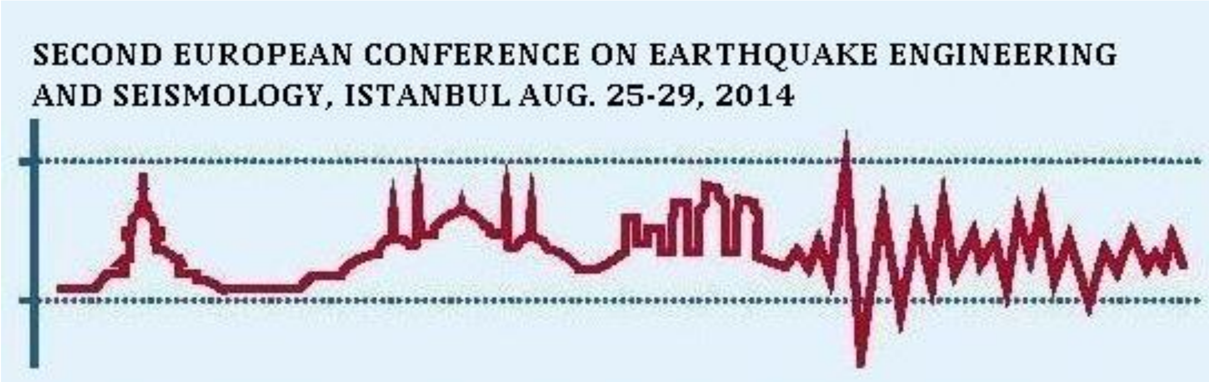


# PERFORMANCE OF MASONRY MONASTERY STRUCTURES IN THE M 6.9 SIKKIM EARTHQUAKE OF 18 SEPTEMBER, 2011: A LESSON

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## ABSTRACT

Sikkim, the second smallest state in India, with a population of 540,493 (CD of Census of India 2001), is located between Latitudes 27-28°N Longitudes 88-89°E, in the Himalayan arc, in between the Main Boundary Thrust (MBT) and Main Central Thrust (MCT) in one of the most tectonically active regions of the world. The M 6.9 Sikkim earthquake of 18 September 2011 revealed once again the vulnerabilities of the built environment in general in the highly vulnerable Himalayan region due to various reasons ranging from poor choice of location, inadequate detailing, non compliance with codes and use of vulnerable construction systems and typologies. Of particular concern is the damage to cultural heritage of the region. Many of the religious buildings, primarily Buddhist monasteries suffered varying degrees of damage from slight to partial collapse. This paper presents an overview of the general performance of some Buddhist monasteries in Sikkim in the September 18, 2011 earthquake and points to the need for urgent intervention for removal of deficiencies.

## INTRODUCTION

India is located in one of the most earthquake prone regions of the world. The state of Sikkim, located in the North-East, is located between Latitude $27^{o}$-$28^{o}$ N Longitude $88^{o}$-$89^{o}$ E, in the Himalayan arc, in between the MBT and MCT in one of the most tectonically active regions of the world. The entire Himalayan belt is prone to earthquakes of magnitude exceeding 8.0, and in a relatively short span of about fifty five years, four such earthquakes had occurred: 1897 Shillong (M8.7), 1905 Kangra (M8.0), 1934 Bihar-Nepal (M8.3), and 1950 Assam-Tibet (M8.6). The high seismicity is due to the subduction of Indian plate under the Eurasian plate at the rate of about 5 cm per year, along the MBT running more or less parallel to the Indo-Gangetic Plain, through the Himalayan Arc (Seeber et al., 1981) (Fig.1).

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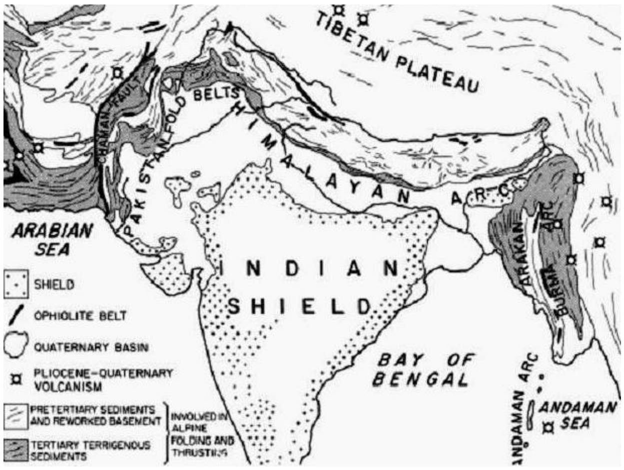


Figure 1. Tectonic setting of the Himalayan Arc

## THE EARTHQUAKE OF18 SEPTEMBER, 2011

An earthquake of magnitude 6.9 occurred on 18th September 2011 at 18:11 hrs IST in Sikkim-Nepal Border region. The preliminary hypo-central parameters of this earthquake, as estimated by the Seismic Monitoring Network of India Meteorological Department (IMD) are given in Table 1(http://www.imd.gov.in/section/nhac/dynamic/eq.pdf).

Table 1. Data on 2011 Sikkim Earthquake.

| |
|---|
| Date of occurrence: 18/09/2011 |
| Time: 18:11 hrs (IST) |
| Magnitude: 6.8 |
| Focal depth: 10 Km |
| Epicentre: Latitude & Longitude : 27.70˚ N & 88.20˚ E |
| Region: Sikkim-Nepal Border region. |

The event, which comes under the category of “Moderate earthquake”, was also reported and widely felt in Sikkim, Assam, Meghalaya, northern parts of West Bengal, Bihar, and other parts of other eastern and northern India. The epicenter lies in a seismically known and active belt called, Alpine-Himalayan seismic belt. Like most other earthquakes the main shock was followed by several aftershocks of low intensity and a few significant aftershocks ($M \geq 4.0$). Many areas in the region such as Mangan, Dikchu, Lachung, and Chungthang were badly impacted by the earthquake. Like most of the houses and establishments in this area, the monasteries too, felt the impact of the earthquake and sustained various degrees of damages.

## MONASTERIES

Buddhist monasteries—places of worship for Buddhist communities and place of scholarship and theological training of Buddhist monks—are the key components of the cultural heritage of Sikkim and have special meaning to the communities. Buddhism came to Sikkim centuries ago and various monasteries or *Gompas* were established as Buddhism spread in Sikkim. The culture of Sikkim is closely linked to Tibetan Buddhism and most monasteries belong to the Nyingmapa Sect or the Kargyupa Sect. These monasteries are decorated with large frescoes depicting ancient Buddhist legends, rare silk and brocade wall hangings, delicately carved wood work, and are repositories of numerous icons, and rare Tibetan manuscripts.

Monasteries in Sikkim are mainly of two types, (1) Tibetan *Gompas* (monastery) which are palace-like structures and used as learning schools for the monks and (2) Mani-Lakhangs which are temples managed by a few monks.

# EARTHQUAKE RESPONSE OF MONASTERIES

Monasteries in Sikkim have experienced a number of major and minor earthquakes in the past (Sikkim Earthquake Mw 6.1, November 19, 1980, Bihar-Nepal earthquake Mw 6.5, August 21, 1988, Sikkim Earthquake Mw 5.3, February 14, 2006). The damages sustained by monasteries in the M 6.9 Sikkim earthquake of 18 September 2011 underscore the need for earthquake risk assessment of monastery buildings and precincts. Sikkim has about 250 monasteries, the oldest dating back to the eighteenth century. Most of the monasteries are comprised of a main masonry structure, with a few less important structures within the precinct (Fig. 2) (Rai et al. (2012). Two notable exceptions are Rumtek monastery (1966) and Ranka Monastery (2001), both of which are multiple structures arranged within large precincts.

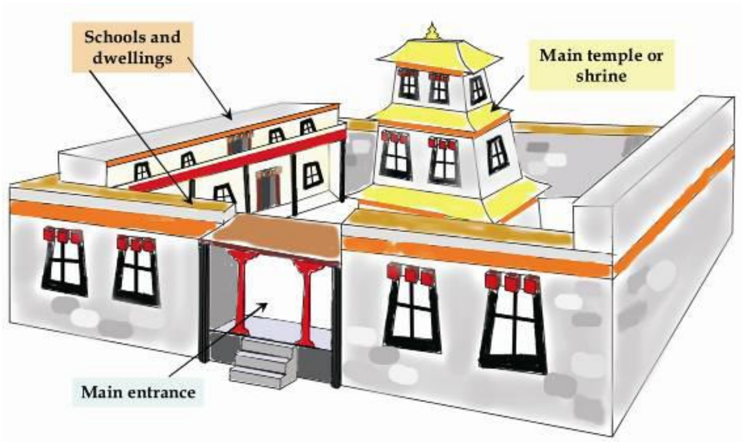


Figure 2. Typical Monastery in Sikkim

A reconnaissance study of a number of monasteries had been conducted by the authors during December 2011 to assess the earthquake performance of monasteries. A summary is provided in Table 2.

Table 2. Monasteries studied during the Reconnaissance Survey in December 2011

| Sl no | Location | Name | Date of Construction | History | Construction Method and seismic configuration |
|---|---|---|---|---|---|
| 1 | East Sikkim: 24 kms from Gangtok | Old Rumtek Monastery | 1730 | Built during the reign of Thutob Namgyal. | 1. Rubble masonry<br>2. Square in plan<br>3. Three storied<br>4. Flat roof<br>5. Wooden beam |
| 2 | East Sikkim: 24 Kms. from Gangtok | New Rumtek Monastery | 1962-1966 | Built during the reign of Thutob Namgyal. | 1. Multiple units<br>2. Large complex<br>3. One 5 storied, other 2 storied<br>4. Flat RCC roof<br>5. RC frame structure |
| 3 | East Sikkim (Gangtok) 20 Km from Gangtok | Ranka | 1997 - 2001 | | 1. Fine example of Tibetan monastic architecture.<br>2. Newly built<br>3. Large structure with multiple units<br>4. RC frame structure |

| Sl no | Location | Name | Date of Construction | History | Construction Method and seismic configuration |
|---|---|---|---|---|---|
| 4 | East Sikkim (Gangtok) 5 kms. from Gangtok | Enchey monastery | 1721 rebuilt in 1948 | Nyingma order reign of Thutob Namgyal | 1. Plan with re-entrant corner<br>2. Single Chinese Pagoda shaped unit<br>3. Stone masonry: 4 storied topped by a golden cupola |
| 5 | North Sikkim 28 kms. from Gangtok | Phodang monastery | The original monastery is rebuilt | | 1. Square in plan<br>2. Single unit<br>3. Stone brick<br>4. Three storied<br>5. Lime mortar |
| 6 | North Sikkim 30 kms. from Gangtok | Labrang monastery | 1814 | | 1. Single unit<br>2. '+' in shape symmetrical in plan<br>3. Two storied<br>4. Re-entrant corner<br>5. Random rubble masonry |
| 7 | North Sikkim | Phensang monastery | 1721 rebuilt in 1948 | | 1. Square in plan<br>2. Single unit<br>3. Stone brick<br>4. Four storied<br>5. Sloped G.I. roof<br>6. Wooden truss |
| 8 | West Sikkim at Gyalshing (140 kms. from Gangtok) in Pelling | Pemayangtse monastery | 17th Century | Belongs to the Nyingma order and all other Nyingma monasteries in Sikkim are subordinate to it. | 1. Rectangular shape<br>2. Stone masonry<br>3. Wooden beam,<br>4. Wooden stair<br>5. Wooden & stone lintel<br>6. Lime morter<br>7. Cement plaster |

## GENERAL DESCRIPTION

The monasteries are of simple construction having one to three storied structures built on a symmetric plan with reduced floor area for upper stories (Figure 3). Initially these were built with timber and stone masonry, but later extensions were constructed with concrete frames and brick masonry. In the older structures, the exterior walls were built in random rubble stone masonry, while the floors and double pitched roofs were of timber construction, using the single post beam system. The timber frames inside are delicately carved and life like imageries are painted on the interior wall surfaces.

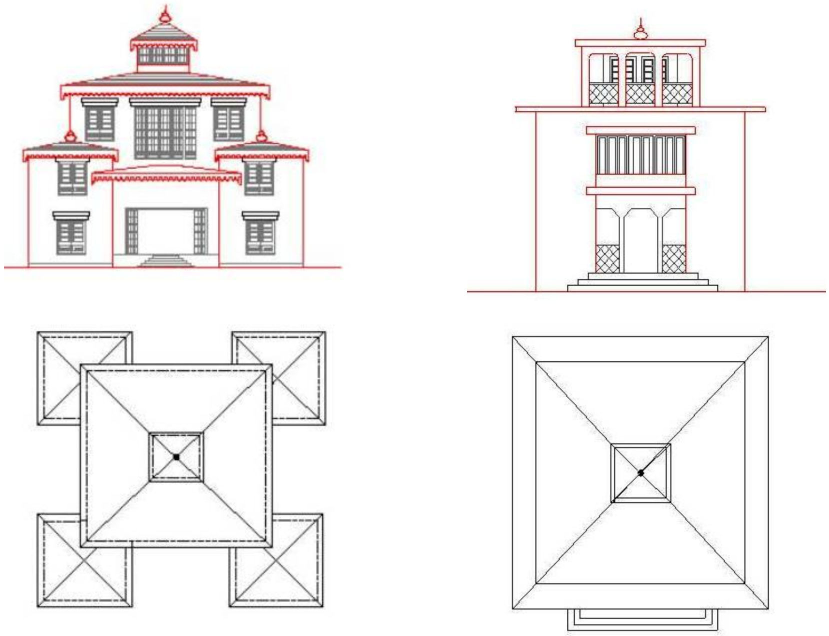

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Figure 3. Symmetrical plans and reducing footprint in the upper floors in Enchey Monastery (left) and Old Rumtek Monastery (right)

New Rumtek Monastery (Rumtek Dharma Chakra Center) was built in the 1960's. Though the main temple did not suffer severe damages, two six storied buildings in the monastery precinct, the Nalanda Institutes, constructed in 1972, sustained significant damages. These buildings sustained damages primarily at wall corners, and at sill, spandrel and pier masonry panels (Fig. 4).

Figure 4. Corner crack

Major diagonal cracks developed in the wall panels. There were cracks in the spandrel masonry panels on all floors, with the cracks running in different directions (Fig 5).

Figure 5. Diagonal crack

Non-structural elements such as window glass panels were broken as a result of the shaking. Building interiors also sustained damages at intersections between two walls, at roof-wall junctions, and also at lintel levels, evidently due to absence of lintel beams. There are instances of separation of door and window frames from the walls due to inadequate connections between these (Fig.6).

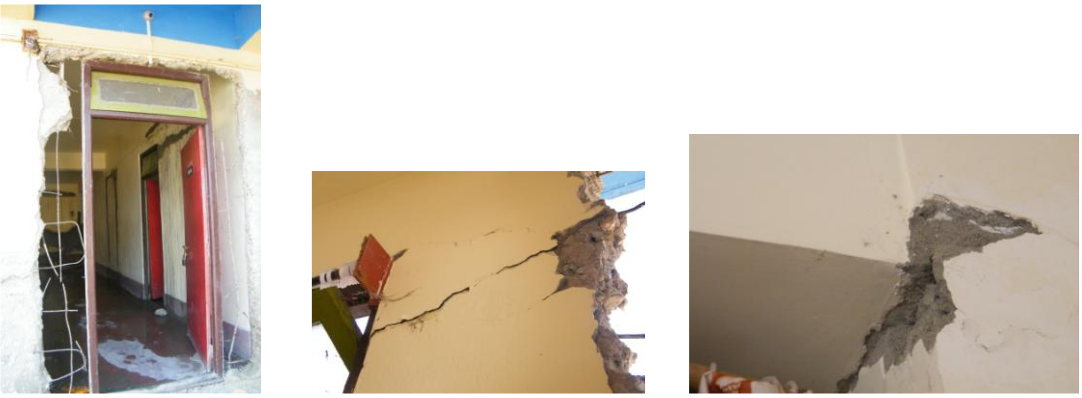

Figure 6 Detachment of door frame (left), Crack on pier masonry panels, (middle),
Crack on spandrel masonry (right)

The Guest house suffered major damages wherein some parts of the RC wall due to poor quality of concrete and inadequate reinforcement (Fig.7).

Figure 7. Collapse in the wall

These damage patterns indicate a general absence of earthquake resistant features in the structure, such as lack of horizontal bands to contain the wall panels against out of plane failures, inadequate number of reinforcement bars in the columns, improper detailing and dimensions of the stirrups and poor workmanship. Other glaring inadequacies include poor tying of stirrups and insufficient lap lengths, $90^{\circ}$ degree hooks instead of $135^{\circ}$ hooks, which led to spalling of concrete from the beams and columns.

The Ranka Monastery was completed in 2001 with better construction practices and this helped in reducing the impact of earthquake shaking. Apart from some minor damage to parapet walls, this monastery was largely unscathed.

The Old Rumtek Monastery, Phodang Monastery, Labrang Monastery, Phensang Monastery, Pemayangtse Monastery are more or less similar in plan configuration. All of these are square or rectangular in plan and have single units. Except Pemayangtse, all the monasteries made masonry infilled RC frame extensions to their original structures. The upper floors had a number of floating columns at the upper levels. These proved disastrous for the structures, resulting in major damages to these upper floors. The top most floor of Old Rumtek monastery had spalling of cover concrete in the floating columns, along with cracks at the beam column junctions, indicating poor flexural performance. Similar damages were noticed in Phodang Monastery. An instance of separation of RC staircase from the floor slab was observed in the Old Rumtek Monastery. Long horizontal separation cracks were observed between the staircase beams and the infill walls of the staircase well. The beams also lacked adequate shear reinforcement and did not have proper ductile detailing (Fig. 8). Staircase separation was also observed in Pemayangtse Monastery due to lack of connection between the wooden staircase and the masonry walls (Fig.9).

Figure 8. Disconnection of stair with floor    Figure 9. Separation of unconnected wooden staircase

This monastery sustained damages primarily in the western and northern facades, at wall corners, sill, spandrel and pier masonry panels of openings. The corner of the north and west face sustained shear cracks in the masonry walls originating at the corner and progressing diagonally along the wall surfaces. Cracks at the first floor window sill levels were seen to progress both diagonally and vertically along the wall face along with cracking in spandrel masonry panels above lintel level. (Fig.10).

Figure 10.Crack on spandrel masonry

Damages in the building interior were seen again at wall intersections and at wall roof connections. due to flexible diaphragm action of the unconnected timber beam roof structure. At the wall corners, corner cracks were seen to stretch from the inside to the outside face of the walls due to lack of connections between the walls in two orthogonal directions. The wooden roof beams are not properly connected with the supporting walls, thus forming flexible diaphragms with evidence of separation cracks between the wall and the roof (Fig.11).

Figure 11.Flexible diaphragm action

Lack of confinement of the window openings by horizontal and vertical bands resulted in the formation of diagonal cracks starting at the corners of the lintels and proceeding horizontally across the pier masonry panels (Fig.12).

Figure 12.Cracks on wall masonry

The Enchey monastery is distinctive and somewhat different from the others. The three-tiered monastery resembles a Chinese Pagoda. The monastery was first built in 1840. It was destroyed in a fire in 1947 and rebuilt in 1948. This monastery suffered damages in the 2006 earthquake and it was repaired with some attention to seismic resistance in the damaged portions only. As a result, this monastery did not suffer any significant damages except for the partial collapse of a random rubble masonry wall at the top floor, around an opening in the wall (Fig.13).

Figure 13. Collapse of random rubble stone masonry wall at top floor

Phodong Monastery situated in the northern part of Sikkim is a three storied structure constructed with stone masonry. It has a simple rectangular plan and has a pitched roof with corrugated G.I sheet above the first floor. The ground and first floors are of same dimension. There is an extension above the first floor with RC floating columns and beams (Figure 14).

Figure 14. Poor column - beam joint

Long shear cracks were noticed both on outside and inside surfaces of the external walls. Short column effects caused serious damages at the top floor and also on the first floor verandah level (Fig.15).

Figure 15. Short column

Pier masonry cracks are evident at the ground floor with horizontal cracks in sill masonry developed below the ground floor windows. Western and eastern walls sustained shear cracks from one end to other. Other irregularities include poor beam column joints, and offset of beams. Poor detailing of shear reinforcement in columns resulted in spalling of cover concrete (Fig.16).

Figure 16. Spalling of concrete

Interior walls in the first floor have shear cracks at the sill level. Cracks and peeling off plaster and frescos were noticed in the first floor.

However, the outhouse of the monastery, made of traditional *Ikra* house having simple configuration with light weight walls, and pitched roof did not suffer any damage at all pointing at the inherent earthquake resilient attributes of vernacular construction in earthquake hazard prone areas in parts of North-eastern India.(Fig.17).

Figure 17. Outhouse of traditional Ikra style

Phensang Monastery, situated in the northern part of Sikkim was built in 1721, and rebuilt in 1948. The main monastery building did not suffer any significant damage during the recent earthquake. Strong column and wooden beam support made the structure stable and safe. Some vertical cracks in the sill masonry were noticed due to the absence of sill bands (Fig.18).

Figure 18. Vertical crack on sill

In the first floor of the two storied brick built outhouse, a continuous deep horizontal crack developed on the wall facing the monastery at the window sill level due to the absence of sill bands (Fig.19).

Figure 19. Horizontal Crack on sill level

Labrang Monastery was built in 1814. Unlike many monasteries which were gutted by fires, this one still retains its original shape and structure. It is a cross in plan, symmetrical about both axes, and double storied with a pitched roof. The roof is made of a truss, covered by corrugated G.I sheets. It has projected wooden verandahs on each side at first floor level. Since the walls are of random rubble stone masonry, no proper bonding exists within the wall masonry; or even between adjacent walls. This appears to be the reason for the development of long vertical zigzag cracks during the earthquake. Shear cracks in the masonry wall facades and wall corners originated from the roof where the accelerations are the highest. Numerous such vertical cracks were noticed. The corner cracks are due to poor connections between the walls. The cracks in pier masonry move down along the wall. (Fig. 20). Similar cracks appear also in the spandrel masonry. Cracking of plaster in first floor wall surface, and shear cracks in the skirting level were noticed (Fig. 21).

Figure 20. Crack on pier masonry    Figure 21. Cracking of plaster

The wooden roof beams resting on stone masonry walls created a flexible diaphragm which was unconnected with the walls and resulted in separation cracks appearing between the walls and roof (Fig.22).

Figure 22. Improper connection of roof beam and wall

# CONCLUSIONS

Most of the monasteries surveyed were constructed using traditional methods and materials. Their age and lack of maintenance made them weak and susceptible to seismic impact. In general the monasteries had symmetrical and simple geometric configurations in plan and reduction of mass in the upper storeys. The regular plan configurations are excellent for resisting earthquake induced inertia forces and the reduction of mass in the upper stories helps to lower these forces. However, in many instances, building extensions and additions did not address earthquake resilience factors, which resulted in irregularities in building configuration in plan and in three dimension. Moreover, the newer additions were not properly connected with the existing structures leading to further irregularities. Inadequate seismic gaps, poor detailing of RCC elements such as columns, beams and beam column junctions, use of floating columns were some contributors to the damages sustained.

The traditional structures, despite their excellent geometric configurations and lightweight roofs, had some inherent deficiencies arising out of lack of connections between the different building elements,namely, walls, and roofs. Walls in orthogonal directions lack horizontal bands for structural hand holding and box action, openings are not protected by all round vertical and horizontal ties resulting in the appearance of corner cracks, and walls are not connected properly with the roof system, which in many cases were flexible diaphragms made up of wooden beams simply resting on supporting walls.

The M6.9 earthquake on September 18, 2011, in Sikkim has pointed out that the historical structures mainly the monasteries have become vulnerable and are in jeopardy. These monasteries are the key components of the cultural heritage of Sikkim and have special meaning to the communities. Their preservation in future seismic events is critical for the Buddhist community.

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