Effects of Construction Methods on Seismic Behavior of Confined Masonry Walls - An Experimental Study

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SUMMARY:
The aim of this paper is to study experimentally conventional constructing methods of confined masonry buildings in Iran and to investigate differences in the seismic behavior of them. In present study the effect of mortar head joints, soaking bricks and extending lintel to the vertical ties in the behavior of confined masonry walls are considered. A series of experimental study are conducted on confined masonry walls in IIEES (International Institute of Earthquake Engineering and Seismology) laboratory. It includes 7 wall specimens which are tested under lateral cyclic loading. Two of them are without mortar head joints, three others are with central opening with and without lintel band and the others are solid walls with filled head joints. Bricks are fired clay bricks and ties are made up of cast-in-place reinforced concrete. Results of these tests are presented and effect of head joints, soaking bricks and extending lintel on overall behavior of them are discussed.

Keywords: Confined Masonry Walls, Experimental Study, Construction Methods, Seismic Behavior

1. INTRODUCTION

Constructing confined masonry buildings is common on many earthquake prone zones worldwide. Obviously, due to difference in local workers' knowledge, skill level and supervision, typical constructing methods vary area to area. The differences can be seen in masonry courses arrangement, filling or not filling head joints with mortar, mortar and concrete construction, brick type, lintel material and so on. Previous studies showed that even minor change in construction process of the masonry structures can lead to major changes in their seismic behavior.

The aim of this paper is to study experimentally the conventional construction methods of confined masonry buildings in Iran and to investigate differences in the seismic behavior of them. Totally seven walls were tested under cyclic lateral loading. All specimens were built as half scaled models. They were constructed using different methods to assess the effect of construction methods on the behavior of confined masonry walls. First two walls (CMSW-01 and CMSW-02) were constructed without filled head joints, which is a common method in many non-engineered masonry walls. Head joints were filled with mortar in the next two specimens (CMSW-03 and CMSW-04) to enable us to investigate the effect of head joints by comparing the results with two first specimens. Moreover, all bricks were soaked in water before constructing the wall. 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 an extra vertical load (4tons).

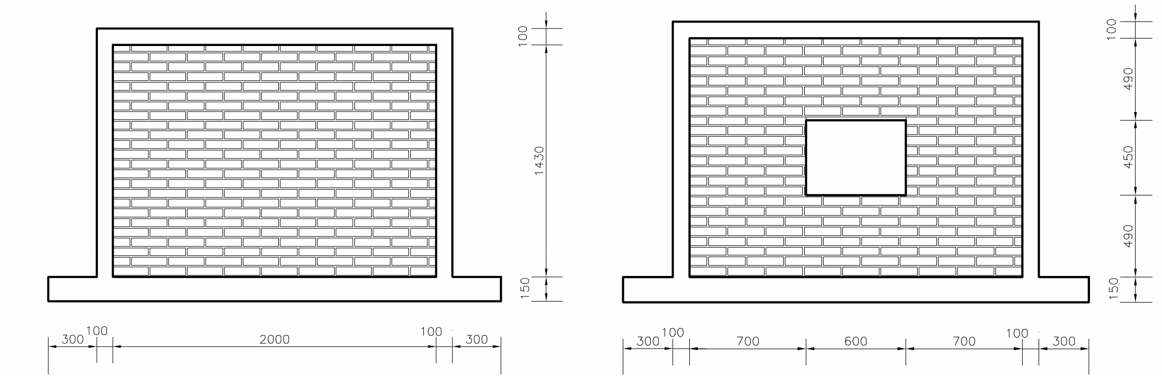
2. EXPERIMENTAL PROGRAM

2.1. Characteristic of specimens

Seven half-scale confined masonry walls were constructed and tested under lateral cyclic loading. 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.

Head joints were filled in all specimens except CMSW-01 and CMSW-02 (Fig. 4). As seen in Fig. 5 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 as shown in Fig. 6. 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. Reinforcement details of the ties are shown in Figure 3. Tie reinforcement is designed according to the Iranian Seismic Code (Standard No.2800-5).



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

Figure 2. Wall dimensions

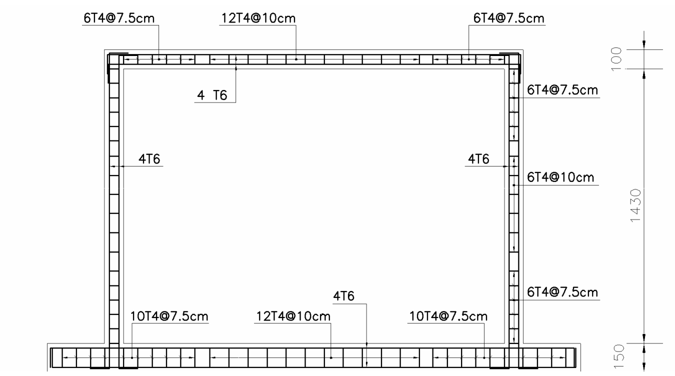
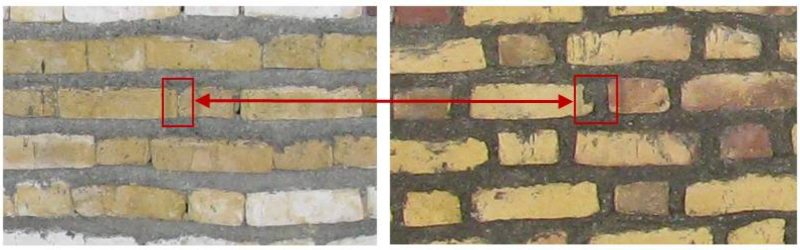


Figure 3. Reinforcement details of the wall specimens (dimensions in mm)



(a) (b)

Figure 4. Construction detail of head joints (a) Unfilled head joint (b) Filled head joint

Figure 5. CMOW-01 and CMOW-03 with 80 cm length lintel

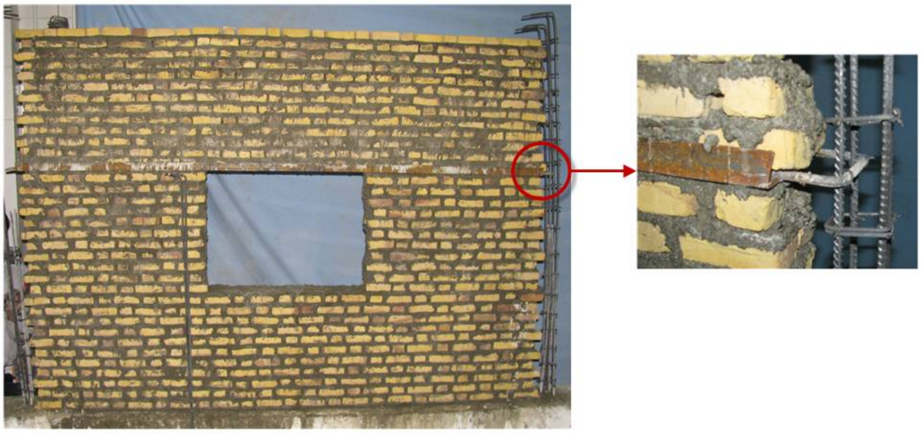


Figure 6. CMOW-02 with lintel band and its connection to the vertical tie

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. 7. 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. 7, 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. 8.

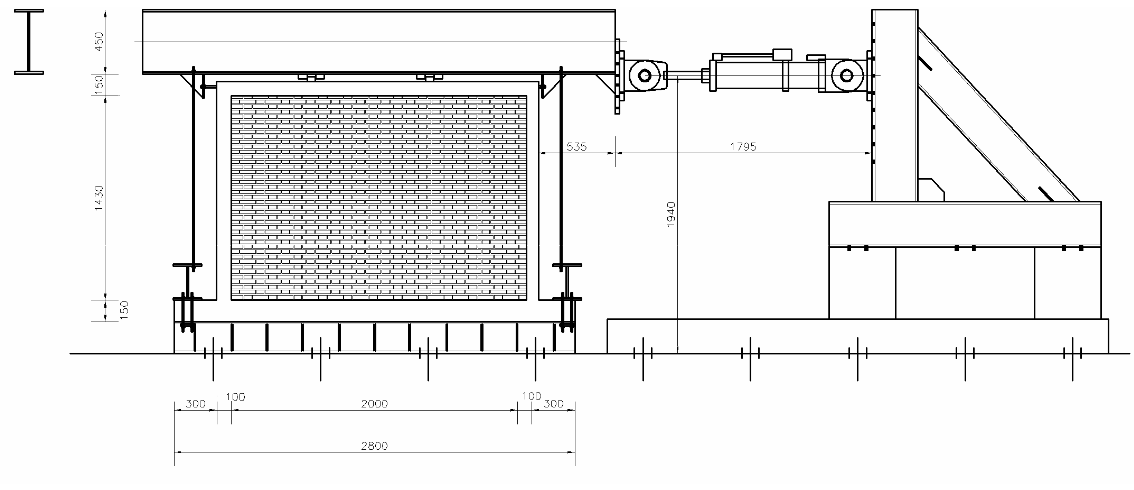


Figure 7. Loading setup

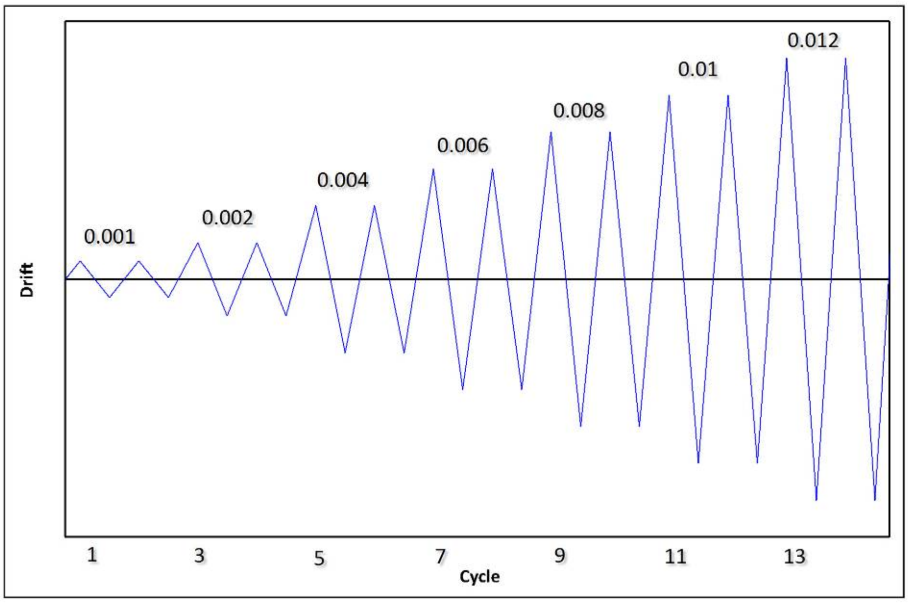


Figure 8. Cyclic loading pattern

3. RESULTS

3.1. The effect of filling head joints

The effect of filling head joints with mortar on the seismic behaviour of confined masonry walls can be investigated by studying the test results of the first four specimens. The first two specimens, CMSW-01 and CMSW-02 for which head joints were not filled, are compared with CMSW-03 and CMSW-04 specimens.

In the first two specimens, CMSW-01 and CMSW-02 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. In the next two specimens connection between the bricks was strong enough so that cracks did not propagate only through joints. Fig. 9 shows cracking pattern of the specimens.

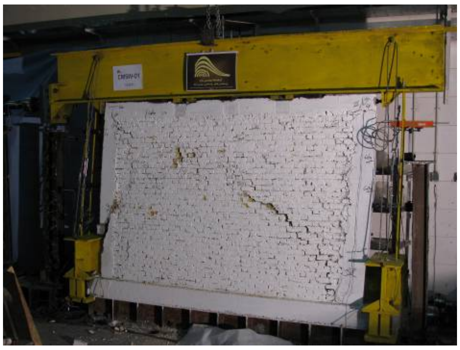
Fig. 10 shows the envelope of the hysteresis curves of the walls. As seen, there is a major difference between the peak lateral strength of specimens with and without filled head joints. This difference shows the significance of filling head joints in masonry construction. Increasing the vertical load from 2 to 4 tons in CMSW-04 specimen resulted in 45% greater maximum lateral strength under cyclic loads compared to CMSW-03 specimen.

3.2. The effect of using steel lintel band

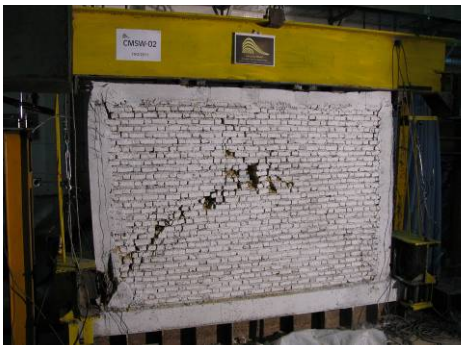
To assess the effect of using a steel lintel band on the behaviour of confined masonry walls with window opening, one of the three specimens, CMOW-02, is tested with an expanded lintel. The area section of the lintel was two 30×30×3 mm angles connected together by six small bars welded to the both angles in the length. These angles are connected to the vertical ties by the aid of U-shaped bars welded to the angles. Two other specimens were tested with central window opening and 80 cm length lintel with the same area section. In CMOW-01 and CMOW-03, two 30×30×3 mm angles, 80 cm in length, were used as a lintel.

Under lateral cyclic loading, the first crack of specimens CMOW-01 and CMOW-02 started from the upper right corners of the opening in approximately 0.4% drift. The cracks propagated towards the upper right and left corners of the masonry panel. Then, it passed through the intersection of the vertical and horizontal ties. But in CMOW-02 specimen cracks started from two lower corners and propagated to corners of the masonry wall. Fig. 11 shows final cracking pattern in CMOW specimens.

As shown in Fig. 12, using a steel lintel band connected to the vertical ties with a simple detail elevated the lateral resistance of the wall by 27%. This method improves energy dissipation capacity of the wall too. Fig. 13 shows cumulative energy dissipation of CMOW specimens.



(a) CMSW-01



(b) CMSW-02

(c) CMSW-03

(d) CMSW-04

Figure 9. Cracking patterns of the wall specimens

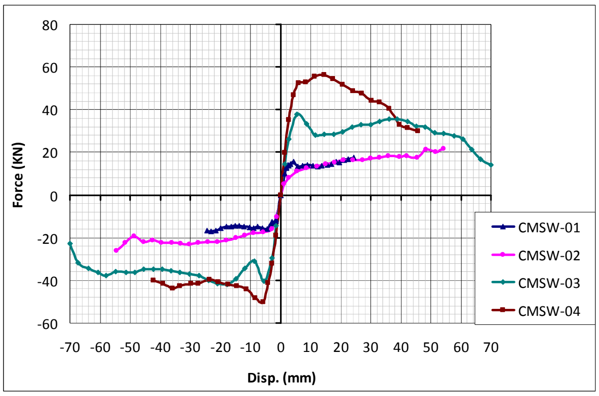
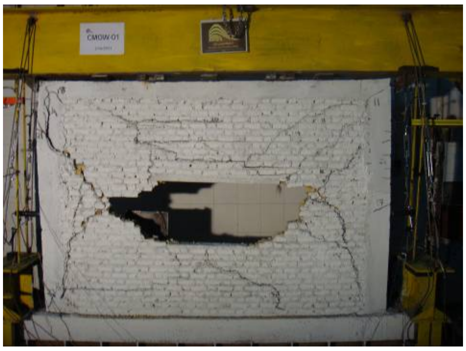
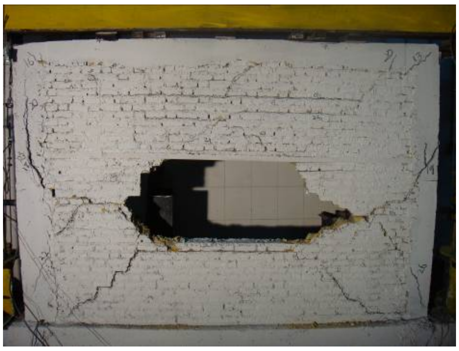


Figure 10. The envelopes of hysteresis curves of CMSW specimens



(a) CMOW-01



(b) CMOW-02

(c) CMOW-03

Figure 11. Cracking patterns of the CMOW wall specimens

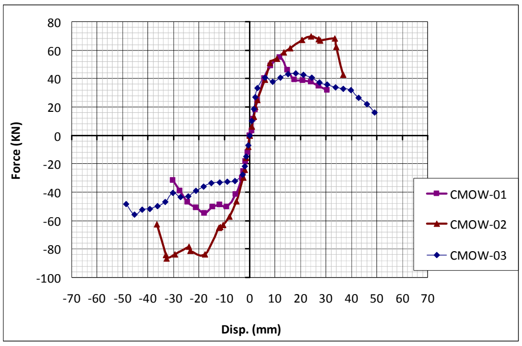


Figure 12. The envelopes of hysteresis curves of CMOW specimens

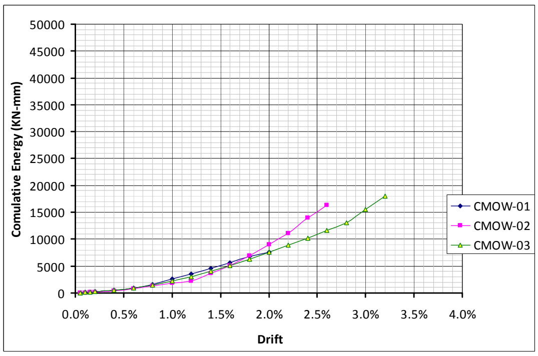


Figure 13. Cumulative energy dissipation of CMOW specimens

3. CONCLUSION

The results of tests on seven half scale confined masonry walls are reported in this paper. The focus of the study was to investigate the effect of construction methods on the seismic behavior of confined masonry walls. The walls were designed according to the Iranian Seismic Code (Standard No.2800-5) and local workers and materials were employed. It can be concluded that:

1. Omitting mortar head joints that occur mostly in non-engineered masonry walls significantly decreased lateral strength and deformation capacity of confined masonry walls.

2. Studying final cracking pattern of the CMSW-03 and CMSW-04 specimens and comparing it with two first specimens, CMSW-01 and CMSW-02, showed that soaking bricks for at least 1 minute in water improves mortar-to-brick adhesion significantly.

3. 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%.

4. The results indicate that minor changes in the construction methods of confined masonry walls will considerably affect their behavior under cyclic loads.

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