STRUCTURAL ENGINEERING/PERSPECTIVE DAMAGE PATTERN OF TEMPLES OF KATHMANDU VALLEY AFTER GORKHA EARTHQUAKE 2015

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Abstract

Nepal is well known for traditional temples. It is found that most of the temples were built in12th century to 17th Century. Most of the temples, built in 17th century, in Kathmandu valley were constructed in pagoda style. Timber along with bricks were used for construction and mud or surkhi mortar was used as a binding material. The Gorkha earthquake, 2015 caused minor to major damages to number of temples. Pictures highlighting damages in the temple were collected during damage reconnaissance and is used for studying its structural systems. Possible causes of damage pattern of temples are discussed and recommendations for future construction are given.

Keywords: *Causes of Damages, Damage Study, Masonry Wall, Traditional Temples.*

1. Introduction

The heritage of Kathmandu valley is mainly temples of old age. They were made with brick masonry and timber. In Kathmandu, Lalitpur and Bhaktapur, there are a number of traditional old temples with very unique typology. Hence, both the architectural and structural system of these temples have developed an interest for national and international architects, engineers and tourists. These temples were damaged in various past earthquakes including Bihar-Nepal earthquake, 1934 and Gorkha earthquake, 2015. In Gorkha earthquake, 2015, these temples were damaged partially and fully and different cracks pattern and collapse mechanism were observed. So, it is required to study the damage pattern of these temples and find the way for future renovation and reconstruction.

The objective of this paper is to visit and collect damaged evidence of the temples of Kathmandu valley in Gorkha earthquake, 2015 and study the damage pattern of temples and explain the possible causes of damaged temples.

2. Methodology

After Gorkha earthquake, 2015, different places of Kathmandu valley were visited for damage reconnaissance. Photographs highlighting the damages in the temples were taken and the construction materials used were noted. Structural system of temples is studied, and the possible reason for the damage is discussed. Recommendation on the basis of experience is given for improvement of structural system for further reconstruction and repair.

3. Observation and Possible Causes of Temple Failure

3.1 Kedarnath Temple, Bhaktapur

Observation:

Kedarnath temple (Shiva temple), located in the western part of Bhaktapur Durbar square, is made of brick masonry with mud mortar which is shown in Figure 1. Temple is almost symmetrical in plan.

There is an opening to enter inside the temple. Temple is one storied above that almost solid core. The outer brick wall of temple was made of traditional decorated brick with mud mortar and inside of core were filled with mud and local bricks which is shown in Figure 2. The outer pillar of the temple was made of single slender stone. Foundation of the temple is in elevated two tired plinths. Timber as a structural element is not seen in this temple. Connection between external walls and internal walls are not provided (Figure 2).

Possible Causes of Temple Failure:

In the Gorkha earthquake, 2015, top part of temple had fallen. Exterior brick walls fell even though interior mud with brick core was partly intact. Shear failure of wall occurred due to the absence of horizontal timber band and vertical timber connection. There was absence of connection between outer brick walls and inner mud with brick core so outer and inner core were separated.

Figure 1: Damage of top part of Kedarnath Temple of Bhaktapur Durbar Square

(Photo source: author)

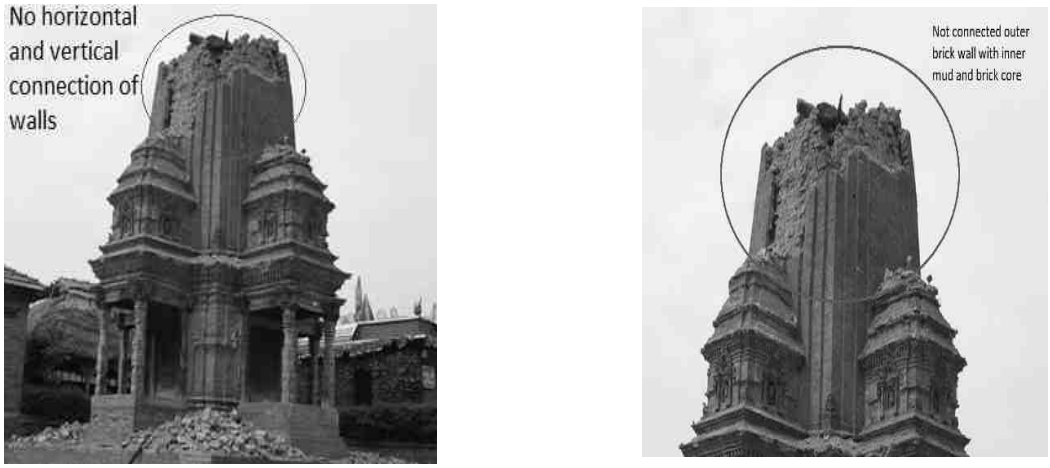

Figure 2: Enlarged view of damage of top part of Kedarnath Temple of Bhaktapur Durbar square
(Photo source: author)

3.2 Shankernarayan Temple, Bhaktapur

Observation:

The small Shankernarayan temple was damaged in the Gorkha earthquake, 2015. Temple is almost square in plan. There is a door from front side. From other three side there is masonry wall. It is one storied temple. Even though this temple of Durbar Square of Bhaktapur is small, it was damaged in the earthquake as shown in Figure 3. It is seen that the temple has vertical longitudinal crack from plinth to roof but did not collapse.

Possible Causes of Temple Failure:

The vertical crack failure might be due to weak bonding between brick elements. There is no connection band horizontally in different layers of temple. The locking of bricks in different layer are missing and hence longitudinal vertical cracks were developed.

Figure 3: Longitudinal vertical joint failure of Shankernarayan Temple of Bhaktapur Durbar Square (Photo source: author)

3.3 Fasi Dega (Silu Mahadev) Temple, Bhaktapur

Observation:

Fasi Dega temple was constructed up to five steps raised platform in Bhaktapur Durbar Square before the Gorkha earthquake, 2015 (shown in Figure 4). One story temple has square in plan and openings from all sides. The structure of this temple was fully collapsed up to raised plinth level in the Gorkha earthquake, 2015 (shown in Figure 5). The temple was rebuilt as brick masonry with mud mortar after it collapsed in Nepal-Bihar earthquake, 1934.

Possible Causes of Temple Failure:

Even though this structure was only around for 75 years, it was again fully collapsed indicating there must be either structural system failure or material quality failure. Structural integrity of masonry wall seems weak. In addition to that, five tired soft plinth steps might have amplified the earthquake effect for the structure.

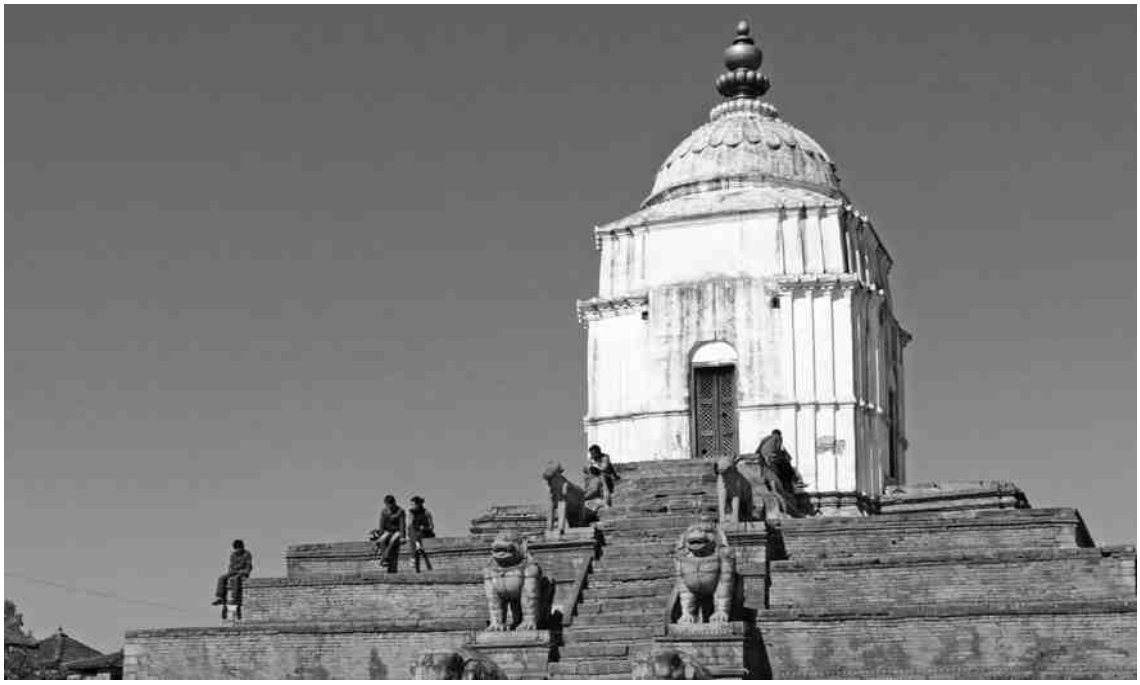

Figure 4: Fasi Dega Temple before Gorkha Earthquake 2015

Source:https://albinger.files.wordpress.com/2017/11/fasidega-mandir-before-the-2015-earthquake1.jpg

Figure 5: Fasi Dega Temple collapsed up to elevated top plinth(Photo source: author)

Figure 6: Fasi Dega Temple after Gorkha Earthquake 2015 (in cleaning stage)
(Photo source: author)

3.4 Vatsala Durga Temple, Bhaktapur

Observation:

Vatsala Durga Temple was constructed on the four tired elevated plinth in sikhara style. It was made of dressed stone masonry. Temple plan is almost in square shape and having door opening from front side. Main load-bearing of temple is mid core stone structure with stone pillars around, which is seen in Figure 7. Total collapse of this temple after earthquake is shown in Figure 8.

Figure 7: Vatsala Durga Temple, Bhaktapur Durbar Square
(Source: researchgate.net)

Figure 8: Collapse of Vatsala Durga Temple, Bhaktapur Durbar Square
(Source: researchgate.net)

Figure 9: Vatsala Durga Temple, Bhaktapur Darbar Square (after cleaning)
(Photo source: author)

Possible Causes of Temple Failure:

Measuring height to width of core wall ratio of temple from the judgment of picture, it can be said that temple is slender for stone masonry structure. Interlock of stone masonry might not be provided. From the damaged picture of Figure 8 shows that inner part of temple was filled with mud and stone bats without any integration with outer stone masonry walls. There might be already micro-cracks between mortar and stone block in different previous earthquakes, staying without good bond. Due to this weak bond between stones with mortar, it lead to complete collapse.

3.5. Changu Narayan Temple, Bhaktapur

Observation:

The structural system of Changu Narayan Temple is brick and timber load-bearing system. The floors are made up of regularly spaced wooden beams above which wooden planks are placed in the direction perpendicular to the beams. The surface of the floor is smoothened by providing a thick mud layer above the wooden planks (Tiwari 2009). Masonry wall transfers the load to the foundation which is generally a huge plinth as in the case of multitier temples.

Like most multi-tiered temples, the foundation of Changu Narayan temple is a wide plinth platform that behaves as a mat foundation. Because of this, stepped footing for the main wall is expected (Thapa 2011).

There are two cores of a wall in the Changu Narayan temple. The outer core extends up to the second floor bearing systems in the temple. The walls are arranged in a box configuration. Wall structures were built with three layers, the inner face is made of sun-dried bricks while the outer face is made of fired clay brick with smooth finishing (Nienhuys 2003).

The bonding mortar inside the massive walls though not visible plays an important role in the structural strength and resistance of the temple. The bonding mortar may be yellow color clay mortar, mud mortar, or sometimes even lime-surkhi mortar (Thapa 2011).

Changu Narayan temple is built in pagoda style having two roofs. Temple roofs have symmetrical pitches springing from the central point of the inner masonry cell. The pitches are constituted of small rafters that spring from corners in a radial arrangement. The dead load of the whole roof is supported by purlins, which are then transferred to the rafters and then to the wall plates originating from the core. The inclined timber struts, which hold the roof, transfer the load from purlin to the wall section. The connection between the strut with rafters and the main masonry wall is not rigid (Suwal and Joshi 2021).

Possible Causes of Temple Failure:

Temple is mainly supported by corner brick masonry and heavy timber openings. On the ground floor, masonry portion of load bearing is less compared to total load-bearing structures. Since heavy panel of opening works as an intact structural element, remaining corner brick masonry is likely to fail in earthquake load. In Gorkha earthquake, 2015, corner masonry walls of the temple failed, which is supported by the computer model analysis (Suwal and Joshi 2021).

Figure 10: Damage in Changu Narayan Temple (North-West corner, top)

Figure 11: Damage in Changu Narayan Temple (North -West corner,bottom)

Figure 12: Damage in Changu Narayan Temple (North-East corner)

3.6. Swayambhu Stupa, Kathmandu

Observation:

Base of Swayambhu Stupa had constructed with massive brick and mud structure. The shape of base is almost semi-spherical dome. It has minor damage in the main dome base. Minor circumferential and radial cracks are observed as shown in Figure13 and Figure14. Minor cracks were observed in the joint of dome and main structure as shown in Figure15.

Possible Causes of Temple Failure:

Mass dome might be weakened due to age and water penetration. Minor cracks are observed due to massive shaking of huge mass of dome which might be less resisting capacity of dome mass in radial and circumferential direction.

Figure 13 Circumferential crack in Swayambhu temple of main base dome
(Photo source: author)

3.7. Anantapur and Pratappur Temples, Kathmandu

Observation:

Anantapur and Pratappur temple of Swayambhu premises are almost in same plan dimension in both directions. It has big door opening in front side of temple. These temples were damaged in Gorkha earthquake, 2015. Anantapur temple was damaged severely as shown in Figure 16. Top part of temple was collapsed totally. Another temple Pratappur is slightly damaged in plinth level. Plinth level brick was damaged in compression crushing and shear. Both the temples were constructed with brick masonry in mud mortar. Both the temples are very slender with respect to base dimension.

Possible Causes of Temple Failure:

Since both temples are slender there are more chances of failure of brick masonry structure in earthquake. Brick masonry was constructed without horizontal band and vertical connection. It is not seen that connection between external brickwork and internal core. Due to these causes, this beautiful structure failed in Gorkha earthquake.

Figure 16 : Collapse of Anantapur temple in Swayambhu premises, Kathmandu

(Photo source: author)

Figure 17: Collapse of Anantapur temple in Swayambhu premises, Kathmandu

(Photo source: author)

3.8. Shiva Parvati Temple, Basantapur, Kathmandu

Observation:

Shiva Parvati Temple is located in Basantapur Durbar Square, Kathmandu. Temple was constructed with brick masonry in mud mortar. Temple is rectangular in shape. Length is comparatively two times longer than breadth. Temple has heavy roof mass in the top. It has larger opening than brick masonry walls on ground floor. It can be seen that temple has diagonal crack failure in short direction. The temple and its crack patterns are given in Figure 18, Figure 19, and Figure 20.

Figure 18: Failure of masonry structure of Shiva Parvati temple

Possible Causes of Temple Failure:

Due to the heavy load in roof and big openings on ground floor and less brick masonry structure part, masonry wall of temple is failed. Since the temple has one direction long and another direction short, cracks are observed in the shorter direction due to the less stiffness or shear capacity of masonry wall in earthquake load.

Figure 19: Diagonal shear crack in south east corner of short side elevation
(Photo source: author)

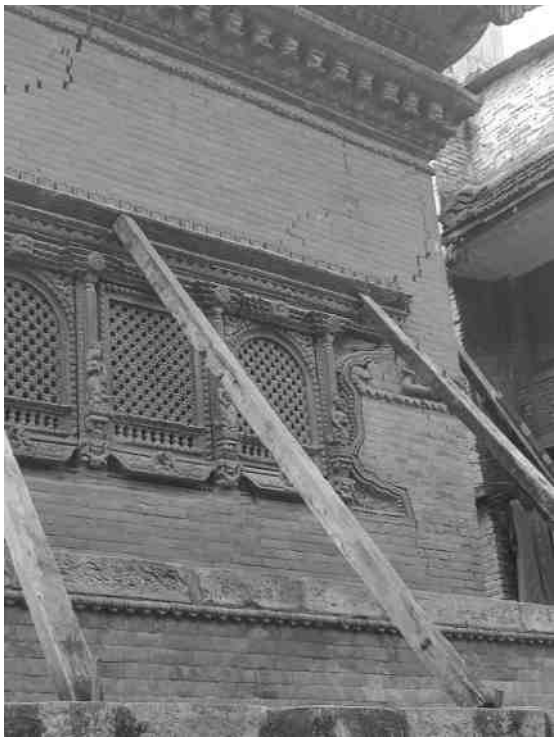

Figure 20: Diagonal shear crack in north east corner of short side elevation
(Photo source: author)

3.9. Narayan Temple, Kathmandu

Observation:

Narayan Temple in Kalmochan temple area, Thapathali, Kathmandu, was made of brick with surkhi+lime+sand mortar. Brick masonry with surkhi+lime+sand mortar seems delaminated due to water penetration in temple building. Temple has small opening in all sides with different sizes. It is one story temple. There is no horizontal timber and brick band in temple. The temple and its crack patterns after Gorkha earthquake, 2015 are shown in Figure 21, Figure 22, Figure 23, and Figure 24. In the premises, main structure of Satya Narayan temple was fully collapsed in the Gorkha earthquake, 2015.

Figure 21: Wall crack in Narayan temple of Kalmochan
(Photo source: author)

Figure 22: Wall crack in Narayan temple of Kalmochan
(Photo source: author)

Figure 23: Crack near the roof of Narayan temple in Kalmochan
(Photo source: Author)

Figure 24: Crack near the roof of Narayan temple in Kalmochan
(Photo source: Author)

Possible Causes of Temple Failure:

Narayan temple of Kalmochan area damaged in masonry wall. Crack of brick masonry of temple seems due to delamination of masonry work. Continuous water penetration in brick masonry might weaken the strength of temple masonry and cracked it in Gorkha earthquake, 2015.

3.10. Mahadev Temple, Kathmandu

Observation:

Figure 25: Crack over opening in brick masonry in Mahadev temple of Kalmochan premises

(Photo source: author)

Figure 26: Close view of crack over opening in brick masonry in Mahadev temple of Kalmochan premises
(Photo source: author)

Mahadev Temple in premises of Kalmochan temple area at Thapathali in Kathmandu was made of brick with surkhi, lime sand mortar. The temple has almost square in plan with small door opening. Brick masonry with mud mortar seems delaminated condition. Bonding between brick with mortar seems already weak. It seems water penetration in brick masonry from roof which made brick masonry weak. Cracks are seen above two edges of opening almost in vertically. The temple and its crack patterns are shown in Figure 25 and Figure 26.

Possible Causes of Temple Failure:

Mahadev temple of Kalmochan area damaged in masonry wall. Cracks on brick masonry of temple seems due to delamination of masonry work. Continuous water penetration in brick masonry weakens the strength of temple. Almost vertical crack above the edge of opening shows weakness of masonry wall due to old age of temple and weakened water penetration and cracked in Gorkha earthquake, 2015.

4. Conclusion

The followings are summery of conclusion:

1. Temples of Kathmandu valley survive so many small and big earthquakes. Due to different earthquakes, bonding between bricks with mortars might become weak. Even though from the

outside view they are intact, in reality, there might be micro-cracks and failures in recent Gorkha earthquake.

2. Temples of Kathmandu valley are already old. They are not maintained periodically so the strength of material was being loosed with time.
3. Due to the leakage of water in certain temples, constructed material was in delaminated condition so failed in the earthquake.
4. Horizontal and vertical connections in temples are not provided which weaken the masonry structure in earthquake.
5. In most of the temples, the structural part of masonry is less with respect to opening so the structure is weakening in shear and failed in brick masonry.

5. Recommendations

1. Most of the temples which are in Kathmandu valley are already old and weak conditions, so need periodic maintenance and repair.
2. The temples are needed to seismically evaluate and do the retrofit or reconstruct if needed.
3. The temples which will be reconstructed, need to follow seismic resistance codal provisions preserving traditional technology and values.

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