Experimental Study on Lateral Strength of Confined Masonry Walls

Behrang Sarrafi
PhD student, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran. (Email: b.sarrafi@iiees.ac.ir)

Sassan Eshghi
Associate Professor, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran. (Email: s.eshghi@iiees.ac.ir)

15 WCEE
LISBOA 2012

SUMMARY:
The aim of this study is to study experimentally the lateral strength of confined masonry walls comprised of solid clay brick masonry panels and concrete confining elements. For this purpose, a series of experimental studies conducted on confined masonry walls in International Institute of Earthquake Engineering and Seismology (IIEES) laboratory are introduced. It contains 7 wall specimens which are tested under lateral cyclic loading. In the construction of specimens, conventional materials and the forms of construction in Iran are adopted. Bricks are fired clay bricks and ties are of cast-in-place reinforced concrete. In constructing masonry walls two different methods of construction, with and without filled mortar head joints, are adopted in different specimens. Three of the specimens are with central opening and all are in half scale. Results of these tests are presented and analyzed with respect to cracking strength, maximum strength, deformation capacity and energy dissipation.

Keywords: Confined Masonry Walls, Lateral Strength, Experimental Study, Cyclic Loading, Clay Bricks

1. INTRODUCTION

Confined masonry walls that form confined masonry buildings are made by masonry panels confined by specific elements called *ties*. Ties can be made of materials like concrete, steel or wood but the most common one is reinforced concrete. Confined masonry buildings are conventional forms in many earthquake prone zones worldwide. Whereas, most of the present design code methods for confined masonry buildings are mostly based on the old provisions for unconfined masonry buildings. Thus, they are not realistic enough to estimate capacity of these systems.

Confined masonry buildings have presented a good performance in past earthquakes. Fig. 1 shows a confined masonry building after Bam earthquake, Iran 2003, which remained undamaged. Although the behavior of confined masonry walls is not well known, due to the lack of experimental studies, in spite of masonry experimental research programs conducted in many countries. The aim of this paper is to study the behavior of confined masonry walls under cyclic lateral loading experimentally. Totally seven walls were tested under cyclic lateral loading. The focus of the study was to consider local construction methods and materials. To assess the effect of filled head joints, vertical load and central openings walls were designed in different conditions. Two walls were constructed without filled head joints (CMSW-01 and CMSW-02), two walls with filled head joints (CMSW-03 and CMSW-04). Other three walls were built with central opening as a window opening. All walls were tested under a constant vertical load (2tons) except one (CMSW-04) that was tested under extra vertical load (4tons).

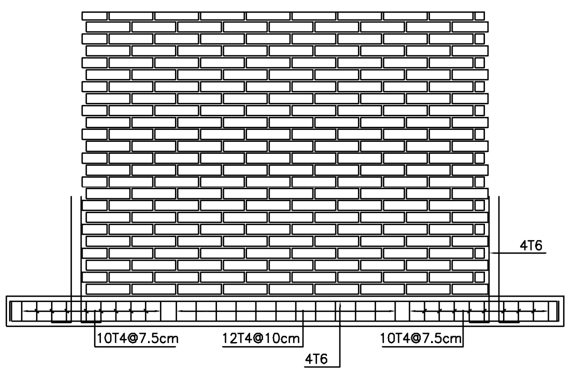
2. EXPERIMENTAL PROGRAM

2.1. Characteristic of specimens

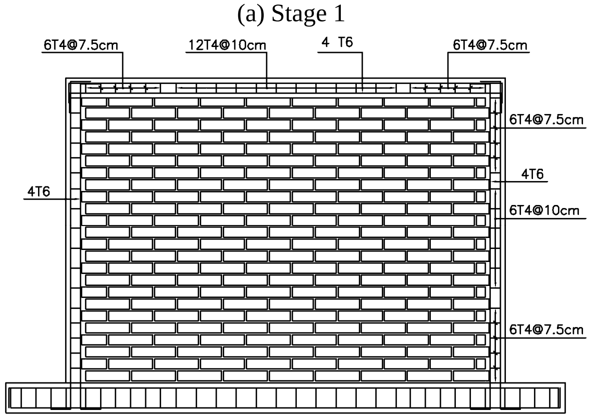
Seven half-scale confined masonry walls were constructed and tested under lateral cyclic loading. In the construction of confined masonry walls masonry panels are built first. Then ties concrete is cast.

Fig. 2 shows construction stages of the specimens and reinforcement details. The first four walls were solid walls called *CMSW-i*, in which “i” is an index to show the sequence of construction and test of specimens. The next three specimens built with a central opening are called *CMOW-i*. The dimension of the central opening was considered 60×45 cm to be a scale of a window opening. Figure 2 shows the dimensions of the so called CMSW-i and CMOW-i specimens. Height and width of the walls are chosen to represent common wall panels designed based on local code provisions. Vertical tie columns and upper horizontal ties are 10 ×10cm. The lower horizontal one is 15×15cm. In CMOW-01 and CMOW-03, two 30×30×3 mm angles, 80 cm in length, were used as a lintel. Three bars were welded to both angles in 3 points to connect them. Lintel in CMOW-02 was expanded and connected to the vertical ties. Similar to CMOW-01, the area section of the lintel was two 30×30×3 mm angles connected together by six small bars welded to the both angles in the length. Wall dimensions are presented in Fig. 3. Tie reinforcement is designed according to the Iranian Seismic Code (Standard No.2800-5).

Figure 1. A confined masonry building that did not collapse after the Bam earthquake, Iran, 2003

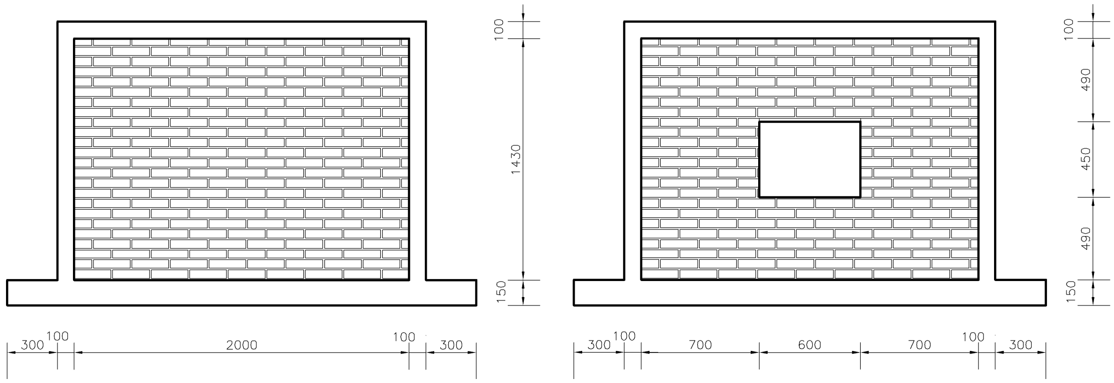


(a) Stage 1



(b) Stage 2

Figure 2. Confined masonry wall construction stages



(a) CMSW-i (b) CMOW-i

Figure 3. Walls dimensions

2.2. Material properties

Solid fired clay bricks are used to construct the walls. A series of material tests were performed to determine properties of bricks, mortars and concrete according to ASTM standards (ASTM, 2005). Table 1 shows the mean value and the coefficient of variation for each parameter of brick units. Two or three specimens were made from each batch of mortar using standard 50×50×50 mm cubes. Also, 16 standard cylindrical specimens were made from different concrete batches. The results of compressive tests on concrete and mortar specimens are shown in Table 2 (Sarrafi & Eshghi, 2012).

Two masonry prisms were constructed with the dimensions 180×100×210 mm (5 brick courses) and four smaller specimens with the dimensions 105×45×70 mm height (2 brick courses) sizes. Prisms were tested in a universal testing machine to measure both compressive strength and elasticity module of masonry. Other samples were tested by another testing machine that measures ultimate compressive strength. Strength correction factors from Mexican Standard (NTCM, 2004) are assigned to masonry piles with different height-to-thickness ratios. The results of tests are summarized in Table 3.

Table 1. Results of tests on brick units

Property	**Dimensions**	**Absorption**	**Comp. Strength**	**Module of Rupture**
Unit	cm	-	MPa	MPa
No. of tested units	10	10	10	5
Mean value	10.4×4.8×3	19.8%	6.54	1.96
Coefficient of variation	0.04	0.07	0.1	0.1

Table 2. Results of compressive tests on concrete and mortar specimens

Material	**Mortar**	**Concrete**
No. of tested specimens	16	16
Mean value (MPa)	7.7	19.6
Coefficient of variation	0.3	0.4

Table 3. Results of compressive tests on masonry prisms

Property	**Comp. Strength**	**Modulus of Elasticity**
Unit	MPa	MPa
No. of tested units	6	2
Mean value	1.7	172.4
Coefficient of variation	0.1	0.1

2.2. Testing procedures

The testing set up is shown in Fig. 4. As shown in the Figure, a 25-ton hydraulic jack connected to the reaction frame acts the lateral force to the loading beam. The wall was constructed on an steel beam. Lateral forces acting on the wall are transferred to the beam by shear keys that are welded to the beam. As seen in Fig. 4, a triangular reaction frame is prepared and connected to the strong floor. Also, an I-shaped steel beam is constructed with proper strength and stiffness to assign vertical and lateral loads to the wall. This lateral load is transferred to the wall at two end points of the tie beam and two shear keys fixed to the tie beam. These four points are chosen to distribute the lateral load over tie beam to simulate the loading from an actual roof.

Cyclic displacement history was defined according to the Mexican standard (NTCM, 2004) except first six force-controlled cycles that replaced by equivalent displacement-controlled cycles due to the hydraulic jack limitations. The applied displacement history is shown in Fig. 5.

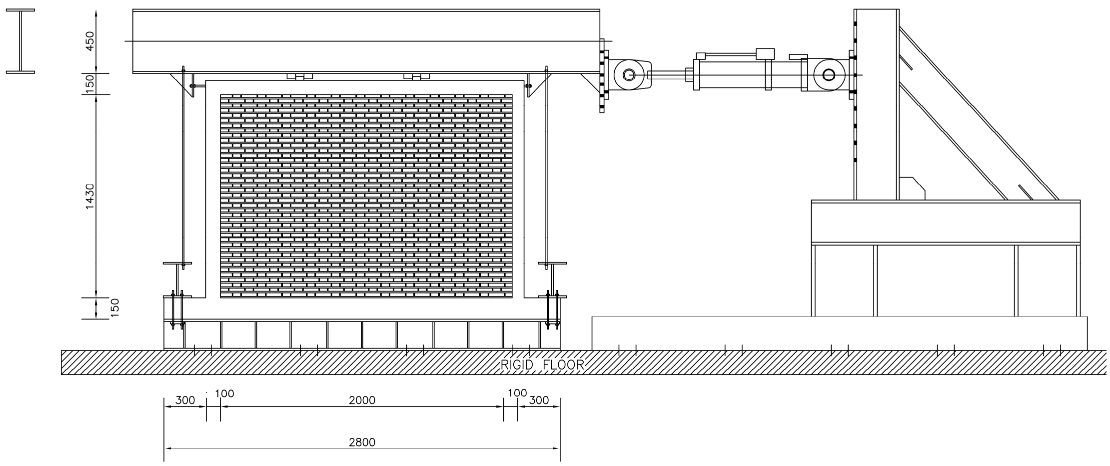


Figure 4. Loading setup

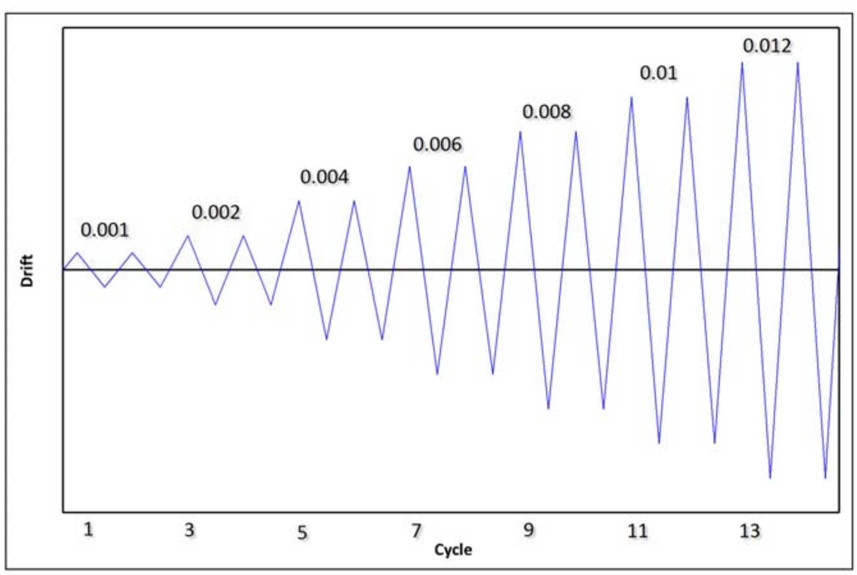


Figure 5. Cyclic loading pattern

3. TEST RESULTS

All the specimens failed in shear. In all specimens cracks started from the mid points of the masonry panel or opening corners and propagated inclined to the ties. At the last stages of loading, cracks appeared in both ends of the vertical ties.

For the first two specimens, CMSW-01 and CMSW-02 for which head joints were not filled, at the end of the test most cracks were through the joints; only very few cracks were through the bricks due to a low adherence between bricks and mortar. For the other specimens, head joints were filled with mortar. Moreover, all bricks were soaked in water before constructing the wall. These modifications made the connection between the bricks strong enough so that cracks did not propagate only through joints.

2.1. Strength capacity

Table 4 shows the loads and displacements corresponding to forming the first crack in the masonry panel and peak shear force of the walls under lateral load. The parameter Fv is the total compressive strength applied on the walls through the loading beam.

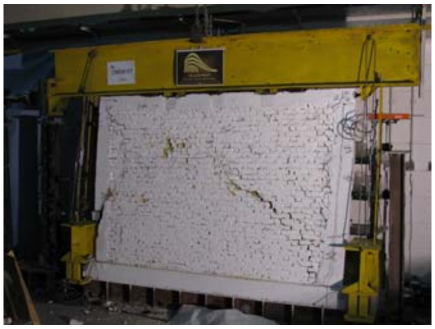
Fig. 6 shows the envelope of the hysteresis curves for CMSW and CMOW walls. As seen, there is a major difference between the peak lateral strength of specimens with and without filled head joints, CMSW-01 and 02 with CMSW-03 and 04. This difference shows the significance of filling head joints in masonry construction.

2.2. Cyclic stiffness degradation

As seen in Fig. 6, at each drift value two cycles were applied. The stiffness at each drift value is defined as the slope of the line joining the maximum positive and negative deformation at the second cycle of each drift. The stiffness is then normalized with respect to K_o, which is the stiffness of the first cycle of the deformations applied to the specimens. Stiffness degradation curves for all walls are shown in Fig. 8.

Table 4. Strength capacity of the walls

Wall	Fv	First crack		Peak shear force	
	(Mpa)	F (kN)	drift	F (kN)	drift
CMSW-01	10	12.8	0.0012	14.2586	0.0102
CMSW-02	10	5.1	0.0008	16.3425	0.0158
CMSW-03	10	26.3	0.0019	38.0	0.0036
CMSW-04	20	32.1	0.0018	50.2	0.0038
CMOW-01	10	40.4	0.0039	54.8	0.0077
CMOW-02	10	50.9	0.0053	69.7	0.0159
CMOW-03	10	33.5	0.0020	40.8	0.0039



(a) CMSW-01

(b) CMSW-02

(c) CMSW-03

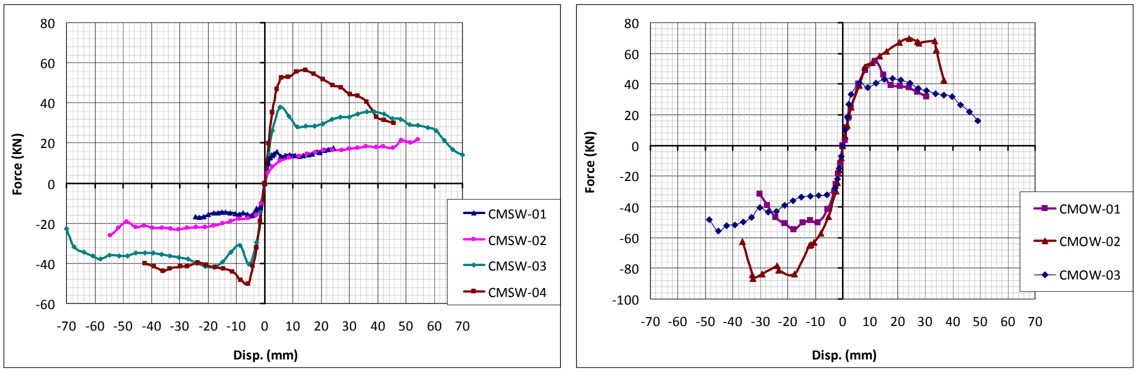
(d) CMSW-04

(e) CMOW-01

(f) CMOW-02

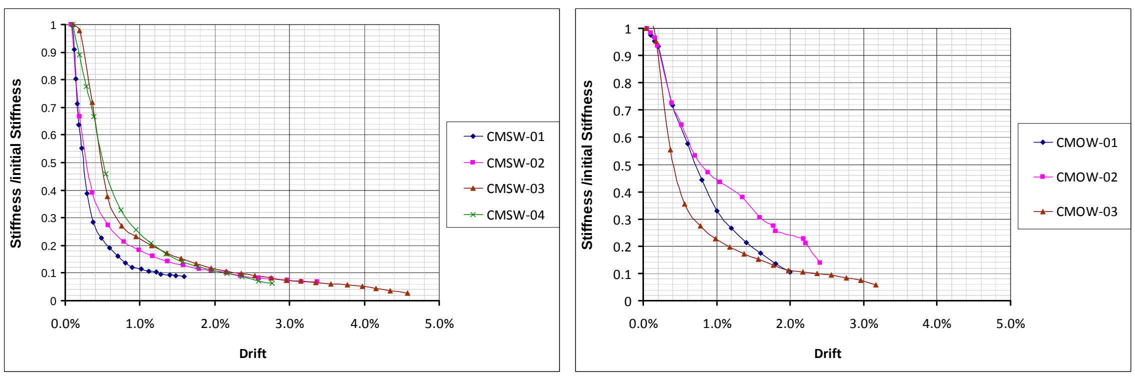
(g) CMOW-03

Figure 6. Cracking patterns of the wall specimens



(a) CMSW walls (b) CMOW walls

Figure 7. Envelopes of hysteresis curves



(a) CMSW walls (b) CMOW walls

Figure 8. Normalized secant stiffness

3. CONCLUSION

Seven half scale walls are reported in this paper. The walls were designed according to the Iranian Seismic Code (Standard No.2800-5) and were subject to lateral cyclic loading. Local workers and materials were employed. The following conclusions can be made from the experimental results:

The results showed that omitting mortar head joints and soaking bricks for at least 1 minute in water significantly decreased lateral strength and deformation capacity of confined masonry walls. It indicates that constructing walls with unfilled head joints should be prohibited by codes including the Iranian Seismic Code.

The amount of vertical load applied on confined masonry walls significantly affected the lateral load capacity. Increasing the vertical load from 2 to 4 tons resulted in 45% greater maximum lateral strength under cyclic loads. However, it did not affect initial stiffness and the first cracking drift of the wall. Moreover, extending the steel lintel to the vertical ties and connecting them with a U-shape bar elevated the lateral resistance of the wall with a central opening by 27%. The lateral resistance of this wall (CMOW-02) was even more than that of a similar wall without an opening (CMSW-02). It shows that complicated and expensive methods of confining openings can be replaced by easier methods such as extending and connecting lintels to the vertical ties.

Overlay, the results indicate that minor changes in the construction of confined masonry walls will considerably affect their behaviour under cyclic loads. The results imply that a number of experimental studies should be performed in order to enable code provisions to consider different circumstances such as local worker skills, material properties, and construction methods.

AKCNOWLEDGEMENT

This study was funded by the Structural Engineering Research Center at International Institute of Earthquake Engineering and Seismology (IIEES) under grant No.7365. The tests were performed in the Structural Laboratory of IIEES. The authors wish to thank its technical staff.

REFERENCES

American Society for Testing and Materials, ASTM (2005), Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile, C-67-03a, *Annual book of ASTM standards*, **Vol. 04.05**, West Conshohocken (PA).

American Society for Testing and Materials, ASTM (2005), Standard Test Method for Compressive Strength of Masonry Prisms, C-1314-03b, *Annual book of ASTM standards* **Vol. 04.05**, West Conshohocken (PA).

American Society for Testing and Materials, ASTM (2005), Standard Test Method for Compressive Strength of Hydraulic Cement Mortars, C-109-02, *Annual book of ASTM standards*, **Vol. 04.01**, West Conshohocken (PA).

American Society for Testing and Materials, ASTM (2005), Test Method for Compressive Strength of Cylindrical Concrete Specimens, C39-04a, *Annual book of ASTM standards* **Vol. 04.02**, West Conshohocken (PA).

Sarrafi, H. and Eshghi, S. (2012). Behavior of clay brick confined masonry walls under cyclic loads. *The Masonry Society (TMS) Journal* , under review.

NTCM-2004 (2004), Complementary Technical Norms for the Design and Construction of Masonry Structures, *Gaceta Oficial del Distrito Federal*, Mexico.