PRELIMINARY REPORT ON THE 2005 NORTH KASHMIR EARTHQUAKE OF OCTOBER 8, 2005

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EARTHQUAKE AND ITS SEISMOLOGICAL SETTING

The M_w 7.6 earthquake on October 8, 2005 struck at 8:50:38 AM local time (9:20:38 India Standard Time) with its epicenter located at 34.493°N, 73.629°E (USGS), which lies in the Pakistan-occupied territory of Kashmir (POK). The epicenter is located at 19 km northeast from the major neighbouring town of Muzaffarabad, which is 170 km west-northwest of Srinagar. (Figure 1).

The event which was similar in intensity to the 2001 Gujarat Earthquake and the 1935 Quetta earthquake and 1906 San Francisco earthquake, caused widespread destruction in POK, Pakistan's North-West Frontier Province (NWFP), and western and southern parts of the Kashmir on the Indian side LoC. The official death toll of 47,700 in Pakistan (including more than 13,000 in NWFP) and 1, 329 in Kashmir, India could increase as the affected areas are in mountainous terrain where access is very difficult which are now impeded by landslides. The earthquake has affected about 4 millions and damage losses are estimated for over 5 billion US dollars.

This earthquake at a focal depth of 26 km is associated with the known subduction zone of 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 Himalayan mountain ranges.

Worst affected major towns on the Indian side of LoC are Tangadhar in Kupwara district and Uri in Baramulla district. Significant damages have also been reported from the Poonch and Rajouri district further south from the epicenter on the Indian side of LoC. The authors undertook a reconnaissance survey on Indian side of LoC and visited places along National Highway NH1A from Srinagar to Uri and along Sopore, Durgwilla, Kupwara, Traigaon on the road to Tangdhar.

GENERAL OBSERVATIONS

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

The region affected by the Kashmir earthquake is mountainous terrain where the settlement is dense in valleys and sparse on hill slopes. Major civil engineering projects in the area are highways, bridges, small dams and micro hydro-electric projects and a few RC framed buildings. The housing units are largely low rise brick and stone masonry load bearing types often in association with timber. The diaphragms varying from pitched flexible roofs to mixed flexible and rigid concrete floors and roofs.

PERFORMANCE OF STRUCTURES

Structures need to have suitable earthquake-resistant features to safely resist large lateral forces that are imposed on them during infrequent earthquakes. Ordinarily structures for houses are usullay built to safely carry their own weight and low lateral loads caused by wind and therefore, perform poorly under large lateral forces caused by even moderate size earthquakes.

The majority of buildings in the affected region use the unreinforced masonry walls as bearing and enclosure walls. These masonry structures can be viewed as box-type structures in which the primary lateral resistance against the earthquake forces is provided by the membrane action of the diaphragms (floors and roofs) and bearing walls. The seismic performance of load bearing masonry structures depend heavily on the structural characteristics (strength, stiffness and ductility) of surrounding walls to resist in-plane and out-of-plane inertia forces and of the diaphragms (floors & roofs) to not only safely resist the shear forces but also to distribute the forces to vertical elements (walls) and maintain the integrity of the structure.

In Kashmir traditional timber-brick masonry construction consists of burnt clay bricks filled 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 their performance in this earthquake has been once again shown to be superior with no or very little damage. No collapse has been observed for such masonry even in the areas of higher shaking. This timber-lacing of masonry, which is locally referred as *Dhajji-dewari* (meaning patch quilt wall) has excellent earthquake-resistant features. Presence of timber studs, which subdivides the infill, arrests the loss of the portion or all of several masonry panels and resisted progressive destruction of the rest of the wall (Figure 2). Moreover, the closely spaced studs prevent propagation of diagonal shear cracks within any single panel, and reduce the possibility of the out-of-plane failure of masonry of thin half-brick walls even in higher stories and gable portion of the walls. 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 could be made of brick or stone masonry (Figure 2a).

In older construction, another form of timber-laced masony, known as *Taq* has been practiced in which large pieces of wood has been used as horizontal runners embedded in the heavy masonry walls, which add to the lateral load resisting ability of the structure (Figure 2b). The concept of Dhajji-dewari has also been extended to develop a mixed construction in which stones are used as filler hard material in wall panels created by a series of piers in softer coursed brick masonry of grater integrity under lateral loads (Figure 2c). The masonry walls with stones confined in such a manner have performed quite satisfactorily, in contrast to usual brick or stone masonry.

In the upper reaches of North Kashmir Himalayas, majority of 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 degree of performance in this earthquake. Unreinforced stone masonry is very durable even in the hostile environment and can accommodate movements and resist natural forces without becoming unstable and falling apart, especially when they are laid in even courses after proper dressing (Figure 3).

However, some forms of stone masonry, especially Random Rubble (R/R) stone masonry construction are extremely vulnerable to earthquakes. Undressed stones are laid in mud or cement mortar and plastered in cement mortar to provide finished surface. Most of government buildings, hospitals, schools, jails, etc., built during the last 4 to 5 decades suffered heavy damage especially when the structure is old. This was primarily due to the fact that the walls could not maintain its integrity during the shaking. The collapsed walls of army buildings in Uri and Kupwara are a few examples. Such out-of-plane failures arising from the dynamic instability of unsupported walls were also evident in collapse tall slender end wall in brick masonry as well. Moreover, masonry walls are weakened by openings for doors and windows (Figure 4).

Deficiencies of stone masonry wall were more evident in R/R type masonry and were responsible for the majority of the observed damage in the earthquake-affected areas. Such deficiencies can render typical brick masonry buildings vulnerable to damage as shown Figure 5. However, timber-laced masonry can maintain it integrity even when the supporting masonry walls in lower stories are severely damaged (Figure 6). 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 (Figure 7).

Pitched roofs have been the most popular choice as a roofing system for buildings. However, there are many variants of pitched roofs with varying degree of seismic performance. 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 of roof failures can be attributed to a combination of deficiencies such as loss of support of roof trusses and rafters due to failure of masonry walls and failure of roof truss itself due to failure of joints and/or members forming the truss or other roof supporting structure (Figure 8).

The area has a number of highway and pedestrian bridges over rivers, rivulets, and gorges. No serious damage to any of the highway bridges was noticed in the areas visited, however, it has been reported that the Aman Setu at India-Pak border on the road to Muzaffarabad had suffered damage. The balanced cantilever bridge at Baramulla over Jhelum river had no observed damage (Figure 9a). The affected region which may experience ground shaking more than IX on MSK scale, has a number of major bridges which are simply supported prestressed concrete girder type with inadequate seating or any provision to prevent unseating (Figure 9b). Most of pedestrian bridges were of suspension types and no particular damage to the bridge structure or to the supporting pylons was noticed.

Roads closer to epicentral area in the mountainous region suffered extensive landslides which resulted in the closure of traffic for many days (Figure 10). The road to Tangadhar from Kupwara was not open even a week after the quake. Fissures on roads were noticed at places which were primarily due to ground movement across unstable slopes. Pipe lines for drinking water supply broke at several places causing severe hardships. An overhead water tank on shaft supported staging in Traigaon suffered circumferential flexure tension and shear cracking which was empty at the time of earthquake (Figure 11). Such damages have been observed in many past earthquakes which highlight the inadequacy of current design of such tanks.

RESCUE & RELIEF OPERATIONS

Relief efforts in the affected areas have been seriously hampered by the difficult terrain and harsh Himalayan weather conditions with the winter around the corner. It has started already snowing in the Tangadhar areas which could not have been reached after earthquake due to number of landslides which had buried the road under rubbles. The army present in the area was the first one to respond for rescue and relief despite being seriously affected by the earthquake. Helicopters were extensively used to carry relief supplies and bring injured to hospital at Srinagar or field hospital setup at Uri.

The Prime Minister visited the affected area and announced ex-gratia of Rs. 100,000 (US$ 2300) to next of kin of those died in earthquake. The immediate requirement is to provide temporary shelter along with medicine, food, blankets, etc. for survivors, before these areas become further inaccessible due to 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 a house re-building aid of Rs. 100,000 for those whose houses were totally destroyed, with the immediate release of first installment of Rs. 40,000. For partially damaged houses, an aid of Rs. 10,000 has been fixed.

CLOSURE

The damage to built environment, economic loss and human casualties caused by Himalayan earthquakes are increasing rather proportionally with the growth of settlements and population in its upper reaches. Significant damage to residential, community and government buildings result from prevailing stone masonry buildings, especially those with random-rubble types, which are well known for poor seismic performance. Buildings should not only meet the functional requirements of occupants but also essential requirements for sound earthquake-resistant design and construction.

Most of residential units in the affected area relied on load bearing masonry walls for seismic resistance. Much of the damage could be attributed to inferior constructions materials, inadequate support of the roof and roof trusses, poor wall-to-wall connections, poor detailing work, weak in-plane wall due to large openings, out-of-plane instability of walls, lack of integrity or robustness, asymmetric floor plans and ageing. Conventional unreinforced masonry laced with timber performed satisfactorily as expected as it arrests destructive cracking, evenly distributes the deformation which adds to 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,, water tanks, etc., which have been constructed without due consideration of high seismic activities of the Himalayan region make such civil infrastructure extremely vulnerable for future earthquakes.

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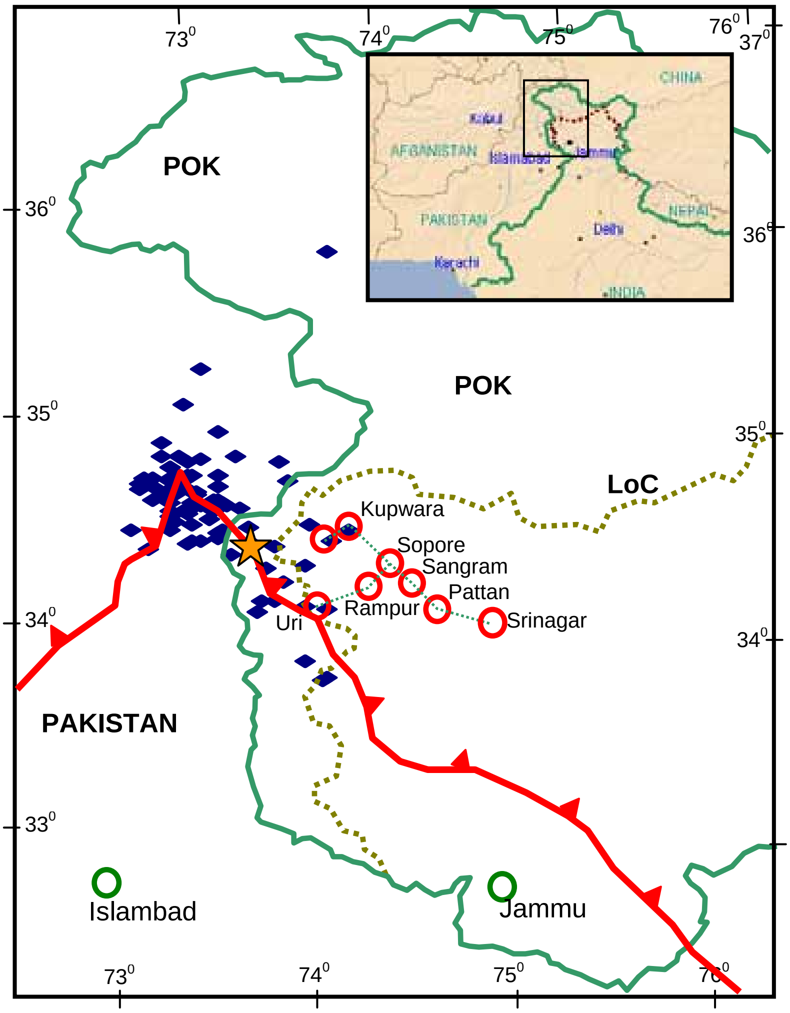

Figure 1. Location of epicenter of the earthquake and its aftershocks, Main Central Thrust fault, and the towns visited in the Indian side of Line of Control (LoC).

(a)

(b)

(c)

Figure 2. Traditional masonry for proven earthquake resistance: (a) *Dhajji-dewari* system of timber laced masonry for confining masonry in small panels (b) *Taq* system of embedding timber logs in thick walls and (c) Brick masonry piers for timbers in stone infilled wall.

(a)

(b)

Figure 3. Examples of mixed construction involving *dhajji-dewari* and dressed / undressed stone masonry and brick masonry.

(a)

(b)

(c)

Figure 4. Out-of-plane collapse of stone masonry walls

(a)

(b)

Figure 5. Damage to brick masonry buildings: (a) Out-of-plane collapse of walls and (b) In-plane failure of masonry walls in lower stories and out-of-plane collapse at uppermost storey

Figure 6. Timber-laced masonry in gable wall suffered little damage whereas extensive damage in stone masonry wall rendered the building unsafe at Uri.

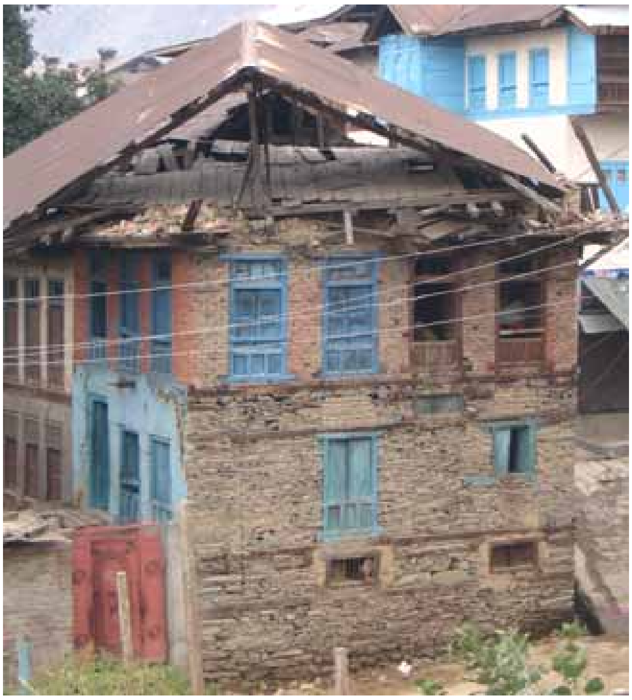

Figure 7. Failure of supporting walls for the roof in a traditional building using *Taq* system of masonry at Baramulla.

Figure 8. All timber building escaped the ground shaking without significant damage at Kupwara.

(a)

(b)

Figure 9. (a) No observed damage to balanced cantilever bridge over Jhelum at Baramulla and (b) Simply supported prestressed concrete girder bridge over NH1A in Zone V. Note lack of restrainers for preventing unseating during earthquakes.

Figure 10. Landslide on NH1A near Uri disrupted the road traffic.

Figure 11. A 50000 gallon water tank at Traigaon developed flexure tension cracks in its supporting shaft rendering it unsafe for use.