Temples and Buildings Standing Over Kathmandu Valley Which is Vulnerable to Earthquakes

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INTRODUCTION : Kathmandu Valley is vulnerable to earthquakes

Kathmandu Valley, the capital of Nepal, is specifically vulnerable to earthquakes. Entire Nepal where most of the land is covered by the Himalayan mountains, falls under the highly seismic zones. Because the Himalayan mountain range was formed by the collision of the Asian and Indian plates that started about 50 million years ago. Universities of Alaska and Colorado have made precise measurements in the Nepal Himalayan and Tibetan Plateau since March 1991 with the help of Chinese universities and authorities. According to the measurement, the Indian plate moves 53-63 mm closer to Asia as Tibet moves 34-39 mm to the same direction each year which means that the Kingdom o f Nepal is rowed by 19-24 mm every year. Steady movement of the Indian plate towards Tibet over periods of centuries is accommodated by sudden slip events (great earthquakes) on a gently north-sloping surface beneath the Himalaya. Besides this, Kathmandu Valley ,as its many parts were once lakes, contents the soil , the quality of which is prone to liquefaction.

History of Past Earthquake in Kathmandu Valley

In Nepal during this century over 11000 people have lost their lives in major earthquakes. The most destructive was Bihar/ Nepal earthquake in 1934. Three earthquakes of similar size occurred in Katmandu Valley in the 19th century: in 1810, 1833 and 1866. The seismic records of the region, which extends back to 1680, 1407,1259 and 1253, suggest that earthquakes of this size occur approximately every 75 years, indicating that a devastating earthquake in inevitable in the long term and likely to take place in the near future.

Present situation of Kathmandu Valley

Today, the situation of the valley is quite different from that it was before 1934 when the latest devastating earthquake occurred. The city and townscape of Kathmandu Valley is chaotic and city planning does not seem to exist. The Valley is becoming increasingly vulnerable to earthquakes because of uncontrolled construction of the buildings in the core part of the valley and the general lack of awareness on earthquake safety and preparedness. A destructive earthquake if unfortunately occurred today in the Kathmandu Valley may cause innumerable loss of lives and properties demolishing all the social, political and economic development of the entire country. Since 1934, the population of the Kathmandu Valley has increased by five times and its risk from earthquakes has increased even faster than its population. In 1934, residents had gathered in open spaces after the earthquake but today, most of such spaces have been occupied by buildings(which are prone to destruction even due to low strength earthquake). In 1934, most homes were a maximum of two stories. Today, homes are routinely built by untrained masons up to heights of five and six stories, making them much more vulnerable to earthquakes.

THE RESIDENTIAL HOUSES OF KATHMANDU VALLEY AND THEIR RESPONSE DURING EARTHQUAKE :

The existing residential houses can be divided into two groups. One group is traditional houses and the other is modern houses

Traditional houses

The typical traditional Newari house of Kathmandu is usually three or four stories high. It has a simple rectangular plan with depth about 6 m and length varying from 3 to 10 meters. The foundation is usually shallow, made out of stones. The superstructure is constructed with locally available sun-dried bricks and mud-mortar. Three walls, two outside walls and one spine wall at the center, support the whole structure. Timber joists over which wooden boards with a thick layer of mud topping is applied support the floors and roof. The roof is doubly pitched and has brick tile roofing.

Modern houses

The structure of modern houses consists of reinforced concrete frame infilled with masonry. Houses are usually 2 to 4 story houses high and have irregular plan with several terraces and different types of cantilevers. Roof is gently slopping with tile or sheet metal roofing or flat with a terrace. Walls are either face-bricked or covered with plaster and painted with pastel colors. Houses have lot of detailing for example in stair, columns, and railings. One typical feature of Kathmandu houses is that on upper floors the intermediate floor slab continues trough the outer wall. This cantilever is used for decorative and sometimes storage purposes.

Reasons for a sever hazard due to the construction houses of Kathmandu valley during the earthquake

(2) Soil and foundations

Both traditional and modern houses have shallow and considering the type of soil in Kathmandu Valley insufficient foundations. Most common solution is the use of separate pad foundations made out of reinforced concrete. Single pad foundations are usually tied together only above ground level. The depth of foundations varies from 1 to 3 meters. Since the soil is alluvial, prone to liquefaction, and tends to amplify earthquake forces, properly designed bearing pile foundations could be the best solution.

2. Shape

Traditional Houses: Most of the traditional houses are simple and symmetric in plan and have uniform distribution of mass and stiffness. Also the openings have been symmetrically arranged the centerline of the structure. This may result to avoiding torsion effects while center of mass and the center of rigidity coincide. However, traditional houses can be slender and thus vulnerable to damage, In urban Kathmandu houses are joined together to form blocks. Hence during severe earthquake, when all houses shake according to their own natural period of vibration, hammering action between adjoining houses can take place.

Modern Houses: Modern houses in Kathmandu Valley are nearly always irregular both horizontally and vertically. Because of terraces they often have vertical setbacks, which causes changes of strength and stiffness in structure, Because of the high cost of building sites in Kathmandu some residential buildings areas also very slender in plan . All this will cause severe problems during an earthquakes.

(3) Materials

Traditional Houses: Masonry is possibly the worst choice for a building material in earthquake prone areas. It is heavy and its tensile strength is very small. Walls of old unreinforced masonry buildings are not properly connected to the floors, roof and transverse walls (interior and exterior). It constitute a threat because the walls start to fall as soon as the building vibrates when subjected to even moderate ground shaking. Sun-dried bricks used for walls in traditional houses are brittle in nature and can not take tensile stresses incurred during earthquakes, thus resulting in large cracks or collapsing of walls. Also the quality of mortar is poor.

The heavy loom roof and flooring used in traditional structure adds only dead weight, without having any kind of seismic-resistant function. The bigger the reactive masses of the building, the bigger the earthquake forces, Traditional houses have some wood-reinforcement which can improve houses performance during an earthquake but in case of a major, considering the age of these structures. It is highly probable that most of these houses will be destroyed.

Modern Houses : The modern houses of Kathmandu Valley consist of steel reinforced concrete with masonry infilling. When large panels of unreinforced masonry are used as veneer or infilling in reinforced concrete buildings, they also constituted a severe hazard because large portions of this panel can easily be dislodged from the frame to the building. Concrete is also relatively heavy material and thus not the optimal solution. Reinforced concrete frame improves house performance during earthquake depending on the amounts and quality of steel used. Pure concrete is expensive in Kathmandu, so different kind of extra aggregates for example stones and bricks are added. This certainly reduces structure capacity to induce earthquakes.

(4) Structure

Traditional Houses: The supporting structure consists of three bearing masonry walls. Walls can be as thick as 60 cm in the level of ground floor. Horizontal wooden ring beams have been applied to walls at every floor to tie together the structure and to distribute the load uniformly. It also supports the floor or roof form collapsing if part of the masonry wall is destroyed. In practice the ring beams are usually discontinuous and possibly decayed over years. There is no vertical wooden support. The floor joists are connected to ring beams with a special systems of " chokus". Timber wedges that allows movement. However due to poor flexural strength of masonry the structure cannot tolerate larger motions. Generally during strong earthquake, sloping roof tend to slide off the wall thus shearing the wall element also in the process. In many traditional houses roof is held relatively tightly to wall by use of wedges and tie members. However roof is heavy and can create problems. Openings are usually carefully placed, all windows are relatively far from corners. Additionally, traditional houses have two complete frames of timber tied to each other around the openings to strengthen them against lateral forces. This can help during minor earthquakes. The main problem is the use of poorly constructed masonry. Simply upgrading the quality of bricks mortar and workmanship would be a major step forward. It is also possible to increase masonry walls strength and ductility by embedment of steel rods or by use of special mechanically interlocks bricks.

Modern houses: It is possible to create earthquake resistant reinforced concrete from structures. However professional does not design the typical modern residential house of Kathmandu. Structures are often too light; columns, beams and slabs can be very slender because of the high cost of sufficient materials. Highly irregular plan causes torsion effect, which is not improved by the poor quality materials and workmanship, used. One problem with the structure is the use of nonstructural masonry infilling between bearing reinforced concrete columns and slab. Steel reinforcement increases concrete structures flexibility but at the same time masonry is very rigid and has no ductility. During an earthquake, the motion of prime structured can make masonry infills literally explode. A small amount of wall in the wrong place can also drastically redistributed the loads and changes the structure's performance. Infill walls either should be figured into the structural concept of detached in such a way that structural distortion will no cause the wall to become stressed. The other problem is irregularity of elevation. Vertical setbacks create problems because of discontinuity, the abrupt change of strength and stiffness. If the building is asymmetrical both in plan and elevation, as it usually is in Kathmandu, very complex and unpredictable torsion forces will be introduced. At least the structural framing of vertical setbacks should include continuous columns but this may not often be the case.

(5) Workmanship and maintenance

Professionals are not generally used for designing residential housing. Architects and engineers are considered expensive. And in fact if the house is designed to be earthquake resistant the cost of structural elements will increase by 20-25 %, Most architectural offices have their own engineering section the creating of overall and structural designs are separated.

Construction of the houses is performed entirely by handed. The labour force is usually not skilled and the quality of equipment is poor. Concrete is mixed on site and is often not treated properly during healing. Because wood and plywood are very expensive the mould for intermediate floors is often made out of metal sheets and held up by sticks of bamboo. Many houses are constructed without proper working drawings. The quality of work is not precise; a common trend seems to be to cover the mistakes up afterwards with plaster.

Since concrete is expensive, all kinds of extra aggregates are used. The quality of building materials is poor; it is of common knowledge that the material failing quality requirements of India is sold advantageously to Nepal. Also steel is very expensive, which leads to minimizing the reinforcements.

Many older residential houses seem to be close to collapsing. The climate with heavy monsoon rains places several demands on material. During monsoon, all surfaces will soon be covered with moss and steel turns rusty. Maintenance seem to be more appreciated in urban areas, whereas is some cases no measures are taken until the building finally falls down.

SOME OF THE EARTHQUAKE RESISTANT MEASURES FOUND IN TRADITIONAL BUILDIGS ARE:

(1) Symmetry:

For earthquake resistant design, it is important that center of mass and center of rigidity of building is nearly coincident (center of rigidity is defined as geometric center of stiffness of various elements of building). If it is not so, the distance between center of mass and center of rigidity will cause torsion in the building.

However this torsion problem is well taken care of in many traditional houses of Kathmandu by having same size of opening in opposite wall that is the openings have been symmetrically arranged around the centerline of the structure, thus making the rigidity of opposite walls the same. This causes no excessive torsion because the center of mass and center of rigidity coincides in traditional building.

(6) Double Framing of Openings:

Great care has been taken in design of openings since jambs of openings are the critical section of a wall panel during earthquake. Traditional houses have two complete frames of timber (tied to each other) around the openings to strengthen it against lateral force. Also location of openings have been carefully controlled keeping all windows at least 3 feet away from corners so as not to weaken them.

(7) Monolithic Charter of The Structure Using Horizontal Ring Beam:

Emphasis has been given for monolithic character of structure so that earthquake force is resisted by the building as complete unit rather than by individual parts. Horizontal ring beams have been used in the walls at every floor to tie the whole structure, and also to distribute the load uniformly to all parts of the building.

For example, when the earthquake force is operating in the direction parallel to central wall. The center wall also with two exterior walls acts as shear wall and take up the earthquake force. The ring beam on top of these walls will distribute the stresses uniformly to the whole building. When the earthquake force is acting in the direction perpendicular to the central wall, the timber joists at every floor will transfer the load to the central wall and two other external walls.

The ring beam on all the walls have got another function also to support individual floor joist in case of local failure of the bearing walls. Without the ring beams, if there is a collapse of a part of the wall, the chances of collapsing of the floor joist resting over the wall at the same time is also high.

(8) **Roof Held Tightly to The Wall**

Generally during strong earthquakes, sloping roof tend to slide off the wall thus shearing the wall element also in the process. However in many traditional Newari houses, roof is held tightly to wall be extensive use of wedges and tie members.

(5) Use of "Chokus" or Wedges

One remarkable feature of the traditional houses of Kathmandu is the system of "Chokus"- that is the timber wedges used to secure various joists in timber member. Generally , floor joists are held tightly to wall by putting wedges on both sides of the wall rather than inserting inside it. This way, the joint becomes a pinned joint rather than a rigid joint, because if one blows up the joint between wedges and wall there will still be a tolerance between the wall and wedge. Due to this gap between wedge and wall, load transfer from one wall to another will not be complete until the floor joists moves through this tolerance (or gap) during earthquake.

In this process of moving the floor joist by the tolerance distance, some energy will be absorbed by the floor joist which is equal to the work done in moving the joist- that is seismic force x tolerance distance.

Thus this mechanism of wedges serves a dual purpose of providing structural integrity between floor joists and wall, and at the same time absorbing some portion of earthquake energy thus reducing the earthquake effect on the building.

The jointing system in wooden wedges have certain advantages over that with nut and bolts. They are

1. The wooden wedges do not rust like nuts and bolts in course of time;
2. Wooden wedges have the same coefficient of expansion as the wooden joists to which it is fixed , whereas iron bolts have different coefficient of expansion with respect to wooden joist. Hence during temperature changes, wedges fare better than iron bolts;
3. Wedges, unlike rigid joints in nuts and bolts are ductile in property, and have slight flexibility of movement, which is desirable for earthquake resistance

STUDY FROM 1934 EARTHQUAKE RECORDS:

Images (Figures 1-5)

List of major monuments which were least effected in 1934 Earthquake:

1. Akash Bhairav , (Indrachowk, Kathmandu)
2. Nyetamari Ajima, (Naradevi, Kathmandu)
3. Nyatapole Temple , (Bhaktapur)
4. Bidhyadhreshwori (Mahabaudha Temple, Lalitpur)
5. Krishna Mandir, (Patan Durbar Square, Lalitpur)
6. Taleju Kathmandu (Kathmandu Durbar Square, Kathmandu)
7. Pashupatinath Temple (Kathmandu)
8. Mahankal Sthan (Kantipath, Kathmandu)
9. Swayambhu (Kathmandu)
10. Baudha (Kathmandu)
11. Lagan Bahal (Kathmandu)
12. Gauri Shanker Temple (Patan Durbar Square, Lalitpur)
13. Bhimsen Temple (Patan Durbar Square, Lalitpur)
14. A building adjacent to 55 Windows Palace (Bhaktapur Dubar Square,Bhaktapur)
15. Dilli Bazzar Adda , Kathmandu

Least Effected Region in Kathmandu Valley in 1934 Earthquake:

1. Kirtipur
2. Gokarna
3. Sundarijal
4. Gaucharan

Most Effected Region in Kathmandu Valley in 1934 Earthquake:

1. Lubhu
2. Harisiddi
3. Khokana
4. Bungamati

Type of Least effected houses in 1934 Earthquake:

1. Houses with few stories
2. Houses with few widows and large gap between them
3. Houses in which more wedges called "chokus" in local language were used between joists and walls to interlock with each other

4. Houses properly connected with each other by interlocking the bricks and wooden beams.It makes no hammer action between two buildings during the earthquake
5. Houses with walls in which two bricks of adjacent layer are perpendicular to each other
6. Houses with light parts on the upper stories
7. Houses made by using good quality lime mortar
8. Houses with more width but low height
9. Houses with more width foundation in good land
10. Houses with later added long rooms with propertion
11. Houses with low height at corners than that at middle.
12. Houses with more wooden pillars than brick pillars

THE CAMPAIGN STARTED BY NEPAL HERITAGE SOCIETY:

Nepal Heritage Society has launched a campaign to get the updated data on the residents of the valley and the managers of historic buildings & monuments. The title of the campaign is " Preparedness, Response and Recovery Strategy of Heritage and Cultural Sites in Kathmandu Valley ". One program of the campaign is case study of vulnerable building and monuments of the valley. The objective of the program is to form a team of young volunteers, mostly with media background to prepare case studies for various vulnerable heritage and cultural sites including traditional buildings in Kathmandu Valley. Most of the volunteers have been involving to list out the traditional houses and temples which were least effected by 1934 Earthquake. They are getting the lists by inquiring with old peoples of age more than 75 year. The cause of least effected are being studied in detail by architects students. The output of the program is then used to compare traditional construction with modern construction and will be followed by the modern construction.

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