Traditional Architecture of Kathmandu valley

-Responsiveness to earthquakes through empiricism[i]

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Indigenous building culture anywhere develops without the benefit of processed knowledge. In such a situation, locally available building materials and the site geology initially influence the development of building technology and forms. Building cultures develop over time and over failures and successes of earlier attempts. The process of development of architecture in indigenous societies, also, shows precedence of response to socio-cultural and religious demands. Technological and material knowledge and skill seem to develop to match these demands as they sought permanency of construction to satisfactory levels. Some societies, conditioned by their understanding of the material universe, have also sought 'perishability' as a requirement of building.

While all such processes in the development of building culture did have their place, the development of technology of building in Kathmandu valley would also have been a continuous attempt to respond to earthquakes, which has been a recurrent natural phenomenon. Tectonic earthquakes have a much longer history than the history of durable buildings, which is only about two thousand years old, in the valley. Kathmandu with its faults in the rocks formations deep below and unconsolidated alluvial sediments in most places in the surface, is very active seismically and falls in seismic zone no. IV. (The Assam area in India is more susceptible in Indian sub-continent with zone no. V classification). In Kathmandu, some of the earthquakes, such as those of 1255[1] and 1344, were so devastating that they have found place in the chroniclers' record. In recent times, the valley suffered huge losses of life and property in 1738, 1810, 1833 and 1934. Damage and devastation in the valley has been serious due to amplification of vibration, a function of the alluvial nature of the surface geology in major settlements area of Kathmandu valley.

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[i] This article is based on a lecture delivered to the Workshop on Seismic Design of Buildings organized by CEC, Institute of Engineering on April 8-12, 1998 at Pulchowk, Lalitpur.

Given such a situation, it should be only natural for builders in this valley to strive for a earthquake resistant construction.

This paper makes a case presentation and discussion of technological (design and construction) details, seemingly developed over time with experimental experience, that have potential to minimize effects of earthquakes on traditional buildings of Kathmandu. We will base our discussions on the tiered temples, where in such efforts and features are applied more seriously due to obvious interest in achieving longer durability.

Action of earthquakes on buildings and their behaviour are complex phenomena. Effect of earthquake on tall buildings is, by nature, more pronounced than in low rise buildings[2]. In this context we should remember that although tall buildings are known to have built since long past, e.g., Kailashkut Bhavan in the seventh century with its seven floors or the seven storied structure remembered in the chariot of Matsendranath, in Malla architecture they are a comparatively late phenomenon. Such buildings appear to have been discontinued for almost a thousand years until the building of the three tiered Taleju temple to a height of 37 meters by king Mahendra Malla in 1564 AD. Earlier state temples of Siva and Narayana were as a rule two storied. Taleju is also the first temple to be raised on a high multiple plinth. These two novel design instructed design features are said to have caused technological difficulties to the builders at that time, as indicated by chronicles of Wright or Hasrat. Following the construction of Taleju, temples with high plinth and three tiers become more common. Three tiers were added to the two-tiered Kumveswor temple (built 1392) of Patan making it five tiered and increasing the height to 24.3 meters by king Yognarendra Malla (1684-1705). In 1702, the temple of Nyatapola was raised to a height of 30 meters with five tiers and a high plinth. The highest secular building rising to about 33 meters, in the Malla style, was built by king Prithvinarayan Shah in 1770[3].

Occurrence of good soil and abundant forest resources in the valley gave the Nepalese builders the two basic materials of construction: mud and wood. Mud used as mortar, bricks and tiles and timber as posts, joists, rafters, struts, doors and windows, characterize the Nepalese architecture. Innovation and artistry in use of these materials summarize the development of architecture over time. The great technological achievements in brickwork, such as manufacturing technique of '*Telia brick*' and its fungi based glazing compound, the wedged brick to cut contact of water with mud mortar, the sealant mortar and similar progress in classification of timber for exposed and unexposed as well as structural and decorative members and their joinery and carvings, all go to show that the Nepalese builder had amassed a wealth of know-how to deal with the elements of nature. Similarly, although earthquake was a tough phenomenon to deal with, discussions below show that a set of details and design methods had been developed over the years to gain over it.

The bane of Nepalese architecture, from the view point of earthquake engineering, has often been said to be thick walls of brick in mud mortar. Used on its own, earthquakes cause '*brittle failure*' primarily due to the lack of tensile strength in mortar and the wall to deal with stresses induced by lateral forces. Other associated problems are heaviness of wall and roof, both of which encourage mass action and consequent failure. But these buildings do have quite a few features that have potential to reduce the impact of earthquakes.

i) *Plan Configuration*: The traditional buildings derive a fair level of earthquake resistance through use of appropriate plan configuration. Use of square plan with full symmetry, in the case of temples, give these buildings perfect symmetry in terms of distribution of mass and rigidity. This has given equal strength to the building in response to any direction of ground wave and lateral forces. Symmetry in position of openings not only avoids location of openings too close to building corners but also effectively make the center of mass and center of rigidity (geometric center for buildings with symmetrical distribution of stiffness) one and the same. This factor has helped reduce torsion during earthquakes. In the case of street facing residential houses, although the center of mass and rigidity are coincident, the general overall proportion is a 2 : 3 rectangle. The courtyard house, a preferred form, is also square, but the whole building acting as one unit is difficult to be achieved practically.

ii) *Triple wall structure of residences*: The residential building structure has a central spine wall parallel to the two exterior long walls and the side walls are non-load bearing. The layout of floor joists and continuous wall tie/plate and the way they are connected to the wall effectively distribute the stresses over the whole building. In later constructions, the central wall is a double timber post and lintel system, with light timber partition cross walls, thus adding to the shear capacity of this wall. During earthquakes, due to the layout of joists and their system of ties, it is always the long walls that take the shear.

iii) *Double framing of openings* : The Nepalese builder's observation of earthquake action and damage and his response through appropriate details can be seen in the critical jamb section of windows. Use of double wood frames going all round the opening on both sides of the thick wall and use of cross ties show his achievements here. This type of detailing is seen in doors also.

iv) *Temple core wall* : The general ground plan of temples is a square sanctum room with a concentric outer wall enclosing a circumambulatory around the sanctum. In later temples, the outer wall is replaced by a double post, odd bayed colonnade opening the circumambulatory. In both the cases, the central core goes up to support the upper structure. If the temple is more than two tiers, then a partial beam floor is made to spring the third wall. Inner core walls are tied (*ring ties*) at short intervals, virtually making it a composite brick and timber wall, to highly augment its shear strength as it is this core which takes most of the shear during earthquakes. In Nyatapola, the last of the major temples built in the traditional style, from third floor upwards several jointing innovations are reportedly used. This inner core wall generally determines the performance of the structure against earthquakes. It may be of interest to note here that the palace of 55-windows shows an effort to use such cores at two ends of the long side seemingly against earthquakes.

(v) *Roof tied to Wall* : The traditional buildings use timber ring plates and wedges to hold the sloping roof tightly to wall to avoid sliding off during quakes. The ridge jointing detail ensures similar linkage and balance. In the case of temples, all the sloping intermediate roofs are tied to both the lower and the upper walls again using the system of ring plates and tightening wedges.

vi) *Reducing load consecutively in upper floors* : Apart from the reduction of wall thickness in upper floors due to lesser load carrying requirement and the use of light partition walls, second and third floor central walls in residential buildings are often total timber frames. This method has not only reduced dead load of upper floor but has also given more shear strength to the spine. In the case of temples, the dead load of *'jhingati'* roof has been reduced greatly by using copper sheet roofing. Gaining *dharma* through this change of material not only added durability but also caused lightness in structure much to increase its earthquake resistance.

vii) *Number of tiers* : The Nepalese constructions rarely use even number of floors when constructing higher buildings (nine, seven, five or three tiers) . Experiments with models have shown that a five tiered temple comes to rest faster than four tiered temples, when subjected to similar vibrations. Use of odd number of floors appear to have contributed to its strength against earthquakes.

viii) *Brickwall corner detailing* : The use of large gateways in the outer wall of the temples (not using colonnaded circumambulatory) has effectively reduced the brick wall to narrow corner piers. In later temples, this aspect has been detailed by introducing timber posts in the four corners and lintel framing over. This new detailing, in conjunction with double framed door jambs, has potentially added to the earthquake resistant capacity of the structure at its vulnerable points.

ix) *Ring ties* : The brittle failure and collapse through mass action associated with heavy brick wall in mud mortar, which must have been observed by the builders early on, appears to have led the builders to use of timber ring ties held tight by tightening wedges. This has contributed in adding shear strength to wall on the one hand and on the other effectively split the brickwork into several small masses, both reducing the vulnerability of brickwork to earthquakes. These ring ties have been artistically portrayed as *Simhama, Nagpasa, Lotus petals chain* etc. At each level where the beam floor has been introduced to support upper wall, a heavier ring tie beam is common.

x) *Use of wedges - allowing movement* : Wedges are one of the most remarkable and extensively used feature of traditional construction. Whether at the joint of cross ties between opening frames or at the joint of floor joists and rafters to walls and ring plates or between the beam floor and upper walls, the use of wedges in single or double pairs are seen at innumerable numbers. These wedges, while allowing the tightening of joints, effectively act as pin joints allowing movement within joint tolerance in the case of action of lateral forces. This designed flexibility and consequent movement of thousands of wedges at critical joints leads to good deal earthquake energy absorption[4] .

xi) *Struts* : Another salient architectural feature of the traditional construction of the valley is the struts supporting the large roof overhangs. These struts are freely rested on a cleat or cornice on wall and are bird-mouthed to support the eaves beam, where also its only horizontal restraint are two wedges on the sides. This pinning support curtails the possible pull/push of the wall during vibrations and roof ends are not subjected to jolts.

xii) *Looking for a rocky site ?* : It must be left for very enlightened building industry to realize that site geology holds an important clue to earthquake devastation. Wave amplification at sites with alluvial deposits are significantly higher than at sites with rock base. The recurrent and painful destruction of building in their settlements, unfortunately sited in areas with lake deposits geology, and the observed safety of temples and houses sited on rocky areas, appears to have provided the local builder with the knowledge about the impact of nature of geology to the destruction of the structure. Thus along with the innovation of beam floor to take the third floor, foundation design for tall temples was changed into massive multiple plinths[5]. The experience in 1934 earthquake was total destruction of the Kumveswor temple in Patan and the loss of top tier only in the case of Nyatapola, seems to vindicate this. Although engineering computations are yet to be undertaken in the case of Nepalese temples, one could hazard a guess here that provision of massive plinth does improve response not only against wave amplification but also in avoiding resonance with ground. (For Japanese pagodas this natural period of vibration has been computed at 1.5 seconds for five tiered structure, whereas ground displacement period in 1923 earthquake there was 1 second.)

xiii) *Lighter walls, jointed struts and pendulum* : Archetypal tiered temples were probably very close to Mandap Pati of Nasamana Tole of Bhaktapur. It has been suggested that the tiered temple form is a derivative of the 'Jallare Chhata', a ceremonial umbrella and original forms may have had a stout timber pole in the center of the structure, around which the temple sanctum was built. Unfortunately for ritual expediency, this aspect seems to have been discarded in Nepal, whereas the Japanese used this feature as a pendulum to dampen vibrations due to earthquakes. The Japanese pagoda also use jointed struts, which add to its strength against earthquakes. Higher frequency of occurrence of earthquakes in Japan probably allowed innovations to be attempted within a lifetime several times, whereas the three to six generation frequency in Kathmandu valley may not have provided continuous impetus to technical personnel for innovation ! So the Japanese went on sharpening the details, through paper walls, jointed struts and the central pole, but we did not go as far. May be this is why only Bhaktapur, that too only towards the very end of Malla period, thought it fit to dedicate a temple to earthquake (Temple of *Bhukadyo* at Ga Hiti south of Taumadhi) ! The Patal Ganesh on its plinth is probably a memory of liquefaction wh ich could have occurred here in history.

Empiricism or Knowledge development ?: Based on the sequence of use of details, given below is a possible sequence of knowledge development in traditional architecture of Nepal in relation with earthquake action. This body of knowledge was not transferred through written documents but were apparently assimilated into the technology and craft of construction. All in all, we may conclude that despite the use of brick and mud mortar, Nepalese traditional builder in the valley has achieved quite remarkable success in dealing with earthquakes. A more sensitive site selection for settlement could have made life quite less painful during earthquakes.

- flexibility -a deliberate intervention
- dessipation of shock as a ruling principle
- knowledge of tension
- knowledge of shear
- foundation design
- timber framed core walls ?

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[1]About a third of the population of the town of Bhaktapur died and fleeing residents returned to town after more than fifteen days- the Gopalarajavamsabali folio 38.

[2]True though this is, this is not to suggest that tall and slender temples are naturally unsafe. Strength against lateral forces, amount of deformation possible and scale all combine to give a amount of potential energy. As long as this is larger than the kinetic energy imparted by the earthquake [m. (xg. t)^2], the building would not tumble down. Based on a study of pagodas of Japan - R. Tanahasi " Earthquake resistance of traditional Japanese structures", proceedings of II World Conference on Earthquake Engineering, Japan, Vol I (pp. 151-163).

[3]Heights are given as measured in 1831 AD. Converted into meters (one haat as being equal to 46 cm) from Gautam Bajra Bajracharya's "Hanumandhoka Rajdurbar"
(pp. 272).

[4]BN Bajracharya : Effects of Earthquake on Traditional Houses of Kathmandu, Journal of Institute of Engineering, Vol 1 no 1, Jan. 1982.
[5]Foundation of extant temples have not been excavated. Archaeological excavations have shown simple nine square pit foundation under the sanctum floor, Satyanarayan site (1st century BC-4th century AD)