Liquefaction-induced Ground Failures and Displacements along the Shiribeshi-toshibetsu River Caused by the 1993 Hokkaido-nansei-oki Earthquake

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ABSTRACT

Widespread and large-scale ground failures due to liquefaction occurred along the river valley of the Shiribeshi-toshibetsu River during the 1993 Hokkaido-nansei-oki Earthquake. By using the aerial photographs taken one day after the earthquake along the river, ground failures such as ground fissuring related to lateral spreading, sand boils and associated settlement were investigated, and the ground displacements both horizontal and vertical were measured by comparing the pre- to post- earthquake photographs. Horizontal displacements ranging to 1 to 3m were measured throughout the area that liquefied. The surface ground moved along a very gentle slope toward crescent lake or channel in most cases. Soil surveys were also conducted in the area where the large ground displacement occurred, which showed a fine and very loose sand deposit existing 2 to 5 m in depth below the ground surface.This paper summarizes the preliminary results of the investigation conducted so far for the above mentioned area.

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INTRODUCTION

An earthquake occurred on Monday, July 12, 1993 approximately at 10:17 p.m. (Japan Standard Time) beneath the Sea of Japan off the Oshima Peninsula in Hokkaido, registering the magnitude of 7.8 in JMA Scale. The earthquake was named as the 1993 Hokkaido-nansei-oki Earthquake. This earthquake caused a tsunami which swept the coasts of the Okushiri Island and the Oshima Peninsula on the Sea of Japan causing over 300 dead and missing.

At the same time large scale ground liquefaction occurred in the alluvial lowlands along the coasts of the Sea of Japan and the Pacific Ocean, causing damages to roads, harbors, housing, lifelines and farm lands. The liquefaction can be described as widespread and large scale but did not cause large scale damages to structures despite its scale, due to the lesser degree of urbanization in the area. Major damages of the liquefaction by this earthquake consisted of damages to the Port of Hakodate, and to the fishing harbors along the coast (both reclaimed lands), damages to buildings and lifelines in Oshamanbe and Kamiiso, etc., to the levees of the Shiribetsu and Shiribeshi-toshibetsu Rivers, the road damage on Route 5 mostly between Kunnui and Oshamanbe plus the agricultural damages in the region.

On July 20, 1993 the author investigated the earthquake damages along the Shiribeshi-toshibetsu River in Kitahiyama which is located on the coast of the Sea of Japan. At that moment it had already been reported that the levees and dikes of the Shiribeshi-toshibetsu River had largely been damaged and that liquefaction had occurred in the farming lands. Makeshift repairs on the levees of the Shiribeshi-toshibetsu River was under way in full scale, thus preventing him from seeing the actual damages to the embankments in most sites. Nonetheless, there were large, systematic fissures in the fields and rice paddies with much sand boiling, and it was presumed that large scale liquefaction and accompanying ground deformation, i.e. lateral spreading and ground settlement had set in.

During the Annual Meeting of the Japan Society of Civil Engineers held in September of 1993, a "Meeting on the Update of the 1993 Hokkaido-nansei-oki Earthquake Damages Investigation" was held. During this session Hirano and Shimizu[1)] demonstrated aerial photos of the Shiribeshi-toshibetsu River taken a day following the earthquake and reported on the damages to the levees. The photos demonstrated that large-scale liquefaction and ground deformation had occurred in the surrounding agricultural lands in addition to damages to the levees.

Then the author and Prof.Hamada of Waseda University examined the aerial photographs at the Hokkaido Development Agency and investigated the sites based on this information in September 1993. It became clear that large-scale liquefaction and accompanying ground deformation had

occurred in the river basin. Repair works for the agricultural lands started by borrowing soil immediately after our investigation was conducted, thus erasing ground deformation in most areas.

Ground liquefaction occurred mostly in rice paddies and cultivated fields along the Shiribeshi-toshibetsu River, in contrast to Noshiro City during the 1983 Nihonkai-chubu Earthquake and Niigata City during the 1964 Niigata Earthquake, almost devoid of ground structures to serve as aerial survey marks. On the other hand, sand boils and fissures were photographed visibly on rice paddies and cultivated fields, presumed important future data base for the study of ground deformation patterns and mechanisms.

The present study started under these circumstances involving collection of aerial photos taken before and after the earthquake and aerial photo survey based on them, collection of maps from the past and present, collection of information on boring data of grounds including levees, understanding of ground conditions for areas with marked deformation. This report has been put together with the objective to record the history of the Shiribeshi-toshibetsu River basin and changes in the topography and grounds based on the results of these investigations.

EARTHQUAKE AND EARTHQUAKE GROUND MOTION

Figure 1 shows the epicenter, approximate aftershock zone and the location of the Shiribeshi-toshibetsu River. The hypocenter is situated on the borderline between the Eurasian and North American Plates, on a reverse fault by east-west compression. The earthquake is said to be of a similar type to the 1983 Nihonkai-chubu Earthquake with magnitude 7.7. The aftershock zone encompasses an oval of 200 km north-south and 100 km east-west with the magnitude of 7.8 in JMA scale. The depth of the hypocenter is said to be approximately 30 km.

Figure 1 also shows the maximum horizontal acceleration. These earthquake ground motions were observed by the Japan Meteorological Agency, Hokkaido Development Agency and Railway Technical Research Institute. Based on this data Figure 2 shows the relationship between the maximum horizontal acceleration and the epicentral distance. It demonstrates that the attenuation of maximum acceleration is somewhat fast in comparison with other earthquakes in Japan. Figure 3 shows the records of strong motion by the Railway Technical Research Institute at Oshamanbe and Yakumo near the Shiribeshi-toshibetsu River. Both were recorded on an alluvial plain with the epicentral distance of approximately 100 km while the distance from the fault is approximately 50 to 60 km. It is assumed from these observations that the Shiribeshi-toshibetsu River basin was exposed to ground shaking of at least 200 to 300 cm/sec^2 in acceleration.

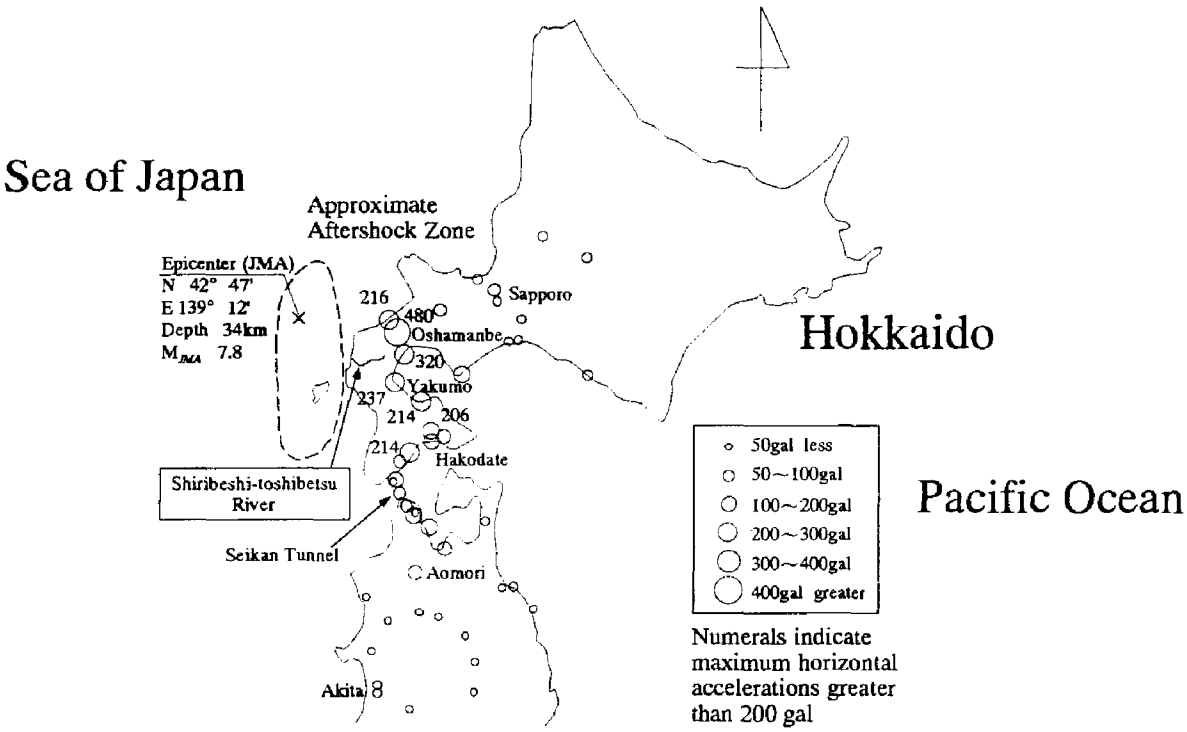


Figure 1 Epicenter of the 1993 Hokkaido-nansei-oki Earthquake, Maximum Horizontal Accelerations Observed[2] and the Location of Shiribeshi-toshibetsu River

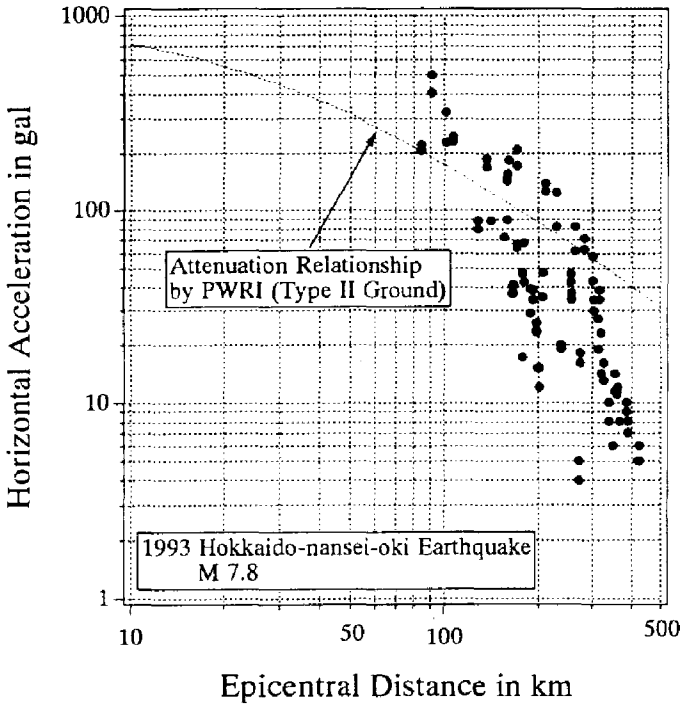
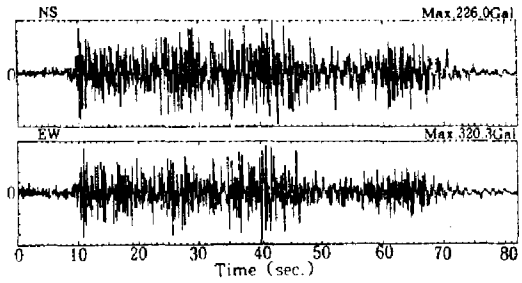
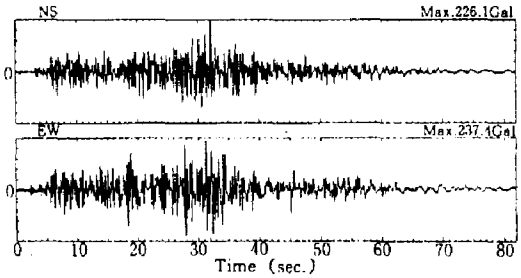


Figure 2 Attenuation Characteristics of Maximum Horizontal Accelerations (A Line in the Figure Indicates an Attenuation Relationship by PWRI[3] for Type II Ground)



(a) Oshamanbe (Alluvium, Δ = 101 km)



(b) Yakumo (Alluvium, Δ = 106 km)

Figure 3 Strong Motion Records by Railway Technical Research Institute[4] (Δ :Epicentral Distance)

Substantial damages to structures by the ground shaking were very few at Kitahiyama, Setana and Imakane Cities along the Shiribeshi-toshibetsu River. (The authors confirmed that a collapsed house at Kitahiyama had an apparent structural problem.)

OUTLINE OF TOPOGRAPHY AND GROUND CONDITION

Figure 4 shows the topography of the area along the Shiribeshi-toshibetsu River. The Shiribeshi-toshibetsu River originates in the divide between the Sea of Japan and the Pacific Ocean and flows into the former with the course length of approximately 80 km. It meanders down to Imakane in the midstream along a narrow gorge and straightens out to a relatively linear form at Imakane. The straight course from the midstream down is a result of large-scale river improvement work, very popular from the 1950s. The river has levees on both sides from the midstream to the river mouth.

The lowland, along the Shiribeshi-toshibetsu River, is 3 km wide at Imakane and 4 km at Kitahiyama on the midstream, and was presumably formed relatively recently by repeated floods of the Shiribeshi-toshibetsu River. The towns of Imakane and Kitahiyama are built on relatively elevated areas. The ground of the lowland is of thick alluvial ground consisting of sandy soil and clay with the exception of partial peat ground to the south. So-called bedrock with the N value of 50 or more appears at the depth of approximately 70 m from the ground surface and is made of extremely soft and deep alluvial ground. Especially there is an extremely loose sand layer with N value of 1 to 3 at the depth of 1 to 5 meters under the ground surface.

The areas where liquefaction occurred are also shown in Figure 4. As shown in the figure, the topography of the river basin and occurrence of liquefaction are closely related to the meandering of the Shiribeshi-toshibetsu River. Figure 5 shows a topographical change of the area from 1890s to the present based on the topographical chart to the scale of 1/50,000 by the Geographical Survey Institute. It is evident that the river has changed its course considerably over the years. As mentioned earlier, riverine improvements were undertaken after the 1950s, making the river linear from the midstream down. These improvements left the old river bed forming the present crescent lakes and small waterways (see Figure 4). It seems that the old river bed which exists in the current topography roughly corresponds to the river bed of 1917. However, there are many spots where the old river bed have been reclaimed leaving no trace of it in the current topography.

LIQUEFACTION AND GROUND DEFORMATION

Figure 4 shows the area where a ground deformation occurred interpreted by using aerial photos of the investigated area taken after the earthquake. Attention should be paid to the fact that the aerial

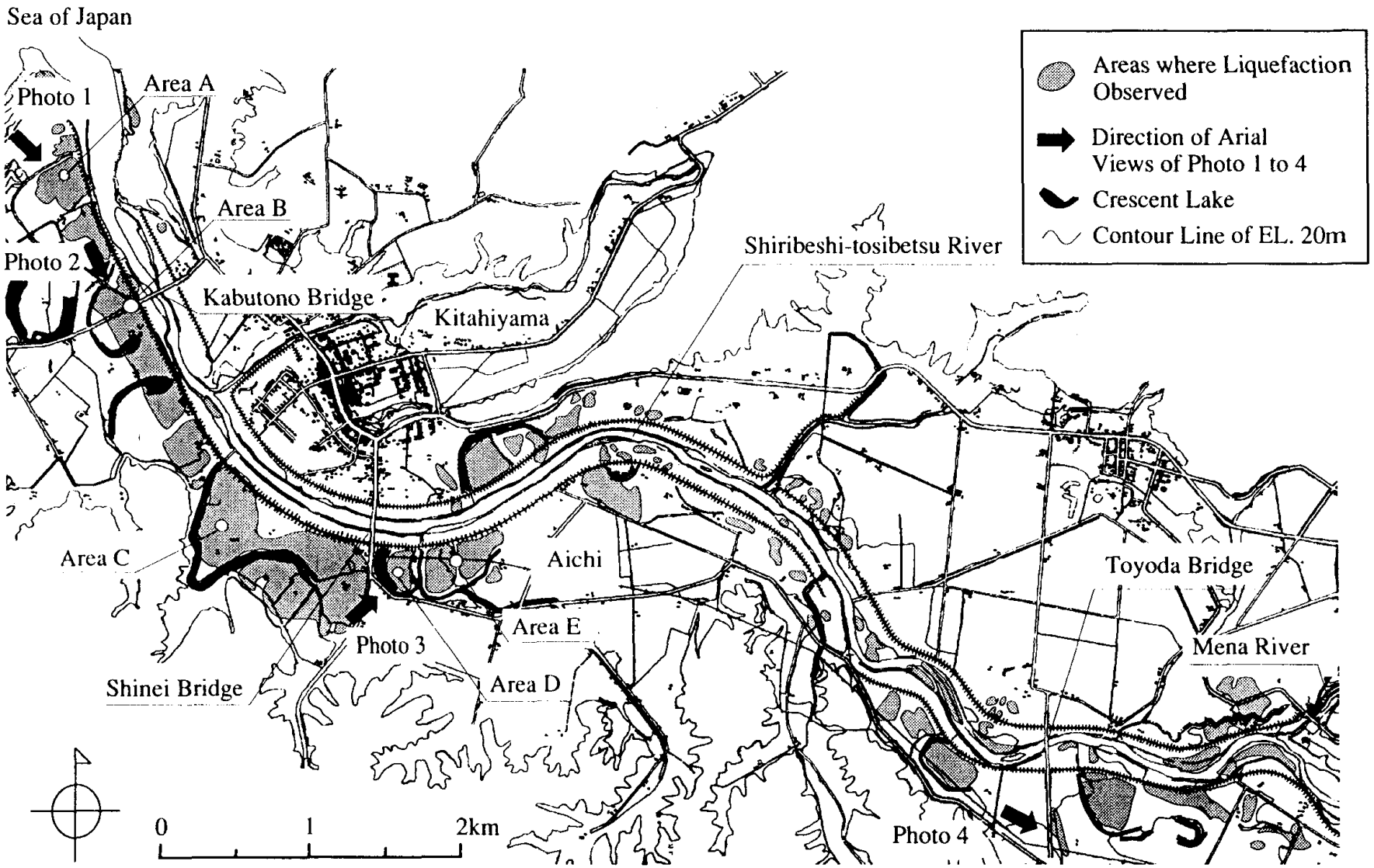
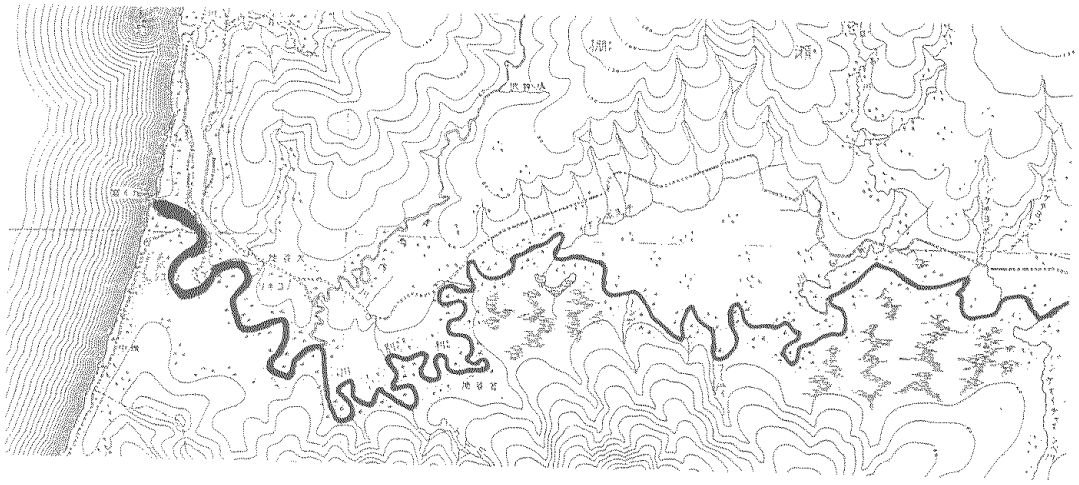
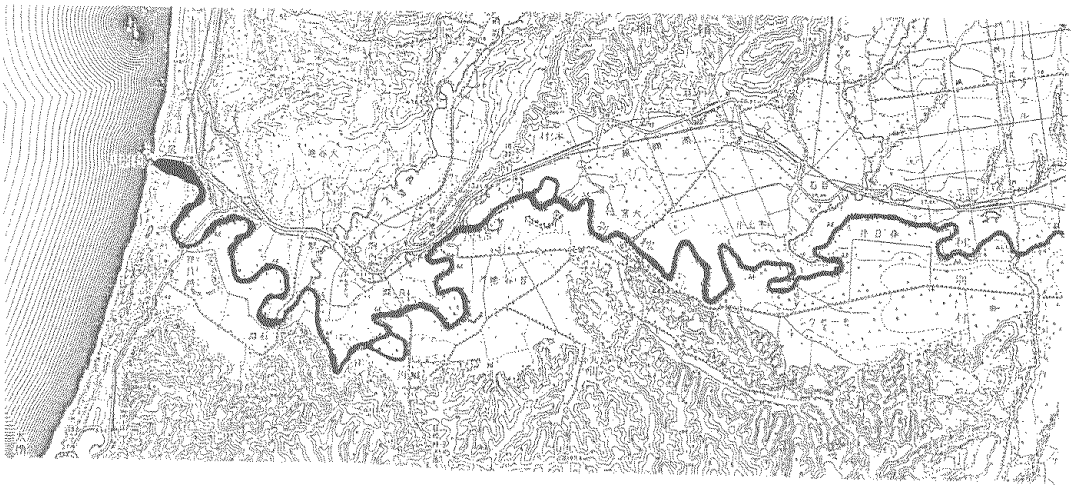


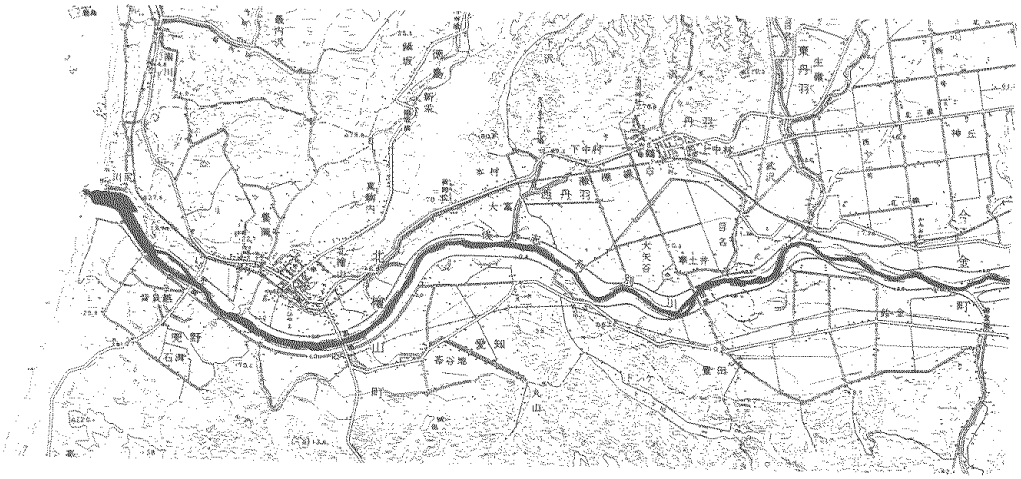
Figure 4 Siribeshi-toshibetsu River and Areas where Liquefaction Observed by Aerial Photograph



(a) 1896 0 5km



(b) 1917



(c)1992

Figure 5 Chronological Change of River Course of the Shiribeshi-toshibetsu River

photos were taken for a damage assessment on the levees and they do not cover all of the surrounding lowland areas. However, most of the areas where severe liquefaction occurred are covered by these photos.

It is evident that the ground deformation occurred from the river-mouth of the Shiribeshi-toshibetsu River up to Suzukane area, approximately 12 km upstream. Liquefaction is prominent on the left bank in the downstream area but occurred on both sides upstream of the Shinei Bridge on Route 229. Deformation is especially prominent on the left bank from the river-mouth to upstream of the Shinei Bridge and in the area from the Toyoda Bridge to the confluence of the tributary Mena River. Typical areas are shown in slanted photographs in Photos 1 to 4. Figure 4 shows overall orientation for these slanted photos.

Interpretation of Deformation

Aerial photos were taken on July 13, 1993, the following day of the earthquake by the Hokkaido Development Agency for assessing damages to the levees. Vertical photos taken were at scales of 1/4,000(altitude 600 meters)and 1/2.000(altitude 300 meters). At the same time, several slanted photos were taken of the river basin(Photos 1 to 4).

Ground deformations were interpreted by experts as ground fissures, sand boiling, water surface (flooded areas) and were plotted on the four topographic charts (1/2,500 scaled) prepared by the Hokkaido Development Agency in 1984.

Aerial Photo Survey

Ground deformations or horizontal and vertical displacements caused by the earthquake were surveyed through comparison of aerial photos taken after the earthquake with those taken before the earthquake. Methods of survey were the same as those employed by the authors at Noshiro and Niigata[5]. The pre-earthquake photos were taken ten years ago in 1984 by the Hokkaido Development Agency.

In order to survey ground deformations by earthquake with aerial photographs taken before and after the earthquake, reference points are required for identification. There were very few such points in the affected area as compared to Noshiro and Niigata. The measurements of displacements must be made for points which are fixed to the ground surface and can be found in both pre- and post-earthquake photos. Ridges between rice paddies, roads, electric poles and roofs of houses, recognizable before and after the earthquake, were used as reference points in this survey.

The accuracy of ground displacement measurements depends on the scales of the pre- and post-