Performance of structures during the Sikkim earthquake of 14 February 2006

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Performance of structures in different areas of Sikkim, during the earthquake of 14 February 2006, is reviewed. The earthquake caused damage to heritage structures as well as modern buildings. Both masonry and reinforced concrete buildings showed poor performance. On the other hand, traditionally constructed wooden houses performed extremely well. The damage seen in and around Gangtok was clearly disproportionate to the size of the earthquake, which was a moderate 5.7 on the Richter scale. This very clearly establishes the high level of seismic vulnerability of the region. The damage is primarily attributed to poor design and construction practices, and lack of quality control. Urgent need for trained human resources and for creation of a system of checks and balances, to ensure safe constructions in Sikkim is highlighted.

Keywords: Masonry structures, reinforced concrete structures, Sikkim earthquake, structural performance, traditional wooden construction.

A moderate earthquake (reported as M_w 5.3 by USGS and as M_L 5.7 by IMD) occurred in Sikkim (India) on 14 February 2006 at 06:25:23 am local time. Its epicentre and focal depth were reported from two different sources as (a) at 27.35°N 88.35°E, near Ralang (South Sikkim), with a focal depth of 30 km (www.usgs.gov), and (b) at 27.7°N 88.8°E, near Lachung (North Sikkim), with a focal depth of 33 km (www.imd.ernet.in) (Figure 1). Shaking was also felt in the northeastern states of India and the neighbouring countries. However, related damage was reported only from the East and South districts of Sikkim. Two soldiers of the Indian Army died in landslides after the ground shaking at Sherathang near Nathula in Sikkim; there were no reports of any other fatalities. Several aftershocks with smaller magnitudes were recorded at the IMD observatory at Gangtok. Soon after the earthquake, the authors carried out field investigations, primarily along three routes, namely (a) from Siliguri to Gangtok along NH 31A in East Sikkim district, (b) from Singtam to Ralang in South Sikkim district, and (c) from Gangtok to Kupup in East Sikkim district.

Most of the structural damage was observed in and around the state capital Gangtok, with the maximum intensity of shaking as VII on MSK scale (Figure 1). Damage observed in buildings in and around Singtam (East Sikkim) towards the southwest of Gangtok, suggested an intensity level of VI. It is interesting to note in Figure 1 that the epicentral locations according to USGS and IMD lie well outside the area of maximum damage (25 km west of Gangtok according to USGS and 44 km north of Gangtok according to IMD). This may be due to inaccurate estimation of the epicentre. It could also be due to varying geological condition in the region; however this needs to be investigated further.

Sikkim is spread out on the Himalayan mountain range with two main thrust faults, the Main Boundary Thrust (MBT) and Main Central Thrust (MCT) crossing the state[1]. Continuous thrusting of the Indo-Australian plate against the Eurasian plate has made most parts of the Himalayan collision zone seismically active. Sikkim is a part of this zone; therefore it had been a moderately active seismic region in historical times[2,3]. Significant earthquakes in the region in the last 50 years include the 19 November 1980 Sikkim earthquake of M_b 6.0, and 21 August 1988 Bihar–Nepal earthquake of M_b 6.5 (ref. 4). Thus, Sikkim is located in seismic zone IV of the Indian seismic zoning map, with the expected maximum intensity of shaking as VIII on the MSK scale.

The entire Himalayan belt is one of the most seismically active regions in the world. In the last 110 years, four great earthquakes (magnitude equal to or greater than 8.0) have occurred along this subduction zone causing large-scale damage in the surrounding areas[5,6]. These are the 1897 Shillong (*M* 8.0), 1905 Kangra (*M* 7.8 to *M* 8.0), 1934 Bihar–Nepal (*M* 8.1), and 1950 Assam (*M* 8.5) earthquakes. The area between the 1934 and 1950 events (Sikkim falls in this region) stands out as a seismic gap that has not produced any major earthquake in the historical times[7]. Another known seismic gap is in the area between the 1905 and 1934 events[8]. There is a high probability of a

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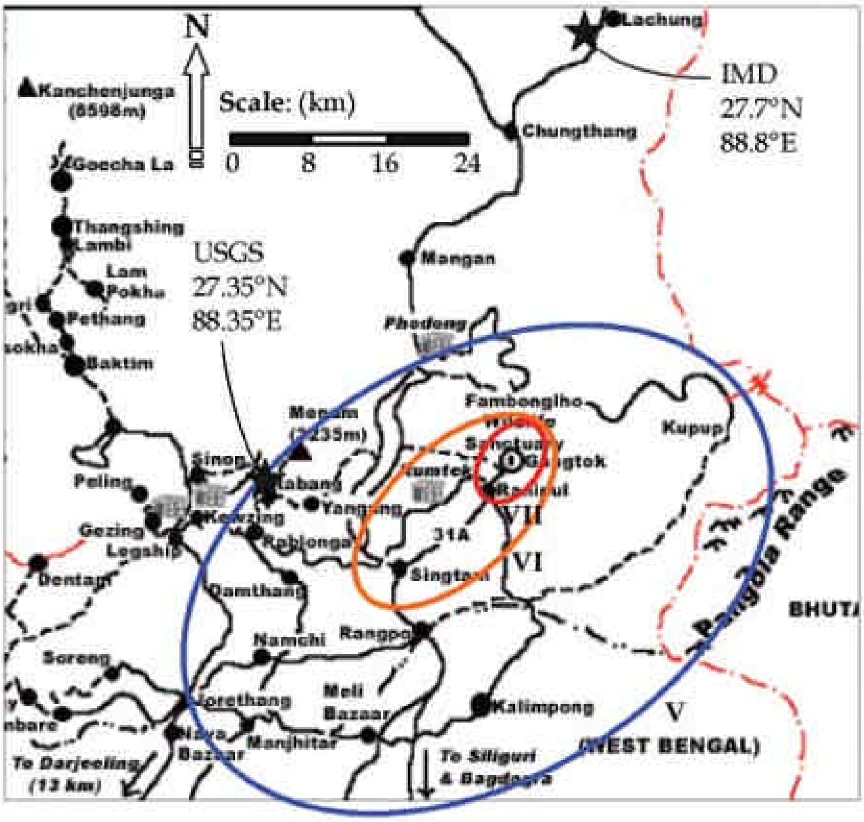

Figure 1. Epicentral locations and proposed isoseismal map of 14 February 2006 Sikkim earthquake.

Figure 2. Traditionally constructed typical Ikra structure in Sikkim (school building at Nandok, East Sikkim).

major event in these seismic gaps in near future[8,9]. It has been reported that there were large-scale damages (intensity VII and above) in Sikkim after the 1897 and 1934 events[10–12]. It may be mentioned here that even smaller earthquakes of 1980 (Sikkim, M 6.0) and 1988 (Bihar–Nepal, M 6.5), have caused damage in Sikkim[4]. Therefore, there is possibility of widespread damage in the state during another major event in the seismic gap regions near Sikkim. The present earthquake of magnitude ~5.3–5.7 was comparatively small; hence damages caused by this event clearly indicate that the region is vulnerable to disaster in the future.

It was common practice in Sikkim to construct residential buildings using wood/bamboo, until the tourism industry got a boost in the early nineties. Such traditional constructions performed well during ground-shaking. Most old buildings in Sikkim are made of stone masonry with mud mortar. Stone-masonry buildings suffered substantial damage during the present earthquake, and several of these were evacuated. Presently, RC-frame buildings with masonry infills are mostly used in private as well as government constructions. There is no formal design practice in Sikkim even for RC-frame buildings. Except for a few RC buildings involving major projects, analysis and design are generally not carried out; structural drawings are prepared simply based on previous experiences of engineers on the basis of a few thumb-rules. Most of the new RC buildings in Gangtok suffered varying degree of damage during this earthquake; however no complete collapses were seen.

Traditional construction in Sikkim consists mostly of typical bamboo houses, known locally as 'Ikra', and also known as Assam-type housing. Ikra houses are single-storey structures consisting of brick or stone masonry walls up to about 1 m above the plinth (Figure 2). This masonry supports the walls consisting of bamboo woven together with a wooden frame, and plastered with cement or mud plaster. The roof generally consists of GI sheets supported on wood/bamboo trusses, which laterally connect the parallel walls. Bamboo superstructure is connected to the masonry foundation walls using steel angles, and flats with

Figure 3. Performance of masonry structures at Gangtok. ***a***, ***b***, Wide shear and vertical cracks in masonry walls at corners and near openings in Enchey Monastery. ***c***, Numerous cracks near door/window openings were observed at Raj Bhavan. ***d***, Good performance shown by retrofitted Archive building (arrows show steel flats used to retrofit the building after the 1988 Bihar–Nepal earthquake).

bolts and nails. There were no reports of any significant damages to Ikra structures during this earthquake.

Generally, stone-masonry structures in the area are of undressed stones with mud mortar. A few important structures have dressed stone masonry with mud and lime-based mortar (e.g. the Raj Bhavan). Stone-masonry buildings suffered damages primarily because of undressed stones used without proper bonding between adjacent courses of masonry, and also at the corners. The mud mortar used as bonding material in these buildings further aggravates their lateral strength capacity. Some of the important masonry buildings damaged during the earthquake are Enchey monastery (Figure 3 *a* and *b*) and the Raj Bhavan (Figure 3 *c*). These buildings were also damaged during the 1980 and 1988 earthquakes[4]. It seems that these buildings were only 'repaired' and not adequately retrofitted against future events. During the present earthquake, several masonry walls of these buildings suffered damages in the form of inclined shear cracks, and vertical cracks (Figure 3 *a*–*c*). These cracks were concentrated at the corners, and also at the location of window and door openings. The two-storey Archive building was previously the Legislative Assembly building at Gangtok, until it was damaged during the 1988 Bihar–Nepal earthquake. Subsequently, this masonry building was retrofitted by fixing horizontal and vertical steel flats of about 50 mm × 8 mm size on all the outer faces of the exterior walls in each storey (Figure 3 *d*). The building sustained no damage during the present earthquake. Clearly, sensible retrofitting of important heritage structures can be critically useful in the future earthquakes.

In rural areas of Sikkim, low-cost school buildings are generally constructed by the state government using stone masonry with mud mortar. Several such buildings suffered severe damage during the present earthquake. Earthquake-resistant features such as horizontal bands at various levels and stones at the corners are generally not provided in such constructions. This resulted in the formation of severe cracks near the corners and at the location of openings in such buildings, when subjected to even mild shaking (Figure 4). In addition, out-of-plane tilting of several masonry walls was observed at some places.

In RC buildings, burnt clay bricks or solid/hollow concrete blocks are commonly used as infills. Noticeable features of this type of construction are (i) absence of RC lintels above doors and windows in private buildings (brickwork is generally supported directly by the wooden frame used for doors/windows), (ii) floating columns in upper storeys, (iii) intermediate soft storey in multistoreyed buildings, and (iv) poor reinforcement detailing. Quality control of materials was observed to be poor in most of the constructions.

Most RC buildings at Gangtok suffered damages of some form or the other, the most common being cracks in masonry

Figure 4. ***a***, ***b***, Severely damaged stone masonry low-cost school buildings in Sikkim. (Government Primary School, Thamidara near Gangtok).

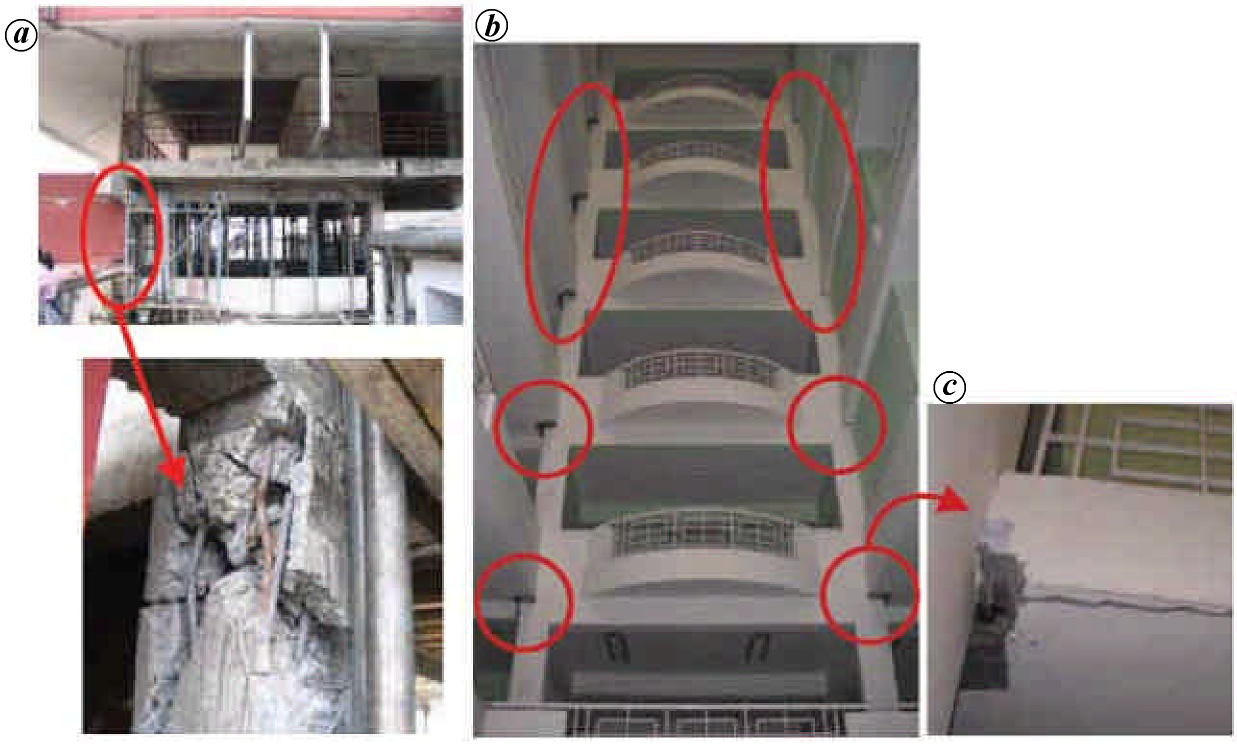

Figure 5. Damages in nine-storey RC hostel building (SMIMS). ***a***, Damaged RC column supporting water tank on the roof. ***b*** and ***c***, Pounding damages at the ends of the two wings took place at all the floor levels.

infills, and separation between RC frame and infill. Several government buildings, including the Legislative Assembly building, Tashiling Secretariat, State Legislators' Hostel, Geological Survey of India (GSI) building at Deorali, suffered varying degrees of damage. Among government buildings, GSI was the worst affected. Fortunately, the shaking was quite moderate and no RC building collapsed.

The nine-storey masonry-infill RC-frame hostel building at Sikkim Manipal Institute of Medical Sciences (SMIMS), Tadong, Gangtok suffered damages in walls and columns. Several masonry-infill walls developed diagonal cracks due to the earthquake. One RC column below a water tank at roof level suffered heavy damage because of inadequate shear reinforcement, and improper lap splicing in longitudinal reinforcement (Figure 5 *a*). A few hostel rooms in the top storey just below the damaged column were evacuated soon after the shaking. Pounding damages were observed between two long wings in the building and corridors connecting these (Figure 5 *b* and *c*). Another four-storey RC building at Deorali suffered damages and was

Figure 6. Damage in residential building at Deorali. ***a***, Severe cracking in infill walls and damaged RC column. ***b***, Exposed mild steel in damaged RC column; and ***c***, Out-of-plane failure of infill wall.

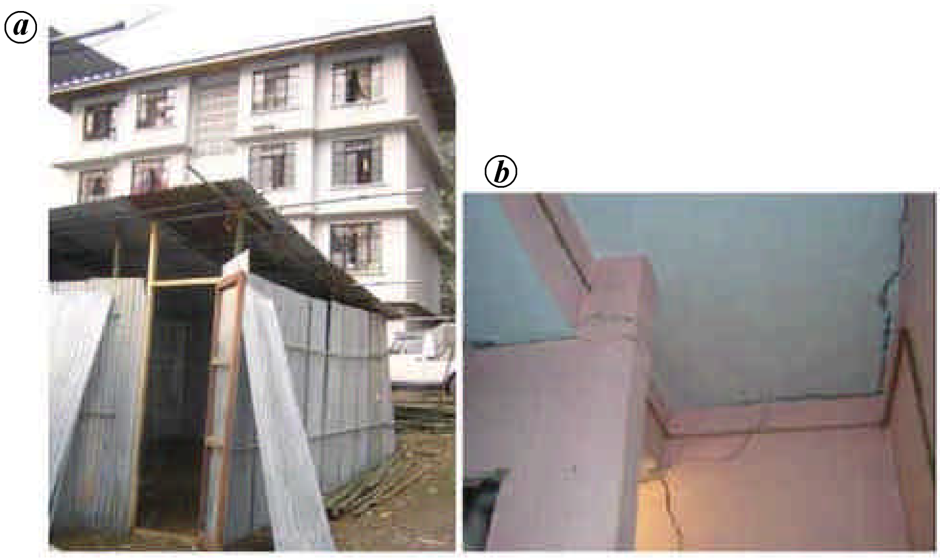

Figure 7. Four-storey government residential building (SNT colony) at Ranipool which suffered severe damage. ***a***, Temporary shelters constructed using GI sheets in the backdrop of the RC quarters. ***b***, Damaged columns and walls in one of the quarters.

evacuated. Severe damages were observed in several RC columns of the building, exposing mild steel bars as main reinforcement (Figure 6 *a* and *b*). Poor material quality and poor connection between perpendicular masonry walls resulted in out-of-plane failure of one infill wall, and severe damage to other infill walls in the building (Figure 6 *a* and *c*).

Similar damage to infills and RC members was noticed in several other government and private RC buildings in the eastern and southern districts of Sikkim. A part of the recently constructed three-storey RC government secondary school building at Sichey was found to be damaged. One masonry infill wall in the first storey tilted out-of-plane along with cracks in several other infills. In several RC columns of the building, spalling of cover concrete due to corrosion of reinforcement bars was observed along with inadequate shear reinforcement. Several RC buildings (up to four-storey high) of Sikkim Nationalized Transport (SNT) colony at Ranipool near Gangtok suffered similar damages (Figure 7 *a*). At least one quarter was severely damaged (Figure 7 *b*), and the government had already given orders for evacuation. At the time of reconnaissance visit, temporary relief quarters (~7 m × 7 m) using GI sheets, bamboo posts and GI pipes were being constructed in front of the RC buildings, and residents were instructed to move into them (Figure 7 *a*).

Figure 8. Two-span RC Tarkhola bridge between Melli and Rangpo appeared to be slightly damaged at the location of roller bearings on top of central pier. ***a***, Bridge overview; ***b***, Closer view of central pier cap showing spalling of concrete and insufficient lateral restrainer made of steel at the top of the pier.

There are several bridges on National Highway 31A, which connects Sikkim to the rest of the country. In the Tarkhola bridge between Melli and Rangpo, spalling of concrete was observed at the top of the central pier near bearings (Figure 8). One needs to ascertain if this was caused by the earthquake. Bridge-deck lateral restrainers, which can prevent the spans from dislodging-off the piers, were observed in most of the bridges along NH 31A. However, these steel lateral restrainers appeared to be insufficient in holding the bridge decks during severe ground shaking expected in seismic zone IV (Figure 8 *b*). An RC pedestrian foot bridge constructed in 1989 near STNM Hospital, Gangtok sustained minor damage in the form of spalling of cover concrete in one RC beam due to corrosion of reinforcement bars. Horizontal cracks were observed in masonry walls of an RC office building of the Sanitation Section, Urban Development and Housing Department, Sikkim, constructed under the foot bridge at one end.

Three-storey RC telephone exchange building at Lower Sichey, Gangtok constructed in 1980 developed extensive diagonal shear cracks in the infill walls near the openings and along concealed pipe fittings in the walls. No significant damage was observed in the RC frame of the building. The two major hospitals (Central Referral Hospital, SMIMS and STNM Hospital) at Gangtok suffered only minor damages in the form of cracks in masonry infills. The electric power supply in Gangtok, obtained mainly from Chukha Hydroelectric Power Project, Bhutan, was disrupted for a few minutes just after the earthquake. No disruption of water supply in Gangtok town was reported after the earthquake. No structural damage was reported from any water supply or electric supply facility in Gangtok.

The present study puts a maximum intensity of shaking as VII (on the MSK scale) in the worst affected areas of Sikkim during the recent earthquake of magnitude ~5.3–5.7. In the absence of proper design and construction methods and lack of quality control, masonry buildings and RC-frame buildings have performed rather poorly. This indicates high level of seismic vulnerability of the region. Discontinuous RC columns were commonly observed in several RC-frame buildings in Sikkim; therefore RC-frame lateral load resisting system could not be developed in such buildings. Such design and construction practices may have severe consequences as seen in Ahmedabad during the Bhuj earthquake of 26 January 2001. Traditionally constructed bamboo structures (Ikra) have performed well during this earthquake. Good construction practices need to be propagated and the seismic codes need to be enforced. People (including engineers) need to be sensitized about basic construction issues, and seismic hazard associated with the region of Sikkim. Another urgent requirement is training and supply of simple literature to government as well as private engineers and to local people on how to incorporate simple techniques in RC and masonry buildings to make them earthquake-resistant. Considering the high seismic hazard in the area, this moderate earthquake has highlighted the urgent need for proactive actions to propagate safe construction practices.

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