# Observations on Performance of Structures during 18 September 2011 Sikkim (India) Earthquake

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**SUMMARY**
On Sunday 18 September 2011 at 6:11 pm a strong earthquake of magnitude $M_w$ 6.9 (as per USGS) struck the mountainous Sikkim-Nepal border region near the boundary between the India and Eurasia plates. Authors undertook port-earthquake reconnaissance survey of the affected areas. The earthquake shaking demonstrated high seismic vulnerability of structures in Sikkim. Severe damage was observed in monasteries, school buildings, reinforced concrete buildings, roads, and water supply pipelines at various places. Many bridges and dams with hydroelectric power plants are located on various rivers in the vicinity of the epicenter, and the performance was found to be satisfactory. This paper summarizes the observations gained during the current reconnaissance visit. An immediate intervention in the form of awareness campaign, sensitization of engineers, contractors, labour, and public, and strict regulations is urgently required to reduce the ever increasing seismic vulnerability of the built environment in the region.

*Keywords: Sikkim earthquake, performance of structures, structural damage, vulnerability of structures.*

## 1. INTRODUCTION

A strong earthquake of magnitude $M_w$6.9 struck Sikkim at 6:11 pm local time on 18 September 2011. Epicenter was reported near Sikkim-Nepal border at 27.723°N and 88.064°E by United States Geological Survey (USGS) and at 27.7° N and 88.2° E by India Meteorological Department (IMD) as shown in Fig. 1. It was followed by a number of aftershocks with magnitudes more than 4.0 (as reported by IMD) on the same evening and on following days. There were reports of several casualties along with significant damages in the entire state of Sikkim and northern parts of West Bengal and Bihar in India. In addition, the earthquake shaking was also felt in other countries including Nepal, Bhutan, Bangladesh, and Tibet (China). More than 100 people have been reported to be killed during the severe shaking. Observed damage in Chungthang and Lachung (in north Sikkim) corresponds to a maximum intensity of shaking of VIII on MSK scale (Murty et al. 2012). The maximum intensity of shaking observed in the state capital Gangtok was VII. Sikkim is located in seismic zone IV of Indian seismic zoning map (BIS 2002) with the expected maximum intensity of shaking as VIII on the MSK scale. Therefore, this was an expected event, and the structures should have been designed to withstand this shaking without any significant damage.

A moderate earthquake of magnitude $M_w$5.3 also struck Sikkim on 14 February 2006, and maximum observed intensity of shaking during this earthquake was VII in Gangtok on MSK scale (Kaushik et al. 2006). The earthquake had highlighted an urgent need for proactive actions to propagate safer construction practices in the region. The 2011 earthquake gave an excellent opportunity to the authors to revisit the affected areas in Sikkim and study the performance of the structures strengthened after being damaged during the 2006 event.

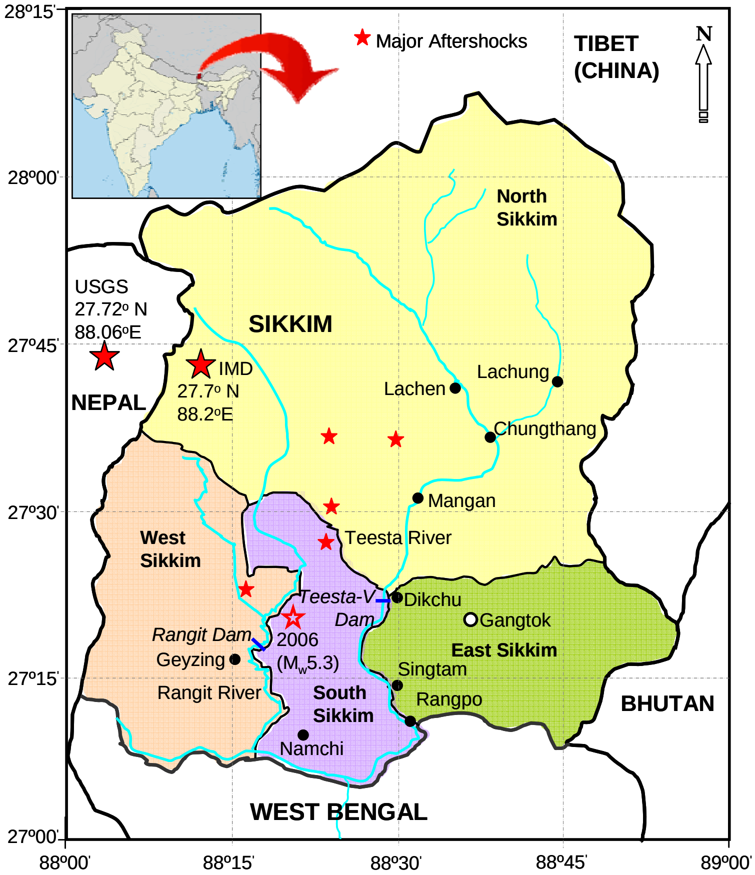


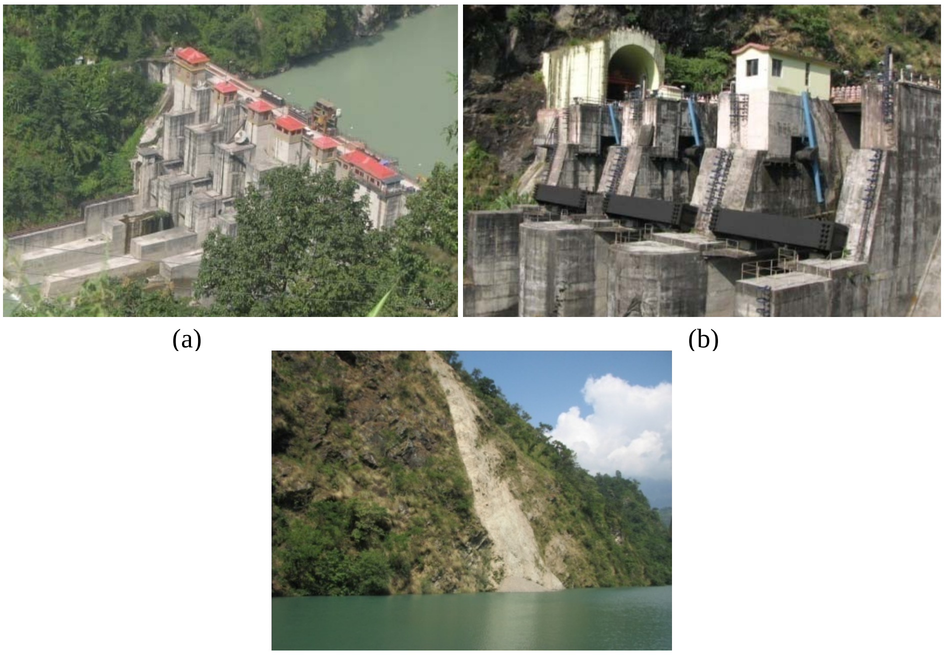

**Figure 1.** Epicenter locations of the 18 September 2011 Sikkim earthquake, major aftershocks, 2006 earthquake, and other details in Sikkim.

## 2. PERFORMANCE OF STRUCTURES

Performance of several types of structures, for example, dams, buildings, transportation systems, pipelines, and other public utility structures during the 2011 earthquake shaking has been discussed in the following sections. Possible reasons for the performance of these structures are also highlighted.

### 2.1. Performance of dams and roads

Sikkim is rich in hydropower potential in spite of its small area and is drained by many perennial rivers. Several hydroelectric power plants are currently in operation in Sikkim over these rivers and many more are being planned. National Hydroelectric Power Corporation (NHPC) has already constructed concrete gravity dams over Teesta River (513 Mega Watt) near Dikchu and over Rangit River (60 Mega Watt) near Rangit Nagar (Fig. 2a, 2b). Authors visited both the dam site and power station site and inspected several structures constructed on these sites including the dams. No damage due to earthquake shaking or landslide was observed in the body of any of these dams. The power stations also 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. 2c). The 2011 Sikkim earthquake will be known for the severe damage caused to properties and lifelines by hundreds of landslides triggered due to the shaking and subsequent rainfall in the region (Fig. 3a, 3b). Subsidence was observed at Ranipool near Gangtok that resulted in settlement of a part of National Highway by about 180 mm (Fig. 3c).



(a) (b)

(c)

**Figure 2**. Performance of dams during 2011 Sikkim earthquake: (a) Project Teesta-V, (b) Project Rangit, and (c) accumulation of excessive debris and silt in reservoirs due to landslides.

(a) (b) (c)

**Figure 3**. Severe landslides and ground movement after 2011 earthquake shaking (a) near Rangpo, (b) near Nimtar, and (c) subsidence resulted in settlement of a part of National Highway 31A at Ranipool near Gangtok.

### 2.2. Performance of vernacular housing systems

Primarily two types of vernacular housing systems, which are mostly non-engineered, are constructed in Sikkim: wooden houses and masonry houses. Most traditional houses in Sikkim constructed privately are typical single story bamboo houses known commonly as the *Ikra* houses (Fig. 4a, 4b). *Ikra* type wooden housing is commonly constructed in Sikkim due to its natural advantages related to light weight, local availability of materials, etc. Performance of traditional *Ikra* houses was extremely good in both the earthquake shakings of 2006 and 2011. The only damage observed in *Ikra* constructions due to earthquake shaking alone (not due to landslides) was to additional class rooms constructed on third story of new building of Government Secondary School at Sichey in East Sikkim as shown in Fig. 4c. The walls of *Ikra* rooms over the terrace of this building suffered out-of-plane collapse. This suggests that *Ikra* type houses may not be suitable for construction on higher stories due to possible amplification of ground motion along the height of the building. Several other wooden vernacular housing systems in other parts of India have also performed extremely well during several past earthquakes (Kaushik and Jain 2007). This observation presents a case for encouragement to construction of vernacular housing systems, especially in seismically active regions.

(a)

(b)

(c)

**Figure 4**. Performance of *Ikra* constructions during past earthquakes (a) Ranka Senior Secondary School - primary sections (b) Thamidara Junior High School – new two storied building, and (c) Government Secondary School, Sichey: damage to *Ikra* walls on top floor of additional school building.

Masonry buildings have been traditionally constructed in Sikkim using undressed stones with mud mortar, though lime-based mortar and dressed stones have been used in a very few important buildings. Two such important buildings are the ancient Raj-Bhavan (Governor's House) and Enchey Monastery, which were constructed more than 110 years back and have out-lived their life span. Both these buildings were moderately damaged during the 2006 shaking after which retrofitting measures were taken up for their strengthening. It is worth mentioning here that both these structures were also damaged during 1980 Sikkim earthquake and 1988 Bihar-Nepal earthquakes, and were subsequently repaired. It has been reported that the Raj-Bhavan did not suffer significant damage in 2011 event, but since the very old masonry building was damaged several times during past earthquakes, a new Raj-Bhavan building is being constructed near the old building.

The main pagoda building of Enchey monastery is a masonry structure that suffered damage during 1980, 1988 and 2006 earthquakes (Kaushik et al. 2006). During the 18 September 2011 earthquake, no significant damage was observed in the first storey of the building, and in the upper storey, cracks below the window sill, local spalling and crushing of masonry pier above window openings and dislodging of masonry blocks below roof were observed. Among the monasteries located around Gangtok, most severe damage was observed in Rey Mindu monastery, located on a diversion from Rumtek-Lingdum road (Fig. 5a). The original masonry structure of the monastery building, which underwent significant damage over the course of time, was constructed more than 100 years ago. Subsequently, in 2005 the masonry structure was replaced by RC buildings with masonry infill walls. Though the building performed quite well in 2006 shaking, both the exterior and interior brick masonry walls underwent severe cracking with several interior walls undergoing demolition and fresh construction after 2011 shaking. The largest monastery complex near Gangtok, the Ranka-Lingdum monastery, suffered minor damage in the form of cracking in masonry walls during both the earthquakes. After 2011 earthquake one RC column in the first storey of new building of the monastery suffered severe damage (Fig. 5b and 5c). Most of these monasteries reportedly suffered minor damage during the 2006 shaking too, and subsequently minor repair works, mostly cosmetic, were carried out.

(a) (b) (c)

**Figure 5**. Damage in Monasteries in Sikkim during 2011 earthquake (a) severe cracks in exterior brick masonry walls of Rey Mindu monastery (b), and (c) damaged RC column in first storey of a new building in Ranka-Lingdum monastery and reconstruction of an adjacent masonry wall.

## 2.2. Performance of Engineered buildings

RC buildings are most common type of engineered buildings in all parts of Sikkim. Though Sikkim is located in a highly seismic-prone region, such buildings are commonly constructed without proper design and without any significant involvement of structural engineers. Poor quality of materials and workmanship, and thumb rules are used for design and construction, which is mostly done by masons. Only some important buildings, such as few school buildings, government offices, officers' colonies, etc, are properly designed and constructed using prevalent codes and guidelines.

### *2.2.1. Performance of school buildings*

Large number of school buildings have been reported to have damaged during the 2011 earthquake shaking. In several cases, buildings were damaged to such an extent that they were abandoned by the administration and classes were held at temporary locations. The old building of Government Secondary School at Sichey is a three storey RC building with brick masonry infill walls and it was constructed in 1969. It suffered significant damage during the 2006 event (Kaushik et al. 2006). Consequently, repair work and marginal change in the vertical configuration of the building (introduction of window opening in one of the damaged infill wall panels) was carried out (Fig. 6a). The renovated old building suffered extensive damage during the 2011 earthquake and the entire school building had to be subsequently abandoned. There were cracks in the infill panel along the column-wall junction and at lintel levels. Extensive cracks were observed in interior walls and in the first storey corridor due to current earthquake shaking. The new building suffered extensive cracking in floors due to ground movement, cracking along the flights of staircase (Fig. 6b) and separation of brick masonry infill panel along the edges of beam and columns (Fig. 6c). RC columns of both building suffered significant damage, especially those located near the door openings and in the corridor (Fig. 6d). Ground deformation at the base of the new school building was also observed resulting in formation of cracks in corridor (Fig. 6e). The same ground deformations also caused movement of the toilet block leading to horizontal separation crack along the pavement (Fig. 6f). Clearly, the retrofitting schemes used to strengthen these buildings after 2006 event appeared to be completely ineffective.

Sernya School at Lower Syari in Gangtok is housed in the first storey of a two storey RC frame building (Fig. 7a). Due to absence of tie beams at the bottom of first storey columns, a portion of first storey collapsed during the 2011 event (Fig. 7b). Damage was also aggravated by ground movement along the adjacent slope. Severe cracking and out-of-plane movement of masonry infill walls was also observed in the building (Fig. 7c, 7d). Subsequently most class rooms of the school were abandoned and temporary repair works were also being undertaken on the damaged columns by the house owner who happened to be a retired government civil engineer (Fig. 7d). One RC column in the first storey was found to be significantly damaged due to vibration of a mobile communication tower fixed at the top of the building as shown in Fig. 7e.


(a) (b) (c) (d)

(e) (f)

**Figure 6**. Government Secondary School, Sichey: (a) overview of renovated old school building, (b) damages in staircase, (c) separation of masonry blocks along beam-column interfaces, (d) damage to RC columns, (e) cracks in corridor of new school building, and (f) separation crack in pavement beside toilet block.


(a) (b)

(c) (d) (e)

**Figure 7.** Damage in Sernya School building: (a) partial collapse of portion of first storey, (b) collapse of walls due to ground movement, (c) out-of-plane movement of masonry infill, (d) repair work in first storey, and (e) vibration of mobile communication tower on top of the building damaged the supporting RC column.

*2.2.2. Performance of residential, commercial and government buildings*

It was observed during 2006 earthquake shaking that government buildings generally performed quite well, and small repair or retrofitting work essential for few buildings was quickly carried out after the shaking. On the other hand, during 2011 shaking several government buildings responded extremely poorly and had to be abandoned. In 2006 shaking, though few buildings suffered severe damage, no building suffered complete collapse. While during 2011 shaking and its aftershocks several buildings collapsed completely and large number of buildings suffered severe damage showing high seismic vulnerability of structures in Sikkim even though several smaller past earthquakes provided sufficient warnings about the poor construction practice in the region. A four storey RC building at Dikchu bazaar constructed about 10 years back on rear side of an old wooden house collapsed completely after two days of the main shock (Fig. 8a). The building was constructed on slope over a RC retaining wall and the slope started failing after the main shock. This resulted in severe tilting of the building along the slope prompting the occupants to vacate the building before it collapsed completely during an aftershock two days later. Poor construction practice, inadequate reinforcement detailing, and inadequate measures to arrest slope failure appeared to be the primary reasons for the collapse. Another two storey RC building constructed on slope and located near the Dikchu dam site suffered partial collapse during the main shock. This building was not being used for residential purposes, and therefore, losses were minimal (Fig. 8b).

A four storey RC building at Singtam market collapsed partially during 2011 earthquake shaking due to failure of several RC columns in the first storey (Fig. 9a, 9b, 9c). The first storey of the building was primarily used for operating commercial shops, and only second storey was occupied by the owner at the time of the earthquake shaking. Plain reinforcing bars with inadequate shear reinforcement were used in most columns of the building, and these bars in several first storey columns buckled during the shaking taking the storey down. Two front RC columns and one internal column in the first storey buckled due to severe shaking resulting in tilting of the whole building along its length towards front side (Fig. 9d). This also resulted in shear failure of one column of the rear side in the first storey (Fig. 9d, 9e). Only one internal RC column of the building suffered complete failure (Fig. 9f); this may have possibly saved the building from complete collapse. Interestingly, only minor damage was observed in the upper stories of the building. A six storey RC building, constructed about 15 years back, and an adjacent nine storey RC building constructed about 20 years back at Baluwakhani in Gangtok tilted severely during the main earthquake shaking (Fig. 10a). The shorter building suffered complete collapse during an aftershock on 23 September 2011. This resulted in further tilting and subsequent pan-cake type collapse of three intermediate stories of the bigger adjacent building (Fig. 10b). Both the buildings were constructed on hill slopes, and failure of foundation of the shorter building along the slope triggered the collapse of both the buildings.


(a)


(b)

**Figure 8**. (a) Collapsed four storey RC building at Dikchu bazaar; (b) a part of two storey RC building near Dikchu dam site collapsed during 2011 shaking.

(a) (b) (c)

(d) (e) (f)

**Figure 9**. Partial collapse of a four storey RC building at Singtam market during 2011 shaking: (a) Overview of the building with failure of front RC columns, (b), (c) closer views of complete failure of front RC columns, (d) tilting of the building along its length, (e) failure of RC columns on the rear of the building, and (f) failure of an internal RC column showing use of plain reinforcing bars and inadequate provision of shear reinforcement.

(a) (b)

**Figure 10.** Collapse of two RC buildings at Baluwakhani in Gangtok: (a) the six storey building collapsed completely due to foundation failure, and (b) adjacent nine storey building suffered pan-cake type collapse in intermediate three stories.

Though performance of a large number of RC buildings in Sikkim was below par, several RC buildings performed exceptionally well during the earthquake shaking. A three storey RC building in front of the Tashiling Secretariat building hosts many Government offices (Fig. 11a). It performed exceptionally well during the earthquake shaking, though the performance of the Secretariat building constructed right across the road was quite poor. One of the major sports stadiums in Gangtok, Paljor Stadium, was constructed in 2005, and performance of the RC and steel supporting structure of the main stadium and the ancillary buildings was very good during the earthquake shaking (Fig. 11b).

(a) (b)

**Figure 11.** Good performance of buildings in Sikkim: (a) A three storey RC building in front of Tashiling Secretariat building, (b) RC and steel supporting structure of Paljor stadium and its ancillary buildings in Gangtok.

## 3. CONCLUDING REMARKS

Sikkim is located in one of the most seismically active regions in India, and therefore, earthquakes occur frequently in this region. Further, Sikkim has a difficult hilly terrain and harsh weather conditions and construction activities in this region should be handled by competent engineers and skilled labours. Construction activities in such regions also require proper planning and strict adherence to the codes of practice and building bylaws. However, in most cases construction in Sikkim and adjoining areas has been carried out in a haphazard way without proper planning, without utilizing services of engineers, without using the codes of practice and building bylaws (Fig. 12). Moreover, construction material available in the region is not of very good quality. This has resulted in extremely poor and seismically vulnerable construction practice in the region. One example of such construction practice is construction of large number of closely constructed six to eight storey RC buildings on slopes of river banks (Fig. 12). As discussed in the above sections, several such buildings collapsed during the earthquake shaking.

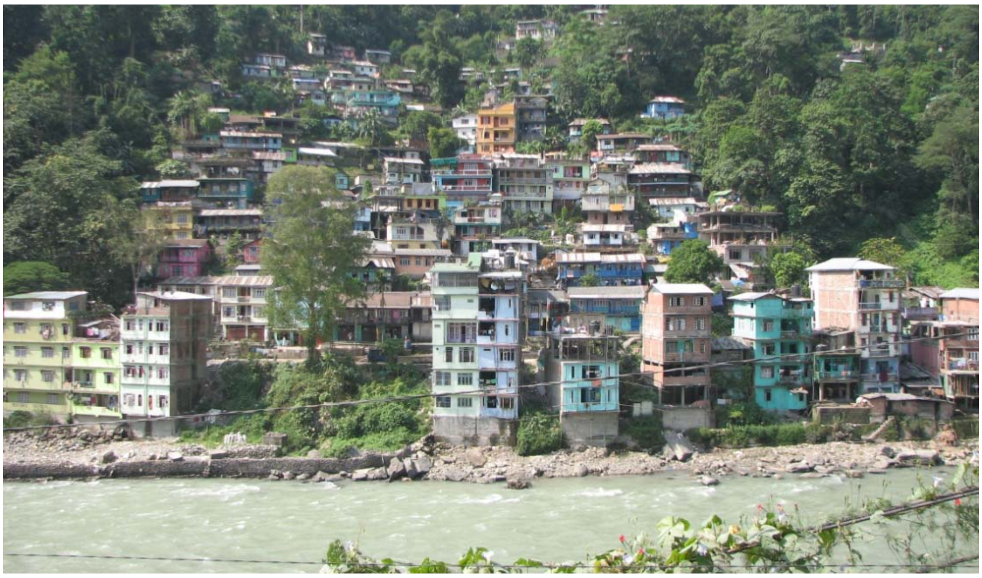


**Figure 12.** Haphazard construction practice in Sikkim

The earthquake shakings caused varying degree of damage to heritage as well as modern engineered and non-engineered buildings. Several buildings were repaired and retrofitted after the 2006 earthquake shaking. Interestingly, as discussed in the above section, most of these buildings suffered more damage during the 2011 event and that too, at the same location and in the same members. There can be no hesitation in saying that seismic vulnerability of different structures in the region is following a rising trend, and similar structures are being added to the vulnerable building stock at an alarming rate. Damage pattern in case of most RC buildings showed similar trend where columns were found to be severely damaged as compared to other components of the buildings. In addition, poor workmanship and construction practices, for example, use of plain reinforcing bars, absence of lintels above openings in walls, inadequate connections between RC members, large cover to reinforcing bars, etc, played a significant role in the poor performance shown by these buildings. Negligence and inability in arresting slope failure lead to massive loss of life and property during the earthquake shakings. It appears that engineers and local authority have failed to learn lessons from the effects of the past earthquake shakings. The strategies used for repairing and retrofitting have not shown promising results in most cases; in fact, the strategies have completely failed in some cases. Creating awareness about good construction practices, development of effective and economical retrofitting strategies, and enforcement of codal provisions in all new constructions in Sikkim are imperative for better earthquake preparedness in the region.

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