SEISMIC RESISTANCE OF TRADITIONAL KASHMIRI ARCHITECTURE

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Abstract - *Kashmir lies in the seismic zone iv and v which is very much vulnerable to earthquakes, so earthquakes are occuring over centuries in Kashmir and people have learnt to live with it. Two old traditional construction systems known as taq and dhajji-dewari exist here and they both have shown reasonable quake-resistant features. This traditional architecture have been adopted since 3,000 years. In ancient era the buildings were mostly made of stones as this is evident from the remains of monumental buildings which were damaged by the earthquakes. After that medieval structures were constructed by the Muslim community. These structures were made of a more economical and sustainable combination of mud mortar, stone and brick, well tied together with timber frames. This sustainable construction system with its use of masonry laced together with timber, was the beginning of the urban architecture in the Vale of Kashmir as we know it today. This architecture have been adopted in Kashmir in ancient times because of easily availability of mud and timber, which makes this architecture economical and more sustainable in winter like conditions. During initial period of the 19th century this architecture evolved to become the two main traditional construction systems: taq (timber-laced masonry) and dhajji dewari (timber frame with masonry infill). This architecture was also adopted in pakistan, In Pakistan, timber-laced masonry is known by the Pashto word bhatar. This traditional economical and sustainable architecture of Kashmir is, however, under threat and is rapidly being lost, especially now, following the earthquake of 2005. In modern era people now prefer latest style of construction in which RCC and steel is mostly used. This paper will try to narrate the seismic advantages of taq and dhajji-dewari system of construction. This paper will highlight the importance of traditional taq and dhajji –dewari construction which can save many lives once they are fully researched, understood and embraced.*

***Key Words*: Earthquake, architecture, timber, mud mortar, taq and dhajji –dewari**

1. INTRODUCTION

In Kashmir the traditional heritage buildings can be classified into two main system of constructions. The ist system is known as taq system of construction. 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. The second system is known as Dhajji-Dewari system of construction. In Dhajji-Dewari system of construction there is a wooden frame which is filled with masonary. There is less knowledge about when these two systems of construction have been introduced, but there are some evidences which gives us hint about these systems being constructed. In Kashmir, historical sources can be found which remark on the timber construction from as early as 1148 by Kalhana in his Rajtarangani **("Chronicle of Kings") who said the "Mansions of the city…reached the** clouds and **were mostly built of wood," and again in 1398 by Tímúr the Tátár, who wrote in his autobiography that "the buildings of the city are very large and all of wood" and they are "very strong and will stand for 500 or 700 years"**. In the 16th century, Muhammad Haidar Dughlát inhis Tarikh-i-Rashidi **("A History of the Moghuls in Central Asia") remarked, "In the town there are** many lofty buildings constructed of fresh cut pine. Most of these are at least five storeys high causing viewers to **bite the fingers of astonishment with the teeth of admiration"** . While these accounts only comment on the use of wood, rather than masonry integrated with wood or confined in a wooden frame, before the advent of modern saws and nails some form of masonry most likely would have been used to enclose the structures

This remarkable vernacular architectural heritage of Kashmir is, however, under threat and is rapidly being lost, especially now, following the earthquake of 2005. Its inherent qualities and great architectural expression, together with its unique construction, are insufficiently recognized or considered important by the citizenry today. Thus this architecture is rapidly being displaced by non-indigenous reinforced concrete buildings, many of which are constructed in a way that has proven to be particularly dangerous in earthquakes, as was demonstrated in 2005.

In addition, the cement plants which have sprung up to supply this insatiable demand have contributed to an assault on the air quality and the environment that threatens to irretrievably diminish the beauty for which Kashmir has been famous for centuries. Too few people today recognize how much Kashmir's traditional residential buildings create the unique character of urban Kashmir and complement the magnificent natural landscape with an equally rich cultural tradition.

In the current age, when energy conservation and the effects of greenhouse gasses have come to the forefront in international debates over humankind's future on the planet, it is important to understand that the conservation of historic buildings can play a particularly important role in any environmental conservation effort. Many have said that timber is too expensive, even when it comes to the maintenance of existing buildings with timber in their construction. Yet wood is the most renewable and least energy consumptive resource that one can use for building construction. In addition, when the timber already in a

heritage structure is left in place and protected from decay, it helps to avoid the loss of timber that is still on the stump. The embodied energy and material assets in existing buildings are considerable, as represented by the energy and resources consumed for their replacement.

2. TAQ SYSTEM OF CONSTRUCTION

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

In taq system of construction the different construction elements are arranged with a modular layout of masonaey piers and window bays tied together just like ladder like construction, as timber is used at each floor level and window lintel level in which masonary is embedded. A combination of wood and unreinforced masonry laid on weak mortar gave [taq] buildings the required flexibility. The wooden bands tied the mud mortar walls and imparted ductility to an otherwise brittle structure.

An important factor in the structural integrity of *taq* is that the full weight of the masonry is allowed to bear on the timbers, thus holding them in place, while the timbers in turn keep the masonry from spreading. The spreading forces can result over time from differential settlement – or in an instant in an earthquake. The overburden weight of the masonry in which the timbers are embedded serves to "pre-stress" the wall, contributing to its resistance to lateral forces.

Fig.1:Showing Taq construction in Srinagar

(Source: 'Randolph Lagenbach book-Do not tear it down')

3. DHAJJI-DEWARI SYSTEM OF CONSTRUCTION

Dhajji dewari is a timber frame into which one layer of masonry is tightly packed to form a wall, resulting in a continuous wall membrane of wood and masonry**.** In Dhajji-Dewari system of construction there is a wooden frame which is filled with masonary. The wooden members used here can be imparted horizontally, vertically or inclined into the masonary wall. These wooden members divides the masonary wall, so that the crack does not propagate to the whole wall and ultimately imparts strength to the masonary wall.

Dhajjidewari is a variation of a mixed timber and masonry construction type found around the world in one form or another, both in earthquake and non-earthquake areas. While earthquakes may have contributed to its continued use in earthquake areas, timber and masonry infill frame construction probably evolved primarily because of its economic and efficient use of materials. The term *dhajjidewari* comes from the Persian and literally means "patchwork quilt wall", which is an appropriate description for the construction to which it refers. The Persian name may provide a clue to Persian influence in the origins of this system of construction. It is also very similar to Turkish *hımış* construction, which was also common beyond the boundaries of Turkey, perhaps in part because of the widespread influence of the Ottoman Empire. *Dhajjidewari* consists of a complete timber frame that is integral with the masonry, which fills in the openings in the frame to form walls.

Dhajjidewari frames are usually "platform" frames, meaning that each storey is framed separately on the one below. In *dhajjidewari*, 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 *dhajjidewari* 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. *Dhajjidewari* construction is very effective in holding buildings together even when they are dramatically out of plumb. In the mountain areas, where soft soils and 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.2: Showing elevation of Dhajji-Dewari Construction in Down-Town Srinagar

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

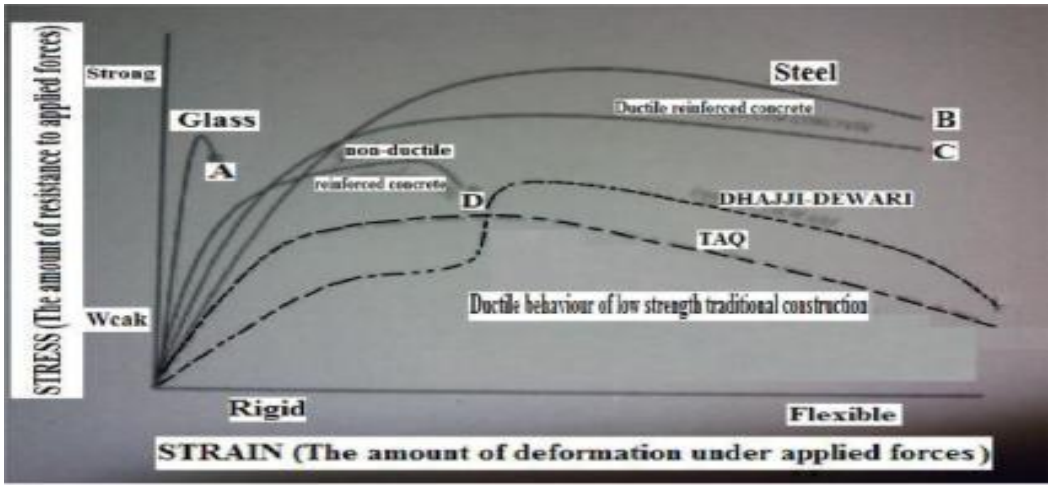

Fig.3: Showing Stress vs Strain relation b/w different materials

This graph 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.

5. 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 masonary walls. These horizontal runners add lateral load resisting ability of the structure. As masonary 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 masonary 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 masonary and timbers and between the masonary 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.

6. 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 t**he 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.

7. CONCLUSIONS

The earthquake performance issue is in fact fundamental for taq and dhajji buildings. As Kashmir lies in the seismic zone iv and v, so this is the biggest threat to the Kashmir valley. One can find the solution to this threat by adopting Taq and Dhajji-Dewari system of construction. These are not just old buildings waiting to be scrapped and replaced, with a few worth setting aside in a theme park or museum: they are buildings that embody 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 by hand 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 even poorer community of the society. Hence could be helpful in saving a lot of lives in the future.

When people understand that traditional pre-industrial materials and methods of construction can be embraced as a source of ideas on how to make new buildings better, they may rediscover parts of their heritage that increasingly have been spurned as backward. Construction technology is an unsung and little known area of architectural and cultural history, but for vernacular buildings, their unvarnished and unadorned construction forms a large part of their cultural significance.

Srinagar's and Kashmir's vernacular architecture with its earthquake-resistant construction is of central importance to all of these issues of cultural preservation, sustainable economic growth and quality of life. One only needs to look at the image on the Khyber Cement Company billboard in the centre of Srinagar , presenting the future of Srinagar as a version of New York or Hong Kong, to understand why. For tourists and residents alike, this is not an image related to the culture and people of Kashmir.

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