

Reliability and Experimental Study on the Seismic Resistance Capabilities of Brick Nogged Timber Frame Construction (Dhajji-Dewari)

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SUMMARY

The state of Jammu and Kashmir, with a total area of 222,236 sq. km., is located in the northern part of Indian subcontinent. Kashmir region falls in a high seismic hazard zone. On October 8, 2005, the Mw 7.6 earthquake occurring at a depth of 26 km, with epicenter at 34.6 0N, 73.0 0E near the town of Muzaffarabad, was felt throughout Pakistan and India and N.W frontier parts of Pakistan. The most severe impact of the earthquake was felt in the state of Jammu & Kashmir. About 90,000 households in the Kashmir Division and 8,000 households in the Jammu Division were greatly affected. Regardless of this destruction and devastation, indigenous construction techniques, namely **Taq** System and **Dhajji-Dewari** have proved to withstand major earthquakes like the Oct 8 2005 and have helped to save the lives of many individuals.

Keeping in view the earthquake resistant features, namely **Taq** system (timber laced masonry) and **Dhajji-Dewari** system (timber frame with infill walls), need to be revived and improved further, on scientific lines. The purpose of this research is to deliberate upon this topic in detail.

Prominent findings of this research shows that the joints are the critical locations in these traditional constructions and increasing the strength enhancement of joints significantly improves the horizontal load capacity, increases the load carrying capacity of the structure. The best possible frame configuration has also been identified through this study.

Keywords: *Taq system, Dhajji-Dewari, Kashmir, Bracing system, loading frame, Infill.*

1. OVERVIEW AND BACKGROUND

In the **Taq** system, large pieces of timber are used as horizontal runners embedded into the masonry walls. These runners are located at floor level and at lintel level. These runners tie together all of the elements of the building and keep the entire structure in concert, thus preventing spreading and cracking of masonry. The runners are joined together with small pieces of timber, giving the shape of a ladder laid over a wall covering two exterior faces of the wall. This generally refers to a modular layout of the piers and window bays which make up this type of construction. Piers are almost 1.5 – 2.0 feet wide where as the bays are about 3.5 feet wide. There is no practice of putting a complete frame of timber. The timber runners act like horizontal reinforcement which ultimately holds the masonry together.

In the **Dhajji-Dewari** system, timber frames for confining masonry in small parcels are used. The timber frames, not only have vertical elements, but also have cross members, which divide the masonry infill into various small panels. The most important characteristic of this type of construction is the use of lean mud mortar. A common practice in the region is to use the **Dhajji-Dewari** system in the upper story walls, especially for the gable portion of the wall.

Dhajji-Dewari has proved to withstand major earthquakes like the Oct 8 2005 and have helped to save the lives of many individuals. In the damage district of the Kashmir valley on the 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. In Turkey, HIMIS, which is similar to *Dhajji*, survived in the heart of the damage districts of the two large earthquakes around the Sea of Marmara in 1999, when hundreds of surrounding concrete buildings collapsed, killing over 17000 people. This finding was confirmed by Turkish researchers who conducted a detailed statistical study in several areas of the damage district. They found and documented a wide difference in the percentage of modern reinforced concrete buildings that collapsed compared to those to the traditional construction. In one district in the hills above Golcuk where 60 of the 814 RCC, 4-70 storey structures collapsed or were heavily damaged, only 4 of the 789, 2 or 3 storey traditional structures collapsed or had been heavily damaged. The RCC buildings accounted for 287 deaths, as against only 3 in the traditional structures. In the heart of the damage district in Adapazari, where the soil was poorer, research showed that 257 of the 930 RCC structures collapsed or were heavily damaged, and 558 were moderately damaged. By comparison, none of the 400 traditional structures collapsed, and 95 were moderately damaged. (Gulhan and Guney, 2000). Thus, both the Kashmir and the turkey earthquakes provided a chance to examine how this type of light frame with masonry infill construction actually performed where the earthquake shaking was large enough to cause widespread destruction of other building types, from un-reinforced masonry to RCC.

2. STRUCTURAL ACTION OF DHAJJI-DEWARI SYSTEM

Inspections of the interiors of the *Dhajji* houses in kashmir, as well as in turkey, provide a better insight about the behavior of *Dhajji* as a structural system under earthquake loads. It was evident that the infill masonry walls responded to the stress of the earthquake by “working” along the joints between the infilling and the timber frame; the straining and sliding of the masonry and timbers dissipated a significant amount of the energy of the earthquake. The only visible manifestation of this internal movement was the presence of cracks in the interior plaster along the walls and at the corners of the rooms, revealing the pattern of the timbers embedded in the masonry underneath.

On the exterior, where there was usually no plaster coating, the movement of the panels was not very visible. The movement was primarily along the interface between the timbers and the brick panels where a construction joint already exists. Because of the timber studs that subdivide the infill, the loss of masonry panels did not lead progressively to the destruction of the rest of the wall. The closely spaced studs prevented propagation of “X” cracks and reduced the possibility of the masonry falling out of the frame. Where it was observed that the large sections did fall out, it could most often be attributed to rotten timbers or over sized panels or both, and the structures involved often barns rather than houses.

An important additional factor in the good performance of the walls was the historical use of weak rather than strong mortar. 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 panel 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 building thus survives the earthquake by not fully engaging with it. This working during an earthquake can continue for a long period before the degradation advance 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 the exterior walls that exist in a standard residential building reduces the likely hood of the catastrophic failure of the frame.

While these structure lack lateral strength, they possess lateral capacity. They respond to seismic forces by swaying, rather than by attempting to resist them with rigid components and connections. This is not an elastic response, but a plastic one. When these structures lean in an earthquake, they do so with incremental low level cracking which is distributed throughout the wall by the interaction of the timber structural components with the confined masonry. In other words, all though the masonry and mortar is brittle, the system – rather than the materials that make up the system- behaves as if it were ductile.

Ordinary un-reinforced masonry walls under lateral earthquake loads develop diagonal tension “X” cracks, which then rapidly progress until the wall collapses. With *Dhajji-Dewari*, the frame of studs and cross pieces prevent the development of large diagonal cracks, thus helping to hold the wall together against both in plane and out of plane shaking.

In addition, the non destructive movement of the panels along the construction joints between the frame and the panels introduces a large amount of friction; which in turn reduces the excitation of the building from the earthquake. This reduces the damage to the rest of the superstructure. In earthquakes in turkey, Greece and the former Yugoslavia as well as in Kashmir, timber frame and masonry infill construction has demonstrated a high degree of frictional damping over many cycles with relatively slow rates of degradation. *Dhajji-Dewari* thus avoids the drawbacks of bearing wall unreinforced masonry, which heavy and subject to brittle failure in earthquakes and fracture from differential settlement. While in Kashmir it is difficult to isolate the influence that earthquakes may have had on the evolution of either the *TAQ* or *Dhajji-Dewari* Technology, there are two examples of Dhajji like timber infill systems that indisputably were developed and promulgated and even patented specifically for their earthquake resistance. One is The GAIOLA frame in Portugal, otherwise known as POMBALINO walls. The other is the CASA Barracatta which was invented under simple circumstances after the Calabria Earthquake of 1783 and later patented. (Barucci 1990)

3. OBJECTIVES

1. To apply the principles of science & engineering to the traditional construction of valley and thereby improve the same.
2. Developing experimental setup to simulate earthquake through static horizontal load.
3. To determine experimentally the horizontal load carrying capacity of different frame bracing arrangements commonly found in Kashmir and to select the best arrangement through experimental testing
4. To study the effect of Joint configurations on the strength of the frames.

4. METHODOLOGY OF EXPERIMENTATION

A 50T capacity loading frame was used for experimentally determining the best bracing arrangement of different frames. Transformation of loading frame into a setup capable to apply horizontal loads and subsequently using the facility to simulate earthquake through static horizontal load was a tedious job. The loading frame has been used for carrying out various tests by applying the loads vertically through hydraulically operated jacks. It was for the first time that the loading frame was used to induce loads horizontally. The most difficult job was to find the position where we could place the jack for the application of the load as it was a critical step for placement of the test sample. After a number of trials, the best position for placement of the jack was at the top of one of the top girder. The height at which the girder was placed was changed so as to have the jack properly placed. The jack was then supported at its back by a solid plate so as to provide it, the necessary reaction to sustain

the horizontal load. It was however imperative, to make sure that, the four vertical rods supporting the platform, on which the hydraulic jack rests, are connected to each other at the top by a plate so that all four rods contribute to provide resistance for sustaining the horizontal load, preventing them from undergoing any deformation. Once the correct positioning of the hydraulic jack was achieved, the next important step was to obtain the possible dimensions according to which the timber frames were to be designed for testing. The following observations were made before testing and are stated below:-

1. The maximum height for which the tests could be performed on the reaction frame was restricted to 1.4478m.
2. The width could be adjusted by loosening the screws of the loading frame from the base and shifting a portion of the frame to either side. This can solve two problems; viz;
 - Possible increase in the width of the specimens/frames that were to be tested on the horizontal reaction frame; and
 - Provision of enough room/space to help facilitate introducing the prefabricated timber frame structure directly into the reaction frame setup which would otherwise be a difficult rather impossible task. The maximum width for the frame was restricted to 1.3716m.

The vertical rods were connected to the beams at the top and fixed to the base at the bottom, which provided lateral support to the frame in case of any overturning. The deflection was measured using two dial gauges placed on the girder at the other end. A proving ring was also provided along the width, in contact with the jack to note the applied loads

4.1 Property of the Test Frames

To test the behavior of different bracing configurations, the five most commonly adopted bracing configurations were studied. These arrangements of the bracing systems were adopted after thorough field survey and exhaustive literature survey. The height and width of the frames was chosen as per loading frame conditions.

The properties of the test frames are as under:

Wood type: **Poplar**

Poisson's ratio: **.318**

Modulus of elasticity: **10900 KN/m²**

Cross section of vertical main posts: **0.1016m × 0.1016m**

Cross section of bracings: **0.1016m × 0.0508m**

Height of frames: **1.4478m**

Width of frames: **1.3716m**

The frames were tested with different joint conditions. For strengthening of joints Iron straps were used.

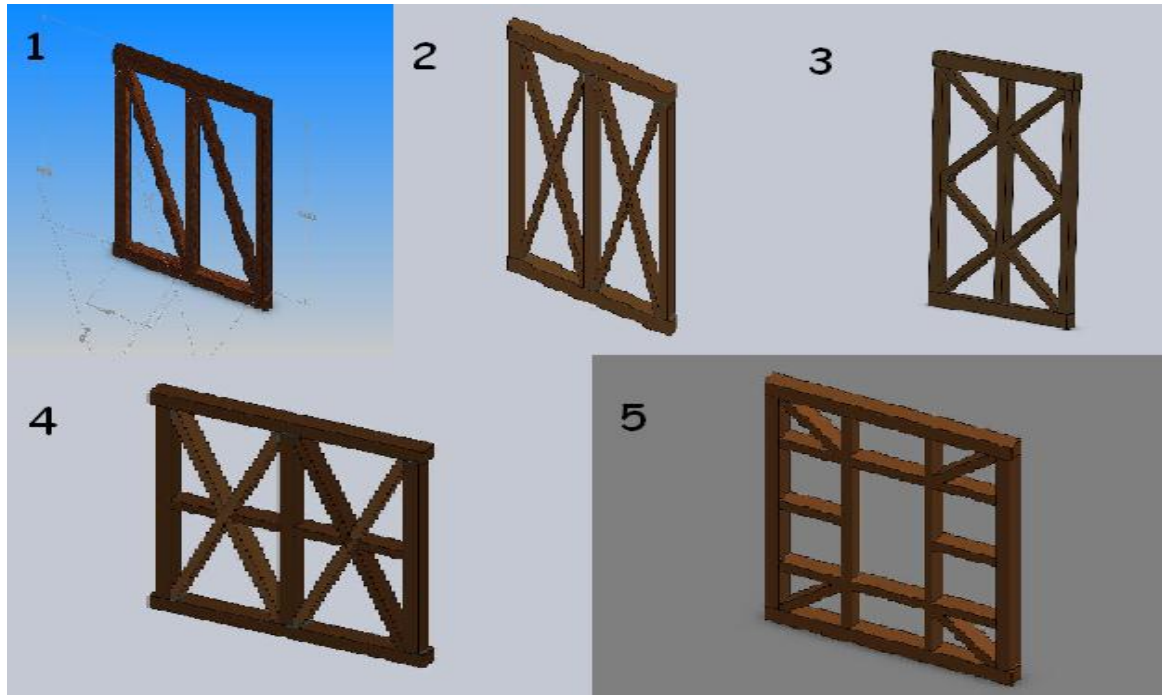


Figure 1. Different test frame samples used in the study



Figure 2. Test samples under test,on the Loading Frame

5. RESULTS AND OBSERVATIONS:

5.1. Failure Patterns Of Various Joints And Posts In The Different Types Of Frames:

The test was performed using a 200 kN jack which was operated by hydraulic pump. The failure patterns in various joints and posts were observed.



Figure 3. Joint failure at the top of Frame 1



Figure 4. Vertical Cracks in the post of Frame 1



Figure 5. Bending induced in the vertical post which caused cracks at the strap levels in the line of nails



Figure 6. Joint failure in frame 2



Figure 7. Brace failure in Frame 2



Figure 8. Bending induced in Bracings of Frame 4



Figure 9. No joint failure in Frame 4

5.2 Load-Deflection Curves for Various Un-Strengthened and Strengthened Frames:

The deflection was measured on the top of the frame and at the centre of the frame using 2 dial gauges. The load deflection curves for different frames are as under:

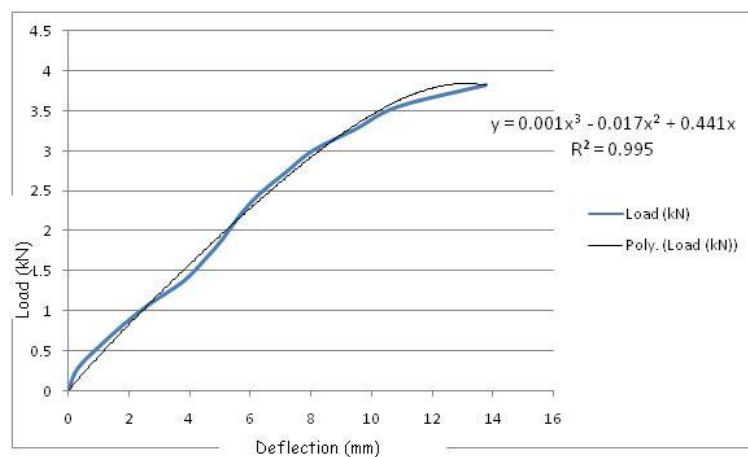


Figure 10. Load-deflection curve for frame 1

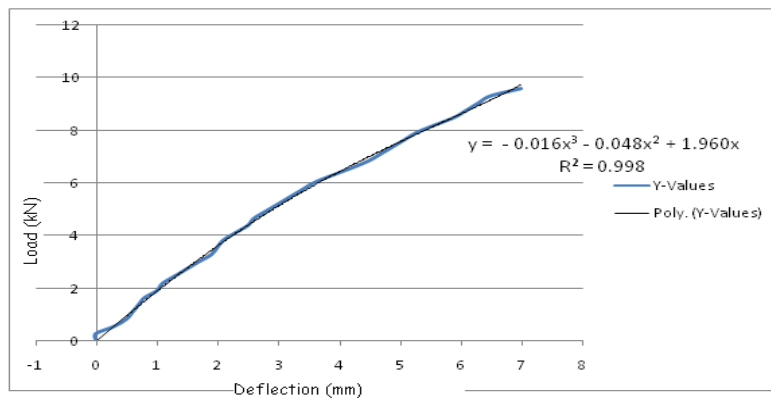


Figure 11. Load-deflection curve for frame 1, with strengthened joints

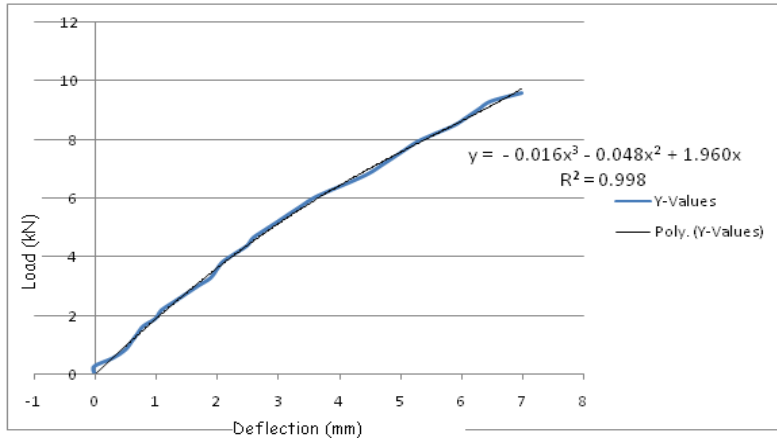


Figure 12. Load-deflection curve for frame 2

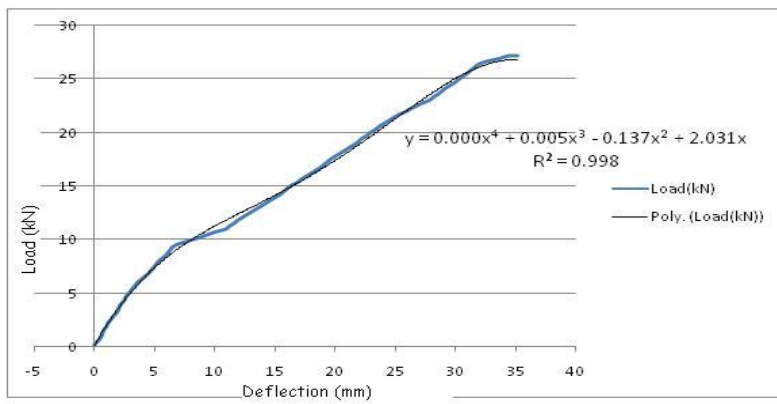


Figure 13. Load-deflection curve for frame 2, with strengthened joints

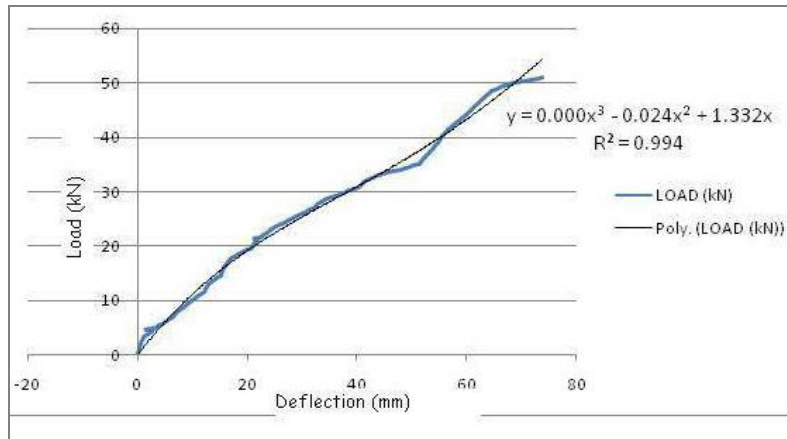


Figure 14. Load-deflection curve for frame 4

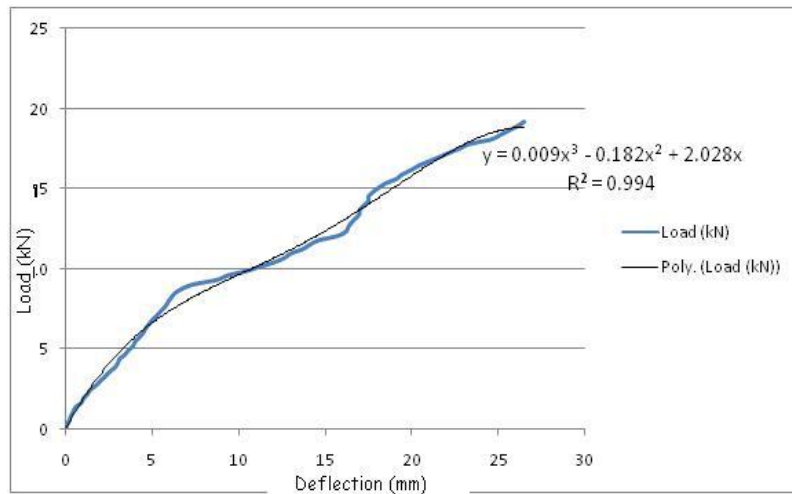


Figure 15. Load-deflection curve for frame 4, with infill of mud mortar

6. CONCLUSIONS

After performing tests on 6 frame types, we could conclude the following from the test results

1. The joints are the critical locations in these traditional constructions.
2. Increasing the bracings by 100% increases the strength by 300%.
3. The strengthening of joints by Iron straps increases the load carrying capacity of the frame by 300%.
4. The mud mortar is better than cement mortar as the damping in the earlier is of the order of 20%, compared to 4% in cement mortar.
5. The best arrangement of the bracing system is

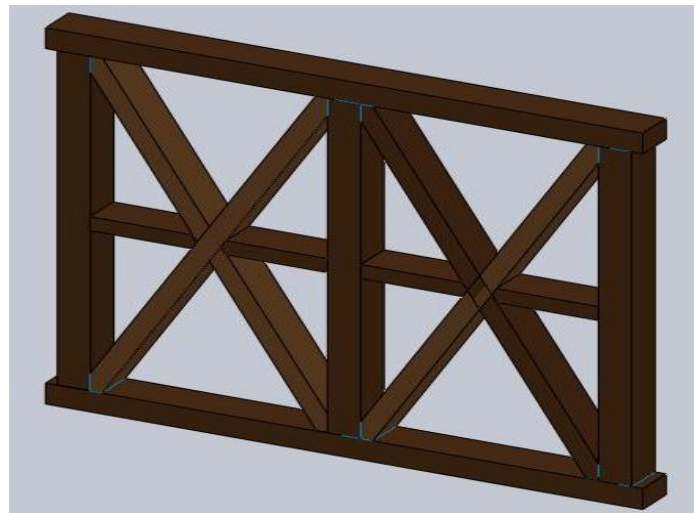


Figure 16. The Best and the most efficient Bracing system

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