# An Experimental Study on the Effect of Opening on Confined Masonry Wall under Cyclic Lateral Loading

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**SUMMARY**
An experimental study was carried out to study effects of opening to strength and stiffness of a confined masonry wall panel and to understand its effects on the overall performance. Two full-scale wall specimens (3 x 3 $m^2$) were constructed following the general construction practice in Indonesia. The first model was a solid confined masonry wall panel without opening, while the second model was constructed with an 80 x 120 $cm^2$ opening in the middle of the wall to model a typical window opening. The opening was framed by a typical timber window frame. The models were then subjected to cyclic in-plane lateral loads. The parameters evaluated were failure mechanism on the wall panels, load resistance, energy dissipation, and ductility. The study revealed that the effect of opening is insignificant on the load carrying capacity and ductility, provided that the window frame can provide some confinement to the masonry walls.

*Keywords: confined masonry wall, opening, experimental study, crack patterns, collapse*

## 1. INTRODUCTION

Masonry walls are commonly used in Indonesia for low story residential buildings as well as for large building, including multi stories building. In one story houses, plain masonry walls without reinforcement or confinement are common. This type of construction is very prone to damage due to earthquake. Confinement by reinforced concrete frame has proven to improve the performance of the masonry wall. However, due to unsatisfactory construction quality and inadequate seismic resistant details, observations after recent earthquakes have shown that confined masonry houses in Indonesia were also prone to damage, even collapse. The vast numbers of 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. This study is a part of our research series to study and improve the performance of typical residential houses in Indonesia to resist seismic load. Several experimental and numerical studies of confined masonry and reinforced concrete frame infilled with masonry walls were conducted to better understand the performance of simple house structure. 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 loads. Various studies also suggested improvements on confining frame and the connection of walls to the frame to increase the capacity and ductility of masonry wall systems.

In a confined masonry residential house, besides the reinforced frame elements, the masonry walls contribute very significantly to the strength and stiffness of the system. Methods to predict the strength and stiffness of a masonry wall are not simple. The problem becomes more complicated when the masonry wall has opening. Typically openings are required on the masonry wall for windows and doors, and these openings are assumed to significantly reduce the performance of the panels. In Indonesia, the wall openings are typically rimmed by wooden frame that installed mainly for aesthetical purpose and for windows and doors attachment. Structurally, the wooden frame can act as confining elements that protect the weakened masonry wall around the opening.

An experimental study was carried out to verify the reduced strength and stiffness of the masonry wall panels due to openings, and to understand their effects on the overall performance. This paper presents the experimental work to study the performance of two full-scale (3m × 3m) confined masonry wall specimens, where one of them is a solid confined masonry wall panel without opening, while the second model was constructed with an 80 x 120 cm$^2$ wooden framed opening in the middle of the wall to model a typical window opening. Both specimens were constructed following the general construction practice in Indonesia. 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 parameters evaluated were failure mechanism on the wall panel, load resistance, energy dissipation, and ductility.

## 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 concrete frame pouring. The wall specimens used moderate quality red bricks and average concrete and mortar quality. The material properties based on averaged material test are presented in Table 1.

**Table 1.** Material properties

| **Material** | | **Properties** | |
|---|---|---|---|
| Steel rebar | Longitudinal | Diameter (deformed bar) | 10.0 mm |
| | | yield stress $f_y$ | 384.9 MPa |
| | Transversal | diameter (un-deformed bar) | 7.8 mm, |
| | | yield stress $f_y$ | 350.9 MPa |
| Concrete | | beam size | 100 x 225 mm$^2$ |
| | | column size | 100 x 225 mm$^2$ |
| | | mixture by volume proportions (cement : sand : aggregate : water) | 1:2:3:1 |
| | | compressive strength | 18.0 MPa |
| Burned Clay Brick | | size | 55 × 100 × 205 mm$^3$ |
| | | compressive strength | 3.8 MPa |
| Mortar | | brick spacing | 15 mm |
| | | mixture by volume proportions (cement : sand : water) | 1:5:1 |
| | | compressive strength | 8.7 MPa |
| Opening | | opening size | 800 × 1200 mm$^2$ |
| | | wooden frame size | 50 x 100 mm$^2$ |
| Finishing | | bare brick wall, not plastered | |

## 3. EXPERIMENTAL SETUP

The details of the two wall specimens are shown in Fig. 1 and Fig. 2. Specimen 1 represents typical confined masonry wall, where typically the concrete members are made with the same thickness with the masonry for simple and efficient formwork. The height/width of the beam and columns are specified such that the area of the concrete elements equal to 15 x 15 cm$^2$, which is the minimum concrete area according to the house construction guideline The Ministry of Public Work, Indonesia (2009). Specimen 2 is similar to specimen 1, except for an 80 x 120 cm$^2$ framed window opening in the centre region. The window frame is made from 5 x 10 cm$^2$ timber with average quality commonly available and used for residential building. Both specimens were not finished by plaster.

The lateral cyclic load was applied at the top beam-column joint. The load came from a hydraulic jack attached to the reaction wall. Fig. 3 shows the test setup for the lateral cyclic load of confined masonry wall. The response of the wall specimen was measured using strain gauges and LVDT (Linear Variable Displacement Transducers). Cracks development and other damages were recorded and marked for each load cycle.

Fig. 4 shows the loading cycles by displacement control 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 equivalent to top displacement of 105 mm.

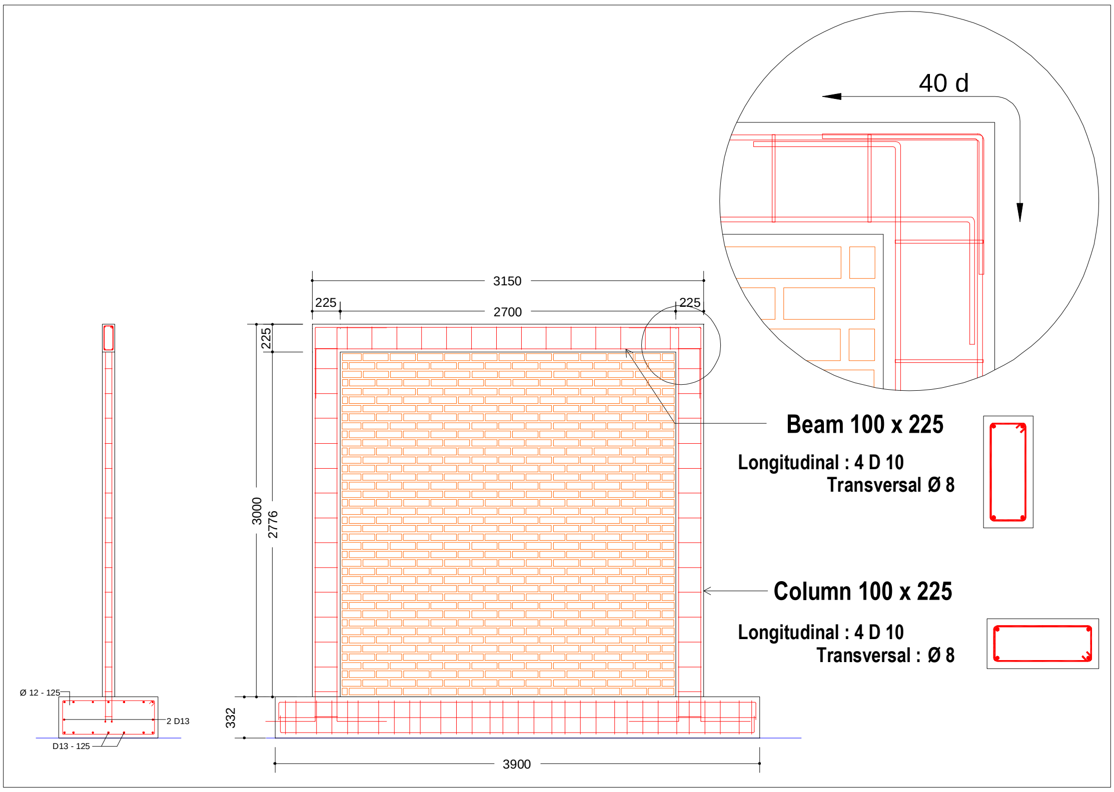


**Figure 1.** Details of wall specimen 1.

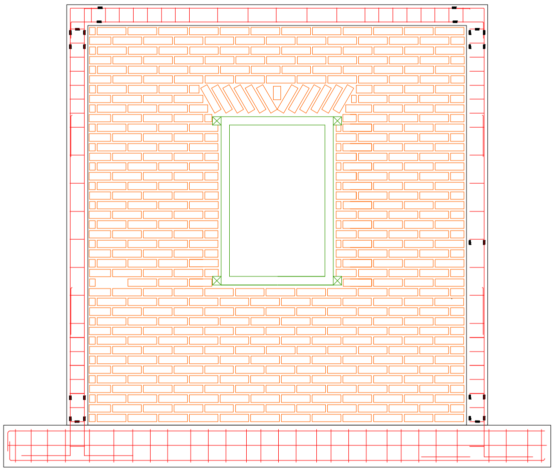

**Figure 2.** Details of wall specimen 2.

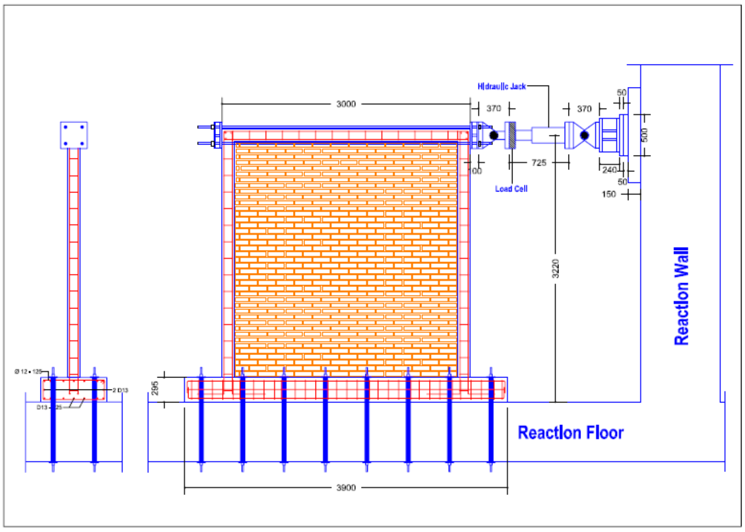


**Figure 3.** Experimental setup.

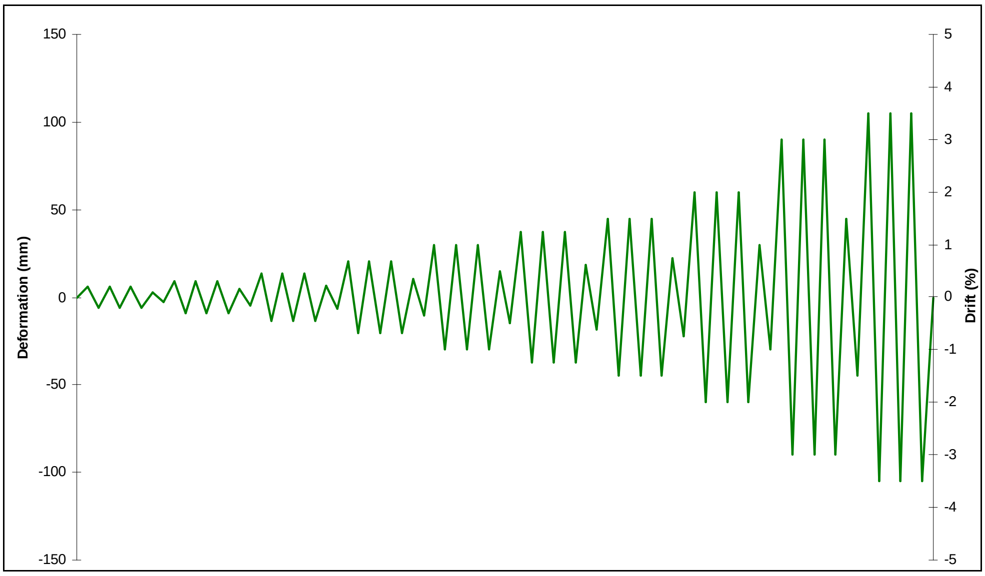


**Figure 4.** Deformation cycles for displacement controlled loading scheme

## 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. Fig. 5 and Fig. 6 show selected pictures of specimen 1 during the tests. Similarly, Fig. 7 and Fig. 8 show selected pictures of specimen 2 during the tests. Fig. 8 shows that the window frame can resist the masonry strut compressive force and act as element that bridge the upper part of the masonry compression strut to the lower part of the strut. The window frame was not seriously damaged until the collapse of the masonry wall element.


**Figure 5.** Damages observed during the test of specimen 1.

**Figure 6.** Damages observed at the corners of the concrete frame during the test of specimen 1

**Figure 7.** Damages observed at the corners of the concrete frame during the test of specimen 2

**Figure 8.** Damages around window frame of specimen 2 near the end cycle of test

### 4.1 Crack Patterns and Failure Modes

Fig. 9 and Fig. 10 present the crack patterns after the tests of specimen 1 and specimen 2, respectively. 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.

On specimen 1, crack initiated at drift 0.1% (displacement 3 mm) along brick to mortar attachment. Wide cracks with sliding shear pattern between mortar and brick initiated at drift of 0.133%. Finally, crack with diagonal pattern initiated to form the complete crack patter as show in Fig. 9. Crack on concrete element initiated at drift 0.25% (displacement 7.5 mm) with bending crack pattern at mid height of the column. At drift 0.5% bending crack started to form at exterior surface of the columns. Cracks on beam-column joint initiated at drift 1.4% with diagonal shear crack pattern. Wide shear crack also formed at the column near the base at drift 0.5%. Collapse of the masonry wall occurred due to large cracks that completely separated a large portion of the masonry wall to the confining concrete frame. The concrete frame remains standing until the end of the load cycles.

In specimen 2, crack initiated at drift 0.025% (displacement 0.075 mm) in several locations with direction crossing the bricks. Wide cracks with sliding shear pattern between mortar and brick initiated at drift of 0.1%. Finally, crack with diagonal pattern initiated to form the complete crack patter as show in Fig. 10. Crack on concrete element initiated at drift 0.2% (displacement 6 mm) with shear crack pattern at the base of beam-column joints. At drift 0.5% bending crack started to form at exterior surface of the columns. Cracks on beam-column joint initiated at drift 0.75% dominated by horizontal cracks parallel to the beam. Separation between columns and masonry wall occurred as continuation of the diagonal cracks. Cracks, spalling and angle change were observed on the beam columns joints. Wide shear crack also formed at the column near the base at drift 0.5%. Collapse of the masonry wall occurred due to large cracks that completely separated a large portion of the masonry wall to the confining concrete frame. The concrete frame remains standing until the end of the load cycles.

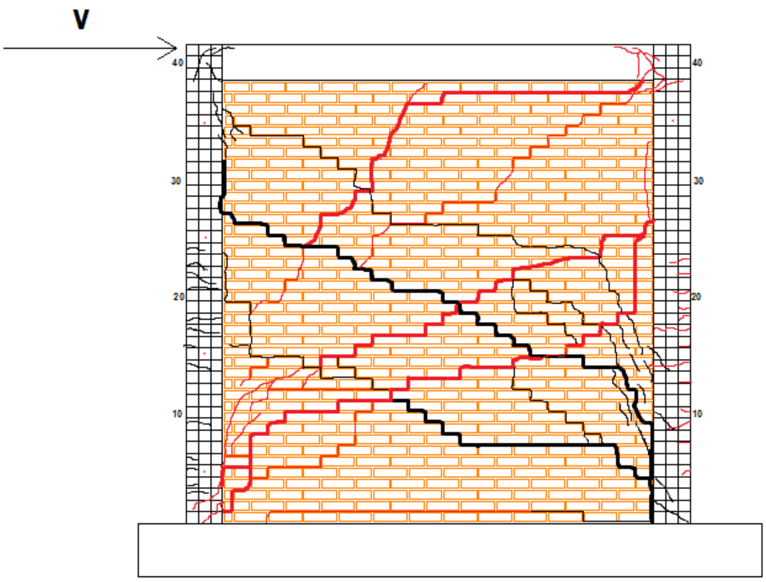


**Figure 9.** Crack patterns of specimen 1

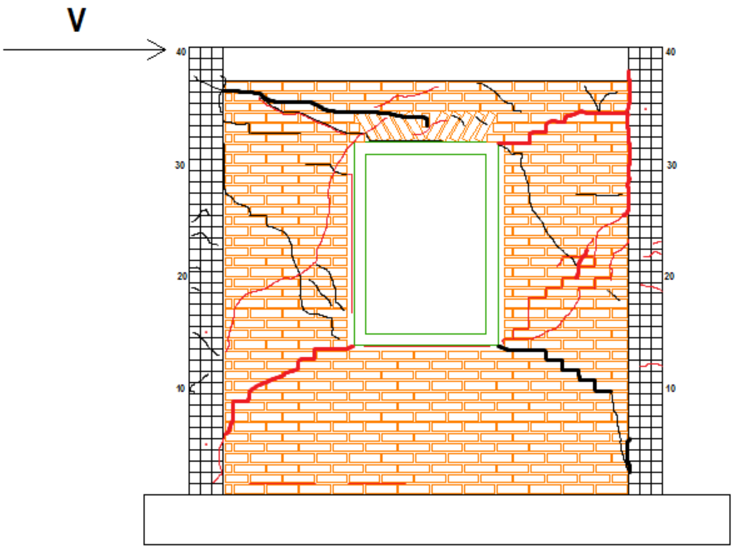


**Figure 10.** Crack patterns of specimen 2

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 bending cracks on the exterior side of the columns occurred due to inability of the masonry cracks to be closed at neutral potion of zero drift. The growing cracks eventually added to the volume of the wall masonry, which then pushed the columns outward.

Similarly, the diagonal crack pattern was also observed for specimen 2. The strut and tie mechanism was also developed in this model. The main difference is that the compression strut cannot form a complete straight line because disrupted by the window opening. However, the crack pattern and the window frame deformation during the loading test show that the window frame resisted the forces from the compression struts and act as link element that fill the gap in the window opening, such that the compression strut can resist and transfer the lateral forces from the top of the wall to the foundation.

### 4.2 Hysteretic Behaviour

Fig. 11 and Fig. 12 present the hysteretic diagram of load-displacement for specimens 1 and 2 during the tests. Fig 13 shows the comparison of envelope curves of the hysteretic diagrams. The two specimens appear to have similar hysteretic behavior, with slight difference in the maximum load. The peak load of specimen 1 occurred at drift 1.75% with peak load 5.18 ton, while the peak load of specimen 2 occurred at drift 1.0 % with peak load 5.83 ton. The slight difference in maximum load probably caused by material and workmanship variations. There is not much difference observed in stiffness degradation and ductility of both models.

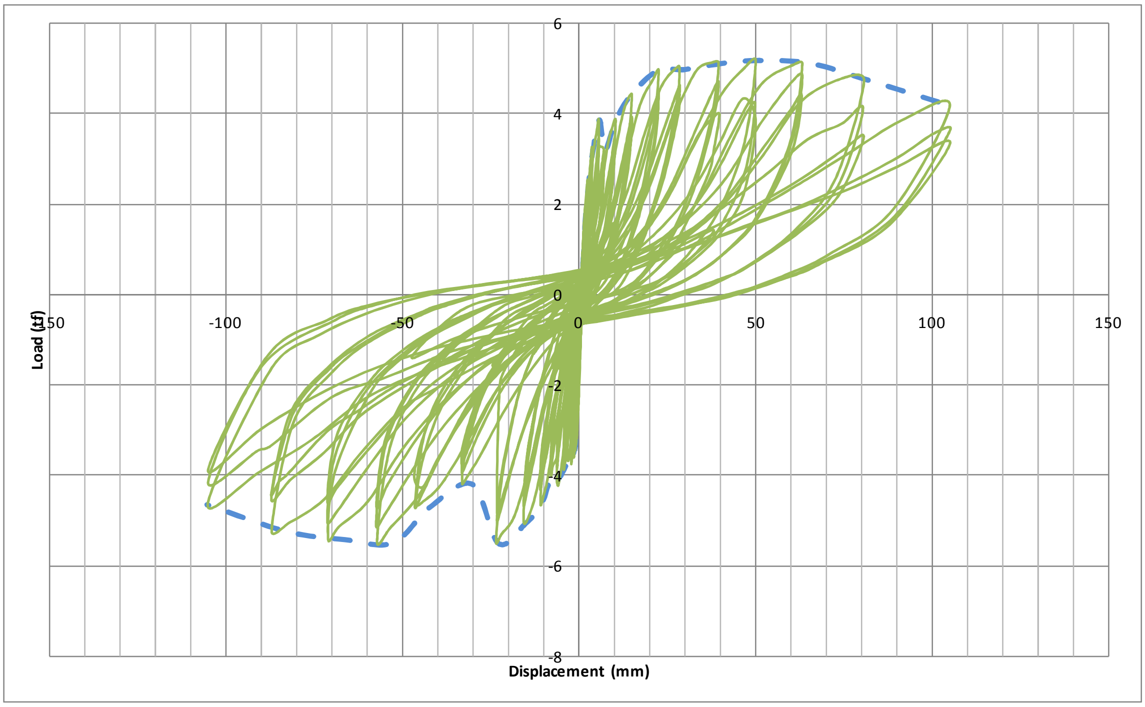


**Figure 11.** Hysteretic load-displacement of specimen 1

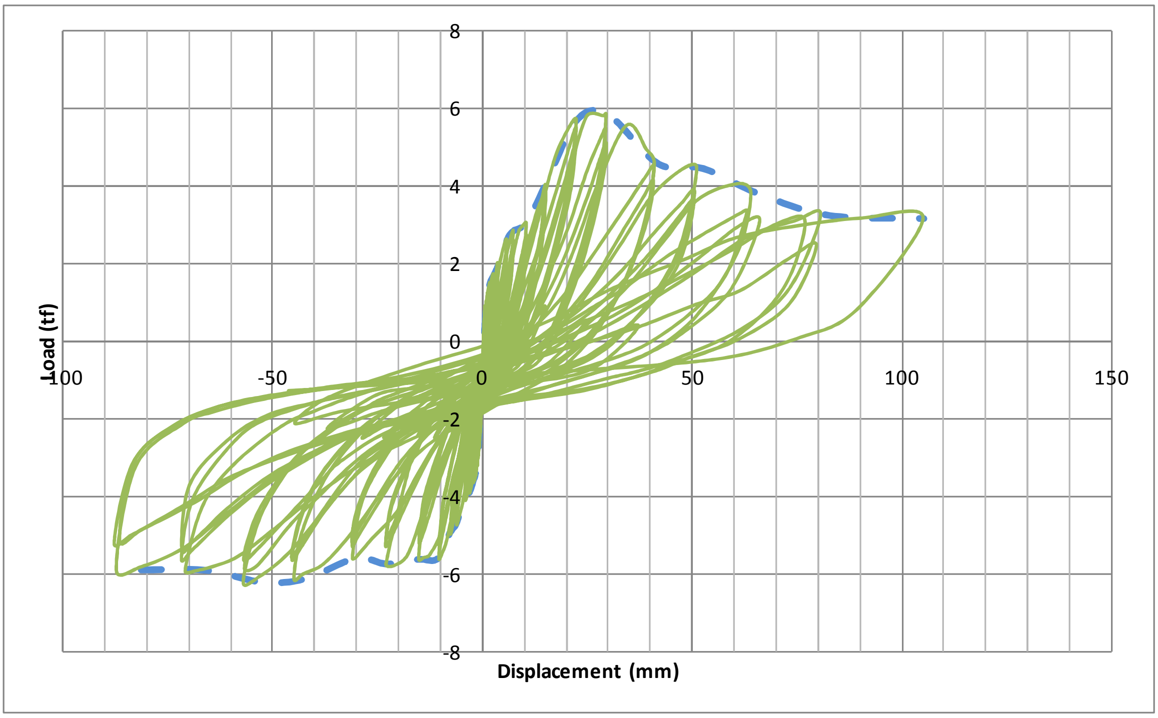


**Figure 12.** Hysteretic load-displacement of specimen 2

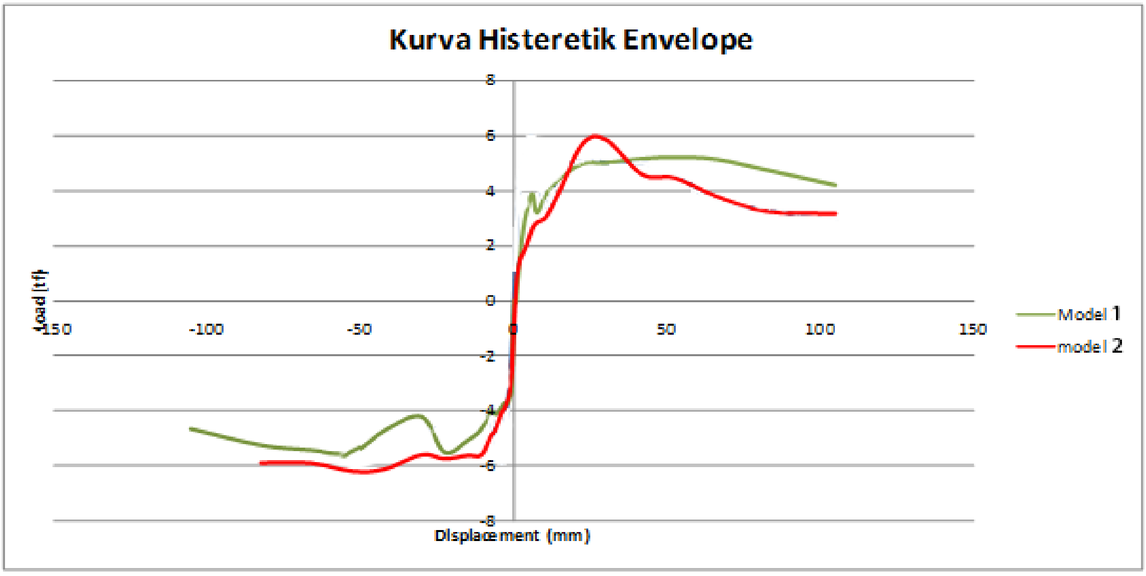


**Figure 13.** Comparison of hysteretic load-displacement envelopes

## 5. CONCLUDING REMARKS

The experimental study was conducted to study the behavior of confined masonry wall with and without opening subjected to cyclic lateral load. Based on the experimental results, the following conclusions were drawn:

1. Crack at the masonry walls initially developed in horizontal direction forming sliding shear failure pattern. However with increased load, crack direction become more dominant in diagonal direction forming diagonal compression failure crack pattern.
2. Both wall without and with opening show crack patter that dominated by diagonal compression failure crack pattern. In the wall without opening, the diagonal compression

struts were formed continuously by undisrupted masonry wall. In the wall with opening, the window frame resisted the forces from the compression struts and act as link element that fill the gap in the window opening, such that the compression strut can resist and transfer the lateral forces from the top of the wall to the foundation.

3. The average size and quality of the window frame commonly used in house construction in Indonesia is adequate to restore the strength and stiffness of a masonry wall weakened by window opening, such that the performance of masonry wall with and without opening become very similar.
4. Proper detailing of beams, columns, and connections is important to prevent major damage on the frame, thus provides confining action to the masonry walls.

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**REFERENCES**

ACI Committee 374 (2005). Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary (ACI 374.1-05), American Concrete Institute, USA.

Mehrabi, A. B., Shing, P. B., Schuller, M. P., Noland, J. L. (1996). Experimental evaluation of masonry-in-plane RC frames. *Journal of Structural Engineering* **122:3**, 228–237.

Tomaževič, M. (1999). Earthquake-Resistant Design of Masonry Buildings, Imperial College Press.

Tomaževič, M., Lutman, M. and Petkovic, L. (1996). Seismic behavior of masonry walls: experimental simulation. *Journal of Structural Engineering* **122:9**, 1048–1054.

Voon, K. C. and Ingham, J. M. (2006), Experimental in-plane shear strength investigation of reinforced concrete masonry walls. *Journal of Structural Engineering* **132:3**, 400–408.

The Ministry of Public Works, Indonesia (2009). *Persyaratan Pokok Rumah yang Lebih Aman.* House Construction Guideline