Preliminary Report on the IIT Kanpur Reconnaissance Survey of the Sikkim (India-Nepal Border Region) Earthquake of September 18, 2011

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Civil Engineering faculty and students of IIT Kanpur, *Durgesh C Rai*, *Goutam Mondal*, *Vaibhav Singhal*, *Neha Parool* and *Tripti Pradhan* undertook a reconnaissance survey of the earthquake affected regions during September 28 to October 5, 2011 and visited worst affected major towns in Sikkim Gangtok, Mangan, Chungthang, and Lachung. *Keya Mitra* of Bengal Engineering and Science University, Shibpur visited Kalimpong and Darjeeling in North West Bengal. Another team consists of *Hemant Kaushik* and *Kaustubh Dasgupta* of IIT Guwahati visited Gangtok and adjoining area during 10-15 October 2011.

Earthquake and its Seismological Setting

The M6.9 earthquake of September 18, 2011 struck at 18:10:48 IST with its epicenter located near India-Nepal border region, about 68 km NW of Gangtok, Sikkim (Fig. 1). It was a shallow focus event, which was felt in India, Nepal, Bhutan, Bangladesh and China. Tremors which lasted for about 30-40 seconds were felt in several Indian states such as Assam, parts of West Bengal, Bihar, Uttar Pradesh, and Delhi. Three aftershocks were also felt in Sikkim within 30 minutes of the initial earthquake. About 100 deaths are reported in India with the maximum of at least 60 in the state of Sikkim. The affected area has low population density of an average of 88 persons/sq. km. The state capital Gangtok is the biggest city in the area (Fig. 2). Chungthang and Lachung in North Sikkim are two major towns which have suffered the maximum damage to structures (Fig. 3 and 4). This region has experienced relatively moderate seismicity, with 18 earthquakes of M5 or greater over the past 35 years within 100 km of the epicenter of the September 18, 2011 event. The affected region lies in the high risk seismic zones of IV of Indian seismic code IS: 1893 with the expected intensity VIII.

General Observations

The earthquake followed by heavy seasonal rains triggered more than 300 landslides, rock/mudslide causing much devastation (Fig. 5). Damage to buildings and infrastructure due to landslides dominated those due to direct ground shaking in some regions (Fig. 6). Landslides cut off the severely affected areas from the rest and hampered the rescue and relief work in this difficult terrain. The immediate requirement was to provide temporary shelter along with medicine, food, blankets, etc. for survivors, before these areas become further inaccessible due to approaching winter.

General damage to buildings and other structures agreed well with the intensity of ground shaking observed at various places, with the maximum of VIII at Chungthang and Lachung, VI in and around Gangtok and Mangan on MSK scale. However, unexpected severe damage at an intensity of VI in Gangtok was observed in buildings such as the secretariat building, two multistory buildings in Balwakhani, 5-storey building in Lumshey Basty and 4-storey building in Dikchu Bazaar (Fig. 7and 8).

Performance of Structures

It was common practice in Sikkim to construct residential buildings using bamboo/wood, until the economic development aided by tourism industry got boosted in early nineties. These traditional constructions (*Shee-khim* and *Ikra* type) have better earthquake resistance as observed in the present and past earthquakes (Fig. 9).

It was rather perplexing to discover that a great majority of both governmental and private RC-frame buildings seriously lacked earthquake-resistant features which are so essential for a satisfactory seismic performance in the design level shaking. Most of the RC buildings in Gangtok and Chungthang suffered varying degree of damage, from moderate to complete collapse during this earthquake (Fig. 10 to 12). Extensive damage to school and hospital buildings was reported in the worst affected regions of Sikkim and North Bengal (Fig. 13 and 14). Many unique and inherently poor construction features such as weak and very slender partition walls in brick/block masonry or in lightly reinforced/plain concrete, extended floor plans in upper stories supported on cantilevered beams and slabs, construction on sloped ground, unstable slopes, weak retaining walls, poor construction material etc., significantly added to the seismic vulnerability of structures. The area has a number of highway and pedestrian bridges on rivers, rivulets, and gorges. Only minor damage to a few highway bridges was noticed in the areas visited (Fig. 15 to 17).

The poor earthquake performance of cultural heritage such as monasteries is a source of concern as almost all historic religious structures suffered varying degree of damages in this earthquake. The exterior walls of monastery temples are constructed of stone masonry mostly random rubble while the interior building frame is constructed of timber using single post beam system. Heavy damages have been observed to exterior walls at several monastery temples at Mangan and Lachung (Fig. 18). In Kalimpong, in West Bengal, two brick spires of the historic Mac Farlene Church have collapsed and the tall load bearing walls at the gable end of the building have numerous cracks (Fig. 19).

National Hydroelectric Power Corporation (NHPC) has constructed concrete gravity dams over Teesta River near Dikchu (Project Teesta-V: 513 Mega Watt) and Rangit River near Rangit Nagar (Project Rangit: 60 Mega Watt). Project Rangit is in operation since last 10 years and Project Teesta-V was completed recently and is in operation since last two years (Fig. 20). No damage due to earthquake shaking or landslide was observed in the body of any of these dams. The hydroelectric power stations performed extremely well; the only visible damage was minor cracking in masonry infill walls at various locations in the power stations. Severe landslides and ground deformations were observed near both the dam sites that resulted in accumulation of excessive debris and silt in the reservoir and on the downstream of the dam (Fig. 20d and 20e).

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. The general pattern of damage to structures, landslides, rockfalls, etc. is consistent with the shaking associated with the M6.9 event, except a few dramatic building collapses due to faulty construction practices and lack of earthquake-resistant features.

Traditional construction like *Shee-khim* and *Ikra* type performed well as expected and needs to be reinstated. Buddhist temples being old and weak were deficient in strength and needs to be safeguarded against future tremors. Despite the available knowledge base, the communities are not adequately prepared. Ever increasing inventory of seismically deficient constructions causing the seismic risk in the region to rise to unacceptable levels which may lead to a large-scale disaster, if the risk is not mitigated.

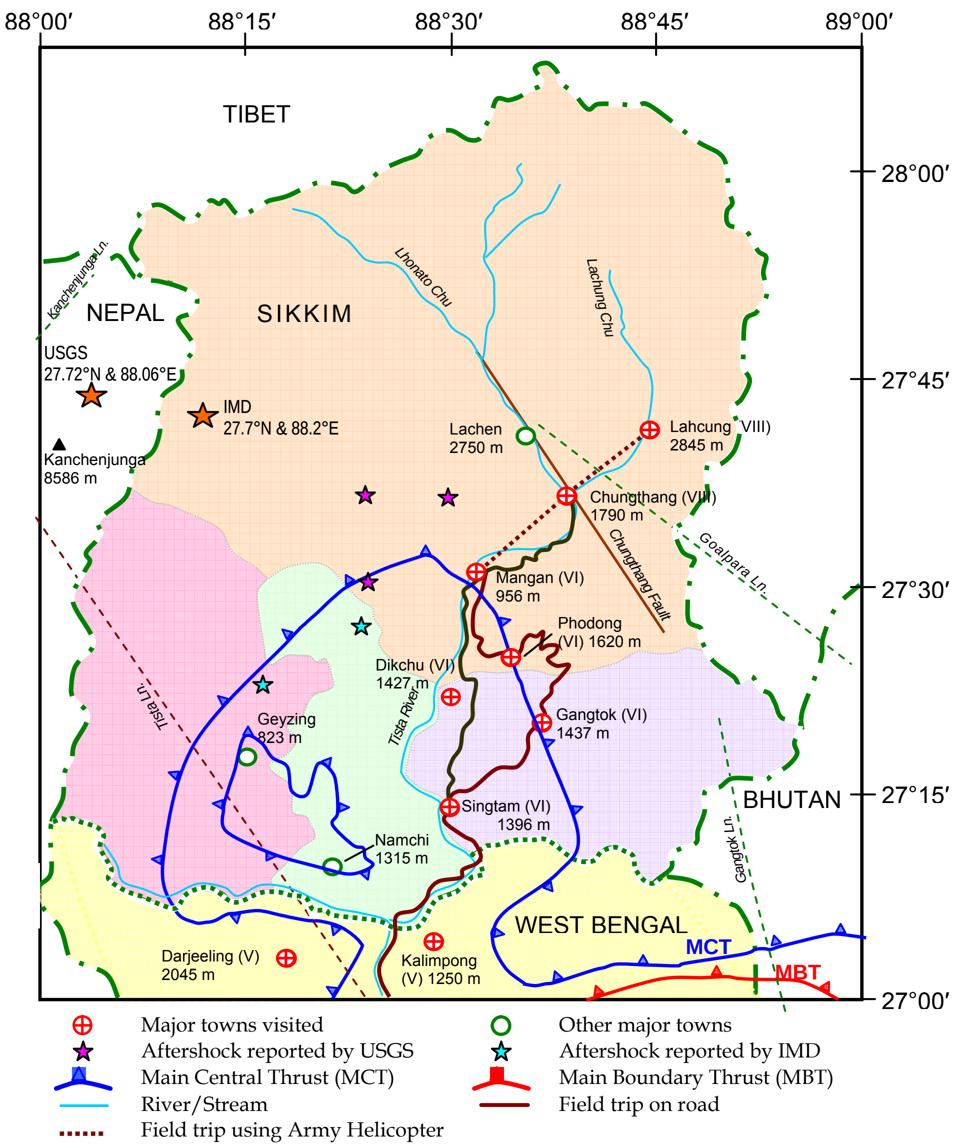


Fig. 1. Location of epicenter of the earthquake and its aftershocks, Main Central Thrust fault (MCT), Main Boundary Thrust fault (MBT) and the towns visited in India.

Fig. 2. Building stock in Gangtok city (Photo: Goutam Mondal)

Fig. 3. Aerial photograph of Chungthang showing damages (Photo: Durgesh Rai)

Fig. 4. Photograph of town Lachung showing massive rockslides (Photo: Vaibhav Singhal)

Fig. 5. Aerial photograph showing typical landslides enroute from Mangan to Chungthang and Lachung (Photo: Durgesh Rai)

Fig. 6. Damage due to rock slide after two days of the event in Lachung (Photo: Neha Parool)

Fig. 7. Collapse of two multistory RC frame buildings at Balwakhani, Gangtok (Photo: Tripti Pradhan)

Fig. 8. Collapsed four story reinforced concrete building at Dikchu Bazaar (Photo: Hemant Kaushik)

(a) (b)

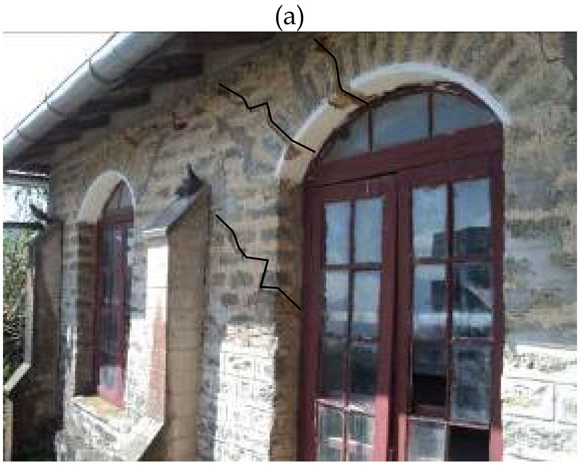
Fig. 9. Traditional construction type (a) Ikra house (Photo: Vaibhav Singhal) (b) Shee-Khim house (Photo: Neha Parool)

Fig. 10. Complete collapse of newly constructed RC building at Lumshey Basty, Gangtok (photo: Neha Parool)

Fig. 11. Pancake collapse of the third storey of the five storey school cum residential building in Chungtang (Photo: Goutam Mondal)

Fig. 12. Complete damage of columns and exterior wall in a building at Chungthang due to poor detailing of column reinforcement, lack of confining reinforcement, improper splicing of rebars, inferior detailing of columns with corbel (Photo: Tripti Pradhan)

(a)



(b)

Fig. 13. (a) Damage reported at Kalimpong Girl's High School (b) Damage to semi-circular arches, diagonal cracks in masonry pier (Photo: Keya Mitra)

(a) (b)

(c) (d)

Fig. 14. Damage observed at Government Secondary School at Sichey (a) old school building, (b) additional school building, (c) damage to RC columns, and (d) damage to Ikra walls on top floor (Photo: Hemant Kaushik)

Fig. 15. Damage to the wing wall of steel truss bridge on Raykhola (photo: Tripti Pradhan)

Fig. 16. Undamaged concrete bridge in North Sikkim (Photo: Durgesh Rai)

Fig. 17. Undamaged steel truss bridge connecting West Sikkim and North Sikkim (Photo: Vaibhav Singhal)

Fig. 18. Partial collapse of stone masonry walls of a Monastery temple at Mangan (Photo: Goutam Mondal)

Fig. 19. Collapse of brick spires of Mac Farlene Church at Kalimpong (Photo: Keya Mitra)


(a) (b)



(c) (d) (e)

Fig. 20. Concrete gravity dams in operation at (a) Project Teesta-V, and (b) Project Rangit, (c) damaged electrical transformer at Teesta-V dam site, (d) ground deformation at Teesta-V dam site, and (e) accumulation of excessive debris and silt in reservoirs due to landslides (Photo: Kaustubh Dasgupta)