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Experimental Study on the Influence of the Opening in Brick-Masonry Wall to Seismic Performance of Reinforced Concrete Frame Structures

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Abstract. Reinforced concrete (RC) frame structures with brick-masonry infills are commonly used in developing countries and high-risk seismic area, such as Indonesia. Significant researches have been carried out for studying the seismic performance of RC frame structures with brick-masonry infills. Only few of them focused on effects of the opening in the brick-masonry infill to the seismic performance of the RC frame structures. The presence of opening in brick-masonry infill is often used for placing doors and windows as well, however, it may reduce the seismic performance of the RC frame structure. In the current study, they influence of the opening in brick-masonry infills to the seismic performance RC frame structure will experimentally evaluated. Five of 1/4-scaled single story and single bay RC frame specimens were prepared, i.e. an RC bare frame, a clay brick-masonry infilled RC frame and three of clay brick-masonry infilled RC frame with openings in the brick-masonry infills. The last three specimens were clay brick infilled RC frame with a center opening, clay brick infilled RC frame with two openings used for placing the windows and clay brick infilled RC frame with opening for placing the door. The specimens pushed over by applying the static monotonic lateral load to the upper beam of the RC frame structures. The incremental of the lateral load and the lateral displacement of RC frame's column was recorded during test. The crack propagation and the major cracks were also observed to identify the mechanism failure of specimens. As the results, the opening in the brick-masonry wall controls the failure mechanism, the lateral strength and the stiffness of the overall of infilled RC frame structure. The diagonal shear crack pattern was found on brick-masonry wall without opening, on other hand the different crack patterns were observed on brick-masonry wall with openings. Although the opening in the brick masonry infill reduced the lateral strength and stiffness of the infilled RC frame, it was still stronger and stiffer than the bare frame.

INTRODUCTION

Reinforced concrete (RC) buildings with brick-masonry infill as exterior and/or partition walls are widely used around the world, including in developing countries with high seismicity. Although this masonry infill contributes to the lateral strength and stiffness of RC frame structure, the presence of brick-masonry infill is usually neglected in seismic design calculations, which assume that it is a non-structural element.

Even though a lot of studies on in-plane earthquake simulation tests of masonry-infilled RC frames have been carried out for studying, the contribution of brick-masonry infill to their structural performance (e.g., [1-5]), only few of them focused on influence of brick-masonry infill with openings to the seismic performance of the RC frame structures. In past study, Maidiawati [6] evaluated the seismic performance of RC buildings according to Japanese's standard, The Japan Building Disaster Prevention Association, 2005, by considering the effects of brick masonry infill, however, the influence of brick infills with opening were neglected in calculation assuming that it did not contribute to seismic performance of RC frame [7]. Even so, a number studies reported that masonry infill with

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opening affects to reduce the seismic performance of infilled frame structure which it depends on ratio of opening area to masonry wall area [8]. This circumstance revealed that, in spite of masonry experimental research program have been conducted in many countries, the behavior of infilled frame with opening brick masonry wall is still not well known. Notably, the major experimental conclusions of the past studies were contradictory and suggest the importance of study related to seismic behavior of brick infilled frame with opening. Therefore, a series structural test was conducted to investigate the influence of clay brick infill with opening which are not considered in seismic design, on the actual performance of RC frame structure. Experimental specimens represented the typical RC building with clay brick masonry elements in Indonesia. This paper compares the test results of seismic performance of RC frame with clay brick infill with and without openings.

EXPERIMENTAL PROGRAM

Characteristic of the Specimens

To experimentally clarify contributions of brick masonry infill with opening to seismic performance of RC frame structure, five of 1/4-scaled single story and single bay RC frame specimens were prepared: an RC bare frame (BF), an RC frame infilled with solid clay brick-masonry (IF$_{SW}$) and three of RC frame infilled with clay brick-masonry with openings. The last three specimens were the infilled frame with a center opening of size 40% (IF$_{OW-1}$), the infilled frame with two openings used for placing the windows with total size of 25% (IF$_{OW-2}$) and the infilled frame with door opening of size 25% (IF$_{OW-3}$).

RC frame elements for all specimens were constructed with identical dimension and detailing structure. The clear height of column were 750 mm with theirs cross-sectional dimension of 125x125 mm, 4D10 longitudinal rebars and ϕ4-50 transverse hoop. The cross-sectional dimension of beam was 150x150 mm with 6D16 longitudinal reinforcement and a hoop of ϕ8-50. Fig. 1 is a detailed drawing of the BF specimen.

After the reinforced concrete was completed, the infill walls were constructed using 1/4 scale clay bricks of dimensions of 55 mm in length, 28 mm in width and 13 mm in height which were laid up in the interior clear height of frames with mortar beds. The average compressive strength of clay brick was 5.0 N/mm^2. No shear connectors were used in the specimens. The parameters studied in this experimental program were the size, location and type of openings on the brick masonry wall. The experimental parameters of specimens are summarized in Table 1. The ratio between the opening area and the total area of wall, α, are included in Table 1. Fig. 2 presents the structural drawing of infilled RC frame specimens.

TABLE 1. Experimental parameters of the specimens

Specimens	Column	Beam	Brick wall	α (%)
BF	Cross-section: 125×125 Main bar: 4D10 Hoop: ϕ4-50	Cross-section: 150×150 Main bar: 6D16 Hoop: ϕ8-50	none	0
IF$_{SW}$			Solid wall	0
IF$_{OW-1}$			with a center opening	40
IF$_{OW-2}$			with two openings	25
IF$_{OW-3}$			with door opening	25

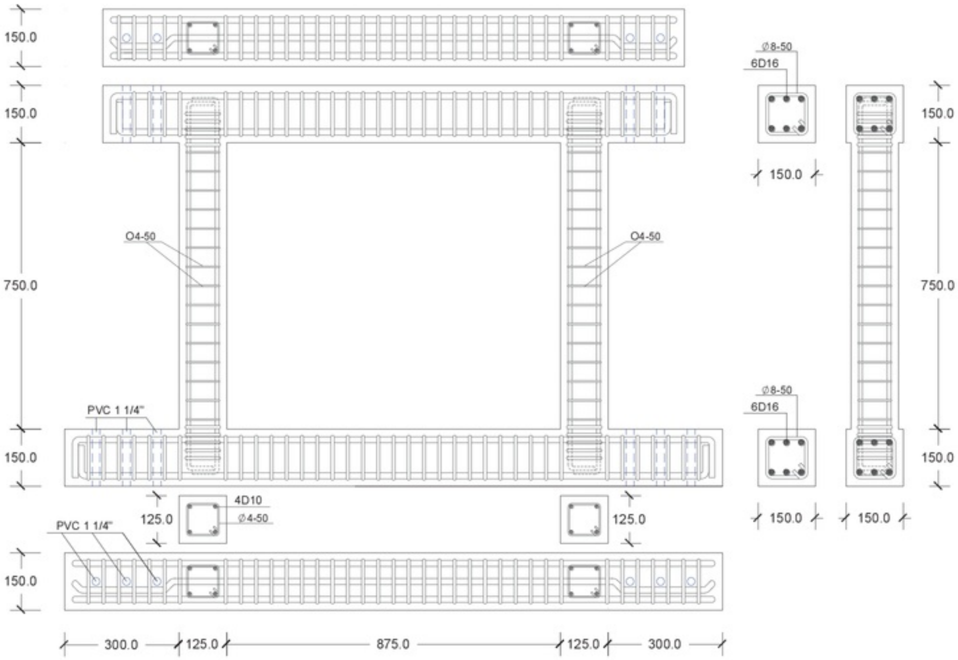
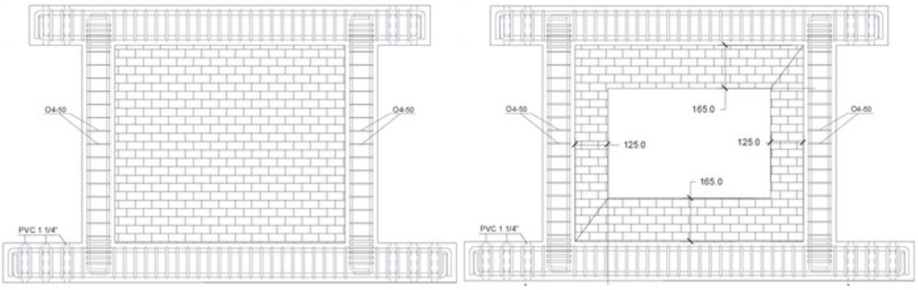
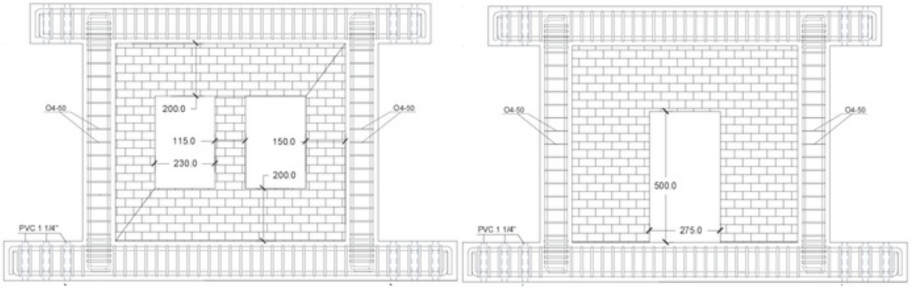


FIGURE 1. Detailed drawing bare frame specimen (BF)



(a) $\mathrm{IF}_{\mathrm{SW}}$ (b) $\mathrm{IF}_{\mathrm{OW\text{-}1}}$



(c) $\mathrm{IF}_{\mathrm{OW\text{-}2}}$ (d) $\mathrm{IF}_{\mathrm{OW\text{-}3}}$

FIGURE 2. Structural drawing of infilled framme specimens

Material Properties

The mechanical properties of the concrete, reinforcements, and brick masonry used in the specimens are presented in Table 2.

TABLE 2. Material properties of concrete, reinforcement, and brick masonry

Specimen	**Compressive strength of concrete, f_c' (N/mm^2)**	**Yield strength of reinforcing bars, f_y (N/mm^2)**	**Compressive strength of masonry prism, f_m (N/mm^2)**
BF	27.3	488 (for D16) 377 (for D10) 365 (for Ø8) 235 (for Ø4)	-
IF_{SW}	27.3		4.3
IF_{OW-1}	27.3		4.3
IF_{OW-2}	27.3		4.3
IF_{OW-3}	27.3		4.3

Test Method

The specimens were tested at testing facility of Material and Structure Laboratory of Civil Engineering Department Andalas University. A schematic representation of experimental testing set-up is shown in Fig. 3. A horizontal monotonic load was applied along the axis of the top beam and the incremental load was controlled by lateral displacement measured with LVDT placed at the top beam, as illustrated in Fig. 3. There was no vertical load applied to specimens. During the test, the incremental of the lateral load was recorded and initial cracks, cracks propagation, major cracks width in the columns and brick infill panel were observed to identify the failure mechanism of specimens. Formation of the final cracking pattern of the specimen was noticed.

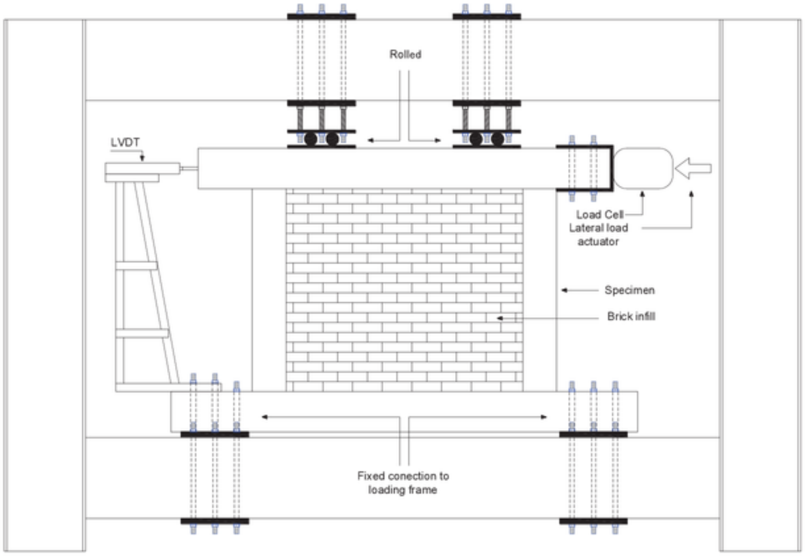


FIGURE 3. Schematic view of test set-up

EXPERIMENTAL RESULTS AND DISCUSSION

Failure Mechanism and Cracks Propagation

Significant differences of performance for the five specimens were observed during experimental works. The sequential failure and cracks propagation of each specimen is described in the subsequent subsections.

BF specimen

Initial flexural cracks appeared at the bottom and at the top of the tensile column at the lateral displacement of 3.9 mm when the structure was subjected to a lateral load of 14.6 kN. The initial shear crack was observed at the bottom of tensile column at lateral displacement of 9.8 mm during the lateral load of 23.4 kN. During the test, shear cracks grew and developed at the ends of both columns. The shear cracks also occurred at the top of beam-column joint areas where the transformation of shear force occurred in this area. The maximum lateral strength of 38.8 kN was recorded at lateral displacement of 37.5 mm. Furthermore, the lateral strength of the RC frame gradually degraded to ultimate condition. The final crack pattern of the BF specimen is shown in Fig. 4a.

IF$_{SW}$ specimen

Significant differences of mechanism failure were observed between IF$_{SW}$ and BF specimens due to existing of brick infill in RC frame. On the infill wall, initial shear crack occurred at the bottom of brick wall at the lateral displacement of 0.74 mm as the specimen subjected to lateral load of 12 kN. Moreover, a diagonal shear crack at the center of brick panel appeared at lateral deformation of 2.06 mm during the lateral load of 26.8 kN. Furthermore, the diagonal shear cracks grew up in brick infill which deduces that the compression strut acting the infill. As a consequence, the high punching shear acts on the infill when suffered to shear deformation. The brick infill wall failed in shear and lateral strength started to decline.

The separation cracks between infill and compression column and between infill and upper beam were observed at the lateral displacement of 37.7 mm and 4.9 mm, respectively. At the lateral displacement of 6.1 mm, initial flexural crack was detected at the middle of tensile column and initial shear crack was observed at the top of tensile column. During the test, shear cracks at the top of tensile column and at the bottom of compressive column grew to ultimate condition. The final crack pattern indicating the failure of the IF$_{SW}$ specimen is shown in Fig. 4b.

IF$_{OW\text{-}1}$ specimen

A vertical crack was detected below of the opening at the lateral displacement of 0.4 mm. Initial shear crack was detected in brick infill at the corner of opening at lateral displacement of 0.5 mm. Moreover, shear cracks grew up at the corners of opening during the test. Initial flexural crack occurred on tensile column at lateral displacement 0f 3.6 mm when the specimen subjected to a lateral load of 28.3 kN. Initial shear crack was observed at the bottom of compressive column at lateral displacement of 6.0 mm corresponding to lateral load of 39.1 kN. The brick wall failed in shear marked with crushing the brick infill at the corner of opening. On the other hand, the column failed in shear by indicating of buckling the longitudinal reinforcement at bottom of compressive column. The crack pattern of the IF$_{OW\text{-}1}$ specimen at the final condition is shown in Fig. 4c.

IF$_{OW\text{-}2}$ specimen

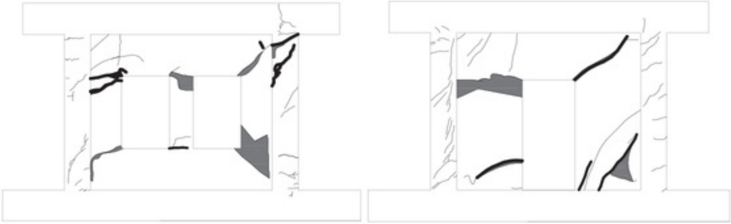
A crack was observed in brick infill between two openings at the lateral displacement of 0.6 mm that it was categorized as an initial shear crack. As lateral load increases to the specimen, shear cracks appeared and grew up at the corners of openings. Initial flexural crack on the tensile column occurred at the lateral displacement of 4.8 mm during the lateral load of 35.3 kN. The initial shear crack appeared on the tensile column at lateral displacement 5.8 mm. Shear failure of infill occurred at the corners of openings of brick infill. On the other hand, shear failure of column occurred at the top of tensile column and at the bottom of compressive column. The crack pattern of IF$_{OW\text{-}2}$ specimen at the final condition is shown in Fig. 4d.

IF$_{OW\text{-}3}$ specimen

Initial shear crack in brick infill was observed at the top right corner of door opening at the lateral displacement of 0.6 mm corresponding to lateral load of 6.8 kN. Moreover, shear cracks grew up at the corners of opening on brick panel to ultimate condition. Initial flexural crack was observed on tensile column at the lateral displacement of 3.8 mm and initial shear crack was detected at the bottom of compressive column at the lateral placements of the 6.3 mm. Shear failure on brick panel was marked by crushing of the brick wall at the top left corner of opening.

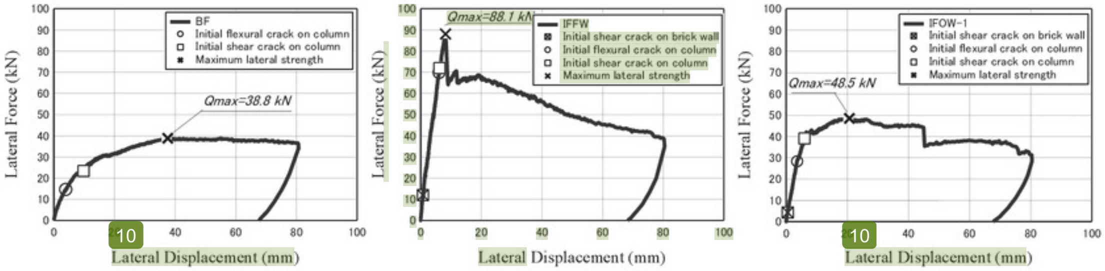
Columns failed in shear that it was observed at the bottom of compressive column and at the top of tensile column. The crack pattern of IF$_{OW-3}$ specimen at the final condition is shown in Fig. 4e.

(a) BF Specimen (b) IF$_{SW}$ specimen (c) IF$_{OW-1}$ specimen

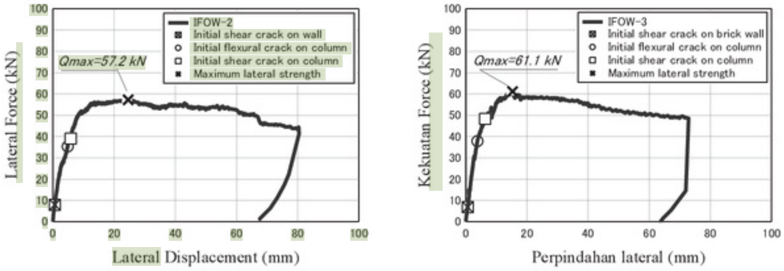


(d) IF$_{OW-2}$ specimen (e) IF$_{OW-3}$ specimen

FIGURE 4. Crack pattern of specimens after the test



(a) BF Specimen (b) IF$_{SW}$ specimen (c) IF$_{OW-1}$ specimen



(d) IF$_{OW-2}$ specimen (e) IF$_{OW-3}$ specimen

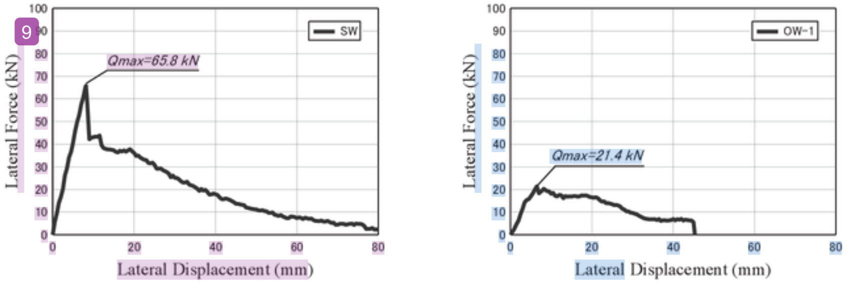
FIGURE 5. Lateral force-displacement relationship of RC infilled frames with openings

Lateral Force-Displacement Relationship

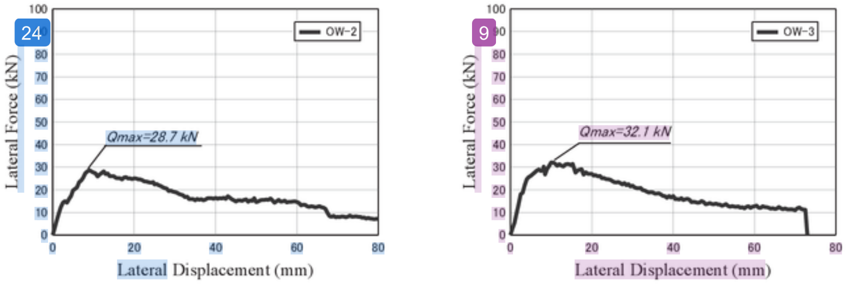
Fig. 5 shows the comparison of relationship between lateral force and lateral displacement of all specimens. The maximum lateral strength of 38.8 was observed at 37.5 mm lateral displacement for the BF specimen. Even though, the maximum strengths reached 88.1 kN, 48.5 kN, 57.2 kN and 61.1 kN at lateral displacement of 8.2 mm, 20.7 mm, 24.6 mm and 15.3 mm for IF$_{SW}$, IF$_{OW-1}$, IF$_{OW-2}$, IF$_{OW-3}$ specimens, respectively. The results revealed that lateral strength increased to 2.3 times as the solid clay brick wall existed into RC frame. In the cases of infilled frames with openings, although the opening in brick infill reduced the lateral strength and stiffness of the infilled frame, it was still stronger and stiffer than the bare frame. The lateral strength of infilled frames with openings is higher than those of bare RC frame of 0.25, 0.47, and 0.57 times for IF$_{OW-1}$, IF$_{OW-2}$, and IF$_{OW-3}$ specimens, respectively. Although the IF$_{OW-2}$, and IF$_{OW-3}$ specimens had the same opening ratios of 25%, the difference of performance was observed between these specimens. It seems that the type and location of opening affect the performance of infilled RC frame structure.

According to experimental results, the lateral load was dominantly resisted by overall structures of infilled frame until the maximum lateral force reached. However, after shear failure of brick infill, the lateral strength degraded, and then the lateral load was resisted by bounding frame.

The infill contribution was evaluated by extracting the difference between lateral forces of infilled frames (IF$_{SW}$, IF$_{OW-1}$, IF$_{OW-2}$, and IF$_{OW-3}$), and bare frame (BF) specimens at the same lateral displacement. As the results, the Fig. 6 shows the lateral strengths of brick infills with and without openings which contributed to the bare RC frame performance. These figures revealed that opening significantly reduce the lateral strength of infill. However, the infill with opening by about 40% size still contributes to increase the lateral strength of the bare frame as shown in Fig.5b.



(a) Solid brick wall (b) Brick wall with a center openingof size 40%



(c) Brick wall with two openings of size 25% (d) Brick wall with a door opening of size 25%

FIGURE 6. Lateral force-displacement relationship of brick infill

CONCLUSIONS

Based on experimental tests on one of 1/4-scaled single story RC frame and four 1/4-scale single story brick infilled RC frames with and without openings, the following conclusions are presented:

1. The presence of solid brick infill and infill with openings in RC frames increases the lateral strength and stiffness of infilled RC frame structures.
2. The openings in brick-masonry infill control the failure mechanism, the lateral strength and the stiffness of the overall structure. Though the opening in brick infill reduced the lateral strength and stiffness, the infilled frame with opening was still stronger and stiffer than the bare RC frame.
3. The diagonal shear crack pattern was found on brick-masonry wall without opening deduced that the compression strut acting the infill, on other hand the different crack patterns were observed on brick-masonry wall with openings.
4. Solid brick infill contributes 2.3 times to increase the lateral strength of bare RC frame. In the cases of brick infills with openings increase the lateral strengths of bare RC frames by about 0.25, 0.47 and 0.57 times, for infill with a center opening of 40% ratio between the opening area and the wall area, infill with two openings of 25% ratio, and infill with door opening of 25% ratio, respectively.

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