Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1537

IN-PLANE BEHAVIOR OF FULL SCALE DHAJJI WALLS (WOODEN BRACED FRAME WITH STONE INFILL) UNDER QUASI-STATIC LOADING

Qaisar Ali[1], Tom Schacher[2], Mohammad Ashraf[1], Akhtar Naeem [1], Bashir Alam[1]

ABSTRACT

This paper presents the in-plane behavior of full scale Dhajji walls, a wooden braced frame with stone infill system, tested under quasi-static loading. This type of construction is commonly practiced in parts of Kashmir, Pakistan and India. As part of this study, three full scale Dhajji walls were subjected to increasing intensities of quasi-static cyclic loading. Strength, deformability, hysteretic behavior, energy dissipation capacity, damping and damage pattern have been studied. The results obtained from the experimental data may be used for the numerical modeling and design of Dhajji house.

Introduction

Dhajji means interconnected in local Kashmiri language or patch quilt wall in Persian. It is a type of traditional construction, used in parts of northern regions of Pakistan, India and Kashmir. In this type of construction, a wooden frame is first erected which is then filled with suitable materials, generally rubble stones with mud mortar, figure 1.

Figure 1. Typical Dhajji Construction in Northern areas of Pakistan

The Kashmir earthquake of October 8, 2005 has caused destruction to many buildings resulting in the loss of lives and property (ADB/WB 2005). However the performance of this traditional construction was found to be extremely good in the October 8, 2005 Kashmir Earthquake (Schacher 2008 and H. Mumtaz 2008). Consequently the ERRA (Earthquake

[1]Department of Civil Engineering, NWFP University of Engineering & Technology Peshawar, Pakistan
[2] Architect, Technical Advisor Swiss Agency for Development and Cooperation

Reconstruction and Rehabilitation Authority), the official body of the government of Pakistan responsible for reconstruction and rehabilitation in the earthquake affected areas of Pakistan and Pakistan administered Kashmir, allowed its use for construction of housing units in some parts of the earthquake hit areas, particularly in Kashmir. The ERRA in collaboration with UNHABITAT prepared pictorial construction catalogues (ERRA 2006) highlighting main features of such Dhajji construction for its onward use by middle and lower level professionals involved in construction industry. However, all this information was based on the qualitatively good performance of Dhajji construction in the past earthquakes and not on a quantitative scientific rationale. Therefore a research project aiming at seismic capacity evaluation of such structures was extremely essential.

This paper presents the in-plane behavior of full-scaled Dhajji walls under quasi-static loading. Three full scale Dhajji walls were subjected to increasing intensities of quasi-static cyclic loading. The research is a part of study titled “Seismic Capacity of Dhajji Buildings” in progress in the Earthquake Engineering Center (EEC) of NWFP University of Engineering and Technology (UET), Pakistan. The results obtained from the experimental data may be used for the numerical modeling and design of Dhajji house.

Experimental Program

The experimental program consisted of quasi-static testing of three full scale Dhajji wall specimens.

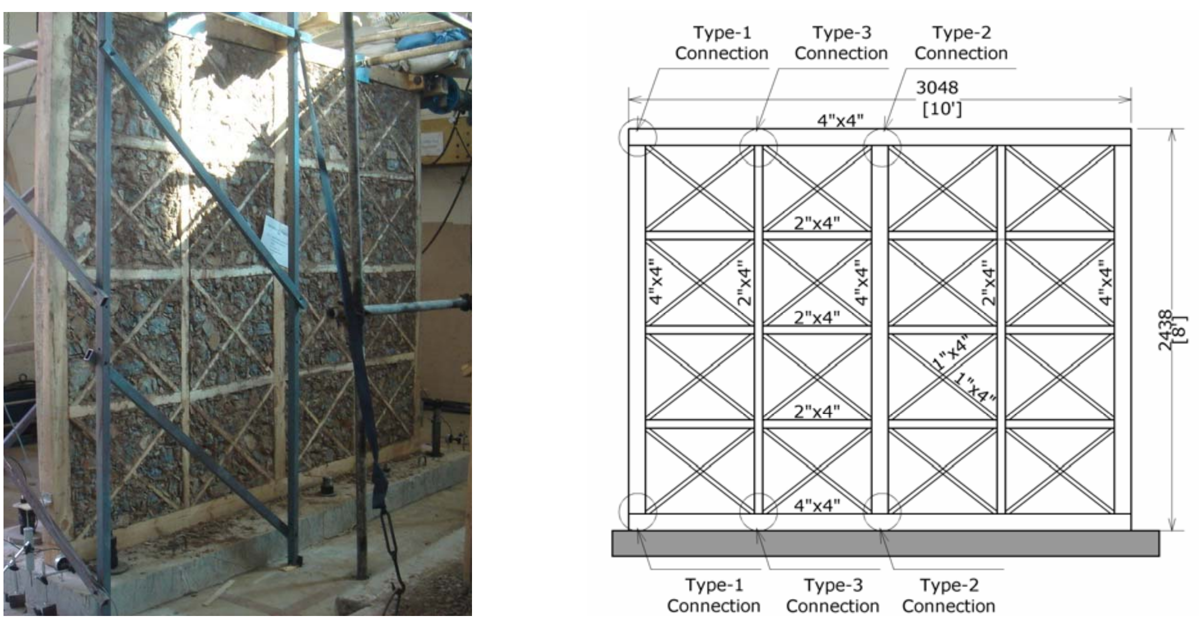

Figure 1. Dhajji wall test specimen, wall and member sizes, and configuration

Test Wall Specimens

Three full scale walls (DW-1, DW-2 and DW-3) were constructed in the EEC of NWFP UET Pakistan. The wall size, member sizes and configuration were chosen to be representative of ERRA specification given in their manual and common construction practice being followed in the area, figure 1. Length of the test specimens was kept equal to 10 ft. Height was kept equal to the storey height. Main and secondary vertical posts were connected to the top and bottom horizontal members through tennon and mortise connection detailed in figure 2. Wooden nails 3″ long made of mild steel were used to fix the connections. The intermediate horizontal members were connected through type-3 connection to the main vertical posts and through two wooden nails 3″ long with secondary posts. Similarly each brace was connected to the vertical post with two wooden nails 2″ long.

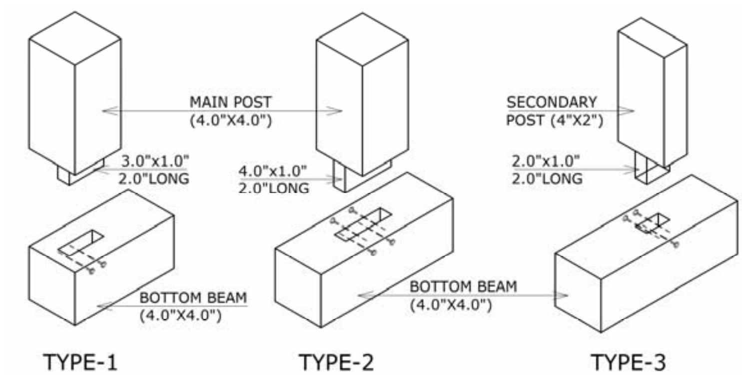

Figure 2. Tennon and mortise connections details

Infill in specimens DW-1 and DW-2 comprise a random rubble stone masonry in mud mortar. The same materials were used in the construction of all walls except the infill material. In DW-1, the infill comprised a stone to mud ratio of 9:1, whereas in DW-2, the ratio was 7:3. Specimens DW-3 was tested without any infill. The purpose of testing DW-3 was to ascertain the effectiveness of infill in the structural behavior of Dhajji buildings. All the three walls were fixed to a 6″ thick reinforced concrete footing using three 3/8″ Φ MS bolts.

Wall Test setup and procedure

The experimental test setup is shown in figure-3. The reinforced concrete footing was fixed with the strong floor of the laboratory. Horizontal load was applied through a hydraulic jack attached to the top horizontal wooden member of the wall. Horizontal load was measured through a load cell of 50 tons capacity. Hinges were provided at both the ends of hydraulic jack to release the horizontal and vertical rotations. 200 kg vertical dead load was applied through sand bags placed on top of each main vertical post to simulate load from roof truss. Eight displacement transducers numbered from 1 to 8 were used to measure displacement. All the gauges were connected to a data acquisition system. Restraints were provided to restrict the out-of-plane movement of the wall but allowing free in-plane movement. In-plane displacement measured with gauge-01 was used as the control displacement.

Both walls were subjected to increasing intensities of quasi-static cyclic loading. Each load cycle consisted of loading the specimen to a specified displacement level, unloading to zero displacement, reloading in the negative direction to the same specified displacement and again unloading to zero displacement. Each displacement cycle was repeated three times.

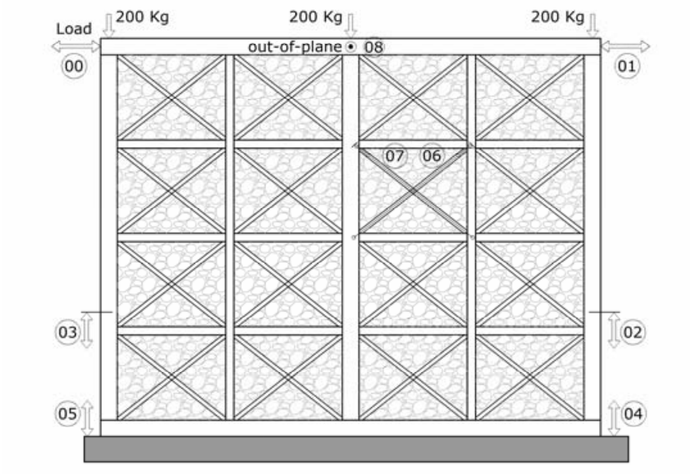

Figure 3. Test setup for Dhajji Wall specimens

Observed Behavior of Dhajji Walls

The behavior of both Dhajji wall specimens DW-1 and DW-2 were almost similar. The pushing and pulling forces caused the opening of various joints and finally the complete separation of the joint members. The walls showed rocking behavior in form of opening and closing of bottom connections from the very beginning of the test, figure 4. Connections of intermediate beams and bracers with secondary post kept on opening and closing with positive and negative displacement. The behavior of walls with infill was more or less similar with the main difference being that in DW-1 the failure initiated from the front bottom connection while in DW-2 the rear bottom connection failed first. The behavior of both walls having been subjected to complete loading cycles is given as follows:

Figure 4. Separation of infill from wooden frame and opening of connections

Behavior of Specimen DW-1

The force-deformation hysteresis loops, positive, negative and average envelope curves and the bilinear approximate curves are shown in figure 5. The hysteresis loops showed a stiffening trend with increasing displacement. Both the positive and negative curves followed same trend up to 25.0 mm displacement. After 25 mm cycle, strength degradation started in the negative loading direction while the load was still increasing in positive load direction. It happened because of the failure of the front bottom connection well before the rear bottom connection. The load in positive direction kept on increasing until the 50 mm cycle during which the rear bottom connection failed and the strength dropped to a value which was almost equal to the strength in the negative direction. Afterward, the behavior was almost similar in positive and negative directions.

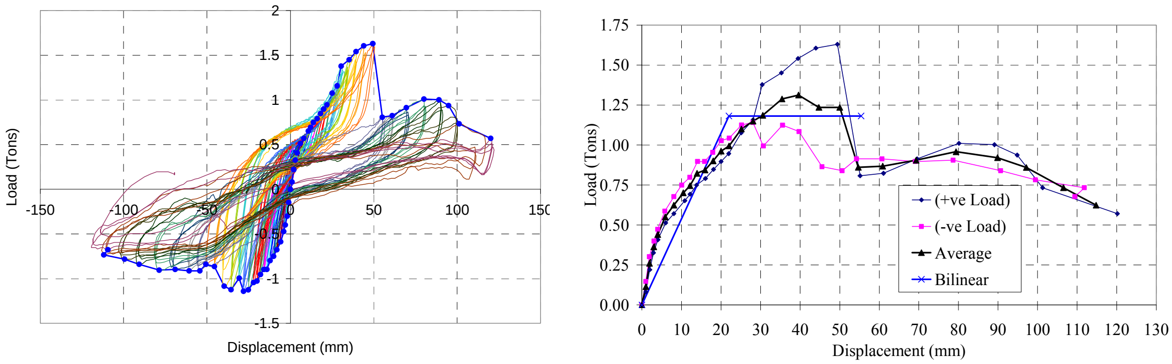

Figure 5. DW-1: Force-deformation hysteresis loops (left) and envelope curves (right)

Behavior of Specimen DW-2

The behavior of wall DW-2 in the positive and negative loading directions was almost same up to the 4.0 mm displacement. But after that, significant decrease in the stiffness was observed in the positive load direction, figure 6. However the stiffness in the negative load direction was changing at a slower rate. The wall reached to its peak resistance both in positive and negative direction at almost same displacement level but the resistance in negative load direction was greater than that in the positive direction. Despite the difference in peak resistance of the positive and negative load cycles, the shape of force-deformation envelope was found to be similar.

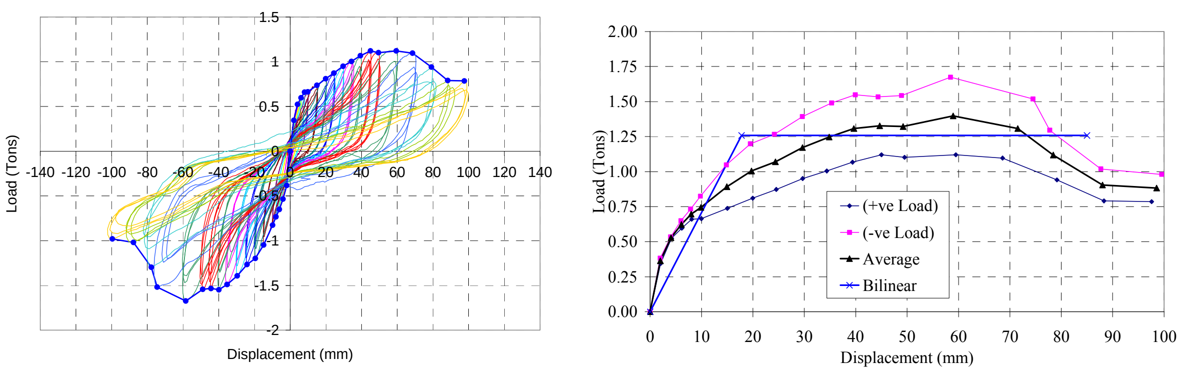

Figure 6. DW-2: Force-deformation hysteresis loops (left) and envelope curves (right)

Behavior of Specimen DW-3

Compared to previous two walls, the behavior of wall DW-3 in positive and negative direction was almost similar, figure 7. Since there was no interaction of frame with the infill, the overall behavior of wall DW-3 was more explicit and symmetric than that of DW-1 and DW-2, figure 8. Moreover it can also be observed from figure 8 that effective stiffness of DW-3 is less than that of DW-1 and DW-2. On the other hand the ultimate displacement capacity of DW-3 is more than that of DW-1 and DW-2. However the ultimate strength of all walls is found to be approximately the same.

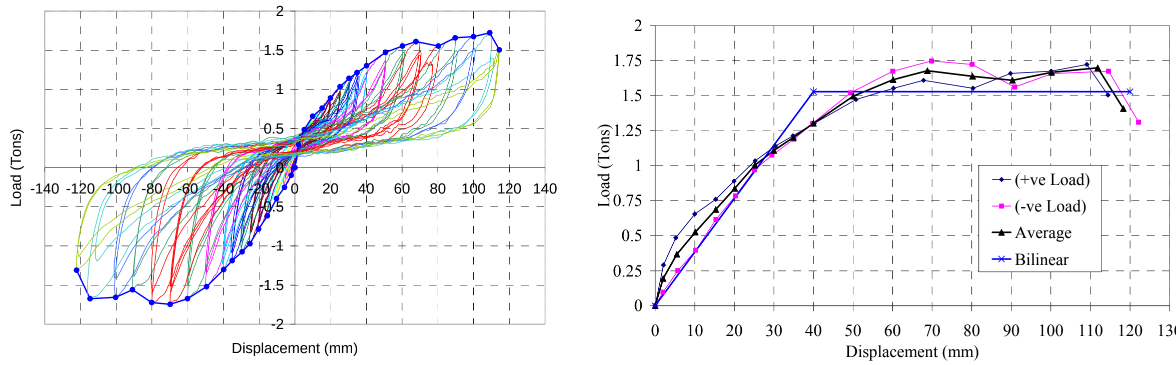

Figure 7. DW-3: Force-deformation hysteresis loops (left) and envelope curves (right)

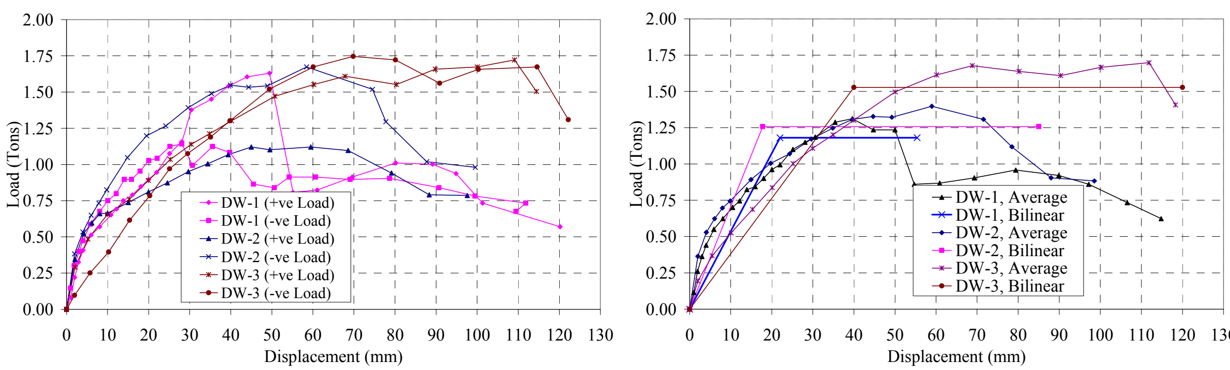

Figure 8. Force-deformation curves of all walls (left), average and bilinear curves (right)

Equivalent Viscous Damping:

Equivalent viscous damping calculated from the hysteresis loops was found to be increasing with increasing drift (figure 9) for walls with infill material. The damping remained constant for specimen DW-3.

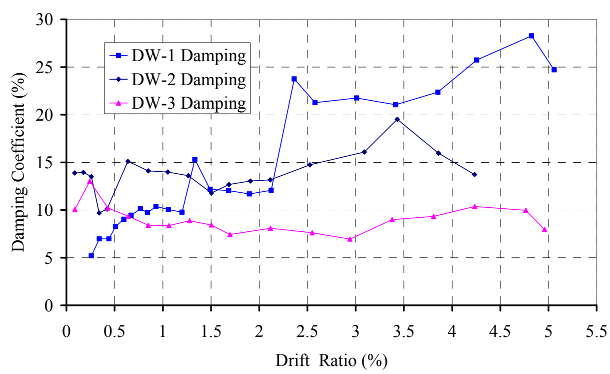

Figure 9 Equivalent viscous damping

Conclusions

- Effective stiffness of DW-1 and DW-2 is more than that of DW-3, the ultimate strength of all walls is however approximately the same. Two important conclusions can be drawn from this behavior of the walls; (a) stone masonry infill does not play any role in increasing the lateral load capacity of the system (b) the ductility of wall without infill is higher than those with infill.

- The elastic hysteretic damping of the system in all cases is around 7 %. However the damping ratio in walls with infill increases from 7 % to 20 % with increase in displacement, whereas the damping of wall without infill almost remains constant at 7 % for all displacements.

- As the main timber members did not suffer any damage in all tests, the type of timber used in such system of construction will not affect the overall performance of structure provided treatment against termite attack and moisture is properly done.

- The energy dissipation occurred mainly around the connections between the main post and bottom horizontal band (end tennon and mortise connection). The investigation of the overall behavior of the system infers that the capacity of these connections will measure the capacity of the whole system. Therefore the construction of this connection shall be properly executed.

- It was observed that the system has a lot of redundancy; therefore distance between the vertical and horizontal posts may be increased from 2 to 3 feet to economize the system. Similarly instead of X bracing, Z bracing can also be used to further economize the construction of the system.

Acknowledgments

The authors greatly acknowledge the financial support from the Board of Advanced Studies and Research at N-W.F.P University of Engineering & Technology Peshawar Pakistan, Higher Education Commission Islamabad, Rectors' Conference of the Swiss Universities of Applied Sciences (KFH) and Philip Morris International. The authors acknowledge the support of lab staff of EEC, Earthquake Engineering Center at N-W.F.P University of Engineering & Technology Peshawar. The authors also acknowledge the support of Maggie Stephenson of UNHABITAT for her valuable suggestions.

References

Hamid Mumtaz et al. 2008. The Challenges of Reconstruction after the October 2005 Kashmir Earthquake, *NZSEE Annual Conference,* New Zealand

ABD and WB 2005. Pakistan 2005 Earthquake, Preliminary Damage and Needs Assessment, www.worldbank.org

Earthquake Rehabilitation and Reconstruction Authority (EERA) Pakistan, 2006. Reconstruction for ERRA approved Dhajji timber frame house reconstruction, www.erra.pk/Reports/Housing/Dhajji

Tom Schacher, Qaisar Ali, 2008. Timber reinforced stone masonry in northern Pakistan in the context of the post earthquake reconstruction efforts, *International Seminar on seismic risk and rehab of stone masonry housing,* Azores Portugal.