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Sustainability and Seismic Adequacy of Traditional Architecture of Kashmir, J&K, India

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Abstract—*Nestled in the Himalaya Mountains, Kashmir has hosted historically divergent cultures with special touch to architecture and engineering. Kashmir valley lies atop a web of active geological faults which paves way for seismic complexities above ground. Most of the areas of Kashmir valley fall in seismic zone IV or V. On October 8, 2005, a massive earthquake of 7.6 magnitude struck Kashmir valley. The damage was huge resulting into 75000 deaths and destruction of millions of homes. But fortunately it was observed that the structures constructed using traditional kashmiri architecture of "Dhajji – Diwari - (timber frame with masonry infill)" and "Taq system - (timber-laced masonry)" suffered very less or almost no damage. This construction practice is generated from use of local materials (bricks, mud and stones) , abundantly available blue-pine coupled together to built these Timber framed house with masonry which satisfactorily suit the local extreme climate, soil type, distinct natural environment and culture and most importantly the high seismic risk of the area. This paper will emphasize on seismic advantage of Taq and Dhajji – diwari system of construction. This study will also consider the social sustainability of traditional kashmiri architecture in terms of economic method of construction thus paving way for – Housing for All.*

Keywords: *Kashmiri architecture, Dhajji – diwari, Taq system, Seismic resistance.*

1. INTRODUCTION

Earthquakes are the most destructive natural calamities which lead to a huge loss of life, property and economy. On 8 October, 2005, a magnitude 7.6 on righter scale earthquake took place the Kashmir valley (A Himalayan disputed region administered in parts by India and Pakistan), also the other areas affected were parts of India, Afghanistan and Pakistan. The Kashmir earthquake took place at 9:25 am (IST) and was Kashmir valley is situated at the fault line of the Indian and Eurasian tectonic plates—the convergence of this Eurasian plate Indian plate caused the creation of the Great Himalayan Mountains— which makes the region prone to hazardous seismic earthquakes. The October 2005 quake was among one of the worst earthquakes to ever hit the area. It resulted in widespread destruction throughout the Kashmir regions, part of India-Ruled Kashmir; Pakistan-administered Kashmir; Pakistan's North-West Frontier Province; and northern areas of Pakistan. Damage to some extent was also reported from Afghanistan and north parts of India. House forms that are of a different kind. A traditional way of life and building construction type is a result of this isolation and hence maximizes the use of locally available resources. This research discusses and analyses the house construction in terms of the above mentioned way of life, but particularly in terms of available local materials and the distribution of these materials through developed construction techniques into a structural system that is flexible and has the potential for seismic resistance. Key construction techniques like the 'DHAJJI-DEWARI' and 'TAQ – System', will be analyzed in detail, while understanding its role within an overall construction system and as compared to the conventional more brittle masonry houses. Throughout Kashmir, traditionally used timber framed brick masonry construction consists timber framework with burnt-clay brick infill which generate a patch-work of masonry, this masonry is held within by small timber panels which can be framed in different configurations. The outcome from this composite combination results in the formation of a new form of patchwork masonry, which has proved to be way more superior and efficient in resisting earthquake forces than conventional brick masonry. In taq system of construction there is a bearing wall construction with horizontal timber lasing embedded into masonary. In taq system of construction horizontal timbers are embedded in the masonary walls at each floor level and window lintel level. *Taq* construction is a bearing wall masonry construction with horizontal timber lacing embedded into the masonry to keep it from spreading and cracking. In taq system , there is a construction of masonary piers of size 1-2 feet square and the window bay (taqshe) 3-4 feetin width. From this the size of the traditional kashmiri house can be depicted as of 3 taq (window bay) to 13 taq in width. . The masonry piers are thick enough to carry the vertical loads, and the bays may either contain a window, or a thinner masonry wall as required by the floor plan and the building's orientation. There was very less or no damage observed in such structures even during

Richter 7.6 magnitude earthquake on 08 October, 2005 hitting Kashmir Valley. Intensity October 2005 earthquake. This Dhajji-Dewari system of construction is believed to posses outstanding Earthquake resistant features.

2. DHAJJI – DIWARI SYSTEM OF CONSTRUCTION

The 'Dajji Dewar' is a much thinner and lighter form of wall construction it consists of timber framing with in fills of brick, (Fig 1, 2) and in a few cases stone masonry. In the case of the 'dajji dewar', walls will have greater ductility and damping. In addition to this the horizontal and vertical cage formed by the timber are braced diagonally against shear. This cross member is usually at the corner, but lends the entire framing a resistance against shear. The closely placed timber studs prevents propagation of shear cracks. This framing also results in breaking up the upper level masonry walls into smaller multiple panels, each of which are independent. The collapse of any one panel will not result in the complete collapse of the wall, and therefore the structure. Small masonry panels surrounded by timber elements have greater safety against out of plane collapse. Dhajji-dewari frames are usually "platform" frames, meaning that each storey is framed separately on the one below.

In dhajji-dewari, the floor joists are sandwiched between the plates. This framing distinguishes it from heavy timber frame construction which depends for its strength and stiffness on the posts which extend through more than one storey. In the first generation of sawn 2" x 4" (5 cm x 10 cm) stud "balloon frame" construction in the USA, the studs were extended through two storeys, and the floor joists rested on a timber that was framed into the studs, but this evolved into platform framing in the early 20th century, which is easier to build. Lacking continuity in its vertical timbers, platform frame construction depends for its stiffness on its enclosure membrane. In North American wood frame construction, this was first provided by diagonal sheathing, and now by plywood; in dhajji construction, it is the infill masonry. While dhajji-dewari construction evolved probably for similar economic and cultural reasons that led to the development of similar forms of construction around the world, its continued common use up until the present in Srinagar and elsewhere in the Vale of Kashmir most likely has been in response to the soft soils, and perhaps also to its good performance in earthquakes. Dhajji-dewari construction is very effective in holding buildings together even when they are dramatically out of plumb. In the mountain areas, where soft soil sand related settlements of buildings are not a problem, its use continued probably because timber was available locally and the judicious use of timber reduced the amount of masonry work necessary, making for an economical way of building. Its observed good performance in past earthquakes may also have been a contributing factor, just as it is now again since the 2005 earthquake. The panel sizes and configuration of dhajji frames vary considerably, yet the earthquake resistance of the system is reasonably consistent unless the panel sizes are unusually large and lack overburden weight.

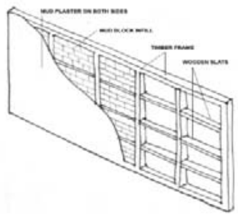

Fig. 1. The details of Dhajji – Diwari

Fig. 2. Dhajji – Diwari in a typical Kashmiri House.

3. TAQ SYTEM OF CONSTRUCTION

Tak, refers to load bearing masonry piers with infill walls. In many cases these are expressed by a different use of material. The piers may be made of stone and the infill walls of brick. Timber runners at each level tie the walls. The infill walls have timber embedded in them to increase their elasticity (Fig 3, 4).

In taq system of construction there is a bearing wall construction with horizontal timber lasing embedded into masonry. In taq system of construction horizontal timbers are embedded in the masonry walls at each floor level and window lintel level. *Taq* construction is a bearing wall masonry construction with horizontal timber lacing embedded into the masonry to keep it from spreading and cracking. In taq system , there is a construction of masonry piers of size 1-2 feet square and the window bay (taqshe) 3-4 feet in width. From this the size of the traditional kashmiri house can be depicted as of 3 taq (window bay) to 13 taq in width. . The masonry piers are thick enough to carry the vertical loads, and the bays may either contain a window, or a thinner masonry wall as required by the floor plan and the building's orientation.

Fig. 3: Details of Taq System.

Fig.4. Taq System of Construction

4. SUSTAINABILITY

The Kashmir house has developed with the use of local materials stone, and timber. These materials are readily available and can have been appropriated from the environment without excessive processing. Building is a community based activity. Families help each other build their houses. This community based organization of labor is prevalent today and was visible after the earthquake for the repair and reconstruction of the damaged houses. Community labor facilitates the transmission and refinement of skill and the technique of building. Through this there develops an indigenous understanding of the material and methods of putting them together. This understanding is holistic and is connected to all the other aspects of living in the particular environment. Thus built into this approach are the checks and balances that prevent the exploitation of the landscape beyond the needs of its inhabitants. Structure too develops to optimize resources, as they have multiple uses. What can be saved from building can be used elsewhere. The technologies that develop in this system are simple yet robust. They develop from the use of by-product so for the life–processes. Thus the mud and dung mortar is a developed product from animal husbandry. This product can also be used for manure. Agricultural waste is often used for insulation, but is most often used for fodder. Stone and mud is a product of shaping the ground, terracing, in order to cultivate it. One understands that the activity of building is deeply woven into the survival of the family and the community. At the heart of this community based system seems to be the doctrine of Reduce, Re-use, Recycle, which is also the slogan of our contemporary movements towards sustainability.

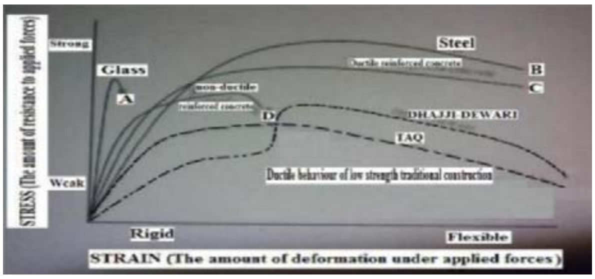

Fig.5. Stress vs Strain relation b/w different materials.

5. STRENGTH VERSUS CAPACITY GRAPHICAL COMPARISON OF TAQ AND DHAJJI DEWARI WITH HOMOGENEOUS AND COMPOSITE SECTIONS

Graph in Fig.5. shows the stress versus strain relationship of Taq and Dhajji-Dewari system of constructions with other homogeneous and composite sections.

In this graph curve a shows the behavior of glass. This curve rises steeply from the initial point, which means glass has less elasticity and ultimately breaks at breaking point. Curve B represents the behavior of steel structures. This curve does not rises steeply indicating steel is ductile in nature.

Curve C represents behavior of reinforced concrete. As reinforced concrete contains steel , so graph shows good amount of ductility. Curve D represents behavior of non ductile reinforced concrete (which lacks the volume and proper placement of steel reinforcement). Many buildings suffer enormous damage during earthquakes in spite containing ductile material this is because of wrong placement of steel and workmanship. Curve E and F shows behavior of Taq and Dhajji-Dewari systems of construction respectively. From these curves it's clear that initial elastic strength of these systems is much lower than that of reinforced concrete , but it's the inelastic behavior of these systems which becomes quite helpful for the survival of these systems in earthquakes because of the ability of these buildings to undergo large inelastic deformation without reaching the breaking point. In these systems of construction this post elastic strength is because of the presence of timber. This high post elastic strength of these systems helps them to release large strain energy during earthquakes without breaking apart. Unreinforced masonry (URM) has not been represented on this chart because such construction can vary in perfor-mance over such a wide range, from rubble stone in mud mortar which tends to collapse very quickly, to well dressed horizontally bedded ashlar which has demonstrated its ability to survive earthquakes, such as the 1999 earthquakes in Turkey where unreinforced masonry mosques with their stone minarets survived intact, while scores of modern reinforced concrete buildings collapsed around them. In general, though, URM lacks the ductile-like behaviour of *taq* and *dhajjidewari* because of the absence of the timber reinforcement.

6. THE EARTHQUAKE RESISTANCE OF TAQ CONSTRUCTION

Taq system of construction has been found to be quite effective in earthquake like conditions. Many observations have been made by different authors regarding seismic resistance of taq construction. According to professors Rai and Murty many of the older buildings were made of taq system of construction, in which large pieces of wood are used as horizontal runners embedded in the heavy masonry walls. These horizontal runners add lateral load resisting ability of the structure. As masonry is laced with timber, so destructive cracks are being arrested, thereby evenly distributes the deformation which adds to the energy dissipation capacity of this system, without destabilizing it's structural integrity and vertical load carrying capacity. In taq system of construction the timber runners tie the short wall to the long wall and also bind the pier and the infill to some extent. The greatest advantage gained from such assembly is that they impart ductility to an otherwise brittle structure. Once the ductility gets imparted into the structure it's energy absorbing capacity gets increased. This increase in energy absorbing capacity becomes the key for Taq system of construction to resist earthquakes. However, what makes the timber laced masonry work well in earthquake is it's ductile like behavior as a system. In taq system of construction energy dissipation during earthquake takes place because of friction between masonry and timbers and between the masonry units themselves. In taq system of construction it's to be understood that the mortar is not designed to hold the bricks together, but rather to hold them apart. It's the timbers that tie them all together. The benefits of energy dissipation are gained from the non destructive friction and cracking that can take place in a masonry wall that is surrounded and thus confined by the timber bands.

7. THE EARTHQUAKE RESISTANCE OF DHAJJI DEWARI CONSTRUCTION

Dhajji-Dewari system of construction too has been found very effective in earthquake like conditions. It has been found that Dhajji-Dewari system of construction occurs less or no damage during earthquakes. The presence of timber studs in Dhajji-Dewari construction, subdivides the infill, arrests the loss of the portion or all of several masonry panels and resists progressive destruction of the rest of the wall. Moreover, the closely spaced studs prevent propagation of diagonal shear cracks within any single panel, and reduce the possibility of out-of-plane failure of masonry of thin half-brick walls even in the higher storeys and the gable portion of the walls. Dhajji-dewari is timber frame construction rather than masonry bearing wall construction. Thus the vertical loads are transferred to the ground primarily, but not exclusively, through the frame. However, the masonry does form an integral part of the structural system, sharing the vertical load path with the timber frame. For the same reasons as explained above for taq construction, the mud or weak lime mortar encourages sliding along the bed joints instead of cracking through the bricks when the masonry panels deform. This sliding also serves to dissipate energy and reduce the incompatibility between rigid masonry panels and the flexible timber frame. The basic principle in this weak and flexible frame with masonry infill construction is that there are no strong and stiff elements to attract the full lateral force of the earthquake. The buildings thus survive the earthquake by not fully engaging with it. This working" during an earthquake can continue for a long period before the degradation. The engineering principle behind the earthquake performance of the dhajji walls is a simple one. The subdivision of the walls into many smaller panels with studs and horizontal members, combined with the use of low-strength mortar, prevents the formation of large cracks that can lead to the collapse of the entire infill wall, while the redundancy provided by the many interior and exterior walls that exist in a standard residential building reduces the likelihood of catastrophic failure of the frame.

8. CONCLUSIONS

The seismic performance of taq and dhajji buildings is in fact excellent and fundamental in view of the global concern for seismic adequacy of civil engineering infrastructure. These are not just old buildings waiting to be demolished and replaced, with a few worth setting aside in a theme park or museum: they are buildings that embody architectural marvels and distinctly modern construction features – features that can save lives once they are fully researched, understood and embraced. These buildings are also significantly more sustainable than modern construction based on steel, concrete block and reinforced concrete. If old buildings built manually with few tools, little formal education, and even less money can outperform new buildings of modern materials and technology in response to one of the largest forces that nature can throw at them, then indeed there is something to learn from them, and from the people and culture that brought them into being. This type of earthquake resistant construction is economic as well efficient to counter earthquake forces. Thus, its affordable for lower income class of population. Hence could be helpful in saving a lot of lives in the future. We have an affordable solution for better seismic performance of our structures if we switch to Dhajji-diwari and Taq systems of construction.

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