Experimental Study on the Behaviour of Plastered Confined Masonry Wall under Lateral Cyclic Load

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SUMMARY
The behaviour of two full-scale (3m × 3m) plastered confined masonry wall specimens under cyclic lateral load was experimentally studied and analyzed in this research. Both specimens had framed window in the middle of the wall and were constructed following the general construction practice in Indonesia. Aside from different detailing, two continuous horizontal anchors were added on one specimen. The parameters evaluated were failure mechanism on the wall panel, load resistance, energy dissipation, and ductility. The results showed that the plaster improved the load carrying capacity of the wall. Additional ductility and development of more appropriate diagonal strut-tie mechanism were also observed rather than sliding mode failure on the unplastered wall specimen. The load carrying capacity increases from 8.7 tons to about 10 tons in the model with horizontal anchorage. In conclusion, the study shows that installing plaster as well as proper wall-frame connection strategies is crucial in improving the structural performance of confined masonry wall.

Keywords: confined masonry wall, plastered masonry wall, experimental study, cyclic lateral load

1. INTRODUCTION

Confined masonry walls are commonly used in residential houses in Indonesia. Observations after recent earthquakes have shown that they were prone to damage, and their behaviour under earthquake load was somewhat unsatisfactory. The vast numbers of residential houses damaged by earthquake greatly affect the number of casualties. Therefore, improving the performance of residential buildings under seismic load has become main priority to reduce fatalities and economic losses. These structures are commonly built without appropriate structural design process. The failures or structural damages of these non-engineered structures were mostly caused by the absence of connection between infilled wall and the confining frame, insufficient detailing and capacity of columns, large distance between columns and poor quality of workmanship.

The typical houses in Indonesia are of stone masonry foundation, reinforced concrete tie column and tie beam as confining frame, with infilled brick masonry wall. The structural element detailing of such structure is often far from the required standard of the code, and varied due to disparities of workmanship and materials. Some typical mistakes that often occur are: (i) inadequate size of column and beam, (ii) using plain bars as main reinforcement and stirrup for beam and column elements, (iii) detailing of beam-column joints are non-compliant to the structural ductility requirement for lateral loading, and (iv) no anchorage between masonry wall and the frame.

Several experimental studies of confined masonry and reinforced concrete frame infilled with masonry walls were conducted to better understand the performance of simple house structures. The studies focused on the parameters of the structural elements such as masonry properties, mortars and concrete used. The studies also covered details of masonry wall confined by reinforced concrete frame resistance to the seismic load.

The installation of plaster on a confined masonry wall has been known to preserve the brick masonry wall, to add connection of walls to the confining frame, and to improve the overall performance of the structure. Although many numerical studies have been conducted on the subject, few experimental studies were carried out to study the effect of plaster on the wall structure. Furthermore, the effect of continuous anchorage on the confined masonry wall maybe different if the wall is plastered.

This paper presents the performance of two full-scale (3m × 3m) specimens of plastered confined masonry wall, where one of them uses continuous horizontal anchorages to improve the wall-frame confinement. Both specimens have framed window in the middle of the wall. The specimens were tested under cyclic loading with increasing intensity until collapse. Prior to the experiments, tests were also conducted on the characteristics of the materials, i.e. red brick unit, mortar, plaster, and frame concrete, to obtain the actual material properties. The results from this study will be compared with results from previous experimental studies to analyze the effects of plaster, window opening, and horizontal anchorage to the response of the confined wall.

2. MATERIAL CHARACTERISTICS

The specimens were constructed following the general construction practice in Indonesia, with the sequence of: reinforcement assembling, concrete foundation pouring, brick laying, and finally conrete frame pouring. The wall specimens used moderate quality red bricks and concrete frame with mixing specifications of 1:2:3 (volume of cement, sand, and coarse aggregate, respectively) with water being added as much as 100% of the cement volume. Frame reinforcement used 10 mm plain bars for the main re-bar and 8 mm plain bar for the stirrup.

The size of the red bricks is 55 mm × 100 mm × 205 mm. Mortar space in between bricks is 15 mm thick with mixing composition ratio of 1:5 (volume of cement and sand, respectively), using the same volume of water as cement.

Compressive tests for the brick, mortar, and concrete samples resulted in average compressive strength of 4.93 MPa for the brick, 14.27 MPa for the mortar, and 23.72 MPa for the concrete. Bond shear strength tests of brick, mortar and plaster specimen gave average shear strength of 0.23 MPa. Uniaxial tensile tests on steel reinforcement specimens resulted in average yield strength of 317 MPa and ultimate tensile strength of 468 MPa.

3. EXPERIMENTAL SETUP

The details of the two wall specimens are shown in Figures 1 and 2. Specimen 1 represents simple confined masonry wall with framed window in the middle of the wall. Specimen 2 is similar to specimen 1, except for two additional continuous horizontal anchorage placed right above and below the window frame.

The lateral cyclic load was applied at the top beam-column joint. The load came from a hydraulic jack attached to the reaction wall. Figure 3 shows the test setup for the lateral cyclic load of confined masonry wall and Figure 4 presents the picture of one of the wall specimens prior to the test. The response of the wall specimen was measured using strain gauges and LVDT (Linear Variable Displacement Transducers).

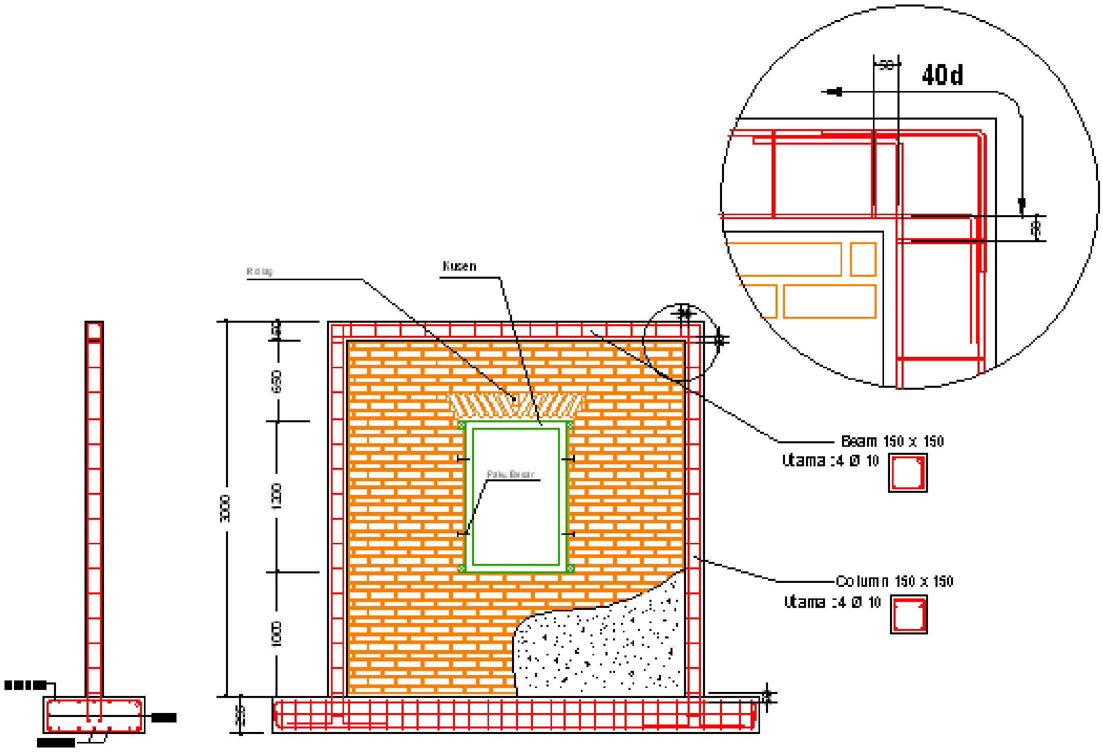

Figure 1. Details of wall specimen 1.

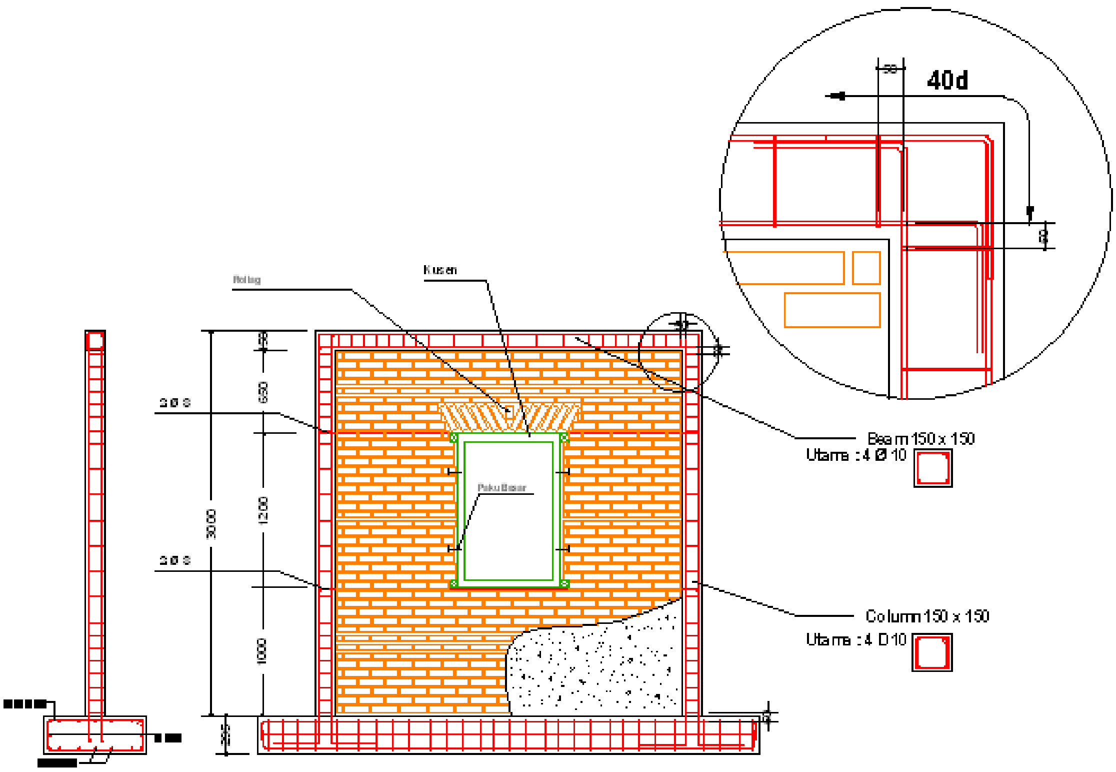

Figure 2. Details of wall specimen 2.

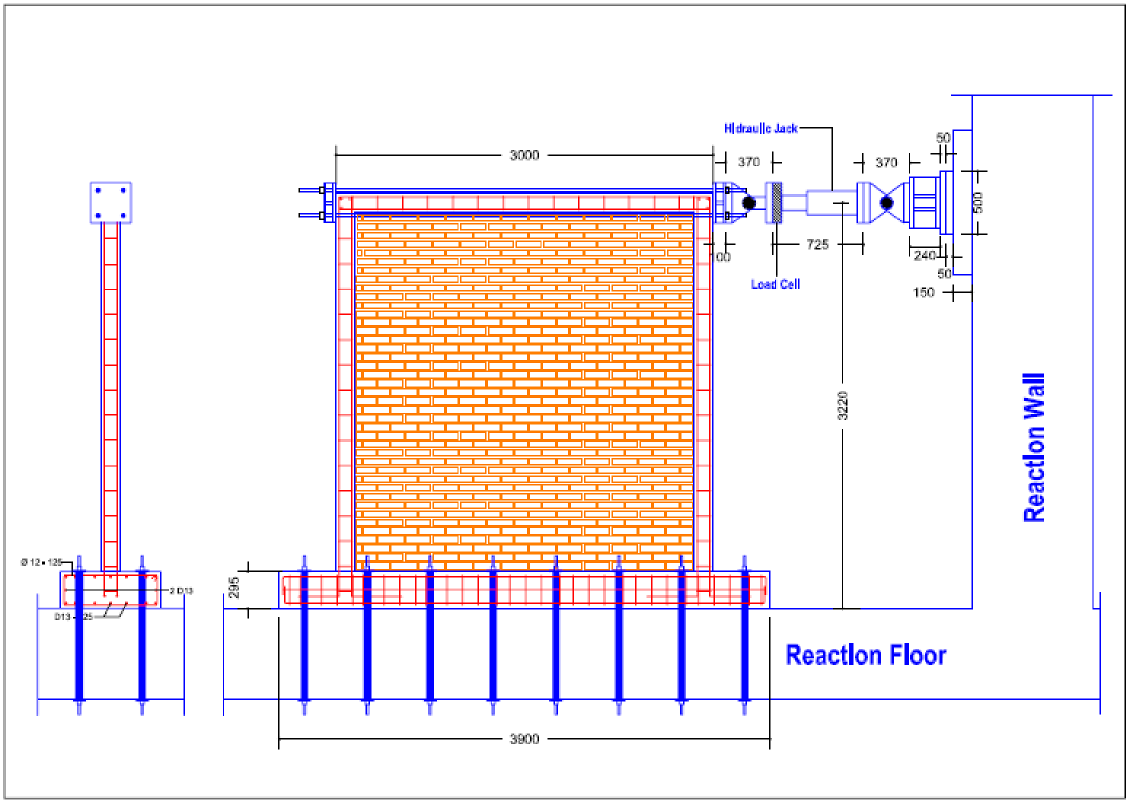

Figure 3. Experimental setup.

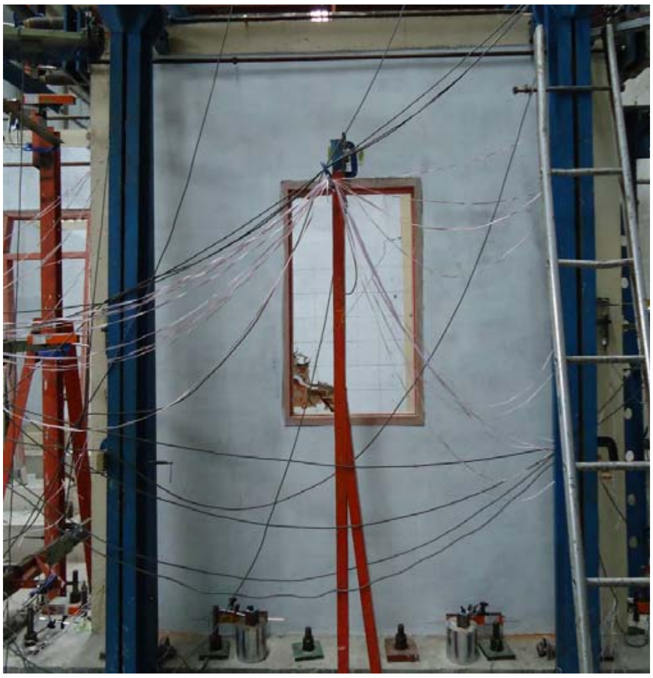

Figure 4. Picture of one of the wall specimens.

Figure 5 shows the loading cycles that were applied during each experiment which follows ACI 374.1-05 recommendation. The specimens were subjected to a series of increasing cyclic lateral load. The largest drift applied on the structure was 3.5 percent or 105 mm.

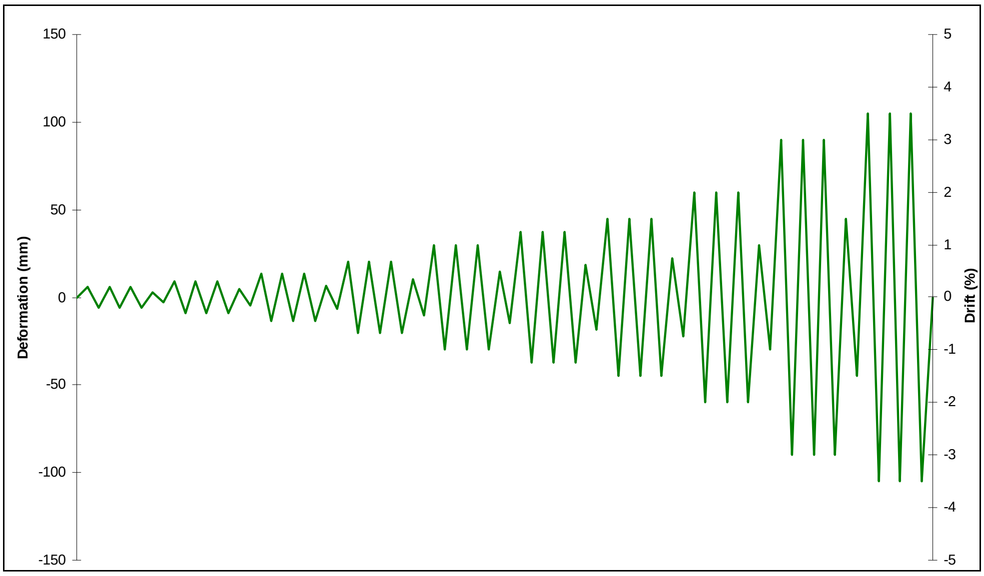

Figure 5. Loading scheme.

4. RESULTS AND ANALYSIS

During the experiments, observation was focused on development of cracks, damage pattern and failure mechanism at the end of each test. Figures 6 and 7 show selected pictures of each specimen during the tests.

Figure 6. Damage observed at the corner of the window frame during the test of specimen 1.

Figure 7. Specimen 2 near the end cycle of test.

4.1 Crack Patterns and Failure Modes

Figures 8 and 9 present the crack patterns of specimen 1 and 2 after the tests. In both cases, crack initiated at the corner of window frame and formed diagonal cracking from there. At the end of the experiment, both models show similar failure mechanism.

Comparing these patterns with the results from unplastered wall (Figure 10), it can be seen that the specimens with plaster developed a more appropriate diagonal crack mechanism rather than sliding mode that occurred in unplastered specimen. It was also observed that cracks were developed at a larger displacement for plastered walls, compared to the specimen without plaster.

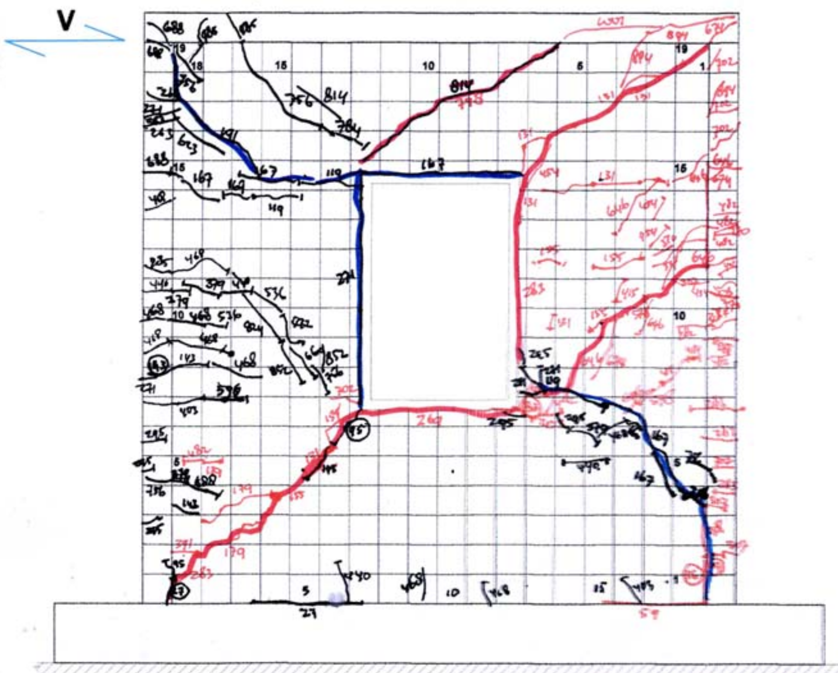

Figure 8. Crack patterns of specimen 1.

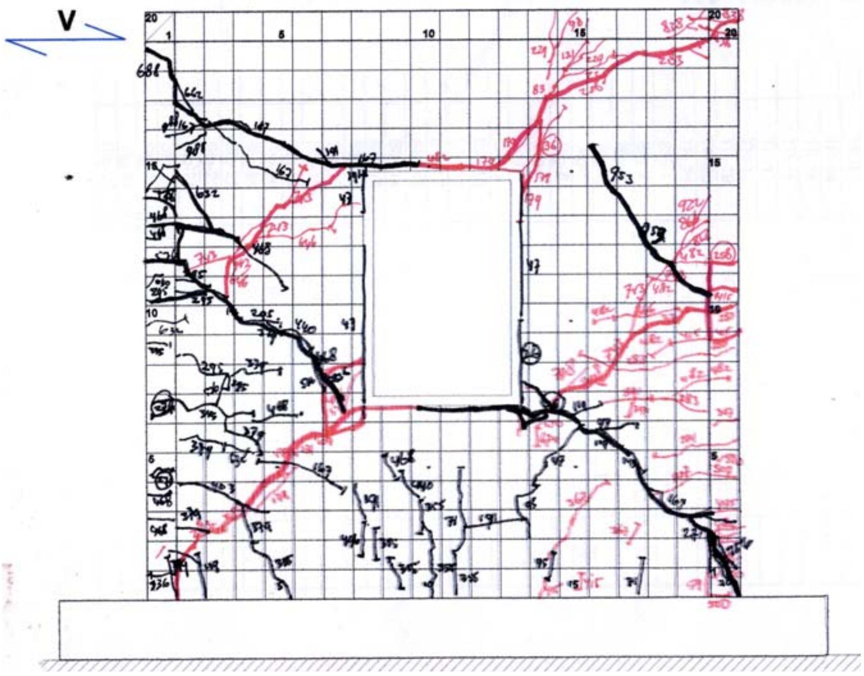

Figure 9. Crack patterns of specimen 2.

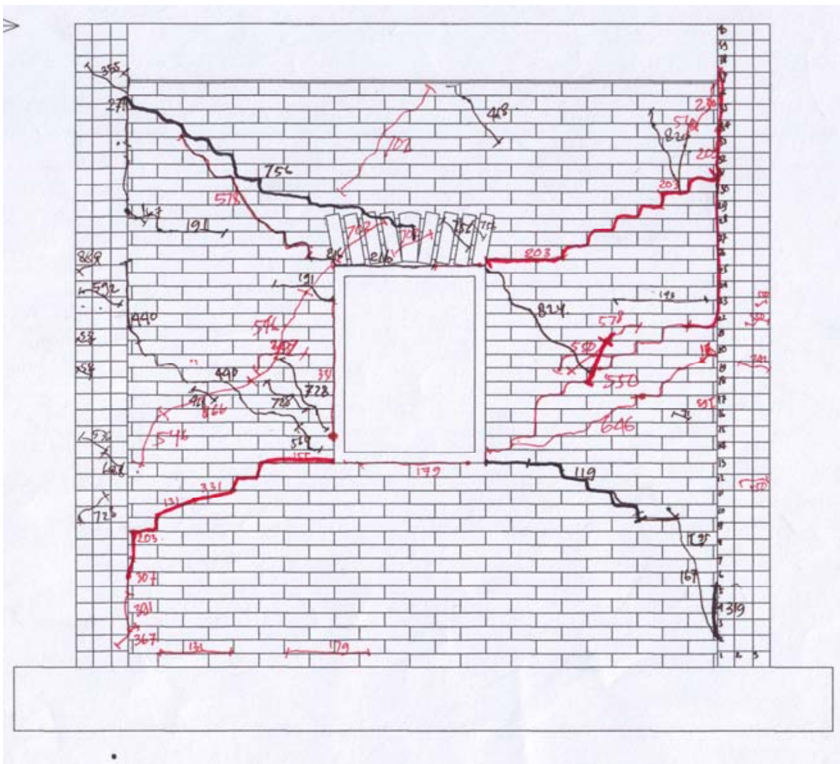

Figure 10. Crack patterns of wall specimen without plaster.

Specimen 1 shows a typical development of diagonal crack pattern, which subsequently developing strut and tie mechanism between the wall and the confining column for lateral load resistance mechanism. The damage was observed on the corners of the opening, as well as the column ends. Due to inability of the cracks on to perfectly fill back at zero drift, the gap consequently added to the volume of the wall panel, which then pushed the columns outward. The confined frame columns were then inflated out in the wall plane (bulging effect). Bulging effect on the confined columns subsequently weakened the confinement and thus reduced the wall strength. The effect was reduced by the existence of plaster, which also confined the masonry wall.

Similarly, the diagonal crack pattern was also observed for specimen 2. The strut and tie mechanism was also developed in this model. However, less bulging of columns were observed on the columns. The installed continuous anchorage seemed to limit the bulging effect on columns, and the model was able to maintain its shape for larger displacement. With the additional strength from the anchorage, the model was able to resist more lateral load, compared to specimen 1. Although less column deformation was observed, specimen 2 developed large crack at the bottom of the right column frame and further observation reveals that two of the longitudinal reinforcement failed near the end of the test. Tthe damage was much severe on this column compared to the other specimens.

Continuous anchorages do not have superior effect on the performance of the wall. The locations of the anchorage that are next to the window frame do not provide additional benefit as expected, since cracks did not develop through the anchorage. The effect of anchorage will be maximum when cracks went through the anchorage, thus allowing the anchorage to develop its tensile strength. From the crack pattern, the possibility of optimum location for the anchorage can be deducted. Using two levels of horizontal anchorage, these locations are: (i) at two thirds of the height of the wall portion between the tie beam and the bottom window frame (approximately 70 cm from the bottom of the wall), and (ii) above the diagonal bricks at the top of the window frame (approximately 30 cm from the top of the window frame). If the anchorages were provided at these locations, it is expected that the better performance of the wall will be obtained.

4.2 Hysteretic Behaviour

Figures 11 and 12 present the hysteretic diagram of load-displacement for specimens 1 and 2 during the tests. Both models appear to have similar hysteretic behaviour, with difference only in the maximum load where specimen 1 can sustain about 8.7 tons while specimen 2 with additional anchorage has a maximum load about 10 tons. The difference in maximum load can probably be caused by the additional anchorage on specimen 2. There is not much difference observed in stiffness degradation and ductility of both models.

In Figure 13, the hysteretic diagram from previous research is shown to analyze the effect of plaster. The specimen was similar to specimen 1, but did not have plaster on the wall. The model without plaster shows a maximum capacity of 6.4 tons, in the tensile direction, and 5.2 in the compressive direction, or average of 5.8 tons.

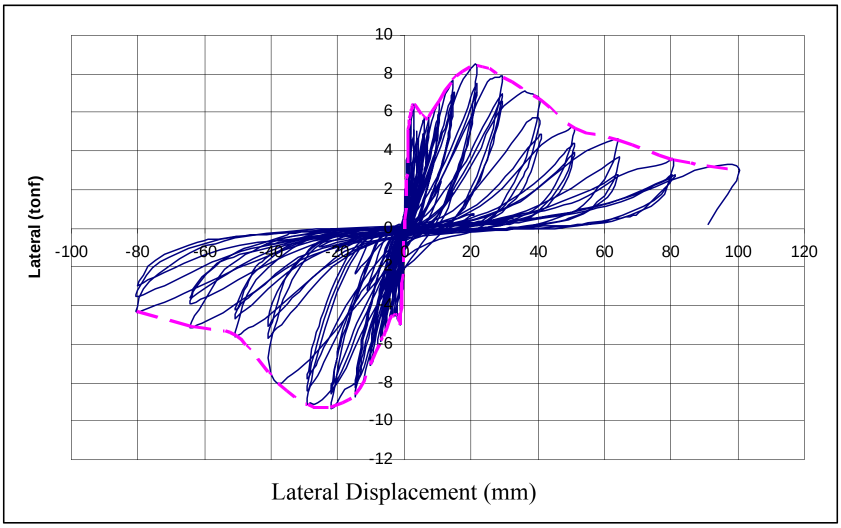

Figure 11. Hysteretic load-displacement of specimen 1.

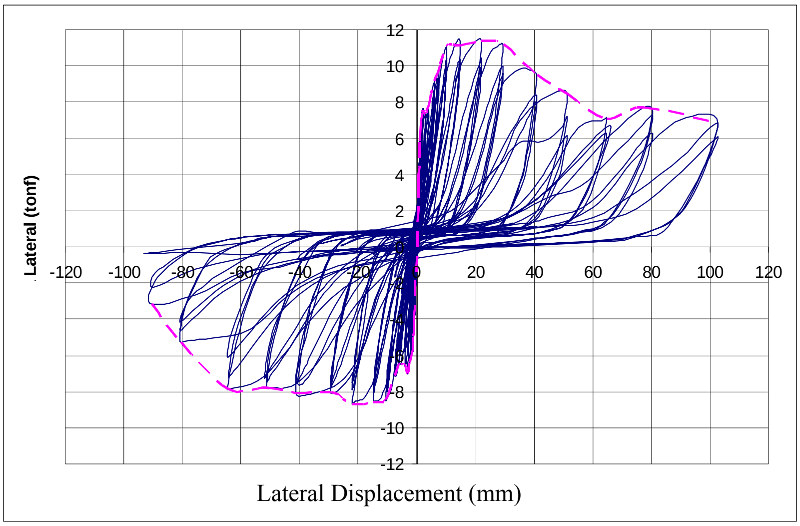

Figure 12. Hysteretic load-displacement of specimen 2.

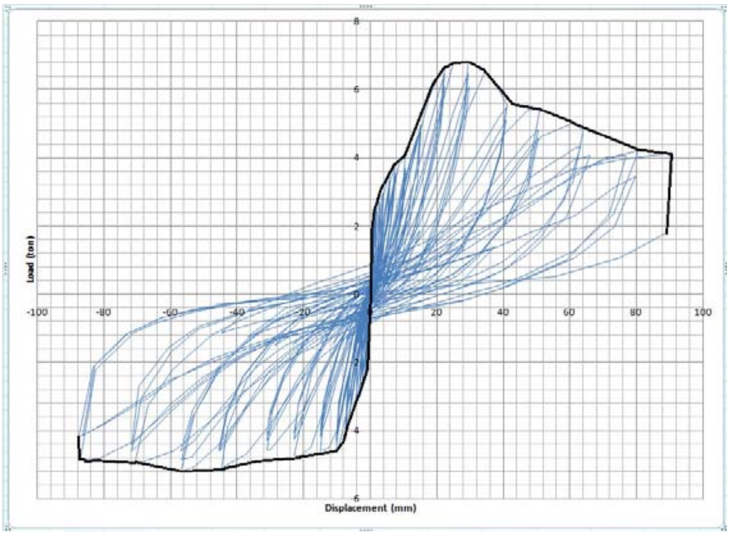

Figure 13. Hysteretic load-displacement of wall specimen without plaster.

Comparing the results of specimens 1 and 2 to the one without plaster, it is clear that both specimen 1 and 2 can resist more lateral load than the specimen without plaster. With approximately 35 percent increase, the additional strength of plaster should be considered in evaluating the performance of confined masonry wall.

A slight increase in ductility is also observed in the plastered wall specimen. Although the significant effect of plaster is assumed to be in the out-of-plane direction, in the in-plane direction, the plaster acts as an additional confinement for the brick masonry wall, thus allowing the model to developed more ductile behaviour.

5. CONCLUDING REMARKS

Based on the experimental results, the following conclusions were drawn:

1. Providing plaster on confined masonry walls increases the lateral load carrying capacity of the wall. The experiments show that the maximum load can increase from 6 tons to about 8.7 tons.
2. Increase in ductility is also obtained with plastered masonry wall compared to masonry wall without plaster.
3. The diagonal cracking mechanism can be developed on plastered wall while on the unplastered

specimen the failure mode showed sliding failure mechanism.

4. The effect of continuous horizontal anchorage in increasing the maximum load is observed, although not as much as the effect of plaster. From the experiments, the difference in the ductility was not clear between the two models.

The study revealed that plaster increased both capacity and ductility of the masonry wall. Cracks were observed at larger displacements compared to the non-plastered model. The plaster added confining effect on the masonry walls, and delayed the formation of the initial crack. Thus, better structural performance was observed for the specimens.

Installing continuous anchorage seems to have less effect than expected. Observation shows that the locations of the anchorage that are next to the window frame do not provide additional benefit as expected, since cracks did not develop through the anchorage. Therefore, installing plaster as well as proper wall-frame connection strategies, i.e. type and location, might be crucial in improving the structural performance.

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