CUEE Report 2011-1

EARTHQUAKE RECONNAISSANCE SURVEY IN NEPAL OF THE MAGNITUDE 6.9 SIKKIM EARTHQUAKE OF SEPTEMBER 18, 2011

Field Investigation Report

Center for Urban Earthquake Engineering (CUEE) Investigation Team:

Anil C. Wijeyewickrema
Kabir Shakya
Deepak Raj Pant
Manika Maharjan

Department of Civil Engineering
Tokyo Institute of Technology

November 1, 2011

Tokyo Tech CUEE

ACKNOWLEDGEMENTS

The investigation team would like to express its sincere gratitude to Prof. Kohji Tokimatsu, Director of Center for Urban Earthquake Engineering (CUEE), Tokyo Institute of Technology for supporting the field investigation and providing financial support.

We are indebted to Prof. Prem Nath Maskey of Institute of Engineering (IOE), Tribhuvan University (TU) for providing useful suggestions and coordinating the field visit in Nepal. We also thank Dean Dr. Bharat Raj Pahari, Prof. Rabindra Nath Shrestha, Prof. Bhakta Bahadur Ale, and Dr. Jishnu Subedi of IOE, TU for their suggestions.

Thanks are due to the earthquake reconnaissance survey team members from Nepal, Mr. Purushottam Karki, Mr. Soyuz Gautam, Mr. Subash Bastola, Mr. Yadin Shrestha, and Mr. Satish Bhagat.

We are grateful to the Nepal Army, Nepal Police, District Administration Offices of Jhapa, Ilam, Panchthar, and Taplejung, and the Nepal Red Cross Society for sharing their field investigation data and providing useful information.

Finally, we express our sincere thanks to all the people who directly or indirectly assisted in the successful completion of the field survey.

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1. INTRODUCTION

1.1 Overview of the Earthquake and Field Investigation

A magnitude 6.9 earthquake occurred in Nepal on September 18, 2011 at 6:25 PM (Nepal standard time). The epicenter (27.72°N, 88.06°E) of the earthquake was 272 km east of Kathmandu, while the focal depth was 19.7 km (Fig. 1.1(a)). The earthquake was complex due to two events occurring within a short interval of time (USGS, 2011). The earthquake is widely thought to be an intraplate event within the upper Eurasian plate or the underlying Indian plate, rather than an interplate event. Several areas of Nepal, India, Bhutan, Bangladesh, and Tibet were subjected to strong shaking during the earthquake and more than 100 fatalities (see Appendix A) and widespread damage have been reported. The shaking was felt throughout eastern Nepal and some parts of central Nepal including Kathmandu. The earthquake had an intensity of VI on Modified Mercalli Intensity (MMI) scale in the towns of Taplejung and Phidim in easteren Nepal and an intensity of IV on MMI scale in Kathmandu (Fig. 1.1(b)). Although several buildings suffered extensive damage, it was fortunate to observe that fatalities in Nepal were relatively low with six reported (three in Kathmandu, two in Sunsari and one in Sankhuwasabha). According to the Ministry of Home Affairs of Nepal, as of October 25, 2011, thirty persons got injured critically, while 134 received minor injuries. The earthquake displaced 12,301 persons of 4,851 families. A total of 6,435 houses were damaged completely, 11,520 damaged partially, and 3,024 houses suffered only minor damage.

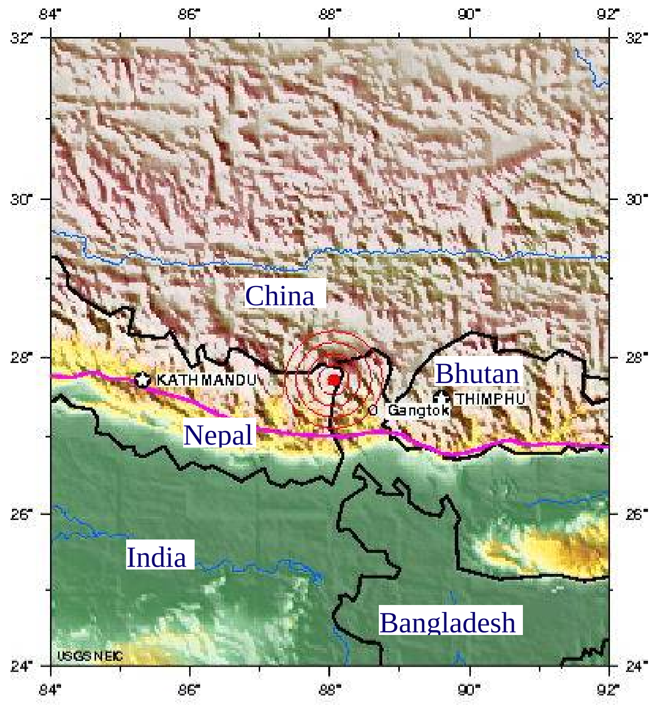
The Center for Urban Earthquake Engineering (CUEE) at Tokyo Institute of Technology (Tokyo Tech) sent a team of researchers from October 11-20, 2011 to investigate the damage caused by the earthquake. CUEE investigation team carried out the field survey in collaboration with Institute of Engineering (IOE), Tribhuvan University, Nepal. The list of team members is given in Appendix B; the itinerary of the visit is shown in Appendix C. The survey sheet used to record the damage to buildings is shown in Appendix D. The objective of the mission was to assess the extent and nature of damage caused by the earthquake, especially in Kathmandu and the eastern Nepal and to propose seismic mitigation measures for structures. While the team conducted its field activities surrounding the densely populated towns, the damage data of the remote villages was collected from the District Administration Offices and the Nepal Red Cross Society. To make the investigation thorough, it was decided to focus on (a) three districts of Kathmandu Valley i.e., Kathmandu, Lalitpur, and Bhaktapur and (b) all the districts of Mechi administrative zone i.e., Jhapa, Ilam, Panchthar, and Taplejung. In particular, the towns of Ilam (el. 1,208 m, Ilam district), Phidim (el. 1,141 m, Panchthar district), and Taplejung (el. 1,441 m, Taplejung district) were investigated (see Fig. 1.2). The road from Bhadrapur to Taplejung is 243 km and includes approximately 200 km of mountainous roads.

1.2 Seismic Hazard in Nepal

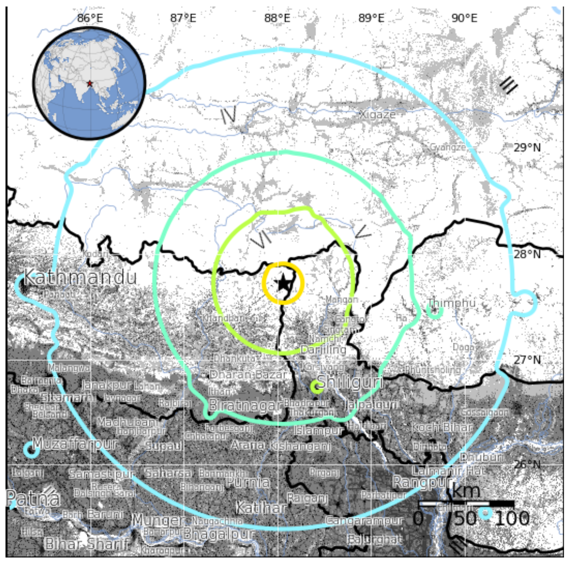
Nepal is a country with diverse geographical setting varying from low lands in the southern part to the high mountains including the world's highest peak Mount Everest (el. 8,848 m) in the north. One third of the Himalayan arc, which marks an active plate boundary between Eurasian and Indian plates (Fig 1.3) lies in the northern Nepal and it is a source of major seismicity in the area (Fig. 1.4). The presence of numerous active faults in Nepal clearly highlights the seismic hazard in this Himalayan nation (see Fig. 1.5). It is further noted that the September 18 earthquake occurred in a region where the Indian plate converges with the Eurasian plate at a rate of approximately 46 mm/yr towards the north-northeast (USGS, 2011).

Nepal has mainly experienced two devastating earthquakes in the last century. A magnitude 8.1 earthquake occurred in January 1934, with epicenter (26.50°N, 86.50°E) close to Nepal-India border region (ASC, 2011) (see Fig. 1.6). The Kathmandu Valley experienced intensities of IX-X in the MMI scale. A total of 8,519 persons were reported dead in Nepal, out of which 4,296 persons died in Kathmandu alone (Pandey and Molnar, 1988). A magnitude 6.8 earthquake occurred in August 1988, with epicenter (26.755°N, 86.616°E) in eastern Nepal (ASC, 2011). The MMI estimated in Kathmandu was VII-VIII and at least 721 people lost their lives in Nepal due to this earthquake (NSET, 2011).

Due to low frequency of the earthquakes being felt in Kathmandu Valley, which is the political and the educational hub of the country, few people in the country understand the risk of earthquakes. However, based on tectonic settings and historical seismicity, it is evident that the country lies in a high seismic region. Although the seismic hazard map produced by the National Seismological Center (Fig. 1.7) is supposed to be followed while designing structures, it has not been followed for designing structures, except a few modern large structures due to insufficient laws and regulations. The expected peak ground acceleration with a 500 years return period near the epeicentral region of the September 18, earthquake is between 0.1g to 0.2g, which is quite low compared to 0.45g expected near Sindhuli and Janakpur (see Fig. 1.6). Despite the high seismic risk in the country, the structures in the remote villages as well as the ancient towns of Kathmandu Valley are made of stone or brick masonry with mud mortar, having little resistance against seismic loads. It is only the modern buildings that use reinforced concrete moment resisting framed system with brick masonry infill walls. Thus a high seismic hazard exists throughout the country.



(a)



(b)

Fig.1.1. (a) Location of the earthquake and (b) Modified Mercalli Inetensity distribution. (Source: USGS)

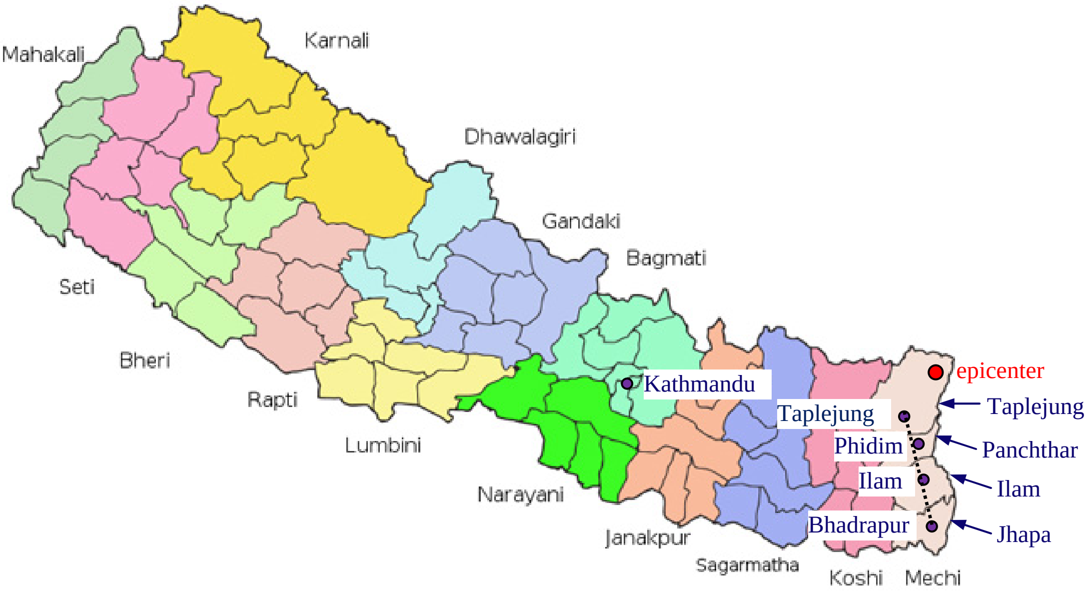
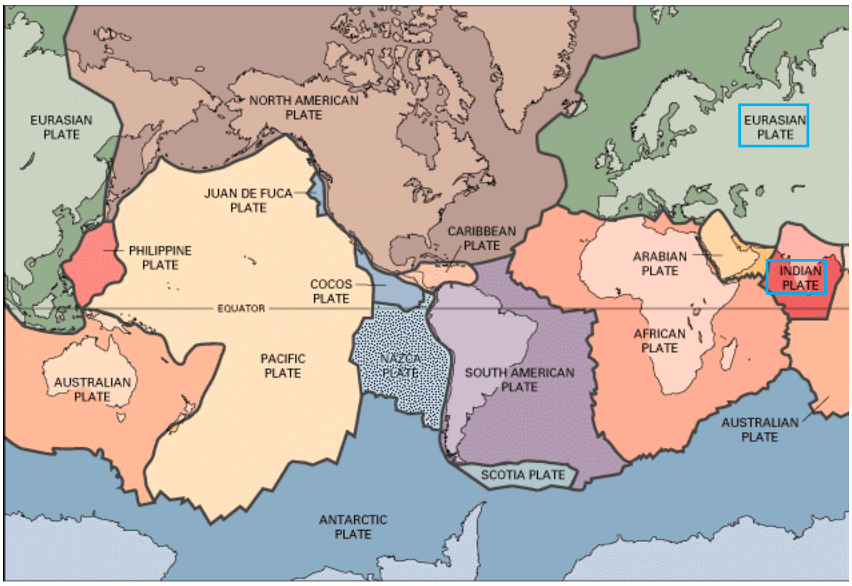


Fig. 1.2. Map of Nepal showing the administrative zones and places visited.
(Source: http://www.nonhores.com/ref-country-npl.php.)



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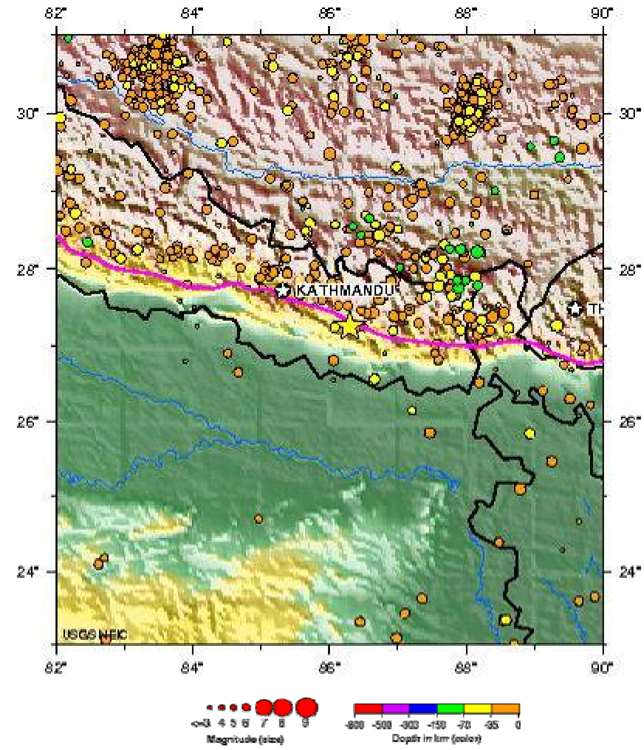

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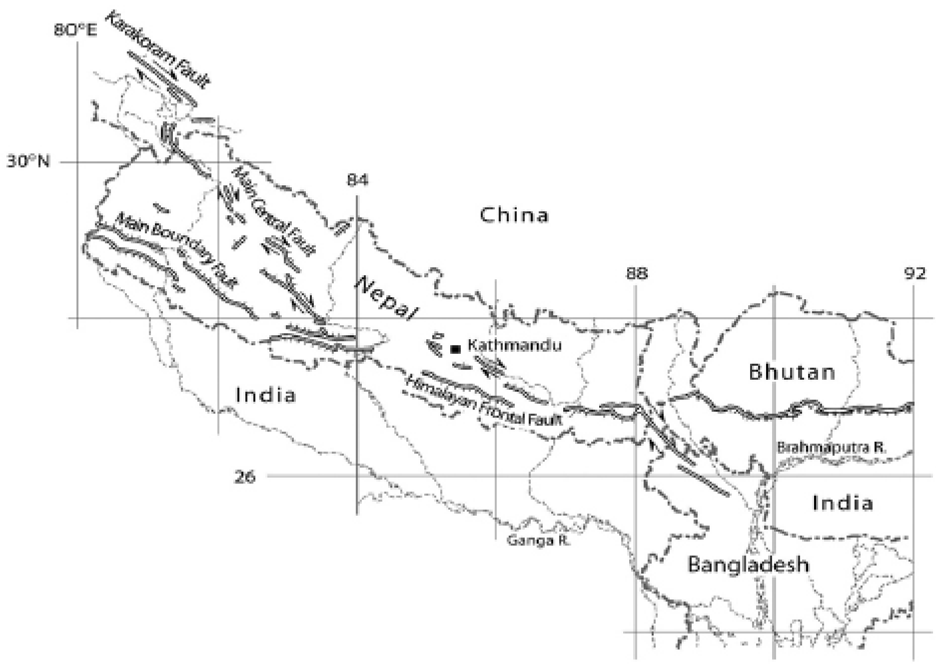

Fig. 1.5. Active faults in and around Nepal Himalaya (Chamalagain, 2009).

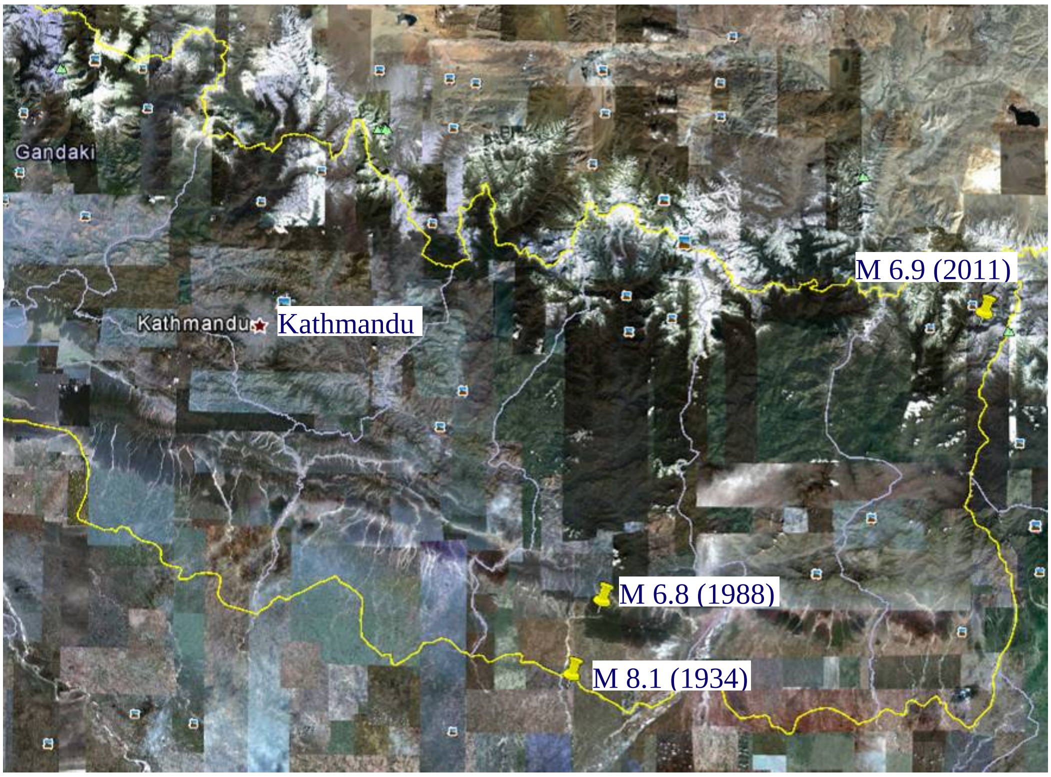

Fig. 1.6. Epicenters of the major earthquakes in the last century in Nepal (source: Google Earth). The border of Nepal is shown in yellow color.

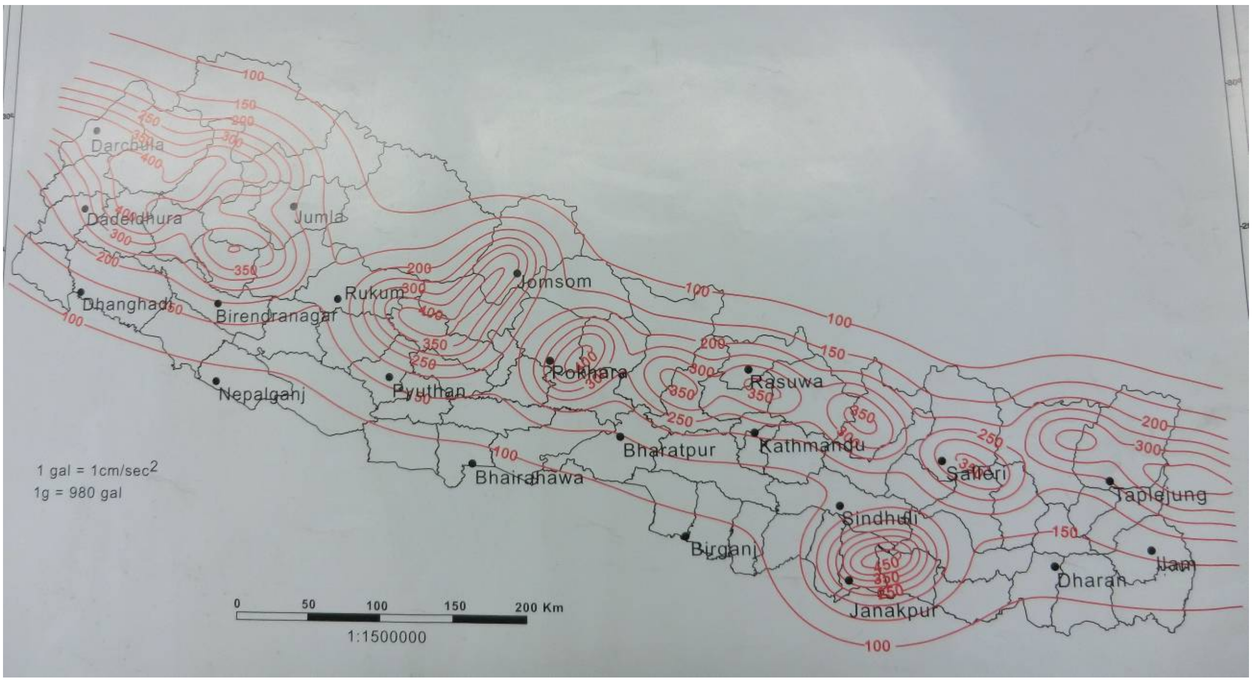

Fig. 1.7. Seismic hazard map of Nepal showing bedrock peak ground horizontal acceleration contours in gals for 500 years return period (source: National Seismological Center, Nepal).

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2. FIELD SURVEY IN KATHMANDU VALLEY

Kathmandu Valley comprises of three districts viz. Kathmandu, Lalitpur, and Bhaktapur (Fig. 2.1). In Kathmandu district, although several old brick-masonry buildings experienced some minor cracking, the major damage that resulted in the death of 3 persons was the collapse of the boundary wall of the British Embassy (Fig. 2.2). The boundary wall had very high length-to-height ratio that invariably resulted in out-of-plane failure of the wall. Despite the existence of several old stone-masonry buildings in poor condition, no significant damage due to the earthquake was observed in Lalitpur district. It was found that the Bhaktapur district was mostly affected by the earthquake. Very old residential buildings, which were not in good condition in the old city of Bhaktapur suffered extensive damage due to the earthquake. It is important to note that the Bhaktapur area also includes Bhaktapur Durbar Square, where no major signs of damage were observed due to the retrofitting works done prior to the earthquake.

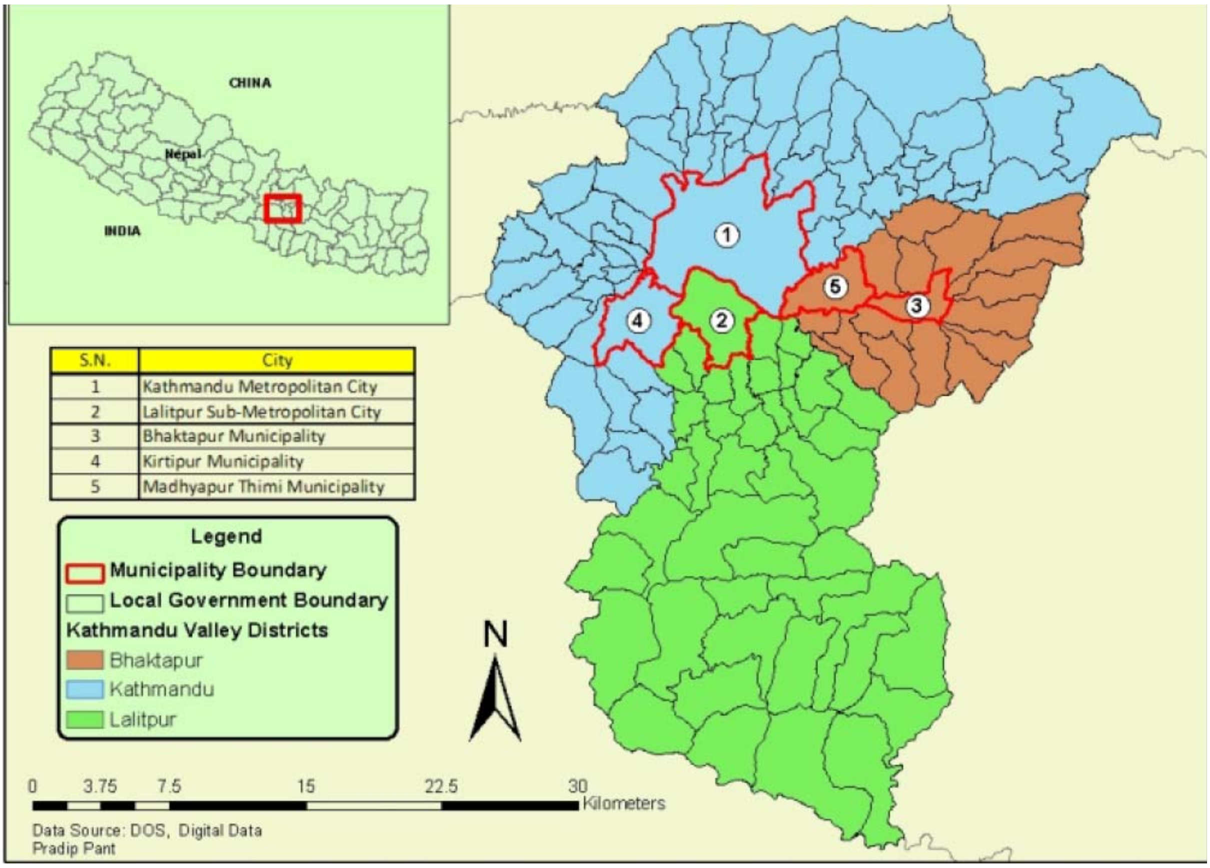


Fig. 2.1. Map of Kathmandu Valley showing districts and municipalities. Kathmandu Valley consists of three districts Kathmandu, Lalitpur, and Bhaktapur. (Source: http://www.eastwestcenter.org).

Fig. 2.2. Collapsed boundary wall of the British Embassy in Kathmandu where three people were killed (source: nagariknews.com). High length-to-height ratio might have resulted in the out-of-plane failure of the wall.

The old city of Bhaktapur consists of houses constructed in blocks of 5-10 buildings sharing common walls. The typical structural system consists of partial-load bearing masonry walls with timber floors and sloping roof, while the common construction material is brick with mud mortar. Numbers of stories in buildings vary from 3 to 5 stories. Some of the buildings in poor condition that were expected to collapse under the earthquake of even a minor intensity survived (see Fig. 2.3). The major damages to buildings are shown in Figs. 2.4-2.7. Typical forms of damage include (a) vertical cracks on walls along the mortar joint at the common face between two adjacent buildings (Fig. 2.4), (b) diagonal cracks in masonry walls starting from corners of walls and lintels and interface between windows/doors and walls (Fig. 2.5), and (c) collapse of the top story (Fig. 2.6(a)). It is noted that several buildings had experienced permanent out-of-plane deformation of walls. According to the local people such deformation existed even before the earthquake. It is expected that the buildings had experienced such out-of-plane deformation due to self weight over the course of time. Although minor to major cracks were present in several buildings in the area, the numbers of collapsed buildings were very few (see for example Fig. 2.7). In addition, none of the buildings was found to be completely collapsed. Only partial collapse, especially collapse of the side walls was observed. Therefore, damage cannot be considered as widespread in Bhaktapur district.

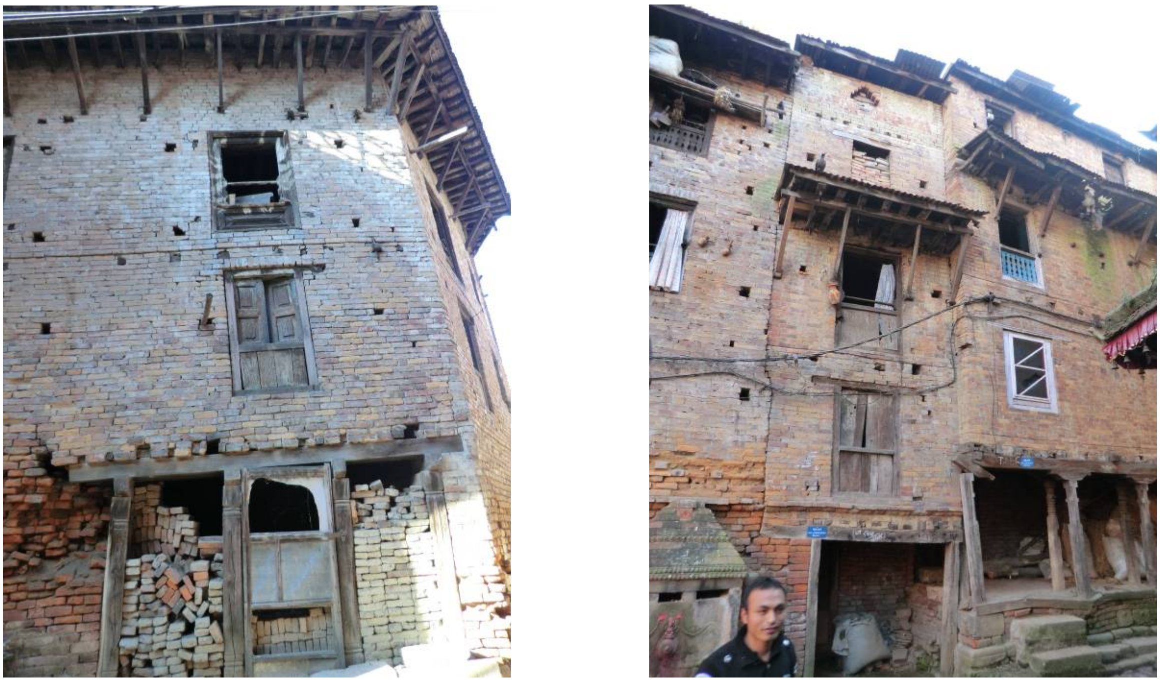


Fig. 2.3. Buildings in poor-condition, partially resting on timber frames, which did not suffer serious damage.

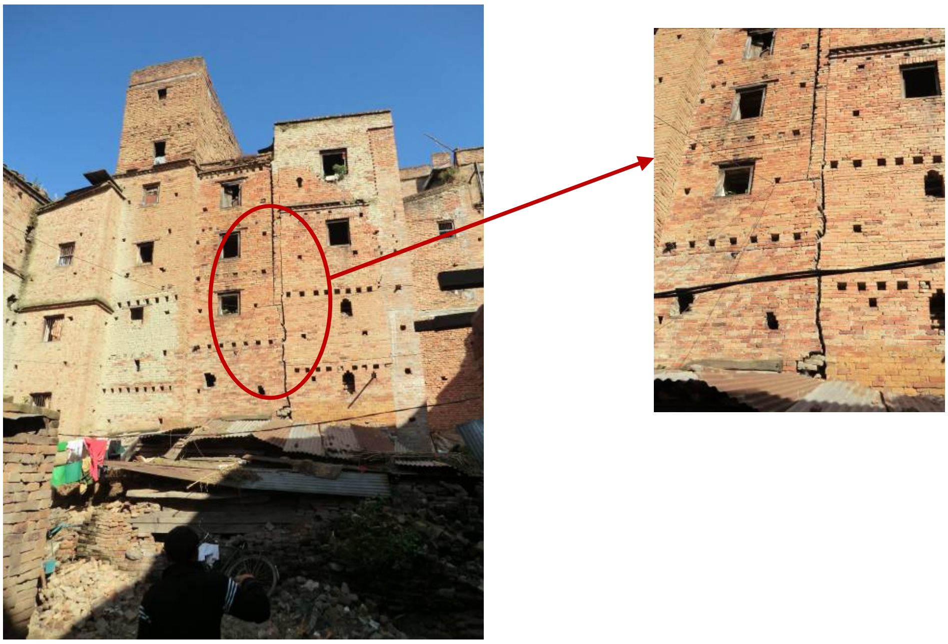


Fig. 2.4. Buildings with vertical cracks on wall along the mortar joint at the common face between two adjacent buildings. The figure also depicts several buildings in a block with shared common walls. Construction material is brick with mud mortar, while the structural system is partial-load bearing.

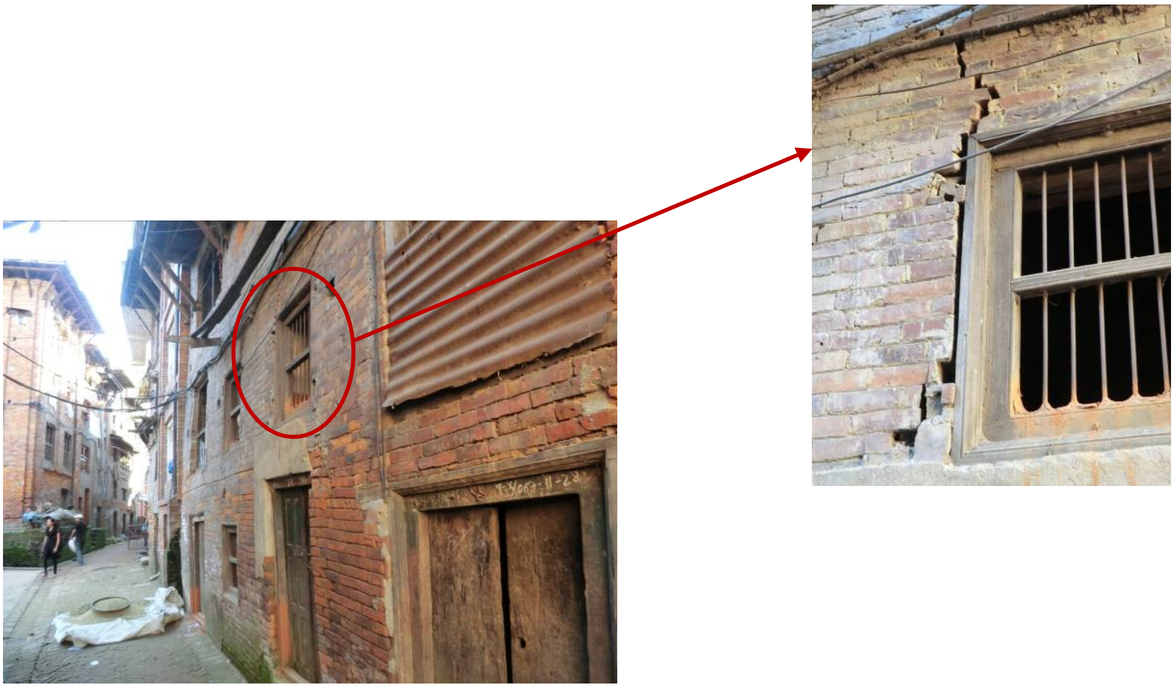


Fig. 2.5. A building with cracks starting from the interface between window and masonry wall. Cracks could also have propagated from the corner of lintels. The figure also shows permanent out of plane deformation of walls, which has resulted due to self weight of the building itself, prior to the earthquake.

(a) (b)

Fig. 2.6. (a) Top story of the left building (brick masonry with mud mortar) collapsed on to the roof of a building (brick masonry with cement-sand mortar) under-construction, leading to the collapse of the roof of the latter. The age of the existing building is 60 years. (b) Separation between two buildings due to the earthquake. The building on the left is made of the *first-class brick*, while that on the right is made of the *second-class brick*. Pounding between adjacent buildings could also have exaggerated the separation.

(a) (b)

Fig. 2.7. A brick masonry building with a totally collapsed side wall: (a) photo taken by the investigation team on October 12, 2011 and (b) photo taken by the news reporters immediately after the earthquake (source: http://www.mysansar.com/).

3. FIELD SURVEY IN EASTERN NEPAL

The epicenter of the earthquake was in Taplejung district of the Mechi zone, which lies in the Eastern Development Region of Nepal (Fig. 3.1). The investigation team carried out an investigation in the major towns of all the districts of the Mechi zone. The data of remote villages was collected from various sources including the District Administration Office, Nepal Red Cross Society, and the local people. It is noted that the areas badly affected by the earthquake are poor and remote villages with houses scattered over a wide region. Although many structures suffered extensive damage, no fatalities were reported in the entire study area. This could be attributed to the fact that most people were outside their homes at 6:25 PM when the earthquake occurred. The field investigation team used the North-South Mechi highway to reach the town centers of the districts. No signs of damage to the bridges along the highway were observed. According to the local people of Jhapa district, no significant damage in whole district was reported hence, the focus of the study was on the three districts Ilam, Panchthar, and Taplejung. This chapter presents the summary of the structural damage observed in these three districts.

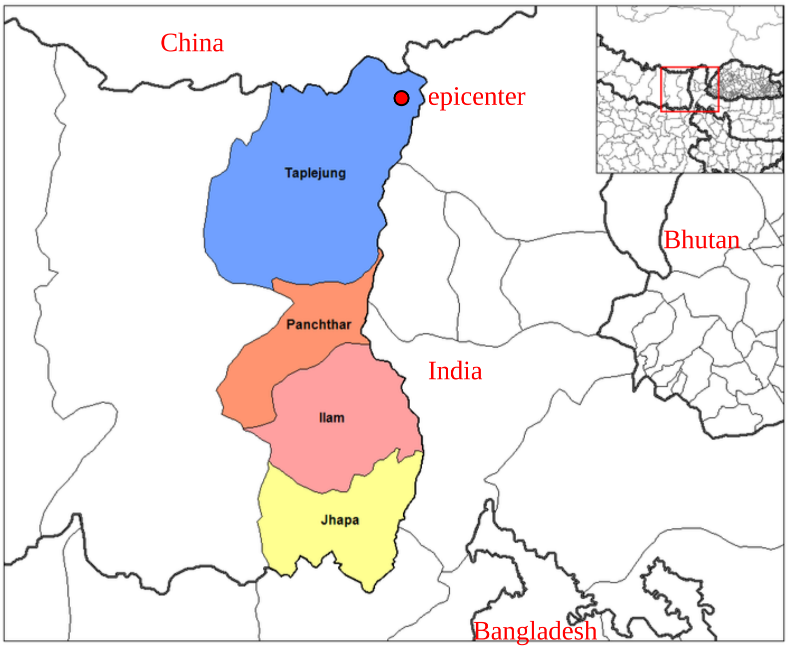


Fig. 3.1. The four districts of Mechi zone Jhapa, Ilam, Panchthar, and Taplejung with the location of the epicenter of the September 18, 2011 earthquake.

3.1 Damage in Ilam District

Ilam district headquarter is located in the town of Ilam (area 1,703 km^2) which has a population of 282,806. There is one municipality i.e., Ilam municipality and 48 Village Development Committees (VDCs) in the district (Fig. 3.2). Typically the buildings in VDCs and outside the Bazar areas of the municipality are structures made of stone masonry with mud mortar. In the Bazar areas of Ilam, most of the structures are reinforced concrete (RC) framed structures with brick masonry infill walls. It was realized that most of the RC framed structures were designed only for gravity loads based on thumb rules and the adoption of design codes is in its infancy. It was found that the most of the Ilam municipality area consists of stiff soil.

While no one died, 3 persons were injured critically due to the earthquake. A total 19,556 persons of 6,114 families were affected by the earthquake, while 7,995 persons of 2,141 families were displaced. Table 3.1 summarizes the damage to the buildings, in which 12 schools remain not functional at all. Mostly affected VDC is Chamaita and least affected are Mahamai, Chulachuli and Danabari (Fig. 3.2). In Ilam municipality alone, total 371 families were affected, 65 buildings damaged totally, and 306 buildings suffered partial damage. No serious health-related problems were reported after the earthquake. As a relief measure, the government has provided relief funds to the affected families. The Nepal Red Cross Society in Ilam had distributed cooking utensils, tents, and clothes.

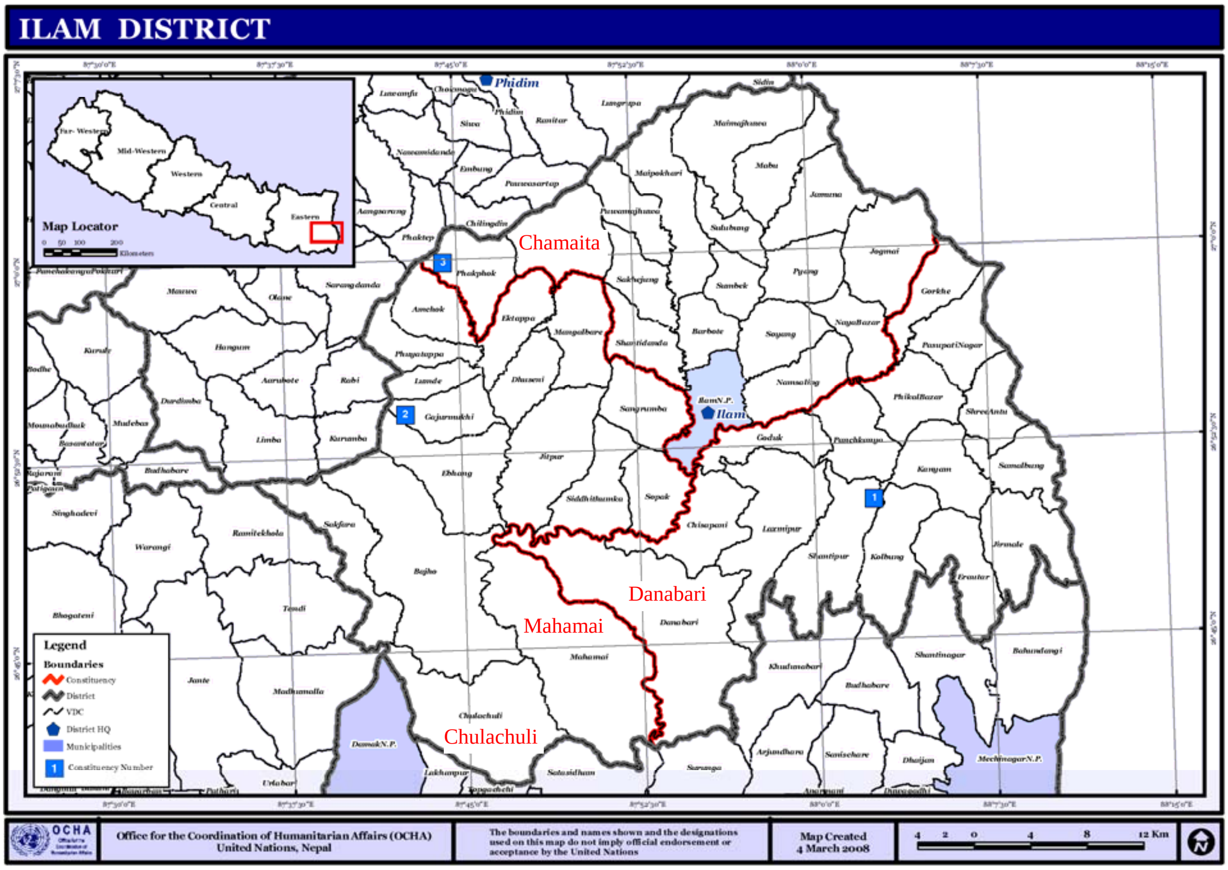


Fig. 3.2. Ilam district map (source: http://wikipedia.org/wiki/File:NepalIlamDistrictmap.png).

Table 3.1. Damage to buildings in Ilam district. (Source: District Administration Office, Ilam.)

Category	Totally damaged	Partially damaged	Total
School buildings	268	230	498
Hospitals	2	2	4
Other government offices	1	10	11
Temples and monasteries	5	7	12
Residential buildings	2,141	4,115	6,256

Figures 3.3-3.13 show typical damaged buildings in the Ilam district. Damage to the buildings made of stone masonry with mud mortar was extensive. Most of such buildings suffered extensive cracks (Figs. 3.3, 3.5), permanent out-of-plane deformation (Fig. 3.4), collapse of a portion of the wall (Figs. 3.8, 3.11(a), 3.12, 3.13(a)) and even total collapse (Figs. 3.11(b), 3.13(b)). Some of the recently constructed buildings suffered severe cracks (Figs. 3.6, 3.9, 3.10) and separation between infill walls and the main frame (Fig. 3.9). Poor design and construction, lack of maintenance, over-occupancy, unnecessary irregularities in the structural system, and local site effects can be attributed to the widespread damage in the Ilam district.

(a)

(b)

Fig. 3.3. A damaged single-story load-bearing stone masonry (mud mortar) building: (a) with cracks initiating from the interface between window and wall and (b) with cracks inside the building. The age of the building is 30 years. The wall thickness in the building is 450 mm, while depth of the foundation is 1.2 m.

(a)

(b)

Fig. 3.4. A damaged single-story load-bearing stone masonry (mud mortar) building: (a) with permanent out-of-plane deformation of back wall and cracks at the base and (b) with permanent out-of-plane deformation of front wall. The permanent deformation at a portion of front wall was about 5 cm. The building has a length of 36 m and width of 7.2 m with no interior partition walls. High length-to-width ratio of the building resulted in the damage. The false ceiling fell down during the earthquake. Although, the building is being used at the moment, the owner plans to demolish it.

(a)

(b)

Fig. 3.5. A damaged single-story load-bearing stone masonry (mud mortar) building: (a) with plaster fallen down and (b) severe cracks extending throughout the thickness of the wall. Although, the building is being used at the moment, the owner plans to demolish it.

(b)

(a) (c)

Fig. 3.6. A damaged modern 3-story RC framed building with cantilevered floor slab and brick masonry infill walls: (a) with cracks in exterior; (b) with cracks in interior; and (c) cracks on the floor along the edge of underground water tank/ septic tank.

(a) (b)

Fig. 3.7. Damage to a single-story L-shaped brick masonry (mud mixed with cow dung and rice husk mortar) building: (a) cracks in a wall and (b) cracks above the door lintel. The roof and partition walls are made of timber. Age of the building is 35 years.

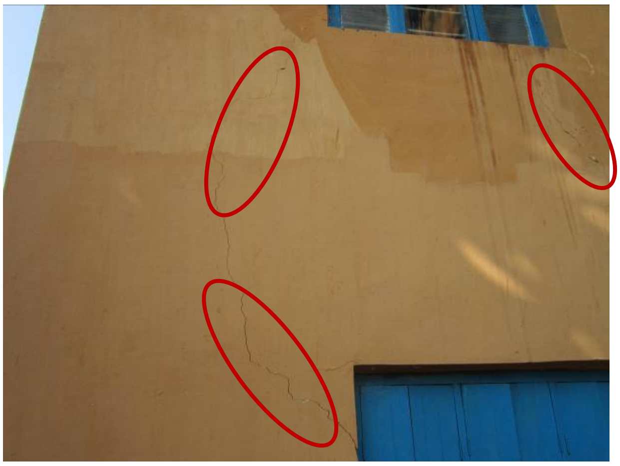
(a) (b)

Fig. 3.8. A damaged stone masonry (mud mortar) building: (a) with collapsed wall at the front portion and (b) with collapsed wall at the back portion.

(a) (b)

Fig. 3.9. Damage to a modern 3-story RC framed building with brick masonry infill walls: (a) separation between RC frame and wall and (b) diagonal crack starting from the corner of lintel and extending up to the floor level. The building has a length of 12.5 m and width of 8 m.

(a)



(b)

Fig. 3.10. Damage to a 25-years old building with RC as well as timber frame: (a) cantilever part in the verge of failure and crack at the floor level and (b) cracks extending between two windows of consecutive floors. The length of the building is 22 m and the width is 14 m.

(a)

(b)

Fig. 3.11. (a) Severe damage to the wall of a stone masonry (mud mortar) building and (b) a completely collapsed building (in the foreground) and a similar building which survived without collapse (seen behind it). (Source: District Administration Office, Ilam).

(a)

(b)

Fig. 3.12. (a) A damaged building (still being used) with collapsed wall in the kitchen and (b) a portion of the collapsed wall of a stone masonry building. (Source: Nepal Red Cross Society, Ilam).

(a)

(b)

Fig. 3.13. (a) A completely collapsed stone masonry building (in the foreground) and a severely damaged building (behind it) and (b) Rubble of the collapsed building in a village. (Source: Nepal Red Cross Society, Ilam).

3.2 Damage in Panchthar District

In Panchthar district, the survey was conducted mainly in the towns of Ranke and Phidim. Through the courtesy of local police and Central District Office, some of the photographs of the earthquake affected sites where our survey team could not visit and descriptions of damages were collected.

In Ranke, most of the buildings were of 1 or 2 storys and were constructed using the locally available materials such as stone, mud and timber. Also, some recently built RC buildings were found. On investigating the damage, it was found that most of the buildings constructed of stone masonry with mud mortar suffered heavy damage including total collapse in some cases. Only minor damage or no damage was observed in the buildings primarily constructed with timbers and reinforced concrete (RC).

Fig. 3.14. Out of plane failure of stone masonry walls (source: Local Police). Note the 450 mm thick stone and mud mortar walls.

Fig. 3.15. Out of plane failure of stone masonry partition wall (source: Local Police).

Fig. 3.16. Collapse of school building at Cheplung, Panchthar (source: Local Police).

Fig. 3.17. Collapse of stone masonry wall in timber framed building (source: Local Police).

Fig. 3.18. Collapse of Laxmi Narayan Temple located north of Ranke on the road to Phidim .

(a)

(b)

Fig. 3.19. A heavily damaged school building with: (a) collapsed wall and (b) a damaged classroom still used for classes.

Buildings constructed of stone masonry with mud mortar are very weak in resisting lateral loads due to earthquakes. One of the examples of failure of such a stone masonry building is shown in Fig. 3.14, where the external wall of this small building was totally damaged due to out of plane failure and in another building, half of the thickness of the wall was torn out in out of plane direction. Not only external walls but also the partition walls also exhibited significant damages (Fig. 3.15). A complete collapse of a school building (Fig. 3.16) also illustrates the inappropriateness of stone masonry mud mortar buildings in seismic prone regions. In some buildings, stone masonry walls were used along with the timber frames in the first and second floors as shown in Fig. 3.17. The stone masonry wall was damaged during the earthquake, the timber frame system performed satisfactorily in the same building due to which the building may be used after some major maintenance in the damaged portion. However, a temple constructed of stone masonry in the first floor and timber frame system only on the second frame (Fig. 3.18) was heavily damaged. It can clearly be seen that after the collapse of the stone masonry walls, the timber posts were hanging from the roofing. Figure 3.19 shows that the presence of the steel frame and truss prevented the total collapse of the building, unlike the school building shown in Fig. 3.16, though the infill stone masonry walls were heavily damaged. Due to the intact steel columns and the roofing that even after the collapse of the infill walls, the classes could be conducted in the school building. One of the poor non-engineered construction practices can be seen in Fig. 3.20. A timber building supported by some timber posts and covered with corrugated galvanized iron (CGI) sheet was constructed nearby the road. During earthquake the supporting timber posts were broken and the building toppled down leaving it upside down. Figure 3.20 was obtained from the local police in Ranke Bazar, prior to the field visit, the rubbles had already been cleared.

Fig. 3.20. Toppled building lying upside down after the failure of supporting timber posts.

Fig. 3.21. Fissure on ground passing through the building.

Fig. 3.22. Fissure on the ground passing through the RC framed building.

Fig. 3.23. Settlement of RC building.

Fig. 3.24. Cracks on the infill masonry wall of RC framed building.

Fig. 3.25. Different types of buildings in Phidim Bazar.

Fig. 3.26. Recently completed RC framed hotel building.

Apart from damage to the buildings due to lateral seismic load, in some locations the fissures on the ground were also observed. It was interesting to note that the fissure was passing through many buildings along the road as shown in Figs. 3.21 and 3.22 causing differential settlement of the buildings (Fig. 3.23) and inducing some minor cracks in the infill walls of the RC building (Fig. 3.24).

Phidim Bazar is located in a small valley of Panchthar District. The bazar is composed of various types of buildings constructed with locally available timber, stone masonry, brick masonry (Fig. 3.25), few reinforced concrete buildings (Fig. 3.26) and some buildings constructed using a traditional building technique locally known as "*Centibera*" (Fig. 3.27). The traditional masonry buildings and *Centibera* buildings are of 1-2 storys and reinforced concrete buildings are of more than 2 storys. The *Centibera* buildings are constructed with the stone masonry walls up to the plinth level or the first floor, on top of which the walls comprised of wooden frames together with woven bamboo mesh and cement mortar plaster or plaster composed of a mixture of mud, cow dung and rice husk are built (Fig. 3.28). During the field visit, it was found that in *Centibera* buildings, there were no cracks (Fig.

3.29), however, in the brick masonry building close to the *Centibera* building many cracks were visible in the masonry walls (Fig. 3.30). Also, the brick masonry infill walls were separated from the adjoining RC frames of the RC building (Fig. 3.31).

Fig. 3.27. No cracks in the building constructed using *"Centibera"*.

Fig. 3.28. *Centibera* construction technique.

Fig. 3.29. No cracks in the building constructed using *Centibera*.

Fig. 3.30. Shear and flexural cracks in the brick masonry building.

Fig. 3.31. Separation between RC frame and infill brick masonry wall.

Fig. 3.32. Collapse of stone masonry building due to structural pounding: (a) collapsed stone masonry building with the two adjacent RC buildings; (b) building configuration; (c) steel rebar band provided in the stone masonry wall; (d) flexural cracks on RC beam supported by stone masonry walls; (e) residual gap between stone masonry building and RC building 1; and (f) shear cracks on both the orthogonal infill brick masonry walls of RC building.

In Phidim Bazar, a collapse of a stone masonry building due to *structural pounding* was also found. When our survey team reached at the site, the demolition of damaged stone masonry building was in progress. Figure 3.32(a) shows the three buildings without any gap between the adjacent buildings. The white colored demolished building is the stone masonry building . The configuration of the buildings is shown in Fig. 3.32(b).

The stone masonry building was constructed 20 years ago, the RC building 1 was 7 years old and the RC building 2 was recently built. The stone masonry building was of 2 story and other adjacent buildings were 3 storied buildings. The provisions of steel rebar band in the stone masonry wall (Fig. 3.32(c)) and RC tie beams on top of walls (Fig. 3.32(d)) were the peculiar features of this masonry building. During the entire field survey, in no other stone masonry buildings such provisions were observed. However, being constructed with mud mortar and attached with other two RC buildings, the stone masonry building could not withstand the seismic load and the impact loads from the adjacent buildings. During the earthquake, the second floor walls including the roof of the masonry building were completely collapsed dumping the rubbles on the first floor slab. Due to excessive load, some of the RC tie beams failed in flexure. Permanently deflected beam with many flexural cracks at the mid span of the beams were clearly visible (Fig. 3.32(d)). Also, there existed permanent gap of about 5 cm (Fig. 3.32(e)) between the stone masonry building and RC building 1 though there was no gap before the earthquake.

(g)

Fig. 3.32. Collapse of stone masonry building due to structural pounding: (g) cracks on all four walls of a room in RC building 1.

RC building 1 also suffered heavy damage. The brick masonry infill wall at the third floor was completely collapsed. Hence, only the bare frame was visible at the third floor in Fig. 3.32. In most of the cases, the shear cracks are formed in one direction of the masonry walls, however, in RC building 1, shear cracks were generated in all the four orthogonal walls of the building as shown in Fig. 3.32(f). It was believed that the shear crack in one direction of wall was due to the earthquake load and that in another direction was attributed by the shear force exerted by the structural pounding between the buildings. In the rooms at the first floor of the RC building 1, shear cracks were clearly visible in all the surrounding four walls as depicted in Fig. 3.32(g).

Significant amount of cracks were developed in the slabs of RC building 1 and RC building 2 (Fig. 3.32(h)) as a result of structural pounding between RC building 1 and RC building 2. Also, the structural pounding caused the formation of shear cracks at the beam-column joint (Fig. 3.32(i)) and a beam of RC building 2 (Fig. 3.32(j)). Hence, the damages on these three buildings shows one of the good examples of structural pounding and also illustrates the vulnerability to structural pounding of buildings, if the provided gap between the adjacent buildings are insufficient.

(h)

(i)

(j)

Fig. 3.32. Collapse of stone masonry building due to structural pounding: (h) induced cracks on the slab of RC building 2 due to structural pounding; (i) shear cracks in the beam-column joint; and (j) shear crack on the beam.

3.3 Damage in Taplejung District

Similar to other sites, in Taplejung district also most of the buildings were made of locally available materials such as stone, mud and timber having 1-2 storys. There were very few RC buildings. Since the construction practice in Taplejung also resembles to the previous sites, no difference in the nature of damages of the buildings were noticed. Typical types of damages are shown in Figs. 3.33-3.35. Some buildings constructed partly with stone masonry and partly with *Centibera* were also observed. Although significant amount of cracks were present in the stone masonry walls, no cracks were visible in *Centibera* (Fig. 3.36). Some repair work had already been completed in the building shown in Fig. 3.36, but some patches of added stone masonry and some minor cracks were still visible when the survey was conducted. Some typical type of shear cracks in the infill brick walls generated from the window openings of the RC buildings were also noticed (Fig. 3.37).

Fig. 3.33. Collapse of school building (source: Red Cross, Taplejung).

Fig. 3.34. Collapse of stone masonry building (source: Red Cross Taplejung).

Fig. 3.35. Out of plane failure of stone masonry wall.

Fig. 3.36. Cracks occurred in stone masonry wall but no cracks in *Centibera*.

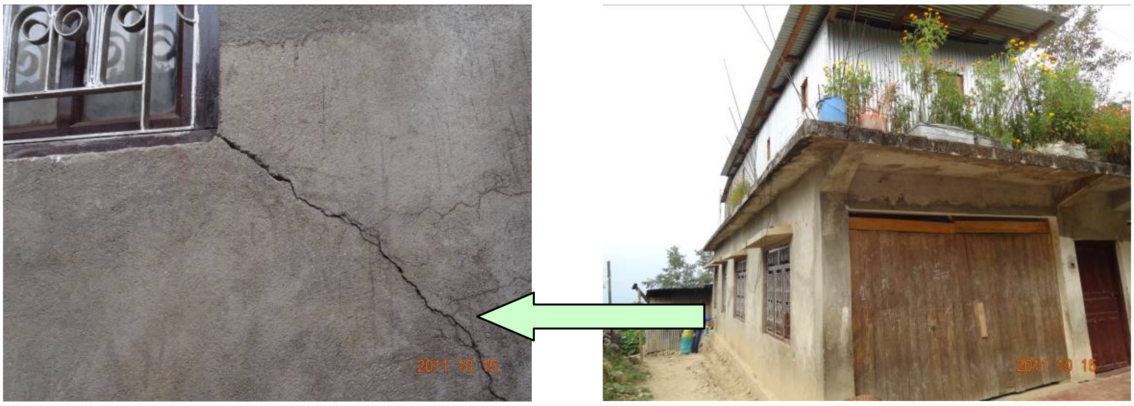


Fig. 3.37. Shear cracks in the infill brick masonry wall of RC building.

3.4 Inspection of Bridges along Mechi Highway

Along the stretch of 243 km of Mechi Highway from Bhadrapur to Taplejung, there were six bridges, four of which are shown in Fig. 3.38. These bridges were also inspected during the survey (Fig. 3.39) but no damage was found.

(a) Kabeli Khola Bridge.

(b) Hewa Khola Bridge.

(c) Khokse Khola Bridge.

(d) Mai Khola Bridge.

Fig. 3.38. Bridges along the survey area in the Eastern Nepal.

Fig. 3.39. Inspecting Khokse Khola bridge.

4. SUMMARY AND RECOMMENDATIONS

The magnitude 6.9 Sikkim earthquake which occurred on September 18, 2011 caused widespread damage to rural buildings in Nepal. Nonetheless, the effect of the earthquake on the urban infrastructure of the country was insignificant. The epicenter located in NE Nepal was 272 km from the capital Kathmandu. The areas mostly affected by the earthquake are remote and poor villages, where buildings had been constructed without considering the effects of earthquake lateral loads. Even in the major towns of Mechi zone, many reinforced concrete (RC) buildings had been built using design thumb rules without following any earthquake-resistant design code. Since most of the people in rural areas affected by the earthquake are farmers, at 6:25 PM, the time of the occurrence of the earthquake, most of the people were not inside their homes. Hence, while more than 6,000 buildings were damaged completely, the casualties were not proportional to the structural damage.

Most of the buildings which suffered severe damage in Bhaktapur in the Kathmandu Valley were made of brick masonry with mud mortar and had been constructed before the building statutes of using seismic design codes were enacted in Bhaktapur Municipality. It is noted that at the present time all the municipalities of Nepal require seismic design of buildings using either the Indian Seismic Code IS: 1893 or the International Building Code (IBC) or any other standard code of practice, but satisfying the minimum requirements of the Nepal National Building Code (NBC). However, most of the buildings in the country have been designed either prior to the enforcement of building laws or have been influenced by poor implementation of the laws. Thus, high seismic hazard exists throughout the major municipalities of Nepal.

One to two story load-bearing stone masonry buildings which are widely used in the villages of eastern Nepal were found to be heavily damaged in Ilam, Panchthar, and Taplejung districts. Weak mortar joints and structural irregularities were identified as a triggering factor for the heavy damage. The buildings which used timber frames suffered less damage compared to load-bearing stone masonry buildings. Typical buildings in the epicentral region of Taplejung district, where the first story is stone-masonry and the upper story is timber-framed, suffered less damage due to the light weight of the upper story. Use of *Centibera* for walls in timber-framed buildings was recognized as a promising technology for low-cost housings. Modern RC buildings suffered negligible damage with few exceptions. Typical damage to RC buildings includes separation of masonry walls from main frame, diagonal cracks propagating from the corners of lintels, and pounding-induced cracks. In addition, no sign of damage to the bridges along the Bhadrapur-Taplejung highway was observed.

Since Nepal lies in an earthquake prone region, the following recommendations are provided to increase the seismic safety of buildings based on the observations made during the field investigation:

- Many existing buildings in remote villages require immediate cost-effective ways of retrofitting using locally available materials such as timber and bamboo.
- Timber-framed masonry structure in the first story and timber-framed *Centibera* structure in the upper story appears to be a promising technology for the construction of new seismic-resistant buildings in the villages.

- All the structures in the major towns of eastern Nepal should be thoroughly investigated for the assessment of their seismic safety and appropriate retrofitting measures should be taken for seismically vulnerable structures.
- Government authorities should ensure that only seismic-resistant structures are designed and constructed, especially bridges, hospitals, and school buildings, in the major towns such as Ilam, Phidim, and Taplejung.

APPENDIX A: FATALITIES DUE TO THE EARTHQUAKE

Table A1. Fatalities due to the 2011 Sikkim earthquake.
(source: http://en.wikipedia.org/wiki/2011_Sikkim_earthquake (Accessed on October 31, 2011)).

Country	Deaths
India	97
China	7
Nepal	6
Bhutan	1
Bangladesh	0

APPENDIX B: TEAM MEMBERS

Team Members from CUEE

Anil C. Wijeyewickrema
Associate Professor
E-mail: wijeyewickrema.a.aa@m.titech.ac.jp

Deepak Raj Pant
Graduate Research Assistant
E-mail: pant.d.aa@m.titech.ac.jp

Kabir Shakya
Graduate Research Assistant
E-mail: shakya.k.aa@ m.titech.ac.jp

Manika Maharjan
Graduate Student
E-mail: maharjan.m.aa@m.titech.ac.jp

Team Members from Nepal

Purushottam Karki
Former Graduate Student, IOE
Tribhuvan University
E-mail: purukarki@hotmail.com

Yadin Shrestha
Graduate Student, IOE, Tribhuvan University
E-mail: edin_stha05@yahoo.com

Soyuz Gautam
Structural Engineer, Hydro Consult Pvt. Ltd.
E-mail: soyuz_gautam@hotmail.com

Satish Bhagat
Student, IOE, Tribhuvan University
E-mail: satish_bhagat2007@yahoo.com

Subash Bastola
Graduate Student, IOE, Tribhuvan University
E-mail: sub37_2005@yahoo.com

CUEE Advisor

Prof. Kohji Tokimatsu

Coordinator from Nepal

Prof. Prem Nath Maskey
IOE, Tribhuvan University
E-mail: pnmaskey@live.com

Fig. B1. Group photos of team members.

APPENDIX C: ITINERARY

Table C1. Itinerary of the field survey.

Day	Task
Oct 11 (Tue)	Leave for Nepal from Tokyo.
Oct 12 (Wed)	Organizational meeting with Prof. Prem Nath Maskey and Dr. Jishnu Subedi and Nepalese team members at Pulchowk Campus. Meeting with Dean Dr. Bharat Raj Pahari of Institute of Engineering (IOE), Tribhuvan University. Field survey in Bhaktapur district.
Oct 13 (Thu)	Leave for East Nepal. Oct. 13 night: Ilam.
Oct 14 (Fri)	Field survey in Ilam and Panchthar districts. Oct. 14 night: Phidim.
Oct 15 (Sat)	Field survey in Taplejung district. Oct. 15 night: Taplejung.
Oct 16 (Sun)	Travel from Taplejung to Biratnagar. Oct. 16 night: Biratnagar.
Oct 17 (Mon)	Travel from Biratnagar to Kathmandu. Field survey in Kathmandu district.
Oct 18 (Tue)	Field survey in Kathmandu and Lalitpur districts.
Oct 19 (Wed)	Earthquake field visit discussion meeting with Prof. Prem Nath Maskey and Prof. Rabindra Nath Shrestha at Pulchowk Campus. Visit Dept. of Civil Engineering and experimental facilities, Institute of Engineering (IOE), Tribhuvan University.
Oct. 20 (Thu)	Leave for Tokyo.
Oct 21 (Fri)	Arrive in Tokyo

APPENDIX D: SURVEY SHEET

Table D1. Survey sheet used to record damage to a building.

Name of Surveyor: Date:

Location: Name of house owner:

No of floors		Age of Building	
Length		Width	

Construction material				
Stone	Mud brick	Mud mortar brick	Brick masonary	RC

Structure type			
Load bearing	Partial load bearing	Framed	Brick masonary

Level of damage			
Slight	Moderate	Heavy	Collapse

Condition of building before earthquake			
Cracks		No cracks	

Remarks