Buddhist Monasteries in Grave Danger in Himalayan Region

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SUMMARY:
The three Himalayan countries (India, Nepal and Bhutan) have a large number of Buddhist cultural structures; of these, the monasteries are important Buddhist heritage structures. Many of these have been severely affected by the 2011 (India -Nepal) Sikkim Earthquake. The older monasteries are made in random rubble stone masonry in mud mortar, while some recent ones in reinforced concrete. Damages were sustained in both these constructions. This paper presents a summary of the damages sustained by monasteries in the state of Sikkim (India) during 2011 Sikkim Earthquake. Also, details of the possible retrofit schemes are provided to save the Buddhist heritage structures in the regions.

Keywords: Heritage structure, Stone masonry, Retrofit

1. INTRODUCTION

1.1. Setting

An M_w 6.9 earthquake struck the Nepal-Sikkim border on 18th September 2011 at 18:10 local time (Murty et al., 2012). A significant number of Buddhist cultural structures in Sikkim were damaged, including few of them beyond feasible repair. Most of these historical masonry structures are built without typical earthquake resistant features required in masonry structures for desirable performance, despite the regularity of seismic activity in the region (19th November 1980 Sikkim earthquake M_w 6.1, 21st August 1988 Bihar-Nepal earthquake M_w 6.5, 14th February 2006 Sikkim Earthquake M_w 5.3). As per the Indian seismic code (IS 1893-1, 2002), the state of Sikkim is in a zone of high seismic hazard (Zone IV) with design peak ground acceleration (PGA) of 0.24g.

The current paper is a summary of observed damage in Sikkim's monasteries, based on a reconnaissance survey conducted by the authors in the affected regions, one week after the event. A striking feature of the earthquake was that the extent of damage was not commensurate with level of shaking, which was VI+ on the MSK scale (Murty et al., 2012), thereby pointing towards augmented vulnerability due to poor quality of construction.

Random rubble masonry (RRM) is the predominant wall typology, which is notoriously vulnerable to even low intensities of ground shaking. The structures surveyed showed lack of interconnection between horizontal and vertical structural components, a critical seismic-resistant feature in masonry structures. Many monasteries have undergone damage in successive earthquakes (IIT Roorkee, 2006), and witnessed structural repairs and alterations with modern materials, such as steel and reinforced concrete (RC). Thus, such structures show more complex behaviour under seismic loads, due to the hybrid structural systems in place. These vulnerable masonry structures in seismically active regions require a comprehensive programme for seismic strengthening and retrofit. Without a concerted scientific effort, with adequate state support, firstly, to document their structural systems and to study the seismic behaviour and then, to propose and implement strengthening schemes, a small but certain fraction of these monasteries, a rich heritage of Sikkim, will be repeatedly lost to earthquakes.

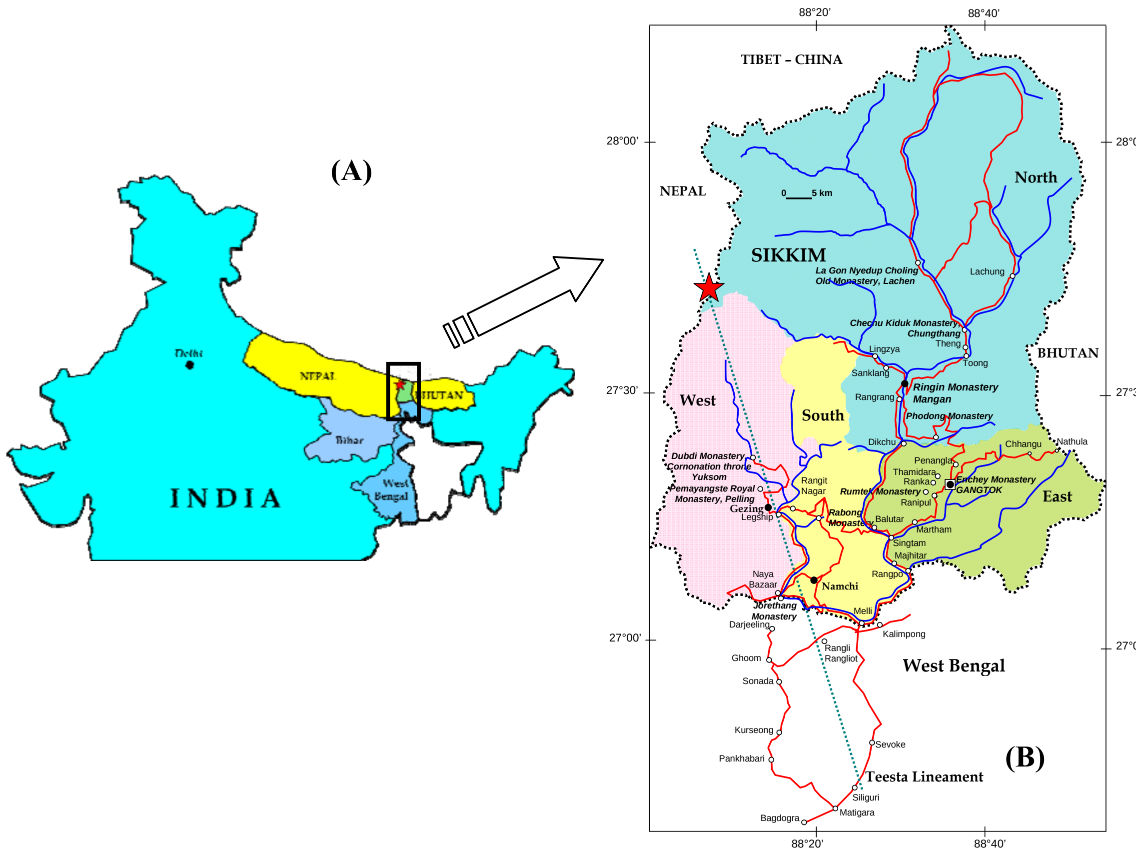

Figure 1. (A) Location map of the earthquake, (B): Monasteries covered in the reconnaissance survey

1.2. Characteristics of the earthquake

Two main thrust faults of the Himalayan region, viz. Main Boundary Thrust (MBT) and Main Central Thrust (MCT) cross the state of Sikkim. The Gangtok and Teesta lineaments (see Fig. 1B), which run transverse to the Himalayas, are responsible for many earthquakes in the region. The focal mechanism solution and field studies indicate that the Teesta lineament caused 18th September 2011 event (Raghukanth et al., 2012). PGA recorded at Gangtok was 0.15g (Murty et al., 2012). In most of the affected areas the maximum intensity was VI+ on the MSK scale; some areas experienced higher intensity of ground shaking, which may be attributed to site amplification. The PGA in the near source region is as high as 0.35g (Raghukanth et al., 2012).

2. STRUCTURAL TYPOLOGY OF BUDDHIST MONASTERIES

2.1. Historical information

Buddhism came to Sikkim in the 17th century, transmutated by Tibetan culture. This marked a new era in the history of the Himalayan state. Buddhism established itself as the single most influential factor in the social, political and cultural development of the land (Das and Ray, 2008). In the present day, monasteries are still the centre of village life and the most striking of architectural features in the State's landscape. Most of Sikkim's monasteries date back to the early 18th century, while few others are recent constructions dating back to a few decades. The famous, original Rumtek monastery was built outside Gangtok, but rebuilt recently (late 1960s) after it was damaged by an earthquake.

2.2. Classification of structural typologies

2.2.1. General

Broadly, the monasteries in Sikkim (and nearby regions) can be categorised into four structural typologies based on the materials of construction and choice of structural system. Monasteries can rise up to four stories, normally with a taller ground storey. In terms of plan configurations, simple structures with a single large hall or have several perimeter chambers around the large central hall. A simple configuration is shown in Fig. 2. The disposition of chambers around the central hall may be symmetrical or unsymmetrical. Typically, timber appendages (timber frames with cross-woven matted infill panels plastered on both sides with mud mortar as in the traditional *Ekra* construction or completely with timber frames and planks) are present on one or more sides of the structure.

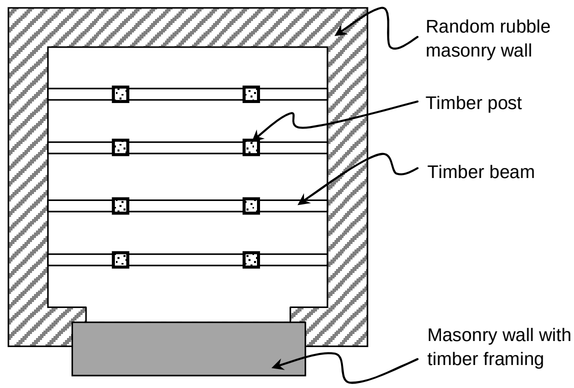

Figure 2. Typical configuration of a historical monastery

2.2.2. Typology I: Old constructions with timber roof, stone walls and timber frame

These structures were constructed in masonry, predominantly with RRM walls, timber framing in the interiors (post and lintel construction) with timber floor slabs, and light roofs with timber trusses supporting them (see Fig. 2). Some structures have masonry walls with timber framework, modelled on the vernacular *Ekra* construction, prevalent in hilly seismic regions of north-east India.

2.2.3. Typology II: New constructions with RC roof, stone walls, RC frame

Some of the newer monastery structures are constructed with a combination of RC frames and stone masonry load-bearing walls, RC floor and roof slabs. Such typologies have been encountered in cases where historical monasteries have undergone expansion, modifications or repairs with the introduction of RC elements. The RC elements, such as columns, beams and slabs, typically replace timber posts, columns and floor planks of the original structure.

2.2.4. Typology III: New constructions with light roof, stone walls, RC frame

New constructions with RC framing elements and stone masonry load-bearing walls and light roofs constituted of steel trusses and galvanised iron (GI) sheeting is also prevalent. In some older monastery structures, steel structural members are used to replace original timber trusses.

2.2.5. Typology IV: New constructions with RC frame, infill masonry and RC roof

RC frame and slab construction with masonry used as infill panels is a preferred choice for some of the recently constructed monasteries in Sikkim.

2.3. Expected behaviour under seismic loading

RRM walls are non-engineered constructions, highly vulnerable to ground shaking due to their poor resistance to out-of-plane excitation. They are inherently very thick, bulky walls. In the absence of through-stones connecting the inner and the outer leaves, they are frequently afflicted by out-of-plane bulging or subsidence due to deterioration of stone and mud or lime mortar over time.

Out-of-plane damage occurs when there is poor or no connectivity:

a. Between orthogonal walls,
b. Between walls and structural system of the floors and
c. Between walls and structural system of the roofs.

Consequently, shear forces are not effectively transmitted from the horizontal structural systems to the vertical structural systems, and either sliding at the interface occurs or the masonry walls on which, the horizontal structural system is supported is damaged due to the thrust. Horizontal structural members such as floor joists and roof trusses have to be anchored adequately to the walls on which they are supported to prevent sliding of the horizontal members and to provide overturning resistance to the walls themselves. Local failure or collapse is observed under low intensities of ground shaking. In-plane shear resistance of masonry walls can be garnered only if local or out-of-plane mechanisms can be effectively prevented through homogenous action.

Structural repair works in the recent years have led to introduction of RC elements (columns, beams and slabs) in these heritage masonry structures. Most of these interventions are ad hoc and non-engineered. Consequently, the response of such structures is complex and requires in-depth study to understand their seismic behaviour, and to develop seismic strengthening schemes. Some monasteries were retrofitted after the 14^{th} February 2006 Sikkim earthquake (e.g. Enchey Monastery, Gangtok: the royal monastery located in the palace premises in Gangtok and used during royal weddings and coronations.), but have suffered damage during the current earthquake.

3. DAMAGE SUFFERED BY MONASTERIES IN THE EARTHQUAKE

3.1. General observations from reconnaissance survey

Extensive damage to historical monastery structures was observed during the reconnaissance survey, with partial to total collapse in several structures. Out-of-plane mechanisms were predominant in most of the masonry structures. Typical seismic damage observed can be classified as follows:

a. Out-of-plane bulging of stone masonry walls, including collapse of walls;
b. Out-of-plane collapse of orthogonal corners of perimeter masonry walls;
c. Sliding of timber roof (horizontal structural system) relative to masonry walls (vertical system);
d. Shear failure of interior RC columns, in masonry structures with RC frames that have replaced timber posts and beams.

Masonry walls have undergone excess out-of-plane deformation due to one of the following reasons:

a. Poor interconnection between the roof truss and the wall;
b. Excessive thrust from roof joists;
c. Failure of corner of masonry walls due to excessive thrust from roof joists;
d. Local damage to walls on which timber joists are supported due to inadequate interconnection.

Out-of-plane damage to low strength stone masonry walls is an expected mechanism in this construction typology because they lack confinement through the wall thickness due to the absence of through-stones. No metal or timber ties are also encountered tying the inner and outer leaves with the poorly consolidated inner core of the walls.

Some monasteries, such as the Enchey Monastery in Gangtok, were affected in the 2006 earthquake and repaired subsequently. The Enchey Monastery is a two-storied structure with thick outer walls in dressed rectangular stone blocks in mud mortar, with timber columns and timber beams spanning in both directions in the interior. The floor is made up of timber planks, while the roof is made up of GI sheeting supported on timber trusses. Damage in the 14^{th} February 2006 earthquake was limited to the exterior stone masonry walls with cracks in the wall corners, owing to insufficient out-of-plane resistance. Cracks were noticed at the corners of the openings in the masonry walls, above the timber lintels. Decorative plaster in the interiors had cracked and spalling had occurred (IIT Roorkee, 2006).

3.2. Specific observations from reconnaissance survey

3.2.1. Ringin monastery, Mangan

Extensive damage to RRM walls was observed in the Ringin monastery in Mangan, North Sikkim. The poorly consolidated RRM walls with no through-stones can be seen in the photograph in Fig. 3B. Thrust from the roof structure has not been resisted by the RRM walls in the first floor of the structure.

The PGA estimated at Mangan using a finite fault seismological model was 0.281g, and in comparison to the PGA from estimated Modified Mercalli Intensity (MMI) for Mangan (VIII) the PGA was 0.25g (Raghukanth et al., 2012). Near total collapse of such a structure is expected under this level of ground shaking.

Figure 3. (A) Extensive damage to the RRM structure of the Ringin Monastery in Mangan, (B) Out-of-plane failure of RRM walls of the Ringin Monastery in Mangan

3.2.2. Dubdi monastery, Yuksom

Partial out-of-plane collapse of semi-dressed stone masonry walls was observed in the Dubdi Monastery in Yuksom, West Sikkim (see Fig. 4A). While the portion of the façade with timber framing and panel work (in the traditional Ekra style) has performed very satisfactorily under the ground shaking, out-of-plane mechanism has formed in the unreinforced masonry wall as envisaged from the widened masonry joints on the façade (see Fig. 4B). Temporary scaffolding to prevent further bulging of walls in which, out-of-plane mechanism has been initiated can be observed. However, this may be inadequate in the event of a strong aftershock. PGA from estimated MMI (VI) was 0.06g; level of damage is much more than what should be expected at this level of ground shaking. The PGA estimated at Yuksom the previously mentioned stochastic model was 0.279g.

Figure 4. (A) Wood frame structure with semi-dressed stone walls in the Dubdi Monastery, Yuksom, (B) Initiation of out-of-plane mechanism in the semi-dressed stone masonry walls

Non-structural damage was also observed in the Dubdi Monastery. Holy scriptures lodged in cabinets on walls have been displaced due the amplified motion at the upper storey (Fig. 5A). Stone masonry stupas are regular feature in the monasteries, marking burial chambers of monks. They are typically RR masonry free-standing structures of different sizes built on a raised plinth, and are normally plastered. They are massive and unconsolidated making them vulnerable to ground shaking due to their sheer mass. One such stupa was completely damaged in the premises of the Dubdi Monastery in Yuksom, West Sikkim. The random rubble blocks used in the construction of the stupa can be seen in the damaged structure (Fig. 5B).

Figure 5. (A) Holy scriptures dislodged from the cabinet in the Dubdi Monastery, Yuksom (B) Collapse of stone masonry stupa in the Dubdi Monastery, Yuksom

3.2.3. Chungthang monastery

The structure of the monastery at Chungthang is rather peculiar due the presence of the RC columns at the four corners of the plastered stone masonry structure (see Fig. 6A). The RC elements are evidently recent additions. The peculiarity is that the RC elements are not framed, but merely provide partial confinement to the corners of the unreinforced masonry structure. The introduction of the RC elements seems to have partially resulted in the desired effect, i.e. in preventing out-of-plane failure of the unreinforced masonry walls. Diagonal shear cracks are noticed in the unreinforced masonry (URM) walls of the structure, implying that the in-plane shear resistance has been garnered (see Fig. 6A). However, the shear strength of URM walls being small, diagonal cracks have formed in all the four perimeter walls. Interestingly, no visible damage is noticed in the timber-framed wall (front façade). Local damage to walls due to pounding from poorly connected rafters is seen (see Fig. 6B). Chungthang experienced a PGA of 0.25 g (MMI VIII).

Figure 6. (A) Wood frame with plastered stone masonry walls and RC columns in Chungthang Monastery, Chungthang, (B) Damage to walls from pounding of rafters

3.2.4. Phodong monastery

From the exterior, the Phodong monastery in Central Sikkim, with wood frames and RRM walls, seems almost intact after the earthquake with signs of initiation of out-of-plane mechanism in the RRM walls (see Fig. 7A-B, 8A). However, this structure has undergone massive structural alterations with the introduction of RC frames in the interior space, most probably replacing the earlier timber post and beams (see Fig. 8B). All the RC columns in the first storey of the structure have failed in shear, rendering the structure extremely susceptible to collapse under any additional load.

Figure 7. (A) Wood frame with RR masonry walls in Phodong Monastery, Phodong, (B) Wood frame with RR masonry walls in Phodong Monastery, Phodong

Figure 8. (A) Out-of-plane mechanism in the RR masonry walls in Phodong Monastery, Phodong, (B) Shear failure of RC columns at roof level in Phodong Monastery, Phodong

3.2.5. Coronation throne, Norbugang

The damaged stone stupa at the Coronation throne in Norbugang, West Sikkim can be seen in Fig. 9A. The sheet has been draped around the portion of the structure where a wide crack has formed to prevent the ingress of water. The nature of the crack can be seen in a similar stupa in the premises of the Pemayangtse Monastery in Pelling, West Sikkim (see figure).

Figure 9. (A) Damaged stone masonry stupa at the Coronation Throne, Norbugang (B) Damaged stone masonry stupa in the Pemayangtse monastery premises, Pelling

3.2.6. Pemayangtse royal monastery

Pemayangtse is a magnificent monastery in Pelling, Western Sikkim, built in 1705 AD and one of the most respected monasteries (Lhatsun Chenpo, one of the three Lamas who brought Buddhism to Sikkim had earlier erected a shrine here). Minor damage can be observed to the semi-dressed stone masonry walls of the Pemayangtse Royal Monastery. In the interiors, damage to the plaster on the walls has been noticed at locations where timber joists are supported on the walls (see Fig. 10B). Such damage can be attributed to the excessive out-of-plane thrust from the horizontal elements (timber joists) to the vertical elements (masonry walls), which are poorly interconnected.

Figure 10. (A) Semi-dressed stone masonry walls with wood frame, Pemayangtse Royal Monastery, Pelling (1705 AD) (B) Out-of-plane damage to stone walls by timber beams resting on them, Pemayangtse Royal Monastery, Pelling

3.2.7. Lachen monastery

La Gon Nyedup Choling Old Monastery at Lachen in North Sikkim is one of the oldest monasteries in Sikkim (see archive photograph in Fig. 11A), a structure in RR masonry and timber frames. In the recent years, the structure has undergone lateral expansion (see Fig. 11B). The structure did not show any visible signs of damage in the earthquake. The PGA estimated from MMI (VII) was 0.13g and that from the stochastic model was 0.297g. Observed performance is does not seem to be commensurate with estimated PGA.

Figure 11. (A) Lachen Monastery, Lachen (archive photo) (B) La Gon Nyedup Choling Old Monastery, Lachen with recent lateral appendages, after the 2011 earthquake

3.2.8. Kalimpong monastery, West Bengal
This small semi-dressed stone masonry monastery in the neighbouring Darjeeling district of West Bengal suffered significant damage to both ground and upper stories (note large openings and reduced pier sizes in upper storey). Large cracks in the arches of the ground storey can be seen in Fig. 12B. The PGA estimated from MMI (VII) was 0.13g and that from the stochastic model was 0.156g.

(A) (B)

Figure 12. (A) Kalimpong Monastery, West Bengal, (B) Damage to arches

4. POSSIBLE REPAIR AND RETROFIT STRATEGIES

Considering the non-engineered nature of the historical monasteries, and especially those with the low strength random rubble masonry walls, providing quantitative strengthening measures would not be practical. System-level strengthening interventions have to improve overall integrity of the structure by addressing interconnections between walls, walls and floors, walls and roofs (e.g. provision of tie rods, bond beams). Component-level strengthening interventions should address inadequate confinement in stone masonry walls and addition of structural members in floors and roofs (Mathews and Menon, 2008). An example of consolidation of RRM walls with thorough stones and vertical steel reinforcement is shown in Fig. 13 A. To improve overall structural integrity, steel ties anchored to ends of walls may be introduced as shown in Fig. 13B immediately under the floor structure.

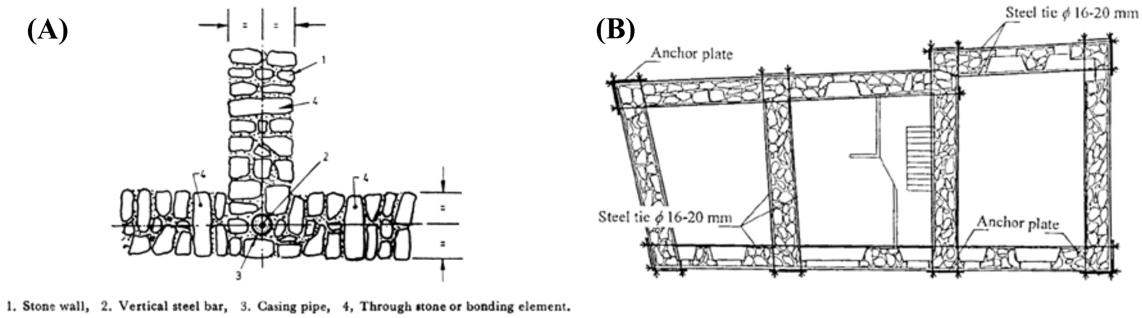

Figure 13. (A) Detail for installation of vertical steel bar in RR masonry (BIS 13828, 1993), (B) Introducing steel ties in a masonry building (Tomaževič, 1999)

5. CONCLUDING REMARKS

The extent of damage observed in the 2011 Sikkim earthquake is not commensurate with the level of shaking. With a maximum intensity of ground shaking of about VI+ (MSK), collapse mechanisms have initiated in almost all historical monasteries. Damage is extensive in structures with RRM walls. None of these structures have earthquake resistant features. Moreover repairs and interventions in old structures are not sensitive to earthquake safety. RC monastery structures suffered lesser damage; however they have not been fully tested in this event due to the moderate level of shaking (MSK VI).

In a seismically active region such as Sikkim, bestowed with a rich architectural heritage in the form of Buddhist monasteries, unless a concerted effort is taken to retrofit the existing historical monasteries, citizens will remain mute spectators to recurring loss of these heritage structures over time. Even under low levels of ground shaking, many of these structures have suffered extensive damage, including almost complete collapse (e.g. Ringin monastery, Mangan). Heritage structures that are so heavily damaged are permanently lost; they cannot be salvaged, only replaced. Many heritage structures along Himalayas have similar features. They need to be assessed for earthquake safety and seismic retrofit-cum-restoration programmes have to be initiated.

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REFERENCES

BIS 13828 (1993) *Guidelines for improving earthquake resistance of low strength masonry buildings*, Bureau of Indian Standards, New Delhi.

BIS 1893-1 (2002) *Criteria for earthquake resistant design of structures – Part 1: General provisions and buildings*, Bureau of Indian Standards, New Delhi.

Das, A. and Ray, S. (2008) *Sikkim: A traveller's guide*, Permanent Black, New Delhi, 3rd edition, pp. 160.

IIT Roorkee (2006). A damage survey report on the Sikkim earthquake of 14th February 2006, submitted to the Ministry of Home Affairs, Government of India, Dept. of Earthquake Engineering, Indian Institute of Technology, Roorkee.

Murty, C.V.R., Raghukanth, S.T.G., Menon, A., Goswami, R., Vijayanarayanan, A.R., Gandhi, S.R., Satyanarayana, K.N., Sheth, A.R., Rai, D.C., Mondal, G., Singhal, V., Parool, N., Pradhan, T., Jaiswal, A., Kaushik, H.B., Dasgupta, K., Chaurasia, A., Bhushan, S., Roy, D. and Pradeep Kumar, R. (2012). The M_w 6.9 Sikkim-Nepal Border Earthquake of September 18, 2011. EERI Newsletter, EERI Special Earthquake Report,. February 2012, 1-14.

Raghukanth, S.T.G., Lakshmi Kumari, K, Kavitha, B. (2012) Estimation of ground motion during the 18th September 2011 Sikkim earthquake, *Geomatics, Natural Hazards and Risks,* **3:1**, pp. 9-34.

Tomazevic, M. (1999) *Earthquake Resistant Design of Masonry Buildings*, Imperial College Press, London, UK, pp. 203-252.