International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 2, Issue 2, pp: (86-92), Month: October 2014 - March 2015, Available at: www.researchpublish.com

Traditional Earthquake Resistant Systems of Kashmir

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Abstract: **Earthquakes have occurred regularly over centuries in Kashmir and people have learnt to live with it. Two old construction systems known as taq and dhajji-dewari exist here side-by-side and both have tested quake-resistant features. The recorded cultural history of Kashmir dates back 3,000 years. The oldest known remains of monumental buildings are the earthquake-damaged ruins of early Hindu and Buddhist temples built of large blocks of stone. Later medieval structures, some of them religious buildings constructed by the Muslim community, were made of a more economical and lightweight combination of mud, stone and brick, well tied together with timber. This construction system with its use of masonry laced together with timber, which is mentioned in texts from the 12th century, was the beginning of the urban architecture in the Vale of Kashmir as we know it today. In our time, Srinagar and other cities and villages in Kashmir are distinguished not only by their great monuments, but first and foremost by their vernacular residential architecture. It is an architecture generated out of a distinctive use of materials and way of building which are adapted to the local climate, culture and natural environment, principally the soft soils and the earthquake risk in the region. At the beginning of the 19th century the systems evolved to become the two main traditional construction systems: taq (timber-laced masonry) and dhajji dewari (timber frame with masonry infill). In Pakistan, timber-laced masonry is known by the Pashto word bhatar. 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. This paper would breakdown the false narrative of traditional construction taq and dhajji-dewari as absolute, insubstantial and symbolic of poverty. Infact paper would argue the taq and dhajji –dewari constructions 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.**

1. INTRODUCTION

Most of the traditional buildings in Srinagar and the Vale of Kashmir can be divided into two basic systems of construction. The first system, taq, consists of load-bearing masonry walls with horizontal timbers embedded in them. These timbers are tied together like horizontal ladders that are laid into the walls at each floor level and at the window lintel level. They serve to hold the masonry walls together and tie them to the floors. The second system, dhajji dewari construction, consists of a braced timber frame with masonry infill, which for example in England is commonly referred to as "half-timbered" construction. Not much is known about when taq or dhajji dewari came into vogue, but the notion of using timber members as braces within weak masonry walls can be found in many cultures through history. 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 in his Tarikh-i-Rashidi (“A History of the Moghuls in Central Asia”) remarked, “In the town 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. Thus, these accounts may be describing the ancient precursors of either taq or dhajji dewari construction. Different variations of taq, with its masonry walls with horizontal timber lacing, may have been in common usage throughout the Himalayan region before dhajji dewari came into general use, but dhajji construction, which was embraced by the British because of its resemblance to the Elizabethan half-timbered construction common in Britain, has continued to be used more often than taq in recent years.

2. OVER VIEW OF TIMBER-LACED MASONRY BEARING WALL CONSTRUCTION (TAQ)

Taq construction is a composite system of building construction with a modular layout of load-bearing masonry piers and window bays tied together with ladder-like constructions of horizontal timbers embedded in the masonry walls at each floor level and window lintel level. These horizontal timbers tie the masonry in the walls together, thus confining the brick mud or rubble stone of the wall by resisting the propagation of cracks. The masonry piers are almost always 1 to 2 feet square and the window bay/alcove (taqshe) 3 to 4 feet in width. The taq modular layout defines the Kashmiri house size measurements, i.e. a house can be 3 taq (window bays) to 13 taq in width. In Pakistan, timber-laced masonry is known by the Pashto word bhatar.

Fig.1: Showing Taq construction in Srinagar

(Symmetrical layout of windows is characteristic of taq and hence this name)
(Source: ‘Randolph Lagenbach book-Do not tears it down’)

3. OVER VIEW OF TIMBER FRAME WITH INFILL MASONRY CONSTRUCTION (DHAJJ DEWARI)

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. The term is derived from a Persian word meaning “patchwork quilt wall”. The frames of each wall consist not only of vertical studs, but also often of cross-members that subdivide the masonry infill into smaller panels, impart strength and prevent the masonry from collapsing out of the frame.

Fig.2: Showing elevation of Dhajji-Dewari Construction in Down-Town Srinagar

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

4. SUMMARY COMPARISON OF TAQ AND DHAJJI DEWARI CONSTRUCTION

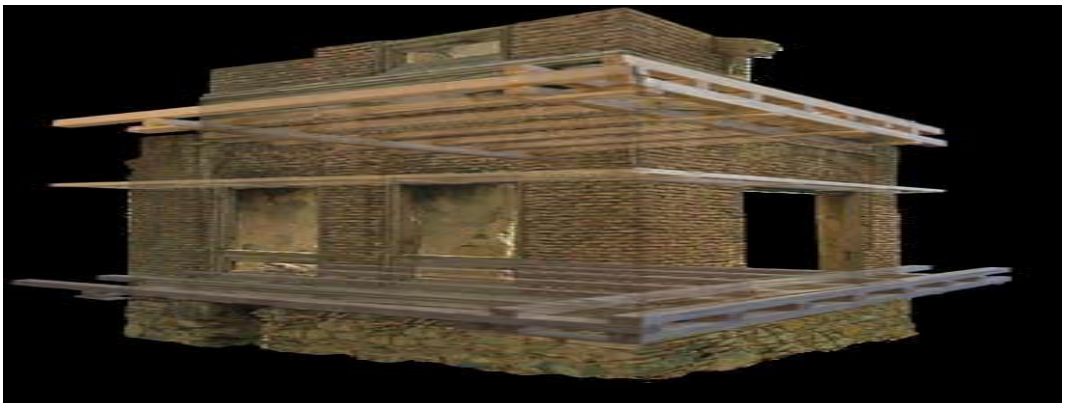

Fig.3: Showing Taq System (Source:)

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

This illustration shows a model of taq timber lacing superimposed onto a photograph of part of a Srinagar taq house. The three timber bands illustrate two floors plus the window lintel band. This shows how the floor joists are sandwiched between double bands and line up with the single band along the opposing walls. The double beams on the inside of the lower floor band represent the extra beam that can sometimes be found when the masonry wall below is thicker.

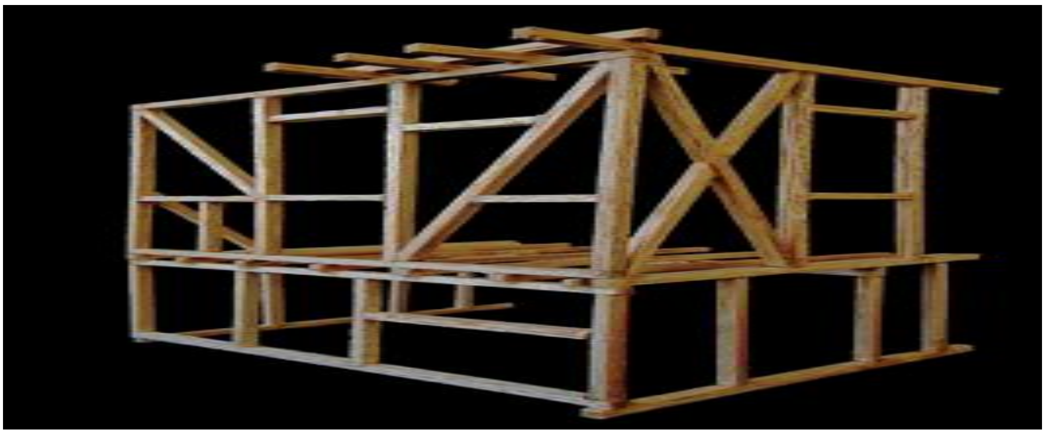

Fig.4: Showing Dhajji-Dewari System

This model shows a portion of a typical dhajji dewari house frame. The floor joists are sandwiched between the horizontal timber plates that form part of each storey of the frame, and the beams which support the joists at mid-span are integrated into the frames on the side. There are often different variations on how the timbers are arranged.This model shows an example of an "X" brace on one side, and a single diagonal brace on the other. Some dhajji houses can be found which have no diagonals. Instead they rely on the brick infilling alone for lateral stability. The top detail illustrates how the top floor joists extend out to form a cornice above which the roof rafters are placed.

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

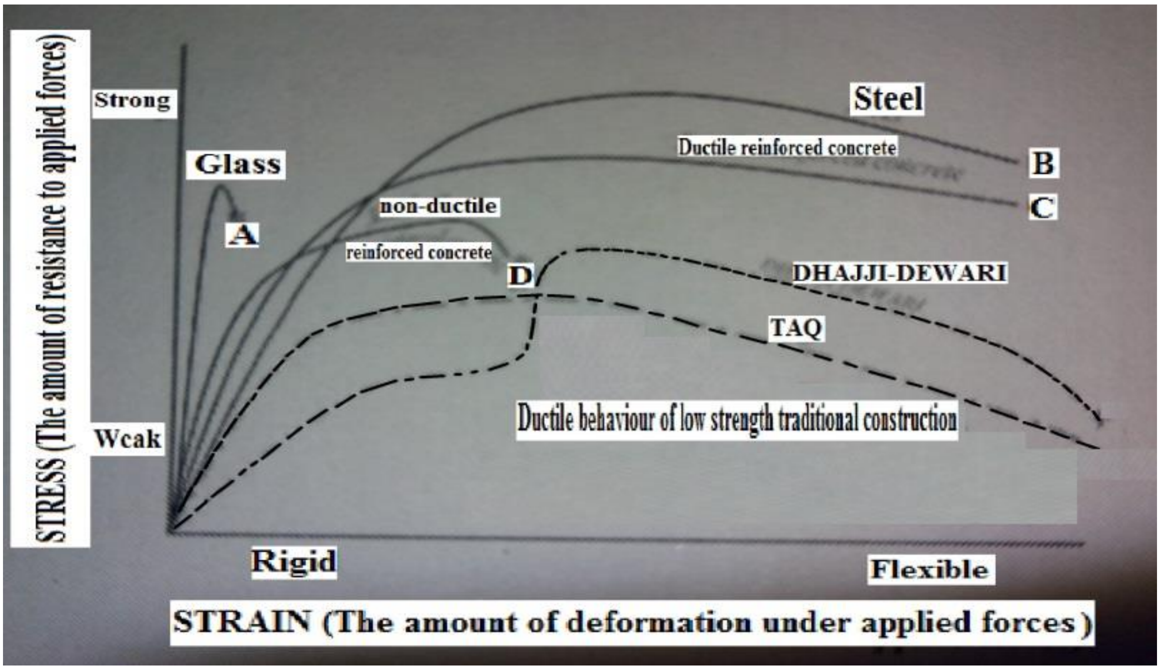

Fig.5: Showing Stress vs Strain relation b/w different materials

Line A represents the behaviour of glass: the line rises steeply indicating very little elastic range and then stops at the point when the glass breaks. Line B represents the behaviour of a properly riveted, bolted or welded steel structure: the line would normally continue off the chart before it breaks, representing the fact that steel has a great deal of ductility. Line C is for a reinforced concrete moment frame that is designed and constructed with ductile detailing in the beam/column joints. Line D represents non-ductile reinforced concrete moment frame construction. Non-ductile reinforced concrete is construction that lacks the volume and proper placement of steel reinforcing necessary to give it ductile behaviour in the inelastic range. Very often, in addition to lacking ductile design, many buildings in earthquake areas in India and other countries also suffer from poor construction practice such as poorly mixed, inadequately hydrated and/or improperly placed concrete, any of which can be the cause of collapse in even a moderate earthquake. Lines E and F represent taq and dhajji dewari respectively. The initial elastic strength of these systems is much lower than that of reinforced concrete, but the inelastic behaviour of the systems is favorable to the survival of the traditional buildings in earthquakes because of the ability of these buildings to undergo large inelastic deformations without coming apart. With taq (line E), the post-elastic capacity in earthquakes has often been found to be substantial because of the presence of the timbers which continue to hold the masonry together after it begins to crack in-plane, and then shift and slide. The timbers also serve to block the propagation of large shear cracks in the masonry and resist the out-of-plane forces, thus helping to maintain the stability of the wall and increase the frictional damping from the myriad of smaller cracks that open instead. In the case of dhajji dewari (line F), the initial shallow slope represents the flexibility of the timber frame, while the kink in the line represents the point at which the infill masonry begins to be compressed against the confining frame of timber as the deformation of the frame increases. The ultimate strength of the system is thus determined by the crushing strength of the confined masonry, mortar, and timbers in combination. The gradual slope to the right represents the continued "working" of the confined masonry panels in their frames, even as they slowly degrade.

6. THE EARTHQUAKE RESISTANCE OF TAQ AND DHAJJI DEWARI FROM DAMPING AND POST- ELASTIC STRENGTH PERSPECTIVES

Soft, loose soils, such as those found in Srinagar and throughout the Vale of Kashmir, tend to amplify the longer-period ground motion characteristic of earthquakes with epicenters distant from the site. In many cases this effect can even make the earthquake last longer and may accentuate building damage. In the 2005 earthquake, with the soft soils, one would have expected the damage to the more flexible traditional taq and dhajji dewari buildings in Srinagar and Baramulla to have been more severe than it was, but this is where the energy dissipation inherent to both of these systems becomes a life-saver. The buildings are flexible but not very elastic. It is the damping from their inelastic behaviour that reduces their resonant response to the ground motion. Site response was a major problem in the 1985 Mexico City earthquake, in which the total collapse of numerous modern tall buildings caused many fatalities. The earthquake occurred 350 km (220 miles) from the city, but very soft soils beneath a 6 km square area in the city amplified the ground shaking, and many tall buildings including even one 21-storey building collapsed because they resonated with this long-period shaking, but lacked sufficient damping to decrease this resonance.

7. THE EARTHQUAKE RESISTANCE OF TAQ CONSTRUCTION

The quotations below from the authors were based on observations made during the first several weeks after the earthquake. Describing taq construction, which they observed in the damage district on the Indian side of the Line of Control, Professors Rai and Murty observed: “In older construction, form of timber-laced masonry, known as Taq has been practised. In this construction large pieces of wood are used as horizontal runners embedded in the heavy masonry walls, adding to the lateral load-resisting ability of the structure. Masonry laced with timber performed satisfactorily as expected, as it arrests destructive cracking, evenly distributes the deformation which adds to the energy dissipation capacity of the system, without jeopardizing its structural integrity and vertical load-carrying capacity”. It is interesting to compare their observation with that of Professors N. Gosain and A.S. Arya after an inspection of the damage from the Anantnag Earthquake of 20 February 1967, where they found buildings of similar construction to Kashmiri taq: “The timber runners tie the short wall to the long wall and also bind the pier and the infill to some extent. Perhaps the greatest advantage gained from such runners is that they impart ductility to an otherwise very brittle structure. An increase in ductility augments the energy absorbing capacity of the structure, thereby increasing its chances of survival during the course of an earthquake shock”. These two reports are separated by almost 40 years. Gosain and Arya ascribe a kind of ductile behaviour to the timber-laced masonry and even say that the timbers “impart ductility” and augment “energy absorbing capacity”, while Rai and Murty use the term “energy dissipation capacity” to describe the same phenomenon. The different ways of describing this behaviour simply reflect changes in terminology, as the word “ductility” is more scientifically correct when used to describe an attribute of a single material rather than that of a combination of materials; but the basic phenomenon remains the same, and other noted scholars have made similar observations in other countries. Rai and Murty in 2005 avoided the use of the term “ductile” probably because the materials in taq are not ductile and do not manifest plastic behaviour. However, what makes timber-laced masonry work well in earthquakes is its ductile-like behaviour as a system. This behaviour results from the energy dissipation because of the friction between the masonry and the timbers and between the masonry units themselves. Another important feature with timber-laced masonry is to understand that the mortar is not designed to hold the bricks together, but rather to hold them apart. It is 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.

8. THE EARTHQUAKE RESISTANCE OF DHAJJI DEWARI CONSTRUCTION

In the 2005 EERI report, Professors Rai and Murty commented more extensively on how dhajji dewari construction was affected by the earthquake: “In Kashmir traditional timber-brick masonry construction consists of burnt clay bricks filling in a framework of timber to create a patchwork of masonry, which is confined in small panels by the surrounding timber elements. This timber lacing of masonry, which is locally referred as dhajji-dewari has excellent earthquake resistant features. The resulting masonry is quite different from typical brick masonry and its performance in this earthquake has once again been shown to be superior with no or very little damage. No collapse was observed for such masonry even in the areas of higher shaking”. They go on to explain the reason for this good behaviour: The presence of timber studs, which 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. As has already been explained, this infill masonry serves a primary role in the case of lateral earthquake loads. In the damage district of Kashmir on both sides of the Line of Control, there were enough buildings of dhajji construction to observe the effects of the earthquake on the construction system. In the mountains on the Pakistan side, the infill material is more commonly rubble stone set in mud mortar, while on the Indian side, particularly in the Vale of Kashmir where clay is abundant, the use of fired and unfired clay brick is more common. 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 advances to a destructive level. Thus 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.

9. CONCLUSION

The earthquake performance issue is in fact fundamental for taq and dhajji buildings. 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 BPL (Below Poverty Line) class..Hence could be helpful in saving a lot of lives in the future.

ACKNOWLEDGEMENT

I thank all staff members of my college and friends for extending their cooperation during my research. I would like to thank my parents without whose blessings; I would not have been able to accomplish my goal. Above all I thank the almighty God for His blessings, without which any of this would not have been possible.

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