and awareness raising.

These capacity building and awareness raising activities should be carried out together with structural and non-structural measures. Recent catastrophic disasters in Myanmar and Sichuan Province in China reminded us again of the importance of and the need for immediate actions to develop and implement a comprehensive school safety programme.

Keywords. Awareness, Disaster Education, Training of Teachers, Emergency Drill, School Safety, Culture of Safety

1. Background and the Disaster Awareness Survey

The unprecedented tsunami disaster occurred on 26 December 2004 was attributed to the absence of tsunami early warning system in the Indian Ocean as well as lack of knowledge about tsunami among the people. However, the latter had not been proved with evidence prior to the Tsunami. Therefore, the Asian Disaster Reduction Center (ADRC) conducted a questionnaire survey on tsunami awareness in 2005, first in Sri Lanka (Galle District), then in Maldives, and lastly in Indonesia (Aceh Province, Simeulue and Nias Districts), targeting at residents, school children, teachers and government officials.

The main objectives of the survey were:

(1) To identify the current status including community's capacity to respond to natural hazards in the tsunami-affected countries; and
(2) To propose strategies for disaster reduction and recovery and to suggest effective disaster reduction activities such as the dissemination of knowledge about natural hazards and raising public awareness.

To complement the questionnaire survey, interviews were also conducted.

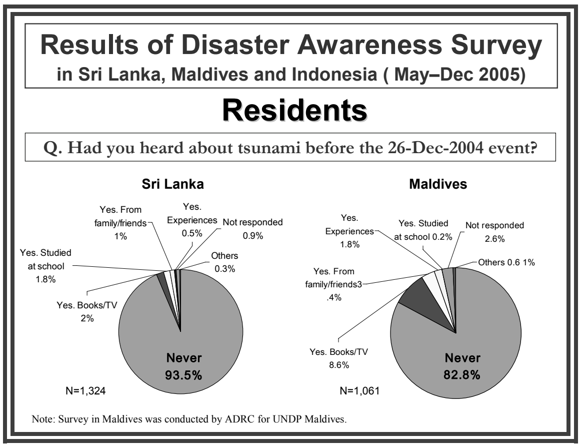
The questionnaire contained the following components:

- For residents: reaction at the occurrence of the Tsunami, information during evacuation, knowledge on tsunami, measures for disaster reduction, etc.;
- For school children: awareness of natural disasters, knowledge on tsunami, communication with family members on disasters, etc.;
- For school teachers: curriculum for disaster study, educational materials for disaster reduction, etc.;
- For government officials: training/seminar on disaster reduction, measures for disaster reduction, measures for protecting tourists, etc.

According to the survey results, 93.5% of the respondents from Sri Lanka and 82.8% from Maldives answered that they had never heard about tsunami before the disaster. Effective early warning systems are highly dependent on such basic knowledge and preparedness of people. Without awareness, people would not respond properly to warning thereby exposing them to higher risks and vulnerabilities.

On the other hand, a ten year old school girl on vacation near Phuket, Thailand, saw the signs of the receding sea and warned her parents and others of possible tsunami to occur, having studied about tsunami in a geography class at school. Her warning saved hundreds of people's lives. This episode testifies that disaster education has great importance.

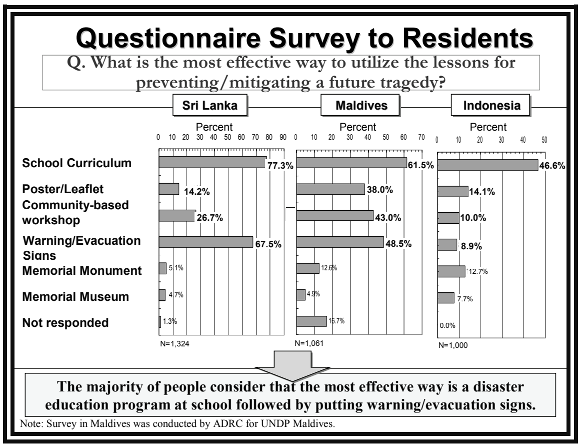
At the same time, a young boy on the Indonesian island of Simeulue had learned from his grandfather what to do when an earthquake strikes. He and all the other islanders ran to higher ground before the tsunami struck, sparing all but eight members of the community.


Results of Disaster Awareness Survey
in Sri Lanka, Maldives and Indonesia (May–Dec 2005)
Residents
Q. Had you heard about tsunami before the 26-Dec-2004 event?

Note: Survey in Maldives was conducted by ADRC for UNDP Maldives.

Fig. 1 Results of Disaster Awareness Survey by ADRC: Question for residents about the knowledge of “tsunami”

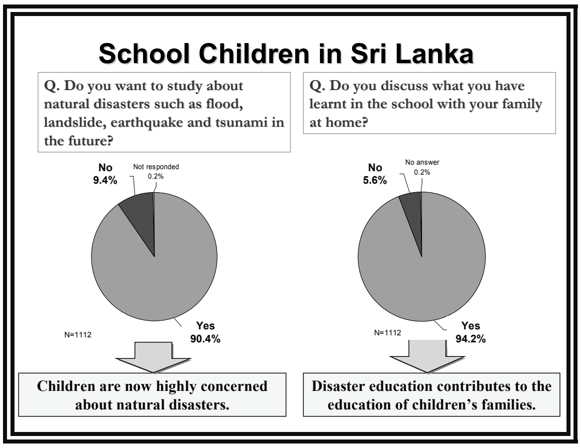
The said survey revealed that education would be vital for disaster reduction: 77.3% of the residents group in Sri Lanka, 61.5% from Maldives, and 46.6% from Indonesia recommended the integration of disaster education into the school curriculum as the most effective way to utilize the lessons from past disasters and for preventing/mitigating a tragedy from recurring.


Questionnaire Survey to Residents
Q. What is the most effective way to utilize the lessons for preventing/mitigating a future tragedy?

The majority of people consider that the most effective way is a disaster education program at school followed by putting warning/evacuation signs.
Note: Survey in Maldives was conducted by ADRC for UNDP Maldives.

Fig. 2 Results of Disaster Awareness Survey by ADRC: Question for residents about future activities for disaster reduction

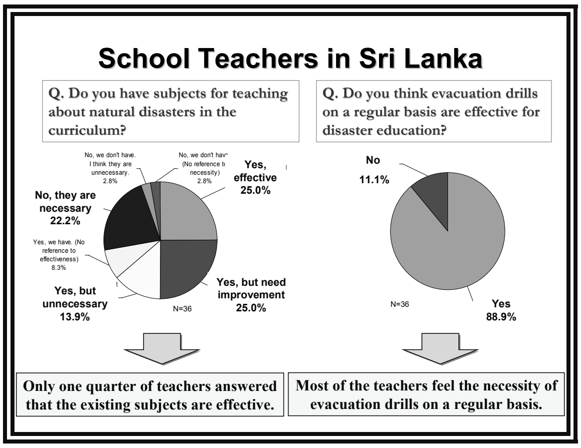
In addition, the survey testified that 90.4% of the school children wish to study about natural disasters, which revealed the children’s high interest for learning about natural disasters. In addition, 94.2% of the respondents answered that they discuss what they learned at school with their family members. This means that through the formal education of children at primary and secondary schools, we can expect information to be disseminated widely to the community.


School Children in Sri Lanka
Q. Do you want to study about natural disasters such as flood, landslide, earthquake and tsunami in the future?
Q. Do you discuss what you have learnt in the school with your family at home?

Children are now highly concerned about natural disasters.
Disaster education contributes to the education of children’s families.

Fig. 3 Results of Disaster Awareness Survey by ADRC: Question to school children about their attitude toward disaster study

Only one quarter of the school teachers’ group in Sri Lanka responded that the existing disaster education programme was effective enough. Another one quarter said that there were subjects for disaster reduction but they needed improvement. About 22 % of teachers answered that there was no programme for disaster reduction and that it would be necessary to create one. We should also pay attention to the fact that almost 90% of school teachers considered evacuation drills on a regular basis is effective for disaster reduction.


School Teachers in Sri Lanka
Q. Do you have subjects for teaching about natural disasters in the curriculum?
Q. Do you think evacuation drills on a regular basis are effective for disaster education?

Only one quarter of teachers answered that the existing subjects are effective.
Most of the teachers feel the necessity of evacuation drills on a regular basis.

Fig. 4 Results of Disaster Awareness Survey by ADRC: Question for school teachers about disaster education at school

The survey, overall, demonstrated the need to strengthen the following:

(1) Promotion of disaster education including introduction of disaster education in school curriculum, training of school teachers and officials, and implementation of

evacuation drills;

(2) Raising of public awareness including community-based hazard mapping (Town Watching) and designation of evacuation sites and display of warning/evacuation signs to make early warning effective;

(3) Enhancement of information management system including improvement of communication system among government officials, and establishment of information dissemination system among government officials and residents; and

(4) Improvement of coordination mechanism in national and local disaster management systems including reinforcement of disaster management

2. Development of Educational Materials for Disaster Reduction

Based on the above survey results, ADRC selected promotion of school education for disaster reduction as a priority area of its activities, and recommended the integration of disaster education into school curricula to the ADRC member countries in Asia.

ADRC then carried out a project in Thailand in 2006 and developed a methodology for the promotion of effective disaster education at school and the development of educational materials for disaster reduction.

1. Step 1: First consultative meeting on promoting disaster education and reviewing the existing educational materials for disaster reduction. This involves officials in disaster risk management and education in the central and local governments, experts and school teachers in these areas within and outside the country;
2. Step 2: Drafting of educational materials at the local workshop with the involvement of both experts and officers in disaster risk management and education;
3. Step 3: Pilot lessons and training of teachers including explanation of hazards as natural phenomena (with scientific information), disaster simulation exercises and emergency drills, and dissemination of knowledge on the implementation of disaster education to participating teachers;
4. Step 4: Second consultative meeting to introduce the education materials and the evacuation plans developed through the project, inviting school teachers, officials and experts in disaster risk management. This exercise includes introduction and review of the results of the pilot lessons and presentation of disaster education action plans; and
5. Step 5: Dissemination of educational materials and promotion of comprehensive education programme for disaster reduction as school curriculum.

Step 1

Compiling and analyzing existing disaster education materials

Step 2

Drafting educational materials in consultation with experts of both DM and education

Step 3

Conducting pilot classes to evaluate and finalizing the materials

Step 4

Organizing a seminar to disseminate materials to teachers and educators

Step 5

Distributing materials to schools and libraries and promotion of comprehensive disaster reduction programme

Fig. 5 Methodology for developing school educational materials

Fig. 6 Textbook and Teacher's Guide for 4th -6th graders developed in Thailand in 2006

Conclusions

Since the completion of the pilot project in Thailand, ADRC has received many requests to implement similar projects and, so far (by September 2008), the projects in Sri Lanka and Indonesia have already been completed. The educational materials were developed in their local languages adapted to their local context. ADRC plans to implement more projects to promote disaster education for disaster risk reduction in the Association of South-East Asian Nations (ASEAN) countries.

Making disaster risk education part of national primary and secondary school curricula is key to promote the priority area No. 3 of the Hyogo Framework for Action (HFA), "Use knowledge, innovation and education to build a culture of safety and resilience at all levels." We know from past experience and also from the result of the above survey that children who are taught about natural hazard risks play an important role in saving lives and protecting members of the community in times of crisis.

In most societies, in addition to their essential role in formal education, schools also serve as a community's central location for meetings and group activities, in normal times, and as centers or places of refuge and shelter in times of disaster. Thus, ensuring school safety, including structurally disaster resilient schools, is vital for developing comprehensive disaster education and school safety programmes, contributing to building culture of safety.

Acknowledgments

ADRC would like to extend our sincere appreciation to the Governments of Sri Lanka, Maldives, and Indonesia for their support and cooperation to implement the survey. We would also like to thank the technical and scientific institutions and experts for providing technical assistance to the survey teams. We also wish to thank all the local people who assisted the survey through the coordination of field activities including translation of questionnaires and serving as interpreters during interviews.

ADRC also wishes to express our gratitude to the Governments of Thailand, Sri Lanka and Indonesia for the support provided to carry out the projects for the promotion of educational programme for disaster reduction and the development of educational and teaching materials for school children and teachers.

Special thanks will go to all the donors who kindly and generously supported these projects to be implemented successfully.

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Simple and Low-Cost Wireless Monitoring Units for Slope Failure

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Abstract. A simple and low-cost early warning system is developed, and its applicability and effectiveness was tested on model slopes under artificial heavy rainfall. The system works with batteries, and transfer real time data via wireless network. It is low-cost and simple so that non-expert residents in risk area can buy and handle it easily by themselves, even in developing countries. Traditional approaches to prevent rainfall-induced landslides, such as stabilization of unstable slopes by installation of retaining walls and ground anchors, has been useful. But, they are not very helpful in mitigation of small slope failures, which are less significant in scale but numerous in numbers, because of their cost of installation. In consequence of recent residential developments in hilly area and water front, the risk of smaller landslides has been realized. There is extravagant number of slopes with potential of such failure, and it is not financially realistic to use traditional approaches for each of them. Low-cost and simple early warning system is needed to deal with such problems.

Keywords. Slope stability, Monitoring, Wireless network, Inclinometer, Warning system

1. Introduction

There is a long history in prevention and mitigation of rainfall and/or scouring-induced landslides. Typical measures to prevent slope failure are retaining walls and ground anchors which improve factor of safety against failure. These measures have been widely used everywhere in the world and have been effective. However, they take a lot of cost, resulting in a limited application only for large scale slopes. In reality, most of landslide occurs at small scale slopes, but with a large number. It is not realistic to apply mechanical reinforcement measures for these slopes with potential risk.

The authors have proposed an early warning system for slope disasters, as one of more feasible countermeasures for small-scale slope disasters. The system watches minimum number of items and places on a slope with low-cost and sophisticated sensors, and the data is transferred through wireless network. Thus, the system is low-cost and simple enough so that the residents in risk areas can handle it to protect themselves from slope disasters (Towhata, et. al. 2005).

Herein, prototype devices developed by the authors are introduced, and some results from verification tests with artificial slope models are described.

2. Proposed monitoring system

The system consists of (1) several sensor units placed at every measurement points, (2) a gateway unit for a site, and (3) a data server on internet. It has two following features:

(a) Wireless data transfer: The sensor unit measures physical values on the slope, and transfer the data to the gateway using low-power radio signal. As relatively lower frequency (429 MHz) is used, the signal can be delivered through 300 to 600 m of distance with a low battery energy consumption. The gateway collects the data and forwards it to the server using cell phone network. The server collects and stores the data so that everyone can access the data via internet, and also issue warning automatically if the data shows a risk of failure. Every sensor unit and the gateway works on battery, without commercial power supply. Being wireless, the system can be quite easy and low-cost to install at site. But, consequently, higher technologies on battery power management and radio communication control are essential.

(b) Simplified measurement items and methods: The items to be measured on the slopes, and the sensors for the measurements, are carefully selected. Orense R.P. et. al. (2003 & 2004) conducted small-scale model tests, and found that gradual deformation on the slope surface and high saturation ratio at the slope toe are observed as precursors of failure. Thus, the one to be watched is rotation on the slope surface. Conventionally, extensometers are commonly used to measure the displacement, but it is not easy to install and manage, because they use long wires along slopes to be kept undisturbed. The proposed system uses inclinometers in place of extensometers, as its installation is quite simple. In addition, a smart inclinometer chip based on MEMS (micro machines) technology is employed. They are cheep (5 to 60 USD), tiny (5 to 15 mm in length), with high resolution (0.001 degree at highest), and with low power consumption (3V, 0.5mA). The other item to be measured is water distribution in the slope ground. A volumetric water contents meter, which measures changes in permittivity of soil with water, is employed in stead of conventional porous cups to measure the suction. This type of sensor is much easier to deal with than measurement of suction which requires careful treatment of the porous cup to keep it fully saturated.

3. Prototype tests (model tests)

In 2006, the authors developed prototypes, and tested them on a 1 m-high model sandy slope under artificial heavy rainfall, whose test was conducted by Public Work Research Institute (PWRI), Tsukuba, Japan (Figure 1). The slope model had a gradient of H=2 : V=1, and it was made of a compacted sandy material (Dmax = 4.57mm, D50 = 0.17mm, Fc = 14.3%, Gs = 2.69, ρd = 1.37 g/cm3, Dr = 80%), and its initial water contents was 19%. After filling water on the back side of the slope to simulate a situation of river dike, an artificial continuous rainfall of 15 mm/h was given. Two sensor units, equipped with an inclinometer and a volumetric water contents meter, were installed on the slope as shown in Figure 1. The installation work was simple, just embedding the unit and the attached water content meter on the slope to a depth of 20 cm, taking less than 30 minutes for each unit. As the power saving techniques were not completed at this time, the power for the sensor units were supplied by cables, but the data was sent to the gateway wirelessly, and recorded every 1 minute. The radio communication worked properly even in heavy rainfall conditions.

Figure 2 shows the behaviours of the inclination and water contents at each sensor unit. The slope failure was progressive starting from the toe, and the lower part with sensor unit 2 was failed around 2 hours after starting rainfall. The inclination showed extraordinary behaviours 30 minutes before that. Such behaviour could be used as a signal for early warning. However, the upper part around the sensor unit 1 was failed after 3 hours of rainfall, but the behaviours of the inclinometer were not clear as the lower part. The behaviour of inclination before failure is case-by-case, and thus, criteria to issue warning should be defined carefully.

On the other hand, the behaviours of the volumetric water contents were shown in Figure 3. As the void ratio is e = 0.935, volumetric water contents will be 0.48 if fully saturated. The measured water contents increased after starting rainfall, but it did not show nearly saturated condition before the failure. Thus, it was difficult to detect precursor of failure only watching water contents. At the lower unit 2, the measured value of water contents suddenly dropped at failure.

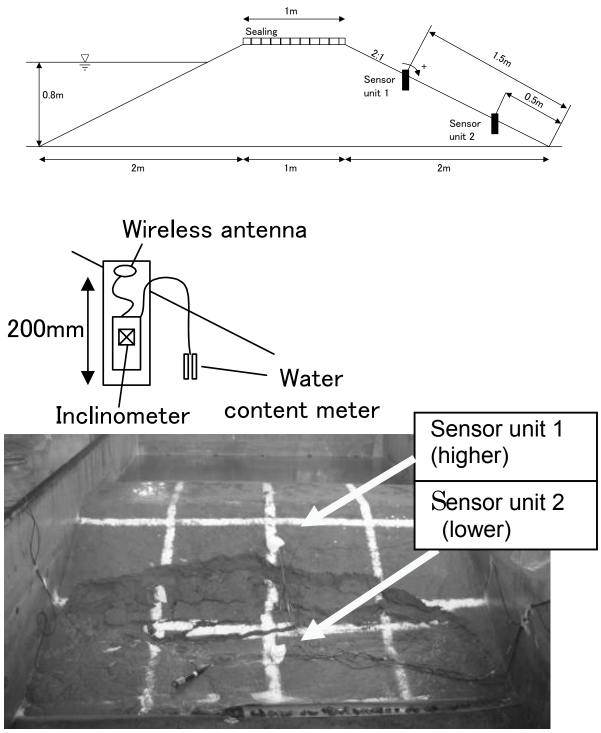

Fig. 1 Arrangement of slope model and sensor units for the test 2006

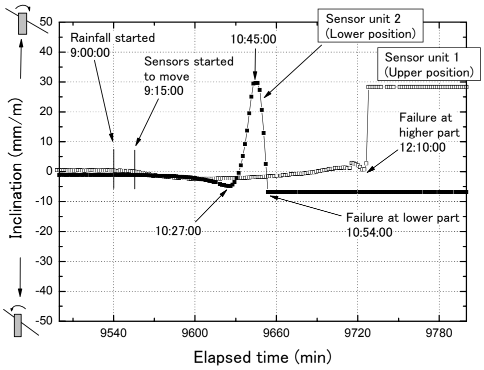

Fig. 2 Behaviours of inclination for the test 2006.

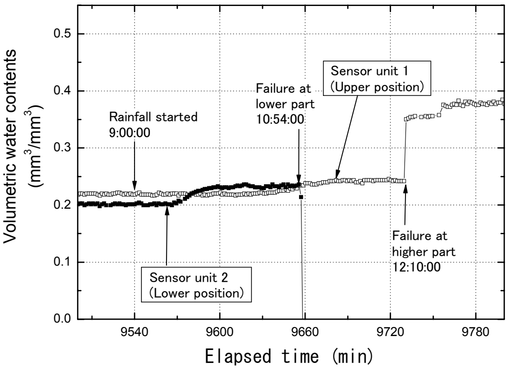

Fig. 3 Behaviours of water contents for the test 2006.

In 2007, a modified version of prototype was developed, and tested on a slope model by PWRI again. This time, a low-power MEMS inclinometer and a low-power micro computer were used, and the power supply for the sensors and radio transmitter was turned off when they were not in use. The power for the micro computer was also cut off by using sleep mode. As a result, the units worked for more than 4 months with 4 AA alkaline batteries, while measuring and transferring the data every 1 minute. The units became completely independent without any wiring works, and its installation became much easier. As the measuring and transferring interval in practical operation will be 10 minutes or more, they can run for several years.

Figure 4 shows the arrangement of the model and the sensor units. The slope is 3 m-high with a gradient of H=2 : V=1, and made of the same material as the previous slope. Four sensor units were installed at the three different levels on the slope (two of them were at the middle height with some horizontal distance).

Figure 5 and 6 show the behaviours of inclination and water contents at each unit, respectively. Again, some gradual changes in inclination were observed more than 30 minutes before the failure at each unit position, but their behaviors are not constant.

The volumetric water contents were also below the level of saturation before failure, but they suddenly decrease or increase after failure. These behaviours of water contents may be due to cracking in the soil around the sensors. When the soil is detached from the surface of sensors, low water contents are observed. And if the crack around the sensor is poured with water, the measured water contents show higher values than saturation.

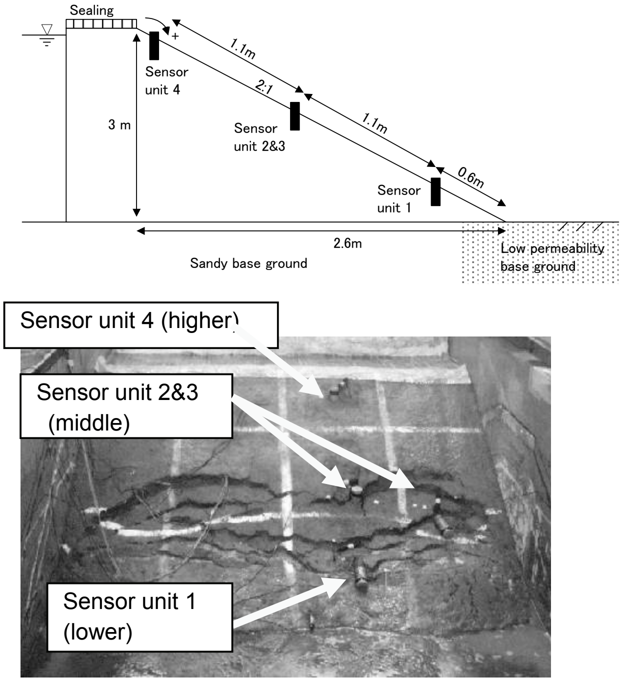

Fig. 4 Arrangement of slope model and sensor units for the test 2007.

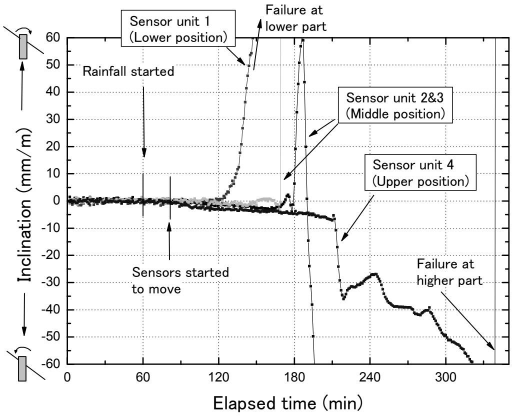

Fig. 5 Behaviours of inclination for the test 2007.

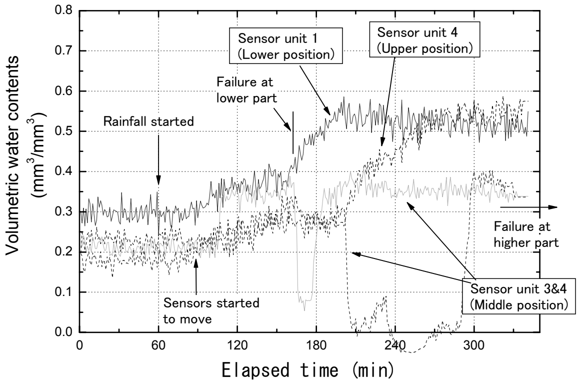

Fig. 6 Behaviours of water contents for the test 2007.

4. Prototype tests (field tests)

The most recent version of the sensor units are installed on a steep slope in Rokko, Kobe City in Japan (Figure 7). The slope has 40 to 50 degrees of gradient with weathered granite, which is a typical soil in this area, on the slope surface. At each monitored point, a steel rod was installed with the bottom end inserted into the slope surface for around 30cm. Then, a wireless sensor unit was attached at the top of the rod. The volumetric water content sensor is installed around 20 cm deep under the slope surface.

Figure 8 shows typical behaviours of the inclination downward the slope and the water content obtained by sensor units B and D for around 3 months. Although there were several times of heavy raining in this region, the slope did not fail in this period. The inclination values fluctuate within a range of 0.03 degrees, which is much smaller than what was observed in the model tests before failure. The water content data shows clear response every time it rains, and it decays gradually after it stops to rain.

Although high water contents due to heavy rainfall causes instability of the slope, it is difficult to evaluate the risk of failure quantitatively based on the values of water content. But, it is easy to know whether it is raining or not, by observing the change in water content values. Thus, a simple but possible way to define the criteria of judgment to issue warning based on the data obtained by the current sensor unit is:

a) A possibility of “abnormal behaviour” is considered if the sensor unit tilted more than a criteria value, which is prescribed in advance according to the data in normal conditions.

b) But, the judgment of a) is ignored to avoid false alarms if it is not raining currently, or if it is after a prescribed period after the last rainfall according to the data of water contents.

Fig. 7 Wireless sensor unit on slope (2008, Kobe).

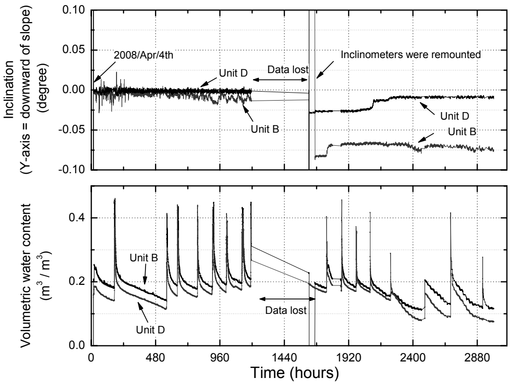

Fig. 8 Typical data obtained by the sensor units (B & D) on slope (2008, Kobe)

5. Power control for wireless sensor units

One of key issues in developing wireless monitoring system for civil engineering use is power management. As the most of subjects to be monitored are in outdoor sites without commercial power supply lines, the systems have to work with batteries. It is essential to keep their power consumption as low as possible to reduce the cost for taking care of the batteries.

The prototype sensor units installed on the slopes in Rokko, Kobe, are activated every 10 minutes, and measure the data for 3 times and send the averaged data by radio module. The most of devices in the units are turned off, and the CPU is also in sleep mode while they are deactivated, except the timer device to control the measurement interval.

Figure 9 shows their current consumption during the period when they are activated. The sensors and radio modules consumes some current by turns. A periodic current is observed also in the sleep condition. In total, consumes 0.12 mA with 3 V battery power in average, provided it measures and transmit the data every 10 minutes. By using four AAA alkaline batteries, 2 in parallel and 2 in serial providing 4000 mAh of power capacity, the system could work for 3.8 years.

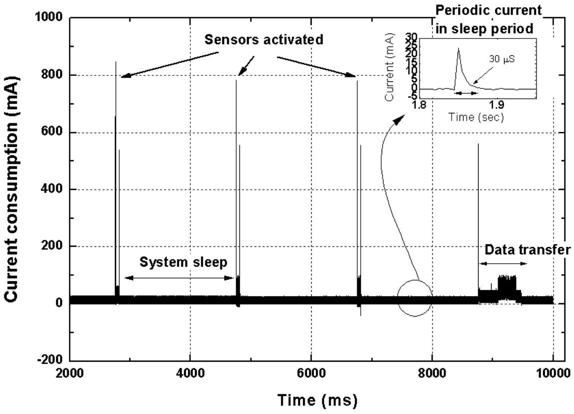

Fig. 9 Current consumption of sensor unit in sensing and data transfer sequences.

Conclusions

A low-cost and simple early warning system is proposed, and its prototypes were tested on a model slopes to be fail in an artificial heavy rainfall. Each sensor unit was equipped with an inclinometer and a volumetric water contents to watch the behaviours of slope. It works with batteries for a long life, and sends the measured data to a gateway periodically. The radio communication worked properly for data transfer even in heavy rainfall conditions.

The inclinations on the slope surface showed gradual change more than 30 minutes before failure, but their behaviours depend on cases. A careful consideration is needed to define the criteria to issue warning.

The volumetric water contents did not show nearly saturated conditions near the slope surface before the failure. The measured values were also affected by the cracking and other deformations on the slope surface. It is recommended to use water contents in combination with other monitoring items like inclination or displacement.

The prototype sensor units worked well also in the actual slope in Rokko, Kobe. The inclinometer data fluctuates within a range of 0.03 degrees under stable conditions, and the water contents data shows clear responses with rainfall on the slope.

Acknowledgments

The authors appreciate the corporation by the Public Work Research Institute, Tsukuba, Japan, who conducted the slope model tests and the field monitoring project and allowed the authors to install the sensor unit to verify the prototype system.

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Landslide Hazard in the Himalayan Region and Need for a Regional Scientific Society on Landslide and Environment

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Abstract. Himalaya occupies only a very small area of the earth's surface, but it causes nearly 35% of the global death due to landslides and constitutes about 30 percent of the world's total landslide-related damage value. More recently climate change is a new dimension added to the Himalayan context and it is already showing definite signs of impact in terms of monsoon precipitation that has undergone changes with decreasing rainy days and increasing high-intensity rainfall events, resulting into increased magnitude and frequency of water-induced disasters - landslides, debris flows and floods. The landslide problem in the region has increased both by natural and man made causes and thereby has increased the risk. For centuries, the whole of the Himalayan area remained essentially remote, rural and underdeveloped. But during last few decades, it has gained momentum in development of infrastructures. Massive construction of high dams, tunnels and barrages for irrigation, hydropower and flood control, and extensive road network expansion has been going on, and many are planned for future. The mountain population has increased many folds in the last several decades, and urbanization is in the rise. Increased population has created demand for more agricultural land and thus has intensified agriculture activities even in the marginal areas. Similarly, demand for more fuel, timer and fodder pushed for accelerated deforestation. People in the Himalayan region are more exposed to landslide and related disasters than any time before.

The increased human activities resulting to exposure to more disasters have necessitated more concerted effort on the study and management of landslides and related phenomena in the Himalayan region. Only this will help in saving lives and livelihood of people, protect infrastructures and environment and ensure sustainable development. Given its unique geographic, geologic and climatic characteristics (for example extreme relief, change of altitude, climatic zones and geologic units within short distance in the N-S direction, varying vegetation types and coverage, and rainfall intensity along its transverse and longitudinal directions etc.) Himalaya is a highly challenging ground for landslide study and management. Perhaps nowhere else has this variability, complexity and frequency of landslide occurrences as in the Himalayan region.

However, despite these uniqueness and challenges, the volume of research on landslides and related phenomena in the Himalaya is only a very tiny fraction of the total research that is being presently carried out world wide. Only few but sporadic serious researches on landslides have been carried out in the region. Landslide is a common problem in many other parts of the world. The knowledge and expertise gained from the research from the Himalayan region will also be equally valuable for others. Having this in perspective, consultation was initiated with prominent people in related fields from across the continents for some action. Most people have agreed on the importance of research on landslide and related phenomena in the Himalayan region and establishing a regional society to promote the research in landslide and environment. As a result the 'Himalayan Society for Landslides and Environment' abbreviated as 'HimSLE' (pronounced as himsl) is being launched at the World Landslide Forum, Tokyo in November, 2008.

Keywords. Himalaya, landslides, environment, society

1. Introduction

The combination of geographical, geological and climatic set up of South Asia has made it the most disaster prone region in the world when counting the human cost and economic losses (Fig. 1). Annual heavy monsoon rains frequently leave a trail of a large number of deaths, sufferings and destruction affecting millions of people in the region. Between two and six percent of South Asia's gross domestic product (GDP) is lost in natural disasters every year. Two third of the South Asia's disasters are climate related, and global warming will increase the frequency, severity and unpredictability of extreme weather events. A great deal of these disasters in South Asia is directly or indirectly related to the presence of the Himalaya at its northern edge.

The Himalaya arc extending for nearly 2500 km in an E-W direction is the highest and the most active and fragile mountain system in the world. It forms the northern edge of South Asia and creates a formidable barrier to the north-drifting monsoon cloud from the Indian Ocean forcing it to precipitate all of its moisture south of the mountain range. Monsoon that lasts only for 3-4 months brings more than 80% of the annual rain in the region and causes serious water induced disasters including landslides, debrisflows and environmental degradation (Fig. 2). The Himalaya is highly fragile and constitutes a severely landslide prone region of the world resulting into yearly loss of numerous lives and heavy losses of property, infrastructure and environmental degradation. Himalaya is also the power house of water resources and directly supports the lives of nearly one billion people in the region.

2. Geology of the Himalaya

One of the important characteristics of the geology of the Himalayan arc is the general continuity and uniformity of the geologic units from east to west (Fig. 3). They are separated by major faults which run along almost the entire length of the range. The southern most mountain range adjacent to the Indo-Gangetic plain is the Siwalik Zone and consists of over 6 km thick pile of non-marine sedimentary rocks of Tertiary to Quaternary age. These are the foreland sediments of the Himalaya that were deposed in the frontal longitudinal basin developed at the southern edge of the mountain.

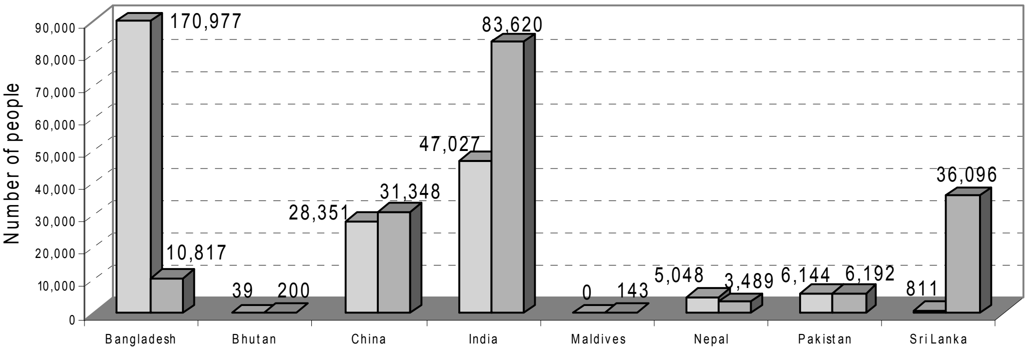
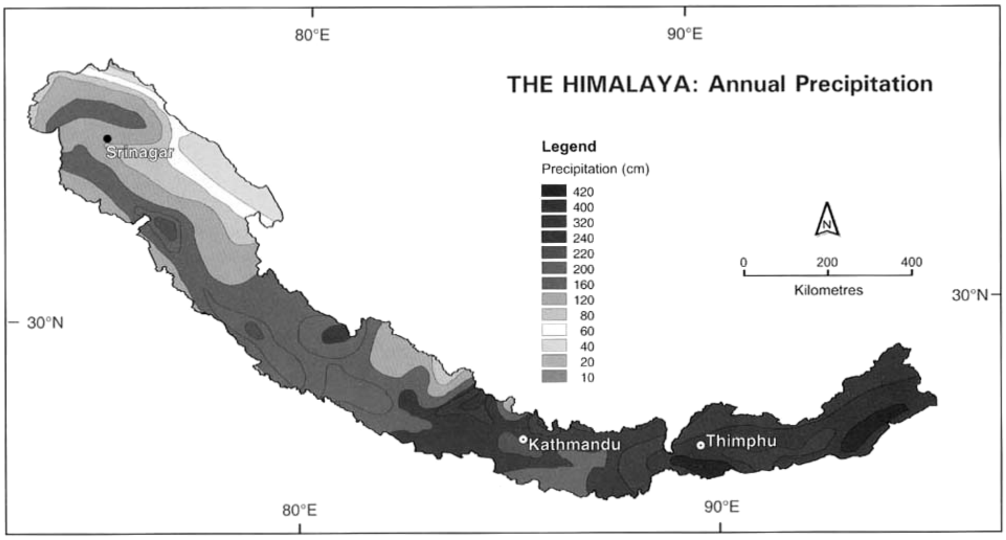


Fig. 1. Total number of people reported killed in south Asia and China 1985-1994 (left column), 1995-2004 (right column) (WDR 2005).



Source: ICIMOD, MENRIS compiled from FAO data

Fig. 2: Annual precipitation along the Himalayan arc (Zurick et al, 2005)

The Siwaliks are separated from the Gangetic plain by the Main Frontal Thrust (MFT). To the north of the Siwaliks lies the Lesser Himalayan zone essentially consisting of a thick pile of marine sedimentary rocks such as slates, phyllites, schists, limestones, marbles, dolomites, quartzites, and amphibolites, ranging in age from Proterozoic to Eocene. These are mostly low grade metamorphic rocks. The zone is separated from the Siwaliks by the Main Boundary Thrust (MBT). To the north, Lesser Himalayan Zone gives way to the Higher Himalayan Zone separated by the Main Central Thrust (MCT). These high grade metamorphic rocks are mostly composed of schists, gneisses and marbles and range in age between Upper Proterozoic and Cretaceous. The rocks to the north of Higher Himalayan zone are called the Tibetan Tethys Sedimentary Zone, and are separated from the southern unit by a normal fault known as the South Tibetan Detachment System (STDS). This zone consists of fossiliferous sedimentary rocks of lower Paleozoic to Cretaceous age. Each of these geologic zones behaves quite differently and poses different kinds of landslide problems.

3. Landslides in the Himalaya

Li (1990) estimates that the annual economic loss due to landslide damage alone in the Himalayan region exceeds one billion US dollars along with the loss of hundreds of human lives. He estimates that the loss due to landslides and related earth flow phenomena in the Himalayan region constitutes about 30 percent of the world's total landslide-related damage value. Data from the Durham landslide fatality database suggests that in 2007 over 1,000 people were killed by landslides in the Himalaya, representing almost 35% of the global total. In Nepal, for example, in the last two decades nearly one third of all deaths due to natural disasters came from landslides and debris flows (Fig 4). Afghanistan, Bhutan, China, India, Myanmar and Pakistan suffer heavily due to landslides and annually a large number of lives and property worth millions of US dollars are lost. In the Himalaya, landslides and debris flows are so pervasive that in one way or the other almost every individual is affected by these hazards.

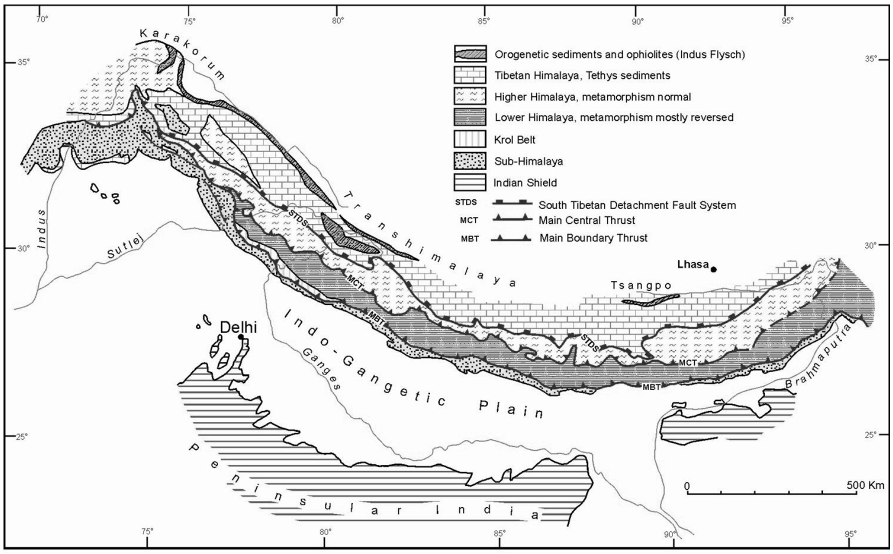


Fig. 3. Geological Map of the Himalaya (after Gansser, 1964)

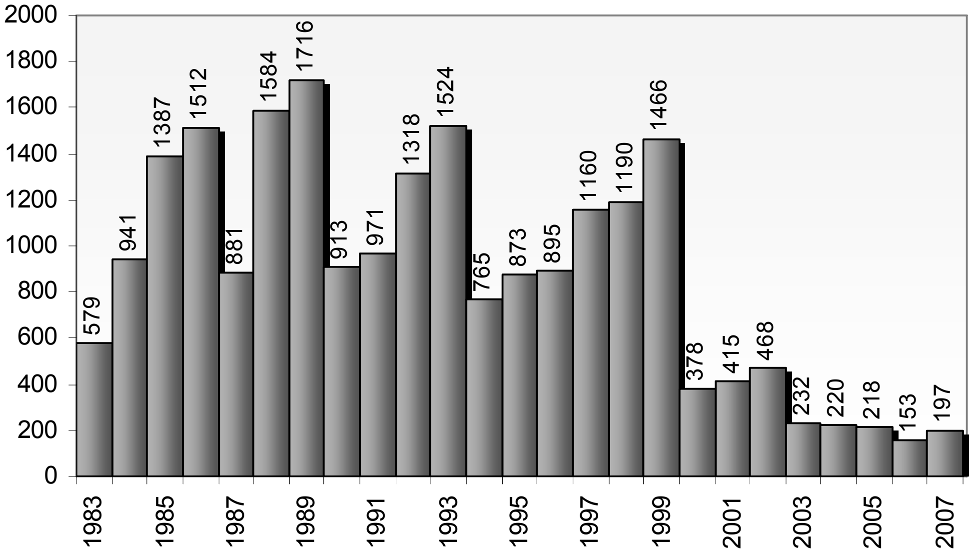


Fig. 4. Number of deaths (figures on the top of the columns) due to disasters in Nepal

Furthermore, Petley (2008) reported 2252 earthquake induced landslides (over 625 m^2 size) and over 20,000 people killed by the landslides in the 2005 Kashmir earthquake in Pakistan. Future earthquakes in the Himalayan region will continue to create similar landslide disasters and landslide damming of rivers. According to him the July 2008 earthquake in Wenchuan, Sichuan Province, China killed 28,000 people representing 35% of the death in the earthquake due to burial by mass movement. It also created hundreds of large and small landslide-damming of rivers causing great potential threats to millions of people and needed timely intervention.

Countries of the region will continue to sustain great losses due to landslides and debris flows and related flood hazards unless serious efforts are made to mitigate the hazard. As current trends of high population growth, increased migration trend, expansion of settlements, urbanization, and infrastructure development continue, vulnerability and, therefore, risks will increase steadily. On an annual average, Nepal spends 12.9% of its development expenditure and 5.39% of its real GDP per year in disaster response and recovery (Tianchi and Berhans 2002). The number of losses of human lives, relief, rehabilitation/ reconstruction cost of damaged and destroyed infrastructures are the direct measure of disaster impact. However, the cost of indirect effects of the landslides and floods, such as the reduction in agricultural productivity, loss in efficiency of hydropower plants, loss of capacity of reservoirs and irrigation canals due to siltation, long-term physical and psychological impacts to the disaster victims, cost of resettlement of people affected, environmental damages, economic losses due to disruption in traffic movement, and disruption in agricultural activities etc. are normally not evaluated properly which may some times amount to a much higher value than the direct cost of damages.

4. Global warming and the Himalayan environment

Global warming is a growing threat to humanity as a whole. The world experienced a surface temperature rise of 0.6°C on average during the 20th century, and the temperature by year 2100 is projected to go as high as 6.4°C relative to 1990 if GHG emissions are not reduced (IPCC 2007). The average maximum temperature in Nepal between 1977 and 1999 has increased by 0.9°C, at a rate of 0.03°C to 0.12°C per year (Shrestha et al. 1999), and is estimated to have gone even higher since then. As a result of global warming, monsoon precipitation has undergone some changes with decreasing rainy days and increasing high-intensity rainfall events, resulting into increase in magnitude and frequency of water-induced disasters - landslides, debris flows and floods. Global warming is going to affect the regional imbalance in rainfall amount, distribution and duration which will become a major cause of increased landslide related natural disasters as well as other environmental degradation.

Global warming is also contributing in the retreat of glaciers of the Himalaya at an alarming rate, and in the process has formed many new glacial lakes and rapidly expanded existing ones. Glaciers in Nepal are retreating as high as 100 m/yr, eliminating many small glaciers, creating new and enlarging the existing glacial lakes. There are already a large number of potentially dangerous glacial lakes in the Himalaya ready to burst and produce devastating Glacial Lake Outburst Floods (GLOF). Flowing through the mountain valleys these floods lead to overwhelming destruction along its trail downstream destroying human settlements, infrastructures, agriculture land and environment and also triggering numerous new landslides producing unstable slopes.

5. Himalayan Society for Landslides and Environment (HimSLE)

Despite the above scenario of serious landslide and debris flow problems in the Himalaya, concerted and systematic research on the landslide processes and environmental changes in the Himalaya and effective mitigative measures to reduce the impacts is yet to begin. Although certain efforts have been made by professionals and researchers of national agencies of Bhutan, India, Nepal and Pakistan, as well as from nongovernmental organizations, international agencies, and academic institutions, the areas of investigation, the methodologies adopted etc, differ considerably. Apart from this, there is a great lack of knowledge transfer and easy exchange of research findings among the researchers of different countries. Moreover, there are very few scientific meetings, workshops and conferences among the geoscientist, environmentalists, engineers and related people who are involved in Himalayan landslide and environmental research. To deal with all these issues in the Himalayan region and to share, discuss, facilitate and integrate the Himalayan landslide and environmental research, it was long been felt that a common platform of geoscientist, environmentalists, and engineers and other stake holders needs to be established. To concretize this idea a group of researchers from across the globe, actively engaged or interested in Himalayan research, have joined together and proposed to establish a society which is named as 'Himalayan Society for Landslides and Environment' and abbreviated as 'HimSLE' (pronounced as himsl).

The main objective of the proposed scientific society will be to set goals and strive for global action on landslide and environmental research in the Himalaya. The society will try to bring all researchers on landslides and environment in the Himalaya under a single umbrella and facilitate and encourage research activities in the region in a more coordinated manner on a global perspective to substantially reduce the present number of deaths from landslides and improve the quality of life of people in the Himalayan region. It will facilitate and advocate the discussions on the major issues of landslide and environmental research that must be addressed to design effective methods for landslide disaster reduction and environmental protection in the Himalayan region. It will help to establish a process to share knowledge, experience and resources about landslide disaster and environmental issues. The society will try to find out the existing technical and institutional gaps and the means to enhance national and regional capacities to monitor and respond to landslide disasters and environmental problems. It will also develop better mechanism of cooperation, networking and coordination of actions among different institutions at the global level for landslide and environmental research in the Himalaya. It will also create a regional high quality landslide disaster database.

The final list of the founder members is going to be announced at the World landslide Forum in Tokyo, Japan.

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Landslide Hazard Zonation of Babolrood Watershed, Iran

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Abstract. Landslides are among the most costly and damaging natural hazards in mountainous regions of the Babolrood Watershed. These landslides are mainly triggered by earthquakes and/or rainfall. Landslide Hazard Zonation (LHZ) maps were produced to evaluate the potential of slope instability in the region. Although the region faces high potential of landslide occurrence, because of the imposing geomorphological characteristics and high density of forest cover, the available information is very limited. Therefore an essential spatial database of landslides was established using GIS techniques. Various data layers namely lithology, fault buffer zones, earthquake induced acceleration, drainage layout, slope degree and orientation, slope degree, rainfall intensity, slope and landuse were considered as main affecting factors. The weighting-rating system based on the relative importance of various causative factors as derived from remotely sensed data and other thematic maps is used. Field observation and data collection on landslides are employed to evaluate and validate the resulting landslide hazard zonation map. According to the analyzed data based on three different methods, it is interpreted that the combination of lithology is the most influencing factor on the occurrence of landslides in the region. Due to the high annual precipitation (over 1800 mm) and sensitivity of clay minerals to absorb water, most of landslides occurred in rock units that contains clay minerals. Therefore marlstone formations of Late Tertiary period underlie some 35% of the landslides developed in the region. The LHZ map is employed to evaluate potential damage to infrastructures specifically the life line system and future development in the region.

Keywords. Landslide hazard zonation mapping, landslide evaluation

1. Introduction

In recent years, growing population and expansion of settlements and life-line projects over hazardous area increased the impact of natural disasters in Mazandaran Province. There is a high potential of landslide events in the Province where over 12% of the land surface has been affected by landslides. These events caused widespread damage to roads, farmland and other infrastructures in the area.

The geology of the area consists of a series of sedimentary rocks mainly limestone, dolomite, marlstone, siltstone and sandstone. These rock units belong to marine geological formations of Jurassic to Late Tertiary age. Quaternary alluvial deposits have a widespread distribution over the land surface, especially in the northern part of the area adjacent to the Caspian Sea. The morphology of the area is directly related to the rock type and geological features of the predominant formation. The geological setting of the area is shown in Fig. 1.

Landslides are a common topic of study: e.g. Varnes (1978), Guzzetti et al (1999), Lan et al (2004), and Neaupane and Piantanakulchai (2006). A number of landslide studies have been carried out in the Province by Uromeihy (2000), Faiz-Nia and Kalarstaghi (2004), and Entezari (2004).

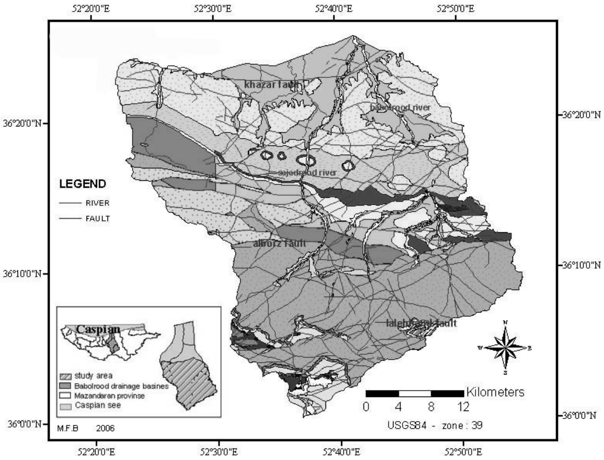

Fig. 1 Geological setting of the study area

Table 1 Classification of factors effecting landslide generation in the Babolrood watershed

	I	II	III	IV	V
lithology	Hard and massive laminated limestone	Jointed rock, sandstone	Marly limestone and dolomite	Marle, shale, fairly cemented alluvial	Uncemented alluvial and rocks
Slope angle	8<	8-16	16-25	25-45	>45
Fault distance (m)	100<	100-400	400-1000	1000-2000	>2000
Drainage distance (m)	100<	100-350	350-700	700-1000	>1000
Precipitation (mm/year)	470<	470-490	490-700	700-1000	>1000
Elevation (m)	0-300	300-500	500-700	700-1000	1000
Vulnerability	Very low	low	medium	high	Very high

2. Zonation mapping

Many factors influence the triggering and development of landslide in the study area. In this study, five factors were considered as the most significant elements. These include rock type, slope angle, faults distance, drainage channel distance, and annual rate of precipitation. Each factor is categorized into five classes according to its effect on landslide development. Table 1, illustrates the details of this classification. The landslide occurrence records regarding these factors are plotted in Fig. 5.

Although landslides are among the major geohazards in the Babolrood watershed, but the information on them is very limited. The first essential step in this study was to establish spatial databases for landslides in ArcGIS, including landslides inventory data and the affecting factors. In order to relate landslide occurrences to the factors, three methods were used. These methods are defined as area density method (ADM), information value method (IVM), and index overlay method (IOM). Landslide hazard zonation maps resulting from each method are shown in Fig. 2, 3 and 4, respectively.

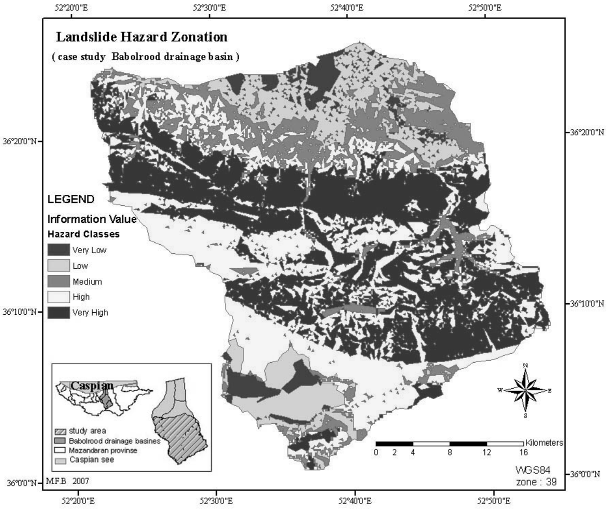

Fig. 2 Landslide hazard zonation map according to the *Area Density Method*.

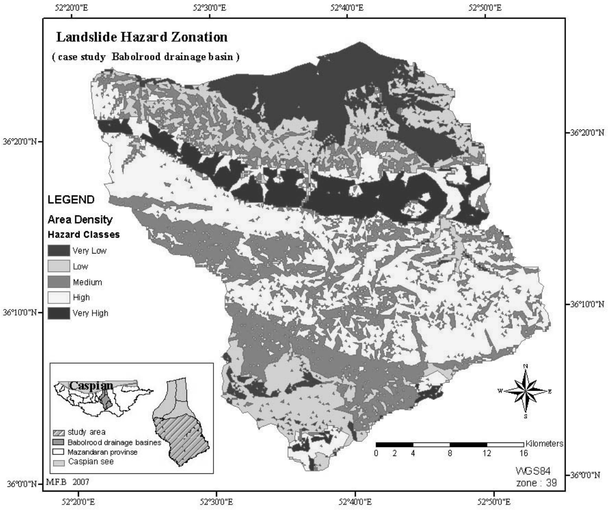

Fig 3 Landslide hazard zonation map according to the *Information Value Method*

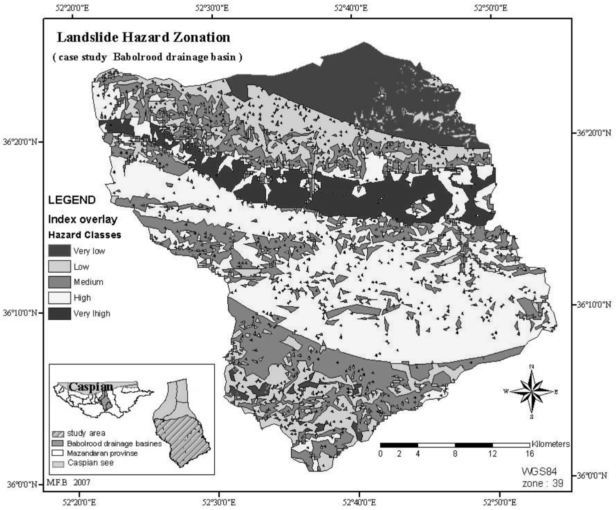

Fig. 4 Landslide hazard zonation map according to the *Index Overlay Method*

3. Conclusions

It is concluded that lithology has a great influence on the development of landslides in the Babolrood watershed area. It was also found that geological formations with higher percent of clay materials have higher potential of landslide occurrence. Most landslides were activated in areas with slope angle between 8 to 25 degrees. The zonation map based on the *area density method* (ADM) showed better results in comparison to the *information value method* (IVM) and the *index overlay method* (IOM).

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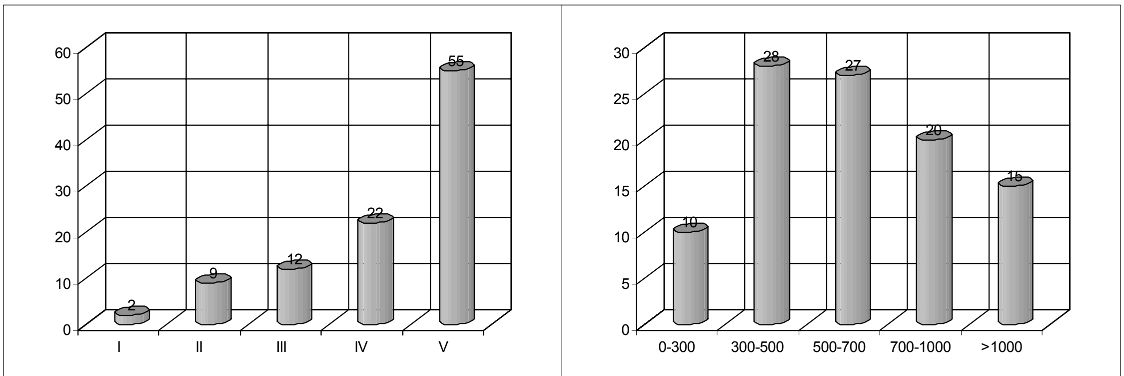
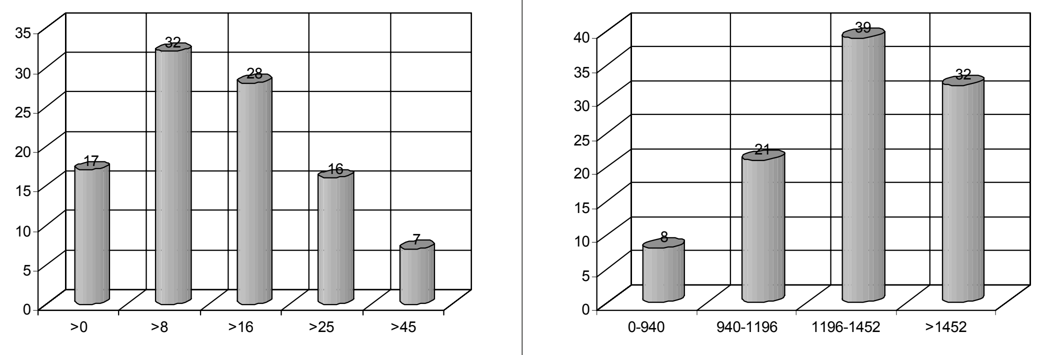


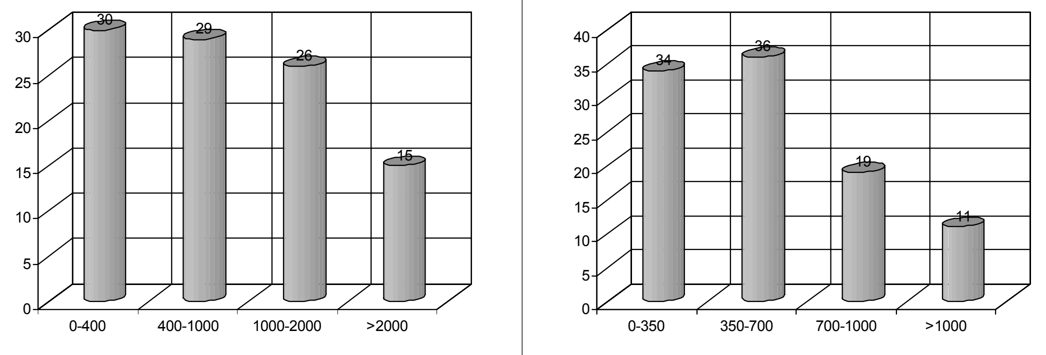
A: Effect of lithology

B: Effect of elevation



C: Effect of slope angle

D: Effect of Precipitation



E: Effect of fault distance

F: Effect of drainage distance

Fig. 5 Effect of various factors on development of landslides in the Babolrood watershed area

Landslide Process Activization on Sites of Cultural Heritage in Moscow, Russia

Valentina Svalova, German Postoev (IEG RAS, Moscow, Russia)

Abstract. Landslides process is one of the most widespread and dangerous processes in the urbanized territories. In Moscow the landslips occupy about 3% of the most valuable territory of city. In Russia many towns are located near rivers on high coastal sides. There are many churches and historical buildings on high costs of Volga River and Moskva River. The organization of monitoring is necessary for maintenance of normal functioning of city infrastructure in a coastal zone and duly realization of effective protective actions. Last years the landslide process activization took place in Moscow. The reasons of activization and protective measures are discussed. Structure of monitoring system for urban territories is elaborated.

Key words. landslide, monitoring, cultural heritage, Moscow, Russia

1.Vorob'yovy mountains landslide area

In Moscow many cult and city constructions are located on coast of the river Moscow and, in particular, on the right high slope. The right coast of river Moscow on its significant extent is struck by deep block landslides with depth up to 90 - 100 m which formation occurred in preglacial time with basis of sliding in Callovian-Oxford clays of Jurassic system on 25 - 30 m below modern level of river Moscow. One of landslide sites is on Vorob'yovy mountains, on a high slope of the right coast of the river Moscow (Fig.1).

Fig. 1 Vorob'yovy mountains

Fig. 2 Andreevsky monastery

Within the limits of a considered site there is a historical monument of federal value - «Andreevsky monastery», based in 1648. It includes Resurrection cathedral (1689 - 1703), church of Saint Andrey Stratilat (1675), bell tower with church of Saint John Bogoslov (1748), being a monument of the Moscow baroque (Fig.2).

Also there the complex of buildings of Presidium of the Russian Academy of Sciences, constructed in 70 - 80th years of 20-th century (Fig. 3), bridge with station of underground "Vorob'evy mountain" and a sports complex (Fig. 4) are located. Landslide slope is in an active condition, and there are many attributes of activization of deep block landslide.

Fig. 3 Presidium of RAS

Fig. 4 Ski jump

2. Kolomenskoye landslide area

Another landslide site is in a southeast part of Moscow, occupying the right coast of river Moscow from museum - reserve "Kolomenskoye" up to station Moskvorech'e. The museum - reserve "Kolomenskoye" represents an imperial manor of XVI - XVII centuries, in which outstanding monuments of Russian architecture were kept (Figs. 5, 6).

The greatest activity is shown with a slope in east part of a site, in area of an arrangement of city collectors. The slope in this place has height of 38 - 40 m.

Motions of deep landslips have begun from 1960 in connection with construction of collectors. In 70th years of the last century there was a strong activization of a slope with formation of cracks by extent up to 500 m and displacement of a landslide in the plan over 1 m. Last serious activization of a landslide has taken place in 2002 with a motion on 53 cm. In the area of Kolomenskoye not once there were observed deformations of the sewerage pipeline in the place of the pass over the Moskva River.

It was determined by instrumental observations (inclinometric and tensometric measurements of bends of stationary tubes in the wells) that the basic sliding surface of the deep landslide lies within a depth interval of 100.5 to 101.0 m, whereas the water level in the river is 114.3 m (Fig.7). It means that the sliding basis is located in black clays of the Oxfordian Range within the Jurassic system below the erosion basis, which is typical of deep blockglide landslides in the given region.

3. Khoroshevo landslide area

Catastrophic activization of the deep blockglide landslide in the area of Khoroshevo in Moscow in 2006-2007, on the left-hand shore of the Moskva River, is threatening to the Holy Trinity Temple in Khoroshevo (monument of XVI century) and living houses (Figs. 8, 9).

A crack of 330 m long appeared in the old sliding circus, along which a new 220 m long creeping block was separated from the plateau and began sinking with a displaced surface of the plateau reaching to 12 m. Such activization of the landslide process was not observed in Moscow since mid XIX century. The sliding area of Khoroshevo was stable during long time without manifestations of activity, though the height of the above-landslide scarp was critical, which indicated to its limit stability.

In the western part of the above-described sliding area, the active development of deformations began in August 2006. Fractures were formed on the territory of Holy Trinity Temple in Khoroshevo (monument of the XVI century) and in the area of two-storied living houses (Fig.10). In the upper part of the slope a new creeping block was formed with a length of about 220 m. The block involved a near-brow 12 m - wide part of the plateau along the length of 180 m. The total length of the area with activated landslide process was 330 m.

It should be noted that the scientific society, geologists and planners did not have a common opinion on the type and scales of the activated landslide. (Osipov et al. 2002, Kutepov et al. 2002, Postoev&Svalova 2005). In particular, under discussion was the idea that the landslide is shallow and has the form of creeping near-surface sandy strata.

Fig. 5 Museum - reserve "Kolomenskoye"

Fig. 6 The church of Beheading of the Honest Head of Iowan Predecessor near Kolomenskoye

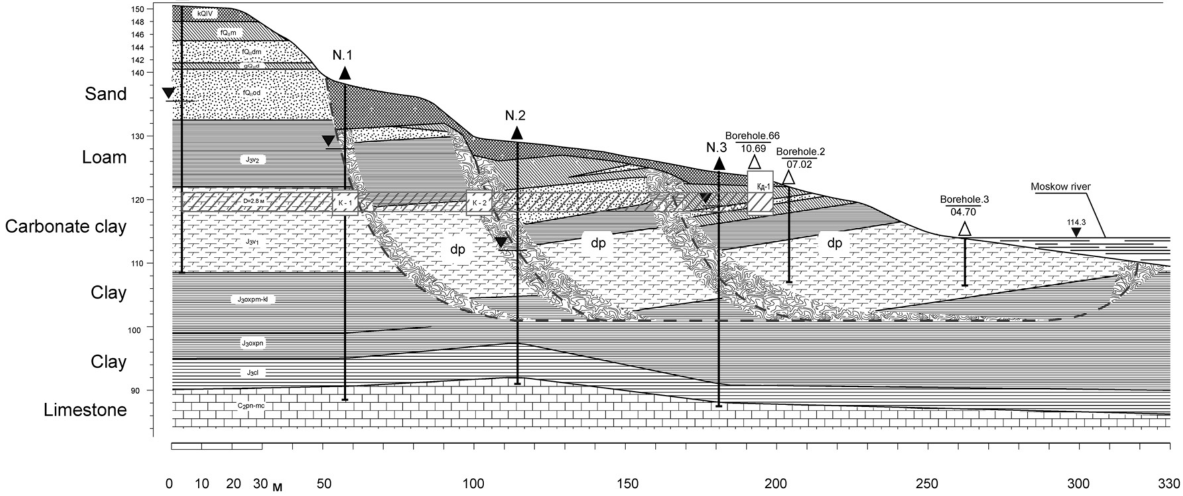


Fig. 7 Example of deep blockglide landslide. Moscow, Kolomenskoe. N.1, N.2, N.3 - extensometers, inclinometers

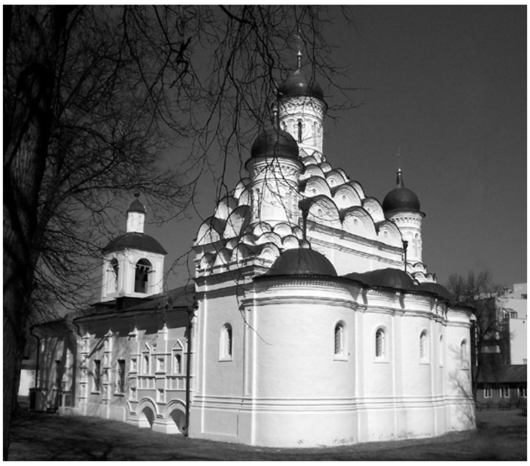


Fig. 8 Holy Trinity Temple

Fig. 9 Living houses in Khoroshevo

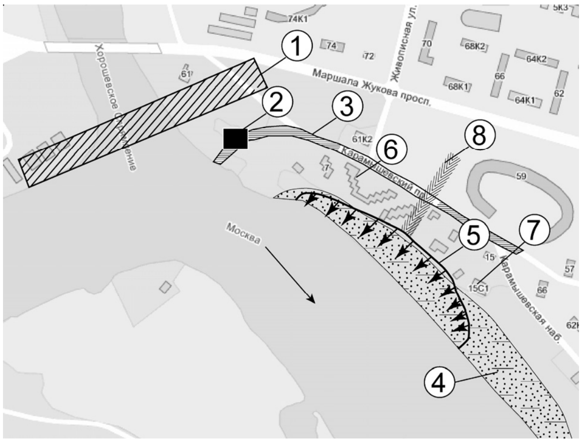


Fig. 10. Plane of disposition of active landslide area. Moscow, Karamyshevskaya enbankment. 1 - bridge under construction; 2. - new treatment plant; 3 - new header; 4 - sliding circus Khoroshovo 1; 5 - place of activisation of sliding deformation; 6 - cottage community; 7 - temple of XVI century; 8 - buried channel.

However, all the indications (i.e. the length of the basic subsided fracture of extension, character of formation and subsidence of the block, form of the bulging swell, uplifted fracture of rock compaction, etc.) indicate that activization of the sliding process has happened in the old landslide circus Khoroshevo-1 in the form of basic (catastrophic) deep landslide displacement with origination and subsidence of a new creeping block, the steep curvilinear sliding surface of which crops out onto the deep inherited, almost horizontal displacing surface under the old landslide body. It was supposed that in accordance with the results obtained by analysis of the situation on the given object and with the experience of studying landslides in other areas in Moscow with similar geological conditions , the existing horizontal part of the sliding surface, along which further movements will take place, is located in a layer of Jurassic clays of the Oxfordian Stage. Possible development of deep movements in the area under consideration is also confirmed by geotechnical analysis of the clay strength and vertical pressure from the overlying layers. Analysis of the situation in the area has showed that a trigger of activization could be the construction works in the Karamyshevsky Pr.Street. The water-conducting pipes and other communications were being lain in a deep trench (depth is about 7 m) in June-July 2006.

This trench could redistribute the fluxes of shallow groundwater and waste waters and direct them through the buried erosion-induced entrenchment (a sink in the area center) into the above-landslide scarp and the existing landslide body. Since Octoer 2006 there was started well drilling, performance of geophysical investigations, geodetic observations of the marks on ground and on houses, measurement of deep deformations (inclinometers, extensometers, tensometric observations).

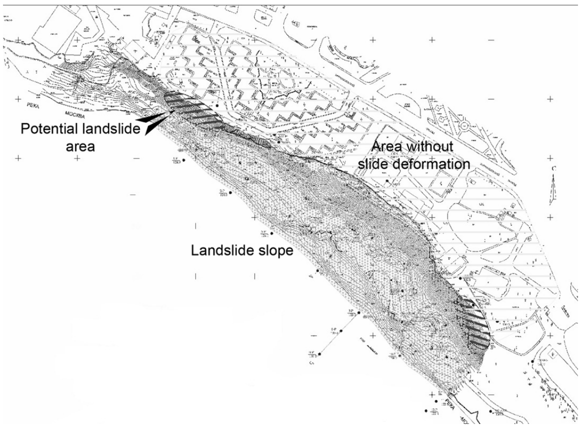


Fig. 11 Deformation zones in the area of landslide activization.

It was established that in January displacements began in the lower part of the slope. The total displacement of this rock massif for two months (December-January) amounted to 13 - 20 mm. Moreover, the position of the sliding surface in the massif was determined instrumentally. It is located in Jurassic clays, involving the Oxfordian Stage near the layer roof . The depth of deformations reached 31 m. Creeping deformations are still going on.

On the plateau, beyond the landslide (on the territory of the Holy Trinity Temple and living houses), deformations are weak and mainly in the form of subsidence of -2 to +1 mm (since October 2006 till January 2007). If to reinforce the sliding block in accordance with the mechanism of landslides of the given type, deformations on the plateau will be stopped. However, in the marginal parts of the active circus where the basic fracture is sinking towards the base of the above-landslide scarp, formation of new sliding blocks is possible according to the property of “self-development” (Fig.11).

Protective measures

Planning of protective measures is implemented simultaneously with carrying out engineering-geological and geophysical investigations of the area and observations within the landslide deformation monitoring system. It is foreseen to carry out regulation of surface water discharge, drainage of shallow groundwater on the sliding bench for prevention of a water level rise; to install a system of detaining facilities in the form of a berm – a counter-banquette (a sandy fill of 3 to 5 m on the surface of the landslide bench) and of a supporting wall – i.e. a reinforced concrete pile rostwerk, "sewing" the landslide body to the undisplaceable bed (pile tips are deepened into the Jurassic clays of the Callovian Stage, $J_3c\ell$) and preventing the overlying active block to displace.

The project of reinforcing is being corrected and developed further with obtaining new information on engineering-geological conditions and dynamics of the landslide.

Landslide motions is extremely actual and difficult problem which decision is necessary for preservation of valuable historical monuments and modern city constructions. Mechanical models and system of complex monitoring of landslide processes are under elaboration.

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Empirical Hydrological Models for Early Warning of Landslides Induced by Rainfall

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Abstract. Empirical mathematical models relating landslide threshold and antecedent rainfall are analyzed. The FlaIR model, in particular, is described. It is composed of two modules: the R-L (Rainfall-Landslide), which consider the relationship between landslide occurrence and value assumed by a mobility function which depends on antecedent rainfall, and the R-F (Rainfall-Forecasting), which allows to evaluate in advance the value that will be attained by mobility function. The main characteristics of early warning system based on FLaIR model are also described. Two different case studies are discussed, concerning Sarno, in Campania Region and two areas in Piemonte Region, respectively in Southern and Northern Italy. As R-F module have been adopted stochastic models in the Sarno case and meteorological forecast in Piemonte case.

Keywords: Risk evaluation, early warning, monitoring, hydrological modeling

1. Rainfall, Landslides, Early Warning

The risk of landslide is extremely variable. In fact, slope movements have a wide range of velocity, size and run-out, thus their magnitude and impact on exposed goods can be either very low or very high, depending on site conditions, material involved and other factors. Velocity not only affects landslide destructiveness, but also the procedures to adopt for risk mitigation. Velocity can range between some tens of metres per second (as for rock falls and avalanches, debris flows and flowslides) and some millimetres per year (as for active slides in clay and some lateral spreads).

Early warning can be defined as the entirety of actions to be taken during the lead time, that is, the time interval between the moment of the event prevision and the moment of the landslide impact. Generally, early warning is the provision of timely and effective information allowing individuals exposed to hazard to take actions in order to avoid or reduce the damage and the loss of life.

From a general point of view, there are four crucial moments in landslide early warning, such as: precursor forecasting (t_1), precursor occurrence (t_2), event initiation (t_3) and impact on people and goods (t_4) (Picarelli et al., 2007).

Early warning systems prove quite efficient when the time (t_3-t_2) or the time (t_4-t_3) is sufficiently long to make decisions and take actions such as evacuation or protection of structures and infrastructures.

When the time between the event and its impact (t_4-t_3) is extremely short, adoption of early warning procedures must be based on precursor measurements. This is the case of rapid landslides, as the time elapsing between the onset of slope failure and its impact on exposed goods is typically in the order of tens of seconds. When the time between precursor occurrence and event initiation (t_3-t_2) is also short the forecasting of the precursor becomes indispensable. This is the case of shallow landslides when the time between the precursor and the event is in the order of tens of minutes.

Rainfall is largely adopted as a precursor for early warning of landslides, owing to the large prevalence of landslides induced by rainfalls.

The identification of the precursor is the most important issue in landslide forecasting, so the relationship between landslide triggering and intensity or duration of rainfall has been largely investigated to identify threshold values.

Based on the collection of data on landslides and related triggering rainfall, thresholds, often based on a combination of rainfall intensity and duration, have been obtained for several regions, as Hong Kong (Finlay et al., 1997), California (Campbell, 1975), New Zealand (Glade et al., 2000), etc. In some of these countries, early warning systems have been conceived to prevent disasters. In fact, these thresholds, in combination with rainfall forecasting and real-time rainfall monitoring, can lead to realize operational landslide warning systems. As an example, in 1977, the Hong Kong Geotechnical Engineering Office established a Landslip Warning System, which has been continuously updated and improved over the years (Chan et al., 2003). Similar systems have been elaborated to prevent the consequences of rainfall-induced debris-flows in the S. Francisco Bay (Keefer et al., 1987). D'Orsi et al. (1997) report the Rio-Watch, an alert system based on a network of 30 telemetered rainfall gauges and weather radars covering the city of Rio de Janeiro, which issued 42 warnings between 1998 and 2003. Similar systems have been set up in the State of Oregon (Mills, 2002) in the UK (Cole and Davis, 2002). Even though a true early warning system has not been set up, in the landslide prone area around Wollongong, Australia, a monitoring system is active and provides continuous information through the WEB with regard to the slope stability conditions (Flentje et al., 2005). Previous considerations show that today prediction of rainfall-induced landslides is mostly carried out through the so-called hydrological models (Fukuoka, 1980; Mitchue, 1985; Cascini and Versace, 1988), which are based on historical data regarding landslides and related triggering rainfall and do not require field instrumentations and measurements. *Hydrological* models are distinct from *physically-based* models, which attempt to reproduce the physical behaviour of the processes involved at hillslope scale. These models are complex and need many field investigations and surveys.

2. The FLaIR model

In Italy, Sirangelo & Versace (1996) have proposed the hydrological model called FLaIR (Forecasting of Landslides Induced by Rainfall) to forecast, in real time, the landslide movements activated by rainfall. It is composed by two modules. The first one, the R-L module (Rainfall-Landslide), correlates precipitation and landslide occurrence. It enables model calibration and permits the reproduction of historical movements. The second one, the R-F module (Rainfall-Forecasting), provides a tool for real-time forecasting. It allows probabilistic evaluation of rainfall events through rainfall nowcasting, by stochastic or meteorological models, indispensable to identify hazard conditions for landslide occurrence with suitable lag time. Using both modules, the model enables a probabilistic evaluation of future landslide occurrence.

The R-L module links the *mobility function* $Y(t)$, which depends on the antecedent rainfall depths, and the probability $P[E_t]$ of landslide occurrence at the time t by the relation:

$$P[E_t] = g[Y(t)] \qquad (1)$$

where $0 \le g(.) \le 1$.

Among the various admissible relationships, in the FlaIR model a simple threshold scheme is often assumed:

$$P[E_t] = \begin{cases} 0 \ \ if\ Y(t) \le Y_{cr} \\ 1 \ \ if\ Y(t) > Y_{cr} \end{cases} \qquad (2)$$

being Y_{cr} a threshold value of $Y(t)$. The mobility function $Y(t)$ is defined as:

$$Y(t) = f[I(u)] \qquad -\infty < u \le t \qquad (3)$$

where $f(.)$ is a generic function and $I(u)$ is the infiltration rate. Under the assumption of linear and stationary behaviour of the natural system, the function $f(.)$ can be expressed in the form:

$$Y(t) = k_0 \int_{-\infty}^{t} \psi(t-u)\, I(u)\ du \qquad (4)$$

where $\psi(.)$ is a filter function, and k_0 is a constant depending on the characteristic of the analyzed case.

A central role is played by the choice of the filter function $\psi(.)$ which can assume different expressions, like the gamma function, beta function or mixture of two negative exponential function, this last one expressed by:

$$\psi(t) = \omega\beta_1 \exp(-\beta_1 t) + (1-\omega)\beta_2 \exp(-\beta_2 t) \qquad \beta_1 \ge \beta_2 \qquad (5)$$

In particular, the eq. (5) is suitable for reproducing the behaviour of an hillslope characterised by two different mechanisms of interaction between rainfall and slide movements. The first one reproduces the effect of the more recent rainfall (short term component), while the second one reproduces the effect of the less recent rainfalls (long term component). The third parameter, ω, is representative of the relative weight of the two mechanisms in the behaviour of the hillslope.

The choice of the filter function $\psi(.)$ and the calibration of model parameters $\underline{\theta}$ can be developed following different techniques (Iiritano et al., 1998), that for the sake of brevity can not be described here. The infiltration rate $I(.)$ is assumed proportional to the rainfall intensity $P(.)$, according to the following simple relationship:

$$I(u) = rP_*(u) \qquad P_*(u) = \begin{cases} P(u) & when \quad P(u) \le P_0 \\ P_0 & when \quad P(u) < P_0 \end{cases} \qquad (6)$$

where P_0 depends on soil characteristic, and r is a factor of proportionality. Because the mobility function is defined up to an arbitrary multiplicative factor, it is possible to choose $rk_0 = 1$ so that:

$$Y(t) = \int_{-\infty}^{t} \psi(t-u)\, P_*(u) du \qquad (7)$$

To increase the lead time for landslide forecasting it is necessary the forecasting of precursor, i.e. rainfall nowcasting. So it can be considered also the time (t_2-t_1). The R-F module of FLaIR model allow this opportunity, as it is able to estimate, at time τ, the probability that at time t the mobility function $Y(t)$ will reaches or exceeds the critical value Y_{cr}. The value $Y_\tau(t)$ that the mobility function will assume at time *t*, carried out at time τ, with $\tau < t$, may be written splitting the convolution integral in two parts:

$$Y_\tau(t) = \int_{-\infty}^{\tau} \psi(t-u) P(u) du + \int_{\tau}^{t} \psi(t-u) P(u) du \qquad (8)$$

The first term is evaluated on the basis of observed rainfall, so it can be considered as the deterministic component, $Y_\tau^{(\det)}(t)$ which depends only on the rain fallen up to time τ. The second one is the stochastic component $Y_\tau^{(sto)}(t)$ that depends, on the contrary, on the rain that will fall in the interval $]\tau;t]$. It can be estimate by applying a meteorological model or a stochastic one, like, e. g., the *PRAISE* model (**P**rediction of **R**ainfall **A**mount **I**nside **S**torm **E**vents) proposed by Sirangelo et al. (2007). Synthetic scheme of the mobility function components is in **Figure 1**.

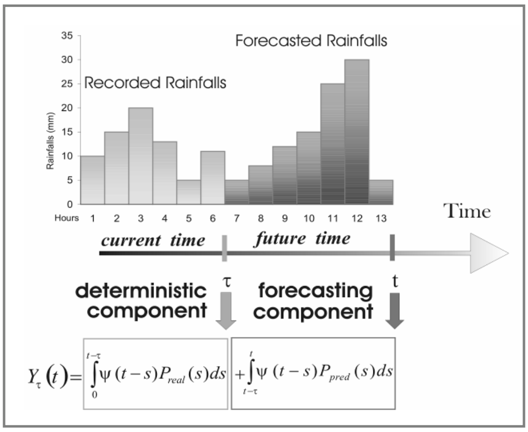


Fig. 1 Synthetic scheme of the mobility function components.

3. The FLaIR model for landslides early warning

In both cases, with or without rainfall nowcasting, the FLaIR model may be usefully employed to forecast the hazard of slide movements triggered by rainfall, allowing the activation of the necessary procedures of civil protection.

The adopted strategy in reducing risks during landslide or inundation events is usually based on three warning levels: "*attention*" (or "*advice*"), with instrumental real-time monitoring and real time simulation model running; "*alert*" (or "*watch*"), involving civil protection agencies and field direct control; "*alarm*" (or "*warning*"), involving population to be evacuated.

A characteristic mobility ratio (*FLaIR index*) $\chi = Y / Y_{cr}$ is associated with each warning level. Using only the "R-L module", each warning status is activated simply when a fixed value of mobility ratio χ is exceeded.

If the early warning system also includes rainfall nowcasting and then also the R-F module is utilized, the activation of each warning status is based on the value of the probability, estimated at time τ, that the mobility ratio $\chi = Y / Y_{cr}$, at time t, would exceed threshold values.

A full description of the approach referred here, can be found in Sirangelo et al (2007). The choice of the values of index χ for each warning level must consider the necessity to have adequate safety margins, that needs the low values of mobility ratio, and to avoid false alarms, then high χ values. The plausible values, already used in different applications are the following: $\chi_1 = 0.40$, for the attention status, $\chi_2 = 0.65$ for alert and $\chi_3 = 0.85$ for alarm status. These values could be quite different if R-F module is also used.

4. Case studies

In this section two applications of the FLaIR model concerning italian experience are described.

An important application regards the mud flows occurred on 5th May 1998 at Sarno, that produced 160 victims and severe destructions in the towns of Sarno, Siano, Bracigliano and Quindici (Versace et al. 2007).

After heavy and persistent rainfalls, the pyroclastic cover of Pizzo d'Alvano relief were affected by more than one hundred landslide movements displacing more than two millions of cubic meters of material. The landslides evolved in about 40 mud-flow, which moved for 2-3 km into the surrounding lowlands and reached the inhabited areas.

The initial movements took place in the steepest parts of the slopes, on surfaces inclined up to 40-45 degrees, often at the head of the gullies. In many cases, the locations of the instabilities appear to have been controlled by the presence of cliffs and by the artificial track-ways crossing the slope.

It was recognised that the physical mechanism of the Sarno movement was significantly different to the other cases happened in Italy, due to pyroclastic soil types that cover the Sarno area (Picarelli et al. 2007).

The FLaIR model has been applied in the Sarno case and is now employed for early warning, by using the stochastic model PRAISE as R-F module. The model was specified by a filter function of the double exponential form (eq.5) and calibrated with parameters $\omega = 0.1$; $1/\beta_1 = 0.75$ *days* ; $1/\beta_2 = 150$ *days*. A value, $P_0 = 7.5 mm/hr$ was adopted in equation (6). The critical value obtained for the mobility function is $Y_{cr} = 9.11$ matched during the catastrophic event of May 5th-6th, 1998, how indicated in **Figure 2.**

The second case study concerns two areas of Piemonte region: Lanzo valleys and Langhe hills, which differ on geological, geomorphologic and climatic features as well as landslide typology.

According to the classification proposed by Varnes (1978), the area of the Lanzo valleys is mainly characterized by landslides of a rapid earth-debris flow type, while, in the Langhe area, translational slides prevail.

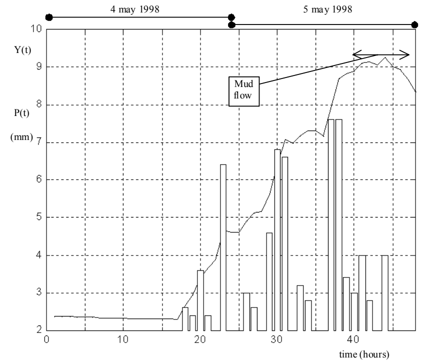


Fig. 2 Observed hourly rainfall and mobility function for Sarno mudflow

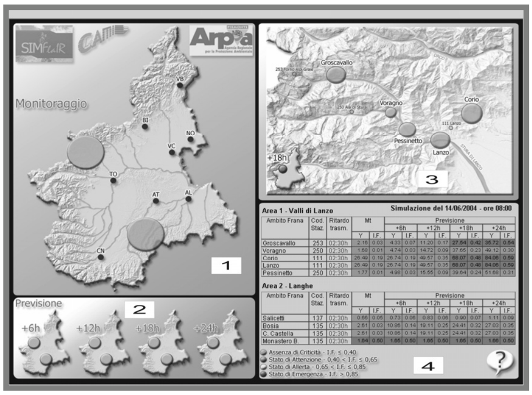
A great deal of significant data, regarding instability phenomena documented since 1950, was collected for each of the two zones. In particular, for each landslide, specific information was obtained about morphological, lithological and kinematical features, dates (day, month, year) of landslides and rainfall recorded by the measuring stations situated near the area studied. 22 landslide events were selected as useful case-studies. The FLaIR model was applied to all selected landslide cases, obtaining for each the shape of the transfer function, the admissibility field of the parameters and the historical pattern of the mobility function for all admissible parameters. The best fit has been given by the gamma function. A warning system, called *MoniFLaIR*, was implemented using these results. It is managed by a regional Agency (Arpa Piemonte). It acquires, in real time, rainfall data transmitted by the rain gauges located near to the landslide area and calculates the value of the mobility function every 30 minutes. The system estimates the FLaIR index χ both with and without rainfall forecasting.

The system, in fact, is composed of both a monitoring module, taking into account the actual rainfall data, and an advanced warning module which employs the data provided by meteorological models, used by the Regional Structure, which give rainfall forecasts for hours.

Figure 3 shows a picture of the MoniFLaIR graphic interface, that is composed of four sections representing:

- monitoring area, with a map of the Piemonte region in the main image and representative polygons of the two monitored areas. These have different colours according to the warning level (attention, alert, alarm) observed in the area (section 1);
- forecast area, with secondary images, with the same features as the monitoring area section, representing the situations for different interval of forecasting (section 2);
- geographical detail area, with a map of one of the two areas where the current or the forecasted situation can be represented, according to operator decision (section 3);
- synthesis area, with a table highlighting quantitatively the warning level reached for each landslide body and

providing the current and future values of both mobility function and FlaIR index (section 4).



Area 1 - Valli di Lanzo **Simulazione del 14/06/2004 - ore 08:00**

Ambito Frana	Cod. Staz.	Ritardo trasm.	Mt		Previsione							
					+6h		+12h		+18h		+24h	
			Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.
Groscavallo	253	02:30h	2.16	0.03	4.33	0.07	11.20	0.17	27.54	0.42	35.72	0.54
Voragno	250	02:30h	1.68	0.01	4.74	0.03	14.72	0.09	37.65	0.23	49.12	0.30
Corio	111	02:30h	26.49	0.19	26.74	0.19	49.57	0.35	68.07	0.48	84.06	0.59
Lanzo	111	02:30h	26.49	0.19	26.74	0.19	49.57	0.35	68.07	0.48	84.06	0.59
Pessinetto	250	02:30h	1.77	0.01	4.98	0.03	15.55	0.09	39.64	0.24	51.68	0.31

Area 2 - Langhe

Ambito Frana	Cod. Staz.	Ritardo trasm.	Mt		Previsione							
					+6h		+12h		+18h		+24h	
			Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.
Salicetti	137	02:30h	0.66	0.05	0.73	0.06	0.83	0.06	0.90	0.07	1.11	0.09
Bosia	135	02:30h	2.61	0.03	10.86	0.14	19.11	0.25	24.41	0.32	27.03	0.35
C. Castella	135	02:30h	2.61	0.03	10.86	0.14	19.11	0.25	24.41	0.32	27.03	0.35
Monastero B.	135	02:30h	1.64	0.50	1.65	0.50	1.65	0.50	1.65	0.50	1.66	0.50

● Assenza di Criticità - I.F. ≤ 0,40
● Stato di Attenzione - 0,40 < I.F. ≤ 0,65
● Stato di Allerta - 0,65 < I.F. ≤ 0,85
● Stato di Emergenza - I.F. > 0,85

Fig. 3 MoniFLaIR system interface

Figure 4 shows the trend of the mobility function from August to November 2004. The function has gone over the critical value on November 2^{nd} when a debris flow occurred at Colle Fea site. Using the R-F module the exceeding was foreseen up to 24 hour in advance.

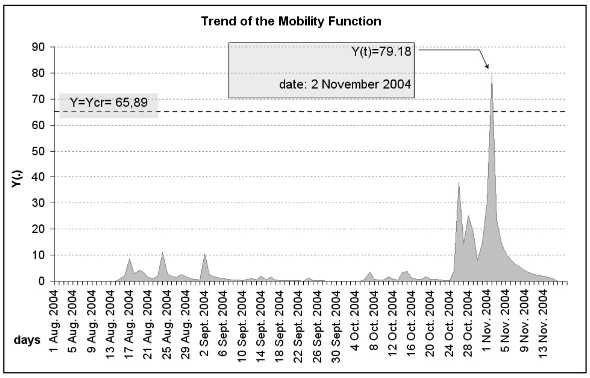


Fig.4 Trend of mobility function recorded between 1st August and 4th November 2004.

5. Conclusions

The empirical hydrological model FLaIR seems very flexible as it mainly depends on the shape of transfer function that can be very different from one case to the another. So FLaIR can be used in very different scenarios like those described in the paper. The model allow to increase the lead time as it can increase time between precursor occurrence and event initiation by using the R-L module, and can also increase the time between precursor forecasting and precursor occurrence by using the R-F module. The FLaIR model also allow to adopt for rainfall nowcasting both stochastic and meteorological models. The case studies reported in the paper show that FLaIR model may be used in early warning systems for different type of landslides. In fact it has been successfully applied in Campania region, Southern Italy, in the Sarno area for mud flows and in Piemonte Region, Northern Italy, in Lanzo valley and Langhe hills where debis flow and translational slides prevail.

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Delimitation of Prehistoric Rock Fall from Huascaran Mt., Peru

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Abstract. The area of rock and ice avalanches from Huascaran Mt. (Cordillera Blanca, Peru) was studied to compare the well documented 1962 and 1970 events with a prehistoric one (or ones?) which was much larger in the sense of volume and reach. The limits (lateral and frontal) were specified more precise compare to former studies in this area. Nevertheless the absolute dating and amount of prehistoric events remain unknown and is a matter for future research. To distinguish the genesis of granodioritic rock blocks at the slopes and foothill of Huascaran Mt. a complex of methods were used. Among them Schmidt Hammer tests were useful tool for relative dating.

Keywords. Natural hazards, rock and ice avalanches, geomorphology, Cordillera Blanca, Huascaran Mt., Peru

Fig. 1 Huascaran Mt. (6 768 m a.s.l.) from SW with large amount of sediments at the foothill, which are of polygenetic origin.

1. Introduction

Huascaran Mt. (6 768 m a.s.l.) is the highest peak in Cordillera Blanca mountain range (part of Western Cordillera). The border between Cordillera Blanca and adjacent range on the West site is the Santa River. As the Santa River valley (Calleyon de Huaylas) is densely populated and recently people have been even moving to the areas affected by the 1962 and 1970 Huascaran Rock and Ice falls (e.g. Lomnitz C 1971, Plafker G et al. 1971), it is very important to outline in detail the hazardous areas and to describe local landforms and their respective forming processes (Fig. 1 and 2).

Catastrophic events from Huascaran Mt. are usually composed of several types of processes and consequently given different names. Bolt et al. (1975) classified them as avalanches, because the starting process was a snow and ice avalanche. They have the character of debris flows or mud flows (Lomnitz 1971). Browning (1973) used the term rock slide. The 1962 and 1970 events were described in detail by several authors (e.g. Plafker and Ericksen 1978, Voight 1978, Vilímek 1995).

To understand the mechanism of origin and behaviour of a much larger prehistoric rock fall (avalanche) from the northern summit of Huascaran Mt. (6,655 m a.s.l.), it is important to outline borders of the enormous mass movement. Large blocks composed from granodiorites located at the slopes and foothill of Huascaran Mt. and even on the opposite slope of Cordillera Negra could be the remnants from this natural event. On the other hand the same type of rock blocks is parts of the glacial moraines.

2. Methodology

To distinguish granodiorites which were moved by glacial action from that ones, which originated by mass movements a complex of methods has been used. From the methodological point of view, we used 1970 infra red aerial photographs and 2006 and 1984 SPOT satellite images interpretation; geomorphological field investigation and mapping focused on identification and description of main landforms and related processes. We also used the N type of Schmidt Hammer device for relative dating of glacial and gravitational deposits originated through glacial and catastrophic gravitational processes - rock avalanches (Goudie 2006). However it is necessary to take into account, that some of the results are not very conclusive (e.g. Evans et al. 1999). One has to be careful to use the Schmidt Hammer (SH) testing for relative dating of polygenetic landforms containing blocks with different weathering history. Statistical analysis of SH tests was used to estimate the R-values of boulders in genetically defined groups (http://www.r-project.org).

3. Rock and ice falls from Huascaran Mt.

The hugest avalanche from Huascaran Mt., which is historically documented (e.g. Cluff 1971), was triggered by the 1970 earthquake (M = 7.75). The avalanche route started under the northern summit of the mountain, and then it followed the present river network and dragged downward a part of moraine material from the Huascaran slope. The major part of the material, which sedimented in the region of former villages Ranrahirca and Yungay, is not of river origin, although it passed through the river network. The transport of material from Huascaran was immense. In the accumulation region, there are many scattered huge blocks originating not from moraine sediments or from the debris mantle, but directly from the Huascaran rock wall. In the centre of the former Yungay village, the debris flow spread and its present surface is only slightly vaulted.

Fig. 2 Photo of the northern summit of Huascaran Mt., where from several rock falls occurred in the past.

In the place, where the Ranrahirca River is mouthing into the Santa River, the direction of the main watercourse of this region (Santa River) it markedly turned under the slopes of the Cordillera Negra mountain range. Probably since a long time already, the Santa River has been "pushed" away (by a huge amount of sediments) from Huascaran against its left riverbank. It has already affected the straight course of the Cordillera Negra foot. A pronounced depression is evident on the western slope of the Huascaran northern summit. The possibility of a huge pre-Columbian (prehistoric) rock-slide was discussed already in Plafker and Ericksen (1978); another attempt was done by Vilímek et al. (2000).

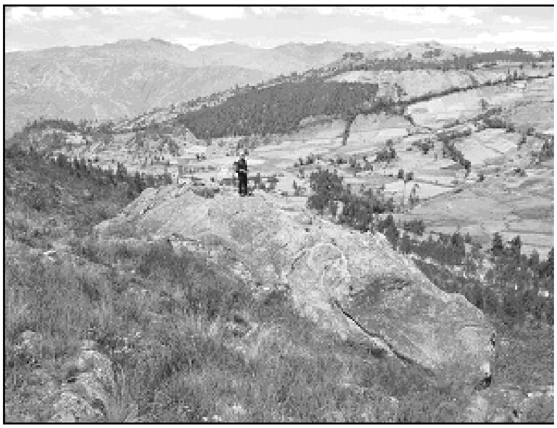

Fig. 3 One of the blocks tested by Schmidt Hammer. The block is part of the lateral moraine.

4. Prehistoric rock falls from Huascaran Mt.

Some rock blocks from Huascaran Mt. document after Plafker and Ericksen (1978) the lateral limits of a giant mass movement; others blocks distinguish the frontal part of an ancient rock fall (paleoavalanche). According to aerial photo from 1970 and numerous eye-witnesses the 1970 rock-fall reached the opposite slope of Huascaran Mt. (behind Santa River). This area, around Matacoto village, is already composed from volcanic material inspire of the granodiorites from Huascaran Mt. (INGEMMET 1995).

According to Plafker and Ericksen (1978) the blocks from pre-Columbian (prehistoric) rock fall runs up to a vertical distance of 123 m on the Cordillera Negra slope – they are located in about 40 m higher position than the 1970 deposit. They describe blocks several meters across from the pre-Columbian deposit compared to the much smaller size of rocks that make up the 1970 deposit at this location.

5. Results

We divided the rock blocks (Fig. 3 and Fig. 5) measured by Schmidt Hammer into three groups based on type and chronology of the depositional processes identified through field investigations, geomorphologic mapping and satellite images interpretation. First group of measured boulders consists of moraine material containing boulders with longest weathering history; second group is formed by boulders most likely brought by the paleo-avalanche. The last group contains boulders transported during 1962 and 1970 rock-debris avalanche events (see Tab. 1).

The highest variability of boulders transported by paleoavalanche supports our hypothesis about the polygenetic origin of its sediments, which contain blocks of originally fresh rocks detached from rock slopes, moraine material and accumulations of previous events (Fig. 6). Moraines are supposed to be at minimum 30,000 B.P. – estimated by Rodbell (1993). The relative age of the paleo-avalanche is closer to the moraine deposits than to the boulders of the 1970 avalanche, but the absolute dating is not clear yet.

The borders of the prehistoric avalanche from Huascaran Mt. were delimited both at the foothill of Huascaran and on the opposite slopes of the Cordillera Negra mountain range. The granodiorites from Huascaran Mt. were recently documented on the slopes of Cordillera Negra (composed mainly from volcanic material) even in a higher position than ever before.

Tab 1. Basic statistical characteristic of the R-values

Group of rock blocks	Mean, $\bar{x}$	Standard deviation, sd	Coefficient of variation
moraine	41.18	5.78	14
paleo - avalanche	45.9	7.44	16.2
1970 avalanche	55.75	2.85	5.1

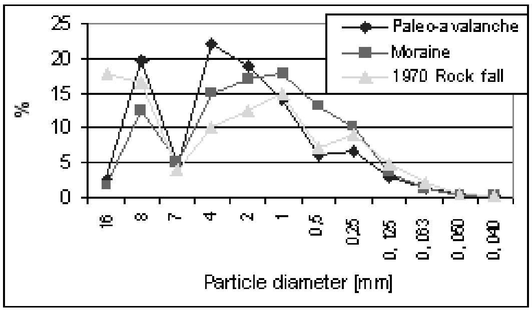

Fig. 4 Grain size distribution for typical samples from moraine and rock fall sediments.

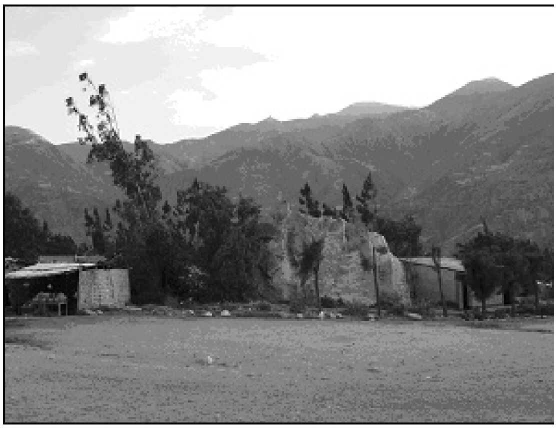

Fig. 5 Rock block from the 1970 Rock fall – in the area of the former Yungay village.

Conclusions and discussion

Detailed geomorphological and engineering-geological research at the foot-hill of Huascaran Mt. (6 768 m a.s.l.) brought new information about the limits of the prehistoric rock-fall (avalanche). Field geomorphological mapping together with aerial photo and satellite interpretation and Schmidt hammer tests allowed to distinguish various types of sediments (glacial moraines and different events of rock-debris avalanches), despite the fact that SH tests have limits in use for material of polygenetic character.

source of data for prehistoric rock fall and 1970 event	highest position (m a.s.l.)	relative height of runup (m)	size of blocks
Plafker and Ericksen (1978)		123	several meters across
Vilímek et al. (2000)	2 540	150	0,3 x 0,5 m (2 boulders)
recent data (Vilímek, Klimeš)	2 554	164	up to 0,3 m
compare the 1970 rock fall	*2 473*	*83*	

Tab 2. Highest recognized position of blocks from prehistoric rock fall from Huascaran Mt. (Water level of Santa River is under Matacoto village at the elevation of 2 390 m a.s.l.). To compare the prehistoric rock fall with the largest historical event - the 1970 rock fall is mentioned too (according to Plafker and Ericksen 1978).

According to relative dating using Schmidt Hammer and the estimated age of moraines (Rodbell 1993) the dating of large prehistoric rock fall is going more close to the age of moraines than to recent time presented here by the rocks from 1962 and 1970 catastrophes. Absolute dating is necessary for future attempt in this subject. It is also not known if there was a single huge prehistoric event or series of smaller rock falls.

Field geomorphological mapping proved that during the prehistoric rock-fall (paleoavalanche) were sediments settled in higher position on the slope of Cordillera Negra (opposite slope of Huascaran Mt.), at the elevation of 2554 m a.s.l. It is higher than ever before mentioned (see Tab 2). On the other hand we can not confirm the lateral limits of the prehistoric rock fall (Plafker and Ericksen 1978) suggested by position of rock blocks from Huascaran Mt. These rocks are parts of lateral moraine.

Fig. 6 Sedimentary material at the bottom of the valleys is mobilized by avalanches. Landslides contribute significantly to the sedimentary load. Through this valley the avalanches from Huascaran Mt. run.

Acknowledgments
The Czech research team was well received by the related agencies in Peru and obtained significant support and cooperation, namely from Ing. M. Zapata and Ing. N. Santillán – INRENA (Instituto National Recursos Naturales), Huarás, Ancash region. The authors would like to thank the Ministry of Education, Youth and Sports of the Czech Republic (Projects MSM 00216 20831) for their financial support.

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Environmental Hazards - the Result of Engineering Geological Failures on Cultural Heritage

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Abstract. Outstanding cultural heritage, which is the evidence of our civilizations and the important source of memory, belongs to the mankind. Throughout the history, however, historical monuments have been suffering from natural and man-made disasters. The latter ones are closely connected with inadequate human interventions into geological environment. As a result a chain of slow long-lasting as well as abrupt and rapid, mostly negative environmental changes occurred in the rocks and soils, groundwater and the air.

Keywords. geologic hazards, rock stability, monitoring, leakage,

1. Introduction

The experience the authors gained during long-term investigations aimed at the preservation of historic town centers as well as historic sites of great value proved that the majority of damage to historic structures has been caused due to changes in the geological environment (foundation ground, subgrade) resulting from both the change of the stress distribution and the change of engineering properties of the soils and rocks triggered by:

- groundwater effects,
- natural geological hazards,
- dynamic effects,
- and static load effects.

As a result set of natural geological as well as man-induced geological hazards (Fig. 1), posing a potential threat with either completely or almost identical consequences, was delineated. Between some of the hazards intricate interrelations may exist (e.g. landslides triggered by an earthquake, river erosion, and heavy rain or by undercutting the slope by a man).

The mode of failure triggered by the non-catastrophic hazards can be attributed to differential settlement or to rotations accompanied with minor damage on historic monument (in complex structures such as medieval castles some parts may suffer from serious damage). Several examples can be found in Slovakia involving both the UNESCO World Heritage sites Banska Stiavnica and Spis Castle.

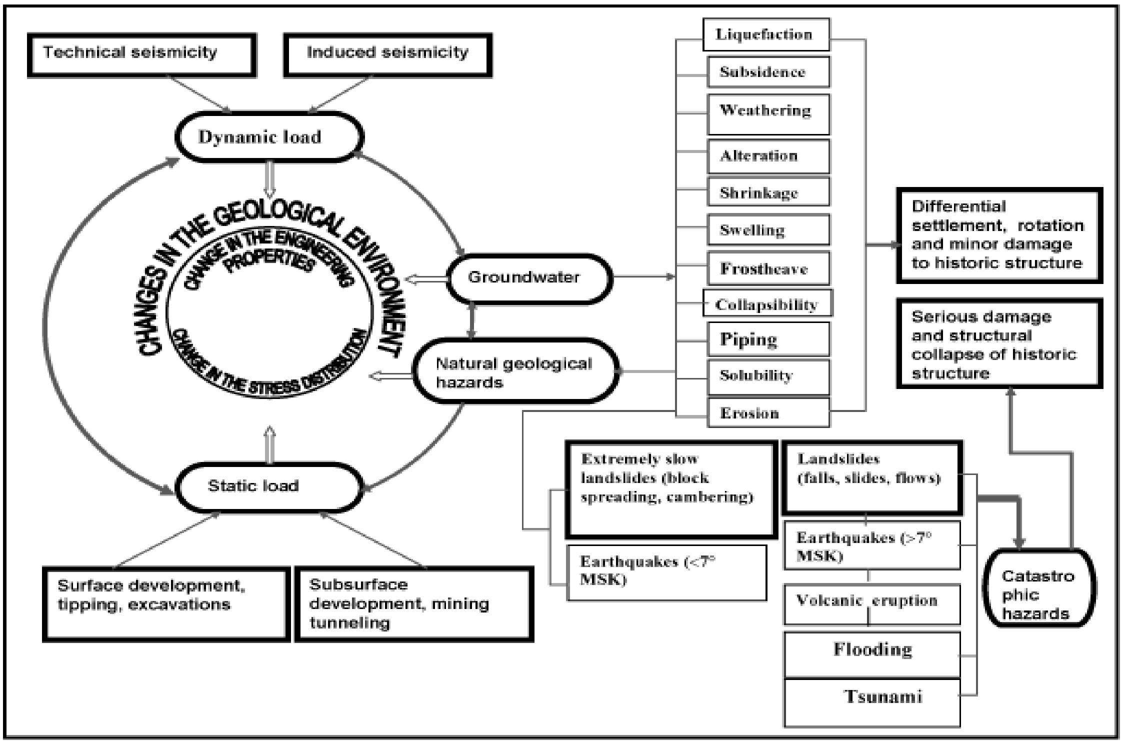

Fig. 1 Environmental hazards causing damage to historic structures (Vlcko, 1999)

2. Banska Stiavnica

The old medieval mining centre grew into a town with Renaissance palaces, 16th-century churches, elegant squares and castles. The urban centre blends into the surrounding landscape, which contains vital relics of the mining and metallurgical activities of the past.

The majority of historic buildings are founded on a soil consisting either of heterogeneous anthropogeneous sediments (fills, dumps, heaps) with unfavorable engineering properties, or of considerably altered pyroxene andesites with frequent discontinuities and fractured zones unfilled with mylonite or argillite.

The Holy Trinity Square, the most valuable architectural spot in Banska Stiavnica has a subterranean irregular network of old mine workings suffering from increased moisture and groundwater leakage from the water-bearing andesite rock mass despite the fact that restoration works on buildings located at the square had been carried out and finished several years ago. The most severe situation occurred at the Municipal Art Gallery (Fig. 2), where the exhibition rooms and depositories strongly suffered by increased moisture. The intensity of leakage shows a direct dependence on precipitation.

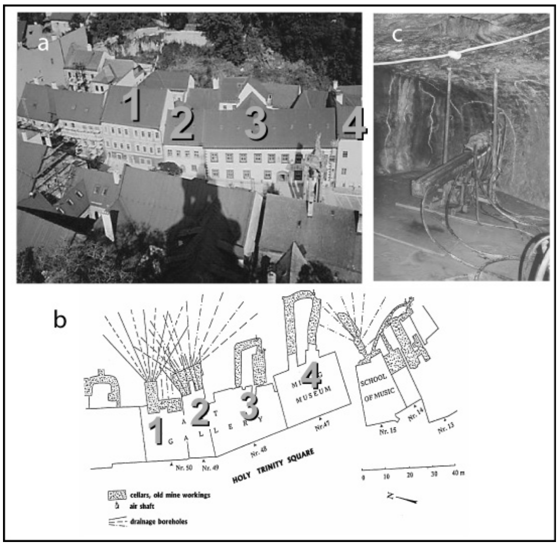

Fig. 2 Historic buildings endangered by ground water in Banska Stiavnica town (a), (b) and the drilling of the drainage boreholes in the basement of the Municipal gallery (c)

The study showed that the structural conditions of many buildings were rather poor with a need of extensive repair. In order to increase the strength of the foundation ground grouting was designed and implemented. This stabilization method on one hand secured the stability of the buildings; on the other hand in front of the buildings an impervious grout curtain was created, which had negatively affected the natural groundwater flow.

As a result several problems have arisen:

- Drenching of the foundation ground through the rainwater percolation directly into the foundations;
- Volume changes of foundation soils (particularly if formed by cohesive soils such as argillites or clays);
- Ultimate bearing capacity excess and differential settlement.

Considering the results of engineering geological investigation horizontal boreholes driven directly from old mine workings were recommended (Fig. 2c). To prevent the rain water percolation from the sloping back-door parts into subterranean parts (cellars and old mine workings) following works were proposed:

- Removal of the superficial soil from the sloping back-door parts.
- Filling in the discontinuities in the weathered and altered andesite bedrock with mortar and shotcrete
- Usage of geosynthetics and green design.

3. Spis Castle

Situated on a travertine rock 200 m above the surrounding land, at an elevation of 634 m, there is one of the most precious cultural monuments in Slovakia - the Spis Castle (Fig. 3).

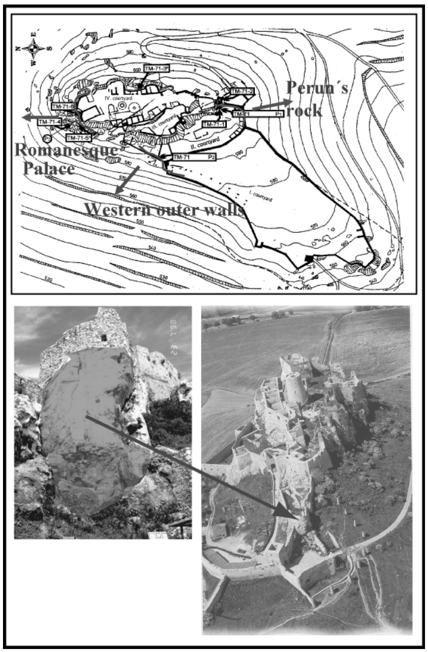

Fig. 3 Spis castle with the location of the Perun`s rock exhibiting displacements due to the lateral spreading of the travertine rock mass.

Based on the results gained during the engineering geological investigation the destruction of the castle is affected by several geological and man-induced factors:

a) Lateral spreading caused by the subsidence of strong upper travertines into soft claystone strata fractured and separated the castle rock into several cliffs. At several places the wide, open discontinuities from the bedrock cross the castle walls and bring significant risk of failure and eventual collapse of the castle walls. The long-term monitoring (Fig. 4) records estimated mean annual rate of displacement reaching 0.8 to 1.2 mm/year as well as visible climatic variations.

b) The results of the karst process can be observed along lines of weakness such as fractures (joints, gravitational-tectonic lines) in the form of widening of open cracks (up to several decimeters) and increasing permeability and softening of the bedrock to accelerate lateral spreading.

c) Weathering of the castle walls is a generally ongoing process that is affected by a number of factors. The original castle walls were constructed by mortaring travertine rubble. The mortar is not as resistant as the travertine to weathering and with time has experienced accelerated dissolution. The most intensive weathering of castle walls was observed at the contact between the stonework and the subgrade. At places along this contact the stonework has dripped off resulting in the development of overhangs.

d) The contribution of seismicity to the deterioration of the castle stonework cannot be discounted even though the area has been assigned to 6° MCS with the Slovak Standards Seismic Loading on Buildings. The presence of NS neotectonic faults between the Branisko Mountains and the Hornádska kotlina Basin further emphasizes the potential importance of seismicity but direct historical earthquake evidence is absent. Finally, lateral spreading and the rate of movement has likely been influenced since 1900 by travertine extraction at the nearby Drevenik quarry.

The results of the engineering geological investigation indicated that:

- The most intensive damage on castle walls occurred at the intersection of the main gravitational tectonic lines and in places where moving cliffs occur.
- The weathering of the stonework and the underlying rocks as well as the widening of open cracks by karst processes are sources of potential instability.
- Past earthquakes and other seismic effects (blasting) in a nearby quarry could promote creep movement.
- The slope stability analysis gained by photogrammetric survey and joint set evaluation proved that attention has to be paid to travertines up to the depth of 4 m where they are strongly weathered and jointed.

4. Devín Castle

Standing on a massive limestone – dolomite rock hill above the confluence of the Danube and Morava Rivers is an unusually impressive landmark. Due to several gravitational-tectonic lines the rock body is separated into huge blocks showing differential instability. To detect early indications of catastrophic rock fall a real-time monitoring was adopted, slope stability calculations and geotechnical stabilization was recommended. The castle is located on the 60 m high cliff composed mostly of limestone, dolomite and dolomite breccias of lower Triassic and early Jurassic age. Structurally is the cliff rather complex controlled by discontinuities of I order oriented in the direction N-S, dipping at 70-85°, and older discontinuities of II. order NE-SW, dipping at 80-89°.Stability of several rock blocks found mostly at the southern slope of the Citadel is controlled mostly by the latter type, however dipping at gentler angles of 50°. Several potentially unstable rock blocks were located on the north-western slope of the castle as well as on the southern slope using laser scanner, and several cross-sections crossing critical zones were identified (Fig.5). In each critical instability zone (Fig.6) factor of safety was calculated using KbSlope software (Fig.7) and stabilisation measures were recommended.

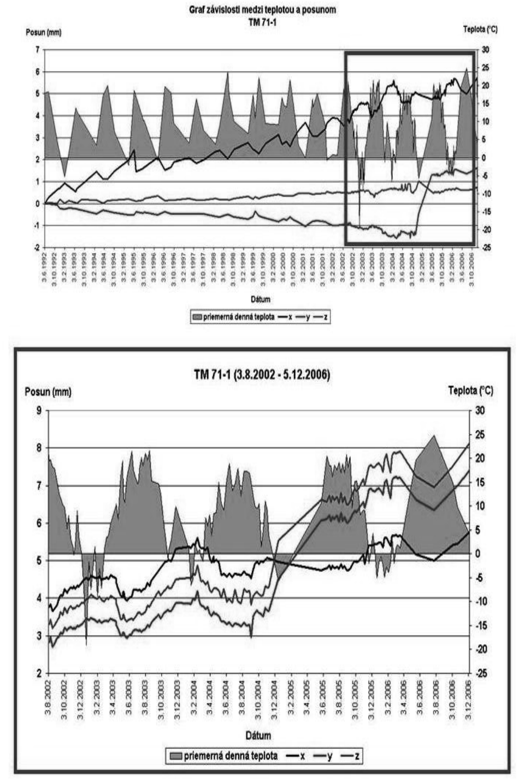

Fig. 4 Data monitoring records from Perunˇs rock at Spis Castle showing permanent lateral movement (crack opening) and strong dependence on temperature variations

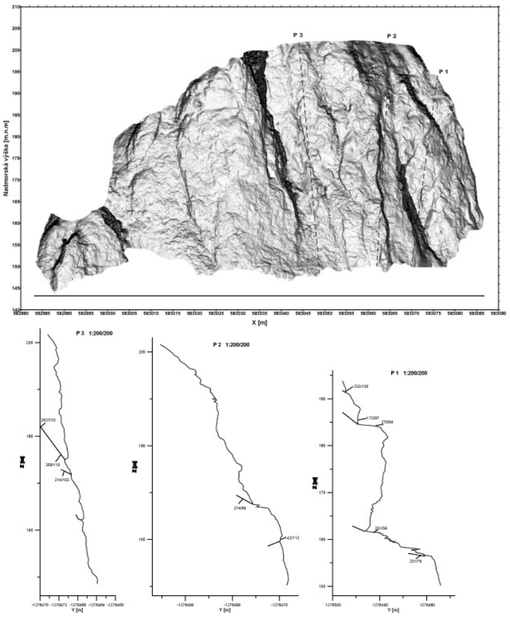

Fig. 5 3D model of NW cliff of Devin castle rock showing software generated cross-sections

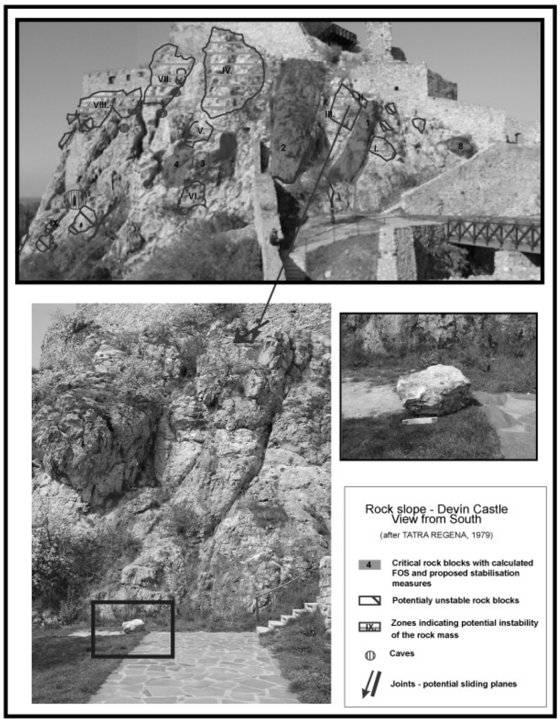

Fig. 6 Devin Castle, southern slope with the marked critical unstable zones and critical blocks (upper part of the photo). The block fallen from the rock face in April 2007 (down)

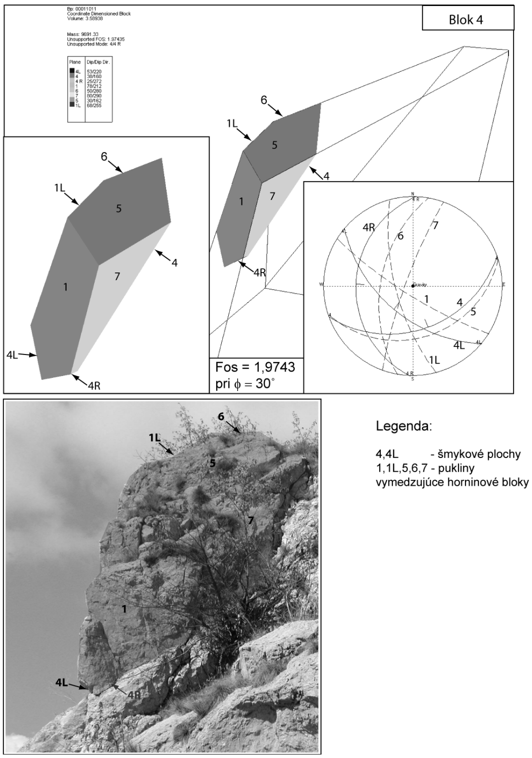

Fig. 7 Devin Castle, factor of safety calculation for block No.4 using KbSlope software

Regular monitoring of discontinuities started in 2004 using portable crack-gauges, followed by fully autonomous monitoring system composed of inductive transducer crack-gauges located at 7 potentially unstable blocks in 2005. The portable crack-gauges were installed on the castle wall near the staircase to the citadel. This wall, originally free-standing, was recently filled with fill material from the back side, which caused the origin of cracks due to active earth pressure.

Latest results from the online monitoring do not show any significant displacements deviating from usual temperature induced changes.

Conclusions

During the past decades UNESCO and many other international partners have been deeply involved in the restoration, preservation and maintenance of seriously damaged cultural property.

This provides a unique opportunity to strengthen the cooperation between relatively diverse disciplines (human, technical and natural).

The common goal of the disciplines involved in the process of safeguarding historic monuments is the identification of relevant factors causing damage to historic structures and the design of effective preservation and protection works which will perform their protective function throughout the lifetime of the historic structure.

Acknowledgments

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Landslide Hazard Strategies in Slovakia

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Abstract. Mountainous landscape of Western Carpathians with variable geology cause potential instability in some parts of the territory. According to latest data almost 4 % of the territory of Slovakia is covered by landslides. On the other hand, from relatively consolidated geological and existing climatic conditions results that the probability of unexpected and huge landslides with catastrophic consequences is relatively low. This idea was changed after catastrophic landslide which affected the mining town of Handlova in winter period 1960/61. The slide damaged a great part of city infrastructure and with its consequences on human property belongs to the biggest natural disasters in the country. For the first time landslide specialists, local and national authorities as well as the population recognised that even in relatively stable environmental conditions may occur the landslide having a character of a disaster with negative impact on the society. Since this event the systematic study of landslides and other slope movements has begun.

The paper deals with the stages of landslide studies in Slovakia and illustrates actual trends of landslides study and methods of investigation.

Keywords. Inventory of landslides, landslide susceptibility maps, risk evaluation, monitoring

1. History of landslide studies in Slovakia

The Western Carpathians constitute a part of the European alpine orogenic system. Landslides are linked to the particular geomorphic and geologic units, primarily to the mountain ranges stretching towards the intra-mountain basins and tectonic depressions. The largest number of landslides has been found in the region of Flysch zone and along the foothills of Neogene volcanites.

Landslide study in Czechoslovakia (now Czech and Slovak Republics) is exclusively linked with the pioneering work and influence in engineering geology of Professor Quido Zaruba in the 1920s and 1930s, who started study of landslides in the West Carpathians in connection with the railway projects passing through the Outer Flysch belt and later on in connection with several dam projects.

The crucial point in landslide hazard study in Slovakia is strongly connected with Handlova catastrophic landslide. In response to landslide destruction a governmental program was established to record in a central archive all landslides of economic significance. The study was carried out in three time periods (in 1962 to 1964, 1974 to 1978 and 1981 to 1991) based on unified principles and methodology and the data were recorded in a landslide database archive. The archive began in 1962 with about 9000 landslide-prone areas, and had expanded to about 15,000 records 30 years later. In accordance with regional landslide study a theoretical background (e. g. famous and widely accepted landslide classification prepared by Nemcok, Pasek and Rybar 1974) and the knowledge about landslide distribution within individual lithological units in Slovakia were recognized.

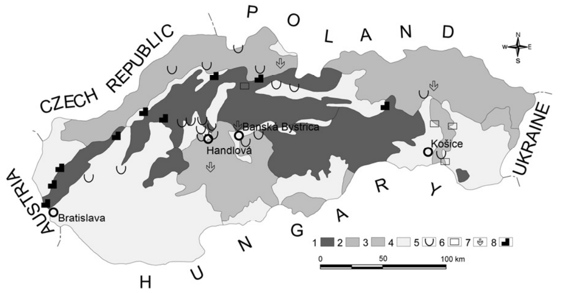

Fig. 1 Schematic engineering geological zoning of Slovakia (Matula, Pašek, 1986) with locations of monitored sites. 1 – region of core mountains, 2 – region of Carpathian Flysch, 3 – region of Neogene volcanics, 4 – region of Neogene tectonic depressions, 5 – landslides, 6 – creep, 7 – road rock cuts, 8 – massifs underlying historic sites

Later on the efforts of landslides inventory lead to the preparation of Slope Stability Atlas of Slovak Republic at the scale 1: 50 000 covering the whole state territory. According to Atlas data, almost 4 % of the Slovakia territory is covered by landslides. Such an inventory, therefore, clearly helps using GIS tools to extract various data as e. g. the delineation of scarps, limits of the zone of accumulation, the number of destroyed houses or other facilities, etc. and to predict where future movement is likely to take place.

2. Actual regional studies of landslides

A regional study was carried out when landslide susceptibility maps for selected regions in Slovakia since seventies of the last century were compiled. After adoption of unified principles in 1996 these maps were integrated into the set of maps of geofactors (1: 50 000) recently covering 70 % of the territory. Malgot and Mahr (1979) started the compilation of susceptibility maps based on the inventory maps since 1976. In accordance with latest trends in landslide research there were also several landslide susceptibility maps compiled adopting statistical methods, namely multi and bivariate techniques (Pauditš, 2005, Jurko, Pauditš, Vlcko, 2005; Bednarik, 2007).

The requirements of engineering practice dealing with urban development in populated areas are at present formulated towards the landslide hazard and risk assessment and decision making. There are several examples varying from the estimation of landslide risk for urban-development plan from the wider area between the towns of Sered and Hlohovec at a scale 1:10 000 (Bednarik, 2007) or for the town Lubietova in detailed scale 1: 2 000.

The "landslide hazard" was the essential feature in urban planning process and design concept prepared for new housing facilities in the town Lubietova and thus a landslide risk map at a large scale (1: 2 000) was one of the most important documents implemented in the planning procedure. The author of the map (J.Vlcko, 2002) adopted different approach in compiling the map. In the first stage traditional landslide distribution map (a qualitative one) was compiled and this map served as a tool for further landslide risk map elaboration based on quantitative basis using geotechnical approach. Geotechnical (deterministic) approach was based on simple stability calculation of each landslide body in relation to designed type of buildings corresponding to the urban plan. Since the majority of residential houses were located at the toe (accumulation part) of several, at present inactive (dormant) landslides, the calculation was done with respect to the dimension of foundation pit (12 x 12 x 3 in depth m). The final landslide risk zones in the map were delineated according to factor of safety calculated for each landslide separately (Fig.2).

3.Local case studies of landslides

There exist several case studies which rely upon quite good understanding of landslide by earth scientists. As an example we bring definite solution of the stability problems related to the mining town of Handlova. After disastrous landslide and after recognizing that both slopes of Handlovka River are unstable, continually moving and the town of Handlova with 15 smaller villages around are still in danger incl. the infrastructure units e.g. industrial plants (power stations), roads, railways, water mains, power pipelines, etc. there was an urgent need to make a final decision and to design measures to stabilize quite large part of territory (10 km^2 in extent).

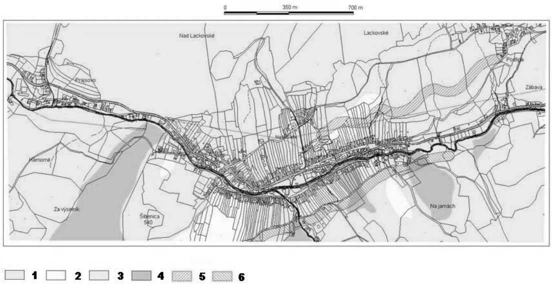

Fig. 2 Landslide risk map. 1-without landslide risk, 2- low landslide risk, 3- moderate landslide risk, 4- high landslide risk, 5- area suitable for housing from urban and engineering geological point of view, 6- area suitable for housing only from urban point of view

The problem was treated by many specialists. In order to stabilize landside area various protective measures were applied: surface drainage, drainage wells and horizontal boreholes. Finally, the optimum economic and environmental problem solution was the construction of a counterweight fill from mine waste materials in the valley floor while the Handlovka River was canalized (Fig.3, 4). The fill is enough heavy to provide additional component of resistance near at the toe of both unstable slopes, the transportation routes crossing the counterweight fill body and the housing are located at stable conditions. From the environmental point of view the mine dumping in the surrounding area was strongly reduced and the waste material was used not only to the stabilization but also to the rehabilitation purposes.

The recent landslide studies in Slovakia are oriented towards probabilistic analysis, elaboration of warning systems, landslide hazard management etc. On this basis a state program supported by the Ministry of the Environment entitled „Partial monitoring system – geological hazards" as a part of the National Environmental Monitoring of the Slovak Republic (Klukanová, Liščák, 2004) was elaborated. In the frame of monitoring of geological hazards the highest priority is given to various types of natural and man induced slope phenomena (e.g. road rock cuts). Specific problems are studied in connection with stability of massifs underlying historic sites. Finally, over 30 unstable sites are monitored. The selected monitored localities are spread across the whole country placed in all geological units (Fig. 1). Each monitored site is of high economic importance because brings potential threat to infrastructure, people and may bring a great loss to the society.

At critical locations, a landslide monitoring system was implemented. This system consists of remote monitoring instrumentation as well as of unified methods of readings, data collection and processing. For monitoring of rock cuts and massifs the methods of photogrammetry and various types of dilatometric measurements are carried out, while slope creep movements are monitored using three-dimensional extensometer TM-71. The majority of monitoring observations are linked to slides. At these sites instruments monitor characteristic landslide failure parameters, including surface movements of the soil, changes in subsurface water pressures, and rainfall. Apart from remote techniques the rate of displacement of landslides is recorded by geodetic measurements, inclinometric drill logging and actual stress state of landslide body is recorded by surface residual stresses measurements and pulse electromagnetic emissions.

The frequency of recordings depends on economic importance and activity of instrumented slope failure.

Data sets obtained by monitoring are stored within an object-oriented database. The database enables interactive manipulation of the primary data set, its processing in the form of secondary parameters and visualization in the form of dynamic charts. Simplified results, based upon the primary data collected are made available to a wide range of users and customers on the internet (Klukanová et al., 2005). The huge datasets form an input into Integrated Information System of the Environment of the Slovak Republic. The representative set of instrumented sites is an open system – those sites with any long-term movement can be abandoned, locations where significant slope movement is detected are as a rule added to a monitoring net. Monitoring of selected sites in Slovakia yields not only much valuable scientific information about the slope deformation behavior in time but also helps to solve practical problems related to recommendation of geotechnical slope stabilization measures and their control. Recent development of monitoring techniques is directed to increasing of real time warning systems at local level and to extrapolation of local information to areas with similar stability conditions.

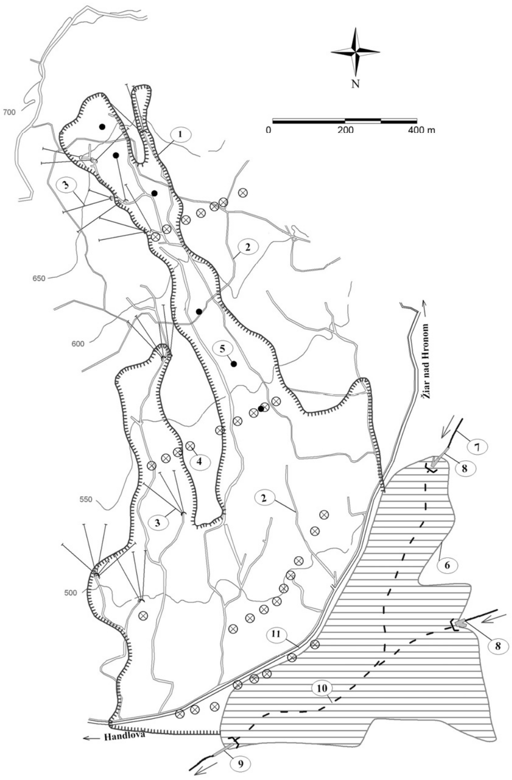

Figure 3. The Handlová catastrophic landslide, corrective measures and monitoring sites. 1 –landslide area, 2 –drainage trenches, 3 – horizontal dewatering drillholes, 4 – geodetic points, 5 – inclinometric boreholes, 6 –counterweight fill body, 7 – Handlovka River, 8 – intake, 9 – outflow object, 10 –Handlovka River canalized in steel tube overlaid by counterweight fill, 11 – state road

4. Conclusions

Slope movements along with the floods belong to the most dangerous natural hazards in Slovakia. The experience gained throughout the last decades confirms the idea that attention must be paid primarily to more economic landslide precautions measures than to application of expensive stabilization measures. Moreover, the landslide problems must be under permanent control not only by the landslide specialists but also by the responsible bodies at both state and local level

Acknowledgments

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Fig. 4 Photos of landslide area in Handlova. A- lide in 1961 (photo by Nemcok and Malgot), B – present state of slope with counterweight fill at the toe (April 2008)

Displacement Monitoring of Shuping Landslide after the First Impoundment of the Three Gorges Dam Reservoir

Fawu Wang (Kyoto University, Japan) · Xuanming Peng (Yichang Center of China Geological Survey)·
Yeming Zhang (ditto) · Zhitao Huo (ditto)

Abstract. Shuping landslide is a reactivated landslide triggered by the first impoundment of the Three Gorges Dam Reservoir, China in June 2003. For the purposes of landslide disaster mitigation in the reservoir area and clarification of the mechanism of landslide deformation caused by water level changes of dam reservoir, a monitoring system mainly consisting of drum style extensometers was installed in Block-1 of the Shuping landslide. The systematic monitoring was started in August 2004 with 13 extensometers. In August 2006, more drum style extensometers were installed to increase the number of monitoring points, and five flexible extensometers were installed near the water level fluctuation area of the reservoir along the longitudinal section. In August 2007, a continuous monitoring line was completed along the central longitudinal section of the Shuping landslide. In this paper, the four-year monitoring by extensometer results from August 2004 to July 2008 are presented, and the deformation mechanism of the Shuping landslide caused by the water level change of the Three Gorges Dam Reservoir and rainfall is examined.

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Keywords. Landslide, monitoring, displacement, water level change, reservoir, rainfall

1 Introduction

The Three Gorges Dam in China is the largest hydropower project in the world. The dam site is located near Maoping town, Zigui County, Hubei Province (Fig.1). The main body of the dam, which is 181 m high and 2310 m long, was finished by the end of 2006, and the reservoir level will reach a maximum of 175 m in 2009, allowing for full electric power capacity.

When the dam was partially completed, water impoundment was started in the reservoir to produce power and control flooding downstream. The first impoundment was achieved on 1 June 2003. In 15 days, the reservoir level was increased from 95 m to 135 m. Coincident with the impoundment, landsliding occurred along the edge of reservoir. Some of the landslides moved for long distances. In addition, some ancient landslides were reactivated and are currently causing ground deformation. One landslide in the Qianjiangping area of Shazhenxi town (Fig.1b) moved rapidly and killed 24 people (Wang et al., 2004; Wang et al. 2008a). Eleven people were killed directly by the sliding mass, and another 13 people were killed by landslide-induced seiches in the Qingganhe River, a tributary of Yangtze River. In the Shuping area, which is along the south bank of the Yangtze River, just 3 km from the Qianjiangping landslide, a large ancient landslide was reactivated during the first impoundment, and caused ground deformation as the reservoir level changed (Wang et al. 2008b).

In this paper, we discuss the movement and deformation of the Shuping landslide, based mostly on the results of extensometer measurements since 2004.

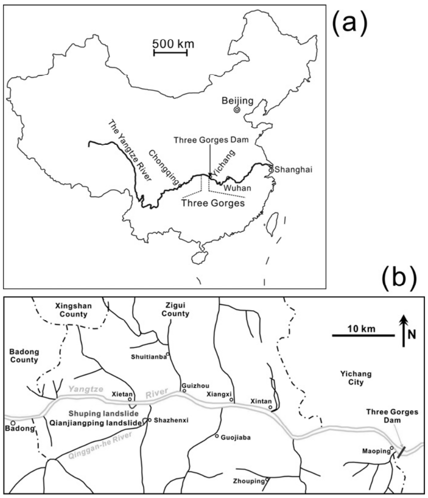

Fig.1 Location map of the Three Gorges Dam (a) and the Shuping landslide (b) in China

2 Characteristics of the Shuping Landslide

The Shuping landslide is located on the right bank of the Yangtze River, about 3 km northwest of Shazhenxi Town, Zigui County, Hubei Province. The landslide is about 60 km upstream of the Three Gorges Dam site (Fig.1b). Preconstruction landslide investigations for the purpose of Three Gorges Dam identified the Shuping landslide as an ancient slide (Chen et al., 1997). The landslide area is underlain by sandy mudstone and muddy sandstone of the Triassic Badong formation (T2b). In the Three Gorges area, many landslides occurred in this unit (Wen et al. 2004). Figure 2 is a photograph of the Shuping landslide, taken from the opposite bank of the Yangtze River. The landslide extends into the Yangtze River and a valley divides the landslide into two blocks designated as eastern Block-1 and western Block-2.

Figure 3 is the plan of the Shuping landslide, which lies between elevation 65 m and 400 m with a width of about 650 m. Boreholes indicate the landslide is between 40 and 70 m thick, and the landslide volume is about 20 million m^3. The average slope of the landslide ranges from 22 degrees in the upper part to 35 degrees in the lower part. According to the local inhabitants, cracks appeared in the roads and houses located on the slope as soon as the first impoundment was finished on 15 June 2003.

To monitor the movement of the Shuping landslide, the Chinese Ministry of Land and Resource installed six Global Positioning System (GPS) stations along the longitudinal axes of Block-1 and Block-2 (GPS-85 to GPS-90 in Fig. 3), and surveyed monthly.

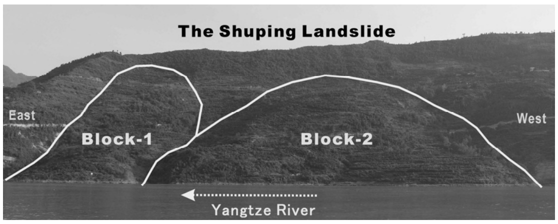

Fig. 2 Photo of the Shuping landslide facing the main stream of Yangtze River (Taken from the opposite bank, facing south)

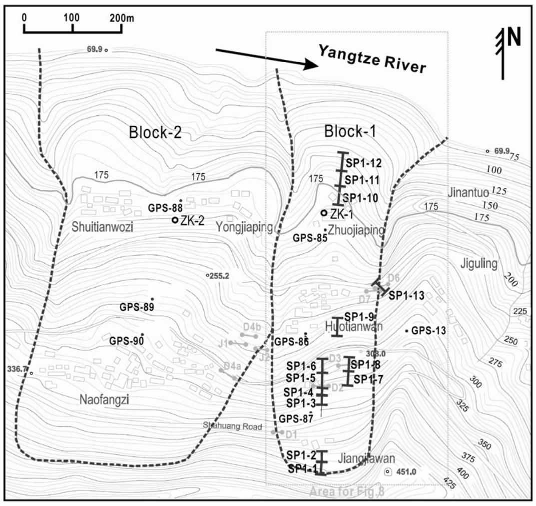

Fig. 3 Plan of the Shuping landslide (The locations of the extensometers shown in this map are those installed in 2004)

3 Extensometer Monitoring Results

3.1 Part 1: August 2004 to July 2006

In April 2004, we installed the first two drum-style extensometers in the Shuping landslide across two ground cracks, one at the east boundary crossing the crack, and the other in the centerline of Block-1. Zhang et al. (2004) summarized the results of the initial movement monitoring.

In August 2004, 11 additional extensometers were installed nearly along the centerline of Block-1 (the locations are shown in Fig. 3). Extensometers SP1-1 and SP1-2 were installed near the main scarp of the landslide. Extensometers SP1-3 through SP1-9 were installed between the Shahuang Road and a local agriculture road (Fig. 3). One of these, SP1-5, crossed a continuous crack. Extensometers SP1-10 through SP1-12 were installed near the toe and the Yangtze River. Extensometers SP1-13 was located along the east boundary of Block-1. In addition, warning alarms were connected to Extensometers SP1-5 and SP1-13. The alarms were set to a trigger when the displacement rate exceeds 2 mm/hour. The maximum measurable displacement of each extensometer is 500 mm. To measure both stretching and shortening, the target of the extensometer was adjusted to the middle of the drum. The extensometer and standing pile were connected by a super invar-line that was protected by a vinyl pipe. The measurements were recorded on both paper and a flash memory card. Data collection was conducted once a month, and at each time, the target was adjusted in order to ensure successful monitoring during the following month.

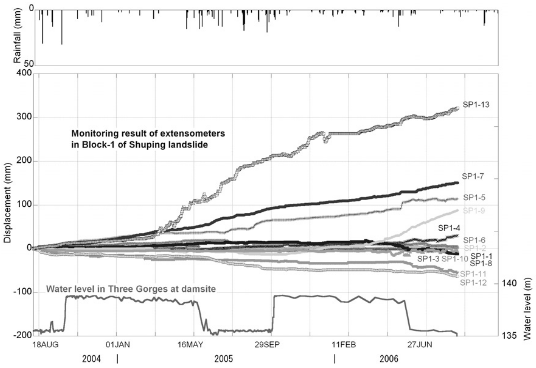

Fig. 4 Monitoring results with the drum extensometers for the period from August 2004 to August 2006 in Block-1 of the Shuping landslide. Rainfall for the period and the water level in the Three Gorges Reservoir are also shown

Figure 4 shows the monitoring results from the extensometers for the two years between August 2004 and July 2006. Rainfall near the landslide and the water level in the Three Gorges Reservoir are also shown. No stretching was detected across the main scarp of the landslide (SP1-1 and SP1-2), but stretching occurred in the middle of the slide (SP1-5, SP1-7, SP1-9, and SP1-13), and shortening occurred near the toe (SP1-11 and SP1-12). The monitored results correspond to observed ground deformation, including ground cracks, at least qualitatively. Deformation (and landslide movement) occurred in conjunction with water-level fluctuations in the reservoir. Notably, the landslide was active when the reservoir level decreased. Locally, such as at SP1-5, the rate of movement increased during the period of rainfall (in the wet season). Thus, movement of the Shuping landslide appears to occur in response to both reservoir-level changes and rainfall.

3.2 Part 2: August 2006 to July 2007

In July and August 2006, an additional 11 extensometers were added to the monitoring system. As a result, a total of 22 extensometers were located in a nearly continuous line along the centerline of Block-1 above 220 m in elevation. In addition, two extensometers were located along the east boundary of the slide. However, our inability to place extensometers across the Shahuang Road and the local agriculture road resulted in two gaps in the monitoring line (Fig. 5). In the area near the high water line, five flexible extensometers consisting of stiff carbon fiber rods connected to an extensometer transducer were installed to monitor the displacement.

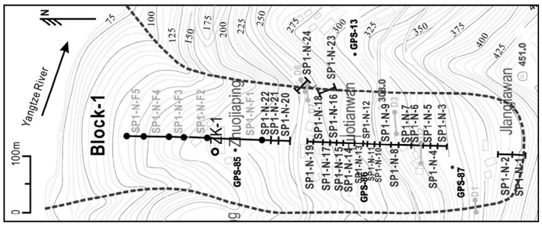

Fig. 5 Location of the extensometers installed in August 2006 in Block-1 of the Shuping landslide (The area of this figure is shown in Fig.3)

Figure 6 shows the monitoring results of the drum extensometers installed along the centerline and the east boundary of Block-1, changes in the reservoir level, and the daily rainfall at Xietan town (See Fig.1b for location) measured by Zigui County Meteorological Observatory, Hubei Provincial Meteorological Bureau. Xietan is a small town on the opposite bank across from the Shuping landslide. Because the rainfall gauge is only about 1 km from the Shuping landslide, the data provides a reasonable estimate of the rainfall at the slide.

In Figure 6a, the monitoring results from areas with the greatest deformation (stretching or shortening) are shown. The most stretching (about 240 mm) occurred at three extensometers, i.e., extensometer SP1-N-5 in the upper part of the slide and the two extensometers (SP1-N-23 and SP1-N-24) along the east boundary. At extensometer SP1-N-7 in the upper part of the slide a period of stretching was followed by a period of shortening. About 85 mm and 60 mm of shortening, respectively, occurred at extensometers SP1-N-15 and SP1-N-11.

The remainder of the extensometers recorded smaller deformations (Figs. 6b to 6d). In general, shortening deformation was more common than stretching in the upper half of the landslide. Continuous stretching was recorded at only three extensometers (SP1-N-4, SP1-N-12, and SP1-N-19) (Figs. 6b to 6d), whereas shortening was recorded at most of the others.

Most of the movement occurred during a period when the water level in the Three Gorges Reservoir is lowered to prevent flooding in the wet (monsoon) season in the region. We speculate the movement occurred as a result of the increased precipitation during the wet season, but the effect of the declining reservoir level on landslide stability requires additional consideration. Our monitoring results suggest that landslide stability is not increased during the period of lower reservoir levels, which has significant implications for landslide disaster mitigation.

3.3 Part 3: August 2007 to May 2008

In August 2007, with two additional extensometers, a continuous monitoring system passing Shahuang road and the local road was completed. During this work, maintenance and adjustment of the drum-style extensometers were conducted. The positions of some extensometers were changed to cross obvious cracks and make the monitoring system better. Fig. 7 shows the modified extensometer line. As a result, a total of 24 extensometers were located in the line along the centerline of Block-1 above 220 m in elevation. In addition, two extensometers (M-25 and M-26) were located along the east boundary of the slide. The five flexible extensometers were kept in the area near the high water line.

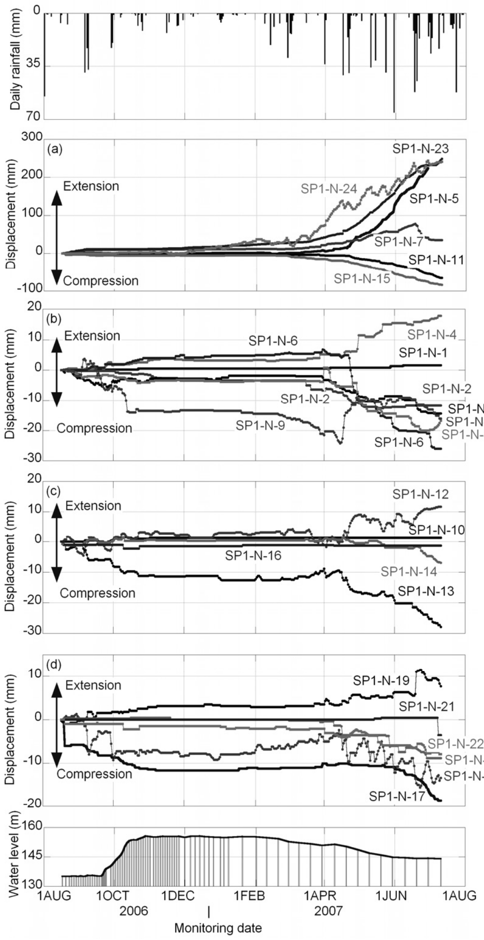

Fig. 6 The monitoring results of the drum style extensometers in Block-1 of the Shuping landslide in the period from August 2006 to July 2007, the changing water level in the Three Gorges Dam Reservoir and local rainfall data

Fig.8 shows the monitoring result from August 2007 to May 2008. It is shown that the displacement of the Shuping landslide became active (1) when water level increased rapidly from 145 m to 156 m in October 2007; (2) during the rainfall period around April. Also, the whole tendency is that the displacement gradually accumulated when the water level decreased from 156 m to 158 m.

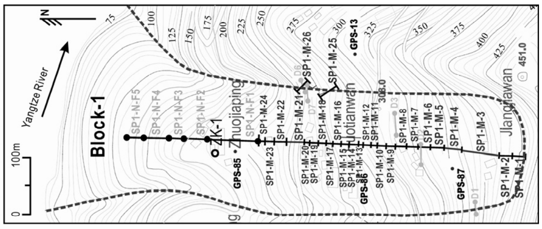

Fig. 7 The continuous extensometer monitoring line completed in August 2007

4 Conclusions

Based on extensometer measurements over a three-year period, we conclude the following:

(1) Movement of the Shuping landslide corresponds to water level change in the Three Gorges Reservoir. Especially, movement occurs during periods of declining reservoir level.

(2) Comparison of displacement and deformation data over a five-year period suggests increasingly complex deformation of Block-1 of the Shuping landslide. Areas of intermixed shortening and stretching occur currently on the slide.

(3) Movement of the landslide occurred during the wet season when reservoir level is lowered for flooding control. Thus, movement monitoring of this landslide is critical even during period of low reservoir level.

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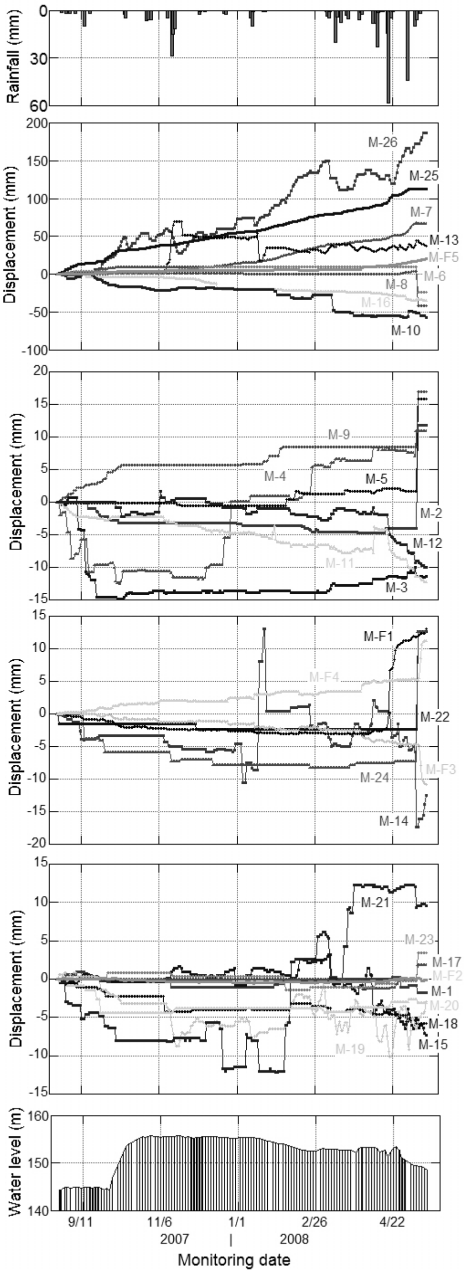

Fig. 8 Monitoring results with the continuous monitoring line from August 2007 to May 2008

Some Catastrophic Landslides Triggered by the May 12, 2008 Sichuan Earthquake

Gonghui Wang (Kyoto University, Japan) · Toshitaka Kamai (Kyoto University, Japan)· Masahiro Chigira (Kyoto University, Japan), Xiyong Wu (South West Jiao Tong University, China)

Abstract. On May 12, 2008, a 7.9M_w earthquake struck Sichuan province of China, causing a huge number of death and injuries, and great loss of properties. The collapse of buildings during the earthquake is the main reason for the casualties. There are a huge number of landslides that had been triggered by this earthquake. Almost all the roads to the mountainous areas had been blocked and many dams were formed by the displaced landslide materials, resulting in great difficulties for the aftershock rescue activities. Also a big portion of the casualties was directly caused by the landslides. The authors performed reconnaissance field trips of the landslides, and conducted preliminary investigation on some of the catastrophic ones. In this report, three landslides, Xiejiadian landslide in Pengzhou city, Donghekou landslide in Qingchuan County, and Xiaojiaqiao landslide in An County, are introduced. The characteristics of deposited landslide masses in Xiaojiaqiao landslide and Donghekou landslide were investigated by means of a multichannel surface wave technique. Two earthquake recorders were installed at the upper part and deposit area of Donghekou landslide. The seismic responses of different parts of the landslides were monitored, and recorded successfully during the aftershocks that occurred in Qingchuan County on July 24, 2008. Some preliminary analyzing results will be presented.

Keywords. Sichuan earthquake, catastrophic landslides, seismic monitoring, geophysical survey

1. Introduction

On May 12, 2008, at the local time of 14:28 an earthquake (M8.0) occurred at the location of 30.986°N, 103.364°E in Sichuan province, China. It was also known as the Wenchuan earthquake, after the earthquake's epicenter in Wenchuan County, Sichuan province (Fig. 1). The epicenter was 80 km west-northwest of Chengdu, the capital of Sichuan, with a depth of 19 km. The earthquake was felt as far away as Beijing (1500 km away) and Shanghai (1700 km away), and also in some nearby countries. Strong aftershocks continue to hit the area even months after the main quake, causing new casualty and damage. As of September 12, 2008, the aftershocks totaled to 29153, among them 224 were between M4.0 and 4.9, 32 between M5.0 and 5.9, and 8 between M6.0 and 6.9 with the strongest one being 6.4 Ms.

This earthquake caused a huge number of losses in both properties and human lives. According to the official reports, as of July 21, 2008, 69,197 are confirmed dead, 374,176 injured, and 18,222 among the missing. The earthquake left about 4.8 million people homeless, although the number could be as high as 11 million. Approximately 15 million people lived in the affected area.

The collapse of buildings during the earthquakes is the main reason for the casualties. And also there are a huge number of landslides that had been triggered by this earthquake. Almost all the roads to the mountainous areas had been blocked and many dams were formed by the displaced landslide materials, resulting in great difficulties for the aftershock rescue activities. Also a big portion of the casualties was directly caused by the landslides (Yin 2008). The authors performed reconnaissance field trips of the landslides, and conducted preliminary investigation on some of the catastrophic ones. In this report, three landslides, Xiejiadian landslide in Pengzhou city, Donghekou landslide in Qingchuan County, and Xiaojiaqiao landslide in An County, are introduced. The characteristics of deposited landslide masses in Xiaojiaqiao landslide and Donghekou landslide were investigated by means of a multichannel surface wave technique. Two earthquake recorders were installed at the upper part near the scarp and deposit area of Donghekou landslide. The seismic responses of different parts of the landslides were monitored, and recorded successfully during the aftershocks in Qingchuan County on July 24, 2008. This paper presents some preliminary analyzing results.

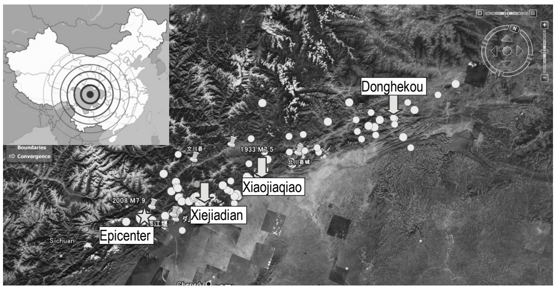

Fig. 1 Location of Sichuan earthquake, epicenter of Wenchuan earthquake and some aftershocks, and the landslides investigated.

2. Geological information of the earthquake area

The earthquakes occurred on the Longmenshan thrust zone, which is located on the eastern boundary area of Tibet plateau, and is one of the significantly deformed regions in China continent with many seismically active faults (Fig. 2). The continuing northward indentation of the Indian plate into the Tibetan crust after the collision between the Indian and Eurasian plates induced uplift and deformation of the Tibetan Plateau. Longmenshan thrust zone is about 60 km wide, and constitutes the topographic boundary between the eastern Tibetan Plateau and the Sichuan basin. The convergence rate across the thrust zone is inferred to be 4-6 mm/yr (Deng et al. 1994). Earthquakes occurred along this zone frequently. In 1933, a M7.5 earthquake occurred in Diexi, 50 km northeast of Wenchuan. During this earthquake, some big lakes were formed by the landslide dam, and 6800 people were killed (about 2500 people were killed by the floods due to the collapse of two landslide dams). In 1976, two earthquakes of magnitude 7.2 occurred in Songpan and Pingwu (northeast areas of Wenchuan), respectively. However, this time, the earthquakes had been predicted successfully based on the vast macroanomaly that had been observed, and residents had been evacuated on time. The dead and injured people totaled to 800 approximately (including 600 light injured), and most of them were due to the landslides that were triggered by the post-earthquake heavy rainfall.

During the Wenchuan earthquake, heavy rainfall was also followed, and triggered vast landslides. However, the landslides introduced in the following sections were directly triggered by the main shock of Wenchuan earthquake.

According to the geologic map of Sichuan earthquake area (China Geological Survey 2008), the settings of Longmenshan thrust zone are mainly composed of old granite, metamorphic sandstone, phyllite, sandy slate and dolomite, etc. The rocks are fragmented due to the strong tectonic movement of this area. Nevertheless, Chengdu basin has been less affected and remained relatively stable throughout the Cenozoic, where the strata of the Jurassic and Cretaceous Periods are covered by the Quaternary alluvium.

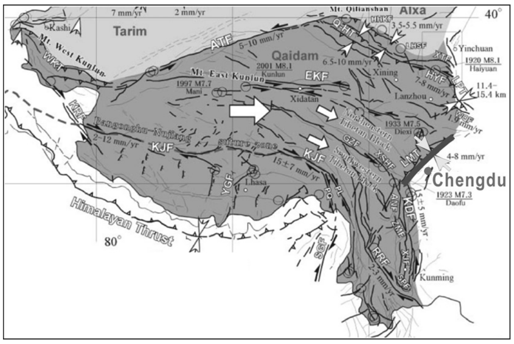

Fig. 2 Active faults in Southwest of China (after He and Tsukuda, 2003)

3. Catastrophic landslides

3.1 Xiejiadian landslide

Xiejiadian landslide is located in Jiufengchun village, Yingchanggou Town of Pengzhou City, about 70 km northwest of Chengdu. Yingchanggou is a very famous resort area for its beautiful nature and silent environment. Many tourists come to this area. The landslide occurred almost at the same time as the earthquake. Fig. 3 presents the location of the landslide and some photos showing its source area, traveling path, and toe area. This area consists of alternation of strata of sandstone and shale with some black mudstone and granite.

The displaced materials included rounded granite blocks, sandstone, shale, and black mudstone. One survivor told us that when he was walking with his grandson outside of his house, the earthquake occurred, and they fell down due to the strong vibration. He struggled to protect the boy by his body, and then came the displaced landslide materials. Everything disappeared within seconds. Namely, the landslide showed very high mobility. 17 families were living on this area. About 100 people, including more than 60 local residents, 30 tourists, 2 policemen in a patrol car and others were buried by this landslide. The displaced materials blocked the river, forming a dam 10m high, 250m long and 70 m wide. The landslide was initiated along the gully and side slopes had been entrained by the displaced mass from the upper part. The length of this landslide was about 1.7 km with a maximum width of about 300 m, and depth of about 40 m.

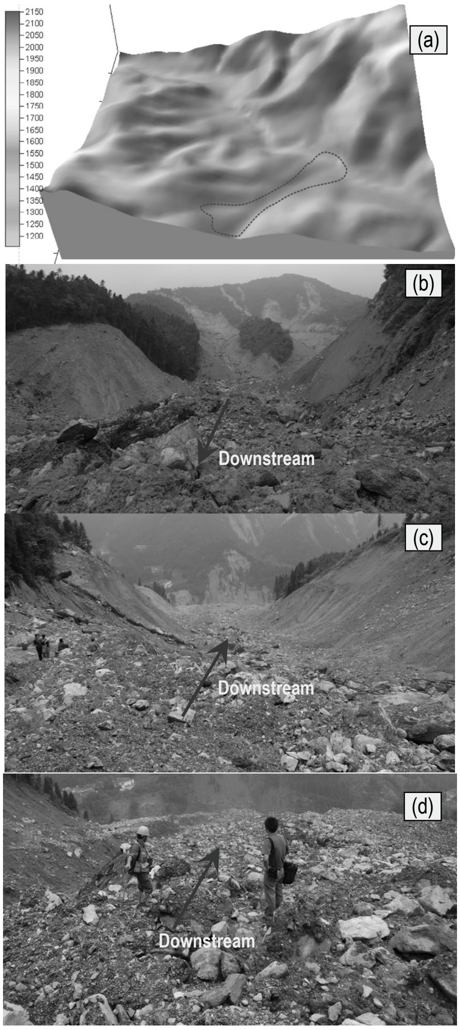

Fig. 3 Xiejiandian landslide. (a): location; (b), (c): views to the source area and downslope area on the middle of landslide travel path, respectively; (d): View of toe part of the deposit area

It is noted that the landslide mass on the toe part of the deposit area consists of mainly colluvial soils that might be originated from the source area of the gully, although there are some big granite blocks on the upper layer or the surface. From the field evidences, we infer that high pore-water pressure was generated within the colluvial soils on the gully during the earthquake, which resulted in the high mobility of the landslide. There are some materials came from the scarp of the landslide, but deposited near upper source area. The possible pore-water pressure generation by the impact force of the sliding materials from the upper source area might be very small. Nevertheless, concerning this mechanism, further research should be performed and are in the plan.

3.2 Xiaojiaqiao landslide

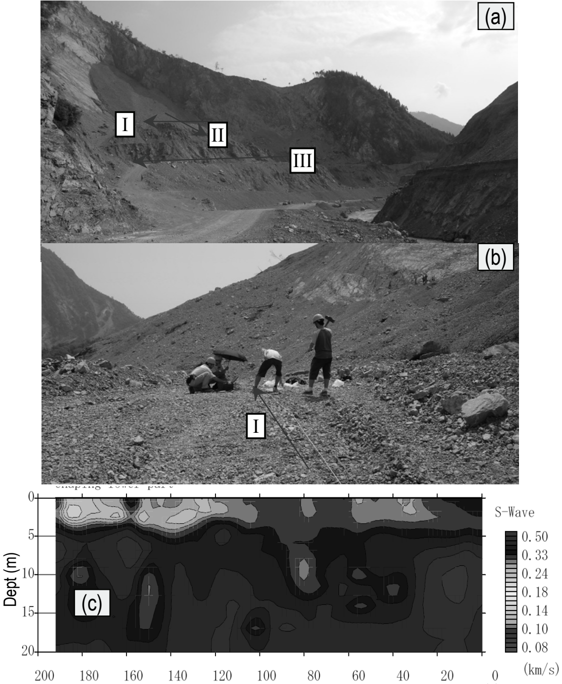

Fig. 4 Xiaojiaqiao landslide. (a): oblique view; (b) geophysical survey on the upper terrace; (c) S-wave velocity profile along L-III

Xiaojiaqiao landslide (Fig. 4a) is located on the right bank side of Chaping River, a tributary of Fujiang River. It originated on a steep slope of weathered dolomite. No ground water was found. Although nobody was killed directly by the displaced landslide mass, the unique road passing the toe of the slope to Chaping town was broken, and a landslide dam was formed. This dam sized approximately 250 m long (along the river), 200 m wide and 80 m high, forming a lake with a capacity of 2×10^7 m^3. More than 100 people were reported dead due to the inundation after the formation of landslide dam. Acknowledging the high risk of dam collapse, emergency countermeasures were taken by digging a channel through the dam to lower the water level on the lake, and now the dam have been lowered to a safe level.

A very smooth surface can be seen from Fig. 4a on the source area, indicating that the slip occurred along the stratification plane of dolomite. The displaced materials slipped down and collided against the opposite river bank, reaching a height of about 80 m. It is also interesting to note that the deposited landslide materials have few big rock blocks, although the bedrocks are in layers with big dolomite blocks. From these phenomena, it is inferred that the landslide was of high mobility.

A multichannel surface wave technique was used to obtain some geotechnical information of the landslide deposits for the stability analysis of landslide dam. The survey had been performed along three traverse lines as shown in Fig. 4a. Two lines were on the upper terrace with one parallel (L-I in Fig. 4b) and the other (L-II) perpendicular to the scarp surface, and one line (L-III) was along the middle terrace. Fig. 4c presents the S-wave profile along L-III, from which the nonhomogeneity of deposited mass can be inferred. This kind of characteristic should be considered during the stability analysis of landslide dam.

3.3 Donghekou landslide

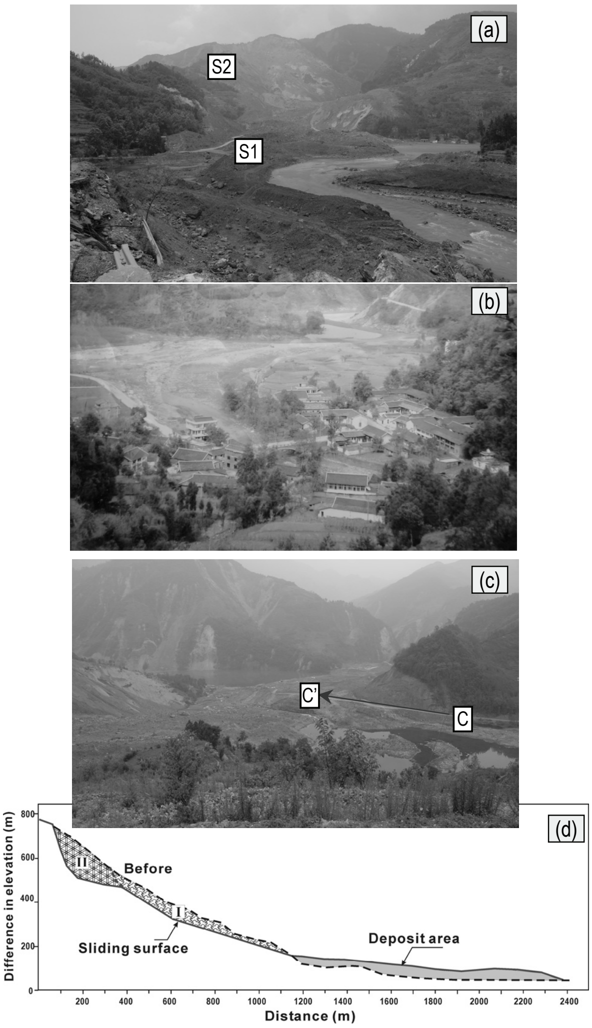

Fig. 5 Donghekou landslide. (a) View from the toe part, (b) and (c) views from the middle part of the right side slope of the source area before and after the earthquake, respectively, and (d) cross section (after Yin 2008)

Donghekou landslide is located on Donghe Village, Qingchuan County, about 250 km northeast of Chengdu. Fig. 5a presents a view of the landslide from the toe part; Fig. 5b and 5c show the downslope view from the right side slope of the source area before and after the earthquake, respectively. The settings of this landslide are mainly composed of dolomite (on the middle and upper part of the source area) and sandy slate (on the lower part of the source area) with some grey-black Siliceous slate and phyllite. The landslide originated from a slope facing the confluence area of Qinzhu River and its tributary, Hongshi River. The displaced mass totaling to 1×10^7 m^3 developed into a flowslide and deposited on the rice paddy after passing through the residential areas with a travel distance of about 2 km and decrease in elevation of about 500 m. Four villages, two buses and a car were buried completely by this landslide, and more than 300 people were killed. Both rivers were dammed by the debris pile 700 m long, 500 wide and 15-25 m high. Overflow occurred about days late, and the dam was partially collapsed then. Fortunately, no further damage on the downstream was induced by the collapse of the dam.

The long traveled distance on the almost horizontal residential area and rice paddies showed that the movement of the landslide mass must be extremely rapid. This can be also confirmed by the witnesses. They said that at first they heard three times of 'explosion sound' from the ground, and then they felt very strong vertical ground vibration such that they fell on the ground, and then they were surrounded by the dust with very big noise. When the dust disappeared, everything was changed and they could only saw the deposit mass. Therefore, all the local people deemed that the landslide mass emerged from the ground. They also told us that the failure on the source area continued two days and finally retrogressed to the ridge of the mountain. Therefore, we inferred that during the earthquake the failure was triggered at first on the lower part of the slope where one village was located and the ground water was rich (area I in Fig. 5d), thereafter the upper part of the steeper slope suffered retrogressive failure (area II in Fig. 5d). Liquefaction might have been triggered within the soil layer rich in ground water. Also, the water from the rivers and rice paddies might have played a key role on the maintenance of high mobility.

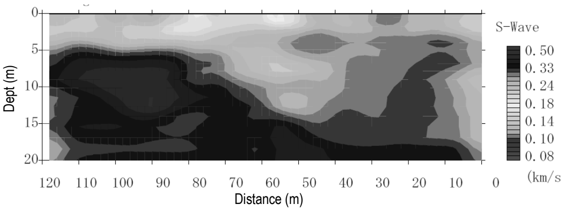

Fig. 6 S-wave velocity profile along line C-C' in Fig.5c

To investigate the geotechnical properties of the deposited landslide mass, the S-wave profile was also surveyed by means of multichannel surface wave technique. Fig. 6 presents the results obtained along line C-C' in Fig. 5c, where the loosely deposited landslide mass can be identified, and the nonhomogeneity of deposited mass is obvious.

To understand the possible response of slope to earthquake, we brought two earthquake recorders from Japan and installed them at the upper part (S2) and deposit area (S1) of this landslide (shown in Fig. 5a) on July 21. It is noted that on July 24, three aftershocks (M5.8, M5.5 and M4.5, respectively) occurred on Qingchuan Country, and the seismic responses were recorded successfully. Fig. 7 presents the time histories of the accelerations in three directions that were obtained on position S1 and S2, respectively during the second aftershock. It is seen that the response of the upper part of the slope was differing from that on the toe part. These data will be helpful for a better understand of the initiation of landslide during the earthquake. Detailed analysis is on the process and results will be presented in elsewhere.

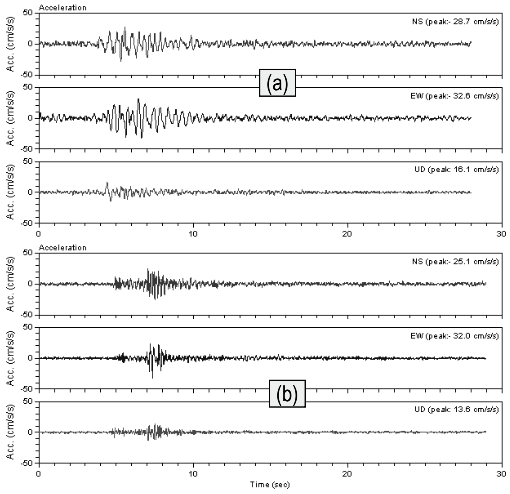

Fig. 7 Seismic recordings monitored on (a) the source area, and (b) deposit area of Donghekou landslide

4. Summary

Wenchuan earthquake is one of the most catastrophic geohazards in the 21 century in the world. Besides its great damage to human life, properties, and infrastructures, it also triggered a huge number of landslides, killing a lot of people, blocking rivers and roads and then causing great difficulties in the rescue and recovery after the quakes. Through the reconnaissance field trip and preliminary investigation, some results can be summarized as follows.

(1)The strong seismic excitation and precipitous mountains as well as the fragmented rocks enabled the occurrence of vast of landslides with high mobility.

(2) The rich groundwater in some gentle slopes might have favored the generation of high pore-water pressure during the earthquake and then resulted in the rapid movement and long runout of the displaced landslide mass.

(3) Many landslide dams had been formed, causing great threaten to the downstream residents. However, due to the different geological background and movement of each landslide, the debris forming the dam is nonuniform and has differing properties. These differences should be taken into account in the stability analysis of landslide dam.

(4) The response of different slope parts to an earthquake may be greatly different. Better understand of these responses will be helpful for the slope stability analysis with high reliability.

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PSInSAR for the Investigating of Unstable Slopes and Landslides

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Abstract. Recent years have witnessed an increasing number of initiatives focused on the exploitation of the space-borne synthetic aperture radar differential interferometry (DInSAR) techniques in geohazard investigations (IGOS Geohazards, 2004). These techniques are attractive because of their capability to provide wide-area coverage (thousands km^2) and, under suitable conditions, spatially dense information on small ground surface deformations (e.g. Gabriel *et al.* 1989; Colesanti *et al*. 2003). Furthermore, the advanced multi-temporal DInSAR methods such as the Permanent/Persistent Scatterers Interferometry (PSInSAR; Ferretti *et al.*, 2001) overcome the limitations of conventional DInSAR and extend the applicability of radar interferometry from regional to local-scale engineering geology investigations of landslides and ground instability in general (e.g. Ferretti *et al.*, 2006; Wasowski *et al*., 2007; Farina *et al.,* 2007). Also, thanks to the regular revisit schedule of radar satellites a long-term monitoring of small surface displacements is feasible.

However, many landslides occur in environmental settings that are not well suited to the application of DInSAR (e.g. vegetated slopes, steep and rough topography). Also, with the exception of urbanised slopes, the density of radar targets usable for interferometric measurements in rural regions is typically low and this makes difficult PSInSAR analysis, as well as introduces considerable uncertainties in the assessments of true ground motions (e.g. Bovenga *et al*., 2006; Ferretti *et al.*, 2006). Furthermore, the interpretation of the exact geological significance of millimetric to centimetric (per year) displacements currently detectable by PSInSAR can be very challenging, because i) very slow ground surface deformations may arise from a wide variety of natural and anthropogenic causes and, ii) most radar targets correspond to man-made objects (e.g. houses) and thus their structural behaviour (and ground-foundation interactions) should be taken into account.

Here, we first highlight the advantages and limitations of the PSInSAR technique (Table 1). Then we offer some examples of PSInSAR applications from landslide-prone towns located in the Daunia Apennine Mountains, Italy (Figs. 1-3) to: i) illustrate the potential of the technique to provide, under suitable conditions, valuable reconnaissance and local scale complementary information with respect to what can be gained through direct and generally more costly in situ topographic/GPS measurements, ii) draw attention to the difficulties in interpreting the exact geological/geotechnical significance of small ground surface displacements; iii) provide some examples of how GIS tools can be used to visualise and assist in PSInSAR data interpretations.

Finally, we indicate that much progress can be expected in the near future thanks to the most recent (e.g. RADARSAT-2, TerraSAR-X, Cosmo SkyMed) SAR dedicated missions with shorter repeat cycles and higher spatial resolution (meters) sensors. This and multidisciplinary approaches that integrate information obtained from space and from ground-based slope instability investigations will help to overcome some current limitations of the technique and difficulties in data interpretation.

Tab. 1 Advantages and limitations of the current SAR satellite systems and PSInSAR technique (modified after Wasowski et al. 2007)

Advantages	**Limitations**
Cost-effective for wide-area applications (hundreds and thousands of km2)	Difficult to anticipate PS distribution without acquiring and processing radar data
High density of radar targets (from tens to hundreds per km2 in urbanised zones)	The PS density can drop to zero in non-urbanised areas without rock outcrops
Use of “natural” radar targets (without deployment or maintenance costs)	A reliance on natural targets implies that their position cannot be chosen freely
High geo-coding accuracy of radar targets (positioning error within 5-10 meters)	About 20 SAR images needed to identify PS (some areas have limited coverage)
High precision (mm) of measurements (comparable to or better than GPS)	Provides 1D deformation data (projection of 3D displacement) along sensor-target LOS
Possibility of retrospective studies exploiting imagery archives spanning over 10 years	A limited range of detectable displacement velocities (usually up to 10 cm/ yr)
Regular satellite re-visiting time over the same areas	Satellite repeat-cycle (currently few weeks) suitable only for low displacement gradients
Possibility of continuous, long-term monitoring (several years)	Interferograms cannot be generated from SAR data acquired by different satellites

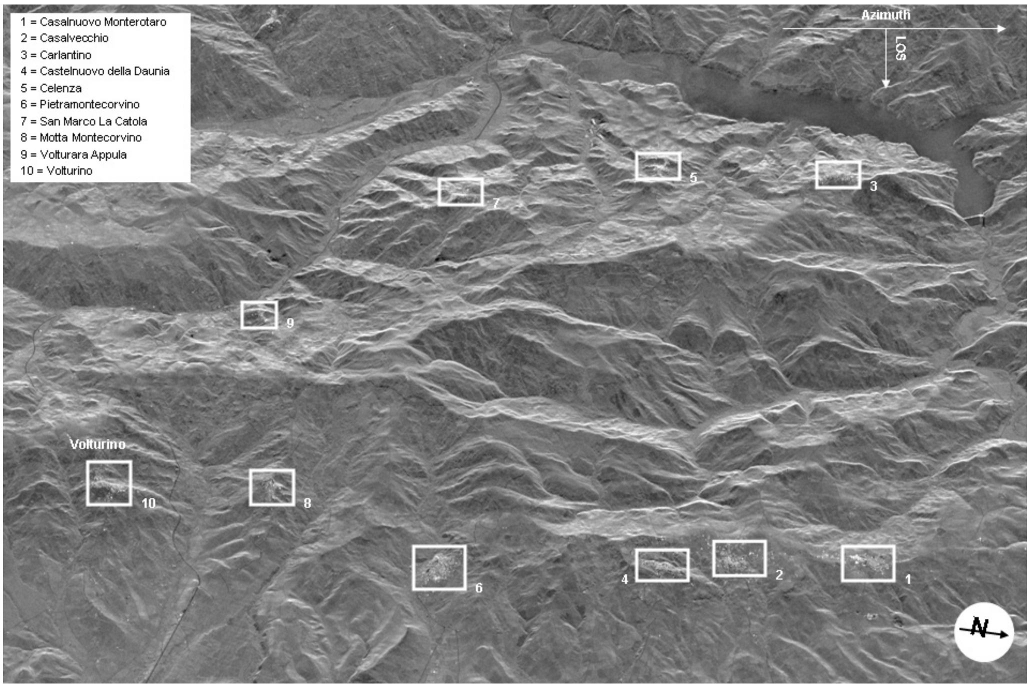

Fig. 1 Average SAR amplitude image of the Daunia study area (28 km × 27 km): white-border rectangles enclose 10 town areas selected for the PS processing. In the case of the town of Volturino the patch is 4 km wide in range and 3.7 km in azimuth. Note the prevailingly moderate relief hillslope topography. Radar dataset: European Space Agency (ESA) ERS 1/2 imagery 1992-1999

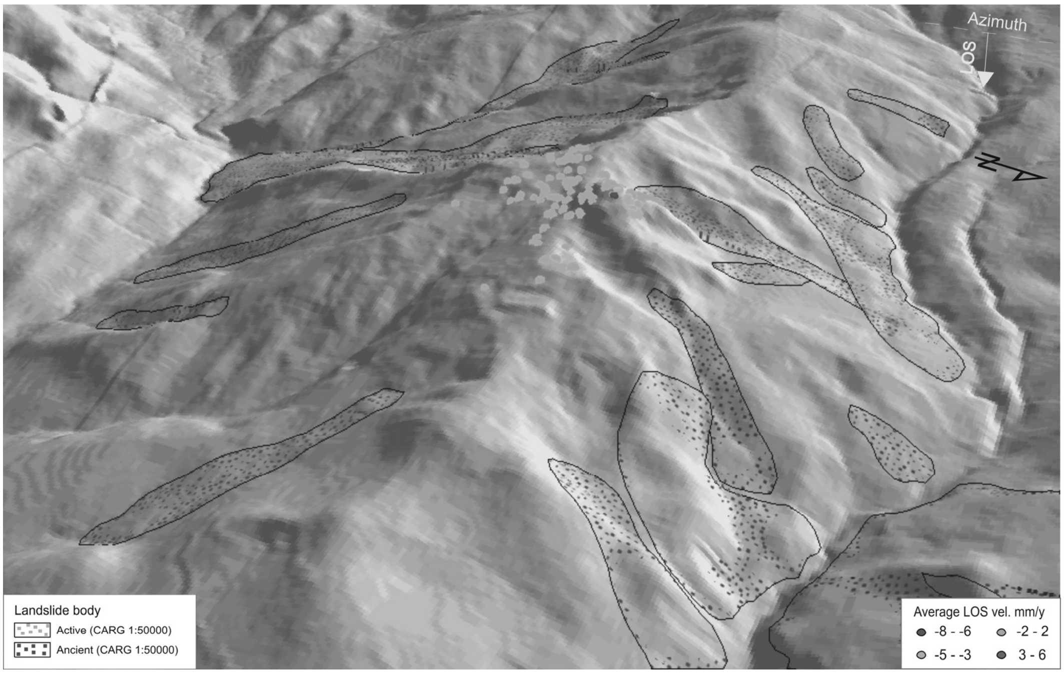

Fig. 2 Distribution and Line Of Sight (LOS) velocity of radar targets (PS - color dots) visualised on a high resolution DEM of the Motta Montecorvino area. Active and ancient landslides are from recent CARG maps (www.apat.gov.it). Moving PS are found only at the N periphery of this hilltop town, characterized by the presence of pre-existing landslides

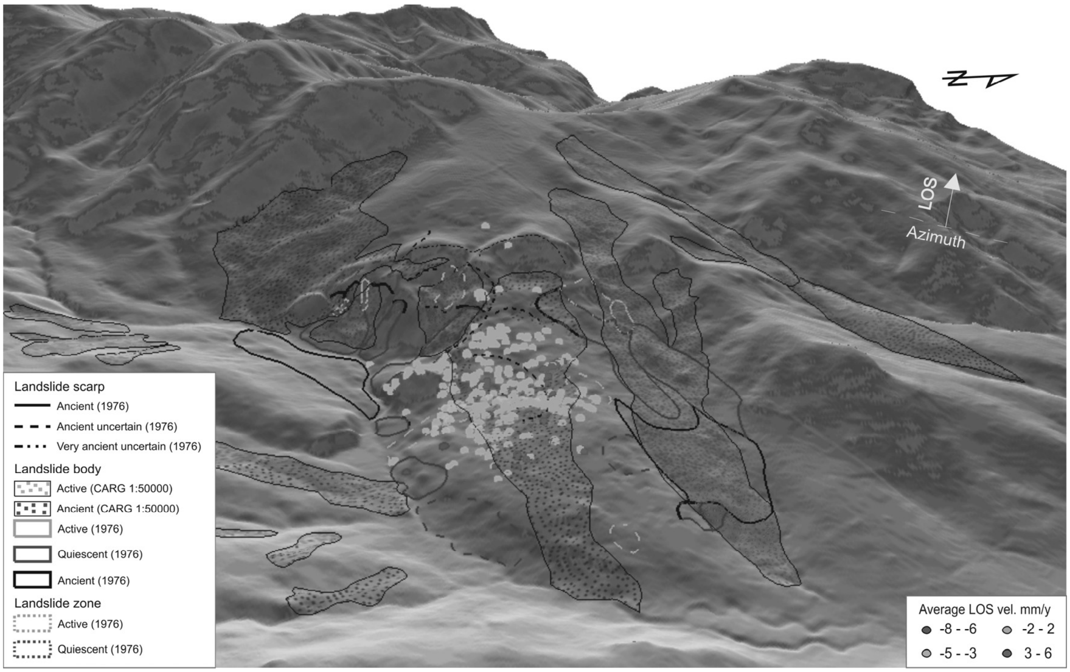

Fig. 3 Distribution and LOS velocity of radar targets (PS) visualised on a high resolution DEM of the Pietramontecorvino area. Landslide features including scarps, mappable bodies, as well as landslide zones are based on 1976 airphoto interpretation (after Zezza *et al.*, 1994); active and ancient landslides are from most recent CARG maps (www.apat.gov.it). Complex relation between very slowly moving PS and landslide legacy of the area suggest that radar detected ground instabilities likely reflect post-failure slope deformations and localized settlements

Acknowledgments

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The Güímar Flank Collapse on Tenerife Island and Evidences for Related Tsunami on the West Coast of Gran Canaria, (Canary Islands, Spain)

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Abstract. Landsliding is a major process of morphological evolution on volcanic edifices. These mass movements are favoured by structure diping according to the slope and by superposition of material of various resistance. They can be triggered by local tectonic before (destabilisations dues to dome), during (phreato-magmatic interactions) and after the eruptive episode (Caldera collapse). In the Canaria Islands, not less than nine major flank collapses were identified.on the base of remaining scars and related large lobate deposits on the ocean floor. The Güímar collapse, that occured on the east flank of la Cañadas volcano on Tenerife is constrained between 840 and 780 ka. The movement involving a tremendous mass of material (45 km3 for the subaerial scar 120 km3 for the submarine debris avalanche deposit) is the only one that was not oriented to the open sea but was focused towards the channel between Tenerife and Gran Canaria. On the north western shore of Gran Canaria, the Agaete valley mouth, facing Tenerife Island, interrupts locally the sheer vertical high cliffs and fans out to the sea. On the walls of the valley, nine patches of enigmatic conglomerate are attached at altitudes ranging between 41 and 188 m asl. Composed of heterometric angular to rounded volcanic clasts and fossils (rhodolites and marine shells) generally broken and never in life position, the deposits decrease in thickness with altitude from 5 to 0.1 m. Internally stratified, the material displays two main layers. The clast supported lower layer is characterized by poor sorting, reverse grading and shows sometimes more than one sequence. The basal contact with the substratum shows clear erosive features (rip-up clasts). The upper one is composed of less coarse material. Also clast supported and poorly sorted, it encloses numerous fossils and is only lightly reverse graded. The study of the clasts (size, morphology and nature) points out that the material is provided by two main sources. One can be related to the beach gravels and pebbles and the other to alluvial deposits along the valley. Measurements of clast imbrications within the conglomerate show that the direction of the palaeocurrent leading to the emplacement of the deposit was landward for the lower layer and seaward for the upper layer. All these sedimentological, stratigraphical and paleontological observations indicate that the assembly of outcrops along the Agaete valley seems to have a common origin. Some of them like clast imbrication oriented landward for the basal layer and seaward for the upper layer, or the presence of rip up clasts of substratum incorporated in the lower layer are determinant to allow linking these conglomerates to a common and single tsunami origin. Lower layers could reflect the runup of the wave in the valley mouth. The high energy of the wave front was responsible for the mobilisation of a huge amount of beach pebbles and alluvial material in the valley that lead to a kind of reverse debris flow with an erosive shearing at the base that leads to the reverse grading formation. The loss of energy with the distance to the sea explains the landward decreasing of the thickness of the deposits. Close to the turning over point, as the energy was close to zero the less coarse material emplaced abruptely. This part of the deposit was remobilized and the clasts were re-oriented seaward by the backwash. Local variations of the runup and backwash direction must be related to the role played by the topography on the uprush and backwash orientation.

The closest source possible for the Agaete tsunami deposits is the Güímar sector collapse on the east coast of Tenerife. Focused towards Gran Canaria Island, his age is compatible with the age of the deposits, poorly constrained between 35 and 1750 ka. The height reached by the water in the Agaete valley during the event (at least 188m asl) doesn't correspond to the real height of the waves but to the runup level that could have been notably increased by the "wave trap" shape of the Agaete valley mouth facing the source of the tsunamigenic sector collapse on Tenerife.

1. Introduction

Life-cycles of volcanoes are punctuated by episodes of flank instability and lateral failures (McGuire, 2003) that lead to massive flank collapses Magma intrusions and oversteepening of edifice slopes due to accumulation of material of various resistance (lava, ash, pumice, lapilli…), with a structure concordant to the topography, bring about natural sensitivity to huge mass movements. Francis and Wells (1988), studying the Andes volcanoes have shown that occurrence of collapses increases with the height of the edifice. In this region, more than three volcanoes out of four that exceed 2500 m in height have been subject to gravitational destabilisations. These flank collapses can be pre- or syn-eruptive when magmatic intrusion or seismic activity lead to the flank failure. This can also be post-eruptive and one process particularly capable of weakening the edifice is hydrothermal activity that can produce high pore pressures and alter strong rock to weak clays (van Wyk de Vries *et al.*, 2000). These mechanisms, combined with physical triggers such as earthquakes, development of a fault system at the base of the edifice, or peripherical subsidence or erosion and heavy rainfall episodes (López and Williams, 1993; Day *et al.*, 1999; Leyrit, 2000; Melekestev, 2002), can lead to large scale flank collapse that evolves in debris avalanches and spread far around edifices. On islands, the movement can also affect the submerged part of the volcano. The volume of the material involved in such movements surpass those of non-volcanic events by the order of magnitude (Hürliman and Ledesma, 2006) and can reach 500 km^3 (Mount Shasta, California). Entering in the sea, a debris avalanche produces a fast momentum transfer. The water surface falls under the weight of the avalanche and, in reaction to this sudden subsidence, a propagation impulsive wave occurs (Harbitz, 1992). The impact of these landslide-triggered waves is more focused than earthquake-induced tsunamis (Iwaski, 1997), and constitutes a serious threat when the movement is oriented toward highly populated coasts.

One of the largest disaster of this kind occurred in Kyushu Islands (Japan) in 1792. Triggered by a strong earthquake, an entire flank of Mount Mayuyama, at the foot of the Unzen volcano, collapsed. Entering into the sea with a thickness of 30m and a speed of about 100 m/s^{-1}, the moving mass generated a tsunami wave train that hit the shores of Ariake Bay, causing more than 10,000 fatalities (Michiue *et al.* 1997).

2. The Güímar collapse on Tenerife

In the Canary Islands, not less than 22 major flank collapses were identified on the basis of remaining scars and related large lobate deposits on the ocean floor (Fig.1).

The movement involved a tremendous mass of 120 km^3 of material that constitutes the submarine debris avalanche deposit (Masson et al., 2002).

The Güímar collapse which affected the north eastern rift-zone of Tenerife (Fig.1, 2a and 2b) is constrained between 840 and 780 ka (Ancochea *et al.*, 1990).

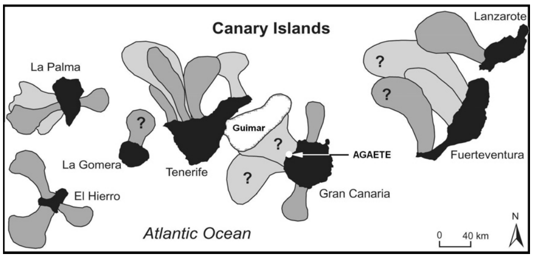

Fig.1 Debris avalanches deposits around Canary Islands

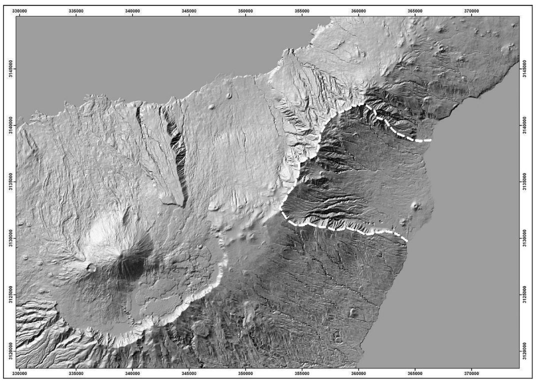

Fig. 2a The scar of Güímar collapse on the eastern slopes of Tenerife Island

On the walls of the valley, nine patches of enigmatic conglomerate are attached at altitudes ranging between 41 and 188 m a.s.l. (fig. 3, fig. 4).

With lengths ranging from a few meters to almost 100 m, deposits generally appear as lenticular patches adapted to the valley walls. Composed of heterometric angular to rounded volcanic clasts and fossils (rhodolites and marine shells generally broken and never in life position), the deposits decrease in thickness with altitude from 5 to 0.1 m (Pérez-Torrado *et al.* 2006). Internally stratified, the material displays two main layers (fig. 4). The clast supported lower layer is characterized by poor sorting, reverse grading and shows sometimes more than one sequence. The basal contact with the substratum displays clear erosive features (rip-up clasts). The upper one is composed of less coarse material. Also clast-supported and poorly sorted, it encloses abundant fossils and is only lightly reverse graded. The study of the clasts (size, morphology and nature) points out that the material is provided by two main sources. One can be related to the beach gravels and pebbles and the other to alluvial deposits along the valley (Pérez-Torrado *et al.* 2006). Measurements of clast imbrications within the conglomerate indicate that the direction of the palaeocurrent leading to the emplacement of the deposit was landward for the lower layer and seaward for the upper layer (fig. 4).

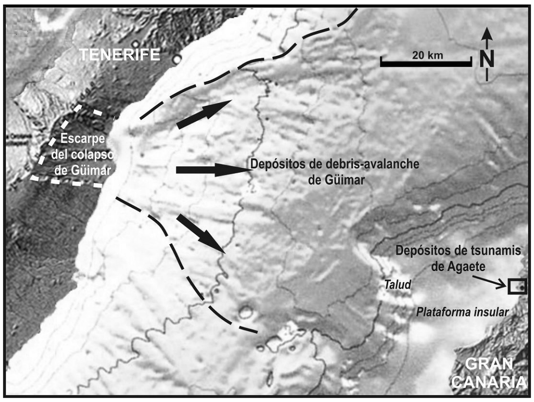

Fig. 2b Güímar collapse embayment and related submarine debris avalanche deposits

The subaerial volume removed from the scar is more than 47 km^3 (Paris, 2002; Paris et al., 2005). This huge landslide is the only one on Tenerife that was not oriented to the open sea, but was focused towards the channel between Tenerife and Grand Canary (Fig. 1 and 2b).

3. Enigmatic conglomerate on the north-western shore of Gran Canaria

On the north western shore of Grand Canary, the Agaete valley mouth, facing Tenerife Island, locally interrupts the sheer vertical high cliffs and fans out to the sea.

4. Discussion

All these sedimentological, stratigraphical and paleontological observations strongly suggest that the assembly of outcrops along the Agaete valley have a common origin. The clast imbrications oriented landward for the basal layer and seaward for the upper layer, or the presence of substratum rip-up clasts incorporated in the lower layer, are diagnostic linking these conglomerates to a common and single tsunami event (Pérez-Torrado *et al.* 2006). Lower layers could record the uprush of the wave in the valley mouth. The high energy of the wave front was responsible for the mobilization of a huge amount of beach pebbles and alluvial material in the valley. These landward movements led to a kind of reverse debris flow, with basal erosive shearing that generated the reverse grading (Paris *et al.* 2004; Pérez-Torrado *et al.* 2006).

The loss of energy with the distance to the sea explains the landward decreasing of the thickness of the deposits. At the turning over point, as the energy was close to zero the less coarse material settled abruptly. This part of the deposit was remobilized, and the clasts were re-oriented seaward, by the backwash. Local variations of the uprush and backwash direction must be related to topographic control.

In the regional setting of the Canary Islands, four processes can be considered to be possible sources for the Agaete tsunami: 1) a seismic event, 2) a submarine volcanic eruption, 3) a pyroclastic flow, and 4) a massive flank failure generating a debris avalanche.

The most probable origin for the Agaete tsunami is the Güímar sector collapse on the east coast of Tenerife. Focused towards Grand Canary Island, his age (<0.83 Ma, Ancochea *et al*., 1990) is compatible with the age of the deposits, poorly constrained between 35 and 1750 ka. The corresponding submarine debris avalanche has been clearly identified (Watts and Masson, 1995; Teide Group, 1997), and its volume was estimated to be 120 km^3 (Masson et al., 2002). The sub aerial volume involved in the scar is more than 47 km^3 (Paris et al., 2005). The altitude reached by the water in the Agaete valley during the event (at least 188 m a.s.l.) does not correspond to the real elevation of the waves but to the run-up level that could have been notably increased by the "wave trap" shape of the Agaete valley mouth facing the source of the tsunamigenic sector collapse on Tenerife. The 2004 tsunami wave train in Sumatra, with a maximum inundation height of about 34 m in the Bay of Lhok Nga (south Banda Aceh), reached locally 51 m in the small bay of Labuhan (Paris, 2007) where a local wave trap configuration increased the run-up of 50%.

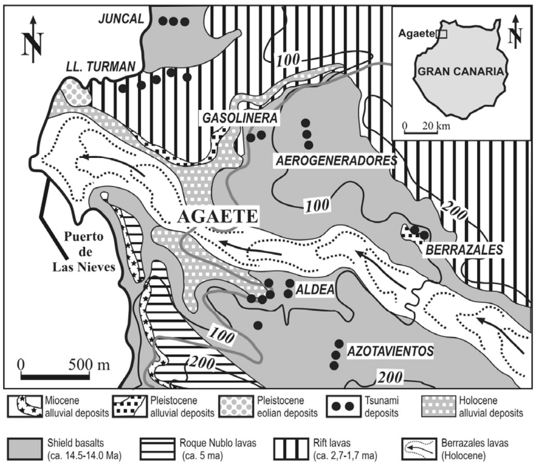

Fig. 3 Conglomerate location in Agaete Valley on the north-west cost of Grand Canary Island

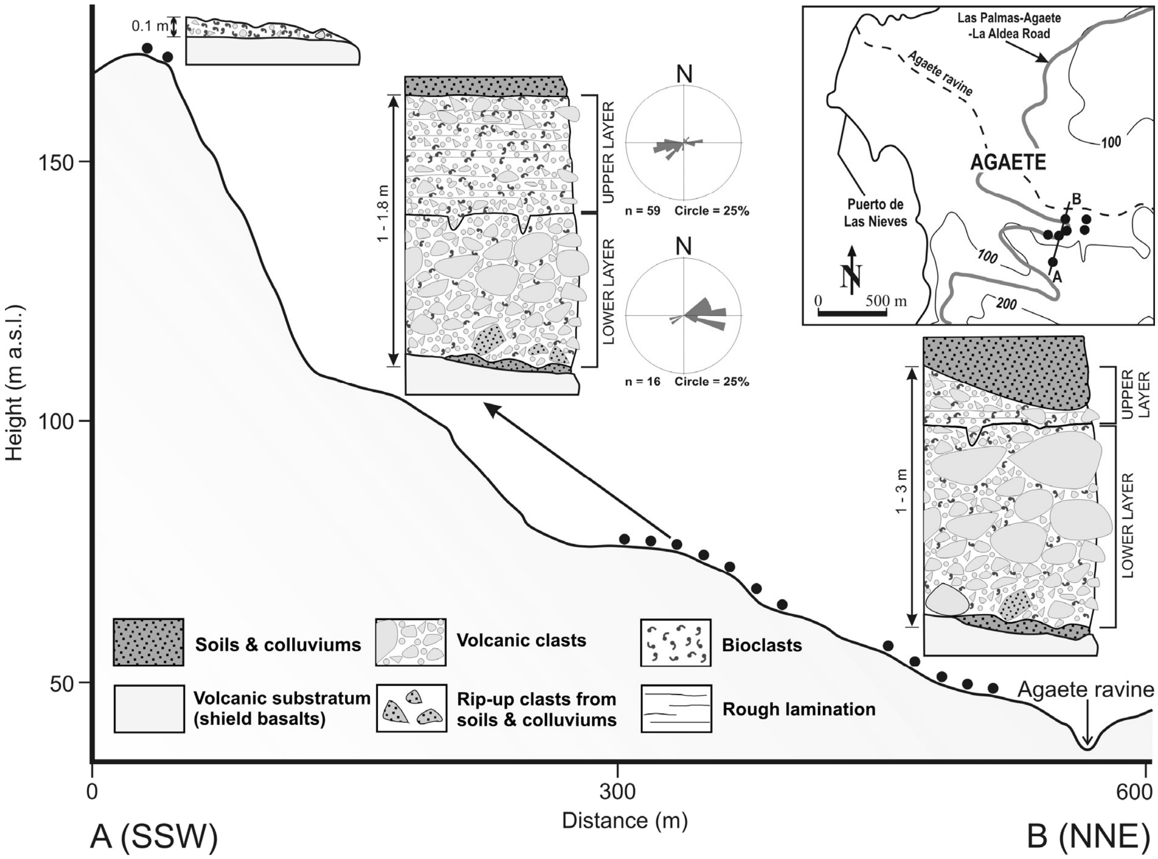

Fig. 4 Characteristics of tsunami deposits related to height above the present sea level in Agaete Valley

Conclusions

Flank collapses on volcanoes facing continental densely populated areas constitute a severe threat for people living on the lower slopes. Apart from the direct hazard due to the high mobility of the material and its ability to spread largely at the foot of the edifices, associated risks can be determined. These risks are generally delayed in time in sub aerial settings. In these situations the damming of a valley by the debris avalanche material can lead to the progressive flooding of large areas upstream. Once the lake is constituted, the possible dam breach could be even more disastrous than the landslide itself.

In a marine context, the collapse of a volcano flank is able to mobilize a tremendous mass of material above and below sea level. The depression of the sea level due to the sub marine movement and to the entrance of the rapid moving sub aerial mass into the sea, can trigger a tsunami wave train. The tsunami, a synchronous hazardous event, generally more focused than those related to seismic origin, and can be locally highly destructive when they hit the shore of a neighbour island. The run up height of 188 m reached by the tsunami flooding related to Güímar sector collapse on the east coast of Tenerife was about 0.80 Ma ago. One can only imagine the consequences of such events in a present day densely populated littoral area.

Acknowledgements

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“Debris-flow Dewatering Brake”: An Efficient Tool to Control Upstream Debris-flow to Secure Road Transportation and Community Safety

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ABSTRACT: The paper intends to illustrate the functions and cost efficiency of “debris-flow dewatering brake” as an important tool to control upstream debris avalanche to protect fragile mountain road networks, the life and livelihood in the remote communities. Due to the population explosion people are forced to live in the remote corners of the world and the possibility to suffer from debris-flow disasters is ever increasing. Under the circumstances, a single breach or a single closure of either embankment or road as an aftermath of a debris flow results in total destruction of community or total closure of road network. A disaster due to debris flow can be prevented with the help of a dewatering brake immediately after its onset or before growing larger by picking up enormous speed and loose materials from channel bed. The screen structure is usually constructed along a channel bed which facilitates the easy removal of debris accumulated on the dewatering screen for its reuse. The high permeability of debris accumulated on the screen, it is expected that deposits of subsequent flows stop at the upper end of the previous deposit. In this process a gully can be filled up with its own debris yielded in the upper reaches as a result if debris is not removed. This phenomenon is referred to as the “wound suturing effect”. “Debris flow dewatering brake” has been proven for its dewatering effect derived from a horizontal screen structure which brakes a debris flow at its initial stage at the upstream, but because of its lack of popularity this efficient structure has scarcely been employed at debris flow prone sites. Recently ICHARM/PWRI has taken initiative to popularize this Japanese technology with financial support from Asian Development Bank for prime venture in the Philippines. This technology and knowhow is efficient, cost effective and could be constructed with local materials therefore, it is best fitted for remote communities, and we recommend the transfer of this technology for the benefit of the communities in the rugged disaster prone terrains and authorities concerned with road network management throughout the world.

KEYWORDS: Debris flows, dewatering effect, horizontal screen structure, counter measures

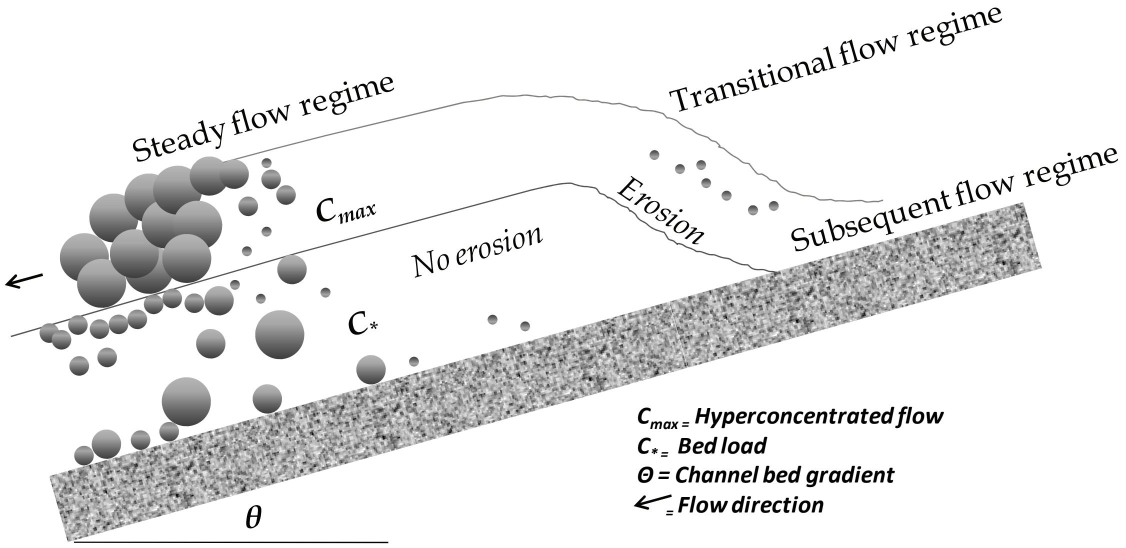

Fig. 1. A schematic illustration of the development process of a debris-flow (modified from Takahashi 2004)

Background: The rugged mountain terrain in the Northern Alps, Japan or elsewhere in the world especially in volcanic area loaded with looses sediment could readily transform into a colossal debris-flow avalanche during torrential rainfall. The debris-flow avalanche phenomena is usually triggered in the high mountains well above the tree-line where the loose sediment is abundant forming coarse hyperconcentrated debris as shown in Fig. 1 which later becomes very dangerous downstream killing people, destroying infrastructures and other properties because it will accumulate more debris along its course gaining tremendous strength. Therefore, long time since various debris-flow control measures has been thought about. The debris-flow control measures depend on the extent of sediment source, geology, slope, valley shape and size. Along with the non-structural measures the physical structural measures are popular and come in varieties depending on the need. In the rugged terrain the engineering methods such as ground sill, gabion, low sabo dams and screen dam for ground and slope stabilization are effective. Besides, concrete and steel slit dams and net are used at the forefront to trap the boulders and coarse sediment generated during the volcanic, tectonic or rainfall event to reduce the momentum and energy of the debris-flow and finer sediment is trapped downstream in the sand pockets or sabo dams. In this manual the **debris-flow dewatering brake** is introduced. The **debris-flow dewatering brake** is a simple engineering structure which filters the fine sediment together with water and traps the course debris on a horizontal screen. This horizontal screen structure is designed in such a way that slit apertures filter the desired debris size thus effectively trapping the expected volume of the debris-flow with the objective to control the tremendous energy of the hyper-concentrated flow.

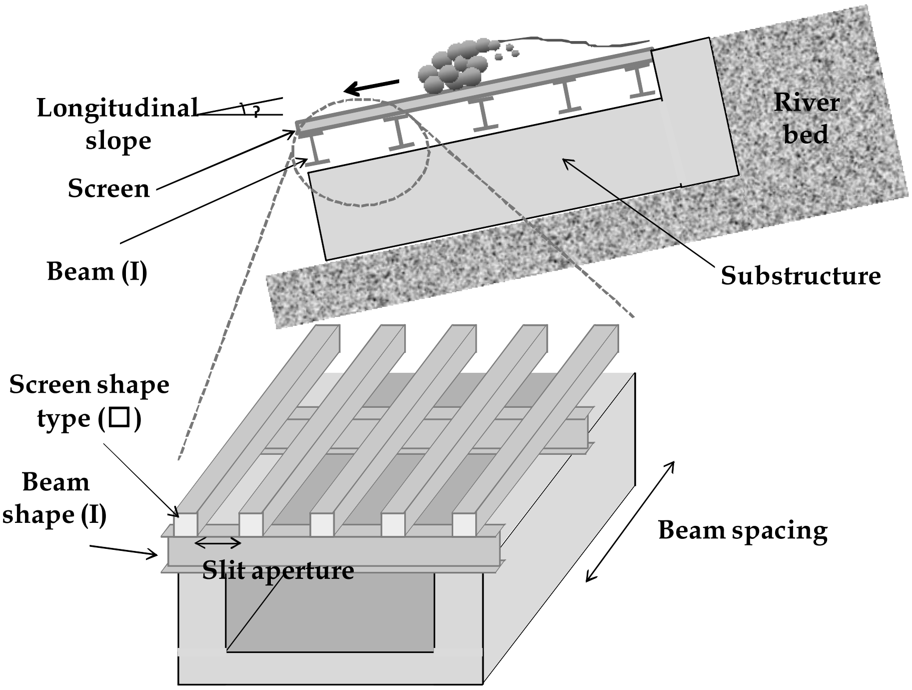

Fig. 2. Longitudinal and cross-sectional view of a debris-flow dehydration brake. In Table 1 we indicated different screen types; in this example we use ☐ for screen and I for beam as indicated in the diagram.

Principle: The principle beyond the system is to check the momentum with the increase of internal friction by filtering water from the debris. To attain this, the dewatering brake is designed in such a way that it filters water along with the finer sediment particles with the screen thus increasing the internal friction leading to velocity reduction of larger materials making it possible to stop over the dewatering brake as shown in Fig. 2.

Limitations of a debris-flow dewatering brake: The dewatering brake are small structures made along a debris-flow path to reduce the intensity of the flow by filtering the fine sediment along with water increasing the internal friction thus retaining the course sediment on the dewatering brake. The finer debris particles are later trapped with different method. Debris-flow dewatering brake method is proven and recognized as an effective course-sediment control measure because they could filter and trap the course sediment with comparatively low cost, with only about one third of the other similar sabo structures, at upstream near its source. Furthermore, the design and construction is simple with the local materials anywhere in the world. The debris-flow dewatering brakes are usually put in place in the bottle neck valleys for the ease, cost optimization and effective sediment trap.

The stability of the bed material in the lower reaches is the prerequisite for its optimum use because filtered water which contains less sediment picks up mobile materials again and generates secondary debris-flow.

		Mt. Fuji			Mt. Yakedake	Mt. Sakurajima	Mt. Tokachidake
Screen	Longitudinal slope	1/10	1/40	1/40	1/14	Horizontal	Horizontal
	Shape type	I	△	△	□	▽	▽
	Size	200*150* 9*16mm	200*200* 25mm	200*200*25mm	200*200* 8mm	255*270*205* 9mm	255*270*205* 9mm
	Slit aperture	10-15cm	15cm	15,60cm	20cm	40cm	40cm
	Transmissivity	50%	35%	56%	50%	66.7%	66.7%
Beam	Shape type	H	H	H	H	H	H
	Size	300*300* 10*15mm	400*400* 13*21mm	400*400*13*21mm	400*400*13*21mm	900*300*16*18mm	800*300*14*26mm
	Spacing	2.925m	2.29m	2.29m	2.5m	3.0m	2.5-3.5m

Table 1. **Important criterias and parameters of debris-flow dewatering brake constructed at four different mountains in Japan . Please see figure 2 for detailed structural information and the screen and beam types used.**

Debris-flow dewatering brakes are often constructed on a steep mountain slope with steel frames and cement as listed in Table 1. Some of these steel frames could be replaced by timber optimizing cost promoting the use of local materials making easier to construct and inject the local economy as well which gives it the advantages to other types of engineering structures for the same purpose. The dewatering brake could be reused as is for subsequent flows if the structure is strong enough. Furthermore the brake is design in such a way that the deposited sediment could easily be cleared making ready for the next perilous event.

Debris-flow dewatering brake technology transfer from Japan is thought to be a precious gift where people are suffering from the impending debris-flow disasters especially in developing countries to help save life and property and a basis for economic development as well. Recently ICHARM/PWRI has taken initiative to popularize this Japanese technology with financial support from Asian Development Bank for the first time in the Philippines and intends to expand it throughout the world.

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RiskCity: A Training Package on the Use of GIS for Urban Multi-hazard Risk Assessment

Cees van Westen (UNU-ITC DGIM, The Netherlands)

Abstract. As part of the capacity building activities of the United Nations University – ITC School on Disaster Geo-Information Management (UNU-ITC DGIM) the International Institute for Geoinformation Science and Earth Observation (ITC) has developed a training package on the application of GIS for multi-hazard risk assessment. The package, called RiskCity comprises a complete suite of exercise descriptions, together with GIS data and presentation materials on the various steps required to collect and analyze relevant spatial data for hazard, vulnerability and risk assessment in an urban environment. The exercises deal with four different types of hazards: earthquakes, flooding, technological hazards, and landslides. The exercises deal with a hypothetical case study, hence the name RiskCity. Most of the data was derived from the city of Tegucigalpa in Honduras, but has been adapted to make the exercises more didactical. They aim to give an understanding of the basic concepts involved in risk assessment, and allow the students to have an idea on how GIS can be used for analyzing the different types of hazards, creating an elements at risk database, assessing vulnerability, making loss estimations using qualitative and quantitative methods, carry out a cost benefit analysis, and use the data for urban planning and disaster risk management. The package has been developed in collaboration with several partner organizations in different continents, and is used as the basis for a series of courses. Currently it is developed into a distance education course.

Keywords. Risk assessment, capacity building, landslide risk, training package, Open source software.

1. Introduction

One of the important components of disaster risk management is capacity building and training of disaster management experts and professionals working in many different disciplines that have an important disaster reduction component, such as planners, engineers, architects etc. The Hyogo framework of action 2005-2015 of the UN-ISDR indicates risk assessment and education as two of the key areas for the development of action in the coming years,

Worldwide a number of organizations are specialized in providing short training courses on disaster risk management related issues (ADPC, 2005). A number of organizations have also prepared training materials that are accessible through the internet, for example the Disaster Management Training Programme (DMTP), or the International Federation of Red Cross and Red Crescent Societies (IFRC). Most of these however are concentrating on community-based methods. Disaster risk management courses at BSc or MSc level are now available in many Universities in all continents.

Relatively few training materials are available on multi-hazard risk assessment. Good textbooks on the subject are still not available. Online training materials can be obtained for example from the websites of FEMA (2008) and EMA (2008). The development of innovative forms of learning and teaching oriented towards building new curricula in the field of natural risk has attracted attention in European initiatives such as DEBRIS (2006) and NAHRIS (2006).

As far as GIS-related material related to multi-hazard risk assessment is concerned, the HAZUS methodology developed in the US can be considered the standard. This comprehensive loss estimation software which runs under ARCGIS is a very good tool for carrying out loss estimations for earthquakes, flooding and windstorms (FEMA, 2008b), but is restricted to use in the USA because of data constraints. Courses in the use of HAZUS can be followed online from the ESRI Virtual Campus (ESRI, 2008). However, complete GIS based training packages on spatial hazard and risk assessment using low-cost or free GIS software are still very scarce, to the knowledge of the author. One example is a training package in English and Spanish developed for Central America in the framework of the UNESCO RAPCA project (ITC, 2004)

This paper describes the main aspects of a GIS-based training package on multi-hazard risk assessment, which has been developed by the UNU-ITC School for Disaster Geoinformation Management.

2. United Nations University – ITC collaboration

The International Institute for Geo-Information Science and Earth Observation (ITC) is an institute for postgraduate training and research in the field of geoinformation directed to capacity building and institutional development of professional and academic organizations from developing countries. In 2005, ITC and the United Nations University have established a collaborative programme on the use of spatial information for disaster management, which resulted in the formation of the UNU-ITC School for Disaster Geo-Information Management. The main activities of the DGIM School focus on training, education, curriculum development, knowledge development and research collaboration. This is done through the establishment of University networks in Asia, Africa and Latin America, of which the member Universities exchange spatial information, course materials and jointly carry out training and research projects.

The DGIM School develops training packages and courses that are given jointly with the partners of the networks in various countries. The materials are uniform, and have been developed in different languages, and the support is given by local University staff who have followed earlier training, and by staff from the UNU-ITC DGIM School.

One of these courses is on Multi-hazard risk assessment, which is centered around a case study on the use of Geographic Information Systems, and Remote Sensing for the assessment of hazard, vulnerability and risk in a typical urban area representative of situations in many developing countries. Rapid urbanization combined with a lack of planning often leads to the spreading of squatter areas located in hazardous areas, such as steep slopes, flood prone areas etc.

3. RiskCity training package

The package, called RiskCity comprises a complete suite of exercise descriptions, together with GIS data and presentation materials on the various steps required to collect and analyze relevant spatial data for hazard, vulnerability and risk assessment in an urban environment.

The exercises deal with a hypothetical case study, hence the name RiskCity. The exercises are based on a case study from Tegucigalpa in Honduras. Tegucigalpa suffered severe damage from landslides and flooding during Hurricane Mitch in October 1998 when the city received 281 mm of rain in 3 days (Mastin and Olsen, 2002). Due to river flooding, an old landslide was reactivated and an entire neighborhood on top of it was destroyed. The landslide caused the damming of the river and resulted in severe flooding in large parts of the city center for several weeks (Harp et al., 2002). These events are well identifiable on the high resolution image which serves as the basis for the exercises (See figure 1). After Hurricane Mitch USGS and JICA carried out extensive work in Honduras and produced extensive datasets.

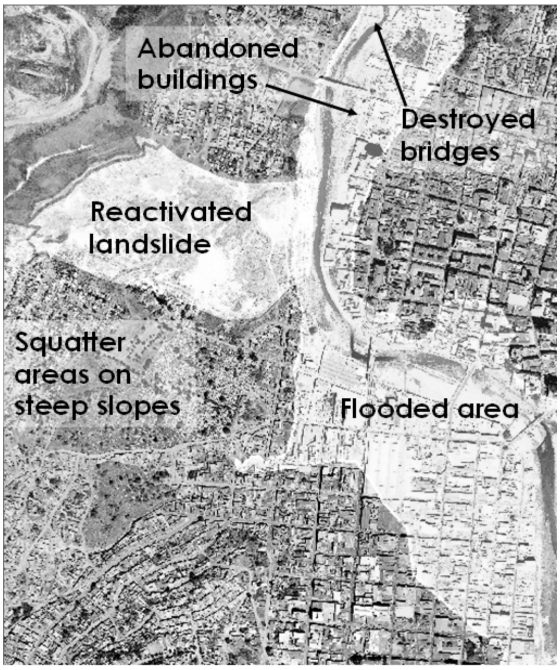


Fig. 1 High-resolution image of the center of RiskCity with some of the hazard and vulnerability features indicated.

Only part of the exercises is based on the actual situation in Tegucigalpa. In order to be able to reach the learning objectives, modifications and additions were made to the original data. It is very difficult to have a dataset for a particular area where all aspects of multi-hazard risk assessment can be properly demonstrated. Either because particular hazard types do not happen in the city or because particular data sets are incomplete, restricted or erroneous.

One important consideration in designing the exercises is that people from developing countries should not be restricted in using it due to financial burdens for software acquisition. Therefore the aim was to use Open Source software as a basis. The exercises are written for the ILWIS software. ILWIS is an acronym for the Integrated Land and Water Information System. It is a Geographic Information System (GIS) with integrated image processing capabilities. It also has its own attribute data analysis, spatial data entry and conversion modules. New modules have been recently added for Spatial Multi Criteria Evaluation, analysis of Digital Elevation Models and for digital stereo image interpretation. The strongest point of the software is the map calculation module that allows extensive modeling with raster maps, also using scripts. The software has extensive help functions and documentation, and can be downloaded from the following web-site: http://52north.org/ilwis. ILWIS is very user-friendly, and allows the participants to concentrate on the risk assessment application rather than on the specifics of the software.

Each of the exercises in RiskCity has its own dataset. The data are all provided in separate directories, including the results of the previous exercises that are needed to make a subsequent one. So it is possible to carry out each of the exercises separately. Also result files and PowerPoint presentations with instructions are included.

4. Structure of RiskCity

The overall structure of the RiskCity training package is given in figure 2, and an overview of the various components is presented in table 1. Four different types of hazards are evaluated: landslides, floods, earthquakes and technological hazards. The training package starts with introductory exercises dealing with the software and with the study area, where students learn the various hazard problems by evaluating high resolution images. An important component of RiskCity is the generation of a database of elements at risk in order to evaluate the vulnerability of buildings and population. Here two options are considered. The first is that there is no spatial data available, except for a high resolution image, and the students have to generate mapping units with homogeneous types of buildings by stereo interpretation and digitizing on the image. Sampling is then carried out to define the number of buildings and population per mapping unit. The second option for generating the elements at risk database assumes there are digital data available in the form of building footprint maps, census information and detailed elevation data from a Lidar survey. These are used to calculate the number of buildings per mapping unit and landuse type, and to characterize the buildings, for instance by calculating their height and floorspace using Lidar data. The floorspace is used then to distribute the census population over the mapping units, and population estimates are made for day- and nighttime scenarios. The elements at risk database contains information on the buildings, with important attributes such as urban land use type, construction type, floorspace and height, as well as on population for a daytime and nighttime scenario.

There are a wide range of hazard assessment exercises, not only the ones dealing with the four types of hazard mentioned before, which are based on the data of RiskCity, but also other ones which use data from other areas for tsunami, cyclone, volcanic, forest fires and land degradation hazard assessment. They use a variety of approaches, such as inventory based, heuristic, statistical and deterministic ones.

The vulnerability assessment includes exercises on the use of vulnerability curves for assessing physical vulnerability, as well as the use of expert based Spatial Multi Criteria Evaluation for the evaluation of social vulnerability and capacity.

Table 1 Overview of the exercise structure of RiskCity.

Component	Exercise
Introduction	Introducing the ILWIS software Introducing the study area and the main problems based on a high resolution image and main spatial data .
Generating an Elements at risk database	Focusing on buildings and population Two different approaches: - when no data is available: use of high resolution images & screen digitizing - when data is available: use of census data, building footprint maps and LiDAR data.
Hazard assessment	Selection of a range of exercises dealing with landslides, earthquakes, floods, technological hazard, volcanic hazard, coastal hazards, tsunami etc.
Vulnerability assessment	Application of vulnerability curves and matrices for physical damage assessment
Loss estimation: qualitative methods	Application of risk matrices, combining susceptibility and vulnerability; use of Spatial Multi Criteria Evaluation for vulnerability and capacity assessment including a range of indicators.
Loss estimation: quantitative methods	Annual loss estimation using risk curves, for earthquakes, landslides, floods and technological hazards
Cost-benefit analysis for disaster reduction measures	Converting of building losses in monetary values for different hazard types; selection of possible risk reduction measures; cost-benefit analysis to select the optimal measures.
Using risk information in urban planning	Spatial Multi Criteria Evaluation in which risk information is combined with other indicator for the planning of new neighbourhoods and infrastructure
Using risk information in emergency preparedness	Modelling of potential sites for evacuation centres, medical support, and emergency centres. Planning of damage assessment campaign.

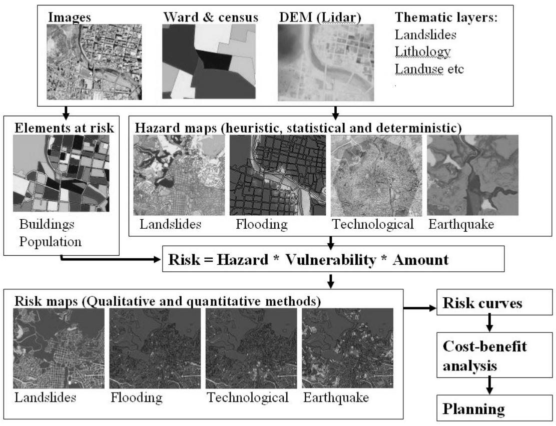


Fig. 2 General structure of the RiskCity training package. See text for explanation

The loss estimation is done using the formula: *Risk = Hazard * Vulnerability * Amount*, in which the various components analyzed in the previous exercises are combined, and risk curves are generated, plotting annual probability against expected losses.

The risk curves form the basis of subsequent cost-benefit analysis, in which for each hazard type, a number of risk reduction measures is evaluated. The investments to implement certain measures (e.g. relocation of houses, flood control) are estimated and compared to the reduction in annual losses that would result if they are implemented. Based on this the most appropriate methods for risk reduction are selected.

The last part of the RiskCity exercises deal with a final project in which the participants are given a particular problem they have to solve with the risk information obtained earlier.

5. Landslide component of RiskCity

Part of the RiskCity training package deals with landslide susceptibility, hazard and risk assessment. These components are also used for giving a separate course on the use of GIS for landslide risk assessment. They are based on methods presented by Soeters and Van Westen (1996) and Castellanos (2008). The landslide related exercises deal with the following tasks:

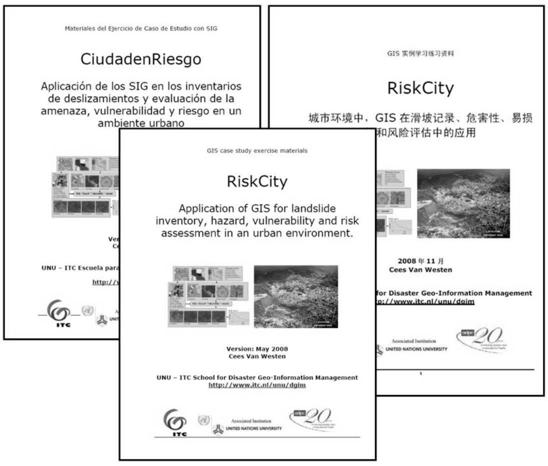
- Downloading of a high resolution image from Google Earth, georeferencing it, and converting it into a digital stereo image through the combination with a detailed DEM derived from a Lidar survey;
- Use of stereo-image interpretation, using the anaglyph image generated and a number of other ones for older periods to digitally map landslides from different times as well as elements at risk;
- Generating a landslide inventory map, with attribute information related to type, age, volume and activity, which is used in the susceptibility assessment;
- Generating a basic landslide susceptibility map, using a simple bivariate statistical method, with the landslide inventory, slope, lithology, landuse and other relevant factor maps. Use of success rate curves to validate the susceptibility map;
- Application of a basic deterministic method, using the infinite slope method, to calculate the factor of safety under different groundwater scenarios;
- The conversion from susceptibility to hazard by multiplication of event probability, based on the success rates, spatial probability, based on the landslide density in the susceptibility classes, and temporal probability, based on estimated return periods.
- Combination of the elements at risk database with the landslide susceptibility map to estimate the number of buildings falling in each of the susceptibility classes;
- Generation of a qualitative landslide risk map using a matrix that combines vulnerability classes with susceptibility classes;
- Generation of a quantitative landslide risk map, by multiplying for each susceptibility class, the spatial and temporal probability of landslide occurrence, the vulnerability and the number of buildings.
- Plotting a risk curve, and analyzing through cost-benefit analysis the most suitable options for risk reduction;

Conclusions

The RiskCity training package is intended as a tool to demonstrate the utility and requirements of spatial data in urban multi-hazard risk assessment. Since the preparation of such a training package takes quite some time, it is normally not possible to adapt the dataset easily to local conditions each time a course is given in another place. This is also one of the reasons why the exercises have been made as generic as possible, by excluding most of the references to the actual city where the dataset is obtained.

The RiskCity training package is constantly being updated and further improved. The plan is to incorporate more Participatory GIS approaches in the training package, as well as to include more hazard modeling, using Open Source software. There is also a plan to make a separate version which is focusing on risk occurring in rural areas taking into account flooding, forest fires, drought and land degration as the main types of hazards.

Discussions are ongoing to make the text of the RiskCity training package available in time on the internet page of an international UN organization. The training package is used regularly in courses and is available in English, with major parts also in Spanish and Chinese (see figure 5). Currently it is developed into a distance education course.



Materiales del Ejercicio de Caso de Estudio con SIG

CiudadenRiesgo

Aplicación de los SIG en los inventarios de deslizamientos y evaluación de la amenaza, vulnerabilidad y riesgo en un ambiente urbano

UNU – ITC Escuela para

GIS 实例学习练习资料

RiskCity

城市环境中，GIS 在滑坡记录、危害性、易损
和风险评估中的应用

2008 年 11 月
Cees Van Westen

for Disaster Geo-Information Management

GIS case study exercise materials

RiskCity

Application of GIS for landslide inventory, hazard, vulnerability and risk assessment in an urban environment.

Version: May 2008
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Fig. 3 Cover pages of the landslide risk part of the guide for the RiskCity training package, available in English, Spanish and Chinese.

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Multi-scale Landslide Risk Assessment; A Contribution to the National System of Multi-hazard Risk in Cuba

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Abstract. Landslides cause a considerable amount of damage in the mountainous regions of Cuba, which cover about 25% of the territory. Until now, only a limited amount of research has been carried out in the field of landslide risk assessment in the country. This research presents a methodology and its implementation for spatial landslide risk assessment in Cuba, using a multi-scale approach at national, provincial, municipal and local level. At the national level a landslide risk index was generated, using a semi-quantitative model with 10 indicator maps using spatial multi-criteria evaluation techniques in a GIS system. The indicators standardized were weighted and combined to obtain the final landslide risk index map at 1:1,000,000 scale. The results were analysed per physiographic region and administrative units at provincial and municipal levels. The hazard assessment at the provincial scale was carried out by combining heuristic and statistical landslide susceptibility assessment, its conversion into hazard, and the combination with elements at risk data for vulnerability and risk assessment. The method was tested in Guantánamo province at 1:100,000 scale. For the susceptibility analysis 12 factors maps were considered. Five different landslide types were analyzed separately (small slides, debrisflows, rockfalls, large rockslides and topples). The susceptibility maps were converted into hazard maps, using the event probability, spatial probability and temporal probability. Semi-quantitative risk assessment was made by applying the risk equation in which the hazard probability is multiplied with the number of exposed elements at risk and their vulnerabilities. At the municipal scale a detailed geomorphological mapping formed the basis of the landslide susceptibility assessment. A heuristic model was applied in the municipality of San Antonio del Sur in Eastern Cuba. The study is based on a terrain mapping units (TMU) map, generated at 1:50,000 scale by interpretation of aerial photos and satellite images and field data. Information describing 603 terrain units was collected in a database. Landslide areas were mapped in greater detail to classify the different failure types and parts. The different landforms and the causative factors for landslides were analyzed and used to develop the heuristic model. The model is based on weights assigned by expert judgment and organized in a number of components. At the local level, digital photogrammetry and geophysical surveys were used to characterize the volume and failure mechanism of the Jagüeyes landslide at 1:10,000 scale. A runout model was calibrated based on the runout depth in order to obtain the original parameters of this landslide. With these results three scenarios with different initial volume were simulated in Caujerí scarp at the scale of 1:25,000 and the landslide risk for ninety houses was estimated considering their typology and condition. The methodology developed in this study can be applied in Cuba and integrated into the national multi-hazard risk assessment strategy. It can be also applied, with certain modifications, in other countries.

Keywords. Risk assessment, multi-scale, susceptibility, hazard, vulnerability, risk, Cuba.

1. Introduction

In Cuba, awareness concerning landslide disasters started in the beginning of the nineties and both the civil defence authorities and the scientific community have put tremendous effort into reducing landslide impacts. Landslides are an important problem in mountainous regions in Cuba, mainly due to tropical storms, but also during prolonged rainy periods (Castellanos Abella and Van Westen 2005). Since the landslide damage is recorded as associated to the main disaster there is no information on how many landslides have occurred and where they are located. The historic record of landslides is incomplete and, before this research, there was no landslide inventory system. Studies of landslides in Cuba are limited and only few hazard, vulnerability and risk assessments have been made with outdated methods.

The National Civil Defence and the various government organizations at various administrative levels are the main organizations in Cuba that are responsible for disaster management. The country was able to setup a warning system for tropical storms, with a warning time ranging from three to five days, which reduced the human casualties to a very low level, although economic losses were still considerable. The role of the National Civil Defence is to identify and evaluate (in co-ordination with government organizations, enterprises and social institutions) the hazard, vulnerability and risk factors as well as to provide the planning needed to cope with them. Each territory should have a disaster reduction plan, as disaster reduction measures will be included in the social-economic plan every year. The Ministry of Science, Technology and Environment is officially responsible as the main co-ordinator for conducting multi-hazard risk assessment in every municipality (169 in all) of Cuba.

Therefore, within the planned system for multi-hazard risk assessment it is very important to know the potential areas for landslide occurrence and the risk of population, infrastructure and economic activities in those areas.

2. Framework of the landslide risk assessment

The main objective of this research was to design a framework for spatial landslide risk assessment in Cuba, considering a multi-level approach and the specific characteristics of Cuba related to landslide types and distribution, availability of data and organizational structure. To do so, a set-up of a national landslide inventory database was made and landslide risk assessment methodology was worked out for four administrative levels and study areas, each one with a different scale, objectives, available datasets and analysis techniques.

The specific objectives were:

1. To design and implement methods for landslide inventory

at different scales using the existing earth observation data in Cuba, and to propose a system for information collection about future events.

2. To design and apply appropriate indicators for landslide hazard and vulnerability at different scales in Cuba.

3. To propose, describe and implement spatial analysis models for landslide hazard, vulnerability and risk assessment.

4. To determine landslide hazard, vulnerability and risk assessment in four levels (scales) in Cuba with specific objectives and expected outputs.

In this study, after a comprehensive review of theoretical background, best practices worldwide and a contextual analysis of Cuba, four case studies for landslide risk assessment have been carried out. The assessment was made at four different scales considering the data availability and the most appropriated methods as summarized in Table 1, and an overview of the study areas with their characteristics is given in Fig. 1.

Table 1 Methods, organization involved and use of risk assessment in Cuba

Level (scale) & Organisation	Method for risk assessment	Use
National (1:1,000,000) National Civil Defence	Semi-quantitative with Spatial Multi Criteria Evaluation (SMCE) Risk index by ranking and weighting	Locating priority areas for regional studies and guide national policy Periodic assessment to monitor local improvement
Provincial (1:100,000) Provincial government and civil defence	Semi-quantitative with SMCE Spatial model via Statistical method and weighting	Provincial disaster risk reduction plan Locating landslides and priority areas for investigating causes and consequences
Municipal (1:50,000) Municipal government and civil defence	Quantitative Terrain Mapping Units and expert judgment (adaptation needed for generalization)	Municipal disaster risk reduction plan Estimating losses and delimitating areas for mitigation actions
Local (1:25,000) Local and municipal government and civil defence	Quantitative Runout modelling based on geotechnical parameters (adaptation needed for generalization)	Local disaster risk reduction plan Identifying elements at risk affected by different scenarios and implementing mitigation actions

3. National scale landslide risk assessment

There are few examples on national landslide risk assessment in the literature (see Yoshimatsu and Abe 2006). At national level the risk was estimated as a risk index, as an indication of the relative risk in the country and not an actual quantification of the risk. The landslide risk index can be compared to similar indices produced by international organizations (e.g. human development index). It was generated making use of data from national data providers such as the national statistics office, national housing institute and the national atlas of Cuba. In the literature some studies present indicators for producing risk indexes (e.g. Nadim et al. 2006). Some are actually duplicating indicators which are usually highly correlated (e.g. population density and other social indicators). Therefore, in this study the number of indicators was limited to avoid such duplications, and main indicators were used as proxies for physical, social, economic and environmental vulnerability.

National authorities could evaluate the evolution of the landslide risk through time by regularly generating a landslide risk index based on updated information. Based on this, the National Civil Defence as a major disaster risk reduction stakeholder could focus its priorities on specific regions such as the eastern provinces or in particular issues such as housing. The landslide risk index map shows different ways to analyze the risk index tabulated for provinces and by average for municipalities. In future, with the development of a national landslide inventory, information on the landslide density should also be used as a main indicator, which would improve the landslide risk index substantially.

4. Provincial scale landslide risk assessment

The provincial level is considered an intermediate level in Cuba, like in many other countries. In this research several types of spatial analyses were applied for this level, consisting of qualitative and semi-quantitative methods. However, once the nationwide multi-hazard risk assessment programme would be completed at the municipal level, the provincial landslide risk map could be made by a re-classification and generalization of the results from the municipal level. Nevertheless, the provincial assessment that was carried out was useful in many aspects. First of all, the hazard assessment was based on the actual landslide inventory, in this case obtained through image interpretation and fieldwork. For the hazard assessment two methods were used (weights of evidence and artificial neural network) for five landslide types using qualitative and semi-quantitative assessment. While the former one was very useful to build the landslide descriptive models, the latter was valuable for susceptibility assessment of slides due to its complexity. The conversion from susceptibility to hazard at this scale involved the multiplication of event probability, based on the success rates, spatial probability, based on the landslide density in the susceptibility classes, and temporal probability, based on estimated return periods. It is a rather general way of obtaining the total hazard probability, as it is questionable whether these three probabilities can be treated independently. Nevertheless, the results give a reasonable indication.

Regarding elements at risk, problems were encountered to link population data available for administrative units, to other elements at risk data, available at larger detail. The spatial analysis allowed estimating the number of people per house based on the population density of the closest settlement where houses and population are registered. Such a technique could be applied to estimate population whenever the houses could be digitally mapped and the level of population registered at certain spatial unit. For the roads differences were found between the road types with cost per kilometre supplied by the ministry of transportation and the road types extracted from the digital topographic maps supplied by the national mapping agency. Future improvements in the spatial data infrastructure should cope with issues like this.

At provincial level, qualitative and semi-quantitative landslide risk maps were obtained. As five landslide types and five elements at risk were processed, specific risk maps were produced for each combination, resulting in twenty five maps. Based on this, it was possible to calculate the risk for each landslide type separately and for each element at risk as well as to integrate them all into a total landslide risk map. By using these outputs the end users can evaluate both the overall risk as well as the specific risk for particular landslide types and elements at risk. The risk assessment was limited to five elements at risk (population, buildings, infrastructure, essential facilities and agriculture), considering the direct risk only. Indirect risks, such as economic damage, as well as social vulnerability issues, were not considered at this scale. The inclusion of these would require another combination using a spatial multi-criteria approach, similar to the one applied on the national scale, but would result only in qualitative risk maps.

5. Municipal scale landslide risk assessment

The municipal level is considered the most important level for generating landslide risk maps in Cuba, as it will be incorporated in the nation wide multi-hazard risk assessment programme. Ideally risk assessment at this level should be quantitative and based on process modelling, which allows the inclusion of stability situation for different spatial and temporal triggering scenarios. However, due to the complexity of the landslide types in the study area, and the unavailability of geotechnical data, it was not possible to carry out such process based models in this case. Therefore, the municipal assessment carried out in this study was based on the outlining of terrain mapping units (TMU), which allowed us to incorporate a detailed description for every unit and landslide found in the area. However, a drawback of applying this method for susceptibility assessment in other municipalities is that it requires mapping experience with photo-interpretation and a detailed fieldwork campaign. Therefore, it is advised to combine this method with other more suitable methods, including process based modelling for shallow landslides, in other municipalities in Cuba that could be implemented by a trained specialist such that they could be more comparable.

Unavailability of temporal landslide information was also a major obstacle at municipal level. The landslide age could be estimated using geomorphological skills and in-depth knowledge of the study area. Similar estimations are reported in the literature either for tropical (Wieczorek 1984) or dry climate areas (McCalpin 1984). We found, however, that the age rates need to be customized for the Cuban environment because of rock types, vegetation and rainfall conditions. In consequence, through the analysis of landslides using different earth observation data four landslide return periods could be estimated.

The risk assessment at this level was made for houses, roads and agricultural lands. This is typical for most municipalities in Cuba which are located in rural areas with few industrial or commercial facilities. Information on building typologies and conditions was collected on a house-by-house basis. The Housing Institute yearly collects this information but it does not have the geographic location of the houses. For the roads the landslide risk was assessed considering the type and cost per kilometre. The actual value for the roads should somehow include its usability, which was missing in this case because of lack of data. For example, path and trails are very low-cost road types, but depending on their location they could result in higher risk values than unpaved roads. In many mountainous areas in Cuba, paths and trails are the only way to transport agricultural products from the various farms to the markets.

A combined landslide risk map was calculated by adding the risk for houses, roads and agricultural lands. This final map allows analyzing quantitatively the distribution of risk including the risk for point elements (houses), linear elements (roads) and polygon elements (agricultural lands).

6. Local scale landslide risk assessment

A detailed analysis was carried out for a single landslide disaster (i.e. the ‘Jagüeyes’ landslide) using all available information. Digital photogrammetry, geophysical survey and runout modelling were successfully applied. The first two supported the characterization of the landslide event by creating the digital elevation model before and after and by reconstructing the sliding surface and geological features. The runout simulation successfully reproduced the conditions under which the Jagüeyes landslide occurred. The photogrammetry, geophysical and runout methods have been applied separately before (e.g. Barlow et al. 2006) but not in an integrated way as presented here. It also demonstrated that in areas with limited information it is possible to reconstruct major landslide events successfully. The application of these tools for landslide research should enhance the opportunities for quantitative landslide risk assessment as a way to improve the characterization of the landslide events.

The use of runout modelling for landslide risk assessment is new and still several issues need to be improved, such as the rheology computation and model calibration. For the first time a landslide runout simulation was calibrated spatially with the depth of the deposit. PEST, a model-independent parameter estimator (Doherty 2004), was linked to the MassMov runout model (Beguería-Portugués and van Asch 2008) running inside the dynamic modelling system PCRaster (PCRaster Environmental Software 2008). The implementation could be undertaken in several possible ways leaving ample space for future research on this topic.

This is considered an innovative way to assess risk based on the parameters generated by the runout simulation like deposit depth, velocity or momentum. This approach substitutes the empirical relationship with runout distance or the empirical estimation of vulnerability based on previous disasters.

Landslide risk assessment for the Caujerí scarp was carried out with the results obtained by simulating the Jagüeyes landslide. The use of previous events to predict the future ones was made early through spatial analysis but not using runout parameters with up-scaling analysis, as was carried out in this study. The main difficulty in the up-scaling analysis was the estimation of potential landslide sites, and the relationship between volumes and possible return periods. The only way to properly address this would be the use of slope stability analysis for all potential landslide sites, which would need major financial investments in surveying and geotechnical testing.

The vulnerability and risk of ninety houses were assessed based on their typology and condition. The population living in the buildings at risk was simply counted as it was assumed that they will be evacuated during the onset of an intensive or prolonged period of precipitation before a landslide occurrence. For the same reason, the estimation of the population at risk for certain time of the day was dismissed. This analysis seems to be more effective for other disaster type such as earthquakes.

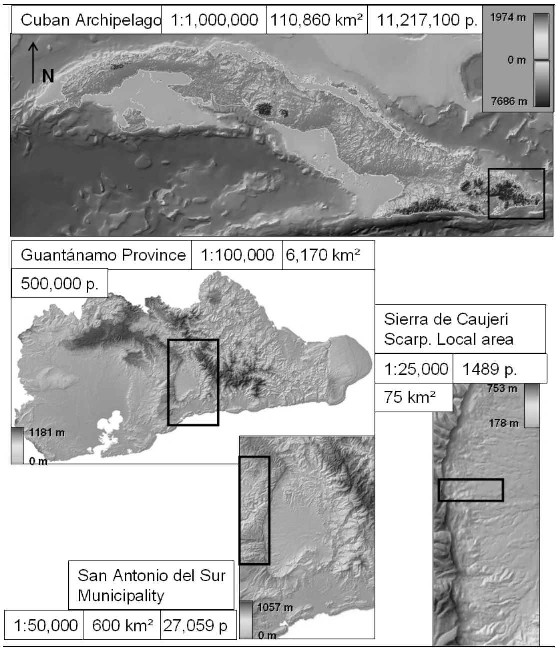

Fig. 1 Overview of the four study areas for multi-scale landslide risk assessment in Cuba. (Adapted from Castellanos Abella 2008)

Conclusions

In Cuba there is strong political willingness for reducing disasters integrating all possible means. The National Civil Defence, as the head organization for disaster reduction in the country, owns its success to a long term improvement process and a continuous adaptation to new conditions. Risk has been reduced throughout the years by social and infrastructural investments. Despite the recognized success of disaster management in the country, economic losses continue to increase, and are affecting the development. After the occurrence of natural disasters in 2004, a task force was installed with a mandate to carry out a multi-hazard risk assessment programme in Cuba. The programme aims to support the 169 municipalities with a standardized methodology for risk based mainly on existing data. Since 2005, the main priority was given to the assessment of risk of flooding, strong wings and sea surge. Also, beginning 2008 a start was made with the risk assessment for landslides. The methodology for landslide risk assessment is based on the results of this research, and the methods presented in this work will initially be applied to twenty municipalities with the highest landslide risk found during the national assessment of this research. It is expected that this work will be subsequently extended in order to encompass provinces with the highest landslide risk. The methodology that is applied nationwide will be an adaptation of the one used in this study at municipal level.

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Forest Management for Landslide Risk Reduction on Alluvial Fans

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Abstract. In mountainous terrain, alluvial fans are conspicuous locations for infrastructure and residential development, and are excellent locations for growing trees, but these landforms can present significant risks because they are frequently the runout zones for landslides. It is possible for forest harvesting to occur in the watersheds of fans without unduly increasing landslide hazards, but if undertaken inappropriately, forestry activities can elevate the natural levels of landsliding. This can have significant consequences for natural and anthropogenic features on alluvial fans. Land use activities on fans such as road construction and forest harvesting can also exacerbate the effects of landslides, increasing the risks to safety and natural and anthropogenic features on fans. This paper presents research results, management strategies, and forest legislation aimed at reducing landslide risk to safety, infrastructure, and environmental values on fans in British Columbia, Canada.

Keywords. landslide risk, landslide prone terrain, alluvial fans, hydrogeomorphic riparian zones, management strategies, protection forests

1. Introduction

British Columbia's mountainous area contains numerous forested watersheds connected to alluvial fans with human development or high natural resource values. Fans are desirable sites for development because of their gentle gradients and workable materials. Unfortunately, fans are often dynamic landforms. They are runout areas for hydrogeomorphic events (i.e., debris flows, debris floods, and floods) originating in their watersheds. Fans commonly have unconfined stream channels that result in the broadcasting of water and sediment across the fan surface. The risk from hydrogeomorphic events influencing a fan must be carefully considered when natural changes occur in a watershed (e.g., wildfire or insect infestations) as well as prior to watershed development (e.g., forest harvesting). This is because of the potential to change water and sediment regimes including the timing, magnitude, and frequency of hydrogeomorphic events. Even without land use changes in watersheds, natural hydrogeomorphic events on fans have resulted in the loss of life and high financial costs throughout British Columbia (Septer and Schwab 1997) and world-wide (Sidle *et al.* 1985). It is therefore important that resource development in watersheds above fans be planned and undertaken with an understanding of the fan-watershed system; the risk to downstream features must be critically considered (Jakob *et al.* 2000). Similarly, resource development on fans must be planned and undertaken with an understanding of the hydrogeomorphic hazards issuing from the watershed (Wilford *et al.* 2003).

Forest legislation related to landslides in British Columbia (BC) is based on over thirty years of research into factors that lead to landslide initiation, runout, and environmental impacts. The legislation specifies that forest management must be conducted in a manner that will not cause landslides, destabilize alluvial fans, impact fish habitat, nor degrade the productive capability of forest soils (BCMOFR 2004). There are a series of key management tools to achieve these objectives: terrain stability assessments and research and publications regarding forest land management, including a recently developed 5-step method of analyzing landslide risk on fans when developing forested watersheds.

2. Alluvial fans

A fan is a cone-shaped deposit of sediment formed where a stream channel leaves the confines of a mountain (Bull 1977). It is an expression of its watershed; the fan is created by and represents a summary of the hydrologic and geomorphic processes in the watershed. The watershed, or catchment, is the source area for water, sediment, and woody debris, the stream channels are the transport zone, and the fan is the deposition zone. Together, they constitute the fan-watershed system which is the basic unit for hazard and risk analyses.

Watershed area and relief are two key factors in recognizing hydrogeomorphic hazards (Wilford *et al.* 2004b). Melton (1957) combined these two factors as the Ruggedness Index (relief divided by the square root of watershed area). It has been used to predict hydrogeomorphic processes for graded or mountainous watersheds (Wilford *et al.* 2004b). This model does not apply to watersheds in plateau terrain because landslides can occur on the plateau escarpment near the mouth of the watershed. For example, Yard Creek in central British Columbia has a watershed area of 100 km^2 which would indicate a very low probability of debris flows reaching the fan, because characteristically debris flow watersheds are less than 10 km^2 (VanDine 1985). However, evidence of high power debris flows initiating on the plateau escarpment directly above the fan are present on the Yard Creek fan surface.

While stream channels in the watersheds of fans transport material, it is common for stream channels on fans to be unconfined: when landslides or flood flows enter onto a fan there is usually a broadcasting of sediment and water. On fans with forests this leads to a characteristic "hydrogeomorphic riparian zone" with buried trees, log steps, scars on trees, and groups of trees of different ages (Fig. 1) (Wilford *et al.* 2005b). Removal of this forest reduces resistance to the broadcasting of sediment and water, and can result in a greater runout or disturbance extent on fan surfaces (Irasawa *et al.* 1991; Wilford *et al.* 2003).

Gentle gradients and workable materials result in fans being desirable sites for development. Unfortunately, the hydrogeomorphic hazards associated with these landforms are not usually recognized until a significant event occurs that impacts infrastructure and human safety. In some cases the events occur naturally (Fig. 2), in other cases the initiating event can be related to land use.

Figure 1. Significant volumes of sediment can be stored and energy dissipated in the hydrogeomorphic riparian zone.

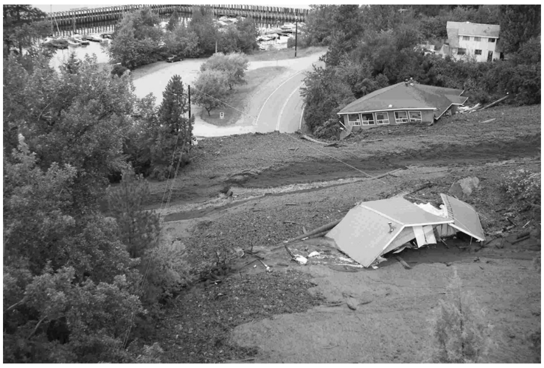

Figure 2. Homes and infrastructure on a fan impacted by a debris flow that initiated during a rainstorm. A severe wildfire had recently occurred in the watershed.

3. Terrain stability analysis and forest management in landslide prone terrain

Under natural conditions it is not uncommon for landslides to occur in mountainous areas (Septer and Schwab 1997). Recognition of where terrain is naturally unstable and where land use practices can initiate landslides is a key element for the management of mountainous areas. As forest harvesting progressed onto steep terrain in British Columbia in the 1960s and early 1970s, it became clear that knowledge and specific management tools and practices were required to address these issues. A five-class terrain stability mapping system was developed that was based on aerial photographic interpretation and professional judgement (Fig. 3). It integrated landscape features, geomorphic processes, hillslope gradient, bedrock, soils and drainage characteristics (Schwab and Geertsema 2008). Class V is used to describe naturally unstable terrain. Class V terrain units are generally withdrawn from the "productive forest land base" and are treated as un-managed forest reserves. Class IV is terrain that is subject to landslides following conventional forestry practices. Detailed terrain field analyses and prescriptions are done in Class IV and V units prior to forestry development (road construction or forest harvesting) (APEGBC 2003). Landslides can occur following conventional forestry practices on Class II and III, however these events are generally small and have limited impacts.

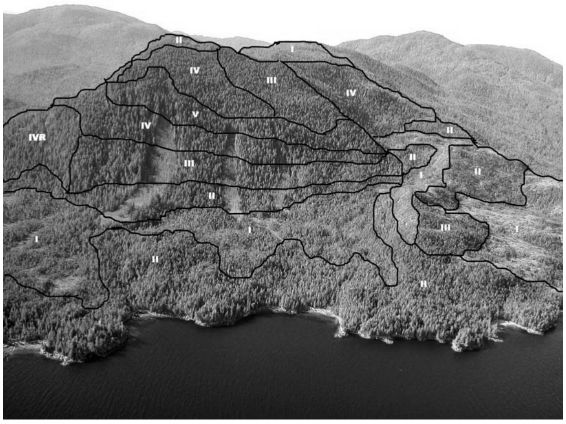

Figure 3. An aerial oblique of a hillslope classified according to the five class terrain stability mapping scheme used in BC: V indicates natural initiation zones, IV indicates moderate likelihood of landslides from timber harvesting or road construction, III indicates low likelihood of landslides, II indicates very low likelihood of landslides, and I indicates no significant problems. Note that even though a unit may have a low likelihood of landslide initiation it can be impacted from the runout of upslope landslides. (Source: Schwab and Geertsema 2008).

Publications regarding the management of landslide prone terrain (Chatwin *et al.* 1994), gullied terrain (BCMOF and BCMOE 2001), applying risk analysis to landslide prone terrain (Wise *et al.* 2004), research results (e.g., Wilford and Schwab 1982; Pack 1995; Rollerson *et al.* 2001), and long term research investigations (Hogan *et al.* 1998; Jordan and Orban 2002) are widely available to forest practitioners in BC. Professional development with field training has been undertaken throughout BC since the early 1990s to support and extend research results to practitioners.

Research on landslides in coastal BC has identified hydrometeorological thresholds for the initiation of landslides (Jakob *et al.* 2006). This research has formed the scientific basis for operational forestry shut-down guidelines that are implemented to improve safety for forest workers on potentially unstable slopes and on areas below potentially unstable slopes, including alluvial fans.

A recent observation in BC has been that severe wildfires can lead to the formation of hydrophobic (water repellent) soils resulting in significant increases in rainfall runoff (Scott and Van Wyk 1990; Moody and Martin 2001) and debris flows (Jordan *et al.* 2004). As a result, forest fire severity maps of burned areas are now being used to identify potentially hydrophobic soils and rehabilitation action is taken where downslope values are significant (usually developments on alluvial fans) (Curran *et al.* 2006).

4. Forest management on alluvial fans

For decades, forest managers in BC experienced challenges with roads and drainage structures in valley bottom locations, but it wasn't until their problems were placed in a landform context that the issues were dealt with appropriately (Wilford *et al.* 2003). By the early 1990s forest managers had come to recognize the need for terrain stability analysis, and a key component of that work is landform mapping. However since the focus was on initiation zones, specific landforms in the gentle terrain of valley bottoms were generally not differentiated. Thus, fans were combined with other landforms and not specifically identified as requiring special forest management prescriptions. An analysis of forest management problems identified key issues and presented a range of appropriate prescriptions to address the hydrogeomorphic hazards on fans (Wilford *et al.* 2003; Wilford *et al.* 2005a). A key aspect was the recognition that hydrogeomorphic hazards on fans are neither rare nor extreme (Innes 1985; Jakob and Jordan 2001), and it is not uncommon for contemporary hydrogeomorphic processes to be actively influencing at least a portion of the fan surface. Another aspect was the understanding that while individual debris flow initiation sites may fail on a scale of hundreds of years, a watershed with numerous initiation sites can produce debris flows on a scale of substantially less than 50 years. Prior to this recognition, hydrogeomorphic hazards on fans were often not identified during forest development planning in British Columbia. As a result, drainage structures on fans were built to accommodate 50 or 100 year flood events (BCMOF and BCMOE 2002) not hydrogeomorphic events, and the decision to retain riparian forests was based on the presence or absence of fish (BCMOF and BCMOE 1995) not on the protection that such forests provide. Not surprisingly, those conventional forestry practices on fans were frequently ineffective for their intended purposes (e.g. growing trees and providing safe access) and exacerbated the impacts of natural hydrogeomorphic processes (e.g. broadcasting of sediment and channel avulsions) (Wilford *et al*. 2003).

5. Forest management in the watersheds of alluvial fans

Currently, researchers are developing a 5-step method of identifying risks to alluvial fans from landslides issuing from their watersheds. Step 1 involves identifying fans and delineating their topographic watersheds. Step 2 involves identifying the elements at risk on fans, such as houses, bridges, and other infrastructure, as well as fish habitat and forest sites. Step 3 involves a detailed investigation of the fan to determine the type and frequency of hydrogeomorphic processes occurring (both natural and human related), and to describe modifications to the fan surface due to land use activities (e.g., removal of the hydrogeomorphic riparian zone, diking, road construction). Step 4 involves a description of the watershed, including landslides and changes to forest cover—both natural (e.g., wildfires and forest health issues) and human related. Step 5 is the application of a framework to determine present and future risk associated with development plans, including potential mitigative strategies. The methodology draws a clear link between forestry activities in remote areas of watersheds and the landslide risks to values on downstream alluvial fans—this link was historically overlooked due to the site-level focus on landslide initiation zones, however several court decisions have identified the critical need for foresters to take a watershed-level perspective. The methodology also provides a framework to assess risks on alluvial fans due to landslides associated with natural factors such as wildfires and insect epidemics.

6. A role for protection forests—in watersheds and on fans

The value of forest cover in landslide initiation and runout zones is recognized in British Columbia with reserves being designated in Class V terrain and riparian areas. However, given a host of forest health issues, abiotic factors, and forest succession, the ability of these reserves to provide benefits for the long-term is questionable. Climate change is also a key factor influencing the forests of BC. It has been identified as a key factor in a mountain pine beetle epidemic that has killed 40,000 km^2 of forests in BC over the last 9 years (Westfall and Ebata 2007). Dieback of cedar in southeast Alaska has led to an increase in landslides from old-growth reserves (Johnson and Wilcock 2002). Reserves have been prescribed for fans to limit the runout of debris flows, but in some cases the stands are sustaining attack from balsam bark beetles and regeneration and growth will take decades to replace the protective value of the stand (Wilford *et al*. 2004a). For centuries, the only action in European protection forests was to ban wood-cutting. This resulted in a series of problems as the forests become over-mature because of the lack of disturbance (Motta and Haudemann 2000). To maintain the qualities desired in forested reserves, it is necessary in many situations to apply silvicultural interventions. This is referred to as "protection forestry." Internationally, some protection forests have been in place for over 100 years (Cheng *et al*. 2002). As with the shift to using terrain stability analysis in forest management in BC, this will represent another paradigm shift as forests are managed to maintain their protective role (Wilford and Sakals 2005; Sakals *et al.* 2006).

7. Conclusion

Forest and watershed management research, legislation, and practices in British Columbia over the past three decades have significantly reduced the risks of landslides to values on alluvial fans. Future application of Protection Forest management strategies to current forested reserves on landslide prone terrain (initiation and runout zones) should lead to even further risk reduction.

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Climate Change Impacts on Debris Flow in Scotland

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Abstract. In August 2004 a series of landslides in the form of debris flows occurred in Scotland. Critically, the A83, A9 and A85 routes, which form important parts of the major road network were all affected by such events. While debris flows occur with some frequency in Scotland, they affect the major road network only relatively rarely. However, when they do impact on roads the degree of damage, in terms of the infrastructure and the loss of utility to road users, can have a major detrimental effect on both economic and social aspects of the use of the asset. Following these events work was put in place to rank the hazards and to develop management and mitigation options. A crucial element of this work is the development of a rainfall threshold to forecast likely periods of debris flow activity. However, this also raises the question of how climate change might affect the frequency and intensity of debris flow and this is considered in this paper.

Keywords. Climate change, debris flow, rainfall

1. Introduction

In August 2004 a series of rainfall-induced debris flows occurred in Scotland. Critically, some of these affected important parts of the major road network, linking not only cities but also smaller, remote communities.

While debris flows occur with some frequency in Scotland, they have affected major communications only rarely in the past. However, when they do impact on roads the degree of damage, in terms of the infrastructure and the loss of utility to road users, can have a major detrimental effect on both economic and social aspects of the use of the asset. Additionally, there is a high potential for such events to cause serious injury and even loss of life although, fortuitously, such consequences have been limited to date.

The impacts of such events can be particularly serious during the summer months due to the major contribution that tourism makes to Scotland's economy. Nevertheless, the impacts of any debris flow event occurring during the winter months should not be underestimated. Not surprisingly, the debris flow events of 2004 created a high awareness of the effects of landslide activity in the media in addition to being seen as a key issue by politicians at both the local and national level.

The rainfall was both intense and long lasting and a large number of debris flows occurred in the hills of Scotland. A small number of these intersected with the major road network, notably the A83 between Glen Kinglas and to the north of Cairndow (9 August), the A9 to the north of Dunkeld (11 August), and the A85 at Glen Ogle (18 August). The rainfall was substantially in excess of the norm; some areas received over 300% of the 30-year monthly average (source: www.metoffice.gov.uk). Subsequent analysis of radar data indicated that at Callander, some 20km distant from the A85 events, some 85 mm of rain fell during a four hour period on 18 August with a peak intensity of 150 mm/hour. The 30-year average rainfall for August varies between 67mm on the east coast and 150 mm in the west of Scotland (Anon 1989).

While there were no major injuries, some 57 people were taken to safety by helicopter after being trapped between the two main debris flows on the A85 in Glen Ogle. The A85, carrying up to 5600 vehicles/day (all vehicles two-way, 24 hour annual average daily traffic), was closed for four days (Fig. 1). The A83 (carrying 5000 vehicles/day) was closed for slightly in excess of a day (Figure 2) and the A9 (carrying 13,500 vehicles/day) was closed for two days prior to reopening, initially with single lane working under convoy (Figs. 3 and 4). The traffic flow figures are for the most highly trafficked month of the year (July or August). Minimum flows occur in either January or February and are roughly half those of the maxima. The figures reflect the importance of tourism and related seasonal industries to Scotland's economy. The events of August 2004 are described by Winter et al. (2006a; 2006b). These events are by no means unique and further debris flows have affected both the A9 and the A83 since August 2004.

Fig. 1. The northerly A85 Glen Ogle debris flow.

This paper briefly describes the response by Transport Scotland to these events. This includes the development of a rainfall threshold to enable the forecast of likely periods of debris flow activity. However, this also raises the question of how climate change might affect the frequency and intensity of debris flow and this is considered in this paper.

Fig. 2. A83 debris fan including boulders up to 9 tonnes.

Fig. 3. The southerly debris flow at the A9 north of Dunkeld (courtesy of Alan MacKenzie, BEAR).

Fig. 4. The clean-up operation at the A9 north of Dunkeld.

2. Response to events

Following the landslide events of August 2004 Transport Scotland recognised the need to ensure that in the future it has a system in place for assessing the hazards and associated risks posed by debris flows. The Scottish Minister for Transport commissioned two studies. The first part was to determine a way forward for dealing with such landslide events in the future (Winter et al., 2005a). The second part involves assessing and ranking the hazards and developing a management and mitigation strategy (Winter et al., 2008a). Progress with the studies is described by Winter et al. (2007; 2008b). A second parallel study (not considered further here) was to examine broader issues, other than landslides, in respect to climate change (Galbraith et al., 2005).

The effects of debris flow on the operation of the road network can be limited by reducing either the exposure of road users to the hazard, a management option, or by reducing the hazard, a mitigation option. The work reported by Winter et al. (2008a) mainly focuses upon exposure reduction. This lends itself to the use of a simple and memorable three-part management tool (Winter et al., 2005b), as follows:

- *Detection:* The identification of either the occurrence of an event or the forecast of precursor rainfall conditions.
- *Notification:* The dissemination of event information to the relevant authorities.
- *Action:* Intervention which reduces the exposure of the road user to the hazard, by for example traffic diversion and the dissemination of hazard and exposure information by signing, ‘landslide patrols’ and by the media.

In the short-term to medium-term this Detection-Notification-Action (or DNA) approach to mitigation must be reactive to debris flow events (Winter et al., 2007). Landslides are often cited as being caused by storm rainfall and the link between high intensity rainfall and debris flows has been widely documented in Japan, New Zealand, Brazil, Hong Kong, Italy, USA and elsewhere. In the longer-term, the detection of rainfall triggering conditions may enable both the notification and action phases to be initiated prior to the occurrence of major events. Work is underway to develop and implement a rainfall trigger threshold for debris flow occurrence on the Scottish road network (Winter et al., this volume). It was this work that led to the consideration of the potential effects of climate change on the frequency and severity of debris flow in Scotland.

Typically, hazard reduction entails physical engineering works to change the nature of a slope or road and the main challenge is in identifying locations that are of sufficiently high risk to warrant major expenditure on engineering works.

3. Scotland’s rainfall climate

The climate of Scotland in terms of its rainfall may be very broadly divided into east and west and rainfall is generally much higher in the latter. Data presented by the Meteorological Office (Anon, 1989) indicates that in the east rainfall generally peaks in August while in the west maximum rainfall levels are reached during the period September to January (Fig. 5). Although rainfall levels in the west are relatively low in August they do increase from a low point in May. Such average values may mask large annual variations and rainfall will be considerably higher in the mountains. However, both scenarios indicate that the soil may be undergoing a transition from a dry to a wetter state at or around August, indicating an increased potential for debris flow and other forms of landslide activity. The central area, as represented by Pitlochry in Figure 5, has a mix of the rainfall characteristics of the ‘east’ and the ‘west’. The rainfall peak is both lower and shorter (December and January) than in the west, but there are also small sub-peaks in August and October.

Clearly, the soil water conditions necessary for debris flows may be generated by long periods of rainfall or by shorter intense storms. It is however widely accepted that Scottish debris flow events are usually preceded by both extended periods of (antecedent) rainfall and intense storms

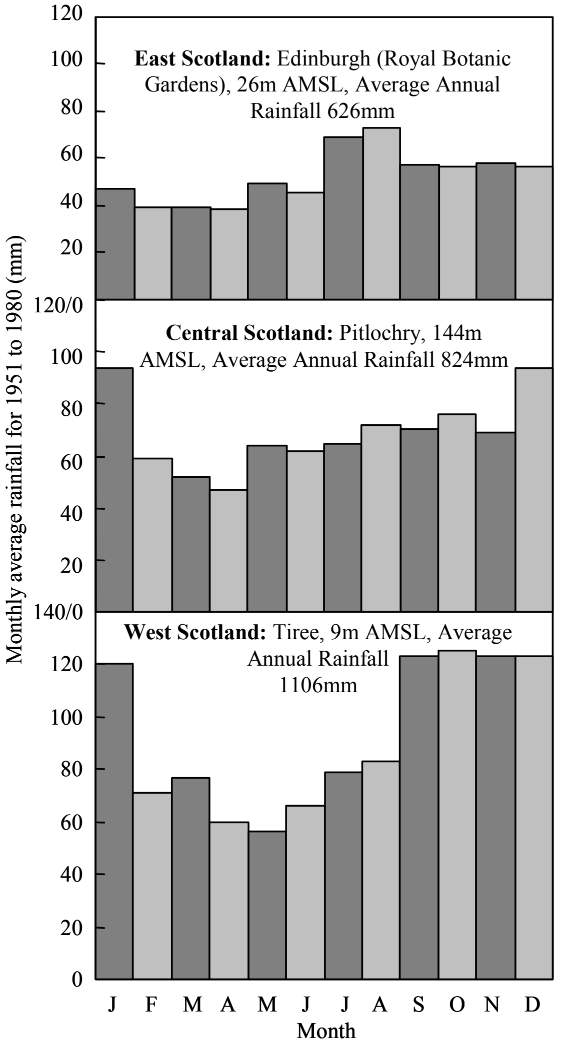

Fig. 5. Average rainfall patterns for selected locations (Winter et al., 2008).

4. Potential climate change

The UKCIP02 (UK Climate Impacts Programme) report considers three periods: the 2020s, the 2050s and the 2080s. In general terms small changes are noted in the predictions for the 2020s, increasing slightly for the 2050s and slightly further still for 2080s predictions, reflecting temporal trends in temperature and precipitation. Whilst climate models generally predict averages and the associated error limits can be substantial, it is also important to note that inter-annual variability is predicted to increase for many climate factors. This means that average changes, as discussed above, may mask more important variability effects.

Climate change models for Scotland in the 2080s (www.ukcip.org.uk and Galbraith et al., 2005) indicate that, while overall precipitation levels will decrease, it will decrease in the summer but increase in the winter. However the models are generally considered to be incapable of predicting localised summer storms. These storms are believed to be at least partially responsible for triggering the events of August 2004, and climate data may not give a full picture of the relationship between precipitation and landslides. Furthermore, it is important to note that climate models generally predict averages and that the error limits can be substantial. Predicted changes in the number of ‘intense’ wet days generally indicate a net increase of less than one day per annum by the 2080s, with slightly fewer intense wet days in the summer and more in the winter. However, by the 2080s extreme storm event rainfall depths are predicted to increase by between 10% and 30%, with intense rainfall in winter increasing slightly more than this, and in spring/autumn by slightly less. Summer extreme rainfall depths are predicted to increase by between 0% and 10%.

Peak fluvial flows are anticipated to increase progressively during the twenty-first century. Eastern Scotland is expected to experience larger increases than north-west Scotland for example. The occurrence of snow and the associated contribution of snowmelt to both fluvial flow and groundwater are, on the other hand, predicted to decrease. Reductions are predicted to be greater for the eastern and southern parts of Scotland and least for central upland areas.

Changes in the factors discussed above coupled with increased potential evapotranspiration (particularly in the summer) and a longer growing season (leading to increased root uptake) are expected to substantially effect soil moisture. The models predict a 10% to 30% decrease in soil moisture in summer/autumn and a 3% to 5% increase in winter. The winter figures reflect the fact that soils can only contain a finite amount of water and most Scottish soils are already close to saturation in the winter.

Reduced soil moisture during the summer and autumn may mean that the short-term stability of some slopes formed from granular materials is enhanced by suction pressures. Soils under high levels of suction are vulnerable to rapid inundation, and a consequent reduction in the stabilising suction pressures, under precisely the conditions that tend to be created by short duration, localised summer storms. In addition, non-granular soils may form low permeability crusts during extended dry periods as a result of desiccation. Providing that these do not experience excessive cracking due to shrinkage, then runoff to areas of vulnerable granular deposits may be increased. Such phenomena could lead to the rapid development of instabilities in soil deposits, potentially creating conditions for the formation of debris flows. The complicating factors are the potential inability of current climate models to resolve storm events and the precise nature of the localised failure mechanisms that will lead to the initiation of an individual debris flow. The measurement of soil suction is unlikely to provide a practical and reliable means of debris flow forecast.

Lower overall levels and changed patterns of rainfall might be expected to increase the pressure on vegetation and thus to reduce its beneficial effect upon slope stability. Additionally, extended periods of exceptionally dry weather could potentially lead to wildfires and associated debris flow such as those described by Cannon et al. (2008).

The importance of the potential effects of climate change impacts on slope stability is exemplified by the existence of a UK Engineering and Physical Sciences Research Council (EPSRC) Network: CLimate change impact Forecasting For Slopes (CLIFFS) (Dixon et al., 2006). This provides a ‘talking-shop’ to develop collaborative working arrangements to study the impacts and develop coping strategies.

5. Mechanics of unsaturated sope failure

That rainfall can cause landslides was vividly demonstrated in February 2005 when catastrophic landslides occurred following intense storms on the western N American seaboard. Property destruction and loss of life resulted from various landslides. Over approximately a seven-month period, the Malibu area of California received over 585 mm (23 inches) of cumulative precipitation. Then in February 2005 an additional 228 mm (9 inches) fell over four days, at which time the landsides occurred (GeoSlope, 2005).

Analyses by GeoSlope, replicating the rainfall conditions experienced in California and British Columbia in February 2005 yielded some interesting results. The analysis confirmed that a typical model slope remained stable for seven months during which 585 mm of cumulative rainfall fell but became unstable after a further 228 mm fell during four days. Typically the failure could not be attributed to increased positive pore water pressures as the failure surface did not penetrate below the water table. GeoSlope attributed the failure to decreases in suction. This type of behaviour corresponds well with that predicted from unsaturated soil mechanics theory (Wheeler et al., 2003) and the broad style of this type of failure mechanism is supported by experiment (Springman et al., 2003).

6. Conclusions

In August 2004 parts of the Scottish road network were adversely affected by a series of landslide events in the form of rainfall-induced debris flows. While such events are relatively common, such a significant degree of interaction with the transport infrastructure is unusual.

Transport Scotland initiated and led a rapid, proportionate and structured response to these events. This involved an assessment and ranking of hazards and the development of a management and mitigation strategy. The main focus of the work involves a management strategy predicated upon the reduction of the exposure of road users to hazards (as opposed to hazard reduction). This is based upon the logical sequence of Detection-Notification-Action (DNA). In the short-term the DNA sequence will be applied in a manner so as to react to debris flow events. In the longer-term a rainfall threshold is under development. Once implemented it is expected that it will be possible detect and notify, and possibly to act, in advance of debris flows occurring.

The forecast of rainfall-induced landslide events will be fundamentally affected by climate change and, in particular, changes to the amount, distribution, intensity and duration of rainfall. Currently long-term antecedent rainfall followed by short intense storm rainfall is believed to characterise many debris flow events in Scotland. Climate change models would appear to indicate that Scotland's climate will become generally drier, but that the frequency, intensity and duration of storm events may increase. It may thus be inferred that the frequency and severity of debris flow events in Scotland seem most likely to increase as a result of climate change.

In developing an understanding debris flow events in a drier summer climate there appears to be a clear role for the application of unsaturated soil mechanics, whether such understanding is to be at the conceptual level or at the analytical level.

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Rainfall Conditions Leading to Debris Flow in Scotland

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Abstract. Following a series of rainfall triggered debris flows in August 2004 a study was initiated by Transport Scotland to assess and rank such hazards and to develop a management and mitigation strategy. The management strategy is largely based upon the reduction of the exposure of road users to risks from debris flow. It operates upon the principle of Detection, Notification and Action (DNA). A key strand of the Detection element is the development of a debris flow forecasting system based upon rainfall. This paper describes the development of such a threshold.

Keywords. Debris flow, triggering, rainfall, forecast

1. Introduction

The rainfall experienced in Scotland in August 2004 was substantially in excess of the norm. Some areas of Scotland received more than 300% of the 30-year average August rainfall, while in eastern parts between 250% and 300% was typical. Although the percentage of the monthly average rainfall that fell during August reduced to the west, some parts still received 200% to 250%.

Long lasting and intense rainfall led to a large number of landslides, in the form of debris flows. A small number of these intersected the trunk, or strategic, road network, notably the A83 between Glen Kinglas and to the north of Cairndow on 9 August, the A9 to the north of Dunkeld on 11 August, and the A85 at Glen Ogle on 18 August (Winter *et al*., 2006a).

Subsequent analysis of radar data indicated that at Callander, 20km from the A85 events, 85mm of rain fell in four hours on 18 August. Some 48mm fell in just 20 minutes and the storm reached a peak intensity of 147mm/hour. The 30-year average August rainfall varies between 67mm on the east coast and 150mm in the west of Scotland (Anon, 1989).

While there were no major injuries to those affected, 57 people had to be airlifted to safety when they became trapped between two debris flows at Glen Ogle (Figure 1).

However, the real impacts were social and economic, in particular the severance of access to/from relatively remote communities. The A85 was closed for four days, the A83 for just over a day and the A9 for two days. Substantial disruption was experienced by local and tourist traffic, and goods vehicles. Maximum traffic flow figures are between 5,000 and 13,500 vehicles per day for July/August. Minimum flows occur in either January or February and are roughly half those of the maxima. The figures reflect the importance of tourism and related seasonal industries to Scotland's economy.

The study initiated by Transport Scotland is reported by Winter *et al*. (2005; 2008a); further details of the events are given by Winter *et al*. (2006a). The study was designed to systematically assess and rank the hazards posed by debris flows (Winter *et al*., 2007a) and to develop a debris flow management and mitigation strategy for the Scottish trunk road network (Winter *et al*., 2006b). The ranking system is intended to allow the future effects of debris flow events to be appropriately managed and mitigated as budgets permit.

Fig. 1 Debris flow: A85 in Glen Ogle, 18 August 2004

The reduction of the exposure of road users forms the main focus of the work. Thus either the number of people exposed to the hazard must be reduced, for example by closure of the road, or they must be warned to exercise caution at appropriate times and places. To reduce the hazard, physical intervention is required. In many cases these will be higher cost and more intrusive options and it is anticipated that relatively few locations will justify such expenditure.

The reduction of exposure lends itself to the use of the Detection, Notification and Action (DNA) management tool (Winter *et al*., 2005; 2008b), as follows:

- Detection: The identification of either the occurrence of an event by instrumentation/monitoring, observation, or by the measurement and/or forecast of precursor conditions (e.g. rainfall).
- Notification: The notification of either the likely or actual occurrence of an incident to the authorities including the Police, Traffic Scotland, Transport Scotland and the relevant Operating Company.
- Action: The proactive process by which intervention reduces the exposure of the road user to the hazard, by for example road closure or traffic diversion.

In the short to medium-term the DNA management approach is intended to be reactive to debris flow events. In the longer term the detection of rainfall triggering conditions may enable the notification and action phases to be taken prior to event occurrence. Work towards understanding relations between debris flow and rainfall in Scotland and the development of a forecast capability are reported here.

2. Rainfall Patterns and Landslides

Landslides are often cited as being caused by storm rainfall and the link between high intensity rainfall and debris flows has been documented in Japan (Fukuoka, 1980), New Zealand (Selby, 1976) and Brazil (Jones, 1973) amongst other places. However, the influence of antecedent rainfall prior to storm events was clear from the events experienced in Scotland in August 2004 (Winter *et al*., 2007b).

In a study based in the Santa Cruz Mountains of California, Wieczorek (1987) noted that no debris flows were triggered until 28cm of seasonal rain fell, thus clearly acknowledging the importance of antecedent rainfall, a factor that has also been recognised in studies in Southern California (Campbell, 1975), New Zealand (Eyles, 1979) and Alaska (Sidle and Swanson, 1982). Wieczorek (1987) also noted that for high permeability soils, such as those found in Hong Kong (e.g. Ko, 2005), the period of antecedent rainfall may be short or even that the amount of necessary antecedent rainfall may be supplied by the early part of the storm event itself.

There have been many studies that include the back analysis of rainfall records to define rainfall threshold levels that lead to conditions likely to cause landslides. These include, for example, Australia, Hong Kong, Italy, Jamaica, Nepal, Norway, Singapore, Slovenia, Switzerland, UK and the USA. Many authors of such studies state that their methodologies either could be, or will be, used for actively forecasting conditions likely to lead to landslides, but relatively few report such uses (Winter *et al*., 2008a).

The back analyses use a wide range of methodologies, however, these are dominated by intensity-duration analyses (e.g. Ahmad, 2003; Aleotti, 2004; Caine, 1980; Flentje & Chowdury, 2006; Hurlimann, *et al*., 2003) which appears to be a viable and well-established way forward. Further details are given by Winter *et al*. (2008a) and a wider-ranging review of rainfall thresholds is presented by Anon (2007).

The rainfall intensity-duration pattern of each storm during, or immediately after, which landslides have occurred can be analysed and a series of points representing a range of rainfall durations (x) and associated intensities (y) can be plotted (Figure 2). Further events may be similarly analysed and if the same durations are used, a series of vertical data columns should be achieved, each one representing events associated with different rainfall intensities at a given duration. The lower boundary of these data points represents the threshold for rainfall-induced landslides.

It is also important to note that most analyses consider both storm and antecedent rainfall, the latter usually for periods between five and more than 40 days. Those areas in which antecedent is not considered, or considered over shorter periods, tend to be those in which storm rainfall is particularly intense and/or geological and geomorphological conditions favour the rapid onset of instability.

An additional element to this approach can be to undertake the same type of analysis for storm events that do not trigger landslides (Winter *et al*., 2007c). This allows the threshold to be defined from below as well as from above, lending an additional degree of surety to the process. Figure 2 illustrates the development of a purely hypothetical threshold in this manner. It should, however, be noted that, while the approach is sound, it is difficult to justify the expenditure of resources to analyse 'non-events'.

The hypothetical rainfall data of Figure 2 have been utilised to develop three (also hypothetical) threshold levels:

- A threshold level above which landslides might be expected to occur.
- A threshold level at which a warning is issued and action taken – set at a lower level to give adequate time for effective notification and action.
- A still lower threshold level at which instruments are checked and key personnel alerted to the possibility of the development of conditions likely to lead to landslides – a precursor to the issue of a landslide warning.

It is important to recognise that threshold levels developed in this way are in no way absolute. They may, for example, simply represent the transition between the landslide density and/or short-term frequency in a given area reaching a limit that is significant in the context of infrastructure operation. This transition is likely to be more complex in larger areas of varied and complex geology such as Scotland.

Intensity-duration relations for a number of different areas are plotted in Figure 3. All of the thresholds plot reasonably close together and broadly parallel although in order to achieve a readable graph, log-log scaling has been used. The data are sufficiently spaced to indicate that a unique threshold for all climatalogical conditions does not exist, as would be expected from variations in climate and geology.

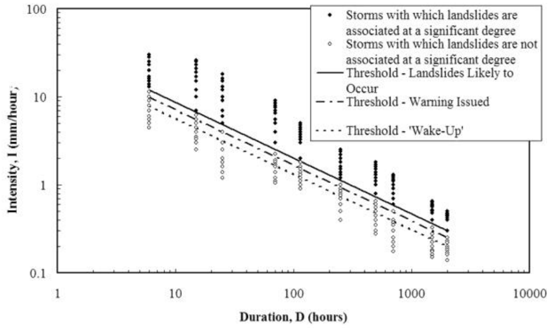

Fig. 2 Development of a purely hypothetical rainfall intensity-duration threshold for landslides

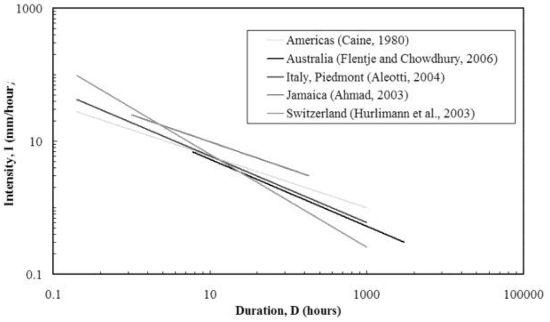

Fig. 3 Rainfall intensity-duration landslide triggers

3. A Trigger Threshold for Scotland

The rainfall gauge network in Scotland is sparse in areas of interest for debris flow forecasting. While the rainfall radar system covers some of the areas of interest at a resolution of 2km, most are resolved at just 5km.

Two rainfall gauges are to be installed, as part of a trial, on land close to the A83 at the Rest and Be Thankful. This area is one of the most active debris flow areas in Scotland and is one of the parts of the major road network most frequently affected. It is hoped that the installation will be in time for the landslide seasons of 2008: July to August and

November to January (Winter *et al*., 2005).

The work to develop a rainfall threshold for debris flow potential involved the analysis of rainfall data for a series of 16 events of known location and timing. Each of these events had been disruptive to the road system to some degree. Analyses considered both short duration and extended antecedent periods and tested analytical methods that could have an application to forecasting similar events in the future. The work thus included the following activities:

- Extraction of comprehensive data sets of rainfall from rain gauge and radar sources for each of the 16 events.
- Analysis of the data in order to make graphical representations for each of the 16 events:
  a) Cumulative antecedent rainfall over 150 days.
  b) Accumulated storm rainfall and intensity for a period of 18 to 24 hours leading up to the time of the event.
  c) The relations between intensity and duration for the combined storm and antecedent periods, to compare the intensity-duration relations for individual events and also on a seasonal and geographical basis.
- To prepare a spreadsheet for analysis of future events (‘Future Back Analysis’), based on the methods for data manipulation and analysis above.

4. Results and Interpretation

Details of the analyses of the 16 events, the results and associated discussion are given by Winter *et al*. (2008a).

In terms of understanding how rainfall may cause debris flow, groups of plots for intensity-duration were examined for summer and winter events, and for events that occurred in the eastern and western parts of Scotland (Winter *et al*., 2008a). The most important observation is that all of the data sets broadly occupy the same area on the intensity-duration diagrams and that there is thus no compelling case for different thresholds on either a seasonal or geographical basis. It is thus appropriate to combine the intensity-duration data for the 16 events onto a single diagram (Figure 4).

As expected there is considerable scatter in the data. However, once ‘outlying’ data points are removed from consideration (Winter *et al*., 2008a) then a reasonably clear tentative trigger threshold can be drawn (Figure 4). Clearly this requires validation and/or development using data derived from future events and such work is ongoing, concentrating upon the Rest and be Thankful area.

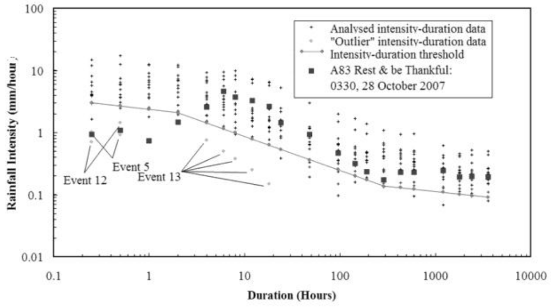

Fig. 4 Combined plot of intensity versus duration data for the 16 debris flow events showing a tentative trigger threshold and the first test thereof

Early testing of the threshold has been undertaken using the results of the analysis of rainfall that led to a debris flow event at the A83 Rest and be Thankful on 28 October 2007 (Winter *et al*., 2008a). The form of analysis was the same as that used in the development of the tentative rainfall intensity-duration threshold. The important difference being that the analysis of the October 2007 event was carried out after the threshold had been determined, thus providing a degree of validation to the threshold. The new and old data are illustrated in Figure 4.

For most of the antecedent period the data plot above the threshold, but for the two hours preceding the event the data plot below the threshold. This may mean that sufficient rainfall had already fallen by this point for the debris flow to be inevitable. The break in the data at 288 hours (12 days) coincides with a change in the threshold slope and may imply that this approximates to the significant antecedent period, at least for this event (i.e. earlier rainfall may have limited influence upon subsequent debris flow events). This is, however, a very tentative conclusion and needs to be verified or otherwise by further analysis (Winter *et al*., 2008a).

Once a validated threshold is available, with any suitable adjustments made, it should be possible to set both ‘Wake-Up’ and ‘Warning’ thresholds (Figure 2). However, the data cannot be ‘viewed’ from time, *t*=0 (actually a low number as the scale is logarithmic) as, in real terms, this corresponds to the time of the actual event. From an operational perspective, the data must be viewed from a point in time preceding the event.

The ‘Wake-Up’ may be ‘viewed’ from a point of view of three days (*t*=36 hours) in advance of an event, with the ‘Warning’ viewed from *t*=12 hours in advance and the actual event threshold observed from the point of view of a short time in advance of an event (say *t*=6 hours) as illustrated in Figure 5. These timings have been assigned very much on an initial basis and require further work prior to the finalisation of a fully-developed system suitable for implementation.

Once sufficient confidence in the use of the threshold has been established, it is hoped to introduce the system to practical forecasting of debris flow events in this area as part of the DNA management procedure described earlier. If that system proves successful, its introduction to other areas prone to rainfall-induced debris flows will be considered.

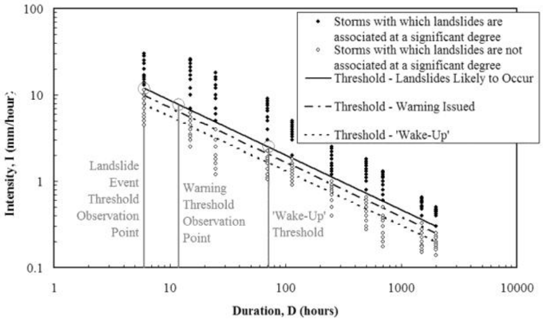

Fig. 5 Hypothetical rainfall intensity-duration threshold for landslides, illustrating observation points for the different thresholds, described in Figure 2 may be used

4. Summary and Conclusions

Clearly weather and climate are key influences upon the triggering of debris flows in Scotland. The ability to forecast conditions during which such events may occur is important now, but may become more so as climate change effects become apparent. The Detection of events prior to their occurrence has the potential to allow the Notification and Action elements of the DNA management approach to be executed proactively.

A wide variety of international approaches to the back analysis and forecast of landslide events resulting from rainfall has been studied. It was found that, back analyses to determine the relations between rainfall and debris flow events are relatively common. However, the implementation of practical systems to forecast the landslide occurrence seems to be relatively rare – albeit with notable exceptions.

A tentative debris flow trigger threshold, in terms of rainfall intensity-duration, has now been developed for Scotland. This threshold needs to be tested against observations in the future to validate its use prior to implementation as a management tool. Notwithstanding this, the first test of the threshold (in the form of the October 2007 event at the A83 Rest and be Thankful) indicates that it has the potential to be successful. Work is ongoing to capture and analyse further such data for the purposes of validation.

A series of high quality data sets from a variety of geographical locations will be needed in order to validate and/or modify the threshold prior to its introduction to the management of the road network in any formal sense. Further data will also be required to enable the limit of the antecedent period of rainfall that influences the formation of debris flows to be defined. Given the frequency of such major events in Scotland it is estimated that this process may take approximately five years.

Once confidence in the threshold has been established working simulations and trials of its use will be required. This would enable lower thresholds for ‘Wake-Up’ and ‘Warning’ thresholds to be set. It would also enable procedures for the use and operation of the threshold to be developed.

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Societal Willingness to Accept Landslide Risk

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Abstract. Landslide hazards are commonplace and the associated risks affect many different cultures. The elements at risk may include infrastructure (e.g. roads, rail), public service buildings (e.g. hospitals, schools), commercial property (e.g. shops, factories, offices) and residential property (e.g. blocks of flats and houses). Clearly these elements at risk will also include, to a variable degree, the risk to life and limb of the users and occupants of such facilities. The type of element at risk and the vulnerability of those elements determines what might be described as a reasonable and proportionate response to a given risk profile. However, it can be difficult to compare such responses to different risk profiles in different parts of the world as the varied social (cultural) factors and economic circumstances can mean that the tolerance of the associated risk is very different indeed. In this paper we attempt to shed some light upon the different approaches to risk acceptance in different countries and regions of the world and in different circumstances. It seems clear that such varied approaches to landslide risk remediation are driven not only by the willingness to accept risk, but also by the willingness to pay to mitigate risk and the willingness to alter the environment in the process. These factors are interlinked using the ternary 'willingness' diagram.

Keywords. Risk acceptance/tolerance, society, economic impacts

1. Introduction

The affirmation that we live in a 'risk-averse society' is becoming a common viewpoint and implies that the willingness to accept, or tolerate, risk is low. In many spheres of life such a statement may well be accurate, but it remains relatively meaningless unless it is viewed in a broader context. Such a context includes the willingness (and/or ability) of society to pay for risk reduction measures and the willingness to alter the environment in order to accommodate such measures. (Society may be defined as an individual, a corporation, an organisation, as a sector of government, or as any other stakeholder or group of stakeholders.)

This is particularly so when the alleviation of risks due to landslides is considered, as risk reduction measures can be both costly and impact significantly upon the environment. In some parts of the world (e.g. Hong Kong) landslide risks are a part of life, albeit not daily life, for the general population. However, in by far the majority of places such risks are both relatively low and manifest at relatively infrequent intervals.

The type of element at risk and the vulnerability of those elements determines what might be described as a reasonable and proportionate response to a given risk profile. However, it can be difficult to compare such responses to different risk profiles in different parts of the world as the varied social (cultural) factors and economic circumstances can mean that the tolerance of the associated risk is very different indeed. In this paper a scheme that attempts to balance the qualitative approach to landslide risk acceptance in a conceptual sense is set out. The term 'Willingness' is introduced as a qualitative measure of risk acceptance, the acceptance of costs associated with risk reduction and with environmental change associated with such measures.

The concept is illustrated by means of examples of different approaches to risk acceptance from the UK and other countries. The concept is also tentatively illustrated in terms of generic approaches to landslide remediation.

2. Willingness - Risk, Cost and Environment

Provided that the willingness to accept risk, pay and alter the environment can be described at a conceptual level then the approaches in different parts of the world and in different situations may be simply and graphically compared to gain a deeper understanding of the drivers for the approach to risk mitigation. This is achieved by means of the ternary 'Willingness Diagram' (Winter *et al*., 2008a; 2008b) (Figure 1). The willingness diagram inter-relates three parameters, thus constraining any one of the three in terms of the levels assigned to the other two. Thus the assumption is implicit that there is a fixed amount of 'willingness' to share between the following parameters:

(1) Willingness to accept (or tolerate) risk.
(2) Willingness (and/or ability) to pay.
(3) Willingness to alter the environment in the pursuit of lower risk.

It is important to note that the diagram is not intended to highlight either incorrect or correct approaches. It is intended to reflect different approaches which may be the result of a wide range of inputs to the decision-making process including engineering, geological, geomorphological, economic, data, information, sociological, political, policy-led and cultural factors.

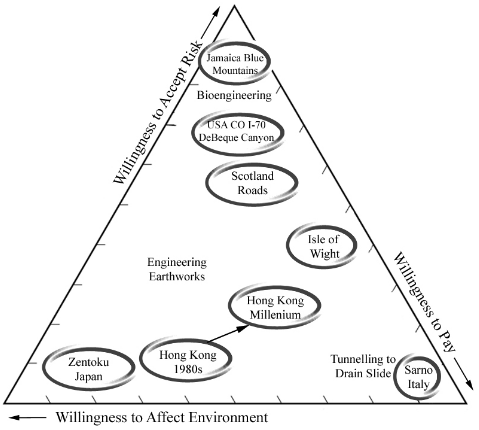

Fig. 1
The Willingness diagram showing the different approaches to landslide risk in the different countries and regions of the World and comparing different generic forms of landslide remediation

3. Approaches to Risk Acceptance in the UK

In the Isle of Wight (Figure 2) the willingness to accept risk is relatively low and the willingness to pay relatively high, despite the fact that the risks are generally to property rather than to life and limb. At the same time the willingness to affect the environment is relatively low, driving the use of discrete and 'invisible' solutions (e.g. deep drainage).

Since 1900 over 50 properties have been lost and many others, as well as local infrastructure, damaged by landslide movement in the Isle of Wight; these and other impacts amount to an estimated annual cost to the economy of £3 million p.a. The impacts of uncertainty over ground conditions and the resulting knock-on effects on the availability of property insurance and the local economy generally were key drivers for research into the nature and scale of ground movement problems. This coincided with the desire by the government to develop planning policy guidance for areas affected by instability and the commission of the 'Ventnor Study' (DOE 1991). This initiative was taken up by the Isle of Wight Council, which extended the study area and developed a 'Landslide Management Strategy' (McInnes *et al*., 2006).

In respect of Scotland's roads both the willingness to affect the environment and the willingness to pay are relatively low, and management solutions are thus favoured over intrusive engineering solutions (Winter *et al*., 2008b). There is thus an acceptance of a certain level of risk although these risks are generally significantly less than those posed by, for example, road traffic accidents.

In Scotland some of the key drivers for the willingness to accept risk are social, economic and environmental, often including elements of all three. Roads in Scotland provide vital communication links to remote communities from both the social and economic viewpoint and the severance of the communities from services and markets for goods is highly undesirable (Figure 3).

The landscape has both a social and an environmental value, but what is often forgotten is that its economic value to Scotland is substantial as it attracts much business in the form of tourism and is especially important to many of the remote communities potentially affected by landslides. The height of the tourist season coincides with the summer landslide season of July and August and thus, in parallel with the need to maintain access, detrimental effects on tourism from negative publicity are unwelcome to both politicians and the public. At the same time adverse visual impacts on the landscape by large defence/remediation structures (e.g. debris basins, overshoots, shelters, etc.) are seen as undesirable. Thus, the underlying philosophy of any remediation must be to preserve the natural landscape as much as is possible even if only to protect what tourists come to visit (Winter *et al*., 2005; 2006).

The avoidance of adverse impacts on other valuable natural resources is also a key issue. Examples of such impacts might include the alteration of the hydrogeological regime of protected peat bogs and adding silt to protected and valuable salmon fishing/spawning rivers.

In the UK an important factor in understanding attitudes to risk acceptance is the contrast between the lack of acceptance of infrequent incidents involving large numbers of casualties (e.g. plane crashes) and the relative acceptance of frequent incidents involving small numbers of casualties (e.g. car crashes).

Fig. 2 Coastal landslides at Ventnor on the Isle of Wight in the south of the United Kingdom

Fig. 3 Debris flow at Glen Ogle in Scotland, United Kingdom

4. International Approaches to Risk Acceptance

An example of the adverse impacts of severance on the socio-economic balance of communities comes from Jamaica. A landslide on the B1 route in the Blue Mountains (Figure 4) effectively severed the local coffee production industry from the most direct route to the international markets, accessed from the north coast, for this high value product. This single landslide event has placed severe constraints on the Blue Mountain economy. However, in this instance the key issue is the limited ability to pay for the substantial remediation measures required to restore the road to active use. This forces the willingness to accept risk to high levels. It also prevents any environmental change due to remedial works. This is driven by both the relatively weak national economy and also by the rather extreme landscape (Figure 5), which renders remediation measures costly.

The United States of America is often cited as a good, if not definitive, example of a risk averse society. However, the evidence does not always support this assertion. For example, the DeBeque Canyon landslide affects Interstate 70, the main national east-west route through Colorado (Figure 6). During the last reactivation of the landslide in April 1998 the road heaved 4.3m and shifted 3m laterally towards the nearby river (White *et al*., 2007). The landslide continues to move possibly forewarning of future rockslides from above and heaving rotation failures of the road. The Colorado Department of Transportation (CODoT) have undertaken a series of remediation measures as described by White *et al*. (2007) and commissioned a long-term monitoring system. However, the overall approach seems to be that the movements described above are at an acceptable level and can be managed on an emergency works basis as and when they happen.

Fig. 4 Landslide on the B1 road at Section in Portland Parish, Jamaica

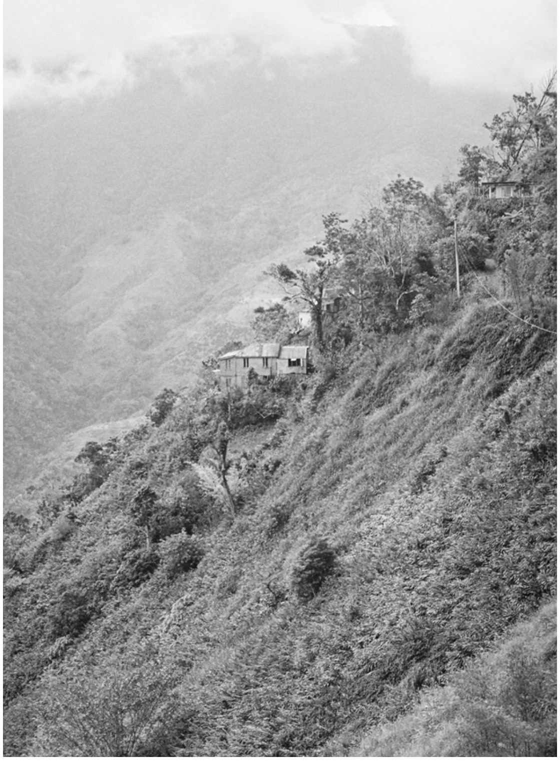

Fig. 5 Typical landscape in the Blue Mountains of Jamaica (B1 road in Portland Parish)

The example of DeBeque Canyon, cited above, implies a high level of willingness to accept risk and an associated low level of willingness to pay, possibly driven by an unwillingness to affect the environment and, potentially, by higher levels of risk elsewhere which may take priority.

Hong Kong provides an interesting counterpoint. Here life has been valued at a high, but nonetheless realistic, level and the willingness to accept risk is relatively low. In the 1980s the willingness to affect the environment was also at a relatively high level with hard engineering solutions often dominating the scene (e.g. Figure 7). This most likely determined the costs and therefore the willingness to pay. In the latter part of the 1990s and beyond there was a shift in the approach in Hong Kong and the willingness to affect the environment was much reduced. This led to softer vegetative solutions where appropriate. This may have been associated with an increase in the willingness to accept risk, as some of the solutions used may be less robust. It may also have led to a potential increase in cost and thus willingness to pay, if only in terms of an increase in maintenance expenditure.

Fig. 6 DeBeque Canyon landslide showing Interstate 70 passing over the toe

Fig. 7 A shotcrete slope in Kowloon, Hong Kong SAR

In Japan, the willingness to accept risk is low. Take for example the case of the Zentoku landslide on Shikoku Island, stabilised with a combination of 20 5.45m diameter concrete piles ranging in depth up to 44m, 280 ground anchors and six drainage shafts with bored drainage arrays (Hong *et al*., 2005; Bromhead 1997); clearly cost was not the significant factor (Figure 8). The combination of willingness to significantly modify the environment with intrusive engineering works and the unwillingness to accept even relatively low levels of risk combine to make the high costs involved almost a side issue – in some respects this extreme example almost renders the willingness diagram (Figure 1) redundant.

In May 1998 a total of 159 people were killed by a series of debris flows in the Italian town of Sarno (Campania). The response has been to construct a series of defence measures (Figure 9) including barriers and debris basins up to around 200,000m^3 capacity (Versace, 2007). The remedial measures have been driven by the desire of the local population to remain in the areas affected, albeit with a lack of willingness to accept further risk. This has led to a willingness to expend resources and to pay for the risk mitigation measures. While the local environment has undoubtedly been changed this is almost incidental and the remedial measures incorporate sports facilities which it could be argued improve both the quality of life and environment for the local population.

Fig. 8 Stabilisation works at Zentoku landslide on Shikoku Island, Japan

Fig. 9 Debris basin at Sarno in Italy

5. Generic Approaches to Landslide Remediation

There are a number of generic approaches to landslide remediation and some of these (e.g. bioengineering) are also represented on the Willingness Diagram (Figure 1).

Bioengineering is generally a least cost but possibly higher risk solution to many slope instability problems. Engineering earthworks may be low cost but a solution that can be rather intrusive and often retain a residual risk. Tunnelling for drainage works is a high cost solution but one which least affects the ground surface environment while reducing the risk associated with future ground movements. This selection is placed in indicative positions on the willingness diagram and shows the positioning of the range of approaches practised in the UK and elsewhere. Work is ongoing to further describe other generic forms of landslide remediation within the realm of the willingness diagram.

7. Conclusions

In this paper we have demonstrated that the affirmation that we live in a ‘risk-averse society’ is not adequate to describe societies’ responses to landslide risk. A broader context is required in order to understand such responses and this includes the willingness (and/or ability) of society to pay for risk reduction measures and the willingness to alter the environment in order to accommodate such measures, as well as the willingness to accept risk.

These factors accommodate the social and economic influences that have a major effect upon the willingness to accept risk and the spectrum of responses to landslide problems fit neatly into the ternary ‘willingness diagram’, illustrating in this triangular plane how different societies have different attitudes to risk acceptance, fiscal expenditure and the modification of the environment.

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GIS Using Landslide Mapping in Niigata Region, Japan

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Abstract: The Niigata Region, Japan, is known as many deep-seated landslides. In particular, most of the deep-seated landslides are distributed in the Neogene mudstone areas. These landslide areas are used for paddy fields which produced delicious rice, such as “Koshihikari” and good Japanese Sake. However, we are discussing the old deep-seated landslides in the volcanic areas related to geomorphology and geology at several areas in Niigata Region, Japan. Namely, we were trying to do landslide susceptibility mapping of Yahiko-Kakuda ranges and Tsugawa Areas and Sado Islands. Finally, we were analyzing the recent landslides triggered by heavy rainfalls and intensive earthquakes in 2004 and 2007 and the other ages, using GIS. These landslides took place hilly mountainous areas consisting of young sedimentary rocks. These landslide affected areas are similar in geomorphology and geology. Therefore, it is possible to compare in characteristics between the landslides caused by different triggers. In conclusion, we have revealed that the heavy rainfall-induced landslides occurred in the mudstone-rich zones rather than the sandstone-rich ones, and that, on the other hand, the intensive earthquake-induced landslides occurred in the sandstone-rich zones rather than the mudstone-rich ones.

Key words. Deep-seated landslides, shallow landslides, heavy-rainfall, earthquake, GIS

1. Introduction

Most of the Niigata regions are composed of Neogene to Quaternary sedimentary rocks and sediments, but Sado Island, Yahiko-Kakuda range and Tsugawa area, consist of Neogene volcanic rocks of variable types. In particular, such Cenozoic sedimentary rocks have been subjected to considerable folding and faulting due to compression of NWN-SES in direction. Therefore, the Cenozoic sedimentary rock areas show remarkable repeated syncline and anticlines of NNE-SSW directions, associated with many faults of the same directions. Geomorphologically, these areas are characteristic of up to 600 high, but they show considerable deep valleys because of highly tectonic compression and high erosion of soft sediments. Furthermore, the Niigata regions are characteristic of much snow conditions. Therefore, since geologic times, the sedimentary rock areas are prone to deep-seated landslides. These landslides are easily reactivated caused by snow melting or upheaving of groundwater. However, in 2004 and 2007, another causes triggered variable type landslides. In Fig. 1, we are circling three areas where different type triggers for landslides. In this paper, we are also summarizing the landslide distribution of old deep-seated landslides and their susceptibility mapping and recent variable triggered landslides in the three areas shown in Fig. 1, using GIS analyses.

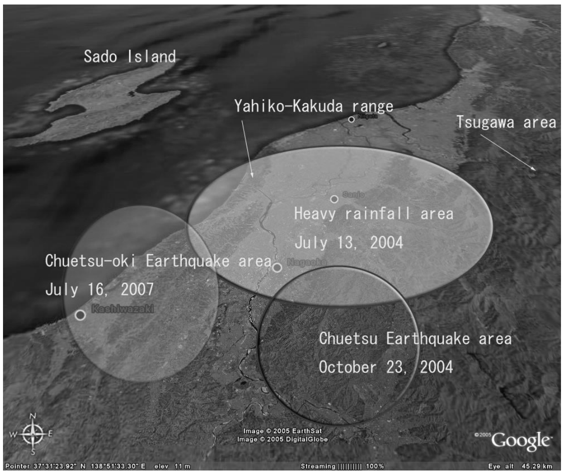

Fig. 1. Locality map of the areas described in this paper. The three elliptical zones are recent landslide areas.

2. Yahiko-Kakuda Range

The range is composed of variable volcanic rocks: the Kakuda-yama is a conical mountain whose peak is 488m high, and is composed of andesitic rocks, while the Yahiko-yama, whose peak is 680m high, and the Maze range between the Kakuda-yama and Yahiko-yama, is composed of basaltic rocks. We are analyzing for landslide susceptibility using GIS associated with logistic regression method after selecting the factors for affecting land sliding as follows; elevation contours, lithology, stratum dipping contours, slope aspect, slope inclination, roads, lineaments (Ayalew and Yamagishi, 2005). The elevation contours, slope aspects and inclinations were derived from 10m DEM (GISMAP by Hokkaido Chizu Co. Ltd). As the results, we draw the susceptibility landslide map as shown in Fig. 2. Actually, deep-seated landslides are idenetifed in the southern part of the Yahiko range through aerial photographs. They are associated with the rhyolitic rocks which were altered into smectite clay.

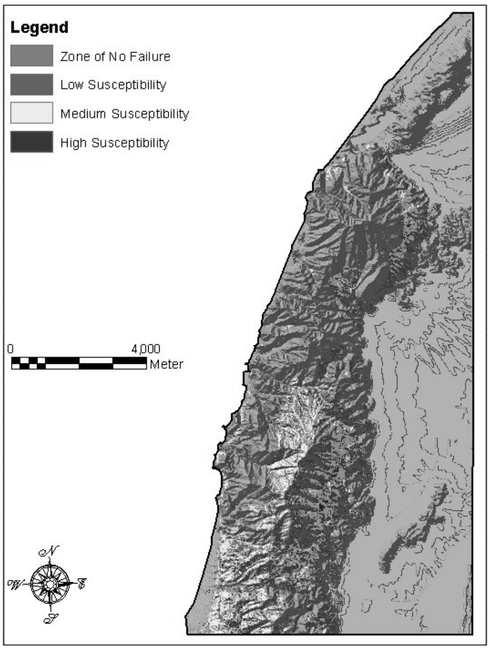

Fig. 2 Landslide susceptibility map of Yahiko-Kakuda range using GIS (Ayalew and Yamagishi. 2005)

3. Tsugawa area

Tsugawa area along the Aganogawa river is characteristic of mostly volcanic rocks intercalated with Miocene sedimentary rocks. The area has many deep-seated landslides related to felsic volcanic rocks and geologic faults. We have interpreted the deep-seated landslides throughout aerial photographs, and classified the dangers using AHP methodology as shown in Fig. 3

4. Sado Island

Sado island is located at 40km offshore of Niigata. This island is composed of small Sado (Ko-Sado) and large Sado (Oh-Sado); the former and latter highest peak is 645m and 1127m, respectively. Both of them are composed mostly of Cenozoic volcanic rocks, particularly, andesitic and rhyolitic rocks (Fig.4). Basaltic rocks are very few. Most of the old deep-seated landslides are located in the andesitic and rhyolitic rocks (Fig. 5). Sado Island is mostly composed of mountains; therefore, it is prone landslides and debris disasters. Niigata Prefecture has been opening the home page on such disaster areas. Actually, in 2003, at the northeast beach of the Ko-Sado, a large scale landslide (Katanoo Slide; Ayalew et al., 2005a).

5. Heavy rainfall-induced landslides in Izumozaki area in 2004

On July 13, 2004, heavy rainfalls attacked Mid Niigata Region, Japan. They are as much as 400 mm in 24 hours, bringing about serious flooding by breaking the river banks. Such heavy rainfalls also triggered more than 3500 landslides. The floods and landslides claimed 15 lives. In particular, the Izumozaki area was characterized by numberless shallow landslides. In this area, such heavy rainfalls were experienced not only in 2004, but also 1978 and 1961 (Fig.6). Fig.6a is a raster data showing slope inclination classification and distribution of all shallow landslides (failures) from 1961-2004. Fig.6b is a graph showing relationship between slope inclination and density of the failures(Number/km^2). While, Fig.7a is showing relationship between lithology division and distribution of the failures, and Fig. 7b is a graph showing comparison in the density between the sandstone rich zone and mudstone rich zone.This graph shows that the shallow landslides by heavy rainfall occurred in the mudstone rich zone rather than the sandstone zone.

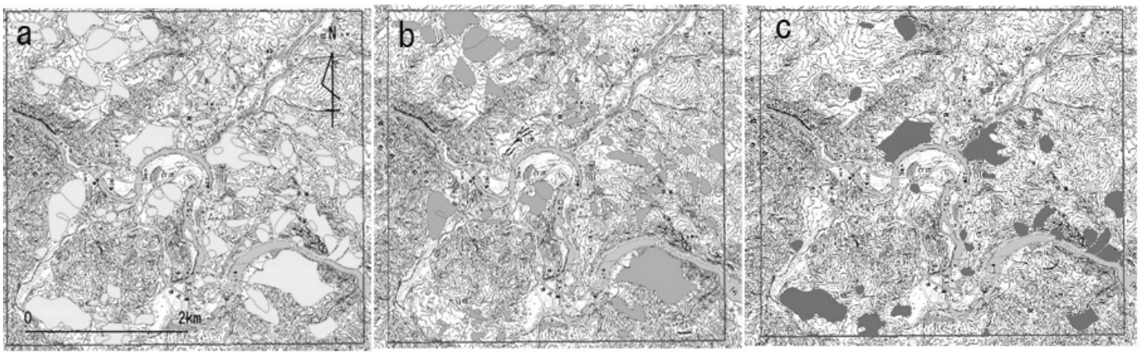

Fig. 3 Deep-seated landslide distribution and stability classification of the Tsugawa area along the Agano river. a) all of the landslides, b) AHP points are less than 2 indicating stable, c) AHP points are more than 39 indicating unstable by AHP.

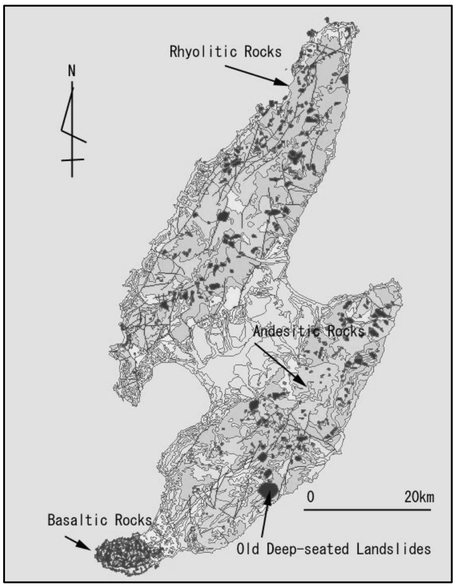

Fig.4. Geologic map and deep-seated landslides of the Sado Island.

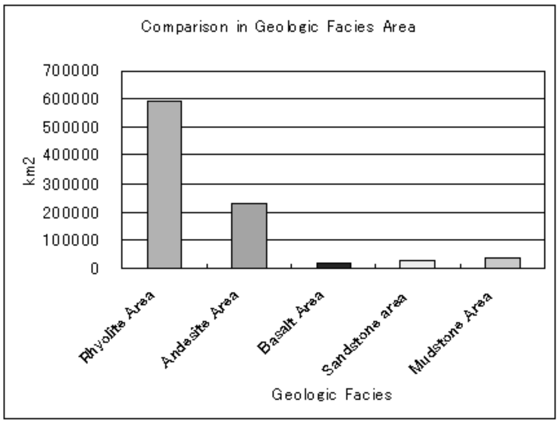

Fig. 5 Graph showing the areas of old deep-seated landslides of each lithology in the Sado Island.

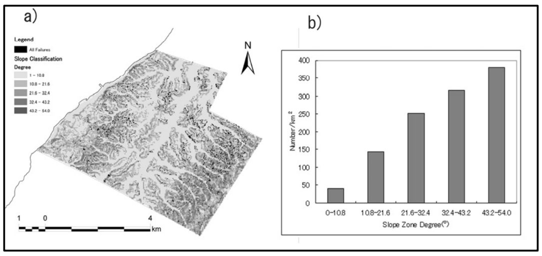

Fig. 6 a)Map showing slope classification and all failure distribution and b) graph showing relationship between slope gradient zones and all of the shallow landslides (failures) from 1961 to 2004 (b).

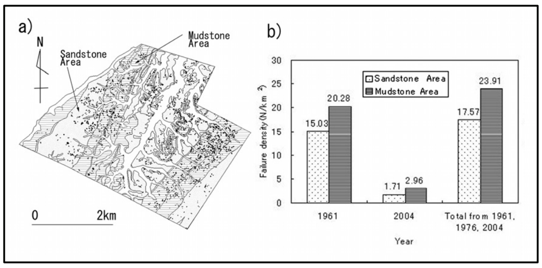

Fig. 7 a) Map showing geologic lithology and distribution of shallow landslides (failures) in 1961, 2004 and 1961 to 2004. b) Graph showing comparison in failure density between the geologic lithology.

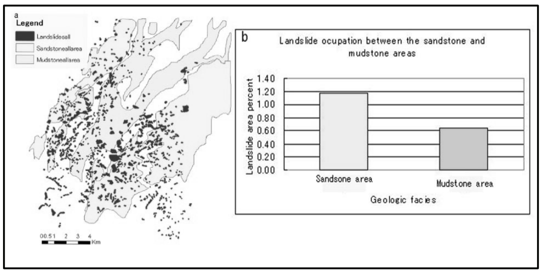

Fig. 8 a) Relationship between the distribution of the Chuetsu earthquake-induced landslides and lithology along the Imogawa. b) Comparison in landslide density between sandstone and mudstone zone (Number/km^2) (Yamagishi and Iwahashi, 2008)

6. Chuetsu Earthquake-induced landslides in 2004

On October 23rd, 2004, intensive earthquake (M. 6.8) attacked mostly the Yamokoshi area, Mid Niigata Region. By the earthquakes, many and variable type landslides were characteristically induced (Fig.8a), because the earthquake area took place in the hills and mountains. Totally more then 65 people were killed. The aerial photograph interpretation and field researching have revealed that the landslides are classified into the following three types (Yamagishi and Iwahashi, 2008): 1) deep-seated slides, 2) long-run slide, and 3) shallow slides. In particular, by these landslides along the Imogawa tributary, more than 10 landslide dams were formed. We were using GIS analyzing the distribution of these all landslides related to geomorphology and geology. As the results, we found that these landslides occurred in the sandstone rich zone rather than mudstone (Fig. 8). It is remarkably different from the shallow landslides by the heavy rainfalls as mentioned above.

7. Chuetsu-oki Earthquake induced landslides in 2007

On July 16, 2007, the Chuetsu-Oki earthquake of M.6.8 occurred and gave also serious damages to the infrastructures such as water, gas and nuclear power plant and 11 people were killed by the collapse of the old houses. Most of the damages were documented in the Kashiwazaki City which is mostly flat and hilly areas, and it is composed of alluvial sand and back marsh deposits behind the sand dunes. In terms of landsliding, the cliffs of the beaches were characterized mostly by shallow landslides (Fig. 9). Particularly, the dip-slipping along the Hijiriga-hana Cape was diagnostic of strongly seismic rock sliding. Hilly areas are also damaged by shallow land sliding, but the numbers are very few compared with the Chuetsu Earthquake on October 23, 2004. The number of the landslides is about 1/10 of the Chuetsu Earthquakes in 2004. The reason why is that the Chuetsu-oki earthquake area shows lower relief than the Chuetsu Earthquake area excepting for the sea cliffs.

Fig.9 Ortho-photo map showing slope failures along the Kannon-zaki beach, north of the Kashiwazaki City. The seismic slope failures were interpreted by Kokusai Kogyo Co. Ltd. The old landslides were downloaded by NIED Web Site

8. Conclusion and discussion

We are discussing the old deep-seated landslides in the volcanic areas related to geomorphology and geology at several areas in Niigata Region, Japan. Namely, we were trying to do landslide susceptibility mapping of Yahiko-Kakuda mountains and Tsugawa Areas (Ayalew et al., 2004) and Sado Islands (Ayalew et al., 2005b). And then we were analyzing the recent landslides triggered by heavy rainfalls and intensive earthquakes in 2004 and 2007 and the other ages, using GIS (Yamagishi and Iwahashi, 2008; Yamagishi et al., 2008). In particular, these landslides took place hilly mountainous areas up to 600 m high, consisting of young sedimentary rocks. These affected areas are similar in geomorphology and geology. Therefore, it is possible to compare in characteristics between the landslides caused by different triggers.

Finally, we have revealed that the heavy rainfall-induced landslides are mostly shallow and occurred in the mudstone-rich zones rather than the sandstone-rich ones, and that, on the other hand, the intensive earthquake-induced landslides are including not only shallow landslides, but also deep-seated slides, and occurred in the sandstone-rich zones rather than the mudstone-rich ones. One of the reasons is possibly that the weathered sandstone has high porosity which is causing easy penetration of water, but the grain structure is prone to easy collapsing by earthquakes, but that weathered mudstone has low porosity and is prone to collapsing as mass by heavy rainfalls.

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Landslide Mitigation Strategy and Implementation in China

Yueping Yin (China Geological Survey)

Abstract: Abstract: China has been implementing a nation-wide landslide investigation and mapping plan since 1999, which covers more than 1500 counties. The preliminary investigation has identified nearly 150000 sites with potential risks. Detailed mapping projects are currently focused on the most hazardous areas. The outcomes of these investigations will include a series of maps on 1:50000 scale as follows: landslide distributions and types; landslide susceptible zones; landslide risk zonation; contours of landslide triggering precipitations; estimation of property losses; landslide prevention plan and engineering measures. With the rapid economic and urban development, landslides associated with man-made activities and engineering developments have become a prime concern. They account for more than 80% of the landslides in China.

China has successfully carried out a number of large-scale landslide prevention projects since the early 1990s, with particular attention given to the Three-Gorges' reservoir area and the cities under rapid development in the western part of China. This paper describes the slope stabilization works for the Lianziyan hazardous rocks and the new Danba city of the Sichuan Province. The weather-based landslide forecast system has been established that covers the landslide prone zone in the nation-wide.. But, the rural areas account for nearly 80% of the total geohazard occurrence. Therefore a project entitled 'Geohazard mitigations in thousands of villages – knowledge and actions' has been carried out. More than 3 million people have joined the training plan and learned some fundamental knowledge how to siting, constructing, monitoring and various precautionary measures to take during emergence situations. This paper also highlights China's state landslide prevention plan, predicting and preventing landslides by masses, i.e., by villagers in or near the landslide, the emergence plans and risk management systems.

Key words: landslide, warning, mapping

1. Nation-Wide Landslide Investigation And Risk Zoning

China suffers from severe landslide hazards every year. Landslides threaten lives and properties in 30 provinces, resulting in an estimated 700 to 900 deaths and damages of properties exceeding $10 billion RMB (Chinese Dollar) annually. Although most of the landslides occur during rainy seasons, human activity is the main factor triggering landslides because of the large scale construction works over a large area.

Since 1990, China has completed a geohazard mapping program at the scale of 1:500,000 that includes 55,000 landslides, 13,000 rockfalls and 17,000 mudflows, with descriptions of locations of these landslides, and the related geologic conditions. More special investigations and risk zoning of landslides have been ongoing since 1999, which covers landslide-prone areas in about 1500 counties. The key task of investigation is to identify the potential of landslides, to provide an emergency preparedness plan, and to establish warning systems for the existing villages. About 150,000 potential landslides have been identified, and 80,000 of them are monitored. This program, called "monitoring and preventing by masses", has proved to be very effectient for landslide mitigation. The success rate of landslide prediction and warning is obviously rising since the mapping and risk zoning plan was conducted.

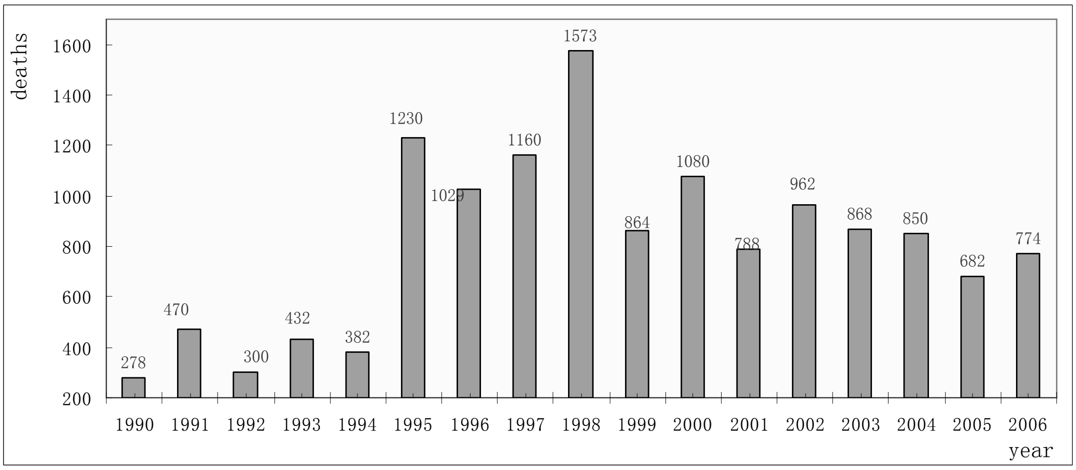

Fig.1 Deaths by landslide hazards in China,1990-2006

2. Detailed Mapping for High Risk Zones of Landslide Hazards

The occurrences of landslides are very complicated in China. More detail surveying and mapping for high risk zones have been conducted on the base of geologic conditions. The relationships between the landslide susceptibility of different kinds of slopes and the landslide triggering factors, such as, rainfall, earthquake, and human activities, are comprehensively analyzed. This survey program is at the scale of 1:50000, resulting in a detailed inventory and distribution maps that cover landslide susceptibility, geological and geo-environment conditions and the impacts of construction projects, such as dams and pipe lines etc in the high risk zones.These documents will be used as guidance for risk assessment for urban development and relocations. In China, the work on landslide hazard reduction is organized by government at central to local levels. Therefore, it is very important that geologists provide concise information for decision-makers. The four sets of maps described above are highly demanded. Through the maps, the government can easily understand the critical issues and make decisions.

A typical case is presented here concerning the Yan'an city of Shaanxi province. Yan'an is located in the central area of a loess plateau. Incised gullies and vertical joints are very common due to soil erosions. The bedrock is also heavily weathered. Rainfalls from June to September are normally very intense. The annual precipitation is about 500 mm. Most of the geohazards are loess slides and slumps. A series of maps depicting landslide hazards have been completed as follows:

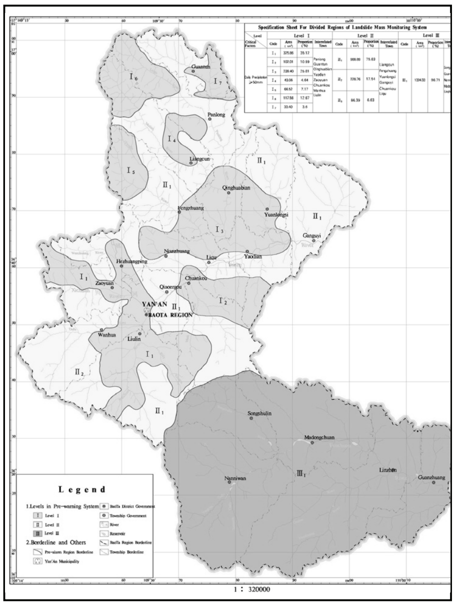

Fig.2 Map of rainfall-based landslide risk alarming

A map of regional engineering geology conditions and zoning. It is a basic map to delineate the controlling factors and geo-environments on landslide occurrences, which include stratigraphy，tectonics, geomorphology, topography, and hydrogeology. In the region, the loess is divided into three groups: Upper, Middle and Lower Pleistocenes on the basis of the geologic epoch. The comprehensive factors show that the highly landslide-prone zone is controlled by the upper Pleistocene loess in the stratum and tributary geomorphology.

A map of engineering activities. It delineates the pattern and intensity of engineering activities, such as housing, damming, road repair, mining, etc. In the region, more than 80% of the geohazards are induced by inappropriate cutting and housing developments.

A map of landslide locations. The map indicates the locations, scales and movement types of landslides. It is important to outline the run out of a landslide may involve. High resolution remote sensing images, such as SPOT and Quick Bird are widely used for investigation purposes.

A map for landslide vulnerability zonation. This map is derived from the map of regional engineering geology conditions, and that of engineering activities, as well as the map of landslide locations. Previously, the natural geologic environment is in the key factor affecting landslide occurrence and human activity is of secondary importance. But now, rapid construction and large-scale cutting has become the prime concern.

A map of landslide risk zonation. The work is in progress. This map is from the vulnerability zoning map. The risk zonation includes assessment of landslide influenced areas and intensity, as well as human activities, such as, houses, schools, power plants, dams, roads, etc.

Maps of expected property losses, landslide-hazards prevention planning, recommended relocation approaches and weather-based landslide hazards warning(Fig.2).

3. Stabilization And Mitigation On Major Landslides

Since 'International Decade of Natural Disaster Reduction' started in 1990, more than 200 major landslides that severely threatened the cities, main river courses, and other key public facilities have been stabilized. The Three Gorges Project is one of the largest water resources development programs in the world. The resettled population of the Three Gorges Reservoir area is about 1.2 million. During the first phase from 1993 to 1997, 82,000 people were resettled, and 550,000 populations were resettled in the second phase of the project from 1997 to 2003. By 2009, over 600,000 people will be resettled during the third phase of the project. The resettlement plan is a great challenge, since in the reservoir area it is difficult to find flat land that is suitable for construction(Photo.1). People have no alternative but to move to landslide-prone areas. A systematic landslide prevention project has been carried out at the Three Gorges Reservoir, which is aimed at protecting and stabilizing unstable slopes and rockfall deposits and solving the engineering problems encountered in the large-scale excavation and filling carried out in the resettlement construction plan since 2001.

Photo.1 the Qianjiangping Landslide after filling of the Three Gorge Reservoir (2003)

4. Weather-Based Regional Landslide Hazard Warning

In 2003, the Ministry of Land Resources (MLR) and China Meteorological Administration (CMA) signed a cooperative agreement on operating a weather-based geohazard warning service during the raining seasons. CMA provides rainfall data, and MLR will make forecast for geohazard risks, and release warning notices through China Central Television （CCTV）at prime times after broadcasting daily weather forecast. In a same manner, the local cooperative agreements have also been signed in various provinces.. The weather-based warning system is part of the landslide prevention program of 'monitoring and prevention by masses'. According to incomplete statistics in 2004, over 700 landslides were successfully predicted and warned, and 46,000 persons were evacuated from risky areas. On 24 August 2004, MRL and CMA jointly issued a warning of a class 4~5 landslide hazard at the Zhejiang and Fujian Province coastal area in anticipation of the "Aily" Typhoon coming on 25-26 August. Two days later, the typhoon brought 400 ~ 600 mm rainfall, which triggered hundreds of landslides. No people were injured or died as tens of thousand of people were removed timely from the risky zones, although 260 empty houses were destroyed.

5. Weathered-based regional landslide hazard warning

In 2003, the Ministry of Land Resources (MLR) and China Meteorological Administration (CMA) signed a cooperative agreement on operating a weather-based geohazard warning service during the raining seasons. CMA provides rainfall data, and MLR will make forecast for geohazard risks, and release warning notices through China Central Television（CCTV）at prime times after broadcasting daily weather forecast. In a same manner, the local cooperative agreements have also been signed in various provinces.. The weather-based warning system is part of the landslide prevention program of 'monitoring and prevention by masses'. According to incomplete statistics in 2004, over 700 landslides were successfully predicted and warned, and 46,000 persons were evacuated from risky areas. On 24 August 2004, MRL and CMA jointly issued a warning of a class 4~5 landslide hazard at the Zhejiang and Fujian Province coastal area in anticipation of the "Aily" Typhoon coming on 25-26 August. Two days later, the typhoon brought 400 ~ 600 mm rainfall, which triggered hundreds of landslides. No people were injured or died as tens of thousand of people were removed timely from the risky zones, although 260 empty houses were destroyed.

6. Geohazard risk assessment for land-use

The surge of infrastructure construction especially in the western mountain areas of China has created a serious concern about geohazards. According to statistics, about 80% of the landslide hazards are caused by inappropriate construction activities. In 1999, the Ministry of Land Resources issued an act that specified a compulsory geo-hazard risk assessment for various land-use purposes before the applications of these projects are approved. The assessment includes: (1) possible geohazards induced or intensified by the project, and (2) risks of geo-hazards induced by the construction project itself.

The largest project on landslide risk assessment in China is related to the natural gas pipeline project linking the Xinjiang Autonomous Region to Shanghai. The 4200 km long pipeline strides across various complicate geological and geomorphologic areas that pose significant constraints on the pipe alignment, construction and operation alternatives of the project. The detailed review of landslides and other geo-hazards for this project helped to avoid many major hazards that may threathen the project.

7. Education and training for geohazard mitigation

In China, development standards in rural areas are behind those in the urban areas. The rural areas are much more hazard-prone due to the low input and poor knowledge regarding landslide prevention. The Ministry of Land Resources of China organized a series of training courses in 19 provinces in 2006. Three million people joined the course and learned some fundamental knowledge about safe housing and construction practices, simple means of observing and issuing warning of landslide occurrence during emergence situations, and evacuating and rescuing actions, etc. Tens of landslide disasters had been successfully warned and avoided in the raining season of 2007 as a result of the education plans.

8. Main actions on landslide hazard reduction

The Chinese government has launched an action plan on geologic hazards mitigation, which includes landslide investigation, risk assessment, design and stabilization of hazardous slopes, and emergency responses. The plan has also incorporated a landslide risk management system from state to provincial levels, and is currently extending to various villages since the 1990s. A framework for landslide hazard reduction plan is suggested within the next decade. The framework includes the following key componenets.

Establishment of the legal system for landslide reductions. Various items in laws and specifications will be officially specified，in conjunction with the publication of technical standards and codes by 2010. The landslide risk zonation will be a part of the state mandatory requirements in land-use and construction. Man-made related landslide hazards will be greatly reduced through rational construction and risk management. The hazard reduction strategy and planning will be an important part of China's modernization processes, such as urbanization, the Western China development plan, Mega-lifeline project, etc.

Improvement of weather-based landslide alarming system. The regional weather-based landslide warning system will be completed in 31 provinces for about 1000 landslide-prone counties. In the key regions, such as the Three Gorges Reservoir, GPS-based real-time monitoring system will be established. Since landslides are widely distributed in China the plan of "monitoring and preventing landslide by masses" is still the main and efficient approach to be adopted in the next decades.

Establishment of professional teams working on landslide reductions. The Ministry of Land Resources has organized a professional system that includes the central administration and its local offices. This organization is responsible for landslide investigation, risk management, rescuring programs, and community risk reduction plans. It is also their responsibility to enhance public awareness, and offer training and education programs. The engineers of the teams are required to get special qualifications, receive regular training and involve in work on landslide-prone areas.

Detailed nationwide landslide investigations. Within the next 5 years, detailed landslide investigations will be carried out in the landslide-prone zones of Sichuan-Yunnan, Qinlin-Dabashan and Hubei-Hunan where landslide hazards account for 78% of the total every year. The nationwide landslide hazard risk zoning, as specified in the mandatory technical standards, will be carried out at a large scale.

Further implementation of the plan 'monitoring and prevention of landslides by masses'. By 2010, this network will be greatly improved. A number of hazardous areas will be equipped with advanced and automatic monitoring facilities. The real-time monitoring and warning systems on major key zones, such as the Three Gorges Reservoir, will be completed, when the reservoir water level reaches the normal operational level.

By implementing this plan, it is expected that, by 2020, landslide occurrence rates and losses of properties will reduce by 70% of the current level. The loss of lives will be 300 per year compared to the current annual fatalities of about 1000. The annual economic damages are expected to be reduced to 5 billions Yuans from the current 10 billions.

Conclusions

This paper reviews the landslide hazards prevention plan carried out in China during the International Decade of Natural Disaster Reduction since 1990. With the rapid economic development in China, landslide hazards are increasing. This paper has briefly discussed various aspects related to this plan. They are the nation-wide landslide investigation and risk zoning; stabilization and mitigation of major landslides; weather-based regional landslide hazard warning; geo-hazard risk assessment on land-use and main actions on landslide hazard reduction. These measures have proved to be successful and will be even more rewarding in the future.

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Distributed Optical Fiber Sensors for Precocious Alerting of Rainfall-induced Flowslides

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Abstract. Monitoring of active landslides is fundamental for the design of stabilization measures, but is also important to check the behavior of stable slopes which may suddenly become unstable, as a consequence of any change in boundary conditions, experiencing a catastrophic failure.

At the Geotechnical Laboratory of the Research Centre in Environmental Engineering (C.I.R.I.AM.), we built an instrumented flume to investigate on the mechanics of flowslides in unsaturated deposits of pyroclastic soils. Research activity led to useful results, allowing to face the problem of risk mitigation with a greater awareness about the factors which really govern flowslide generation.

Monitoring of soil deformation has been performed by using a stimulated Brillouin scattering (SBS)-based optical fiber sensor. The sensor is able to provide distributed strain measurements along a single-mode optical fiber. We show some preliminary results, demonstrating that optical fibers can be used as efficient precocious alerting of rainfall-induced flowslides.

Keywords. Monitoring, precursor stage of landslide, early warning

1. Flowside occurrence in Campania region

In Campania Region flowslides and liquefied debris flows represent one of the natural risks with major consequences due to frequency of events, extension of areas which can be subjected to invasion and number and value of exposed goods.

After the catastrophic landslides of 1997, 1998 and 1999, the engagement of the scientific community has become remarkable, leading to reliable hypotheses about the mechanics of initiation and evolution of flowslides. To this aim, small-scale physical modeling is extremely useful (Iverson & Lahusen 1989; Eckersley 1990; Wang & Sassa 2001; Olivares & Picarelli 2006). In fact, instrumented flume tests allow to capture important aspects of slope behavior and to check current hypotheses about the mechanisms which lead to flowslide generation. As a result, the research can speed up to shortly set up new and advanced tools for risk mitigation, and to develop and test innovative monitoring systems.

At the Geotechnical Laboratory of the Research Centre in Environmental Engineering, C.I.R.I.AM., an instrumented flume has been built to investigate on the mechanics of flowslides in unsaturated deposits of pyroclastic soils (Olivares et al. 2003; Damiano 2004). The instrumented flume permits to achieve some useful results which allow to face the problem of risk mitigation with a greater awareness about the factors which really govern flowslide generation (Olivares & Damiano 2007). Using such a flume as a basic tool for experiment, a strict cooperation among geotechnical, hydraulic and optoelectronic engineers is now opening new scenarios of research to recognize and assess the indicators of event and to set up new criteria for precocious landslide alerting through simple site monitoring.

The paper describes an innovative procedure which has been tested at C.I.R.I.AM., based on the use of distributed optical fiber sensors for precocious alerting of rainfall-induced flowslides. A number of preliminary experimental results are reported, demonstrating the feasibility of these sensors as precocious alarm sensors.

2. Distributed sensors based on stimulated Brillouin scattering

The effect of stimulated Brillouin scattering (SBS) can be employed in order to perform distributed temperature and strain measurements along a standard single-mode optical fiber. If an acoustic wave propagates in a medium, the variations in pressure give rise to variations in the refractive index of the medium, via the strain-optical effect. Some acoustic waves will always be present in a medium, above the absolute zero of temperature, since the molecules are in motion and will couple some of their energy into the dynamic modes of the structure. Optical scattering from these thermally excited acoustic waves gives rise to the phenomenon of spontaneous Brillouin scattering. However, as the optical pump power is increased the wave scattered backwards from an acoustic wave will increase in amplitude and will interfere significantly with the forward-traveling pump wave. An optical beat signal arises within the fiber, which generates a pressure wave having the same frequency as the optical beat signal, via the phenomenon of electrostriction (Fig. 1); this pump-induced index grating scatters the pump light through Bragg diffraction. Scattered light is down-shifted or up-shifted in frequency because of the Doppler shift associated with a grating moving at the acoustic velocity V_A. This positive feedback, backscattering process is known as the stimulated Brillouin scattering (SBS).

Stimulated Brillouin scattering leads to much larger backscattering at the Stokes and anti-Stokes frequencies than in the spontaneous case and, indeed, may cause depletion problems in narrow-band optical-fiber telecommunications systems. On the other hand, the same effect can be exploited in order to realize a distributed optical fiber sensor.

The basic arrangement is shown in Fig. 2. A coherent pulse of light acts as the pump, and a counter-propagating continuous-wave (CW) beam is scanned in frequency around the Stokes line. When it coincides with the Stokes line it will receive gain from the pump via the SBS process.

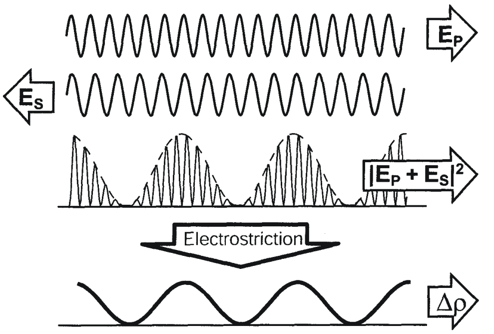

Fig. 1. Principles of stimulated Brillouin scattering in optical fibers.

Essentially what is happening in this case is that the CW is giving rise to a large-amplitude interference with the pump, thus generating the acoustic wave from which the pump is strongly reflected. By observing the probe level as a function of time and frequency as the pump propagates, the Stokes frequency can be mapped as a function of position along the fiber.

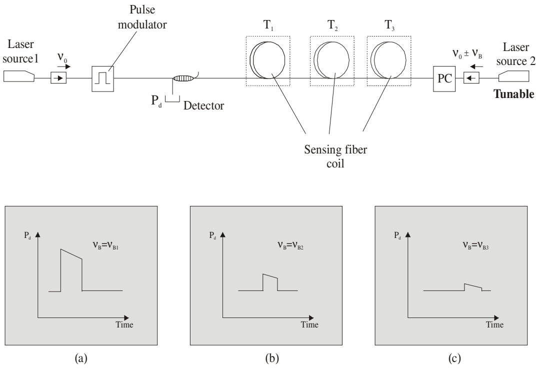

Fig. 2. Basic configuration for BOTDA. (a), (b) and (c) show the Stokes signals acquired when the frequency offset between the two lasers is tuned to the Brillouin frequency shift at region T_1, T_2 and T_3, respectively.

The frequency difference between the Stokes beam and the pump is known as Brillouin frequency shift (Agrawal 2001). As the latter is linearly dependent on temperature and strain of the fiber, a distributed temperature and strain sensor can be realized by using a scheme such that depicted in Fig. 2. Essentially, a Brillouin gain spectrum (BGS) is measured for each fiber section, such a spectrum being usually well modeled by a Lorentzian function. The spectral position of the peak of each Lorentzian curve gives a measure of the local Brillouin frequency shift (and hence of the local temperature and strain condition).

Spatial resolution in SBS-based sensors based on the use of a pulsed pump light is strictly related to the pulsewidth, such that shorter pulses give rise to better resolutions. On the other hand, it must be underlined that achieving a spatial resolution below 1 meter compromises the accuracy of the sensor, become of some physical limitations related to the lifetime of the phonons involved in the scattering process (Thevenaz et al, 1998).

The major advantage of BOTDA, with respect to spontaneous scattering based systems, is that of a strong signal, thus an easing of detection problems, with the associated beneficial spatial resolution trade-off. This provides valuable performance over very large distances. The major disadvantage, apart from a more demanding requirement on the source coherence, is that, differently from spontaneous Brillouin scattering, there is no dependence of the signal power on temperature or strain, since the scattering process is now controlled by the wave interference rather than by the intrinsic fiber properties. Consequently, it is not possible to measure strain and temperature simultaneously, as in the spontaneous case. Each can only be measured if variations in the other are known to be absent, or are independently determined. The most practical way to achieve this consists in deploying the fiber in such a way that half of it is subjected to only temperature changes, whereas the other half is mechanically attached to the structure to be monitored, so that both temperature and strain changes are detected. Brillouin frequency shift measurement in the first region allows subtracting temperature effects from the measurement taken in the second half (Smith at al. 1999).

Fiber strain is an important parameter to be measured for assessing the reliability of optical-fiber cables, because strain can cause degradation in fiber strength (stress corrosion), leading eventually to fiber failure. Therefore, Brillouin-based strain measurement has found many applications in the research and development of optical fiber and cables and their related technologies (Horiguchi et al. 1995). Reports have been published on the strain evaluation of optical-fiber communications cables (Tateda et al. 1990).

Strain sensing by SBS-based sensor has been also proposed for pipeline monitoring. A structural health monitoring (SHM) system for pipeline networks would permit to monitor continuously their structural integrity, reducing the overall risks and costs associated with current methods. Note that pipeline monitoring could be of use also in geotechnical applications, in which the deformation of a buried pipeline can be correlated to landslide movements. Zou et al. (2006) showed that high-spatial-resolution Brillouin sensing can be adopted in order to detect the formation of pipeline buckling, resulting from excessive concentric and bending loads. A technique for monitoring pipeline dislocation has been also demonstrated (Bernini et al. 2008), in which a Brillouin sensor is used in order to measure the strain distribution along three longitudinal directions running along the pipeline.

Optical fiber sensing may also represent a powerful tool for landslide monitoring. An experimental demonstration of the use of optical fibers for landslide monitoring has been reported by Aulack at al (2004), in which fiber micro-bending was employed as sensing mechanism. However, micro-bending only permits sensing at discrete sections along the fiber. On the contrary, distributed sensors such those based on stimulated Brillouin scattering, permit spatially distributed sensing by use of a single optical fiber, and hence may represent a more cost-effective solution.

3. Experimental system for rupture alerting

In this section, we describe the set-up used for distributed strain measurements in our experiment. A sketch of the set-up is shown in Fig. 3. Light emitted by a distributed-feedback (DFB) diode laser was first split in two arms by a fiber-fused coupler. An acousto-optic modulator (AOM) was used to provide pulses with widths down to 10 ns (corresponding to 1-meter-spatial resolution), whereas the CW probe signal was generated by the electro-optic modulator (EOM), using the sideband technique (Nikles et al 1997). The detector (DET) consisted of an InGaAs photo-detector, whose output was sent to an A/D converter connected to a notebook via USB port. The acquired data were periodically transferred to the notebook which also performed data processing. A frequency shift of 300 MHz was induced by the AOM on the pump optical frequency, so that only one of the two sidebands could effectively interact with the pump wave for Brillouin scattering generation. This provides an inherent stability to the system, as it is totally immune to any drift of the source wavelength (Bernini et al. 2004).

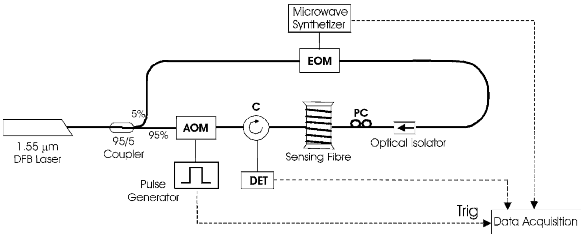

Fig. 3. Experimental set-up for SBS-based fiber-optics measurements (C = optical circulator , PC = polarization controller)

A number of 1000 averages were taken for each fixed pump-probe frequency shift, in order to achieve a sufficiently high signal-to-noise ratio for the measurements. The acquired waveforms were finally processed by a standard Lorentzian fitting technique. Considering the time required to perform the whole process (acquisition + processing), the system was capable to provide a new updated Brillouin frequency shift distribution measurement every about five minutes. The sensitivity of the sensor to the longitudinal strain applied to the optical fiber was estimated to be ±20 με (corresponding to 1-MHz change in Brillouin frequency shift). The fiber employed for the experiments was a single-mode standard optical fiber, protected by an outer PVC jacket with a diameter of 900 μm. The total length of the fiber was about 25 m.

4. Experimental results

The instrumented flume used for the experiments is shown in Fig. 4. Two strands of the optical fiber, each having a length of 1 meter, were embedded into the soil under the longitudinal direction of the flume. Each strand was fixed at both ends of the flume. By placing the fiber in such a configuration, any deformation of the soil was expected to induce a tensile strain to the embedded fiber strands, which could be revealed with high accuracy by our SBS-based measuring set-up.

In Fig. 5, the dashed lines indicate the two fiber sections embedded into the soil.

After this measurement, the slope of the flume was tilted to an angle of 40°; then, a uniform rainfall with intensity of 40 mm/h was produced through spray nozzles located 0.4 m above the ground surface, until soil failure occurred. During the whole experiment, optical measuring set-up was operated continuously, so that an updated strain profile, similar to that shown in Fig. 5, was available every five minutes.

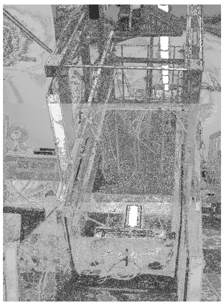

Fig. 4. The instrumented flume

A preliminary measurement of the tensional stress along the sensing fiber was performed before the experiments took place, so that any successive measurements could be compared to it in order to reveal any changes in the measured signals. The result of this measurement is shown in Fig. 5, in which the Brillouin frequency shift is plotted as a function of the distance along the fiber.

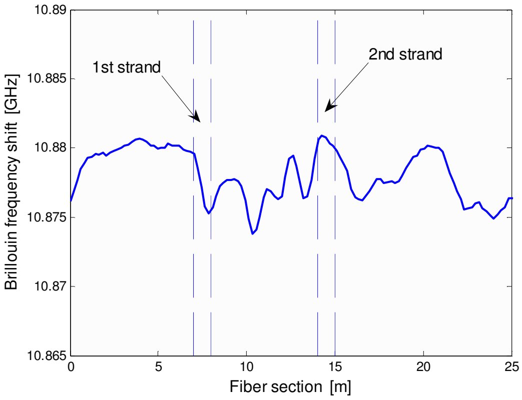

Fig. 5. Brillouin frequency shift profile along the fiber, as measured before rain-falling. The dashed lines enclose the fiber regions embedded into the soil

Soil failure occurred about 65 minutes after that the rainfall was started, so that a number of 13 strain profiles were captured during the experiment. It is interesting to show the temporal evolution of the Brillouin frequency shift in correspondence of the embedded fiber section comprised from z=14m and z=15m (Fig. 6). It can be seen that the tensile strain of the fiber strand gradually increases during the experiment, indicating a progressive deformation of the soil. Note that the occurrence of soil slipping could be detected much before soil rupture. Actually, Fig. 6 indicates that Brillouin frequency shift increases of about 10 MHz before soil rupture, corresponding to a fiber deformation of about 200 με. This value is an order of magnitude higher than the minimum strain change detectable by our set-up. On the other hand, the other embedded fiber strand, i.e. the one comprised from z=6m and z=7m, did not show a similar behavior in terms of Brillouin frequency shift increase. This should be attributed to a not perfect bonding of the fiber strand with the slipping soil.

It can be also useful to compare the whole Brillouin frequency shift profile, as acquired at the beginning of the experiment, to the profile acquired immediately before soil rupture. The comparison is done in Fig. 7, in which the increase in Brillouin frequency shift along the second strand is evident. As stated before, such an increase can only be attributed to soil slipping, as independent measurements, carried out by use of a thermocouple, permitted to verify that the local temperature kept constant during the experiment. On the contrary, the changes in Brillouin frequency shift along the fiber regions not embedded into soil, shown in Fig. 7, are to be attributed to changes in fiber temperature, resulting from both room temperature changes and rainfall-induced fiber cooling.

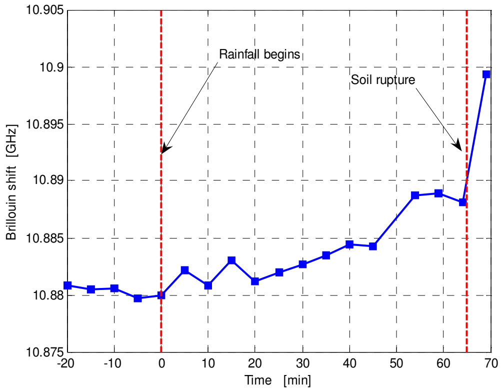

Fig. 6. Brillouin frequency shift of one of the two fiber strands embedded into the soil, monitored during the experiment

In conclusion, we have demonstrated that distributed optical fibers based on stimulated Brillouin scattering are able to sense even small soil deformation foregoing soil rupture. This allows to get continuous spatial and temporal information concerning the slope behavior, prefiguring the use of distributed fiber optical sensors as effective, precocious landslide alerting systems.

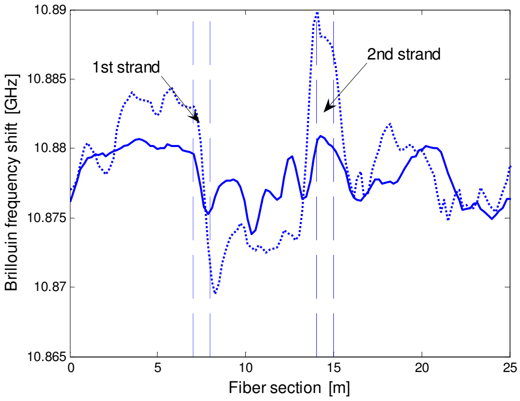

Fig. 7. Brillouin frequency shift profile along the fiber, as measured before rain-falling (solid line), and immediately before soil rupture (dotted line). The dashed lines enclose the fiber regions embedded into the soil

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Test Model Study of the Possible Failure Mode and Mechanism of the Xietan Landslide when Exposed to Water Level Fluctuation

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Jian Wu (China Three Gorges University, China)

Abstract. Hydro-geologic conditions of bank slopes in the Three Gorges Reservoir will change greatly due to the fluctuation of water level in the reservoir, which will affect the stability of the bank slopes. The probable failure mode and mechanism of the Xietan landslide is presented using a physical model in order to test varying conditions of water level fluctuation. The results will give insight as to the failure modes and mechanisms of landslides that have engineering geological conditions similar to those of the Xietan landslide.

Keywords. Xietan landslide, Three Gorges Reservoir, model test, failure model and mechanism

1. Introduction of Xietan Landslide

The Xietan landslide is located in Xietan Town, Zigui County, Hubei Province, China, is situated on the left bank of the Yangtze River, and is 48 km away from Three Gorges Dam. The location of the landslide is shown in Figure 1. The landslide takes on long tongue shape, the front part of the landslide is broad and the back part is narrow. The elevation of the landslide is 60～380m from the top to the bottom, the length in the longitudinal direction is 780m, the width of the rear part is 140m. The width of the front part is 460m, the thickness of the front half part of the landslide is about 45m and that of the back half part is about 20m. The volume of the landslide is 894×10^4 m^3. There are three platforms that have developed on the landslide. The gliding mass of the landslide is composed of 4 layers which are slope wash, debris, slipping zone and bed rock from top to bottom, respectively. The thickness of the slope wash is from 0.5 to 4.4 m and the slope wash is composed of silty clay with reduced and block stone. The average thickness of the debris is 30 m, the greatest thickness is 45 m, and the debris is composed of reduced and block stony soil with a ratio of soil to stone that is variable in different parts. The thickness of the slipping zone soil is 0.7 m - 2.7 m, which is mainly composed of reduced stony soil. The structure of the debris is un-compacted, and the cementation condition of debris material is poor, which will break up the structure of the broken debris when the debris is exposed to reservoir water. A photograph of the landslide is shown as Figure 2.

2. Fluctuation of Reservoir Water Level

The landslide has been exposed to the 135 m and 156 m water level impoundment of the Three Gorges Reservoir. The reservoir water level reached 135m on June 15, 2003 (Li 2003) and 156m on October 27, 2006 (China Three Gorges Project Corporation 2006; Luo et al 2007), and the process of the rise of 135 m to the 156 m water level impoundment levels is shown in Figure 3 and Figure 4. The reservoir water level will rise to 175m in 2009, and the fluctuation of reservoir water level during the course of subsequent seasonal operation of the reservoir is shown as Figure 5 (Yangtze-River Water Resource Commission 1992). The landslide will be exposed to the 175 m water level impoundment in 2008 and will experience continuous fluctuation of reservoir water level during the course of the operation of the reservoir.

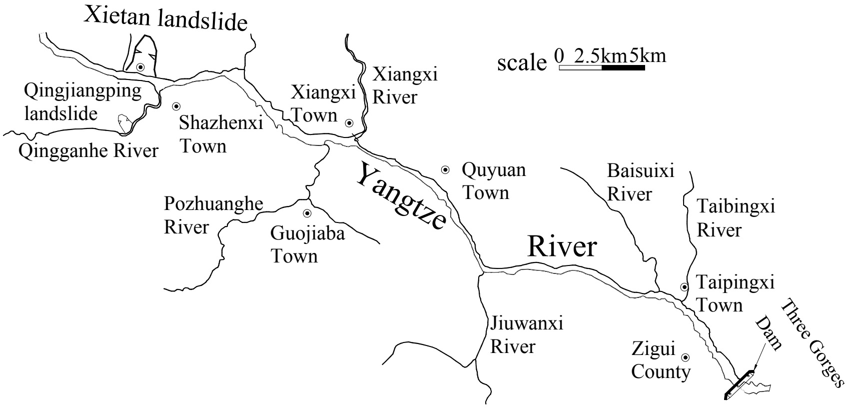


Fig.1 Location of the Xietan landslide

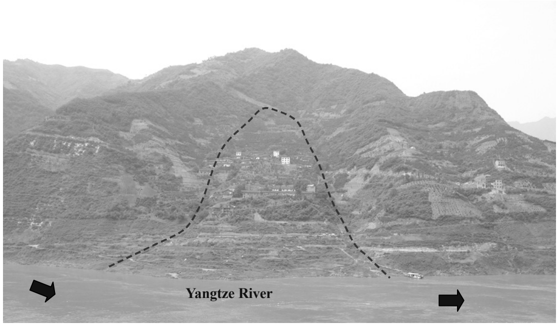


Fig.2 Photograph of the landslide

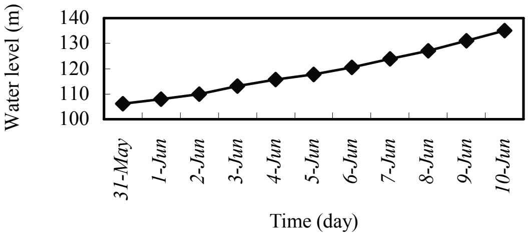


Fig.3 The process of the 135m water level impoundment of the Three Gorges Reservoir

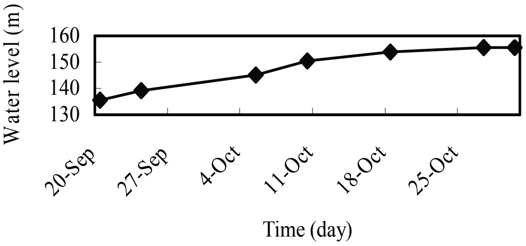


Fig.4 The process of the 156m water level impoundment of the Three Gorges Reservoir

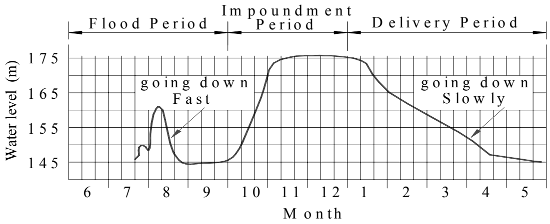


Fig.5 The fluctuation of reservoir water level during the course of the reservoir operation

3. Physical Model Test

3.1 Apparatus for the model test

The test system is composed of a flume, a lifting apparatus and a series of water supply apparatus for simulating the fluctuation of reservoir water level. The dimension of the flume is 150cm × 15cm × 100 cm (length × width × height), and the sketch and picture of test system are shown as Figure 6 and Figure 7. The water supply apparatus of the reservoir water level is composed of an upstream water tank in the back edge of the slope with the downstream water tank in the front of the slope. A stable supply of water for the back edge of slope is obtained through the upstream water tank at the back of the slope, and the fluctuation of water level is simulated by adjusting the supply of water obtained through the downstream water tank. Lifting and turning of the model flume can be accomplished by means of a fixed hinge and jacking apparatus in the bottom of the mode flume. The maximal turn angel was 20° , so the failure tests of slopes with different inclinations can be tested in the flume. There are 5 piezometric tubes placed in the bottom of the model flume in order to measure the underground water table in slopes, and to drain water in the flume as well.

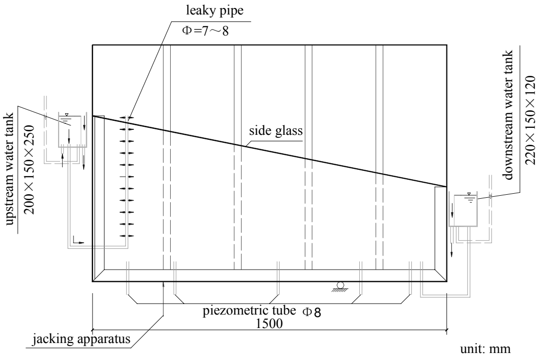


Fig.6 Sketch of the test system

Fig.7 Photo of the test system

3.2 Section plane selection for model test

According to the report on geologic investigation of the landslide, the main sliding direction is in accordance with II-II section plane, so II-II section plane was chosen for the plane stress model test in order to study the failure mechanism of the landslide undergoing the conditions of reservoir water level fluctuation. The II-II section plane is shown in Figure 8.

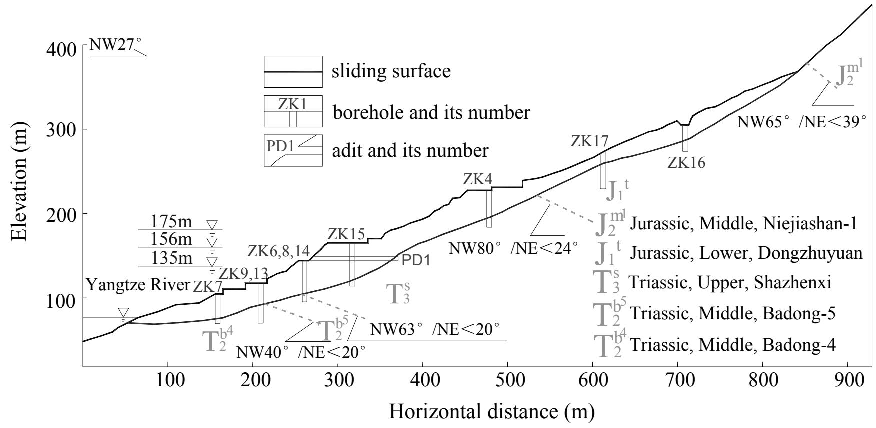


Fig.8 The II-II section plane sketch of the landslide

3.3 Preparation of Similarity materials for model test

3.3.1 Formulation of similarity material of model test

According to the similarity law, the geometric similarity ratio of model and prototype is 1:530. So the angel of slope of sliding surface was 16.1°, and the total length of the slipping surface was 155cm. The value of cohesion and friction angle of sliding surface material of the model should satisfy the similarity law. Through comparison of four sliding surface materials which are double-layer plastic film, flint-glazed plastic film, soap daub and artificial mixed material containing talc powder and the material test, artificial mixed material containing talc powder was chosen as the sliding surface material due to its value of cohesion and friction angle being very close to that satisfying the similarity law and the fact that it is waterproof.

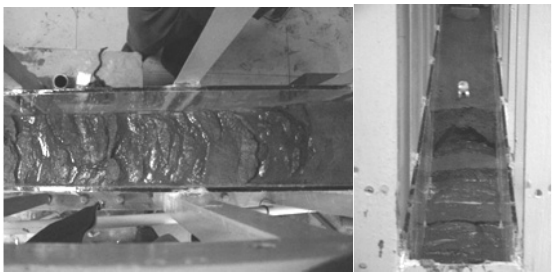
Slide mass material was determined according to the similarity material tests. The mass material was filled and compacted in laminate, the mass weight was about 45kg, and is composed of the mixture of sand and clay with different proportions (shown as table 1).

3.3.2 Simulation of fluctuation of reservoir water level.

A stable water supply from the upstream water tank at the back of the landslide model was used to simulate the underground water of the landslide, and the supply altitude of its prototype was 315.35 m. The fluctuation of reservoir water level is obtained from pooled water whose water level is controlled by the downstream water tank at the front of the landslide. The fluctuation of reservoir water level of the prototype is caused by reservoir impoundment and operation which can be determined by the process of the 135m, 156m and 175m impoundment water levels and the reservoir operation as mentioned above. According to the similarity law, the geometric similarity ratio 1:530 of model and prototype was used to determine the fluctuation of reservoir water level of the physical mode. The relationship between the time of model test and the prototype follows the following formulation according to similarity law: $t_m = \sqrt{t_p}$, Where, t_m is the time of physical model, t_p is the time of prototype.

3.4 Model test phenomenon and its analysis

When the upper osmotic valve is turned on, the failure process of the landslide under the condition of seepage of groundwater and fluctuation of reservoir water level is described as follows.



a) top view **b)** elevation view

Fig.9 The Slide mass sliding part by part from the front to the back

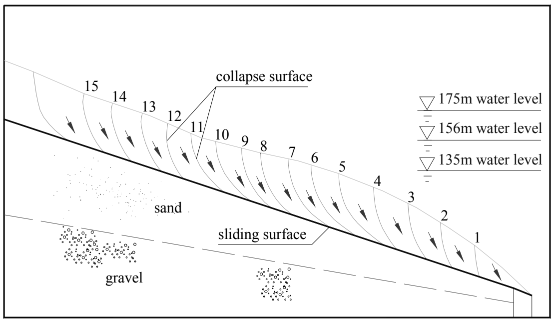


Fig.10 The development of the failure process

Upstream water flowed through a leaky pipe and into soil layer of slide mass, and when seepage streamline and saturation line moved gradually to the front part of the slide mass, the water supply was stopped. During the course of the 135m water level impoundment, a lateral crack appeared at the surface of the soil layer at the front of the landslide, the cracks developed gradually, and then arc collapses happened in the front of the landslide. This kind of arc collapse of soil layer in front of the landslide appeared one by one. When the water level went to 135 m and remained until the time when reservoir water level started to go up to 156 m, there were five collapses. When the water level rose to 156 m and remained at that level until the time when reservoir water level started to go up to 175 m, seven other collapses occurred. When the water level went to 175 m and remained at that level until the time when reservoir water level started fluctuating (Fig.5), there were five additional collapses. The development of failure process of the landslide is shown in Figure 9 and demonstrated in Figure 10.

Table1 Physical properties of the slide mass for physical modeling

Composition	Compact bulk density (g/cm^3)	Apparent density (g/cm^2)	Porosity (%)	Water content (%)	Remark
20% sand+80% clay	1.8	2.60	30.8	15.0	Fine sand< 2.0mm

4. Failure Mode and Mechanism of the Landslide

In light of the results of above tests and analyses, the take-off point of deformation and failure of the landslide was in the front of the landslide during the course of reservoir water level impoundment. A partial small collapse happened at first, which caused a free-face to appear in the back part of the slide mass. When the reservoir level continued to go up, a new collapse occurred; with the reservoir water level going up, the slide mass slid part by part from the front to the back (shown as Figure 9 and Figure 10), and at last, the whole slide mass failed. The failure phenomenon of the landslide after 135 m water level impoundment can be seen in Figure 11.

During the course of impoundment of Three Gorges Reservoir, The underground water table in the foreside of the slope increased with the reservoir water level (shown as Figure 12), and the pore water pressure of the front part of slide mass which was under the reservoir, increased, which causes the soil structure under the underground water table to become broken. Meanwhile, the shear strength of this part of slide mass near the reservoir water level decreased, which made the slide mass near the reservoir water level fail.

5. Exploration of the Failure Mode of Other Landslide Similar to the Landslide

The failure mode of the landslide is attributed to three factors: the first one is fluctuation of reservoir level, the second one is the composition of slide the mass (which is debris and is easily broken when it is exposed to the reservoir water) and the third one, a slip surface, is a gentle incline and regular. If the three factors mentioned above are present in the other old landslides in the Three Gorges Reservoir Area the failure modes of the landslides should be expected to be characterized by the mass sliding part by part, from the front to the back.

Acknowledgments

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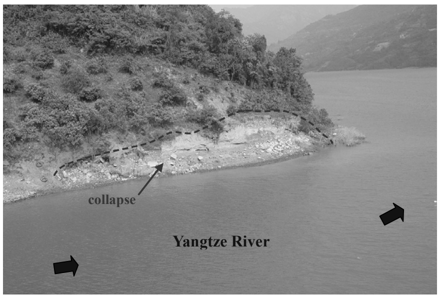

Fig.11 Partial collapse of the landslide after the 135m water level impoundment

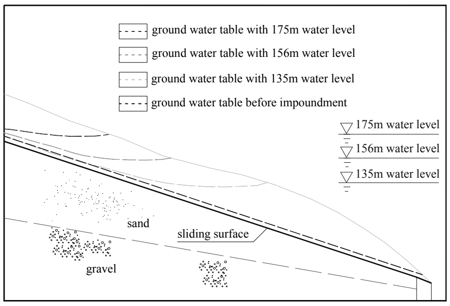

Fig.12 Underground water tables with different reservoir water level

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New Challenges of Safety Monitoring of Rock Slopes: The Third Wave

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Abstract. Multi-dimensional phase space analyses and nonparametric modeling of propagations of system trajectories through multi-dimensional spaces have been used to enable automated evaluation of big amounts of monitoring data from unstable rock slopes. They have shown a substantial increase in pattern-recognition ability of monitoring signal analyses – i.e. an increased diagnostic sensitivity, and more realistic results of modeling of those patterns then any regularly used idea- and data-driven methods.

Keywords. precursor diagnostics, rock fall prediction, complex systems theory. multidimensional phase space analysis,

1. Introduction

Any analysis of signals by landslide displacements, whether they are supposed to be produced by deterministic or stochastic process is based on fitting them to some model. In current engineering geology, there are two classes of models – the idea driven models of geomechanics (deterministic or linearly stochastic), and the data-driven ones. The main point of the latter is that they are strictly based on real observable – i.e. they do not need any preliminary assumption about causal mechanism of the process in question as the idea-driven ones.

Many natural information sources are generally considered to be intrinsic nonlinear nowadays (e.g. Turcotte 1997, Sivakumar 2004), i.e. systems producing highly correlated time series, which are not adequately modeled under typical statistical assumptions of linearity, independence, and identical distributions. Therefore, the current, mathematically sound but by linear Newtonian physics and current statistics driven geomechanical models has often shown themselves to be rather unsatisfactorily in their comprehension of complex reality. Valuable information embedded in time series, which existence was even indicated by patterns, that were visible by an unaided eye, was completely hidden from the linear analytic methods (e.g. Kantz, Schreiber 1997, Zvelebil 1998).

Empirical-phenomenological, mainly qualitative, rather ineffective, and only by experts operable models of the first wave have been step by step replaced by new generations of soundly mathematically-physically on theory of complex systems (e.g. Bossomaier, Green 2000). based models. Those models can be put into computer algorithms to tackle with even increasing amounts of data produced by computer operated monitoring systems to enable speed of data evaluation, which meets the data acquisition one, and to unfold some of the hidden information.

During the second wave, monitoring time series were scrutinised numerically to filer out all meteorologically derived noises out of the signal to reveal their intrinsic dynamics of slope failure process (Paluš *et al.* 2004).

The third wave has been characterized by a revival of ideas about dynamics as geometry (Abraham, Shaw 1992), i.e. tools of mathematical topology has started to be used.

2. Methodical remarks

An unstable slope should be modelled as a non-equilibrium, complex, self-organizing, and dissipative system (cf. Zvelebil 1988, 1998). This type of system should feature two qualitatively different stages of its instability, as defined by Priggogine and Stengers (1984).

'Near-to-equilibrium' (NTE) instability corresponds with stationary state – i.e. with convergence of system dynamics to a limit cycle producing minimal entropy. This stationary state is independent to initial conditions, but fully dependent to boundary conditions. Any responses to perturbations of such system are reversible and behaviour of the perturbed system is pointed back to the stationary state. Behavior of NTE systems is predictable, even with regards to the changes of boundary conditions. In the field of slope dynamics, the NTE state should be represented by time series exhibiting irreversible, long lasting slope movement deformation, which embodies a long-time linear trend and reversible auto-regulations of perturbed states.

The *'far-from-equilibrium'* (FFE) dynamics can response to some perturbance by self-sustaining amplification of that perturbance so that sometimes it can overpower the whole system and force him to produce new, behaviour qualitatively different from its predecessor. That behaviour is unpredictable by classical thermodynamic means, which can be applicable to NFT systems. The FFE stage should stand for the final, from months to a few years lasting stage of rock fall preparation process. This stage is characterized by the highest risk level of rock fall occurrence (e.g. Zvelebil, Moser 2001).

All data used in this paper have come from systematic, long-lasting, safety monitoring of sandstone rock slopes in NW Bohemia, Czech Republic (e.g. Zvelebil, Nechyba, Paluš, 2008). To avoid of any possible distortion of intrinsic dynamics by the filtration process, raw monitoring signal has been used as inputs of the implemented models.

3. Phase space construct and its analyses: Increasing Sensitivity of Computerized Diagnostics

Any individual measurement of slope displacement can be taken as a representant of an individual state of slope system (N) at time of measurement (t). Then the variability of such states as represented by the data sequence of monitoring record are called *dynamics of the system*. All theoretically possible states of the system, including as the states already observed, as well as the ones only possible but not yet observed, form *state space of that system*.

Any *state of the system* is represented by a single point that is defined by its coordinates (values of its variables) within its *state space*. *State space* is defined as an abstract, multi-dimensional space, whose axes are given by all variables of the dynamical system in question. The change from the state (N_t) to the nearest following one (N_{t+1}) is called *trajectory of the system in its state space.*

To describe dynamics of the system, one has to describe geometry of all trajectories by which the system states propagate themselves through its state space – i.e. *to make a state portrait of that system*.

State space can be theoretically unbelievingly vast. Nevertheless, state portraits usually occupied only a tiny section of that vastness, making a cluster of concentrated state points, there. This point cluster represents all characteristic patterns of the real behavior of the system. The densest part of that cloud, which establishes the basic pattern and to which all trajectories are more or less drawn-attracted, forms its center and is called *attractor* – the basic patterns of system behavior. The gauzily part of the cloud, which still remains under gravity of this basic pattern, is called the *basin of attractor*. It represents behavior not so frequent, nevertheless, repeating is some similar form at least sometimes.

The main point of the state space models is, that - thanks to mathematical work by Takens (1981), *state space of any dynamical system, even if the exact mathematical description of that system is not known, can be principally reconstructed from its observable.* Formally, when the state space is reconstructed from time series observable rather than from actual variables of underlying system, then such construct is called *phase space*.

Phase Space Model of landslide dynamics can express all its important patterns and to follow their changes in time (reconstructing their attractor) using only one variable delivered by monitoring time series.

Knowledge of the characteristic features of the Phase Space Model construct can be used: x) *To fix basic type of underlying dynamics*. There are several groups, which contract each other by typical phase space topology – i.e. by attractor geometries. They represent collections of similar but not necessary equal types of system dynamics (do not confuse the latter with mechanisms) producing them (e.g. Abraham, Shaw 1992). xx) *To spot hidden deterministic patterns* that are, as illusory white noise by random behavior, hidden from detection ability of current analytical tools based on linear mathematics. xxx) If there is some degree of determinism, f*uture can be predicted from the past featured by an embedding map of phase space* (e.g. Kantz, Schreiber, 1997), because the latter preserves the structure of original underlying dynamic.

For reconstruction of phase space, *time-delay embedding of time series* is commonly used (ibid). Nevertheless, to construct a well-behaved Phase Space Model – i.e. the one, which best reveals the dynamical futures of the system in question, a proper choice of the time delay τ and the embedding dimension M is critical.

From the point of view of user, there is an antagonism of demands: On the one hand, regarding the fidelity of model to complex process of slope failure development, the multi-variable, outer perturbance accounting, methodically more demanding model should be used. On the other hand, regarding its practical use - the model tool should be as simple as possible.

3.1. Visual Analysis of Low-Dimensional Phase Portrait

The critical choice of construction parameters is simple for the 2D and 3D phase portraits. Both, time delay τ and M $(M=2$ or $M=3)$ can be approximated aiming the best/most synoptic view of phase trajectory for the time series in question. If the former does not work well - i.e. we are still facing the inadequately-behaved visualisation (more than three variables are dominating the dynamical changes), then time for high-dimensional portrait is coming.

In spite of several theoretical and practical weak points, even the simple phase portrait of the “raw”, i.e. noise biased data can reasonably help to ensure safety against an unexpected slope collapse.

Fig. 1.2 presents visualization of the distinct manifestation of critical state of transition from the NTE to FFE state. There are several points of that type of visualization:

- The clustering of systems states around the attractor makes phase portraits of time series more synoptic than the current, still prevailing Cartesian time-displacements plot, especially when long time series have to be studied. All characteristic patterns are visually well defined. Any system trajectory which repels off the central cloud of attractor distinctly marks an aberration of that typical behavior.
- This higher, diagnostically profoundly important sensitivity of the simple 2D phase portrait of raw monitoring data is obvious in a comparison with the currently used Cartesian plot of the same time series (Fig. 1.1).
- In comparison with empirical-phenomenological model and Cartesian plot, the Visual Analysis of 2D Phase Portrait presented one year earlier ability to detect the NTE/FFE transition.

Possibility of automated detection of the NTE-FFE transition and early warning launching: An envelope of the segment of the phase space occupied by a thin-bodied clustering of the trajectories forming the NTE attractor can roughly represent a boundary of NTE attractor basin (γ in fig. 1.1). That boundary could be defined as a warning threshold, and then crossing of that threshold can be automatically, in-real-time continuously checked by a simple computer algorithm, which can eventually switch an automated launching of early warning on.

3.2. Recurrence plot analysis of High-Dimensional Phase Portrait and Nonparametric Prediction of System Trajectories

It is impossible to directly assess attractor geometries in more then 3D. They are viewed indirectly as transformed into recurrence plots.

Recurrence plot visualizes the recurrence behavior of the trajectories of dynamical system as they progress through the predefined part of their nD phase spaces. Each passing that part of nD space makes a point in the Recurrence Plot. The dots of trajectories passing nearby each other then come fall to groups to make bigger areas with some geometrical patterns. The denser, distinct, and more spatially reaching is the pattern, the more similar and more times repeating is the corresponding behavior of the system.

Recurrence plot is not as straightforward as it is with other, "conventional" types of graphs. Its analysis and interpretation requires some experience and care. Nevertheless, there are *etalon recurrence plots* from paradigmatic systems. Pre-defined categories of both, large- and small-scale patterns of Recurrence Plots are used to identify individual characteristic typologies of embedded dynamics (for more information see Marwan et al. 2007) .

There are several software packs available for construction of recurrence plots: Command-line, Recurrence Plots, Dataplore 2.2, TISEAN 3.0.1, etc. Software Pack VRA 5.1. by Konov (2007) was used for this paper. It is as simple, user-friendly, nevertheless, powerfully designed, as well free-downloadable to be at the disposal (www.myjavaserver.com/~nonlinear/vra/download. html).

VRA 5.1. uses the modified Recurrence Plot – the Distance (Global Recurrence) Plot. Therefore, its plot does not express the real recurrence within the predefined space as digitally expressed but a relatively quantified distance. Thus, a plot of calibration scale is an inevitable part of such Recurrence Plot. The L_2 – (Euclidean) and L_∞ – (Maximum/Supremum) norms were implemented for this paper when using VRA 5.1. The L_∞ – norm was rather stressed, because it is computationally faster and allows studying some Recurrence Plot's features analytically.

The proper choice of the time delay τ and the embedding dimension M was done using two methods, both of them provided by the VRA 5.1. menu.

For primary approximation of lag τ for proper time-delay embedding, *Average Mutual Information function* was used; for embedding dimension M, method of *False Nearest Neighbors* was applied.

When some degree of determinism is revealed by the first approximation plot, the time-lag τ and the embedding dimension can be fine tuned by nonparametric prediction of system trajectories. The best prediction ability of individual recurrence plots, which differ each other in τ and M, is searched for.

Figs 2-3,4 present two Recurrence Plots made for the time series documenting the NTE-FFE transition, which was already plotted in Fig.1.

The 2.3 recurrence plot represents the first approximation of the time-lag τ and the embedding dimension M by Average Mutual Information and False Nearest Neighbors procedures. The 2.4 graph states for the Recurrence Plot, which τ and M were fine tuned by the nonparametric prediction making.

In comparison with the low-dimensional Phase Space construct, the high-dimensional ones when interpreted with the use of Visual Recurrence Analysis has brought even higher diagnostic sensitivity to detecting of the NTE-FFE transition:

- The detection by 4D Recurrence Plot shows first precursors at 450 samples – i.e. approximately 1.17 year before the final fixing of the transition state by the means of 2D Phase Space Portrait. The confirmation of that state becomes at interval from 520 to 550 samples – i.e. from 0.3 year before, till the same time as by the 2D Phase Space Portrait construct.

The fine tuned, 25D Recurrence Plot, which has taken into account even fine fluctuations of the monitoring signal, arrived to horizon of 350 samples to fix the first precursor (another 1.17 year before the precursor fixing by 4D recurrence plot), and 450 samples for the final fixing - i.e. or 2.34 years before the fixing ability of both, as the 4D Recurrence Plot, as the 2D Phase Space Portrait, or 3.34 years before the fix by empirical-phenomenological model).

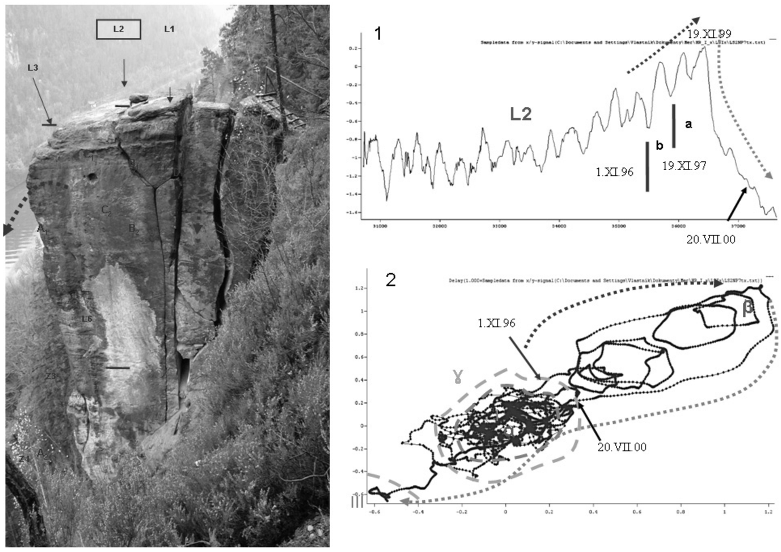
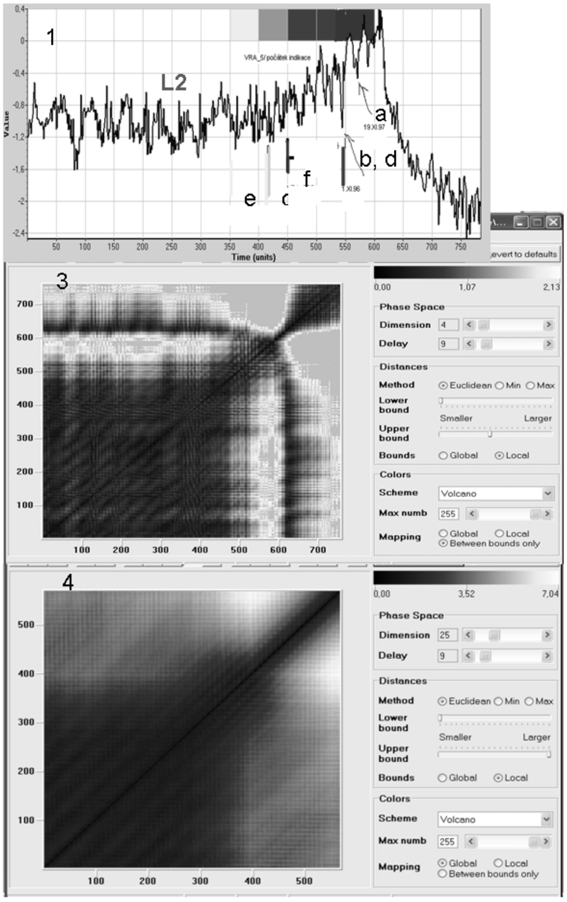


Fig. 5 Regular time–displacement Cartesian plot (1) and phase portrait (2) of time series from the site L2 show the transition from (α) near-to-stability (NTS) to (β) far-from-stability (FFE) states of slope system dynamics. The time–displacement plot enabled us to empirically detect markers of the NTE–FFE transition in November 1997 (a), whereas the 2D Phase Space Model (b) allowed us to detect this same information one year earlier, when a state trajectory heading out of the NTE attractor was clearly defined.



Phase Space
Dimension 4
Delay 9
Distances
Method ● Euclidean ○ Min ○ Max
Bounds ○ Global ● Local
Colors
Scheme Volcano
Max numb 255
Mapping ○ Global ○ Local ● Between bounds only

Phase Space
Dimension 25
Delay 9
Distances
Method ● Euclidean ○ Min ○ Max
Bounds ○ Global ● Local
Colors
Scheme Volcano
Max numb 255
Mapping ● Global ○ Local ○ Between bounds only

Fig. 2 Regular time–displacement Cartesian plot (1) and recurrence plots of time series from the site L2. The first approximation of the time series dynamics by 4D Phase Space Portrait and its Recurrence Plot (3) have provided the first precursors (c) of NTE-FFE transition at 450 samples – i.e. approximately 1.17 year before the final fixing of the transition state by the means of 2D Phase Space Model (b; cf. fig. 10), and the final fixing in the interval from 520 to 550 samples – i.e. from 0.3 year before, till the same time (d) as by the 2D Phase Space Model construct. The finely tuned 25D Phase Space Portrait and its Recurrence Plot (4) have brought sensitivity able to fix the first precursors (e) at 350 samples – i.e. another 1.17 year before the 2D Phase Space Model fix, and the final fix (f) at 450 samples – i.e. 3.34 years before the empirical-phenomenological fix.

4 Conclusions

I. State Space model can be considered as a pure, data driven model.

II. Our findings realised by the phase space construction methods have supported authors' earlier expectations and partial findings done by the nonlinear, numerically based methods (Paluš et al 2004) that: a) Dynamics of preparation of rock slope collapse can be successfully modelled as dynamics of complex, highly interactive, non-equilibrium, self-organizing system. b) The qualitative difference between fluctuation patterns of NTE and FFE time series is possible to identify not only by numerically based nonlinear methods but also by phase space construct. c) State Space based analyses can assist the nonlinear numerical methods as the second, methodically independent method for earlier unravelling precursors of the NTE-FFE transition. That unravelling is always prior to the one by currently used empirical-phenomenological model: α) 2D phase space construct make possible the identification 1 year earlier; β) Numerical tests of intrinsic slope movement permit the identification even 2 years earlier .- i.e. 1 year before 2D phase space construct; γ) The recurrence plot of high-dimensional phase space enables the same sensitivity like 2D phase space portrait, when the first approximation of time-lag and embedding dimension is used (4D portrait). When it is fine tuned (25D portrait), it can facilitate even 3.34 years before the empirical phenomenological fix.

III. All the new findings have to be considered as the preliminary ones due to: X) Need to be backed by more supporting results. Xx) Possibility to be improved or modified in the process as of optimization of the used methods, as of looking for and implementing of another, from the point of view of nature of the monitoring data suitable methods.

3. Acknowledgement

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