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PERFORMANCE OF BRICK MASONRY CAVITY WALLS WITH DIFFERENT WALL TIES

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ABSTRACT

This paper presents a study about the behavior of brick masonry cavity walls. Three types of cavity walls were tested, each having two wythes of 4½ inches thickness and 2 inches cavity between the two wythes. The first type did not have any ties, the second types had I-shaped ties while the last one had Z-shaped ties. A total of six specimens were fabricated and tested, two specimens for each of the three wall types. The specimens were then subjected to constant vertical and horizontal cyclic loads in a displacement controlled environment. Lateral strength, stiffness and ductility of the walls were determined and compared. Test results show that use of ties increases stiffness of cavity walls, the increase being higher in the case of I-shaped ties compared to Z-shaped ties. The ductility also increased with I-type wall ties. However, wall ties have no effect on the lateral strength.

KEY WORDS: *Wythe, shear connectors, lateral strength.*

INTRODUCTION

A cavity wall consists of two wythes of masonry separated by an air space or cavity of varying dimensions. Various types of materials can be used in masonry wythes. Common materials that are used in wythes are burnt clay bricks, clay tiles and concrete blocks. Furthermore, same or different types of materials can be used in the internal and external wythes[1]. The two wythes are connected with each other with the help of metal ties. According to the National Research Council of Canada the ties should be corrosion resistant and a bend of at least 2 inches should be provided at both ends. The size of cavity may range from 2 inches to 4-1/2 inches. The cavity may be a void or filled with some kind of insulating material. Cavity wall is a widely used construction technique throughout the world. Cavity walls are preferred over solid masonry walls because they have better thermal insulation, resist moisture penetration, and offer high resistance to sound transmission and fire [2]

In the modern era, cavity walls have gained popularity since 1950. Initially the use of cavity walls was limited to low-rise buildings but with the passage of time their use also started in high rise buildings [3]. Sound structural design, appropriate details, quality materials and good workmanship are required for high performance of cavity walls. Currently, masonry cavity walls are used extensively throughout the world in various types of buildings. However, this construction technique is virtually non-existent in Pakistan. Since insulation capabilities of cavity walls are well recognized so this research is primarily focused on the structural characteristics of cavity walls.

Published literature report a few studies about experimental testing of cavity walls. Li et al[4] performed cyclic tests on cavity walls models with different types of openings, without openings, and using different types of ties. They prepared twelve specimens; four with door openings, four with window openings and four without openings. Numerical model for cracking load and ultimate load was developed. It was concluded that ultimate load bearing capacity of the cavity wall is 10-15% lesser than that of solid masonry wall. The action of tie bar was to enhance the load bearing capacity of the inner wythe and to prevent the cracked wall from collapse during an earthquake. Wang et al[5] studied the behavior of full scale shear connected cavity walls under various loading conditions. The parameters investigated include material properties, aspect ratio, width of cavity and load eccentricities. A numerical model was developed to simulate the experimental results. From this research, it was concluded that shear connectors improve capacity and stiffness of slender masonry cavity walls. The failure of shear connectors can be avoided by spacing them closely and the stiffness of the shear connectors reduces the effect of the cavity width on

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the overall stiffness of the masonry cavity wall.

The aim of this paper is to evaluate the behavior of brick masonry cavity wall subjected to constant vertical and horizontal cyclic load in displacement controlled environment. For this purpose different types of cavity walls are tested with different shapes of wall ties.

EXPERIMENTAL WORK

Six specimens of cavity walls were tested under constant vertical load of 110 psi in a displacement controlled environment. There were two specimens for each type of wall. The length, height and thickness of these walls were kept as 48 inches, 36 inches and 11 inches respectively (Figure 1). The thickness comprised of two 4-1/2 inches thick brick wythes and 2 inches spacing between the two wythes as shown in Figure 2. The specimens were designated as CW, CWZ, and CWI. In specimens CW, no wall ties were provided. In the other two types, the two wythes were connected with the help of wall ties. In CWZ, Z-shaped ties were used while in CWI, the ties used were I-shaped. The Z-shape ties had 3/16 inches diameter bent at both ends to form 2 inch legs. I-shaped ties were made of flat iron having a thickness of 16 gauges. Both types of ties are shown in Figure 3. In both cases, the ties were spaced 18 inches horizontally and 15 inches vertically.

MATERIALS

For the construction of specimens, locally available first class burnt clay bricks were used. Average nominal size of the brick was 8.6 x 4.25 x 2.65 inches with average compressive strength of 2602 psi and water absorption of 21.25%. The bricks were sampled and tested as per ASTM c.67[6]. For all the specimens mortar was prepared by mixing one part of cement with four parts of sand. The average 28 days compressive strength of mortar cube was 1851.36 psi[7]. The position of wall ties within the masonry wall is shown in Figure 1.

TEST SETUP

All the specimens were tested in the Structural laboratory, Department of Civil Engineering, University of Engineering & Technology Peshawar (Pakistan). Specimen was fixed at the base with fixed steel girder. The assembly was made in such a way to behave as fixed at the bottom and free at the top. For

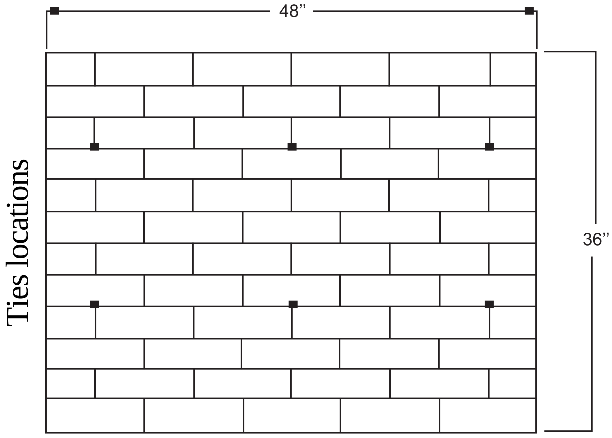

Figure 1: Size of specimen

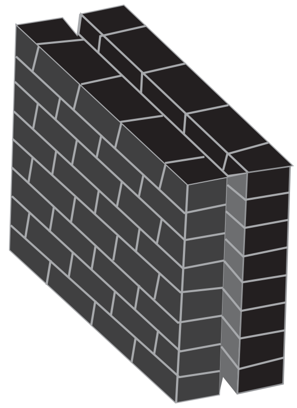

Figure 2: 4.5" wythes with 2" cavity

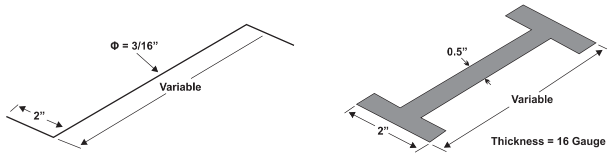

Figure 3: Z type and I type wall ties

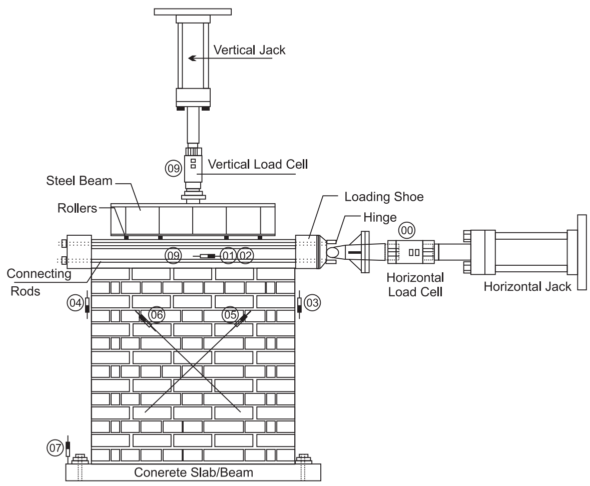

Figure 4: Test Setup

this purpose, four horizontal lubricated steel rollers were placed to make the wall free to horizontal displacement at the top concrete beam of specimen. Above these rollers, steel beam was placed. Vertical load was applied to a steel beam placed on the rollers. Horizontal and vertical load was applied through hydraulic jacks. Load was measured through load cells, which were attached to hydraulic jacks and connected to data logger. Horizontal hydraulic jack was attached to the ends of the top concrete beam. Specimen was pushed and pulled in horizontal direction using the same hydraulic jack as shown in Figure 4.

Displacement at various locations was measured using displacement transducers. Displacement transducer-1, measuring horizontal top displacement on the front face and displacement transducer-2, measuring horizontal top displacement on the back face of the pier at the horizontal load level, were used as control gauges for horizontal displacement of piers. Transducers-3 and 4 were used to record the vertical rocking displacements of masonry wall. Transducers-5 and 6 were installed diagonally, recording the shear distortion of the pier. Transducer-7 was attached to the bottom beam recording any possible horizontal slipping on the bottom beam. Transducer-8 was attached to the top beam to record out-of-plane displacement. Horizontal load was measured using gauge “0” while the vertical load was measured using gauge “9”.

TEST PROCEDURE

All the gauges were checked and initialized to zero. First the vertical load was gradually applied to the specimen. Displacement transducers were connected at top beam on both sides to measure horizontal displacement. In most of the walls test, displacement transducer-1 was used as controlled gauge, while in some cases displacement transducer-2 was used as controlled gauge.

A constant vertical load was applied at the top while a cyclic horizontal load was applied in N-S direction. Horizontal load was applied in terms of displacement cycles. Each cycle was repeated three times. Figure 5 shows the displacement profile for the cyclic load test. The behavior of the wall assembly was then observed by taking photographs and marking cracks on the wall during each displacement cycle.

DAMAGE PATTERN

CW1 and CW2 were the two samples in which no shear connectors were used. At 0.56% drift, vertical flexure cracks appeared both within the mortar and masonry unit. At 1.13% drift, diagonal shear cracks appeared. The failure mode was partly due to diagonal shear and partly due to toe crushing. Similarly in CW2, vertical cracks were found at 0.28% drift and diagonal shear cracks at 1.49%. Diagonal shear cracks were dominant in CW type masonry wall specimens as shown in Figure 6.

The two cavity wall specimens of type CWI in which I-shape metal ties were used, showed the same damage pattern. In both samples, vertical cracks appeared both within the masonry unit and mortar joint at 0.28% drift. Diagonal shear cracks appeared at 0.37% drift as shown in Figure 7. Diagonal cracks extended throughout the wall at 0.64% drift. At 1.12% the diagonal cracks widened and the specimen failed.

In specimens of CWZ type, diagonal shear cracks were dominant. Vertical flexure cracks appeared at 0.19% drift followed by diagonal shear cracks at 0.56% drift. At 0.93% drift the failure cracks formed partly by crushing and partly by diagonal shear as shown in Figure 8.

Sliding shear cracks appeared in the upper part of the sample at the interface of brick masonry wall and concrete beam. Similar cracks appeared in the bottom part at 0.47% drift. At 0.56% drift, flexure cracks appeared followed by diagonal shear cracks at 0.94% drift.

RESULTS AND DISCUSSIONS

Hysteresis loops were developed for all the specimens between the lateral load and horizontal displacement. Positive and negative envelope curves were developed by joining the peak point of each cycle. Average envelope curve was developed from positive and negative envelope curves. Bilinear idealized curve was developed for each specimen from positive and negative envelope curves.

Hysteresis loop and bilinear idealized curve of CW is shown in Figure 9. Hysteresis loops show that at initial cycles slope of the loops is less.

Hysteresis loops and bilinear idealized curve of

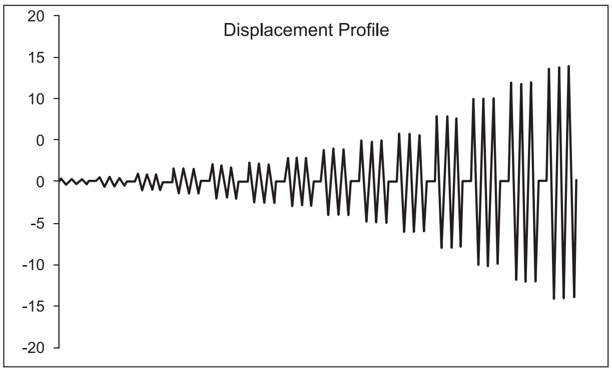

Figure 5: Displacement profile

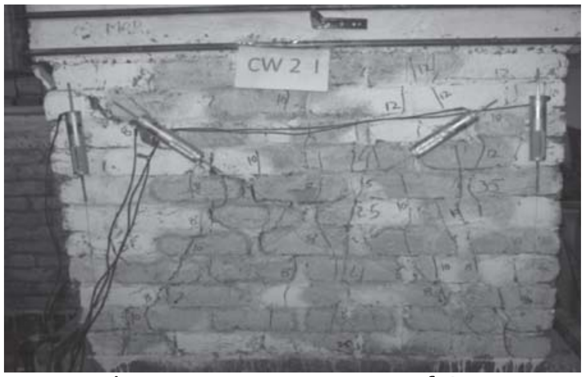

Figure 7: Damage pattern of CWI

Figure 6: Damage pattern of CW

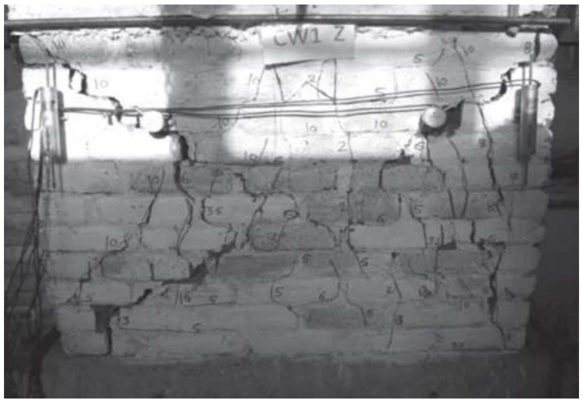

Figure 8: Damage pattern of CWZ

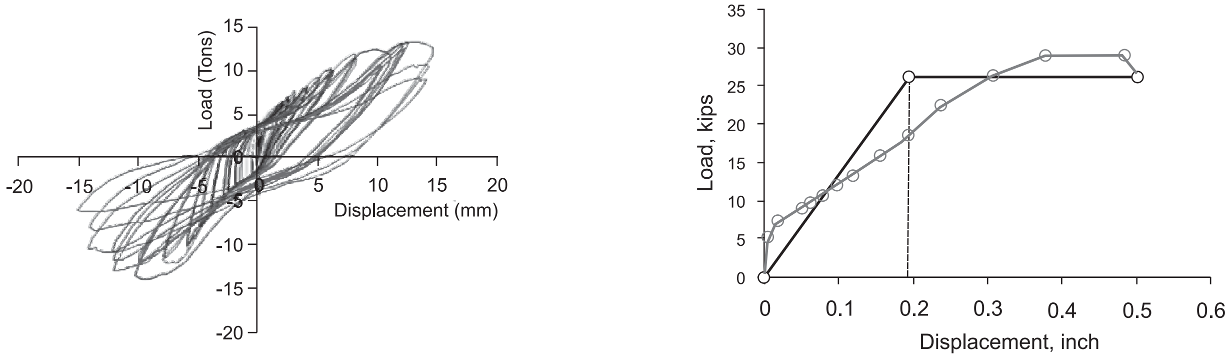

Figure 9: Hysteresis Loop and Bilinear Idealized curve of CW

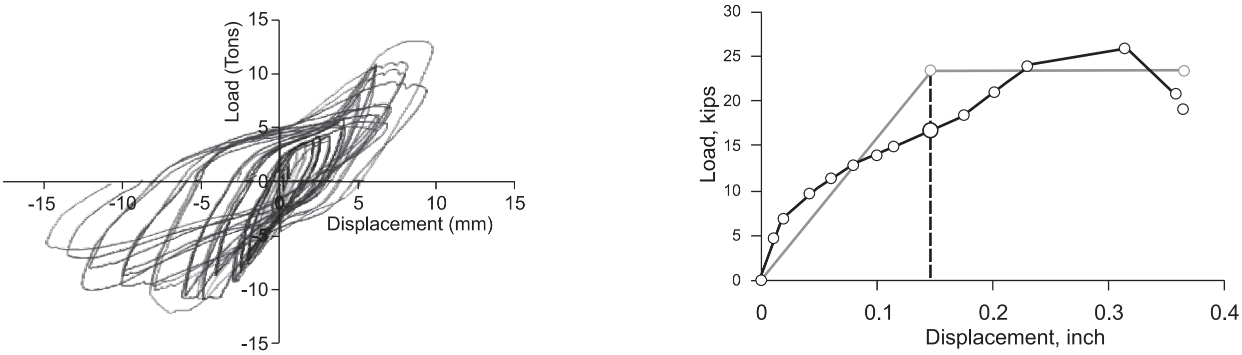

Figure 10: Hysteresis loop and Bilinear Idealized Curve of CWI

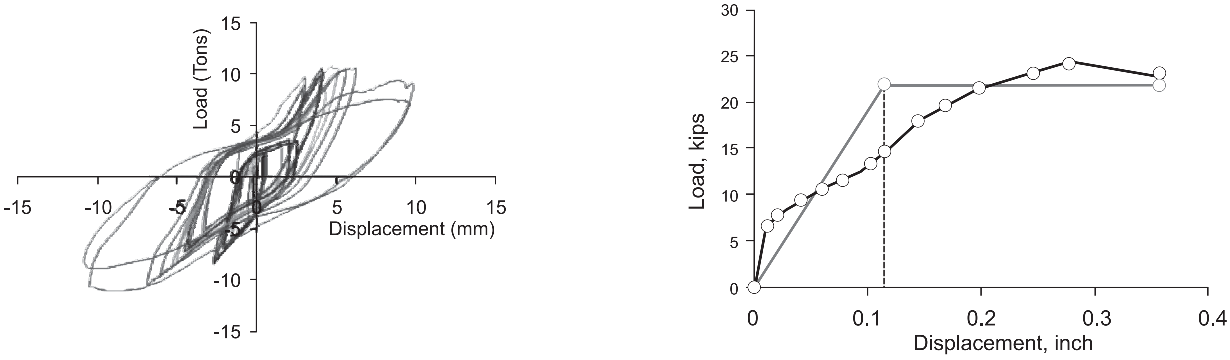

Figure 11: Hysteresis Loops and Bilinear Idealized Curve of CWZ

Table 1: Initial Stiffness, Lateral Strength and ductility

Wall Type	Shape of Wall Ties	Initial Stiffness (Kip/in)	Lateral Strength (Kip)	Ductility
CW	No Ties	141.45	23.97	2.39
CWI	I Shape	174.12	22.07	2.5
CWZ	Z Shape	159.31	20.47	2.42

CWI (Figure 10) shows that the slope of loops decreases at initial cycles and remains almost same at later cycles. Initially, the energy loss is low but with increasing cycles the energy loss increases.

Hysteresis loops and bilinear idealized curve of CWZ is shown in Figure 11. The slope of loops decreases at initial cycles and remains almost same at last cycles. Hysteresis loops are tight initially and the nature of cracks is diagonal shear. Initially the energy loss is low but by increasing cycles energy loss increases.

The initial stiffness, lateral strength and ductility ratio of each type of wall is calculated from bilinear idealized curve. These values are summarized in table 1.

Experimental results show that the initial stiffness of cavity wall increases, by 25% using the I-shape metal ties and by 15% using the Z-shape metal ties. On the other hand, ductility of cavity wall increases by 10% using the I-shape metal ties while Z-shape metal ties do not affect the ductility. Lateral strength of cavity wall is almost similar for I-shape, Z-shape, and without metal ties. This may be attributed to smaller dimensions of the walls.

CONCLUSIONS

Based on the tests conducted and analysis of the results the following conclusions are made.

- Initial stiffness increases by 25% by using the I-shape metal ties .
- Initial stiffness increases by 15% using the Z-shape metal ties .
- Both types of metal ties do not affect lateral strength of cavity walls; and,
- Ductility of cavity wall increases by 10% by the I-shape metal ties.

Further research should be carried out by using different types of shear connectors, aspect ratios and wythe sizes to ascertain the effect of shear connectors on the mechanical properties of cavity walls.

REFERENCES

1. *Brick Industry Association , Technical Notes-21 Brick Masonry cavity walls (August 1998) , Reston, VA*
2. *Canadian Building Digests NRC-IRC publication.*
3. *Design guide for taller cavity walls, Masonry Advisory Council (2002), USA*
4. *Li H.N., Zhang J.W., Liu L., (2004). Seismic behavior of insulated hollow-brick cavity walls using Quasi-static experimentation, Society for Experimental Mechanics, Vol.44, No. 4, 396-406.*
5. *Wang R, Elwi A.E., Hatzinikolas M.A., and Warwaruk. J. 1996. Behaviour of Masonry Cavity Walls Under Vertical Eccentric*

Loads. Structural Engineering report No 212, Department of Civil Engineering, University of Alberta, Admonton, Alberta, Canada.

6. *ASTM C 67,* "Test Methods for Sampling and Testing Brick and Structural Clay Tiles", *4th Ed., Philadelphia.*

7. *ASTM* C *109,* "Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2-inch or 50 mm cube specimens)" *4th Ed., Philadelphia.*