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LATERAL RESPONSE OF REINFORCED MASONRY SHEAR WALLS WITH DOOR OPENINGS: AN EXPERIMENTAL STUDY

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ABSTRACT

Introducing openings in masonry shear walls reduces their flexural and shear strength and alters their response to lateral loads. A research program was conducted at Drexel University to study the lateral ,response of shear walls with openings through testing thirteen 1/3-scale reinforced concrete masonry shear walls. In this study, a simple analysis approach employing plastic hinge failure mechanism was used to predict failure mechanism, lateral load carrying capacity, and internal forces at ultimate load. The test specimens were designed to behave mainly in a flexural mode by forming plastic hinges at the member ends (i.e. enough shear reinforcement was provided to suppress shear failure in different wall elements). In this paper, the results of only five walls are presented. The main parameters are size and location of door openings. The walls behaved mainly in a flexural mode as intended and failed by forming plastic hinges at the members ends. The test results showed that while the opening size has a significant effect on wall strength and stiffness of shear walls, the location of the opening has a minor effect on wall response. Through the test results in this study, it has been demonstrated that the plastic hinge model provides a simple and efficient analysis approach to predict the failure mechanism, ultimate strength and internal forces for flexural-dominated masonry shear walls with openings.

connected to a magnification arm as shown in Fig. 4. The magnification factor had been changed from one test to another based on the expected ultimate load and displacement for the test specimens. The test lateral load was transmitted from the magnification arm to a distributor steel tube beam (through a pin connection) which consequently transmitted the load to two steel tube beams (loading beams) on both sides of the reinforced concrete slab as shown in Fig. 4. The lateral load was then transmitted from the steel tube beams to the specimen through four pins (loading pins) welded to steel plates. These steel plates were attached to the lower face of the reinforced concrete slab using the steel bolts which were embedded in the slab concrete at time of casting. It should be noted that the steel plates were attached only to the slab parts over the piers to avoid any composite action with the slab parts over the opening(s) (coupling element(s)). The test specimen was braced against out-of-plane movement by a set of rollers on both sides of the slab.

Instrumentation

Different types of instrumentation were used to monitor the wall behavior. The following measurements were recorded during the test:

(a) Measurement of actuator load and displacement using a load cell and control LVDT (Linear Variable Differential Transducers).

(b) Measurement of wall lateral displacement using wire device.

(c) Measurement of wall flexural deformations at critical sections (expected plastic hinges) using LVDTs.

(d) Measurement of wall panel drift angles (panel rotation) using sets of diagonal and vertical LVDTs

(e) Measurement of slippage of wall panels relative to reinforced concrete footing and reinforced concrete slab using dial gages.

Figure 5 shows the typical arrangements of instrumentation for one of the tested walls.

Test Procedure

All walls were tested under a displacement control loading. The test wall was laterally loaded with a uniformly increasing displacement up to the test termination which was carried out by the testing machine when the specimen lateral load resistance dropped to a 50% of the peak load. In all cases, the data acquisition process was carried out during loading using a suitable time rate. The data were saved periodically on the computer hard disk. During the test, the walls were visually inspected, all cracks were marked, and photographs were taken.

Pre-test Analysis

Since the test walls were proposed so as to satisfy certain design philosophy, it was necessary to conduct a pre-test analysis for the test walls to insure that they satisfy the objectives of the study and meet the preset criteria. The pre-test analysis was carried out using plastic hinge model (PHM) which is an approximate method for analysis of flexural-dominated shear walls with openings in which the wall is idealized as an equivalent frame where the failure state is reached by plastic hinges formation at the members ends, in such a way that the structural system of the equivalent frame becomes unstable. The sequence of the plastic hinges formation depends on the relative strength and stiffness of the elements. The PHM was originally developed by Levia and Klingner 1991. However, the PHM in its original version was not able to predict the actual failure mechanism and the solution was based on assumed failure mechanism which consequently gives an upper bound for the true solution. Therefore, during the course of the current study, the PHM underwent further development to enable it to predict the actual failure mechanism, actual ultimate failure load, and internal forces at ultimate stage. The improved PHM was used to analyze the test walls and the results are summarized in Table 3. More details regarding the development of the PHM are given in References Elshafie et. al. 1997 and 1996.

TEST RESULTS

Crack Patterns

Figure 6 shows crack patterns for the walls at failure. On these patterns, heavy lines indicate wide (major) cracks and hatched areas indicate crushing or spalling of the masonry. It is evident from Fig. 6 that the walls behaved mainly in a flexural mode where the shear cracks (diagonal) did not progress with loading, while the flexural cracks at the critical sections started to widen up and the walls finally failed by either fracture of flexural reinforcement or crushing of masonry at critical sections.

Failure Mechanisms

Both crack patterns and instrumentation measurements were used to identify the location of plastic hinges. Figure 7 shows the failure mechanisms for the walls under consideration.

Lateral Load - Overall Drift Angle Curves

The lateral load - overall drift angle curves for the five walls are given in Fig. 8. The overall drift angle is defined as the in-plane displacement at the top of the wall divided by the wall height.

DISCUSSION OF TEST RESULTS

Effect of Opening Size

As shown in Fig. 2, walls W1, W4, and W10 had the same overall dimensions and flexural reinforcement content but with different sizes for the door opening. Walls W1, W4, and W10 had opening sizes (as percentage of the wall overall size) of 0%, 22%, and 49%, respectively. Comparison of lateral load - overall drift angle curves for these walls (see

Fig. 8) shows that stiffness (secant at 75% of ultimate load) and lateral load capacity of shear walls with openings decreased significantly with the increase of the opening size while ultimate displacement increased.

To illustrate the effect of the opening size on the behavior of masonry shear walls, Fig. 9 shows changes in solid wall stiffness, strength and ultimate displacement due to introducing door opening with different sizes. It is evident from Fig. 9 that, for shear walls with the same overall dimensions and flexural reinforcement content, the reduction in stiffness and strength due to introducing a door opening is almost linearly proportional to the opening size (opening width). It is noticeable that the effect of increasing the opening size is more significant in reducing the stiffness than the strength. It is interesting to notice that the ultimate displacement of shear walls with openings increased remarkably with the increase of the opening size as shown in Fig. 9. By considering the ultimate displacement as a measure for the wall ductility, it can be concluded that ductility of perforated shear walls increases significantly with the increase of the opening size. Introducing large openings in shear walls results in walls comprised of elements with high aspect ratios which have high ability to rotate and to deform beyond the elastic limit.

Effect of Opening Location

As shown in Fig. 2, walls W2 and W7 are similar except that they have different locations for the openings; wall W2 has a concentric opening, while wall W7 has an eccentric one. Comparison of lateral load -drift angle curves for these two walls (see Fig. 8) reveals that masonry shear walls with concentric opening had higher ductility and slightly lower stiffness and strength compared to walls with eccentric opening. Shifting the opening location from the center results in a wall characterized by two unequal piers, one of them is wide and stiff, while the other is narrow and flexible. The behavior of such a wall is dominated by the behavior of the wide pier which obviously has high stiffness and strength and low ductility because of its low aspect ratio.

Comparison of Pre-test analysis and Experimental Results

As discussed earlier, all walls behaved mainly in a flexural mode as intended and failed by forming plastic hinges at their members ends. The success in getting all walls to follow what has been intended in the design demonstrates the effectiveness of the PHM as an analysis tool for shear walls with openings. Furthermore, the ability of suppressing all shear failure modes demonstrates the effectiveness of the PHM in predicting the internal forces.

Comparison of predicted and observed failure mechanisms (see Table 3 and Fig. 7) shows excellent agreement. The PHM was able to predict the correct failure mechanisms for all walls. Furthermore, the PHM was able to predict the ultimate lateral loads with a good accuracy as illustrated in Fig. 10.

CONCLUSIONS

1. All walls behaved mainly in a flexural mode as intended and failed by forming plastic hinges at their members ends.
2. Stiffness and lateral load capacity of perforated shear walls decrease significantly with the increase of the opening size while the ductility increases remarkably.
3. For shear walls with the same overall dimensions and flexural reinforcement content, the reduction in stiffness and strength due to introducing a door opening is proportional to the opening size.
4. Masonry shear walls with concentric opening have higher ductility and slightly lower stiffness and strength compared to walls with eccentric opening.
5. The plastic hinge model provides a simple and accurate analytical tool to predict failure mechanism, lateral load capacity, and internal forces at ultimate stage for flexural-dominated shear walls with openings.

ACKNOWLEDGMENT

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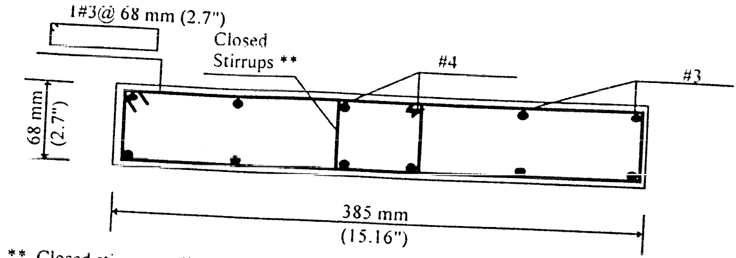
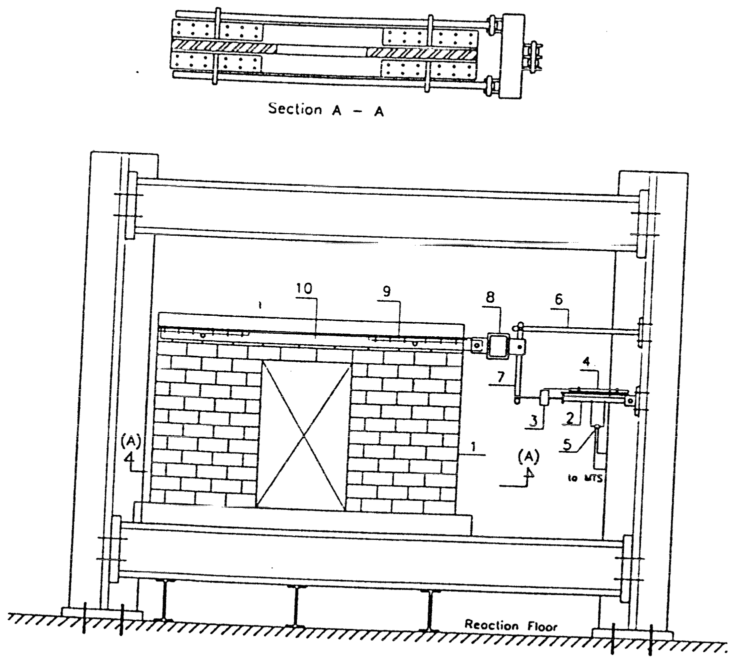


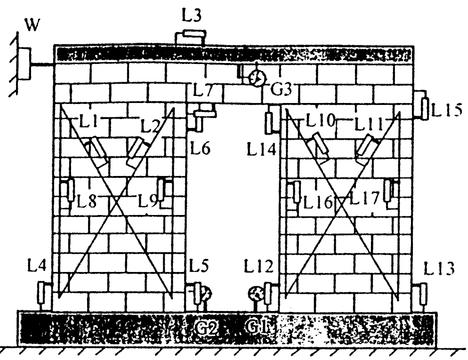
** Closed stirrups = #3 @ 68 mm (2.7") For walls W1,W4, & W10
#3 @ 23 mm (0.9") For walls W2, & W7

Figure 3: Dimensions and Reinforcement of the Concrete Slab.



1- Test specimen
6- Reaction arm.
2- Lateral loading jack.
7- Magnification arm
3- Load cell
.8- Distributor beam
4- Control LVDT
9- Steel plates
5- Servo Valve.
10- Loading beam.

Figure 4: Test Set-Up



L = LVDT W = Wire device G = Dial gage

Figure 5: Typical Instrumentation.

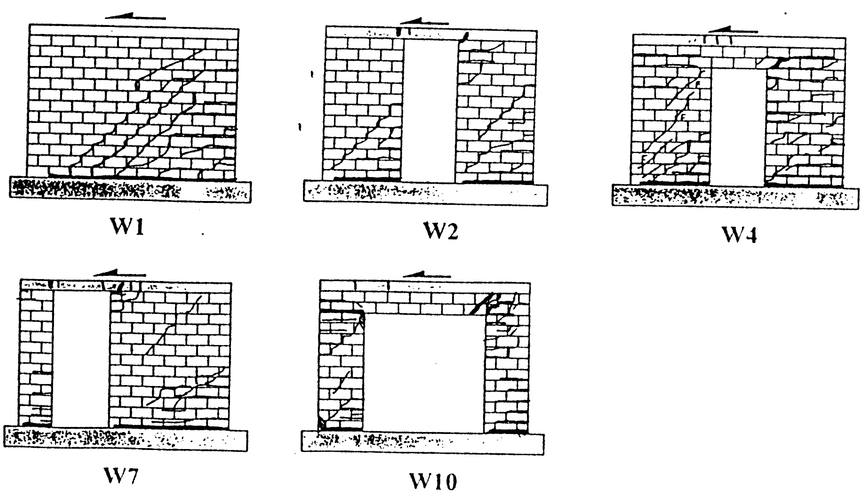


Figure 6: Crack Patterns.

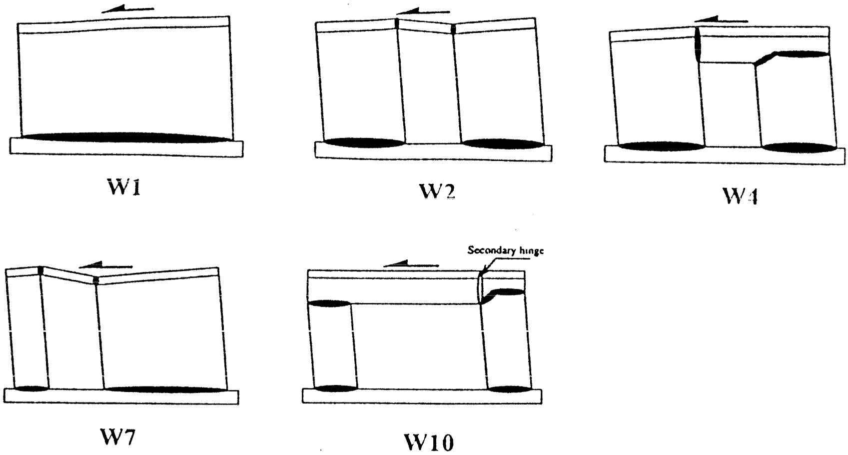


Figure 7: Failure Mechanisms.

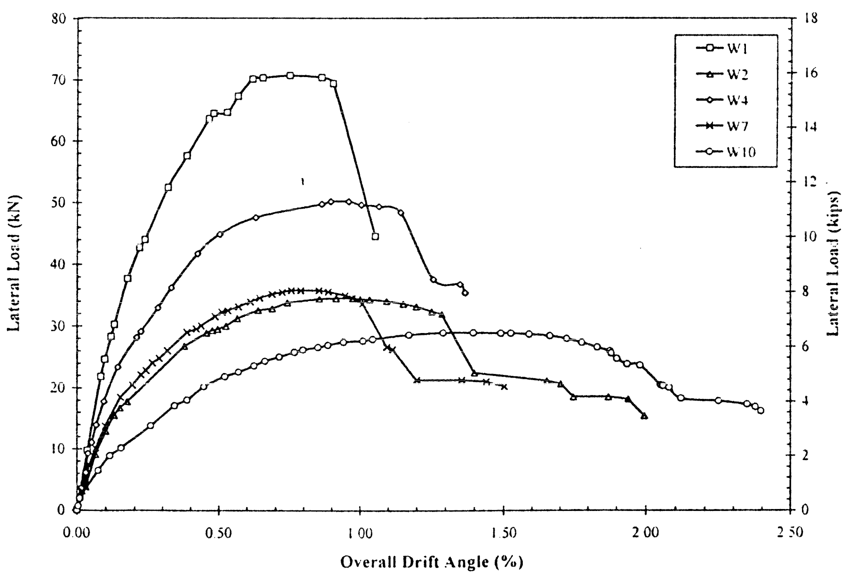
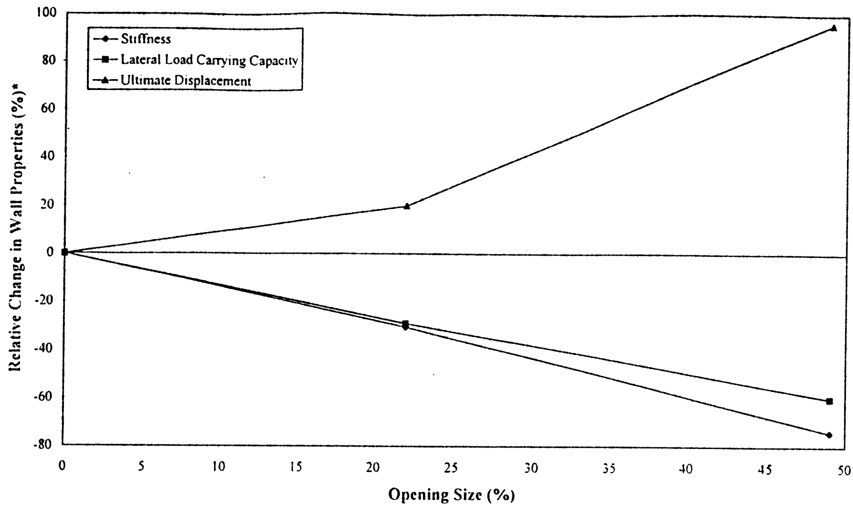


Figure 8: Lateral Load - Overall Drift Angle Curves for the Walls.



* Relative to the solid wall, W1.

Figure 9: Relative Change in Wall Properties due to Increasing the Opening Size.

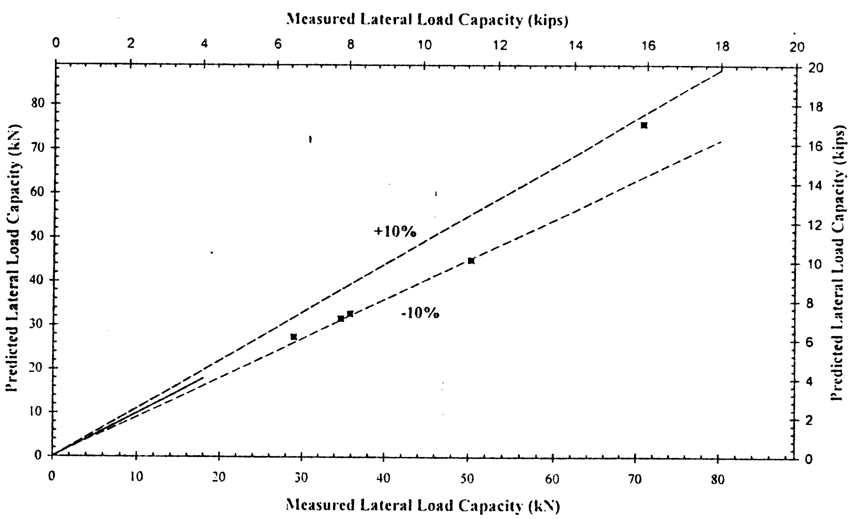


Figure 10: Predicted Lateral Load Capacities versus Measured Capacities.

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SHEAR STRENGTH ANALYSIS FOR CLAY BRICK MASONRY WALLS

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ABSTRACT

Shear strength is an important material property for masonry structures, especially for seismic design and performance analysis of structures in earthquakes. Because of its importance, there have been a large number of projects and studies involving shear behaviour of masonry structures and structural members including static and dynamic tests, numerical analyses, case studies and concept discussions. This paper makes a contribution to that body of knowledge.

Based on the analysis of a series of test results on clay brick masonry shear walls, the paper provides a discussion of theories and presents equations for the calculation of shear resistance of both unreinforced and horizontally reinforced clay brick masonry walls.

INTRODUCTION

In many countries, masonry is one of the main forms of building construction. It is therefore very important to optimise its structural performance, especially in earthquake zones or where strong winds exist.

Damage to structures in earthquakes is primarily caused through horizontal loads (Fig. 1), as indicated in the Kobe earthquake in Japan [Fleming, 1995] a few years ago. Although there have been some reported cases of vertical movements [Li, 1986], most codes of practice on seismic design only consider horizontal loading effects. In these circumstances the shear strength of masonry walls is obviously significant.