How safe are our rural structures? Lessons from the 2011 Sikkim Earthquake

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Increasing frequency and intensity of earthquakes has renewed the urgency in improving the preparedness and in making the infrastructure earthquake-resistant. Sikkim, a northeastern Indian Himalayan state, was hit by a 6.9 magnitude earthquake of intensity VII on 18 September 2011, which triggered hundreds of boulder falls and landslides, causing extensive damage to public and private infrastructure. An assessment of the strengths and weaknesses of the various structures present in rural areas was carried out. Assessment of the quantum of damage indicated that though half of the 90,000 rural houses in the state had suffered various degrees of damage, there were only a few deaths due to these houses, highlighting their inherent earthquake-safe character. This earthquake is a wake-up call to enforce building and seismic codes, making building insurance compulsory along with the use of quality material and skilled workmanship. Mass training of masons and orientation of the local community is needed to make earthquake-resistant house construction a standard practice in future.

Keywords: Damage assessment, earthquakes, preparedness, rural structures.

THE Sikkim region falls between Nepal and Bhutan and comprises the lesser active part of the 2500 km stretch of the active Himalayan belt. The seismic hazard scenario of Sikkim Himalaya appears to be underestimated considering its zone IV status in the seismic zonation map of India, unlike zone V for most of the Himalayan front (IS1893, 2002). One cannot overlook the fact that this region is surrounded by great earthquake occurrences during the past, namely the 1934 Bihar–Nepal earthquake (*M* 8.3) to the west, the 1897 Shillong earthquake (*M* 8.7) to the southeast and the 1950 Assam earthquake (*M* 8.7) to the east[1]. In the recent past, Sikkim experienced an *M* 6.1 earthquake on 19 November 1980 and more recently on 14 February 2006 an *M* 5.3 earthquake. Seismic hazard in the Sikkim region is further accentuated due to site amplification, which increases from north to south along the Tista and Gangtok lineaments[2,3]. This is attributed to the presence of sedimentary and low-grade metamorphic rocks in the Lesser Himalayas.

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The Sikkim earthquake

Sikkim was rocked by an *M* 6.9 earthquake of intensity VII at 18:10 IST on 18 September 2011. The earthquake was centred about 64 km northwest of Gangtok, at a shallow depth of 19.7 km. This earthquake caused strong shaking in many areas adjacent to its epicentre lasting 30–40 seconds. Although earthquakes in this region are usually interplate in nature, preliminary data suggest that the Sikkim earthquake was triggered by shallow strike–slip faulting from an intraplate source within the overriding Eurasian plate. Initial analyses also indicate a complex origin, with the perceived tremor likely being a result of two separate events occurring close together in time at similar focal depths. The strongest shaking occurred in Sikkim, with tremors also felt in Nepal, Bhutan, Bangladesh and China. In India, the tremors were felt in Assam, Meghalaya, Tripura, parts of West Bengal, Bihar, Jharkhand and as far away as Uttar Pradesh, Rajasthan, Chandigarh and Delhi. This earthquake was followed by three aftershocks of magnitude 5.7, 5.1 and 4.6 respectively within 30 min of the initial earthquake[4].

Sikkim has a fragile ecology, being one of the steepest and highest state in the country, and the third highest landscape globally. It is a mountainous state crisscrossed by narrow valleys and steep cliffs. The young fold mountains are characterized by a weak geology, comprising sedimentary and low-grade metamorphic rocks which are prone to landslides. The state also experiences heavy monsoons with the average annual rainfall being to the

Figure 1. Weak geology, fragile ecology and heavy rainfall all combined to amplify the impact of the earthquake resulting in thousands of natural calamities in the form of landslides and slips, boulder falls and flash floods and causing colossal collateral damage. ***a***, Boulder falls. ***b***, Landslides. ***c***, Flash flood in Lachung, North Sikkim. ***d***, Cliff caves in on the national highway. ***e***, Landslides block the national highway.

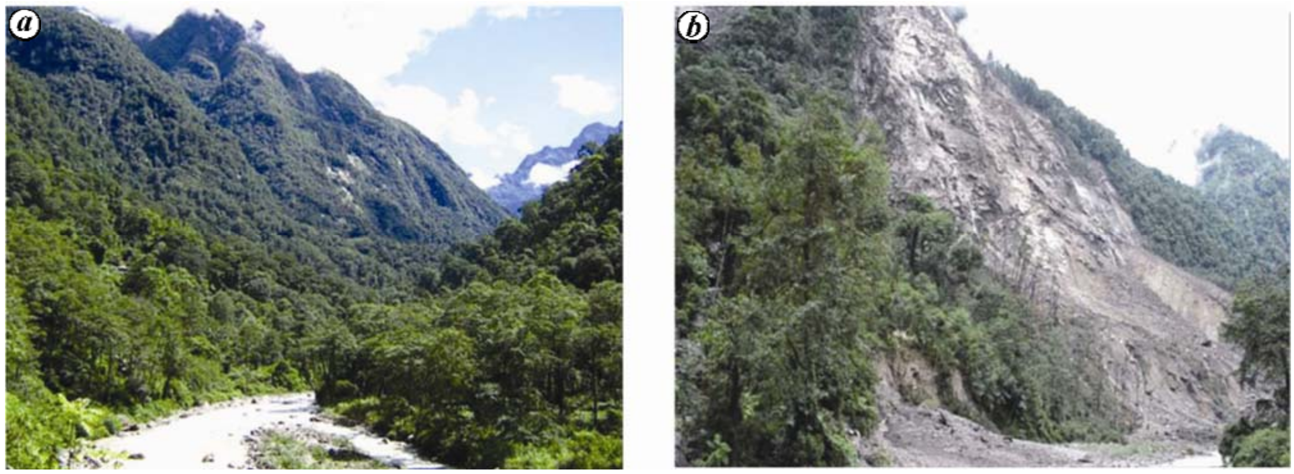

Figure 2. Bay village located in the heart of the Dzongu Tribal Reserve, in the highest district in the country – North Sikkim. The whole village was severely impacted by massive landslides following the earthquake. ***a***, Before the earthquake; ***b***, After the earthquake.

tune of 2800 mm. There was colossal collateral damage due to a combination of precipitous terrain, weak geology, fragile ecology and heavy rainfall which amplified the impact of the earthquake creating a multiplier effect resulting in hundreds of natural calamities in the form of landslides, boulder falls and flash floods, thereby magnifying the damage to human life and property several times (Figure 1). Dzongu region in North District which was the closest to the epicentre was the worst hit (Figure 2).

In coastal areas tsunami poses a formidable post-earthquake threat, as was evident during the 2011 Japan earthquake and the 2009 Thailand earthquake. In fragile mountain areas like Sikkim, the major damage is caused by landslides and boulder falls triggered by the shaking. So far 354 new landslides have been identified after the earthquake by the National Remote Sensing Centre using remote sensing images[5].

Loss and damage

Upon impact, tens of thousands of residents evacuated their homes, and many areas suffered from communication and power outages. The strong shaking caused significant building collapse and mudslides; at least 60 people were confirmed killed by the effects of the earthquake within Sikkim, and hundreds of others sustained injuries. As the earthquake occurred in the monsoon season, heavy rain and landslides rendered rescue work more difficult. Extensive pan-state damage was reported to public infrastructure comprising transportation infrastructure (road networks, bridges, tunnels, culverts, retaining walls, village footpaths), energy infrastructure (generation plants, electrical grid, substations, transformers and local distribution), water management infrastructure (drinking water supply, drainage systems, irrigation and flood control systems), governance infrastructure (government offices along with residential buildings), social infrastructure (schools, hospitals, colleges, ICDS, etc.), economic infrastructure comprising marketing hubs, manufacturing centres, agriculture, horticulture, animal husbandry, forestry and fisheries infrastructure, recreation infrastructure like community halls, playgrounds, stadiums, sports complexes, etc. and cultural heritage infrastructure like historic monasteries, monastic schools, chortens, temples, churches, etc. Privately owned infrastructure like houses, lodges, hotels, commercial establishments, toilets, cattle sheds, stores, etc. was also badly hit.

The present study

The increasing frequency and intensity of earthquakes with growing risk due to rapid urbanization has renewed the urgency in improving the preparedness and making the infrastructure earthquake-resistant. The present study was undertaken to assess the vulnerability of the structures in the rural areas. The rural housing sector has long been a priority sector of the government and has received sizeable public investments. It is an important social infrastructure providing safety, identity and dignity to the owner. There are a total of 90,000 rural households with a population of 4.5 lakhs in the state[6]. This study aims to bring about a better understanding of the structural strengths and weaknesses of these rural habitations under the impact of the earthquake and provide indications of the way forward towards reducing their vulnerability in future. This study was conducted by undertaking field visits to the affected villages during September and October 2011.

Findings

Traditional houses

The rural houses were found to mainly have a traditional design and built using local materials, with only a handful of houses built using bricks and reinforced cement concrete. The prevalent house design is a two-storeyed structure with light ekra (bamboo reinforced wall) or wooden walling and plastered with mud or cement plaster on thick stone masonry walls. Generally these stone masonry walls are of undressed stones laid in mud mortar with height up to 2 m above the plinth. The light-weight sloping roof was made up of corrugated galvanized iron (CGI) sheets having rafters and purlins made of wood or bamboo (Figure 3). While the top floor is normally used for residential purposes, the ground floor is used to keep cattle or as a storehouse. In spite of being non-engineered structures, these houses have a proper system of bamboo/ wooden beam-column and fulfil most of the earthquake safety requirements of having a proper connection between different elements, due to which such houses act as a single unit and ensure box action.

These houses were found to be extensively damaged in various degrees owing to the following reasons:

- Failure of the stone masonry walls that bulged or collapsed (Figure 4 *a* and *b*). These load-bearing walls are poor in carrying horizontal earthquake inertia forces along the direction of their thickness owing to the use of multiple irregular stones in the cross-section and absence of ‘through stones’ (Figure 5).
- Houses were built near the stone masonry retaining wall where filling had been done. The shaking of the

Figure 3. Traditional houses are typically two-storeyed, with framed structure made from woven bamboo or wood having a light CGI sheet roof.

Figure 4. Partially collapsed load-bearing stone masonry wall supporting light-weight bamboo/wooden house with CGI sheet roof. ***a***, ***b***, House with (***a***) wooden walls and (***b***) with bamboo and wooden frame. ***c***, ***d***, Retrofitting with wooden posts.

Figure 5. Cross-section of the stone masonry wall with mud mortar. ***a***, 'Through stones' in stone masonry wall are vital in preventing the wall from collapsing. ***b***, Bulging is more prominent in stone masonry walls because of the absence of 'through stones' and needs to be retrofitted with wooden posts.

earthquake resulted in uneven settlement of the filled earth, thus damaging the foundation of the houses and leading to tilting.

- Houses with long and tall walls of stone masonry (more than 5 m long) which did not have reinforcement or buttress were found to be damaged.

Assessment of the post-earthquake damage indicated that though nearly half (54,000) of the rural houses in the state had suffered various degrees of damage, there were only a few deaths due to these houses, highlighting their inherent earthquake-safe character. While the superstructure of these wooden framed houses with bamboo walling and a light iron-sheet roof was found to be mostly intact, the stone masonry load-bearing walls laid on mud mortar and not having reinforcement suffered maximum damage. Though these stone walls were damaged or partially collapsed, the upper storey made of ekra with wooden frame and CGI sloping roof had tilted and can be retrofitted locally and made liveable again (Figure 4 *c* and *d*).

Brick/hollow concrete block masonry houses

These houses not very common in rural areas, were typically single-storeyed with brick masonry/hollow block and cement mortar walling and light weight CGI roofs. Generally brick infill showed better performance than stone masonry with mud mortar. However, hollow concrete block walling suffered severe damage. A few of these houses showed subsidence wherever built near the stone masonry retaining wall, where filling had taken place (Figure 6). Due to the shaking the filled earth shifted down, thus damaging the foundation of the house. Also these houses did not have reinforcement in the form of reinforced concrete (RC) columns, plinth beam or lintel band.

Heritage buildings

More than 50 heritage buildings, comprising mostly of several centuries old Buddhist monasteries were severely impacted. These buildings are typically made from stone masonry with dressed stones and cement mortar. The walls are often very wide (often 0.6 m) and two storeys tall with a CGI sheet roof. In most cases, the stone masonry wall collapsed resulting in damage to the ancient relics, historical artefacts, religious manuscripts, and wall and ceiling frescoes (Figure 7).

RC-frame buildings

Private houses with RC-frame structure with brick masonry infill and CGI sheet roof performed well, showing non-structural damage mostly in the form of cracks in the infill walls (Figure 8 *a*). Severe damage took place in buildings where the new owner had carried out vertical extension of several storeys without taking into consideration the structural strength of the earlier constructed house. Multi-storeyed, RC-frame, engineered buildings like schools, government offices, etc. were severely damaged (Figure 8 *b*). These buildings have suffered from corrosion of reinforcement bars, from damage to columns and beams, failure of gable wall, severe cracking in infill walls and separation between RC-frame and infill.

Discussion

Earthquakes in the Himalayan region have a history of causing extensive damage to housing infrastructure. In Sikkim, during the *M* 5.3 earthquake of 2006, traditional houses performed well and suffered little damage[7]. However this time around about half of the 90,000 traditional houses suffered various degrees of damage largely due to the collapse of the stone masonry wall; however, human casualties were limited to 63, caused mostly by landslides and boulder falls. The traditional houses in the Western Himalaya predominantly have load-bearing random rubble masonry wall in mud mortar with the roofing system usually of thatch, tin sheets, slate tiles or RC slabs. During the Chamoli earthquake of 1999, the traditional houses performed poorly and caused most of the deaths and injuries due to the collapse of these constructions[8]. The traditional houses in Sikkim Himalaya are lighter having wooden framed structure with bamboo walling and CGI sheet roof. The cage-like reinforced structure helped them perform better compared to the traditional houses in the Western Himalaya.

However, improved stone masonry construction design will help strengthen the traditional houses in Sikkim during future earthquakes. The main deficiencies in the traditional design include excessive wall thickness, absence of interlocking in the wall, and use of irregular stones (instead of dressed ones). Use of 'through stones' in stone masonry walls is critical to prevent the wall from collapsing (Figure 5). The wall thickness should not exceed 0.45 m. Irregular stones should not be used; instead they should be dressed using chisel and hammer. Cement–sand mortar (1 : 6 or richer) should be used instead of mud mortar. The unsupported length of walls between cross-walls should be limited to 5 m; for longer walls, buttresses should be provided at spacing not more than 4 m. The height of each storey should not exceed 3 m (ref. 9). In order to facilitate better know-how in the making of new traditional houses with earthquake-resistant design, mass practical trainings of the local masons and orientation of the local community are needed. These along with illus-

Figure 6. Damage to brick masonry houses with CGI sheet roofs. ***a***, Subsidence due to sinking of the fill part of the foundation. ***b***, Cracks extending up to the plinth, indicating the need for plinth beam to hold the structure together.

Figure 7. Extensive damage to stone masonry walls of tall heritage structures. ***a***, Dubdi monastery, Yuksam, West Sikkim. ***b***, Ringhim monastery, Mangan, North Sikkim.

Figure 8. Damage to RC-frame buildings. ***a***, Non-structural damage in the form of diagonal cracks in the infill walls and separation from RC frame. ***b***, Severe structural damage to multi-storeyed, engineered school building.

trated booklets in the local language indicating the improvements will go a long way in ensuring that these principles become a standard practice in traditional house construction in the rural areas. Brick masonry structures need to be reinforced with plinth-level beam and lintel band. Care should be taken so that they are not built near the retaining wall where filling has been done. Traditional buildings like historical monasteries need to be retrofitted by reinforcing the tall stone masonry walls by providing RC-frame, lintel bands, buttress walls, etc.

In RC construction, good construction practices need to be propagated, and the building and seismic codes need to be enforced (IS:1893 2002; IS:13920 1993; IS:4326 1993)[7,10]. Light CGI sheet roofs should be preferred over RC slabs, lintel band should be introduced and infill walls should be tied to the RC-frame. Building and seismic codes should be strictly enforced, and material and workmanship quality improved. Another urgent requirement is training and supply of booklets to government as well as private engineers and to the local people on how to incorporate simple techniques in buildings to make them earthquake-resistant. Compliance to these codes can be improved by making building insurance compulsory for all new constructions. The insurance companies will ensure that all the building safeguards are incorporated. This earthquake should serve as a wake-up call to different stakeholders (architects, engineers, masons, contractors, material manufacturers, public, etc.) to safeguard against future earthquakes.

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