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Case Study on Aseismic Traditional Architecture

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Abstract

Earthquakes are caused by rupture of rock zones called faults. The earth's surface consists of tectonic plates which move relative to one another building strain energy along the plate boundaries. When this energy exceeds the capacity of the rock materials along the fault surface, the fault ruptures with seismic waves transmitted through hard bedrock layers. When an earthquake occurs, seismic waves radiate away from the source and travel rapidly through the earth's crust. When these waves reach the ground surface, they produce shaking that may last from seconds to minutes. The strength and duration of shaking at a particular site depends on the size and location of the earthquake and on the characteristics of the site. Traditional techniques of house building have proven in past earthquakes their ability to withstand these seismic waves. During the 1905 Kangra earthquake, the traditional Kat-Ki Kunni houses in Kullu valley made up of timber remained unaffected. The Dhajji-Diwari buildings remained intact in the 1885 Srinagar earthquake. In Uttarkashi the traditional 100 years old multistoried buildings called Pherols have incorporated basic features of earthquake resistance. This paper focuses on the study of these traditional buildings ability to resist earthquakes.
Keywords: Convex Geometry, Concave Geometry, Dhajji-Diwari, Kat-Ki Kunni, Pherols, Stiffness, Strength, Ductility

I. INTRODUCTION

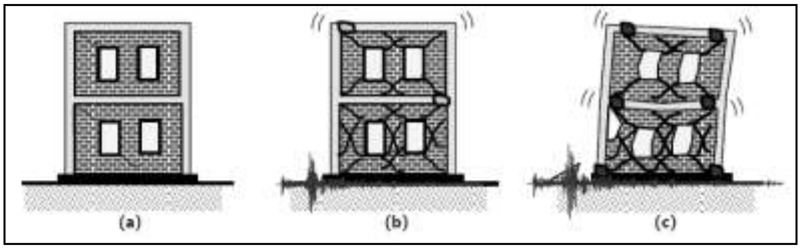
A disaster can be natural or human induced event, results in widespread human loss, livelihood and property, causing suffering and loss in a definite area. Disruption in the normal functioning of the society affecting a large number of people, large scale loss to life, property and livelihood and a big blow to the country's economy are the main features of the disaster.

Earthquake can be defined as the shaking of earth caused by seismic waves moving on and below the earth's surface and causing: surface faulting, tremors vibration, liquefaction, landslides, aftershocks and/or tsunamis. Earthquakes are one of the nature's greatest hazards on our planet which have taken heavy toll on human life and property since ancient times. The sudden and unexpected nature of the earthquake event makes it even worse on psychological level and shakes the moral of the people. Mitigation and preparedness for earthquakes becomes very important factor several steps must be taken to save human lives and reduce property loss. However as we know 'Earthquake don't kill people it's the building do', the failure of buildings depend on the structural design, building material used etc. People in ancient times have build structures that are much safer than our today's highly engineered structures. They had proven their ability to withstand the earthquake in past and still they are standing on grounds. We can learn from these structures and from our past experienced earthquakes, in developing new safer structures. It is also true that no structure can be 100% safer to earthquake but we can mitigate the disasters.

II. BASIC DESIGN ASPECTS OF SEISMIC DESIGN

The design of a building depends on the mass of it. The mass of building controls it behavior during earthquake, also mass controls stiffness of the building, because earthquake induces inertia forces that are proportional to the building mass. Designing buildings to behave elastically during earthquakes without damage is economically not feasible so some deformations is allow and dissipate the energy input during earthquake. The earthquake-resistant design philosophy requires that normal buildings should be able to resist -

1) Minor (and frequent) shaking with no damage to structural and non-structural elements;
2) Moderate shaking with minor damage to structural elements, and some damage to non-structural elements; and
3) Severe (and infrequent) shaking with damage to structural elements, but with NO collapse (to save life and property inside/ adjoining the building)

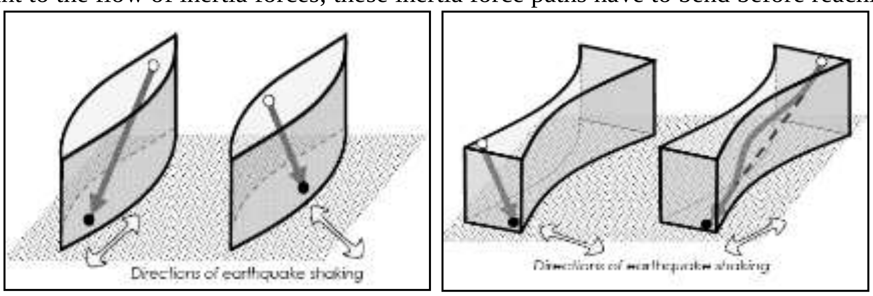


The buildings are only designed for the 8 – 14% fraction of the force they experienced. If they were designed to remain elastic during the expected strong ground shaking, and thereby permitting damage. But sufficient initial stiffness is required to be ensured to avoid structural damage under minor shaking. Thus, seismic design balances reduced cost and acceptable damage, to make the project viable. Structural damage is not acceptable under design wind forces. Design against earthquake effects is called as earthquake-resistant design.

There are mainly four aspects of earthquake resistant building design that are widely used by the architects and engineers. This includes seismic structural configuration, lateral stiffness, lateral strength and ductility.

A. *Seismic structural configuration*

Seismic structural configuration deals with the three main key aspects (a) geometry, shape and size of the building, (b) location and size of structural elements, and (c) location and size of significant non-structural elements. Building architectural geometry includes to specific terms Concave and Convex geometries. Convex geometries are preferred over Concave geometry because of its superior earthquake resistant performance. Buildings having convex geometry have direct load paths for transferring earthquake shaking induced inertia forces to their bases for any direction of ground shaking, while in case of concave building geometry necessitate bending of load paths for shaking of the ground along certain directions that result in stress concentrations at all points where the load paths bend. Further from this study, buildings are classified into simple and complex structure. Simple structure includes rectangular plans and straight elevation whereas complex includes the buildings with setbacks and central opening which offer geometric constraint to the flow of inertia forces; these inertia force paths have to bend before reaching the ground.



(i) (ii)

Fig. 1: (i) Convex Geometry, (ii) Concave Geometry

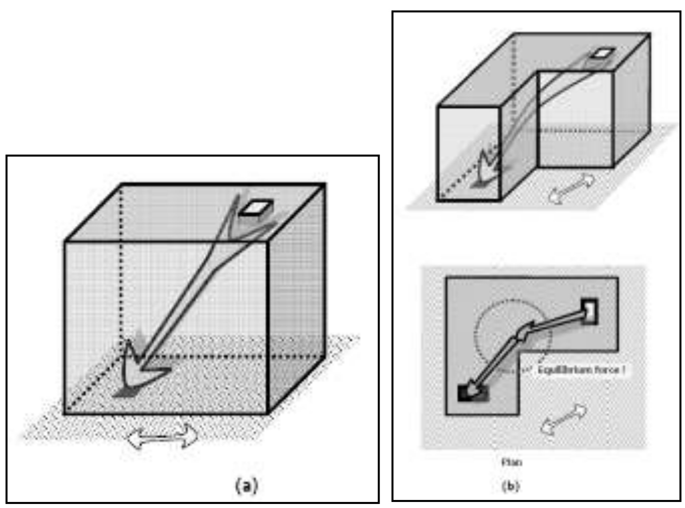


Fig. 2: Classification of buildings (a) Simple, (b) Complex

B. *Structural Stiffness, Strength and Ductility*

The three properties of a building are shown below with the help of figure, through the lateral load -lateral deformation curve of the building. Lateral stiffness refers to the initial stiffness of the building, even though stiffness of the building reduces with increasing damage. Lateral strength refers to the maximum resistance that the building offers during its entire history of resistance to relative deformation. Ductility towards lateral deformation refers the ratio of the maximum deformation and the idealized yield deformation. The maximum deformation corresponds to the maximum deformation sustained by it, if the load-deformation curve does not drop, and to 85% of the ultimate load on the dropping side of the load-deformation response curve after the peak strength or the lateral strength is reached, if the load-deformation curve does drop after reaching peak strength.

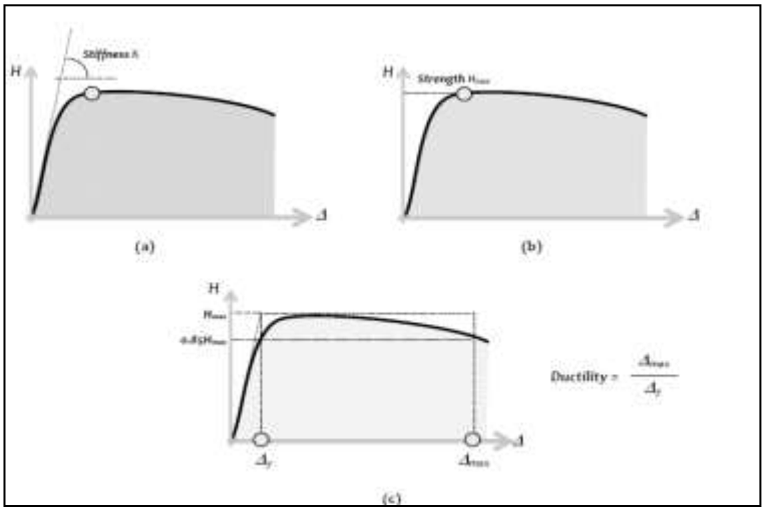


Fig. 3: Structural Characteristics: Overall load deformation curves of a building, indicating (a) lateral stiffness, (b) lateral strength, and (c) ductility towards lateral deformation

III. SOME ASEISMIC TRADITIONAL ARCHITECTURE

A. *Kat-Ki Kunni*

In central Himachal Pradesh in the Kullu and Mandi districts, and parts of Shimla and Solan districts traditional architecture named 'Kat-Ki Kunni' can be seen normally. Kat-Ki Kunni literally means 'timber cornered'. These architectures are massive and very old several are of 100 years old like Palaces, Temples etc. After the 1905 Kangra earthquake these structures came into the notice of officers from Geological Survey of India, that these structures shows the lack of damage to buildings from earthquake.

The architecture of these structures is similar to the Pherols of the Uttarkashi. These buildings can be easily noticed due to their top heavy appearance which is especially accentuated by the external balconies on upper storey and the use of the upper stories as granaries. Timber is extensively used in these type of structures. A variety of structures fall within this architectural style – ranging from the ornate palace of the Maharaja of Kullu to the some of the massive towering temples of Mandi district, to simpler houses in old Manali.

The prominent aseismic features of this type of construction are as follows:

1) *Timber- Tie band*

A pair of parallel wooden beams traverse the entire length of the walls at regular intervals. The pairs of wooden beams alternate in direction; the alternating pairs are placed perpendicular to each other (Figure 4). The space between the beams in the pair is usually filled with dry stone masonry, although there are variations depending upon locally available materials. These also serve to course the stone masonry in the walls. These beams act as tie bands and connect the superstructure, helping the building resist tension and lateral forces.

Fig. 4: Corner construction detail of Kath-Ki-Kuni style housing.(The timber bands run along both sides of the wall and are connected by pins along their length and at the corners)

2) *Interconnection & Corner Reinforcement*

The pair of timber beams are interconnected at regular intervals along the length of the wall with wooden pegs, and at the corners, the perpendicular pairs of beams are interconnected vertically at four points at the corners (Figure 5). This provides vertical as well as lateral tying of the structural elements in the building. This helps in the strengthening of corners and distributing the load vertically, and also in preventing the wall from splitting under high compressive force.

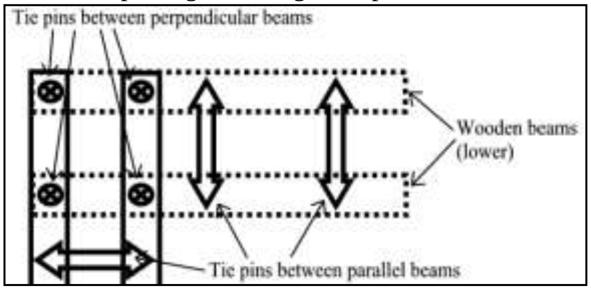


Fig. 5: Overhead view of Kat-Ki-Kuni walls.(Schematic representation of the interconnection between parallel and perpendicular wooden beams)

3) Well-dressed stone masonry

Although the composition of the walls varies by location, usually they are composed of dry stone masonry, and the stones used are long and flat stones, which are well laid in order to evenly distribute compressive strain vertically and prevent outward movement of stones in the wall (Figure 6). Many of the older kath-ki-kuni buildings have massive, almost monolithic stone blocks which have been well dressed. The massive construction stands testament to the technological capacity of the indigenous masons. The walls range in thickness from 40 cm. to over 100cm. in some cases, and the thickness of the walls give much-needed insulation from the cold and also distribute compression in these load-bearing structures.

Fig. 6: Detail of Dressed stone in Kath-Ki-Kuni structure. (The use of long, flat stone distributes the compressive loads evenly)

4) Small Openings & Low Storeys

Doors and windows are kept small and have heavy wooden reinforced frames, which help bear the accumulated stress on the openings during an earthquake (Figure 7). The placement of openings is also staggered so as to avoid vertical alignment of the openings, which would weaken the wall. The frames and doors have diagonal bracing elements also, which are exquisitely carved. The heights of storeys are also kept low, which keeps the centre of gravity low.

Fig. 7: Small reinforced openings are key features of Kat-Ki-Kuni.(This beautifully hand-crafted door in the maharaja of Kullu's palace has elements hewn from solid blocks of wood.)

5) Stable Geometry

The floor plans of Kath-Ki-Kunni houses reveal that structures are very nearly square, and the ratio of the sides usually lies within a 3:2 ratio. This reduces excessive strain on longer walls, and maintains a shear centre close to the centre of gravity. Taller structures have wide bases and a tapering construction, to reduce overturning moments. Thus even massive structures like the temples of Jungi village in Mandi district (Figure 8) are very stable.

Fig. 8: Shiva Temple in Jungi village, Mandi District, H.P.(According to locals this massive 50 foot tall temple is 200 years old.)

6) Roofs:

The roof frames in Kath-Ki-Kunni houses are most commonly made of bamboo, which is generally available in this region. In some areas, the construction is of wood, or of both materials. Bamboo is an excellent material for roof frames, since it is flexible and has high tensile strength, which are essential qualities to negotiate the compression and tension of vibrations in the roof during earthquakes. The roof tiles in Kath-Ki-Kunni architecture are thick slabs of slate, which are very heavy, and a very sturdy roof frame is needed to support the weight of the roof.

The above are the aseismic qualities of the Kat-Ki Kunni. Materials used in the construction like stone, slate, wood, mud and bamboo reflected primary use of local resources, and an intimate knowledge of the qualities. Apart from this type of construction shows great adaptation to traditional livelihoods, environmental conditions and cultural norms.

B. Dhajji-Diwari

In Himachal Pradesh, this type of architecture is found in different regions, and shows a great deal of variability in form and application. Dhajji Diwari is a traditional architecture found both in India and Pakistan administered Kashmir. Similar forms of construction are found in Britain, France, Germany, Central America, South America, Turkey, Greece, Portugal and Italy and most likely other Eastern European countries. Dhajji uses wooden braced diagonals of timber the spaces left in the braces or frames are filled with the stone making a thin wall and usually plaster with the mud mortar. The Dhajji is usually build on shallow foundation of stones and the structure is only 1-4 storeys tall and the roof may be a flat timber and mud roof, or a pitched roof with timber/metal sheeting. After the 8th October 2005 earthquake, this construction type has been adopted by many people for reconstructing their houses as they have seen how Dhajji houses have performed better than many other building types, including rubble stone construction that often had been used by those same owners prior to the earthquake. Dhajji was also in priority because of availabilty of materials, speed and cost effective. Over 100,000 houses constructed using this construction method in Kashmir.
Design features of Dhajji-Diwari includes –

1) Diagonal Bracing

The use of wooden diagonal timber bracing provides high resistance to the shear force, which causes great damage to longer walls and corners of opening. Diagonal bracing provides triangular stability to the walls, which means that deforming forces of compression, tension and shear are distributed and dissipated by the frame. At the intersection of the bracing, triangular blocks of wood are used to stabilize the brace and iron pins are used to tie these elements, and add further tensile strength.

2) Light Structure

The roofs are made of corrugated iron sheets, or wooden frames with tiles, which reduces the mass of the structure and lowers the centre of gravity. The walls are also generally thinner, since they do not have to bear the weight of a heavy roof (Figure 9).

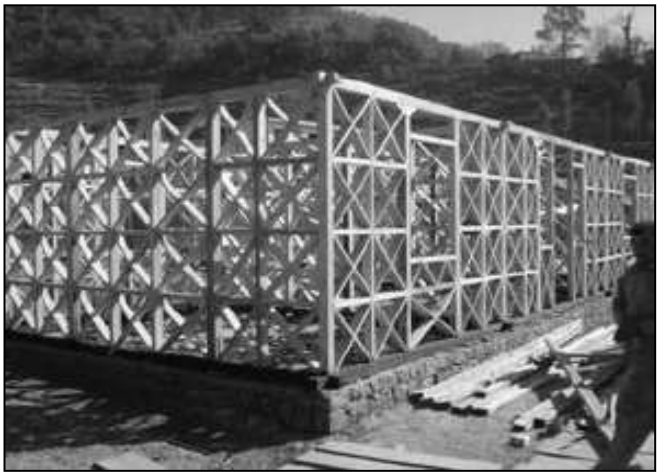


Fig. 9: Dhajji frame under construction

3) Plan Shape

The typical plan length and width ranges from 10 meter to 20 meter and 5 meter to 20 meter. The length and width ratios are in the order or 2:1 or 3:1. High-rise multi-storey Dhajji is usually approximately square in plan and is typically three bays wide in each direction. For construction on sloping terrain, these buildings are sat usually on manmade narrow terraces, which impose the adoption of a rectangular building plan layout for the building.

4) Gravity load bearing and lateral resisting system

Infills are adopted in the bracing system in building the building frame. The infill fulfils functional (enclosure and partitioning) and structural requirements.

(a). Because of the low infill panel strength and high flexibility of the timber frame, due to the generally loose timber connection, the in-plane wall panels crack in the very early stages of ground shaking. This softens the frame and has the effect of immediately decoupling the Dhajji buildings period of vibration from the likely predominant period range of an earthquake. This results in reduced inertial forces being imposed on the building. It is thought that the first phase of earthquake response is movement along the masonry-timber interfaces, before the masonry itself is stressed enough to begin to crack. In other words it is thought that there is much friction along these construction joints even before cracking of the masonry starts. (b).The cracking and sliding of masonry units along mortar joints increases the hysteretic damping levels in the building thereby reducing the earthquake loads. (c).During long duration earthquakes a few isolated infill panels may topple without jeopardizing the stability of the building as the timber frame essentially remains elastic and maintains a vertical load path and lateral stability to the building structure. (d). The closely spaced timber framing and bracing mitigates out-of-plane toppling of the infill walls by providing support point from which the masonry panels can retain their stability through arching action which ensures that the friction force is greater than the inertia force that wants to dislodge the infill pieces from the walls. It is important that long walls are regularly connected to perpendicular walls to avoid a global out-of-place failure of wall panels. Some infill failures do occur when the infill is poorly compacted because the masonry units are unable to develop proper arching action between the timber boundaries. Equally failures also seem to occur due to geometry such as inverted triangles with the long side at the top of a wall.

Fig. 10: Construction of Dhajji wall with stone and mud mortar inside diagonal bracing

5) Wall openings

In this type of buildings openings are well distributed. Openings are in the range of 20% to 30% of the gross external wall area. If the building constructed on the sloping, the uphill long side and the short side are usually solid wall with all the openings being concentrated on the downhill side of building and openings can make up to 50% of the total wall area. The arrangement gives an unsymmetrical provision of the walls resulting in an increased torsional response of the building under earthquake excitation. The structural walls are evenly distributed internally of the building to ensure even lateral resistance to the seismic loads.

C. *Pherols*

Pherols of Uttarkashi are similar to the Kat-Ki-Kunni structures in Himachal Pradesh. Pherols are strong especially in the use of heavy slate roofs, thick walls, wooden tie-bands, and corner bracings, multistoried construction, geometry and functions of different proportions of building. Since these are similar to Kat-Ki-Kunni structures these also resembles the traditional construction techniques, social conditions and cultural conditions of the region and the locally available building materials.

IV. CONCLUSION

After studying, the different aseismic traditional architectures following are the key points that summarizes the case study. The points are as follows -

1) Kat-Ki-Kunni traditional building construction combines the solidity and durability of stone with the flexibility and earthquake resistance of wood. Energy induced by seismic forces is largely dissipated to the wooden joints which allows the structure slight displacements. In this construction technology wooden bands tie the stone masonry at the regular intervals reinforcing the corners which are most fragile section of the building respect to the seismic forces. In addition, the pivoted joints at the corner allows the adjustments which helps in the tensile stresses.
2) Dhajji-Diwari shows the result that this structure can resist the high seismic waves in any part of the world if it is constructed properly. Seismic energy dissipated through friction between masonry panels and timber frame and within the yielding of the connections. From material point of view the materials used in this construction of traditional housing technique is easily locally available and economically feasible.
3) Pherols are similar to the Kat-Ki-Kunni building housings and can easily identify due to its heavy slate roofs, thick walls, multi-storied construction. They resemble the seismic resistant properties with these all-traditional architectures mentioned above. Pherols are also constructed by the stones and mud mortar with locally available timber. All the above-mentioned traditional architecture with pherols addition with seismic resistant properties holds social and cultural significance in Himachal Pradesh region.

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