control larvae excreted faeces as loose particles without membranous structure (Figure 3). Microscopic examination revealed that the non-cellular membranous structure was suspected to be the peritropic membrane (PM). It has been documented that the root extract of *Derris* affects peritropic matrix structure of *A. aegypti*[13]. It has been recognized that the PM separates food from epithelial cells of the gut involved in digestion and absorption of nutrients from the gut lumen, and acts as a protective barrier against various chemical, physical and microbial food components[14].

It may be argued from our results that the *C. inerme* powder taken by the larvae along with other food materials caused damage to the PM and subsequently affected the process of digestion and absorption. Disruption of growth of the larvae to pupae observed in this study may be the result of disturbances in the digestive process, which led to inadequate supply of nutrition to the larvae.

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ACKNOWLEDGEMENT. Financial assistance provided by UGC, New Delhi is acknowledged.

Received 15 February 2005; revised accepted 10 December 2005

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Effects of the 2005 Muzaffarabad (Kashmir) earthquake on built environment

Studying the effects of earthquakes has long been recognized as a necessary step to understand the natural hazard and its risk to the society in the long term. A rapid assessment of general damage survey and documentation of initial important observations, not only help management of emergency response and rehabilitation activities, but also help to assess the need of follow-up areas of research[1,2]. The Muzaffarabad earthquake of 8 October 2005 which caused major devastation on both sides of the Line of Control (LoC) in Kashmir, presented another opportunity to further our understanding of earthquake risk in the region.

The *Mw* 7.6 earthquake on 8 October 2005 was a major earthquake at a depth of 26 km from the surface with its epicentre located at 34.493°N, 73.629°E, 19 km northeast from Muzaffarabad, the capital town of the Pakistan Occupied Kashmir (POK) and 170 km west-northwest of Srinagar, Jammu & Kashmir, India (USGS). The event which was similar in magnitude to the 2001 Gujarat earthquake and the 1935 Quetta 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 of LoC. This earthquake is associated with the known subduction zone of active thrust fault along the Himalayan mountain ranges in the area where the Eurasian and Indian tectonic plates are colliding and moving northward at a rate of 40 mm/yr (Figure 1).

The 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 epicentre on the Indian side of LoC. During the reconnaissance survey we visited places along National Highway NH1A during 14–19 October 2005 from Srinagar to Uri and along Sopore, Durgwilla, Kupwara, Traigaon on the road to Tangdhar.

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[3]. However, the collapse of stone walls of random rubble types was a surprise even with much lesser shaking. It has been well established that the local soil site and topographical conditions play a significant role in modifying the nature of ground motion which leads to varying degree of response to similar structures. Structures located on ridges and along steep slopes were subjected to a greater degree of damage in comparison to those located in valleys, during this earthquake as well. The affected region lies in the top two high risk seismic zones of IV and V of Indian seismic code IS:1893 (ref. 4) with an expected intensity of IX or more in the zone V and of VIII in the zone IV.

The region affected by the Muzaffarabad 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 vary from pitched flexible roofs to mixed flexible and rigid concrete floors and roofs.

Structures need to have suitable earthquake-resistant features to safely resist large lateral forces that are imposed on them during infrequent earthquakes. Ordinary structures for houses are usually 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 depends 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 and 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 was observed in 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 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 2 *a*).

In older constructions, another form of timber-laced masonry, known as *Taq* has been practiced in which large pieces of wood have been used as horizontal runners embedded in the heavy masonry walls, which add to the lateral load resisting ability of the structure (Figure 2 *b*). 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 greater integrity under lateral loads (Figure 2 *c*). 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

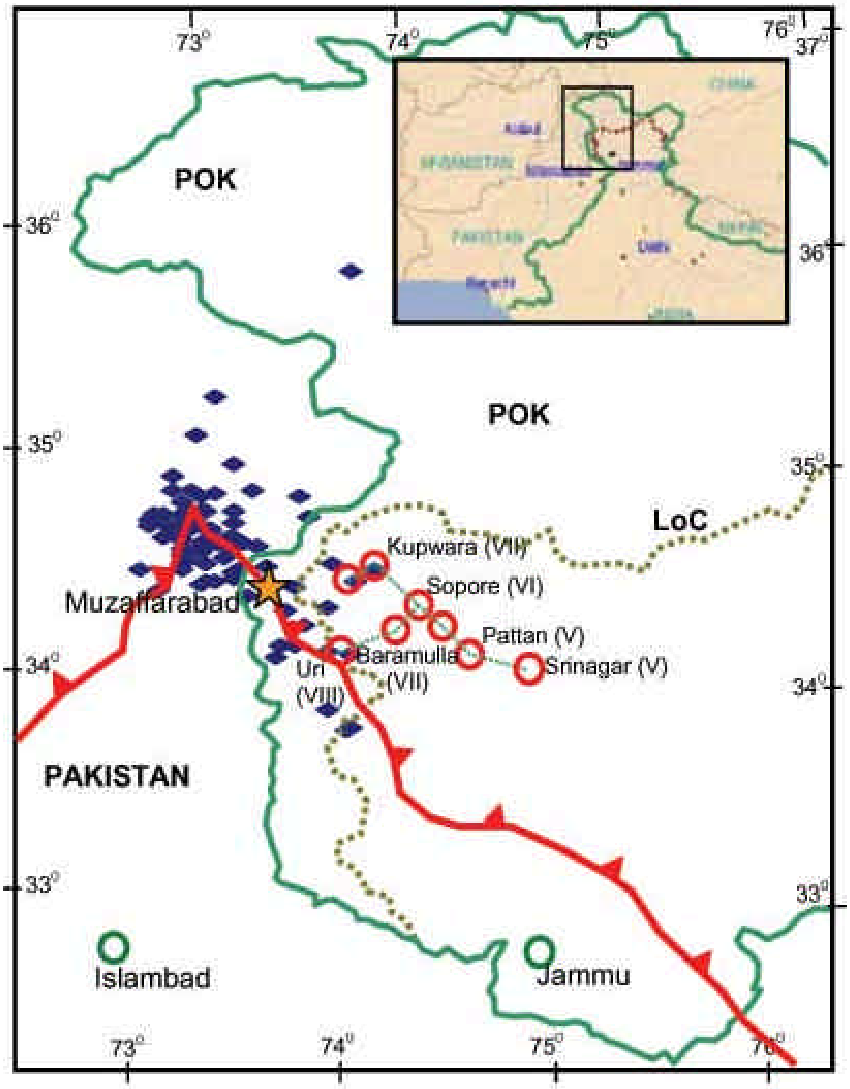

Figure 1. Location of epicentre of the earthquake and its aftershocks, Main Central Thrust fault, and the towns visited in the Indian side of Line of Control (LoC).

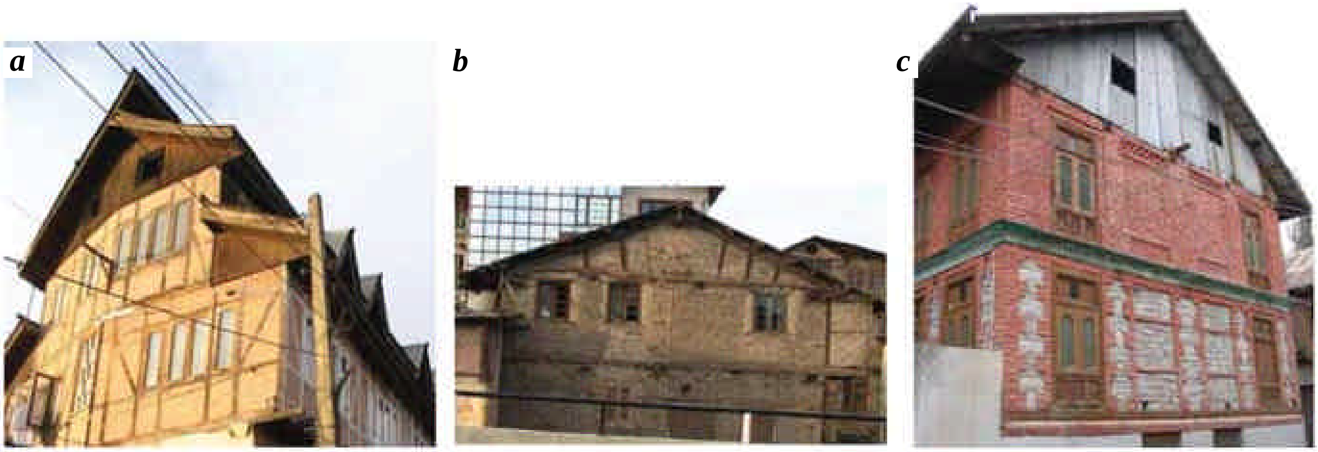

Figure 2. Traditional masonry for proven earthquake resistance. ***a***, *Dhajji-dewari* system of timber laced masonry for confining masonry in small panels; ***b***, *Taq* system of embedding timber thick walls; ***c***, Brick masonry piers for timbers in stone infilled wall.

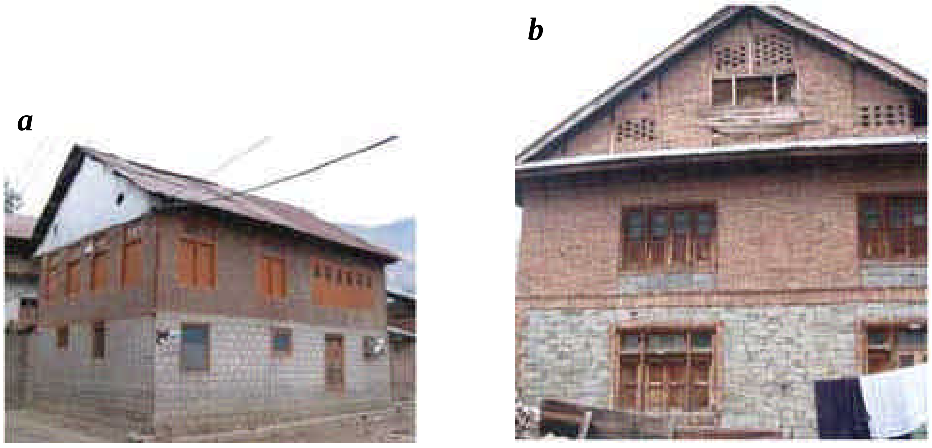

Figure 3. Examples of mixed construction involving *dhajji-dewari* and dressed/undressed stone masonry and brick masonry.

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

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 their 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 collapsed 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 walls 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 in Figure 5. However, timber-laced masonry can maintain its integrity even when the supporting masonry walls in lower stories are severely damaged (Figure 6).

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, 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. Corrugated Galvanized Iron (CGI) sheets have also been used as a roofing material in many cheaply built school buildings. These roofs are inherently weak in shear and cannot 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 7).

a

b

Figure 5. Damage to brick masonry buildings. ***a***, Out-of-plane collapse of walls; ***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. Simply supported prestressed concrete girder bridge on NH1A in Zone V which lacks restrainers for preventing unseating during earthquakes.

Figure 9. Landslide on NH1A near Uri disrupted the road traffic.

The area has a number of highways and pedestrian bridges over rivers, rivulets, and gorges. No serious damage to any of the highway bridges was noticed in the areas visited away from the epicenter. However, it has been reported that the Aman Setu at India-Pak border closer to the epicenter has suffered damage. Most of pedestrian bridges were of suspension types and no particular damage to the bridge structure or to the supporting pylons was noticed. 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 no provision to prevent unseating (Figure 8).

Roads closer to epicentral area in the mountainous region suffered extensive landslides which resulted in the closure of traffic for many days (Figure 9). 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. Pipelines 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 10). Such damages have been observed in many past earthquakes which highlight the inadequacy of current design methods of such tanks.

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

Figure 10. A 50000 gallon water tank at Traigaon developed flexure tension cracks in its supporting shaft rendering it unsafe for use.

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 residential units in the affected area relied on load-bearing masonry walls for seismic resistance. Much of the damage could be attributed to inferior construction 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. The seismic performance of such masonry systems should be researched and guidelines developed for their cost-effective implementation which can optimally exploit their inherent ability to resist seismic actions.

Modern bridges, roads, water tanks, etc., which have been constructed in the Kashmir region without due consideration of high seismic activities of the Himalayan region making such civil infrastructure extremely vulnerable for future earthquakes. There is an urgent need that prevailing standard codes of practices for earthquake-resistant design and construction should be adhered to, and wherever these provisions are deficient, detailed studies should be undertaken to evaluate and improve them. Similarly, seismically deficient structures need to be strengthened to reduce their vulnerability.

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ACKNOWLEDGEMENTS. We thank the numerous officers and staff of IRCON International and Military Engineering Services (MES) in the affected area who provided help and support during the field visit. Special thanks are due to Professor Sudhir K. Jain, IIT Kanpur, for encouragement and support in carrying out the reconnaissance studies in one of the most difficult areas of the country. We thank DST for financial support.

Received 24 October 2005; revised accepted 17 February 2006

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Reassessment of earthquake hazard in the Himalaya and implications from the 2004 Sumatra–Andaman earthquake

In earlier accounts of seismicity and long-term forcasting of earthquakes, three great earthquakes with magnitude ≥8, namely 1905 Kangra, 1934 Bihar–Nepal and 1950 eastern Assam in Himalaya and a fourth one, i.e. 1897 western Assam with magnitude *Mw* 8.0 were recognized[1–3] (Figure 1). Regions between the rupture zones of these earthquakes were recognized as seismic gaps[4], which were interpreted to have accumulated potential slip for generating future great earthquakes[4,5]. In recent years re-examination of old recorded data has led to revision of the magnitudes and rupture zones of these earlier classified great earthquakes[6,7], with new information being extracted from the archives for calculating magnitudes of historical earthquakes: 1505, 1803, 1833 and others[8]. GPS[9] and palaeoseismological studies[10] have added another dimension to our understanding of the kinematics of seismogenic faults and seismotectonics.

The great Kangra earthquake of 4 April 1905 was assigned magnitude 8.1 with its rupture zone extending ~300 km from Kangra to Dehra Dun[1,11]. This magnitude has been recently revised to *Mw* 7.8 with rupture extending 90 km along the strike[7]; the intensity VIII estimated at Dehra Dun is interpreted as a separate triggered event. The epicentre of