RECONNAISSANCE REPORT

SIKKIM EARTHQUAKE OF 14 FEBRUARY 2006

By

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Photographs on the cover and back pages show different construction practices and performance of different types of structures in Sikkim during the earthquake shaking of 14 February 2006.

PREFACE

This report is the result of a Reconnaissance Study in Sikkim (India), immediately after the earthquake of 14 February 2006. The study was undertaken by the National Information Center of Earthquake Engineering (NICEE) at IIT Kanpur with support from TATA STEEL LIMITED, India. The objective of the study was to document perishable information and collect on-site data on the behaviour of buildings and structures in Sikkim under the impact of the 14 February earthquake.

The earthquake caused damage to heritage structures as well as modern buildings. Both masonry and reinforced concrete buildings showed poor performance. 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. Such disproportionate damage is a direct consequence of poor design and construction practices in an inadequate professional environment that is challenged by the lack of trained human resources in the state.

There is consensus in the scientific world that Sikkim and its adjoining areas will likely witness major earthquakes in the future. This, combined with the poor construction practices prevalent in the area, spells tremendous risk for the population of this region. The only solution to this problem lies in opting for safer constructions through choice of appropriate construction systems, incorporation of earthquake resistant technology, use of good construction materials and their quality control, and involvement of competent manpower for design, construction and supervision. Furthermore, it will require sensitizing common people about the seismic hazard and the very real and tangible seismic risks that the 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.

The task is enormous and must perforce, involve all sections of society—the Government, NGOs, professionals, industries, and the common man. It is time already that this task is initiated and taken forward, in the interest of the safety of the community, given the huge seismic vulnerability of the region, as was clearly demonstrated by the 14 February 2006 earthquake. Everyday, more and more unsafe buildings are being added to the already existing huge stock of such buildings. Clearly, the time to act is now and the February 2006 earthquake should be treated as a wake up call, as a not-to-be-missed opportunity to equip the state in seismically safe practices at a holistic level.

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INTRODUCTION

The moderate earthquake (reported as M_w 5.3 by USGS and as M_L 5.7 by IMD) occurred in the state of Sikkim (India) on February 14 2006 at 06:25:23 a.m. local time. The earthquake's epicenter 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*) as shown in Figure 1.

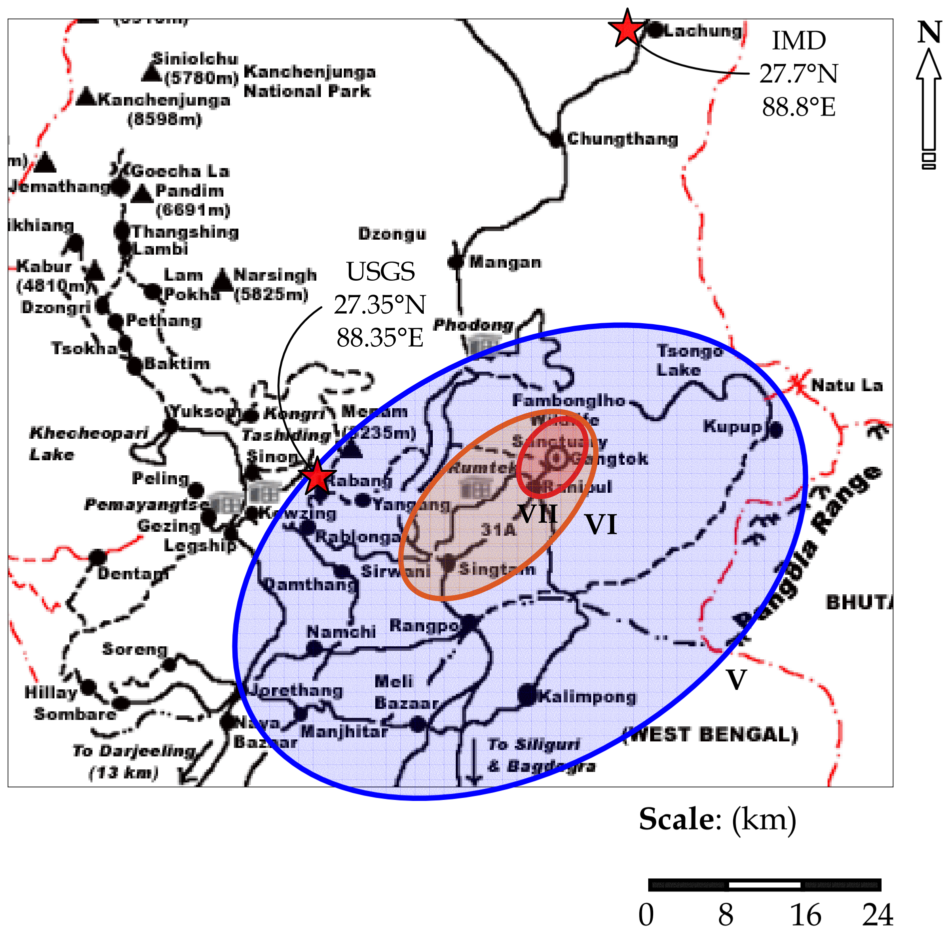

Figure 1: Epicentral locations and proposed iso-seismal map of 14 February 2006 Sikkim earthquake.

The shaking was also felt in the North-Eastern states of India and in the neighbouring countries. However, shaking-related damage was reported only from the East and South districts of Sikkim. Two Indian Army soldiers 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 shaking, 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). Damages observed in buildings in and around Singtam (East Sikkim) towards the south-west of Gangtok, suggested an intensity level of VI. It is interesting to note in Figure 1 that the epicentral location as per USGS and IMD lies well outside the area of maximum damage (25 km west of Gangtok as per USGS and 44 km North of Gangtok as per IMD). This may be due to inaccurate estimation of the epicenter.

PAST SEISMICITY

The state of Sikkim is spread on the Himalayan mountain range with the two main thrust faults, Main Boundary Thrust (MBT) and Main Central Thrust (MCT) crossing the state (Dasgupta et al. 2000). Due to continuous thrusting of Indo-Australian plate against the Eurasian plate, Sikkim has been a moderately active seismic region in the historical times (De and Kayal 2003; Nath et al. 2000). The significant earthquakes to have caused shaking 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 (Jain 1992). These are corroborated by the fact that the state of Sikkim is located in the seismic zone IV of 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 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 (Bilham 2004). These earthquakes are: 1897 Shillong earthquake of magnitude 8.0, 1905 Kangra earthquake of magnitude 7.8 to 8.0, 1934 Bihar-Nepal earthquake of magnitude 8.1, and 1950 Assam earthquake of magnitude 8.5. 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. Other known seismic gap is in the area between the 1905 and 1934 events. There is a very high probability of a mega-event in these seismic gaps in near future (Bilham et al. 2001). There were large scale damages (intensity VII and above) in Sikkim after 1897 and 1934 events (Narula and Sharda 1997; Oldham 1899; Dunn et al. 1939). It may be mentioned here that even during smaller magnitude earthquakes of 1980 (Sikkim, magnitude 6.0) and 1988 (Bihar-Nepal, magnitude 6.5), damages were observed in Sikkim (CBRI 1988). Therefore, there is a possibility of wide spread damages in Sikkim during another mega-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 highly vulnerable to a major disaster in the future.

CONSTRUCTION PRACTICE

It was a common practice in Sikkim to build residential buildings using wood/bamboo, until tourism industry got a boost in early nineties. Such traditional constructions performed quite well during the ground shaking. Most major old buildings in Sikkim are made of stone masonry with mud mortar. Generally, stone masonry buildings suffered substantial damages during the present earthquake shaking, and several of those 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 very few RC buildings involving major projects, analysis and design are generally not carried out; the 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 damages during this earthquake; however no complete collapses were seen.

PERFORMANCE OF BUILDINGS

Traditional Constructions

Traditional construction in Sikkim consists mostly of typical bamboo houses, known locally as *Ikra*, same as what is otherwise known as *Assam type* housing. Typically, *Ikra* houses are single storey structures consisting of brick or stone masonry walls up to about 1 m above the plinth (Figure 2a).

(a)

(b) (c)

Figure 2: Traditional construction in Sikkim: (a) Typical *Ikra* structure (School building at Nandok in East Sikkim); (b) *Ikra* house under construction near Nandok; and (c) internal view (note use of wooden trusses and GI sheets in roof construction).

This masonry supports the walls consisting of bamboo woven together with wooden frame, and plastered with cement or mud plaster (Figure 2b). Roof generally consists of GI sheets supported on wood/bamboo trusses which laterally connect the parallel walls (Figure 2c). Bamboo *superstructure* is connected to the masonry *foundation* walls using steel angles, and flats with bolts and nails. There were no reports of any significant damages to *Ikra* structures during this earthquake.

Masonry Constructions

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.*, *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* (Figures 3a, 3b, 3c) and *Raj Bhavan* (Figure 3d). These buildings were also damaged during the 1980 and 1988 earthquakes (CBRI 1988). 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 (Figures 3a-3d). These cracks were concentrated at corners, and also at location of window and door openings. The two storey Archive building was previously the legislative assembly building at Gangtok until it was damaged during 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 3e). The building performed well in the present earthquake and sustained no damage. Clearly, sensible retrofitting of the important heritage structures can be critically useful in the future earthquakes.

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

(a) (b) (c)

(d) (e)

Figure 3: Performance of masonry structures at Gangtok: (a), (b), (c) wide shear and vertical cracks in masonry walls at corners and near openings in *Enchey Monastery*; (d) numerous cracks near door/window openings were observed in *Raj Bhavan*; and (e) good performance shown by retrofitted Archive building (arrows indicate locations of steel flats used to retrofit the building after 1988 Bihar-Nepal earthquake).

(a) (b)

Figure 4: Severely damaged stone masonry low cost school buildings in Sikkim: Government primary school, Thamidara (near Gangtok).

Reinforced Concrete Constructions

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 (Figure 5a), (iii) intermediate soft storey in multistoreyed buildings (Figure 5b), and (iv) poor reinforcement detailing. Quality control of materials was observed to be poor in most of the constructions.

(a) (b)

Figure 5: Poor construction practice in Sikkim: (a) floating columns (shown by arrows) in the upper storey of an RC building; and (b) multistoreyed building with intermediate soft storey.

Most RC buildings at Gangtok suffered damages in some form or the other, the most common damage being cracks in masonry infills, and separation between RC frame and infill. Several Government buildings including legislative assembly building, *Tashiling* Secretariat, State Legislators' Hostel, Geological Survey of India (GSI) building at Deorali, suffered varying degree of damages (Figure 6). Among Government buildings, GSI building was the worst affected. Fortunately, the shaking was quite moderate and no RC building collapsed.

(a)

(b)

Figure 6: Damages to masonry infills in RC buildings at Gangtok: (a) cracks at beam-wall interface in Secretariat building; and (b) damages in walls near openings in GSI building at Deorali.

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 earthquake shaking. One RC column below a water tank at roof level suffered heavy damages because of inadequate shear reinforcement, and improper lap splicing in longitudinal reinforcement (Figures 7a, 7b, 7c, and 7d). A few hostel rooms at 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 those (Figures 7e, and 7f). Another four-storey RC building at Deorali suffered damages and was evacuated. Severe damages were observed in several RC columns of the building exposing mild steel bars as main reinforcement (Figures 8a and 8b). Poor material quality, and poor connection between perpendicular masonry walls resulted in out-of-plane failure of one infill wall, and severe damages to other infill walls in the building (Figures 8a and 8c).

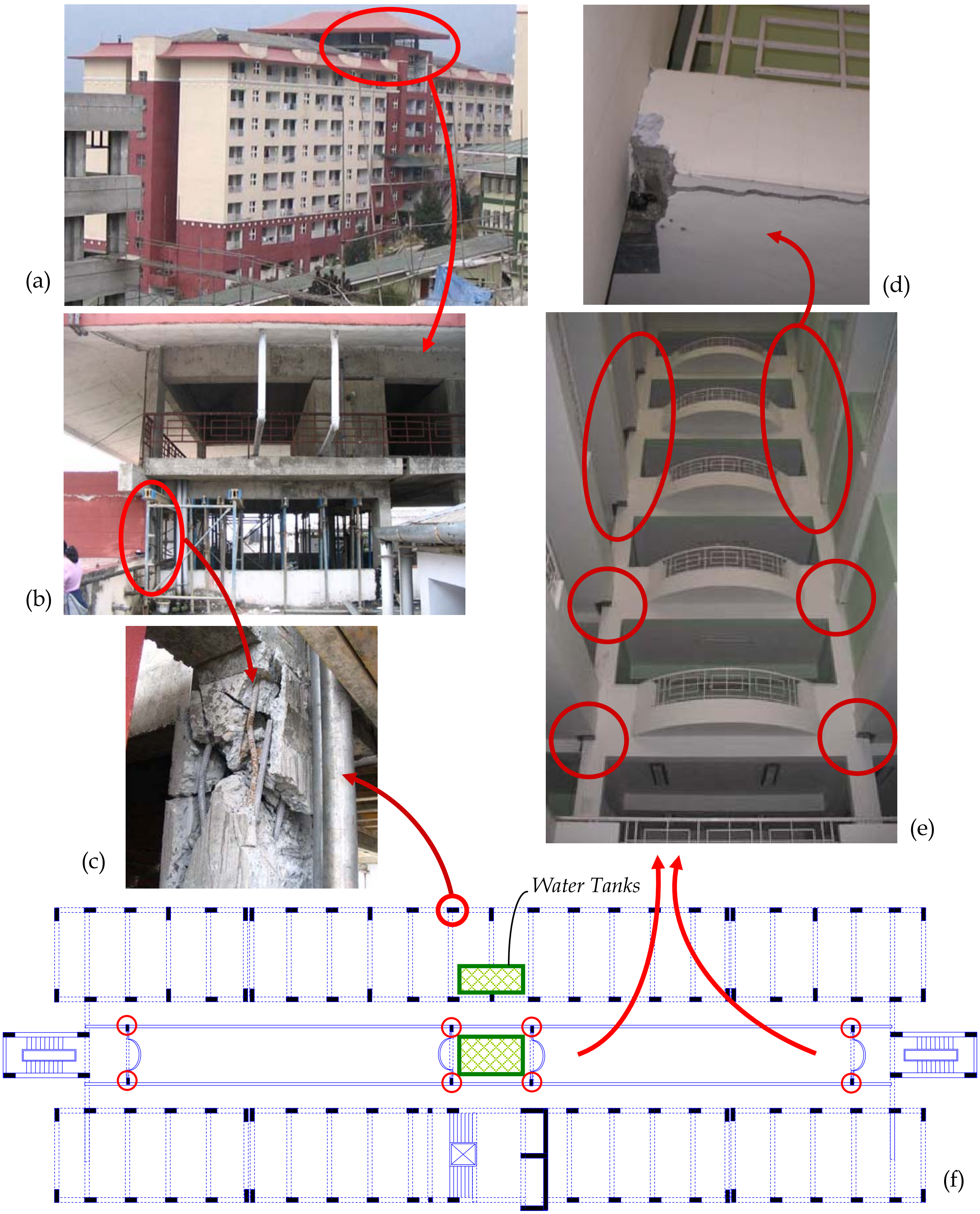

Figure 7: Damages in nine-storey RC Hostel building (SMIMS): (a) elevation of the building; (b) damaged RC column supporting the water tank on the roof; (c); (d) pounding damages at the ends of the two wings took place at all the floor levels, (e) close view of the damaged column; and (f) plan of the building.

(a) (b) (c)

Figure 8: 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.

Similar damage to infills and RC members was noticed in several other government and private RC buildings in eastern and southern districts of Sikkim. A part of 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 (Figure 9a) 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 (Figure 9b).

(a) (b)

Figure 9: Government secondary school building at Sichey suffered moderate damages: (a) out of plane tilting of masonry infill wall, (b) inadequate shear reinforcement in columns, and spalling of cover concrete in columns at several locations due to corrosion.

Several RC buildings (up to four-storey high) of Sikkim Nationalized Transport (SNT) colony at Ranipool near Gangtok suffered similar damages (Figure 10a). At least one quarter was severely damaged (Figure 10b), and the government had already given orders of evacuation of several quarters. 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 10a).

(a) (b)

Figure 10: One quarter of four storey government residential buildings (SNT colony) at Ranipool suffered severe damages: (a) temporary shelters constructed using GI sheets in the backdrop of the RC quarters, (b) damaged columns and walls in one of the quarters.

Lifeline Structures

There are several bridges on National Highway 31A, which connects Sikkim to the rest of country. In the Tarkhola Bridge between Melli and Rangpo, spalling of concrete was observed at the top of central pier near bearings (Figure 11). One needs to ascertain if this was caused by the earthquake shaking. 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 for holding the bridge decks during severe ground shaking expected in seismic zone IV (Figure 11c). An RC pedestrian foot bridge constructed in 1989 near STNM Hospital at 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 Sanitation Section, Urban Development and Housing Department (UDHD, 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 openings and along concealed pipe fittings in 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.

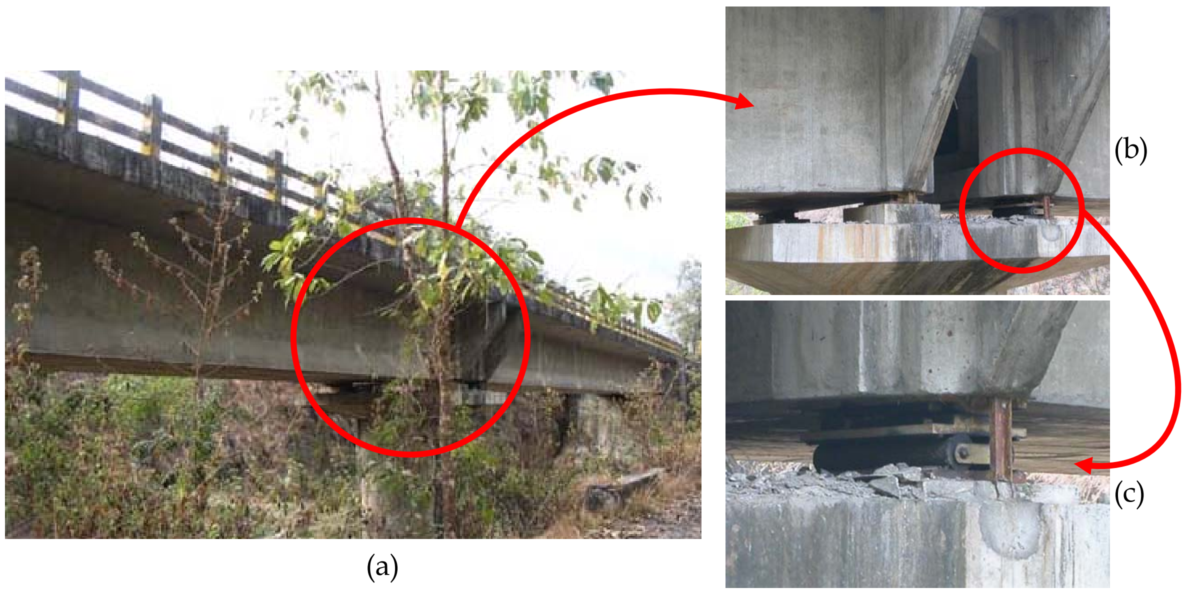

Figure 11: Two-span RC Tarkhola Bridge between Melli and Rangpo appeared to be slightly damaged at the location of roller bearings on top of central pier: (a) bridge overview, (b) closer view of the central pier cap, and (c) spalling of concrete and insufficient lateral restrainer made of steel at the top of pier.

CONCLUDING REMARKS

The present study puts a maximum intensity of shaking as VII (on MSK scale) in the worst affected areas of Sikkim during the present 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 very 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 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 (IS:1893 2002; IS:13920 1993; IS:4326 1993). People (including engineers) need to be sensitized about basic construction issues, and seismic hazard associated with the region of Sikkim. Systematic changes are required in building industry for better training of engineers, and involvement of different stake holders (architects, engineers, material suppliers, contractors, material manufacturers, public, etc) in actual construction process of structures. 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 buildings to make them earthquake resistant. *National Information Center of Earthquake Engineering* (NICEE) at IIT Kanpur is one such organization in India, which distributes several such publications in simple language that can be understood by common people. These publications include: *Earthquake Tips*, and *IAEE Guidelines for Earthquake Resistant Non-Engineered Construction*. Some of these materials are freely available on the web site *www.nicee.org*.

Existing deficient buildings, particularly the important heritage structures, should also be repaired/strengthened on priority. Resource materials on repairing and strengthening of existing RC and masonry structures, such as, IS:13935 1993, and IITK-GSDMA Guidelines on Seismic Evaluation and Strengthening of Existing Buildings (downloadable from *www.nicee.org*) can be quite useful in this.

In most RC buildings in Sikkim, the grade of concrete being used currently is M15, as against the specified minimum grade of M20 for general RC structures (IS:456 2000). It was observed that mild steel bars are being used as main reinforcement in RC members. But for proper bonding with concrete and desirable characteristics, high yield strength deformed (HYSD) bars of good quality steel are recommended. For masonry buildings, lime mortar or cement mortar with desirable characteristics should be used instead of mud mortar.

Considering the high seismic hazard in Sikkim, this moderate earthquake has highlighted the urgent need for proactive actions to propagate safe construction practices. Government departments, NGOs, industries, and material suppliers can collectively bring about a change for the seismic safety in the area.

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