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Damages on Unreinforced Masonry Buildings in Kathmandu Valley After Gorkha Earthquake 2015

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ABSTRACT : *Unreinforced masonry buildings are ubiquitous in Nepal due to the use of locally available materials, straightforward building techniques and economic viability. However, the Gorkha Earthquake 2015 affected these masonry buildings the most. This paper assembles the information collected during the reconnaissance of the unreinforced masonry buildings after the earthquake in Kathmandu Valley. It highlights the damages caused by Gorkha Earthquake 2015 in the unreinforced masonry buildings in Kathmandu Valley and attempts to identify the possible causes of the damages. This paper also presents some recommendations for the construction of unreinforced masonry buildings so that such catastrophic devastation can be avoided in the future.*

KEYWORDS: *Unreinforced Masonry Building, Damages Type and Causes, Gorkha Earthquake*

I. INTRODUCTION

On April 25, 2015 at 11:56 AM (Nepal Standard Time), Nepal witnessed an M 7.8 earthquake, the most powerful earthquake since 1934 Nepal-Bihar Earthquake, with its epicenter at approximately 34km east-southeast of Lamjung, Nepal, and hypocenter at a depth of approximately 15km. This earthquake left the whole nation—especially 35 out of 75 districts including Kathmandu Valley—in a rather vulnerable situation. The occurrence of this earthquake is the outcome of thrust fault at the location of the earthquake, where the Indian plate is converging with Eurasian plate at a rate of 45mm/yr towards north-northeast (USGS, 2015a). After the occurrence of this major earthquake, a number of aftershocks followed, the most consequential being an M 6.7 earthquake on 26th April 2015 at 12:54 PM (Nepal Standard Time) As a result of this earthquake, about 9000 deaths and 17000 injuries have been reported, as of May 25, 2015. Along with that, about 50000 of public houses and about 1000 of the government houses are reported to have been fully destroyed, whereas 270000 of public houses and 3000 of the government houses are recorded as partially destroyed. Damages were reported in some parts of India, China and Bangladesh too [Home Ministry Nepal].

II. HISTORY OF EARTHQUAKES IN NEPAL

The first ever recorded earthquake in Nepalese history was in 1255 A.D. Then after, in 1833 earthquake, about 4600 houses were destroyed and 500 deaths were recorded. In 1934, an M 8.1 earthquake struck Nepal which was named as Nepal-Bihar earthquake, and about 10700 deaths were recorded then. The 1980 earthquake killed 178 people and 40000 homes were destroyed. The 1988 earthquake at Udaypur caused 722 fatalities, 12000 injuries and severe damages of 460000 houses. Similarly, 2011 Nepal-Sikkhim earthquake resulted in 6 fatalities, 30 injuries and about 1300 severe building damages in Nepal [Al Jazeera, 2015].

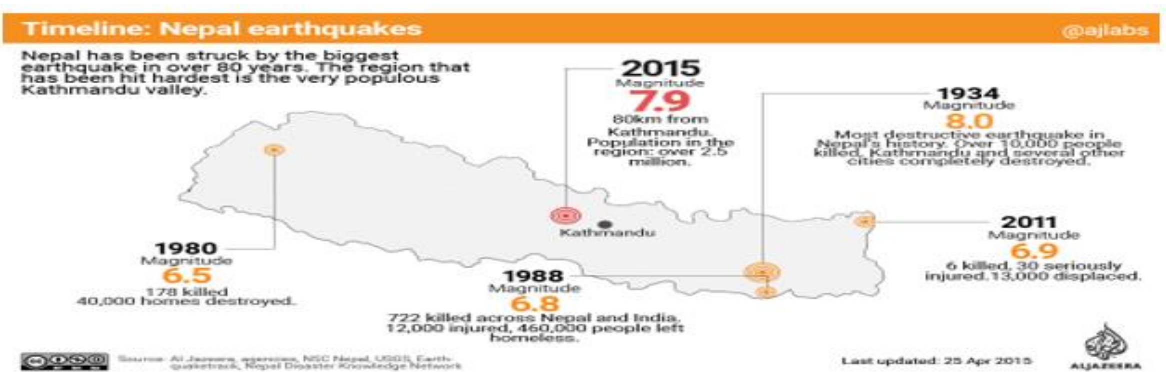

Fig 1: Timeline of Nepal earthquakes (Al Jazeera, 2015)

III. SEISMIC VULNERABILITY OF NEPAL

The seismic vulnerability of Nepal is due to the continental-continental convergence of Indian and Eurasian Plates. The northward movement of Indian plate under the overriding Eurasian plate has caused huge amount of stress to build up within the Earth's crust, which is periodically released in the form of vibration of the earth i.e. earthquakes along the faults [USGS, 2015b]

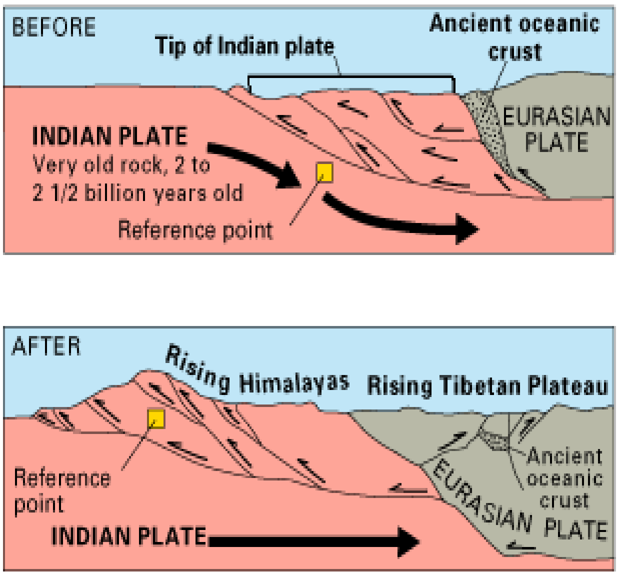

Fig2: https://pubs.usgs.gov/gip/dynamic/graphics/left.gi

The tectonics of Nepal Himalayas can be classified in three different zones: Main central thrust (MCT), Main boundary thrust (MBT) and Main frontal thrust (MFT). These are the reasons for high seismic activity in Nepal. Above all this, Kathmandu Valley is at risk to strong earthquakes due to the type of soil comprising layers of sediments, clay deposits, and mixture of sand and clay deposits that is underneath which makes the valley susceptible to liquefaction [Shrestha BK, 2005].

IV. UNREINFORCED MASONRY BUILDINGS IN KATHMANDU VALLEY

Masonry construction started in Nepal before 2550 years ago. The type of construction in the rural areas of Nepal are mostly adobe, wooden framed, or rubble masonry type; however, in the urban areas, stone masonry, brick masonry, and in the earlier days even RC constructions are more common [Gautam D et al., 2016] Regarding Kathmandu Valley, about 60 percent of the buildings are unreinforced stone/brick masonry bounded by mud/cement. Most of the unreinforced masonry construction can be found in the suburban areas of Bhaktapur, Bungamati, Sankhu etc. The bricks used in the construction are mostly sun dried bricks and normally mud mortar is to found to be used in residential buildings. The walls are usually 450 to 600 mm thick [Shrestha B, 2015].These traditional buildings had many deficiencies including the lower strength of mortar, lack of proper connections, lack of integrity, and many more, due to which the buildings had to suffer various damages during Gorkha Earthquake 2015.

V. DAMAGES OBSERVED IN UNREINFORCED MASONRY BUILDINGS IN KATHMANDU VALLEY

V.1.Diagonal Cracks: Diagonal cracks due to an earthquake in buildings basically occur when the tensile stresses developed due to the vertical loads and horizontal seismic load exceed the tensile strength of the masonry material i.e. weak unreinforced masonry is one of the causes of diagonal cracks. Moreover, the diagonal cracks are normally inclined at 45 degrees to the horizontal plane, but depending on the magnitude of the horizontal loads and vertical loads, the inclination might differ [Bayulke N, 1978]. This category of crack is among the most common types of cracks that were observed after the earthquake. In case of the traditional buildings in Kathmandu Valley, the buildings suffered from diagonal cracks due the absence of horizontal bands (floor bands, lintel and sill bands). The diagonal cracks observed passed through the mortar rather than bricks, from which we can infer that the mortar used, were weaker than the bricks. The diagonal cracks can be well observed in fig 1.a and 1.b.

Furthermore, as seen fig 1.c and 1.d, the diagonal cracks mostly emanated from the corners of the openings, since the corners are the points of stress concentration.

Fig. 1.a: Diagonal shear crack

Photo Source: Rajan Suwal

Fig. 1.b: Diagonal shear crack

Photo Source: Rajan Suwal

Fig. 1.c: Diagonal shear crack

Photo Source: Rajan Suwal

Fig. 1.d: Vertical shear crack

Photo Source: Rajan Suwal

V.2. Corner Failure: Corner cracks occur as a result of stress concentration at the corners. In the traditional masonry buildings in Kathmandu Valley, the slabs used were basically made up of timber, which are not rigid enough to hold the adjacent walls together. As a result of this, during earthquake, the walls tend to separate at the corners resulting in corner cracks. As shown in fig. 2.a and fig. 2.b, we can see the corner cracks as indicated, which might have occurred due to the irregularity in the plan of the building and accumulation of stress at the corners. Also, due to the irregularity in the plan of the buildings, the regular bays might have moved as separate units, hence causing the cracks to appear at the corners. The corner failure as seen in fig. 2.c and 2.d is due to the lack of connection in between the two perpendicular walls. The failure could have been prevented if the two walls were constructed integrally or if corner ties were provided.

Fig. 2.a: Corner Crack

Photo Source: Rajan Suwal

Fig. 2.b: Corner crack

Photo Source: Rajan Suwal

Fig. 2.c: Corner failure

Photo Source: Rajan Suwal

Fig. 2d: Corner failure

Photo Source: Rajan Suwal

V.3. Vertical Cracks

Vertical cracks occur in the walls when the out of plane failure causes the walls to separate around the corners. This is intensified by the lack of anchorage at the corners of the walls.

Fig. 3.a: Vertical crack

Photo Source: Rajan Suwal

Fig. 3.b: Vertical crack

Photo Source: Rajan Suwal

Fig. 3.c: Vertical crack at corner

Photo Source: Rajan Suwal

Fig. 3.d: Vertical crack at corner

Photo Source: Rajan Suwal

As in fig. 3.a we can observe vertical cracks in the directions of both in plane and out of plane failure. A number of diagonal cracks can also be seen in the building which implies that the initial shaking of the earthquake caused the diagonal cracks, and then, as the trembling intensified, the vertical load carrying capacity of the building lowered and vertical cracks might have appeared and slowly propagated. Similarly, vertical cracks can be seen in fig. 3.b. These cracks in the adjacent walls might have appeared due to the increase in tensile stresses in the walls due to out of plane failure. Moreover, the lack of anchorage at the corners must have been the cause of the vertical cracks as shown in fig. 3.c and fig. 3.d.

V.4. Out of Plane Failure: This kind of failure occurs in a wall when the direction of earthquake load is perpendicular to the wall and the wall is not sufficiently anchored to the adjacent walls, floors or the roof, such that it decreases the possibility of prevention of failure. Fig. 4.a and 4.b show an out of plane failure. Here, the possible cause is the lack of anchorage with the roof at the top of the wall due to which the wall was unsupported at the upper end and since the inertia force is higher, the wall clearly couldn't resist the lateral earthquake load. In addition to this, the first floor of the building as shown in fig. 4.b might have suffered from out of plane failure due to the lack of rigid diaphragm to act as a rigid support of wooden columns.

Fig. 4.a: Out of plane failure of top floor

Photo Source: Rajan Suwal

Fig. 4.b: Out of plane failure

Photo Source: Rajan Suwal

Fig. 4.c: Out of plane failure

Photo Source: Rajan Suwal

Fig. 4.d: Out of plane failure in lower stories

Photo Source: Rajan Suwal

Similarly, the out of plane failure as seen in fig. 4.c might have been due to the absence of cross wall over the length of the overturned wall. The wall must have failed due to its inability to resist the earthquake force during seismic activity in lateral direction. Moreover, the failure of the building in 4.d might have occurred due to the lack of proper connection to the cross wall on one side and to the timber column and floors at the other side. Along with it, even the flexible diaphragm might have aggravated the out of plane failure.

V.5. Roof Supporting Wall and Gable Wall Failure: Roof wall and Gable wall failure are the failure that occurs in the top of roof and triangular part of the roof. During earthquake, inertia force is greater at the top of a building, so provided that the top part is not adequately supported in plane and laterally, the wall is liable to fail. The top roof wall and gable wall, when not restrained by the bands, gable bands, goes through the above process resulting in gable wall failure.

Fig. 5.a: Top roof wall failure

Photo Source: Rajan Suwal

Fig. 5.b: Gable roof wall failure

Photo Source: Rajan Suwal

Fig. 5.c: Top roof wall failure

Photo Source: Rajan Suwal

Fig. 5.d: Gable roof wall failure

Photo Source: Rajan Suwal

Fig. 5.a and fig, 5.c show the failure of top roof wall. Fig. 5.b and fig 5.d show gable wall failure. We can clearly observe the timber frames that have been apparently used as frame of the gable. Gable bands of timber or other material are absent in both of these buildings due to which during the earthquake, the walls failed as a result of higher inadequate restraints and inertia force.

V.6. Delamination of Wythe's: The separation of different layers of a wall is referred to as delamination of wythes. This can occur as an outcome of poor masonry, poor bonding or lack of integrity among different layers of a wall and even age factor of the buildings might be the cause of this failure. Similarly, poor quality of bricks stacked in between external layers of brick walls can also be another cause of separation of wall layers.

Fig. 6.a: Failure of outer layer of brick wall

Photo Source: Rajan Suwal

Fig. 6.b: Failure of outer layer of brick wall

Fig. 6.c: Failure of outer layer of brick

Photo Source: Rajan Suwal

Fig. 6.d: Failure of outer layer of brick

Photo Source: Rajan Suwal

Regarding the houses surveyed in Kathmandu Valley, the quality of mortar was found to be low. The delamination of wythes caused in fig. 6.a, fig 6.b, fig.6.c and fig. 6.d are also most likely due to improper bonding between different layers and due to low quality of mortar.

VI. CONCLUSION AND RECOMMENDATION

1. Diagonal cracks have been observed in most of the buildings due to the absence of floor bands, lintel bands and sill bands and also due to the weak mortar. It is recommended to use such horizontal timber bands in traditional building to avoid diagonal cracks in the future.
2. The lack of connection in between the perpendicular walls has triggered the corner failure and vertical cracks too. In addition to this, the irregularity in the plan of the buildings has caused stress accumulation around the corners hence exacerbating the situation. It is, thus, suggested to connect the perpendicular walls sufficiently and also separate an irregular building into regular blocks by creating some gap in between.
3. Lack of rigid diaphragm, lack of enough anchorage with the cross walls and undesirably long unsupported length of walls have been found to be the causes of out of plane failure. To avoid this failure in the future, rigid diaphragm are to be used, cross walls are to be placed to support the whole length of the walls and properly anchored to them.
4. Lack of gable band has been found to be the main cause of gable wall failure. Thus, gable bands are a must to avoid such failure.
5. It has been concluded that the delamination of wythes have resulted due to the use of poor masonry and lack of bonding in between the bricks used. This can largely be avoided by the use of masonry of good quality and proper connection of different wythes of masonry wall.

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