Learning from Earthquakes

First Report on the Kashmir Earthquake of October 8, 2005

Overview

On October 8, 2005, at 08:50 am local time, a M_w7.6 earthquake struck the Kashmiri region of Pakistan and India, causing widespread destruction in Pakistan's Azad Jummu and Kashmir (AJK) and Northwest Frontier Provinces (NWFP), and in India's western and southern Kashmir—an area of 30,000 km^2 (see Figure 1). This was the deadliest earthquake in the recent history of the sub-continent, with more than 80,000 fatalities, 200,000 people injured, and more than 4 million people left homeless.

The epicenter of the main earthquake was located at latitude 34° 29′ 35″ N and longitude 73° 37′ 44″ E, and the focal depth was determined to be 26 km (USGS). The main shock was followed by more than 978 aftershocks of magnitude M_w 4.0 and above, until October 27, 2005. This earthquake is associated with the known subduction zone of an active thrust fault in the area where the Eurasian and Indian tectonic plates are colliding and moving northward at a rate of 40 mm/yr, giving rise to the Himalayan mountain ranges. Almost all the buildings—mainly stone and block masonry laid in cement sand mortar—collapsed in areas close to the epicenter. Up to 25 km from the epicenter, nearly 25% of the buildings collapsed, and 50% of the buildings were severely damaged.

The major affected towns in Pakistan were Muzaffarabad, Bagh, Rawlakot and Balakot. In addition, Islamabad, Shinkiari, Batagram, Mansehra, Abbotabad, and Murree were damaged. Initial rescue and relief efforts were hampered by the mountainous terrain, bad weather, and damaged or collapsed infrastructure.

Government agencies and NGOs are racing against the weather to deliver relief supplies and temporary housing to remote areas before winter sets in. Several EERI members visited the region shortly after the earthquake and sent back initial reports.

Figure 1. *Map showing areas affected by the earthquake of October 8, 2005. Heavy line: the boundary between Pakistan's provinces of AJK and NWFP. Dotted line: the 1972 Line of Control.*

PAKISTAN

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The epicentral area is a very rugged mountainous area with deep narrow valleys and relief of 5,000 or more feet and slopes of 45-50 degrees. A large number of smaller settlements and houses are on valley walls, right up to ridge tops. Muzaffarabad—about 10 km southwest of the epicenter—is the largest city in the region, with a population of about 200,000, and was severely damaged (see Figure 2). Pakistan reports more than 72,000 people dead, and 2.8 million displaced.

Ground Motions

Shaking intensity: Based on observations of buildings and infrastructure, team members estimate MMI X+ in Balakot, MMI VIII-IX in Muzaffarabad, and MMI VII-VIII in other locations south of Muzaffarabad.

Liquefaction: None was observed, and it doesn't appear to have occurred to any significant degree, probably due to a low water table in this arid region, as well as to alluvial deposits being generally coarsely graded (due to steepness of stream beds).

Figure 2a. Typical terrain of affected area in Pakistan.

Figure 2b. Destruction in Muzaffarabad caused by the Kashmir earthquake. ▼

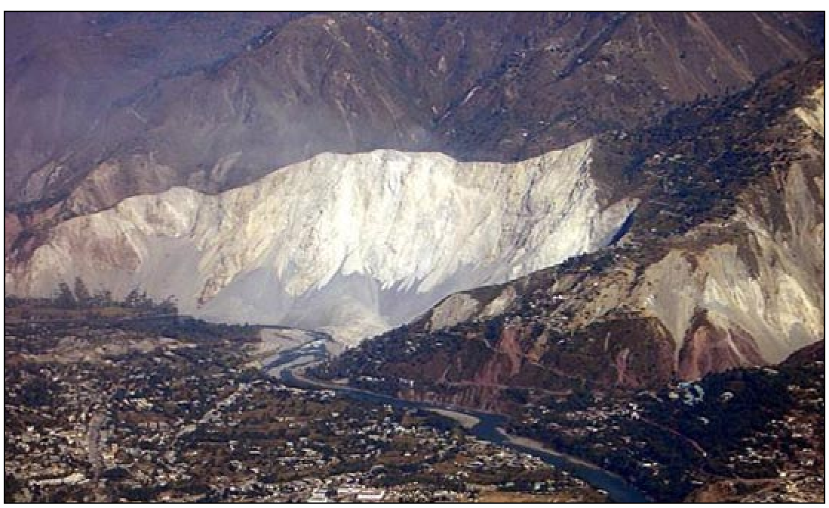

Figure 3: Large but surficial landslide just north of Muzaffarabad. Note relatively minor amount of talus.

Landslides: There were numerous landslides, generally minor to moderate but massive in some instances, causing some deaths and injuries and blocking roads. A dramatic but surficial landslide occurred on the moutainside to the north of Muzaffarabad (Figure 3). It should be noted there was evidence of similar pre-earthquake slides in the same area.

A massive landslide about 40 km SE of the epicenter appears to be a failure of an entire valley wall perhaps 5,000 feet high (Figure 4). Debris flowed down and across the valley, damming it with a crest approximately 2 km in length. The scale of this slide is analogous to the 1959 Hebgen Lake (Montana) slide. The slide warrants further investigation.

Structures

The structures in the affected region consist of earthen wall unreinforced stone, concrete block and brick masonry, and reinforced concrete frames with concrete block or brick masonry infill panels.

Unreinforced Stone Masonry Buildings: A significant number of casualties and injuries in the rural areas were associated with the total collapse of single-story unreinforced earthen wall stone masonry buildings. The stone masonry walls consisted of irregularly placed undressed stones, mostly rounded, that were laid in cement sand, mud mortar, or even dry in some cases (Figures 5a and 5b). A number of features seem to be responsible for widespread collapse of buildings.

Stone masonry buildings are more common in the villages than in the cities. The quality of mortar and stones used and the level of workmanship are poor, due to the economic constraints on the people. Stone masonry set in plain earth (i.e., mud) is not unusual. Cement

Figure 4. *Large landslide about 40 km SE of Muzaffarabad. Head to toe is about 2.9 km (1.8 miles). Volume is estimated at 1-to 2 million cu. m.*

mortars when used consist of one part of cement to 10 parts sand. The crushing and shear strength of such mortar is approximately 300 psi and 5 psi, respectively. The rounded and smooth stones also contribute to the poor bond.

No horizontal bond beams are provided at the levels of plinth and roof. Lintel beams are provided only above the openings and are not run continuously along the perimeter of the walls. No vertical members of concrete or wood are provided in the walls and, therefore, the collapse of a particular portion of the wall progressed in an uninterrupted manner to other portions of the walls and buildings.

Unreinforced Solid Concrete Block Masonry Buildings: Concrete block masonry buildings are widely used in the cities and less so in the villages. Solid concrete blocks 6” thick, 6” wide, and 12” long are laid in cement sand mortar. The collapse of block masonry buildings was responsible for a major portion of deaths and injuries in cities (see Figure 6). The most probable reasons for the failures were (1) poor quality of concrete used for fabrication of blocks, which rendered low strength blocks; (2) poor quality of mortar; (3) inadequate thickness of walls—the main shear-resisting elements; (4) no integrity of the wall in the transverse direction; and (5) weak connections at corners.

Unreinforced Brick Masonry Buildings: By and large, brick masonry buildings are the most common form of masonry in towns, and performed better than the stone or concrete block masonry buildings. According to the Earthquake Engineering Center at NWFP UET Peshawar, unreinforced one- and two-story brick masonry buildings, with RC slabs as roofing, comprise 25% of the total building stock of the cities near the epicenter. About 30% of these buildings collapsed, while the rest suffered slight damage. Because the unit cost of brick masonry is higher than that of other forms of masonry, the owners are people with financial resources. Along with better workmanship, good quality mortar is used in the construction of brick masonry buildings. However, no evidence of either bond beams or other earthquake-resistant improvement techniques was found in such buildings (Figure 7).

Reinforced Concrete Framed Buildings: For the past 15 years, reinforced concrete frame buildings have been increasingly used for the construction of government offices, colleges, hospitals, hotels, markets, and apartment houses. Many such

Figure 5a. *Failure of unreinforced stone masonry walls in Muzaffarabad.*

Figure 5b. *Collapsed stone masonry building (metal roof)*

Figure 6. *Collapse of unreinforced concrete block masonry houses in Kamsar near Muzaffarabad (Latitude N34° 24.6' and Longitude E73° 28.5').*

buildings collapsed and more were seriously damaged (Figure 8). In severely damaged buildings, columns were observed to have cracked at the beam-column intersection. Figure 9 shows the formation of a plastic hinge in one of the columns of a building. Inclined cracks were also found at the mid-height of some columns. Beams were found to be intact and undamaged, but infilled 4½" masonry walls were extensively damaged.

The failures of reinforced concrete frame structures may be attributed to deficient design for seismic forces, improper length and location of column splices, improper spacing and anchorage of lateral ties in columns, and poor quality of concrete.

Lifelines

In general, lifelines sustained relatively little damage compared to structures, with water and electricity generally restored within one week. Roads were blocked at numerous locations by landslides, with 1,300 km of roads reportedly destroyed in AJK. Bridges were virtually undamaged. Cellular phone service was available in most locations, and landline service was available in towns.

Response and Recovery

There are approximately 3 million persons in Pakistan whose houses have collapsed, many of them in high mountain villages. Snow began falling in late October in upper elevations, and it will reach areas at approximately 2,000 feet by late November.

Large numbers of people are reluctant to leave their land, due in part to the need to care for their livestock through the winter.

Pakistan is thus confronted with the need to provide minimal shelter in remote locations with limited institutional and other resources, and has made appeals to the international community for assistance.

The United Nations, the International Federation of the Red Cross, the United States, Japan, Turkey and other nations have provided military and civilian assistance, and many NGOs and individual Pakistani citizens are involved in trying to assist the people in a large area of rugged terrain.

Figure 7. *Severely damaged unreinforced brick masonry wall in Muzaffarabad.*

Figure 8. *Collapse of Sangam Hotel, an 5 storeyed RC framed building in Domel, Muzaffarabad (Latitude N34º 21.3' Longitude E73º 28.3').*

Figure 9. *Formation of plastic hinge in the column near the beam-column joint in a hospital building in Mansehra.*

Lessons Learned

The building performance appears to provide few new lessons, although the landsliding deserves study, particularly the very large slide discussed above. Basically, the poor-quality building construction caused the large number of fatalities. The difficult response and recovery, which is taking place in a relatively unique setting, will be of interest and a valuable learning opportunity for planners, emergency responders, and social scientists.

INDIA

Durgesh C. Rai and C.V.R. Murty of the Department of Civil Engineering, Indian Institute of Technology Kanpur, India, undertook a reconnaissance survey on the Indian side of the LoC and visited places along National Highway NH1A from Srinagar to Uri and Sopore, Durgwilla, Kupwara, and Traigaon on the road to Tangdhar.

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The affected region lies at the top of two high risk seismic zones (IV and V) of Indian seismic code IS:1893, with an expected intensity of IX or more in zone V and an intensity of VIII in zone IV. Damage to buildings and other structures in general corresponded well with the intensity of ground shaking observed at various places, with a maximum of VIII at Uri, VII at Baramulla and Kupwara, and V at Srinagar on the MSK scale. However, stone walls of random rubble construction collapsed at levels of much lesser shaking.

Structures

In Kashmir, traditional timber-brick masonry construction consists of burnt clay bricks filling in a framework of timber to create a patchwork of masonry, which is confined in small panels by the surrounding timber elements. The resulting masonry is quite different from typical brick masonry, and its performance in this earthquake has once again been shown to be superior, with no or very little damage. No collapse was observed for such masonry even in the areas of higher shaking.

This timber-lacing of masonry, which is locally referred as *Dhajji-dewari* (meaning patchwork quilt wall) has excellent earthquake-resistant features. Timber studs, which subdivide the infill, arrest the loss of masonry panels and resist progressive destruction of the rest of the wall (Figure 10). Moreover, the closely spaced studs prevent propagation of diagonal shear cracks within any single panel, and reduce the possibility of out-of-plane failure of masonry of thin half-brick walls even in the higher stories and the gable portion of the walls.

The dhajji-dewari system is often used for walls of upper stories, especially for the gable portion of the wall, even when the walls in bottom stories are made of brick or stone masonry (Figure 10a).

In older construction, another form of timber-laced masonry, known as *Taq* has been practiced. Large pieces of wood are used as horizontal runners embedded in the heavy masonry walls, adding to the lateral load-resisting ability of the structure (Figure 10b). The concept of Dhajji-dewari has also been extended to a type of mixed construction in which stones are used as filler hard material in wall panels that are created by a series of piers in softer coursed brick masonry, which has greater integrity under lateral loads (Figure 10c).

In the upper reaches of the North Kashmir Himalayas, the majority of


(a)

(b)

(c)

Figure 10. *Traditional masonry for proven earthquake resistance: (a) Dhajji-dewari system of timber-laced masonry for confining masonry in small panels; (b) Taq system of embed-ding timber logs in thick walls; and (c) brick masonry piers for timbers in stone infilled wall.*


(a)

(b)

Figure 11. *Out-of-plane collapse of stone masonry walls.*

Figure 12. *Timber-laced masonry in gable wall suffered little damage, whereas extensive damage in stone masonry wall rendered the building unsafe at Uri.*

houses use stone masonry in mud mortar for walls, and flexible diaphragms for floors and roofs consisting of timber. Stone masonry is produced from a wide range of materials and constructed in many different forms that have shown varying degrees of acceptable performance in this earthquake. However, some forms of stone masonry, especially random rubble (R/R) stone masonry, are extremely vulnerable to earthquakes.

Undressed stones are laid in mud or cement mortar and plastered in cement mortar to provide a finished surface. Most government buildings—hospitals, schools, jails—built during the last tour or five decades suffered heavy damage, especially when the structure was old. Such out-of-plane failures arising from the dynamic instability of unsupported walls were evident in the collapse of tall slender end walls in brick masonry as well. Moreover, masonry walls are weakened by openings for doors and windows (Figure 11).

However, timber-laced masonry can maintain its integrity even when the supporting masonry walls in lower stories are severely damaged (Figure 12). There are many small scale buildings using all timber construction which have generally performed satisfactorily. Even large buildings in timber had no observed damage whereas neighboring stone masonry buildings suffered partial to total collapse.

Pitched roofs have been the most popular choice as a roofing system for buildings. In rural areas and low cost houses, the roofs are either composed of wooden joists and planks or simple wooden trusses and rafters. In government buildings, wooden planks are placed on rafters to support the roofing material.

Galvanized corrugated iron (GCI) sheets have also been used as a roofing material in many cheaply built school buildings. These roofs are inherently weak in shear and can not tie the walls together even when they are properly connected to them. Most roof failures can be attributed to a combination of deficiencies such as loss of support of roof trusses and rafters due to a failure of masonry walls and the failure of the roof truss itself due to failure of joints and/or members forming the truss or other roof-supporting structure.

Lifelines

The affected region may experience ground shaking of more than IX on the MSK scale, and has a number of major bridges that are simply supported prestressed concrete girder types with inadequate seating or no provision to prevent unseating.

No serious damage to any of the highway bridges was noticed in the areas visited, but there were reports that the Aman Setu bridge at the India-Pakistan border on the road to Muzaffarabad suffered damage. The balanced cantilever bridge at Baramulla over the Jhelum River had no observed damage. Most pedestrian bridges were suspension types and no particular damage to the bridge structure or

Figure 13. *Landslide on NH1A near Uri disrupted the road traffic.*

to the supporting pylons was noticed.

Roads closer to the epicentral area in the mountainous region suffered extensive landslides which resulted in the closure of traffic for many days (Figure 13). The road to Tangadhar from Kupwara was not open even a week after the quake. Fissures on roads were noticed at places that were primarily due to ground movement across unstable slopes.

The pipelines for drinking water broke at several places, causing severe hardship. An overhead water tank, on shaft-supported staging in Traigaon and empty at the time of the earthquake, suffered circumferential flexure tension and shear cracking. Such damage has been observed in many past earthquakes, highlighting the inadequacy of the current design of such tanks.

Response and Recovery

The army present in the area was first to respond with rescue and relief, despite being seriously affected themselves by the earthquake. Helicopters were extensively used to carry relief supplies and bring injured to the hospital at Srinagar or a field hospital set up in Uri.

The prime minister visited the affected area and announced grants of Rs. 100,000 (US $2,300) to the next of kin of those who died in the earthquake. The immediate requirement is to provide temporary shelter along with medicine, food, and blankets for survivors, before these areas become further inaccessible due to the approaching winter. The Government of India has supplied more than 15,000 tents to the affected region against the estimated 35,000 tents required to house the earthquake-affected population.

The government has announced house-rebuilding aid of Rs. 100,000 for those whose houses were totally destroyed, with the immediate release of the first in-stallment of Rs. 40,000. For partially damaged houses, aid of Rs. 10,000 will be given.

Conclusions

The damage to the built environment, economic loss, and human casualties caused by Himalayan earthquakes are increasing proportionally with the growth of settlements and population in the upper reaches of this region. Significant damage was observed in the prevailing stone masonry residential, community, and government buildings, particularly those of random-rubble, a type which is well-known for poor seismic performance.

Much of the damage can be attributed to inferior construction materials, inadequate support of the roof and roof trusses, poor wall-to-wall connections, poor detailing work, a weak in-plane wall due to large openings, out-of-plane instability of the walls, a lack of integrity or robustness, asymmetric floor plans, and aging. Buildings should not only meet the functional requirements of occupants, but also the essential requirement for safety, based on sound earthquake-resistant design and construction.

Conventional unreinforced masonry laced with timber performed satisfactorily, as expected, since it arrests destructive cracking and evenly distributes the deformation, which adds to the energy dissipation capacity of the system, without jeopardizing its structural integrity and vertical load-carrying capacity. There is an urgent need to revive these traditional masonry practices, which have proven their ability to resist earthquake loads, in contrast to contemporary colonial-style masonry buildings.

Modern bridges, roads, and water tanks that have been constructed without due consideration of the potential high seismic forces associated with the Himalayan region make such civil infrastructure extremely vulnerable for future earthquakes.

Acknowledgments

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Photo credits: Figures 2a, 3, 4, and 5b: Charles Scawthorn; Figures 2b, 5a, 6, 7, 8, and 9: Earthquake Engineering Center, NWFP UET Peshawar; Figures 10 and 12: Durgesh Rai; Figures 11 and 13: C.V.R. Murty.

Future Reports

In mid-November, EERI sent a small reconnaissance team from the United Status to Pakistan, led by EERI member Saif Hussain and including Ahmed Nisar and Bijan Khazai. Geologist Grant Dellow of New Zealand also joined the team. They coordinated closely with colleagues in Pakistan. More information from the field will be included in upcoming issues of this *Newsletter*.

Based on its experience after the Indian Ocean tsunami, EERI has launched a section of the virtual clearinghouse to provide information on rebuilding. Manuals, guidelines, and reports are posted on the site at **http://www.eeri.org/lfe/clearinghouse/kashmir/resources.html**. Members are encouraged to contribute to this site.