Damage Pattern during Sikkim, India Earthquake of September 18, 2011

M.L. Sharma, B.K. Maheshwari, Y. Singh & A. Sinvhal
Indian Institute of Technology Roorkee, Uttarakhand, India

ABSTRACT:
There was wide spread ground failure and structural damage during the recent Sikkim Earthquake (Magnitude M_L = 6.9) of September 18, 2011. Soon after the earthquake, authors visited different parts of Sikkim located in North-East Part of Himalaya in India and carried out the damage survey during September 25-29, 2011. The extensive survey was carried out in the Gangtok City, Capital of the Sikkim state. The team visited all 4 districts of Sikkim i.e. East Sikkim, North Sikkim, South Sikkim and West Sikkim. The main objective of the survey was to observe the effects of 18th September earthquake and aftershocks on build environment in terms of seismological, geotechnical and structural damages. The paper presents the damage pattern correlating it with level of shaking and epicentral distances at different locations. It was found that many buildings damaged due to poor design and workmanship though level of shaking was not very high.

Keywords: Sikkim Earthquake, Damages, Intensity of Shaking

1. INTRODUCTION

Performance of structures and ground during earthquakes need to be examined for understanding the behaviour of these structures under seismic loads. Past earthquakes have caused widespread damage in the world (Day 2002). Recent Indian earthquakes include Killari (1993), Jabalpur (1997), Chamoli (1999), Bhuj (2001), Sumatra (2004), Kashmir (2005) and Sikkim (2006). For further details, refer to Earthquake reports (DEQ, IIT Roorkee) India being a densely populated country, effects of these disasters are significant in terms of casualties and economic losses. The country had witnessed a number of historical earthquakes in past and seismic awareness has increased since 2001 Bhuj earthquake (www.nicee.org). Though it is more than a decade since then, however, the country is hardly prepared yet to face such major earthquakes.

A disastrous earthquake of magnitude 6.9 (www.usgs.gov) occurred in India’s northern state of Sikkim at 6:11 PM (IST) on September 18, 2011. According to IS: 1893-2002, the region falls in seismic zone IV (second highest). The Sikkim earthquake left behind a trail of death and devastation, killing about 112, injuring more than a thousand, and rendering more than twenty thousand people homeless. According to USGS, the location of the earthquake was at Latitude 27.723°N and Longitude 88.064°E at India-Nepal border region with estimated focal depth of 19.7 km. The earthquake epicenter was located at 68 km NW of Gangtok. However, according to India Metrological Department (www.imd.gov.in), the magnitude of earthquake was 6.8 and the focal depth of the earthquake has been estimated as 10 km. The event, which falls under the category of “Moderate earthquake”, was also reported to be widely felt in Sikkim, West Bengal, Assam, Meghalaya, Bihar, parts of other eastern and northern regions of India. The neighboring countries i.e. Nepal, Bhutan, Tibet and Bangladesh also felt intense shaking of the quake. The epicentre lies in a seismically active belt called, Alpide-Himalayan seismic belt characterized by two major fault systems (MBT and MCT) associated with the collision of the Indian and Eurasian plates (Valdiya 1964).

Soon after the earthquake, authors visited different parts of Sikkim and carried out the damage survey during September 25-29, 2011. The extensive survey was carried out in the Gangtok City, Capital of the Sikkim state. The team visited all 4 districts of Sikkim i.e. East Sikkim, North Sikkim, South Sikkim and West Sikkim. The major 4 tracts visited by the team were

(a) Rangpo-Singtam-Ranipol-Gangtok (East Sikkim)

(b) Singtam-Temi-Legship (South Sikkim)

(c) Singtam-Temi-Jorthang (West Sikkim)

(d) Gangtok-Lachung (North Sikkim)

The team required the services of helicopters of Indian Army and Indian Air Force between Gangtok and Lachung, as at that time the north Sikkim was not accessible by road due to massive landslides. The team members interacted with local government authorities, NGOs and public at large.

The surveyed damages include landslides, slope failures, ground failures, settlement of soils, failure of retaining walls, failure of foundations, damage to roads, failures of beams and columns of buildings, monasteries, government buildings, and bridges. Damage buildings include both brick masonry and RCC frame buildings. In this paper, the damage pattern is correlated with level of shaking and epicentral distances at different locations. It was found that many buildings damaged due to poor design and workmanship though level of shaking was not very high.

2. GEOLOGY AND METROLOGY OF SIKKIM

The geology of Sikkim is similar to that of the Eastern Himalaya where four distinct geomorphology based transverse zones namely- Sub-Himalaya, Lesser Himalaya, Higher Himalaya and the Tethys Himalaya, are separated by major tectonic dislocations. The geology consist of 4 Precamarian Rocks i.e. Everest Pelitic Formation, Sikkim Group, Chungthang Formation, Kanchenjunga, Gneiss Formation (Bhasin et al. 2002). The tectonic frame work and the seismicity of the northern eastern states including Sikkim are considered as a result of collision tectonics in the Himalayan arc and subduction tectonics below the Myanmarese arc. Studies have indicated a very complex tectonic setting of the region due to constant movement of the Indian plate from South to North & Myanmarese from East to West.

The area of Sikkim is about 7300 km^2 and the elevation in different parts range between 244 m to 8534 m. Thus this indicates that there is large variation in elevation. A number of rivers and tributaries flow through the state, among them Teesta and Rangit are major rivers. Much part of the Sikkim lies in watershed of Teesta River. The intensity of rainfall is very high and variation of precipitation during the year is also high. Average annual precipitation in Gangtok is 3539 mm (Bhasin et al. 2002).

3. SEISMICITY AND TECTONICS OF SIKKIM REGION

Many earthquakes, having medium to large size, have occurred in and around Sikkim as per data based on historical records as well as that based on instrumental recording at Shillong and other foreign seismological observatories. The noteworthy earthquakes which affected the region are: Cachar earthquake of 1869 (magnitude 7.5), Assam earthquake of 1897 (magnitude 8.7), Srimangal earthquake of 1918 (magnitude 7.1), Dhubri earthquake of 1930 (magnitude 7.1), Bihar-Nepal earthquake of 1934 (magnitude 8.3), Assam earthquake of 1950 (magnitude 8.5), Assam earthquake of 1975 (magnitude 6.7) and Nepal-India border earthquake of 1988 (magnitude 6.4). The maximum intensity experienced in Sikkim region during the Great Assam earthquake of 1897 was VIII and during Bihar-Nepal border earthquake of 1934 was VII. Recently, an earthquake of magnitude 5.7 occurred on Feb. 14, 2006 in Sikkim. This earthquake was widely felt in Sikkim and caused some damage to life and property in the epicentral region. In the Eastern Himalayas, the seismicity is considered as a result of collision tectonics and correlated with the MBF and MCT. Fig. 3.1 shows the tectonics of the region and locations of places visited during damage survey.

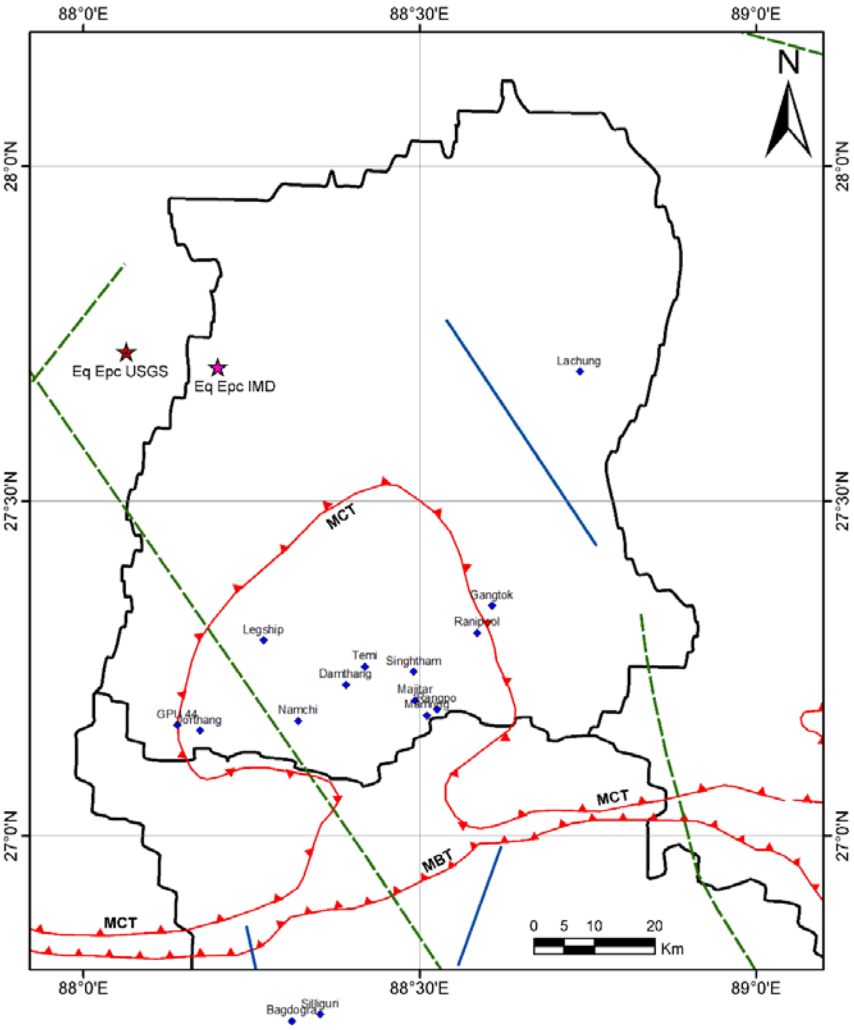

Figure 3.1. Location of the places visited during the damage survey with respect to the tectonics of the region

Sikkim Himalaya is the result of sediments deposition in Tethyan sea subjected to intense deformation and upheaval due to the convergence of Indian plate from south against the Eurasian plate. The geological set up of Sikkim Himalayas can be best described with reference to central crystalline region comprising the migmatite, gneisses, granite massifs in the highest geographic tract. The southern part has a foot hill of Siwaliks and tectonic block of Gondwana. Coal-bearing Gondwana rocks occur in the foothill belt as thrust slices overlying the Siwalik. At the inner part thick cover of Daling, Darjeeling and Chusthang metamorphites are present. The rocks are characterized by green schist to amphibolite facies of metamorphism.

The geology of Sikkim is similar to that of the Eastern Himalaya where four distinct geomorphology based transverse zones namely- Sub-Himalaya, Lesser Himalaya, Higher Himalaya and the Tethys Himalaya, are separated by major tectonic dislocations. The Lesser, Higher and Tethys Himalaya of Sikkim are typically arranged in a domal shape or arch of thrust surfaces in the form of culmination across Teesta river, popularly known as Teesta culmination. The core of the Teesta culmination is occupied by Proterozoic Lesser Himalaya low grade metapelites of Daling Group of rocks. The distal part is made up of medium to high-grade Proterozoic Higher Himalaya crystalline complex, the Main Central Thrust (MCT) separates the Lesser and Higher Himalaya. One of the important tectono-stratigraphic feature present in Sikkim is the Gondwana Group of rocks exposed in a tectonic window, known as Rangit Window (Narula et al. 2000). Gondovana (Carboniferous to Permian) and Buxa Group of rocks are exposed in the Rangit window zone, small window near Rorathang, East Sikkim and as thrust/fault slices in South Sikkim. The Tethys Himalaya is represented by Cambrian to Eocene fossiliferous sediments of the North Sikkim Tethyan zone which tectonically overlie the Higher Crystalline Complex.

The two major structural elements in the Eastern Himalaya are the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT (Hodges, 2000). The Foot Hill Thrust (FHT)/Main Frontal Thrust (MFT) along the Southern edge of the Himalayan bring the Siwaliks in Juxta-position with the thick recent sediments of the Indo-gangetic plain. There are also a large number of prominent lineaments in this region, some of which are reported to extend for several kilometers beneath the Himalayan Foredeep. The Teesta lineaments which pass through Parbatipur area of Bangladesh to Bhadrapur area of Nepal, is considered to demarcate the Western limit of Eastern Himalayan seismicity.

4. GEOTECHNICAL ASPECTS OF DAMAGES

The geotechnical damages include landslides, slope failures, ground failures, settlement of soils, failure of retaining walls, failure of foundations, damage to roads. In this section, the pattern of some of the geotechnical damages is presented.

4.1. Landslides and Mudslides

All four districts of Sikkim witnessed massive landslides due to earthquake. It has been reported that earthquake triggered more than 300 landslides. Extremely high occurrence of landslides is attributed to the geology of the region and intense rainfall. High intensity of rainfall contributes to rapid erosion and weathering of rock mass. The increase of water level causes instability in natural slopes. Further, human activities such as excavation work for buildings, roads and embankments add to instability (Mehrotra et al., 1996). Earthquake provides just a triggering action to already unstable or marginally stable slopes. As per landslide hazard zonation map of India, Sikkim lies in second highest zone categorized as “high zone”. This spells the risk state inhabits for landslides. Recent earthquake just validated this unfortunate fact.

Figure 4.1. Massive mudslide in Singring, Lachung (North Sikkim)

Fig. 4.1 shows a mudslide in Singring, Lachung (North Sikkim, shaking intensity VIII+). Due to incessant rain followed by earthquake, a water stream changed its path and created a new stream This phenomena is known as Landslide Lake Outburst Flood (LLOF) . In this stream, water flown at such a high velocity that debris of rock also flown with it and created mud mountains at both sides of this stream. This may be attributed to reduction in strength of rock material due to saturation (Kramer 1996) and then it slid due to earthquake force carrying huge boulders and rock pieces with it. The locals were trying to divert the path of this new stream as it poses threat to the buildings at downstream. There were massive landslides in other parts of the Sikkim too.

4.2. Failure of Retaining Walls

In hilly areas, normally toe line of multi-storey buildings are founded on loose soil which is supported by a flexible retaining wall. Due to earthquake, many of these retaining walls damaged which led to failure of supporting foundations. Fig. 4.2 indicates collapse of retaining wall in Ranipol, Gangtok, (intensity VII) where this failure damaged a building. It was observed that the retaining wall on the backside of the building has wide cracks with a gap of more than 15 cm. The cracked portion of retaining wall has moved away from the building, creating a wide gap. Due to earthquake, the stair case separated from the wall of the building by about 15 cm. It was observed that this failure of retaining wall was up to a considerable distance on both sides of the building.

Figure 4.2. Failure of a retaining wall in Ranipol, Gangtok (East Sikkim)

4.3. Ground Failure and Damage to Roads

(a) (b)

Figure 4.3. Ground failure and damage to roads in Lachung (North Sikkim)

In Lachung, wide cracks with a gap of about 20 cm were observed on the road (Fig. 4.3a) which can be attributed to the failure of backfill on riverside. Also the road was damaged due to falling of heavy rock pieces (Fig. 4.3b). This ground failure in Lachung indicated high intensity of shaking (VIII+).

4.4. Foundation Failures

Figure 4.4. Collapse of ground and first floor of a building in Jorthang (West Sikkim)

The damage survey was carried out in Jorthang (West Sikkim) which is located on the terrace of Rangit River. Jorthang has epicentral distance about 66 km and intensity assigned is VIII. One of the buildings in Jorthang was totally damaged (Fig. 4.4) in which 2 of the floors (G+1) were collapsed. As the ground floor of the building is completely collapsed, perhaps this is due to foundation failure which may be due to excessive settlement caused by shaking. However, the foundation of the building could not be inspected.

5. STRUCTURAL ASPECTS OF DAMAGES

In this section, structural aspect of damages is discussed. This includes failures of buildings, monasteries, government buildings, and bridges. Both brick masonry and RCC frame buildings were damaged during the earthquake.

5.1. Non-structural Damages

During the survey, several buildings were visited in Rangpo (intensity V-). This is the place where the permit is issued to the visitors for visiting Sikkim. Two of the buildings which were constructed on the slope of the mountain down side of the road towards the Teesta River were inspected for the reported damage. One of the buildings was the Godown used to store the waste material. These buildings were found to have minor cracks as shown in Fig. 5.1

Sikkim Manipal University at Majitar (intensity VII) was visited. Some of the cracks were developed on the main entrance as shown in Fig. 5.2.

Figure 5.1. Minor cracks in the building in Rangpo (East Sikkim)

Figure 5.2. Cracks developed at the main entrance of the Sikkim Manipal University, Gangtok

5.2. Structural Damages

Figure 5.3. Column failures at the gap between 2 blocks of the secretariat building, Gangtok

Secretariat building in Gangtok is one of the most important buildings of Sikkim, which houses the offices of chief functionaries of state government, including the Chief Minister. The building was damaged earlier during the earthquake of February 2006 and similar damage is repeated during this earthquake, also. The building has undergone major damage particularly to the columns at the interface of the two blocks, apparently due to pounding (Fig. 5.3). The infills have been badly damaged particularly at the corners of the building. In Sikkim, it is a practice to provide the infills outside the columns. This makes the corners very vulnerable and the infills fail in wedge type corner failure combined with out-of-plane action.

A collapse of a 9 storey building after 3-4 days of the earthquake has occurred in the balokhani area of Gangtok. The RC building has 9 storeys on the downhill side and 4 storeys on the uphill side (above the road). The building survived the earthquake with severe damage to columns of 5th storey, which was apparently used for storage and hence kept partition free and acted like a soft storey (Fig. 5.4). It was reported that the building was vacated after the damage due to earthquake but the heavy loads of stored goods from some other buildings on the storey with damaged columns led to collapse after few days of earthquake. A smaller 3 storey RC building, existing adjacent to this building was also pushed and collapsed due to this building. Based on the damage an Intensity VII+ has been assigned to Gangtok.

Figure 5.4. Collapse of 5th storey of the 9-storeied building and the adjacent smaller building, Gangtok

6. INTENSITY OF SHAKING

Based on the study of macroseismic effects of the earthquake occurred on September 18, 2011, the Intensity has been assigned to each locality. Interviews of the local public and the administration have helped the team to assign Intensities to the places. For assigning earthquake intensity Medvedev-Sponheuer-Karnik-1964 (MSK) scale has been adopted. MSK scale provides comprehensive details for quantifying damage to various buildings.

The intensity was assigned at a specific locality keeping in view, the type of structure, the grade of damage to each structure (e.g., Grade I to Grade V) and the number of structures suffered specific grade of damage (e.g., single/few, many or most). Earthquake intensity being a subjective quantity, it is difficult to apply a uniform criteria and considerable element of judgment is involved in its assignment. At several visited localities, the intensity was assigned after careful examination of the extent of structural damage, type of materials used for construction, pre-earthquake conditions and workmanship of buildings, and in-depth discussions among the fellow team members. The Intensities thus assigned to various places are given in Table 6.1.

Table 6.1. List of Places and Assigned Intensities

SN	Station	Lat	Long	Approximate Distance in Km from Epicenter	Intensity
1	Bagdogra	26.6993	88.3168	117	V
2	Silliguri	26.7098	88.3582	118	V
3	Savoke	26.8902	8847.31	102	V+
4	Rangpo	27.1746	88.5313	77	VI-
5	Mamring	27.1750	88.5168	76	VII
6	Majitar	27.1876	88.4997	74	VII
7	Singhtham	27.2317	88.4974	70	VII
8	Ranipool	27.2909	88.5914	71	VII
9	Gangtok	27.33195	88.6135	71	VII+
10	Temi	27.2391	88.4252	65	VII-
11	Namchi	27.1565	88.3263	68	VII+
12	Jorthang	27.1417	88.1805	66	VIII
13	GPU 44	27.14573	88.1476	78	VII
14	Damthang	27.2119	88.3967	64	VII-
15	Legship	27.2795	88.2749	54	VII+
16	Lachung	27.6890	88.7429	68	VIII+

7. SUMMARY AND CONCLUSIONS

This paper presents the result of a reconnaissance study in Sikkim, immediately after the earthquake of September 18, 2011. The objective of the study was to document perishable information and collect field evidence on the behaviour of buildings and ground under seismic loads.

It was observed that many buildings damaged due to poor design and workmanship though level of shaking was not very high. The damage observed in and around Gangtok was far more than expected for the intensity of shaking (PGA) assigned. This reflects the poor design and construction practices followed in the area. Given that Sikkim lies in high seismic zone, it may witness major earthquakes in the future. Therefore, it spells tremendous risk for the region. The importance of the earthquake resistance design of structures in this region shall not be underestimated.

There is an urgent need to sensitize the common people about the seismic hazard and tangible seismic risk that community is facing on account of using unsafe construction practices. Awareness and capacity building of human resources at all levels and the creation of suitable and effective enforcement mechanisms are integral components of the road map for steering the state towards seismic safety. This task is enormous and must involve all sections of society. Following recommendations have been made as follows:

(i) Seismic monitoring including a network of strong motion instruments
(ii) Microzonation and land use planning including slope stability
(iii) Development of building bye-laws in view of model building bye-laws

(iv) Earthquake resistant design of new structures and foundations including geological and geotechnical investigations.

(v) Seismic evaluation and retrofitting of existing structures and their foundations

(vi) Special attention to lifeline structures

(vii) Long term monitoring of slopes and selected structures

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- Sikkim State Disaster Mitigation Authority, Gangtok
- Mr. Tashi, Geologist and former Principal Director, Govt. of Sikkim
- Mrs. Devika Chettri, Additional Chief Town Planner, Govt. of Sikkim
- Mr. Raju Tamanag, Asst. Er., UDNHD, Govt. of Sikkim
- Mr. Emera, Structural Engineer, NORSAR, Norway