

Enhancing Lateral Load Performance of Traditional Timber Wall (Dhajji-Dewari) by Strengthening of joints

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Abstract. Traditional timber structures, known as Dhajji Dewari, are mostly found in the Northern areas of Pakistan and Kashmir. Very limited research is available to validate the seismic performance of Dhajji Dewari construction. It has experimentally been proved that Dhajji construction is suitable for earthquake resistance and the prominent features include its affordability, superficial ability to tolerate earthquakes and the fact that it is within the technical means of local, less skilled personnel for house building. This paper presents experimental work conducted on typical Dhajji Dewari wall found in northern areas of Pakistan and Kashmir, to evaluate the in-plane lateral load response by strengthening of critical joints. The experimental work includes in-plane monotonic testing on four reduced scale walls, one wall was used without any strengthening (Conventional wall) other walls were strengthened by different strengthening techniques (bamboos, metal strips, and metal gusset plates). Test results show that the connection functionality, particularly at the joint of vertical posts and bottom plates, controls the overall performance of the wall. Strengthening of these joints not only enhances the lateral load carrying capacity of the wall, but also significantly augment the energy dissipation capacity of the system. Further, based on cost benefit analysis it is concluded that wall strengthened with metal strips give the best reinforcement of Dhajji walls keeping in view the additional cost of strengthening and load deformation behavior of wall.

1. Introduction

Dhajji Dewari is a non-engineered construction which can be easily constructed by locally available materials i.e. Wood, Stone and Mud [1]. This construction type is 200 years old and still in practice in northern areas of Pakistan specially those area where wood is abundantly available [2]. Dhajji means “Patch work quilt” and Dewari means “Wall” in Kashmiri Language [3]. Dhajji Dewari is the construction type composed of traditional timber frame with stone infill, which is the prevailing construction for residential buildings in Northern areas of Pakistan and Kashmir. Dhajji most commonly consists of a braced timber frame, stone and mud. The spaces left within the timber frame are filled with a thin wall of stone traditionally laid and plastered with mud mortar [4]. Dhajji Dewari provides efficient use of material even with single layer of infill compared to modern construction techniques [5].

Dhajji buildings are rectangular in shape and mostly constructed as single story structure but multi storey structures also found in Indian occupied Kashmir [6]. These traditional structures have performed well in October 2005 Earthquake [7,8]. The magnitude of earthquake was $M_w = 7.50$, its epicenter found in Kashmir. This earthquake destroyed 5000 schools, 460000 homes, 800 health facilitation center, 4000 villages, leaving nearly 3.50 million people unsheltered. Most of the losses were endorsed to non-ductile reinforced concrete structures and unreinforced masonry structures resulting in overall economic loss of 0.90% of annual GDP of Pakistan [9]. Dhajji houses in the region performed better than the conventional reinforced concrete structures, which was a point to ponder upon. Based on the performance, ease in construction and availability of construction material inhabitants adopted traditional way of construction [10].



Various studies on Dhajji walls indicate that connections especially those between vertical and horizontal posts of wall usually fail in rocking. So in this study our main focus will be to apply the different joint strengthening techniques to enhance the lateral load performance of Dhajji wall by directing the rocking. The main objective of research was to investigate the lateral load capacity, ductility, energy dissipation, stiffness degradation and failure behavior of Dhajji walls before and after strengthening.

2. Experimental Program

Construction of Dhajji Dewari incorporates distinctive bracing techniques, panel sizes and infill material, the material availability and construction techniques are easily implementable for local personnel. Four Dhajji Dewari walls (DDW1, DDW2, DDW3 and DDW4) were constructed and three different strengthening techniques like Bamboos, Metal Strips and Metal gusset plates were used on separate walls.

2.1. Material Characterization

The materials used for construction of Dhajji walls were timber, stone and mud. Material properties were determined using standard test methods. There are many different types of timber used in construction of Dhajji Dewari houses. The choice of timber mainly depends on the low price and local availability. For this experimental work, Partal (Himalayan spruce) wood, available readily in market and used mostly in construction of furniture and doors etc., is used with cross bracings. Mechanical properties of timber used in wall construction were determined according to British Standard Methods of testing small specimens of timber (BS 373:1957) and are shown in table 1

Table 1. Mechanical Properties of Timber

Sample No.	Compressive strength parallel to grains (MPa)	Tensile strength perpendicular to grains (MPa)	Moisture Content (%)	Density (Kg/m ³)
1	33.50	3.35	8.45	464
2	39.60	2.23	7.11	544
3	36.50	2.91	8.01	458
Average	36.50	2.83	7.86	488.6

Marghallah Stones (local term “Water Bound”) were used for filling the panels and sieve analysis of stones indicate that 90% particles were having size ranges between 19 mm to 50 mm. Remaining 10% particle were less than 19 mm in size. Soil engaged from local excavation site and particle size distribution of soil indicate that 11% particles were having size between 0.60 mm to 5 mm, 63% of particles were in range of 0.075 mm to 0.60 mm and remaining particles were having size less than 0.075 mm. There was no direct method to find the water soil ratio so quantity of water used was depending on the consistency of mud.

2.2. Test Panel Properties

There are many different types of bracings used in construction of Dhajji Dewari house but for this experimental work cross bracing was used to incorporate the most common field practice. Dhajji Dewari walls were constructed with three sets of members having cross sectional dimensions 50 mm X 50 mm, 25 mm X 50 mm and 12.50 mm X 50 mm, half scale values of a typical Dhajji wall. The 50 mm X 50 mm members were used as main vertical posts and top and bottom horizontal bands. The 25 mm X 50 mm members were used as secondary horizontal bands and Studs (Intermediate vertical Posts). Similarly, 12.50 mm X 50 mm members were used as cross bracers. The length of each specimen was kept 1500 mm, and height was 1200 mm, half scaled dimensions of a typical Dhajji wall as shown in figure 1.

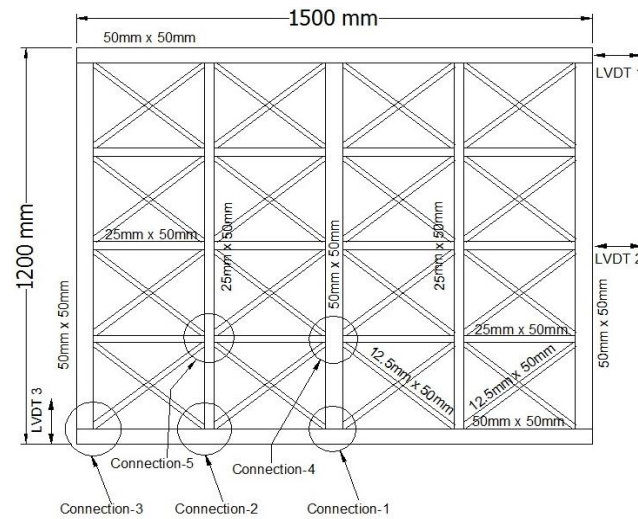


Figure 1. Detail of Members and LVDT

The main vertical posts and studs were connected to top and bottom main horizontal bands through type 1 to 3 connections. Similarly secondary horizontal bands were connected to main posts and studs through type 4 and 5 connections. Wooden nails made of steel having yield strength 250 MPa were used to fix the connections.

Vertical load having magnitude 1 kN was applied to mimic roof dead load. Iron molds were designed for application of pre-compression point load on main vertical posts of wall and using the magnitude of pre-compression load resulting in final sizes of 18" dia. circular moulds which were later bolted on top of main posts. Load was applied with the help of aggregate filled with in containers.

To meet the field conditions and for measuring the storey drift, walls were bolted with floor to restrain horizontal movement. Bottom triangular portion of walls were left empty, in main bottom horizontal posts for purpose of bolting at four different locations. After drying of infill, walls were fixed on the specified locations and then empty portions were filled with infill material.

2.3. Test Panels Description

Four Dhajji walls were used for the experimentation and out of four walls, one wall was used without any strengthening and considered as reference wall. The rest three walls were strengthened with three different strengthening techniques. The detail of walls is as under:

Dewari Wall 1 was used without any strengthening as shown in figure 2a and consider as reference wall to check the behavior of conventional wall and for comparison purposes with strengthened walls. Dhajji Dewari Wall 2 was strengthened with Bamboos on periphery of wall and along tension and compression struts for purpose of enhancing lateral load performance by strengthening the joints. Detail is shown in figure 2b.

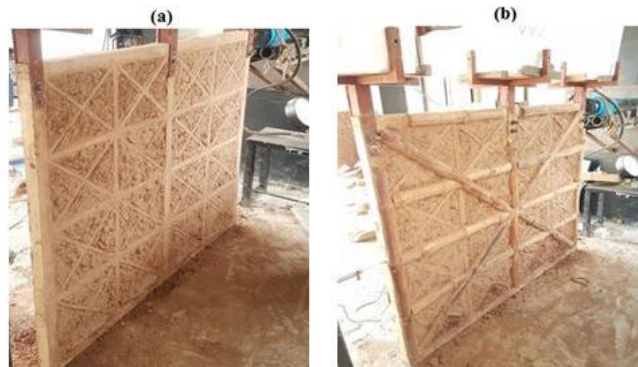


Figure 2. (a) DDW1 (Reference Wall) (b) DDW2 (Wall strengthened with Bamboos)

Dhajji Dewari Wall 3 was strengthened on the connection of main horizontal and vertical posts of wall with metal strips. Two types of strips were used and bolted on both sides of wall. The shape of strips used was depending on the location of connection i.e. L-shaped strips were used on bottom corner joint and T-shaped strips were used on bottom middle joint as shown in figure 3. The size of strips was random, length was taken according to spacing of bolts and by keeping in mind the timber strength, thickness was 2 mm and width was selected according to width of post.

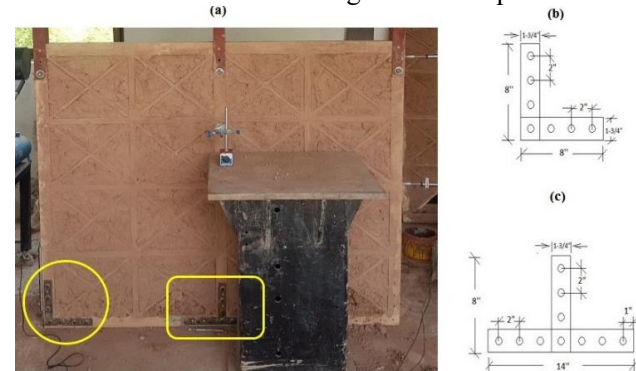


Figure 3. (a) DDW3 (b) L-Shape Strip (c) T- Shape Strip

Similarly, Dhajji Dewari Wall 4 was strengthened with metal gusset plates on connection of main horizontal and main vertical and secondary vertical posts. Two types of plates were used and bolted on both sides of wall. The shape of plates used was depending on the location of connection i.e L-shaped plates were used on bottom corner joint and triangular shaped plates were used on bottom intermediate joints as shown in figure 4. The size of strips was random, length was taken according to spacing of bolts and it was less than metal strips' length, the reason behind that was the large surface area of plates, thickness of strips was 2 mm and width was selected according to width of posts.

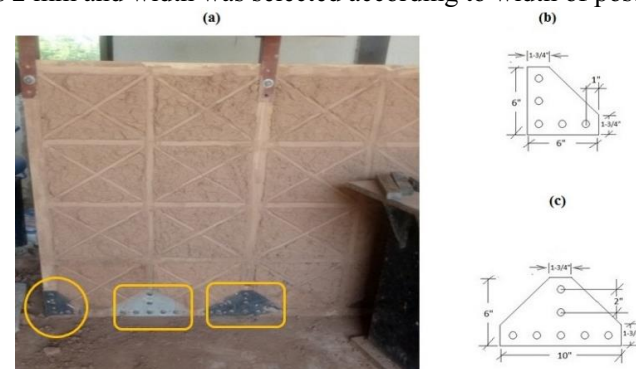


Figure 4. (a) DDW4 (b) L-Shape Strip (c) T- Shape Strip

2.4. Test Setup

Lateral load was applied using 500 kN capacity hydraulic Jack. Displacement was measured using three linear variable displacement transducer (LVDT). The position of the hydraulic jack and LVDTs is shown in figure 5. LVDT 1 and 2 were used to measure the displacement at top and mid height of the wall panel. LVDT 3 was attached at the bottom to measure rocking of panel during test.

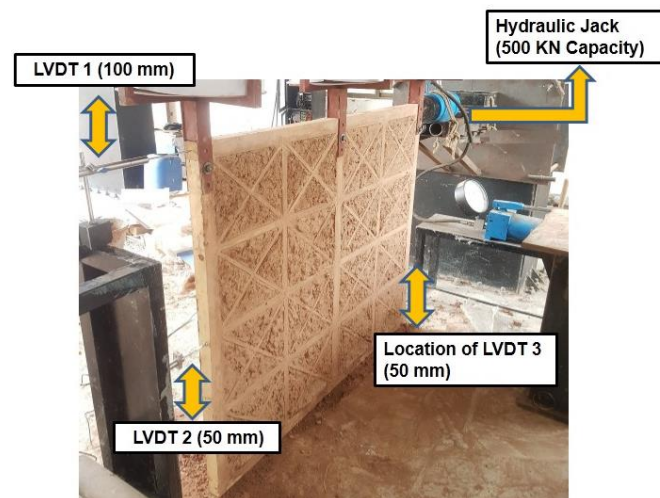


Figure 5. Test Setup

3. Analysis of Results

In-plane monotonic test simulates in a simple way, it provides important information regarding the overall mechanical behavior of wall subjected to lateral loading

3.1. Load Displacement Behavior

The load displacement curves presented in figure 6 refers to the horizontal displacement at top of wall vs. lateral load applied to the wall.

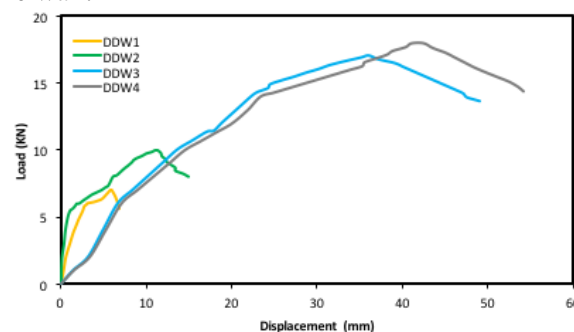


Figure 6. Load Displacement curves of all panels

The main results obtained from Monotonic test were in the form of load displacement curves which give further information in terms of ultimate displacement, energy dissipation, ductility and stiffness degradation. Load displacement curves are important to study the behavior of connections of timber frame walls. Curves represent that all the strengthened wall show good lateral load behavior and stiffness of walls gradually decreasing with the increase in load.

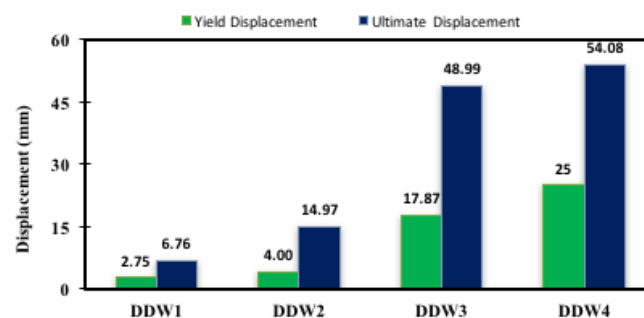


Figure 7. Comparison of Lateral Displacement at Different Stages

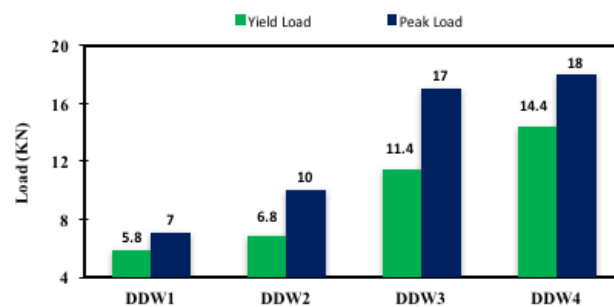


Figure 8. Comparison of Lateral Load at different Stages

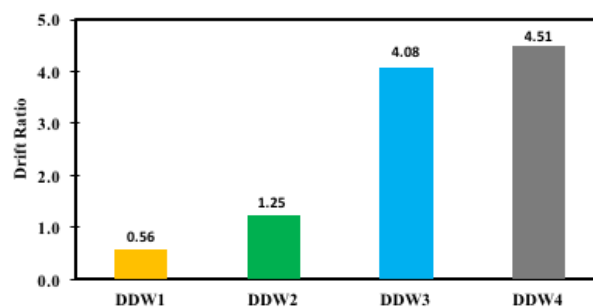


Figure 9. Comparison of Drift Ratio

3.2. Energy Dissipation

The load displacement curves presented in figure refers to the horizontal displacement at top of wall vs. lateral load applied to the wall. Factors upon which energy dissipation of traditional walls depend upon are (1) the friction along joints, (2) crack propagation, (3) formation of new cracks, (4) crushing of wood, (5) rocking and joint detachment. Failure mode of traditional wall also affect the energy dissipation; for brittle failure its value will be less compared to ductile failure of wall. Figure 10 represent the energy dissipation of all specimens during loading stage.

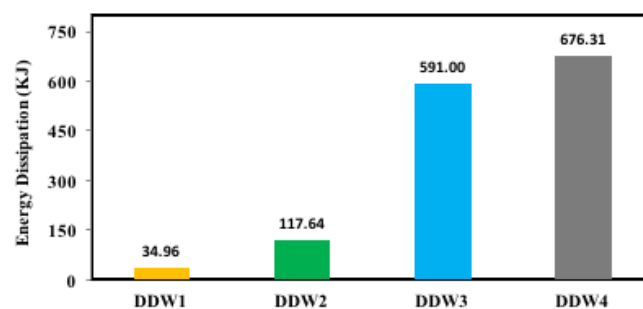


Figure 10. Comparison of Energy Dissipation

3.3. Response and Ductility Factor

Response factor is an important criterion for designing structures present in seismically active zones. The response factor represents the ductility of a structure. Ductile structures withstand the seismic forces more efficiently. The response factor of all the specimens determined by using the relationship given by Paulay and Priestley [11].

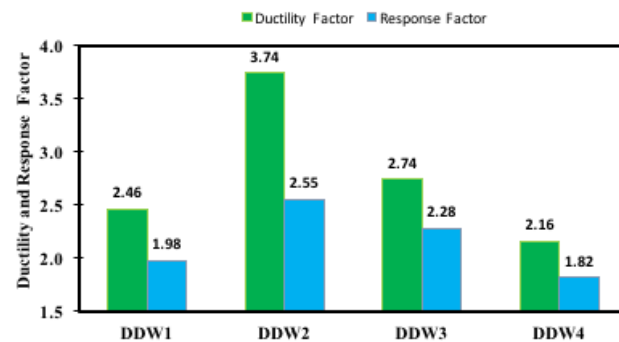


Figure 11. Ductility and Response Factor of all specimens

3.4. Test Setup

Stiffness degradation represents the damage accumulated at the connection of traditional timber wall, which is related with the deformation and nail pull out of wall. It tells the rate of stiffness reduction after yielding. Lower value of stiffness degradation indicates good seismic capabilities. Stiffness degradation ratio was determined for each specimen and is shown in figure 12. The overall stiffness behavior of walls is shown in table 2. The initial stiffness of DDW2 was almost doubled compared to DDW1.

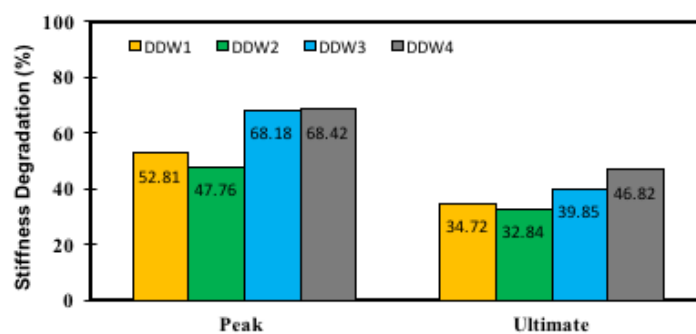


Figure 12. Stiffness Degradation Ratio of all specimens

Table 2. Stiffness Values of all specimens

Stiffness	DDW1	DDW2	DDW3	DDW4
Effective Stiffness	2.49	4.75	0.84	0.68
Stiffness at Yield	2.045	1.34	0.66	0.57
Stiffness at Peak load	1.08	0.64	0.45	0.39
Stiffness at Ultimate load	0.71	0.44	0.263	0.267
Stiffness Degradation	0.35	0.33	0.40	0.47

3.5. Behavior of Walls at Failure

The lateral drift and base uplift are the important parameters for describing the failure mode. The higher values of base uplift 6.72 mm and 11.95 mm for specimens DDW1 and DDW2 were due to rocking failure. Similarly for specimen DDW3 and DDW4 the base uplift values 2.73 mm and 3.21 mm were comparatively less and values of lateral drifts were higher which indicates that these panels have experienced ductile shear failure. depending on the consistency of mud. Failure patterns of all 4 walls are shown below.

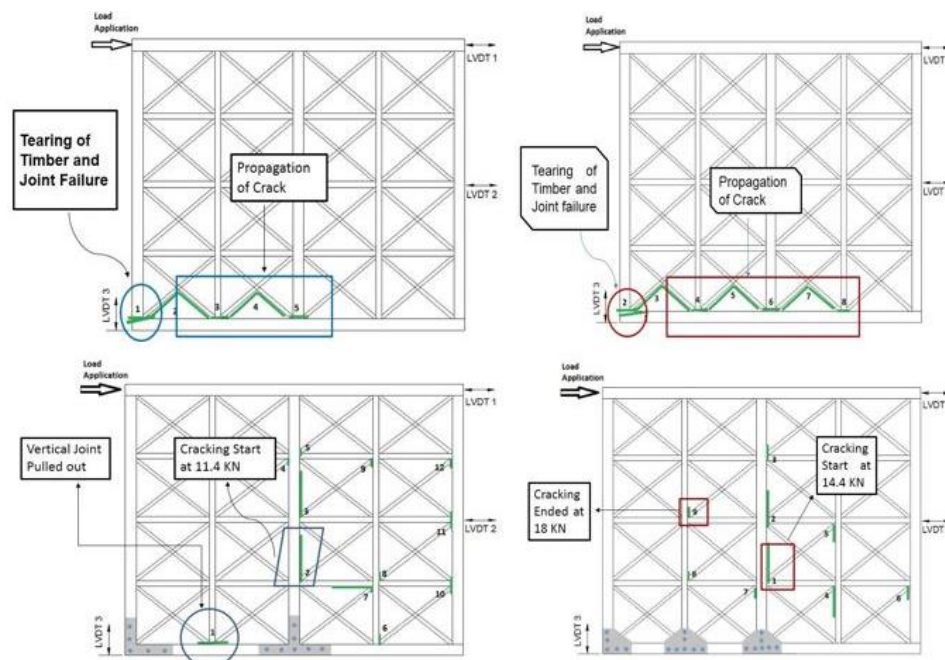


Figure 13. Line Diagram of DDW1-4 Failure

4. Conclusion

The experimental analysis was carried out on four reduced scale DD walls and joint strengthening was applied to three panels using Bamboos, Metal strips and Metal gusset plates. Failure Patterns changed after joint strengthening and trend shifted toward the ductile shear failure instead of brittle failure. Based on lateral load behavior and cost, DDW3 (Panel Strengthened with Metal strips) is better among the four panels tested and metal strips are suggested as the strengthening technique for Dhajji walls.

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