

## Learning from Earthquakes

# The Kashmir Earthquake of October 8, 2005: Impacts in Pakistan

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House. This report summarizes the salient portions of the information gathered during the visit.

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## Introduction

On October 8, 2005, at 8:50 a.m. local time, a magnitude  $M_w = 7.6$  earthquake struck the Himalayan region of northern Pakistan and Kashmir. The earthquake epicenter was located approximately 19 km north northeast of the city of Muzaffarabad, the capital of the Pakistani-administered part of Kashmir, known as Azad Jammu Kashmir (AJK).

The Pakistani government's official death toll as of November 2005 stood

at 87,350, although it is estimated that the death toll could reach over 100,000. Approximately 138,000 were injured and over 3.5 million rendered homeless. According to government figures, 19,000 children died in the earthquake, most of them in widespread collapses of school buildings. The earthquake affected more than 500,000 families. In addition, approximately 250,000 farm animals died due to collapse of stone barns, and more than 500,000 large animals required immediate shelter from the harsh winter.

It is estimated that more than 780,000 buildings were either destroyed or damaged beyond repair, and many more were rendered unusable for extended periods of time. Out of these, approximately 17,000 school buildings and most major hospitals close to the epicenter were destroyed or severely damaged. Lifelines were adversely affected, especially the numerous vital roads and highways that were closed by landslides and bridge failures. Several areas remained cut off via land routes even three months after the main event. Power, water supply, and telecommunication services were down for varying lengths of time, although in most areas services were restored within a few weeks.

Massive landsliding was a particular feature of this event. A very dense, high-frequency band of landslides was triggered along the fault rupture trace in the midslope areas; however, it quickly dissipated with distance away from the fault rupture zone. Almost all landslides were shallow, disaggregated slides, with two of them larger than 0.1 km<sup>2</sup>. Due to the generally arid landscape, liquefaction was not observed or reported by others.

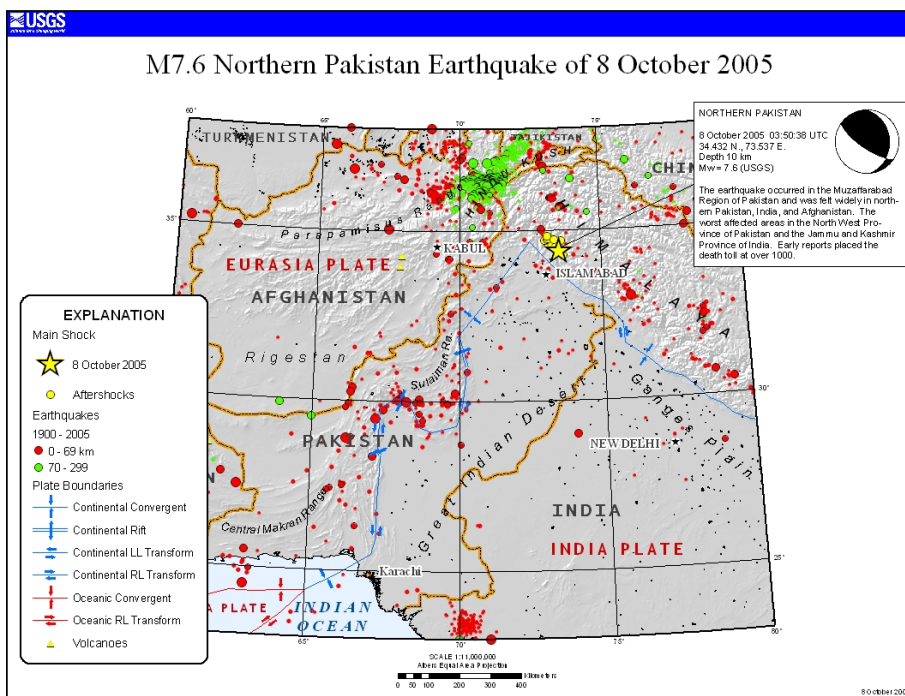
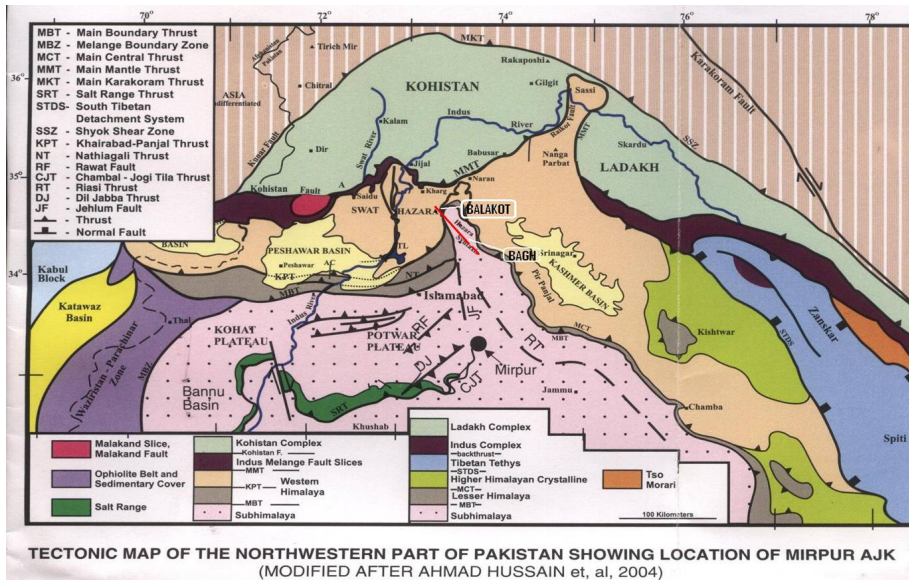


Figure 1. General location map,  $M_w = 7.6$  Kashmir Earthquake



**Figure 2.** Tectonic map of northwestern Pakistan (Hussain et al. 2004).

## Seismotectonics

Seismic activity in South Asia is a direct result of the collision of the Indian and the Eurasian plates, which results from the northwestern motion of the Indian Plate at the rate of 4-5 cm per year (Figure 1). The resulting collision has fractured the Indian plate into several slices beneath the Kashmir Basin and is known as the Indus-Kohistan seismic zone (Seeber and Armbruster 1979).

The earthquake occurred within the Hazara-Kashmir syntaxis of the Himalayan fold belt. The main identified feature in this zone is the Balakot-Bagh fault (Hussain 2005), which is the likely source of the earthquake (Figure 2). The fault plane solution shows a strike of 338 degrees, dipping about 50 degrees in the N-NE direction near the surface with a more gentle dip at depth. Net slip for this event, estimated by field survey and radar range changes, is  $4.2 \pm 0.5$  m, with a maximum slip of approximately 5 m. The reported focal depth for this event ranges from 13 km (MSSP), to 20 km (USGS), to 26 km (IGS).

The intensity distribution estimated and interpreted by the Pakistan Geological Survey is closely associated

with the rupture zone. Outside the narrow (5-10 km) width of the rupture zone, the signs of damage appeared to be fairly minor. While there was damage in more distant locations such as Abbotabad (35 km from rupture zone), Islamabad (64 km), and Lahore (> 250 km distant), it can be attributed to local site effects or poor construction rather than direct intense shaking from the earthquake. Within the rupture zone, the city of

Muzaffarabad suffered great damage (IX-X on MMI scale), and the city of Balakot was almost totally destroyed (X on MMI scale). The distribution of subsequent after-shocks, in the Balakot, Batagram, Allai, and Beshram Qila areas, suggests that the fault rupture extended in the NW direction.

The surface trace of the causative fault can be interpreted from the map of ground displacements from radar amplitude measurements (COMET 2005). The surface expression of the fault can also be clearly detected in images of lithology change from Landsat data. A 3-D relief projection shows the expression of this fault not only in the surface geology, but also in the surface geomorphology. Figure 3 shows ground deformation that appears to be tectonic in nature, possibly but not necessarily associated with the main rupture trace.

Because of the lack of instrumentation, there are no strong motion records within the zone of intense shaking. Observational data and reports from locals suggest a



**Figure 3.** Localized zone of uplift.



**Figure 4.**  
*Landslide  
concentration  
along mid-  
slopes.*



strong vertical component and 30–45 seconds of strong shaking. Strong motion records in Abbottabad (35 km from rupture zone), Murree (34 km), and Nilore (54 km) show maximum horizontal peak ground accelerations (PGA) of 0.231g, 0.078g and 0.026g, respectively; and vertical PGAs of 0.087g, 0.069g and 0.03g, respectively (MAEC, 2005). Maximum horizontal PGA was 0.16g at the crest and 0.1g at the base of Tarbela Dam (located approximately 78 km distant), and 0.1g at the downstream toe of the Mangla Dam (approximately 90 km distant) were also reported (Ilyas 2005).

## Landslides

Landslide concentrations along the rupture zone were very high, but quickly dissipated within as little as 2 km of the surface projection of the fault. During the aerial reconnaissance of the affected area, landslide damage appeared to be most severe on the hanging wall, with relatively low concentrations on the footwall side. A very high concentration of large and small landslides was observed in the mid-slope area along the surface projection of the fault (Figure 4).

The number of slope failures also increased significantly along slopes

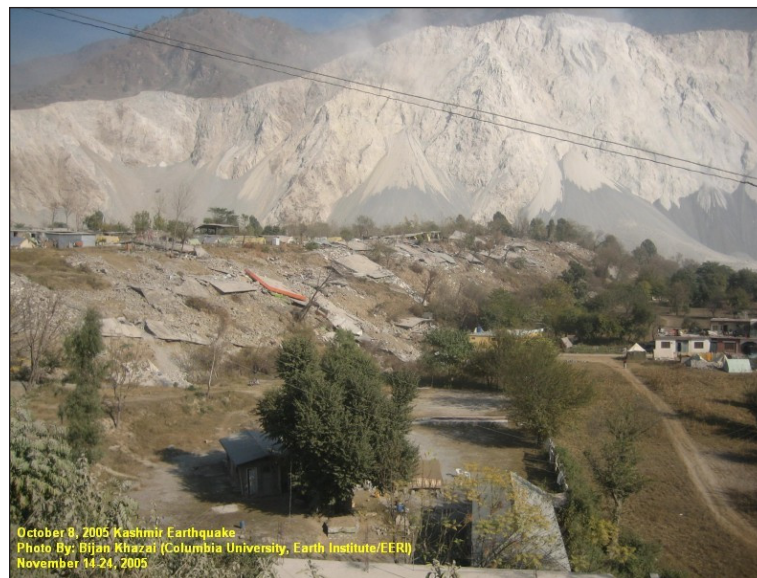
with aspects in the fault-normal direction, showing strong indication of rupture directivity effects. Other effects such as topographic ridge top amplification were widely observed, especially in the case of elongated ridges with steep slopes. In some cases, where the ground motion was perpendicular to the ridge axis, damage was noted on one side of the ridge slope, but not on the other. This variability may be due to active road-building that created a weakness in the direction of total collapse, in addition to the structural/geologic component, thereby adding to the greater susceptibility of one of these slopes.

## Shallow, Disrupted Landslides:

Ubiquitous shallow landslides and rock falls on steep natural slopes and in steep road cuts were initiated during the earthquake. They posed the largest threat to mountain roads and structures at slope bases. Even though relatively small in scale, the shallow landslides had a pervasive nature that significantly contributed to damage caused by the earthquake, particularly in the lower slopes inhabited by large human populations. Many of these slopes, such as along the river terrace in Muzaffarabad, continue to pose a major hazard due to the presence of large tension cracks as far back as 10 m, especially since emergency shelters have been set up in such areas.

The shallow landslides were not associated with specific geologic units and/or type of slopes. They were as deep as the root zone of the vegetative cover, anywhere from several decimeters to a meter deep, and consisted of dry, highly disaggregated and fractured material that cascaded downslope to flatter areas at or near the base of steep slopes.

**Deep-Seated Landslides:** Deep-seated landslides were far less numerous than shallow slides. The



**Figure 5.**  
*Note mas-  
sive land-  
slide in the  
background,  
completely  
collapsed  
structures  
in the fore-  
ground with  
only roofs  
intact.*

two most significant ones (larger than 0.1 square km) were noted in Muzaffarabad and in the Jhelum Valley. The former, located north of Muzaffarabad, occurred in a dolomitic limestone unit that had previously failed and dammed the Neelum River for a day. There was evidence of a pre-existing landslide in this formation that had also dammed the river. The enormous, deep-seated failure in the Jhelum Valley was 36 km southeast of the epicenter and within 3 km of the surface projection of the fault in a jointed sandstone unit. The landslide was over 1 km wide and the distance between the top of the slip surface and the toe of the debris was more than 2 km. (See the special earthquake report insert in the December 2005 *EERI Newsletter* for further discussion of this slide.) The landslide debris created a dam that blocked the convergence of two small rivers at the bottom of the valley.

**Rock Falls:** Rock falls involving large rocks or boulders were common and resulted in considerable damage and disruption to roadways, structures, and communities. Many such slides, triggered by frequent aftershocks, resulted in significant fatalities.

## Structures

Most building damage resulted from ground shaking, though a large number of buildings located mostly on or near slopes were destroyed by ground failure due to landsliding or subsidence (Figure 5). The largest concentration of destroyed or damaged buildings was in Muzaffarabad and Balakot. Other cities such as Bagh and Rawlakot also had significant damage, but were not visited by the EERI team due to limited time. It is estimated that in Muzaffarabad, 30-50% of the buildings were either destroyed or badly damaged in the main event. Major damage concentrations in Muzaffarabad were in areas of deeper allu-



**Figure 6.** Man in front of his sister's house in Muzaffarabad that collapsed and killed her. Masonry bearing wall construction.

vial deposits along the Neelum and Jhelum rivers. Damage in Balakot was directly related to fault rupture. In Abbotabad, damage was due to local site response in the Cantonment area that was reportedly developed on former marshland. Several other towns located along the rupture zone (Bagh to Batagram) also suffered significant damage to their building stock. The widely photographed collapse of the high-rise Margala Towers in Islamabad, located over 80 km from the epicenter, may have been due to construction-related issues.

A helicopter survey revealed that a large number of buildings in the more rural, mountainous areas—perhaps as much as 50% in areas proximate to the fault rupture—were destroyed or severely damaged. These were mostly farmhouses belonging to migratory and non-migratory mountain slope farmers. The government of Pakistan estimates that more than 80% of the total destroyed buildings were located in rural regions.

**Bearing Wall Construction:** Most of the buildings in the affected area are of nonengineered unreinforced masonry (URM) wall construction. The typical structure consists of one or two stories of unreinforced stone, solid brick or solid concrete block masonry-bearing walls with reinforced concrete floors. Roof structures are flat or pitched. Flat roofs in smaller towns and villages consist of wood (non-machined) beams and straw-reinforced mud slabs and occasionally lightly reinforced concrete slabs ("Tayyar Chath") or GI (galvanized iron) sheets. Larger towns have buildings built of reinforced concrete slab roofs. Pitched roof construction, gabled, with or without hips, is framed with wood or light steel trusses with corrugated sheet metal roofing. Tiled roofs can also be found in this region. The smaller villages also contain adobe structures that, as expected, performed poorly in the earthquake.

Foundations are constructed mostly of stones or bricks bearing on native soils about two to three feet





**Figure 7.** Failed column at a storefront showing three aspects of damage: (1) column failure; (2) soft/weak story at storefront; (3) infill walls preventing total collapse of building.

below grade and 18 to 24 inches wide. The only steel reinforcing found in most of the bearing wall construction is in lintels (window or door headers), and normally consists of four #4 bars in a 9 x 9 concrete beam with stirrups or ties at 9-12 inch spacing. Typically, no bond beams are part of the wall and no positive ties exist between the walls and the floors/roofs. The performance of the URM wall buildings in the earthquake was varied and seems to have depended on factors such as redundancy in structural walls and quality of materials and construction (Figure 6).

In areas of strong shaking, most stone masonry-bearing wall structures collapsed or suffered severe damage. A majority of these structures were constructed of non-dressed round stones with mud or weak cement mortar. The weakness of the mortar was clearly evident; the mortar would crumble even when manipulated with bare hands. Issues with concrete block construction were poor block

strength, weak mortar, and lack of seismic detailing. In general, fired-clay brick masonry wall buildings appear to have performed better than the other types of wall construction.

**Framed Construction:** A small percentage of buildings in the area, mostly larger multistory buildings in the larger towns, are nonductile reinforced concrete stick frame construction with nonstructural infill block or brick walls with plaster finish (Figure 7). The floors are mostly of beam and slab construction supported by columns resting on pad foundations. There is no lateral force-resisting system, and it is mostly infill walls that provide some amount of lateral strength and stiffness. A number of buildings, some of them three or four stories tall, were seen resting entirely on “nonstructural” infill walls while the columns had failed just below the first elevated floor. Many soft/weak story failures were observed in mixed use multistory buildings with open storefronts at the first/ground floor level and walled office/residential space in the upper stories.

**Schools and Hospitals:** Virtually all school buildings are government-built and owned, and every community has an elementary school, even the remote villages. Anecdotal evidence suggests catastrophic damage to a much higher proportion of public schools than nongovernmental buildings in the same areas. Poor quality of construction and lack of seismic design has been faulted in these building collapses. Although most school buildings collapsed totally or partially, many schools were open and functioning with the classes being held in the adjacent school yard.

Many hospitals in the region also suffered severe damage or collapsed. Of the two main hospitals in Muzaffarabad, the main Combined Military Hospital (CMH) totally collapsed, killing or injuring many patients and workers. Residents of the city had to

rely on emergency medical aid from the military and NGOs like the Red Crescent/Red Cross as they mobilized for the rescue effort 24 hours after the earthquake.

A major hospital in Abbotabad, the Ayub Medical College, was a critical care facility lost due to lack of a proper post-earthquake assessment process. The hospital was evacuated and patients relocated to the front yard of the facility due to mistaken categorization of nonstructural damage as major structural damage. This resulted in significant disruption of hospital operations. A similar problem occurred with the Abbas Medical Institute in Muzaffarabad.

The issue of post-earthquake safety assessment is a significant one even for ordinary buildings. Due to lack of qualified personnel, a number of homeowners uncertain about the safety of their homes temporarily relocated to distant towns or tents, even though their homes did not appear to have any significant damage.

## Lifelines

**Transportation:** Road closures completely cut off land access to the Jhelum, Neelum, and Kaghan valleys. Landslides were the predominant cause of the closures. The problem of slope failures along road cuts was exacerbated by a road-building process that uses explosives in weak structures and cuts into toes of pre-existing landslides. Many road closures were due to shallow disaggregated slides and rock falls that rarely caused the complete loss of the roadway bench. However, the unstable nature of the debris and the presence of disrupted rock masses along the slopes above the roadway created ongoing challenges in clearing and opening the roads.

The problem of road closures was so significant that the army dedi-



**Figure 8.**  
*Shearing failure of bridge tower foundation, Balakot.*

There was no damage to cables or cable anchorage, except in one bridge where the cables were fractured after the collapse of the towers due to a fire in an adjacent store containing gas cylinders.

Reinforced concrete bridges in the area typically consisted of single or multiple span reinforced concrete decks supported on reinforced concrete columns or pier walls. Damage to reinforced concrete bridges ranged from sliding of deck or significant movement of wing walls.

**Water Supply:** Private water storage in the form of roof-mounted storage tanks is prevalent in the area. In the earthquake zones, many overhead water tanks shifted or collapsed. Municipal water supply to Muzaffarabad comes from the River Neelum. River water is lifted from six intake lines and treated in a series of rapid sand filters and clarifiers. Damage to this water system ranged from damage to clarifier baffles, motor control units, and distribution piping in some areas. With help from UNICEF, the system was repaired fairly quickly—untreated water was returned within five days, and treated water was available ten days following the earthquake.

cated 12 engineer battalions to open roads. Due to the army's extensive experience with road building, and the availability of skilled builders in the mountain communities after many years of building the Karakoram Highway, the opening and reconstruction of roads was handled efficiently. At the time of the reconnaissance, the Jhelum Valley Road, the Kaghan Valley Road, and the Karakoram Highway had been cleared and opened. The Neelum Valley Road, the only other major road in the affected area, had only a 5-km stretch remaining to be cleared. While most major roads have been reopened, there is a vast network of tertiary roads serving the mountain community in the higher elevations. Many of these roads remain closed, cutting off populations that did not even experience the direct effects of the earthquake and hampering relief efforts.

Several bridges were damaged, especially within the Jhelum Valley and in Balakot. However, a number of bridges did not suffer much damage and were open to traffic. Within the earthquake-affected zone, the most prevalent bridge type was either suspension bridges or reinforced concrete multiple span

bridges. The former consist of a wood deck supported on steel girders suspended by steel cables on either side of the deck. The cables are supported by a tower at each end and anchored in a concrete anchor block. In addition, the deck is prevented against sway by cables attached to a longitudinal cable on each side below the deck elevation and anchored in concrete anchor blocks. The suspension bridges are typically for pedestrian use, with some allowing vehicular traffic. Damage to suspension bridges ranged from shearing of the tower foundation (Figure 8) to complete collapse of the towers (Figure 9).



**Figure 9.** *Collapsed suspension bridge, Jhelum Valley.*



In smaller villages and hamlets, water comes from private ground water wells or natural streams. In one case, a hamlet located between Mansehra and Ghari Habibullah experienced a significant drop in water elevation in its wells two weeks after the earthquake, and the locals reported high turbidity.

**Other Lifelines:** While land telephone service was not operational, new wireless telecommunication towers were erected within days of the earthquake, and communications were fully restored relatively rapidly after that.

Electricity to the Muzaffarabad area is supplied from Mangla Dam and from a local 30 megawatt Jhangra hydroelectric power plant. Power loss in Muzaffarabad was due to fallen transformers and broken lines. Electricity was fully restored to most of the city in five to six days. Main transmission towers fared very well, with no damage to the towers even in the area of intense shaking. In one case, however, a landslide damaged the transmission line near Balakot.

Heating is provided from either electricity or LPG. There are no natural gas supply lines to Muzaffarabad.

### Seismic Planning Provisions and Building Codes

Even though Pakistan has designated seismic zones, the area that suffered in the earthquake was either not classified or was deemed to be Zone 2 (equivalent to UBC Zone 2: low to moderate risk). The major cities of Peshawar (Zone 2), Islamabad (Zone 2), Karachi (Zone 2) and Quetta (Zone 4) had been classified, but not in a way that agrees with those given in Appendix III of Chapter 16 of the 1997 UBC, where Islamabad, Peshawar, and Karachi are all classified as Zone 4. Seismic hazard is not

given a great deal of attention in urban planning and policy decisions, and seismic design does not appear to be high priority, except for major or high profile projects.

In meetings with public officials, it became apparent that there was no code enforcement in the region. It appears that most practicing engineers in major urban areas use the UBC for building design. The use of ACI codes and British Standards is also common. In a meeting of the EERI team with the Prime Minister of Pakistan, it was mentioned that the development of a proper national building code with appropriate seismic design provisions had been outsourced to local consultants, and they had been given one month to produce such a document. A draft of this code document was not available for review at the time this report was written. Many people have already started reconstruction without building codes or enforcement.

### Response and Recovery

The earthquake affected a population of approximately 3.5 million people either directly or indirectly, and the logistics of administering aid and relief efforts have been extremely daunting. In addition to the staggering numbers of deaths, the human cost includes amputees, orphans, unhygienic conditions resulting in dis-

ease, and severe malnutrition. The early days of the disaster response were marked by uncoordinated efforts among a whole host of organizations involved in relief work. There was little information on who was doing what and little oversight. A coordinating structure was later created by the government under the Federal Relief Commission (FRC) and the ERRA (Earthquake Relief and Rehabilitation Authority) to coordinate activities with other international agencies and NGOs. According to the World Bank, the relief work will cost \$2 billion. According to another estimate, approximately 0.5 million tents, 3.5 million blankets, 60,000 tons of food, and 3,000 tons of medicine have been required.

Shelter strategy was organized around three populations: people who lived in houses in the lower elevations, people living in higher elevations who could come to the lower elevations, and people living in inaccessible snowline areas (5,000-7,000 feet). People in the former two categories were provided with tented villages managed by some agency (Figure 10). People in the last category were not compelled to descend to the tented villages. Survivors are being taught to build transitional shelter using material from retrieved debris,

**Figure 10.** Children in makeshift playground in front of their tent camp. White plastic sheets have been added to the tents to protect against rain.



October 8, 2005 Kashmir Earthquake  
Photo By: Bijan Khazai (Columbia University, Earth Institute/EERI)  
November 14-24, 2005

reinforced with locally available materials such as timber and hay in addition to the corrugated galvanized iron (CGI) sheets provided to them.

Recycling CGI sheet roofs from destroyed homes has been problematic because of people's preference for using the retrieved material for their permanent structures later on and not for temporary structures. Outlets for provision of construction material are being devised. The government has created an incentive for people to use their own materials by giving free CGI sheets to people who use half of their own material. NGOs working in Neelum Valley noted the problem of people carrying heavy GI sheets, weighing 8-9 kg each, to higher altitudes. Alternative lightweight materials such as plastic sheets have been suggested, but their inability to carry the weight of the snow does not make them a viable alternative. Debris clearance has been slow because much of the heavy equipment has been tied up in road clearance and repair. Other sensitivities regarding debris removal include bodies and people's possessions still buried under the rubble and an unwillingness to part with potentially useful scrap. Dumping of rubble collected from the city into valleys and gorges has also been a problem, as people are putting their lives at risk by attempting to retrieve rebars with sledge hammers and bare hands. Debris from chemical warehouses, hospitals, and pesticide storage areas is a significant cause of environmental concern. Currently, the Pakistan Government estimates 20-30% of debris is yet to be removed.

About 67% of the educational institutions in the affected area were destroyed. The cost of rebuilding schools in the affected areas is estimated at about \$614 million. Many students and teachers have been displaced, and some migrated as

far away as Islamabad. Students, parents, and teachers want the schools to reopen, but few schools in affected areas are functional. Some tent schools have been opened, and gradually life is returning to normal. Trauma counseling for the students will be necessary for quite some time.

The earthquake destroyed 782 health institutions, so the area was nearly devoid of any type of health facility after the earthquake. Despite the base and field hospitals that worked around the clock, it was difficult to get the right kind of medical teams and equipment to the affected areas due to the difficult terrain. The earthquake also badly affected maternal health because most traditional birth attendants either died or moved to safer places. Pregnant women will not get needed pre- and post-natal care. Mental health programs are being administered by both the government and international agencies. A task force of psychiatrists has been formed by the government that is funded at \$5 million to administer treatment for post-traumatic stress.

Managing the displaced populations in the shelter camps has proved to be a major challenge, and some people had not relocated to camps as of this writing. Prevention of disease in camps has government officials concerned. Diseases such as diarrhea, respiratory infection, and scabies in crowded tent settlements have sprung up in the weeks following the earthquake. Instructions on hygiene are being published to create awareness among the people in relief camps. Because the population is not used to living in such an environment, social and cultural issues are creating difficulties. According to one relief worker, issues of modesty compel many women to wait until dark to use the communal toilet facilities.

A long-term project for reconstruction and rehabilitation is set to begin by mid-February (the 18th week follow-

ing the disaster). It is estimated that approximately 400,000 houses will be reconstructed by the government. Numerous groups and individuals are presenting ideas on earthquake-resistant construction, but they are apparently not being coordinated properly at the present time. Organizations interested in constructing houses will have to follow the standards and procedures set forth and coordinated by the Earthquake Reconstruction and Rehabilitation Authority (ERRA), when those become available.

According to a World Bank estimate, \$3.5 billion will be needed for reconstruction and rehabilitation.

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