

## Seismic Vulnerability and Mitigation on Non-Engineered Traditional Buildings of Bhutan

Chimi<sup>1</sup>, Tshering Cheki<sup>2</sup>

<sup>1</sup>Assistant Lecturer, CST and Final year, Master of Architecture, SRM University

<sup>2</sup>Assistant Lecturer, CST, Royal University of Bhutan

**Abstract:** Earthquake is one of the most deadly phenomena which disturb the harmonious living among human beings and claimed large number of lives without any notice and warning. However one should always be ready to learn, how to live with seismic hazard and minimize its adverse effect on built environment, as its happening can't be prevented. The 6.1 magnitude Earthquake of 21<sup>st</sup> September, 2009 caused huge damage in the eastern part of Bhutan and adjoining areas like Indian states and Bangladesh. This incident has now exposed to the seismic vulnerability and raised concerns over the safety of the built environment in Bhutan – particularly, the traditional stone and timber houses, some of which were badly affected during the earthquake. This paper presents an overview of damages observed in the region and its causes and performances of building during earthquake. It also describes, the seismic performance of those structures can be improved from life safety point of view, by adopting simple low-cost modifications to the existing construction practices and material selection with alternative solutions to make building earthquake resistant.

**Keywords:** Earthquake, Building Structures, Stone masonry, Seismic design, Eastern Bhutan

### I. INTRODUCTION

Many part of the world has been encountered with a lot of destruction due to Earthquake. Similarly, Bhutan has been by the earthquake several times, until 21st September 2009, when earthquake of magnitude 6.1 has occurred in eastern Bhutan around 2:53:05pm local time. According to the Situation report: Earthquakes in Bhutan, India and Myanmar, the epicenter was located 27.351°N, 91.425°E, in Mongar district of 10km depth, around 177km away from capital Thimphu as shown in Figure 1. This disaster had claimed about 12 people, 5 in Mongar, 4 in Samdrup Jongkhar and 3 in Trashigang districts. Almost seven more tremors were felt after the earthquake, with the first few tremors occurring every half an hour. The tremor was also felt in the north-east states of India, including Assam, Arunachal Pradesh, Bihar, Meghalaya, Sikkim and West Bengal, beside China and Bangladesh. The report states, major damage to infrastructure were occurred in Mongar and Trashigang district including 100houses, 21chorten (religious structures), 14 lhakhangs (Buddhist temples), 6 gup office (sub-district office) and then 4 school buildings partially damaged in Mongar.

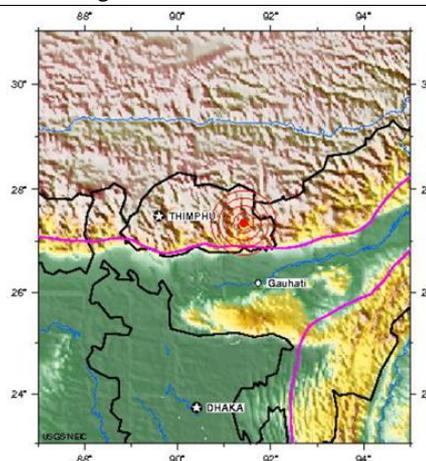


Figure1: 2009 earthquake location, Source: <http://www.reliefweb.int>

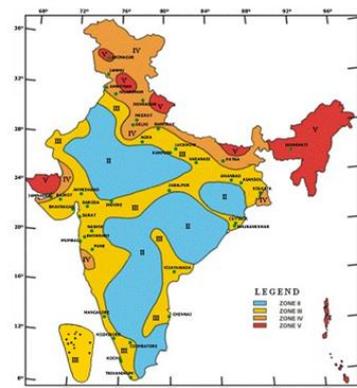


Figure 2: Seismic zone map of India, Source: <http://rahat.up.nic.in>

## II. BACKGROUND HISTORY

Earthquake being one of the most destructive natural disasters, it has claimed many lives and damaged huge amount of infrastructure. It is also reported that casualties occurred due to earthquake exceeds 50% compared to other natural disasters. (Walling and Mohanty, 2009)

Bhutan, a small landlocked Himalayan country is indeed located on, one of the most seismic active zone (Zone V, as per Indian Seismic code IS1893: 2002), as shown in Figure 2 due to subduction of Indian plate into Eurasian plate, which is stated to be moving at an average of  $20 \pm 3$  mm/year (Bilham et al., 2001). This makes earthquake of various sizes occur in Bhutan inflicting heavy casualties and damages for centuries.

The first recorded earthquake was reported in 1713 which was believed to have occurred in the Eastern Bhutan near Arunachal Pradesh (Bilham, 2004). It was reported to occurred in the night of spring with heavy casualties to human lives and build environments, though its exact time, size and location of epicenter was not specified exactly. Among 32 earthquakes occurred in and around last seven decades, the earthquake of magnitude 6.75 in 1941 was most notable in Bhutanese history (Dorji, 2009). According to Walling and Mohanty (2009), following list of earthquake has hit Bhutan; Mw=8.7 Shillong Plateau in 1897, Mw=8.3 Bihar-Nepal border in 1934, Mw=7.7 Assam in 1947 and Mw=8.6 Arunachal Pradesh in 1950. Figure 3, shows the earthquake occurred in and around Bhutan.

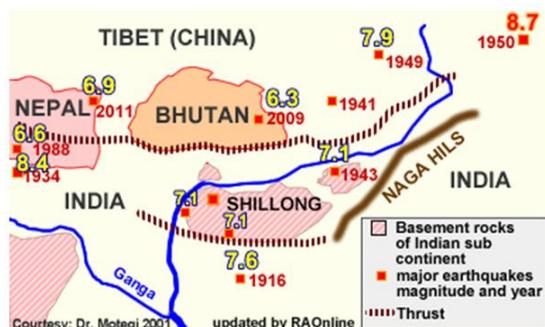


Figure 3: Earthquakes in and around Bhutan (Motegi, 2001)

Despite Bhutan being victim for many past earthquakes, it was found least bothered to prepare for next upcoming earthquakes. As of now, Bhutan still lacks in formulating its own seismic code. All the built environments are designed and constructed as per the Indian Seismic code IS1893: 2002, by assuming the seismicity of Bhutan same as that of north eastern states of India which is designated zone V.

## III. GENERAL PERFORMANCE OF NON-ENGINEERED MASONRY WALLED BUILDINGS DURING EARTHQUAKES

It is observed that many masonry buildings consisting of walls constructed from stone have following damages during seismic vibrations:

- Since masonry walls are weak, both in tension and shear, it is found that it cracks easily in various portions of building when it is shaken horizontally. Vertical bending cracks were found near vertical edges and horizontal bending cracks below roof, floor and above plinth. The diagonal cracks near corners of openings and star pattern crack in the vertical piers between openings are seen. (Murty, 2005)
- Gable ends of buildings with trussed roofs are unstable, due to its triangular vertical cantilevers, which will have easy lateral failure. In that case, hipped roofs are superior in the seismic behavior of the building. Therefore replacing gable masonry truss with light sheet covering would be more efficient (Arya, 2000). Similarly, flexible roofs without diaphragm actions and no-binding effect on masonry walls are also prone to failure due to separation and disintegration of walls and roofs during earthquake.
- According to Guidelines of Earthquake resistant non-engineering construction, buildings with flexible roofs and floors, the perpendicular walls tends separate from each other. Due to absence of diaphragm action of roof and floors, the wall are subjected to the force of inertia to their plane and fails by overturning, leading partial or total collapse of a house. Therefore it should either eliminate or properly reinforced or tied to the lower structure.
- Random rubble masonry walls built with mud mortar are observed very weak both in tension and compression. During earthquake, the cohesive force between mortar and building units (stones) becomes very weak, thus shattered completely. Its strength further reduces, when the wall is drenched with rain. It is observed that two storied buildings

provide very bad performance even in moderate earthquakes and collapse completely (M.S.K. intensity VII and more) (Arya, 2000).

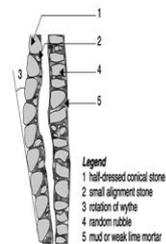


Figure 4: Wall delaminated with buckle wythes. Source: IABEE



Figure 5: Double storied Bhutanese house. Source: Chhundu



Figure 6: Construction process in rural area. Source: Kuensel

- e. Usually during the earthquake, the random rubble and half-dressed stone walls suffers from the problem of delamination from the middle, the two wythes collapsing separately in both inward or outward causing total collapse of the stone masonry wall of building (Haseeb, et al, 2011), as shown in figure 5.
- f. In most parts of the world, many buildings used the wooden joists or round logs as roof or floor beams with small length of bearing inside the walls that cannot fully hold at the ends. These become loose while shaking and the walls move out freely, making roof and floor to collapse (Arya, 2000).
- g. Most of the modern buildings like hospital, schools, offices, etc. are planned with unsymmetrical layout (C, U, L shapes) with several projected wings and blocks. These suffers a lot of destroy due to severe torsional effects caused by the eccentricity of seismic forces about the center of rigidity of buildings (Murty, 2005).
- h. According to the Guidelines of Earthquake resistant non-engineering construction manual, the relative size of the openings (doors and windows) to the size of the wall and its location also contributes to effect on the strength of wall. It was noticed, openings very close to the edge of the wall are unsafe and perilous. Large and huge amount of openings also reduces its strength to resist both lateral and vertical loads acting on the wall.



Figure 7a, 7b & 7c: Traditional house in Eastern Bhutan heavily damaged by 2009 earthquake. Photo: Rohit Jigyasu, Bank

- i. The performance of wooden houses has generally been good, particularly that of the wooden frame during earthquake. Wooden frame consist of sheeting, boarding, ekra walling, bamboo matting, etc. However the infill has frequently shown movement out of the plane of frames. The major drawback wooden buildings has been their biodegradation and poor fire resistance as fire hazard followed earthquakes, due to kitchen fires and short circuiting (Arya, 2000).
- j. A general observation, it is noticed that properly maintained buildings exhibits better performance during earthquake than the neglected ones.

#### IV. STONE HOUSES IN EARTHQUAKE AFFECTED AREAS

Houses constructed from natural stone are predominant in the hilly areas, especially in eastern part of Bhutan, due to its availability of basic building unit (i.e. stone). Natural, rough cut and dressed stone have been used traditionally depending on the financial affordability of the rural inhabitants. The courses of stones are laid with clay mortar in most of the cases except in government buildings. The thickness of the wall is around 450 to 500mm, with roof constructed from wood logs, timber joist which was initially covered by bamboo mats and wooden shingles, later replaced by CGI sheets.

It was observed that seismic performance of random rubble masonry are similar to adobe buildings in western part of Bhutan but the potential to cause human injuries and death is more than adobe houses, due to its heavy weight. Most of the buildings are double storey with ground floor fully masonry wall with few openings, and top storey with half wooden framed structures called Rabsel (traditional Bhutanese facade). Most of the buildings have ekra facades as shown in figure 6.

Most of the foundations are constructed with stones (larger in size) about 2-3 feet below ground and wider than masonry wall thickness. The lintels and sills are almost all constructed from timber. The wooden rabssel is segregated from the stone masonry dung (middle belt), which is not properly integrated with masonry walls. It was

observed that there is absence of good ties between wall and the floors/roofs in most of the structures.

### V. CRITICAL OBSERVATIONS IN EARTHQUAKE AREAS

The quality of construction method and materials used during construction of building is seen to affect the seismic performance critically. Some commonly seen construction defects are the following:

- Lack of proper bonding between building units.
- Unfilled vertical joints between the units.
- Improper usage of tooth joints between perpendicular masonry walls/edges
- Lack of Through stones on masonry walls
- Unstable configuration of stones

### VI. CAUSES OF FAILURE

The main causes/destruction of building structures during earthquake of 2009 are following;

- Non-engineered and low quality construction
- Lack of awareness about the earthquake resistant engineering methods
- Mason and carpenters, following the traditional Bhutanese guidelines without proper understanding its structural significance
- Absence of building codes for different building typologies
- Anonymous usage of mud taken from mountain slopes and farms
- Some building constructed on mountain slope are without proper balance
- The joinery between the timbers is not efficient as indicated in traditional Bhutanese guideline

### VII. DESIGN FOR EARTHQUAKE RESISTANT CONSTRUCTION

The fundamental basis of seismic design are mainly based on the application of construction technologies, methods, criteria, etc. which are extensively used to design and construction of building structures that are exposed to earthquakes (Masjid, 2001). Therefore the most suitable and appropriate stiffness, strength requirement, configuration and ductility of buildings are provided in seismic design (Robert, 1982). Earthquake resistant constructions are also defined as implementation of the seismic design and building codes to assure the building structures survive throughout earthquakes.

C.V.R Murty in his Earthquake tips states that, size of the building plays vital role in safety measures. Longer building has more damaging effects. Simple layout of buildings provide better performance than building of C,U,L and cross shaped buildings. For example, to have efficient

performance, complex shaped buildings are broken into two or more rectangular layouts, as shown in figure 8.

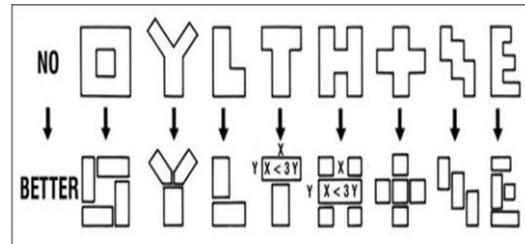


Figure 8: Simple plan performs well during earthquake. Source: <http://www.earth-auroville.com>

### VIII. MITIGATION TECHNIQUES FOR STONE MASONRY WALLS

Improvement and enhancement on existing material usage and construction techniques on existing practice are considered to be the best solution for long term and sustainable earthquake safety and mitigation process (Haseeb, 2011). The primary focus for most of strengthening techniques are stressed on walls, as it endures both gravity and lateral loads beside live and dead loads. This is stressed to enhance the integrity with roof and other floors and carry capacity of wall to ensure the prevention of wall from collapsing.

Following methods are the most suitable to strengthen the masonry walls out of numerous ways and means, according to Guidelines for earthquake resistant non-engineered construction as follows;

1. Height of storey should be maintained between 2.5 to 3.5 m. Single storied house is preferred with attic floor and light roofing materials.
2. It is preferred to have tapered wall for taller building, but thickness of wall should be 300-400mm.
3. The maximum length of wall should be limited to 6-7m between cross walls.

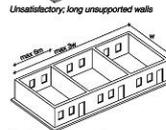
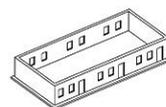


Figure 9: Nature of enclosures, Source: A.S.Arya

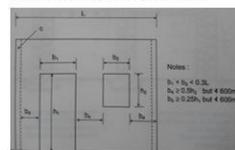
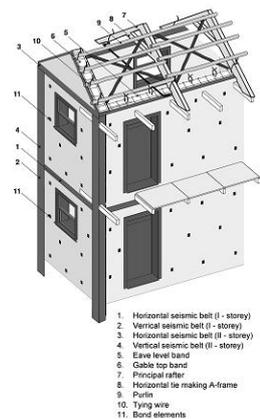


Figure 10: Recommended openings in rubble masonry, Source: IAEI



1. Horizontal seismic belt (I - storey)
2. Vertical seismic belt (I - storey)
3. Horizontal seismic belt (II - storey)
4. Vertical seismic belt (II - storey)
5. Eave level band
6. Gable top band
7. Principal rafter
8. Horizontal tie making A-frame
9. Purlin
10. Tying wire
11. Bond elements

Figure 11: Overall arrangement of reinforcing masonry buildings, Source: A.S.Arya

4. The openings should be recommended to be minimum, small and centrally located as shown in figure 10.
5. To increase the strength of wall, usage of clay mortar should be minimized and it is preferred to have cement mortar mix of 1:6.
6. In random rubble masonry, the courses should not be lifted more than 600mm for its stability.
7. For horizontal binding, Murty states that, a building should have roof bands, lintel bands and plinth bands with cross wall connections as in figure 11. Providing bond beams can achieve better integration of roof and wall.
8. To integrate the Wythe of walls together, through stone of length, which is equal to wall thickness should be provided in every 600mm lift and 1200mm apart horizontally. Well-seasoned wood bars of 38mm x 38mm can be also used as through stones as shown in figure 12.

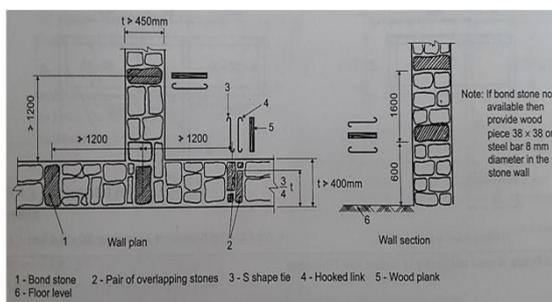


Figure 12: Through stones or Headers for integrity of stone walls, Source: IAEE

9. The connection of perpendicular walls (T and L junctions) to enhance building integrity can be performed by tying the walls together using wooden frames as shown in figure 13. It can also do by materials having higher tensile strength and ductility. It includes: (i) wire mesh reinforcing (ii) use of polypropylene bands (iii) use of corner stitches (L and T-stitch) made of reinforced concrete as shown in figure 14&15.

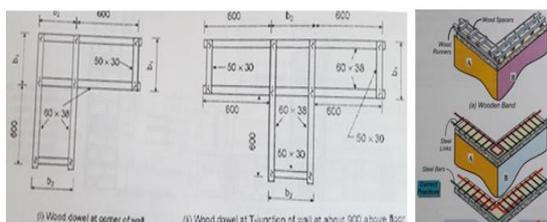


Figure 13a & 13b: Details of wood and steel reinforcing at corners and T-junctions Source: IAEE

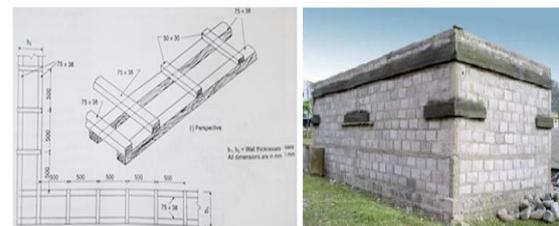


Figure 14: Lintel level wooden band on all load bearing walls, Source: IAEE

Figure 15: Roof band beam and wall L-stiches, Source: M. T. A. Chaudhary

## IX. RECOMMENDATION AND CONCLUSION

Earthquake has been one of the most hazardous natural disasters that bring tremendous loss to many human lives and properties due to collapse of buildings and non-engineered dwellings. Based on the evidences and analysis, the damages occurred to non-engineered construction in the past earthquakes, some important structural details are studied and reviewed in this paper.

These engineering judgments and analytical results could improve the prevention of collapse and life safety of built environment during earthquakes. Bhutan lies in the earthquake prone region, the following recommendations are provided to increase the seismic safety of buildings based on the observations studies carried;

1. Awareness on traditional constructions techniques and improvements in its technologies that has proven their ability to resist earthquake loads. This should be reinstated and integrated with modern construction practices to have better design for strong and safe built environment.
2. The concerned agencies should generate region's own seismic codes and compliance methodologies. The guidelines for seismic evaluation and strengthening of existing buildings must be strictly followed.
3. Good construction practices and quality material usages should be promoted with alternatives, besides following traditional building guidelines.
4. Promotion of earthquake resistant building typologies should be encouraged. Locally available materials such as bamboo and timber alternatives which are sustainable and new building typologies of proven earthquake performance, such as confined masonry need to be introduced.
5. General public at large must be educated about the importance of geological setting, geotechnical concerns and earthquake-resistant construction and their role in mitigating the future seismic risk.

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