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Effects of Single and Multi Openings in Brick Infills on the Seismic Response of Infilled RC Frames

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Abstract. Many researchers have performed a lot of studies of the seismic behavior reinforced concrete (RC) frame with masonry infill. They found that masonry infill affects the lateral strength, stiffness and ductility performance of the RC frame structures. However, when openings appeared in the panel infill for door and windows, the responses of the overall structure are entirely changed. The primary purpose of this study is to experimentally investigate the behavior of brick infilled RC frames possessing single opening and two openings. Four specimens of 1/4-scale single bay RC frames with brick infills were made that were one bare frame, one frame with full infill and two frames with infills having a central opening and two openings with the opening ratio of 25%. The specimens were tested under lateral reversed cyclic loads. Consequently, different responses of failure mechanism, lateral strength, stiffness and energy dissipated were observed among the specimens. The brick full infill failed in shear with propagation cracks in central part of the panel, but in the case of the infills with single and two openings, the cracks were dominated at the corners of the openings. The in-plane strength, stiffness and dissipated energy of infilled frames decreased when openings appeared in the panel. However, the seismic performance of brick infilled frame with the opening of 25% of panel area is better than those of bare frame. The brick infilled frames with a central opening and two openings are similar in lateral strength and dissipated energy. It seems that area and position of the openings control the seismic response to the overall infilled frame structure of the openings

1 Introduction

Brick masonry walls are very commonly used as partition in reinforced concrete (RC) buildings around the world, including in Indonesia as one of the high seismicity regions. Mostly, the brick-masonry wall is assumed as a non-structural element and ignored in seismic design calculations.

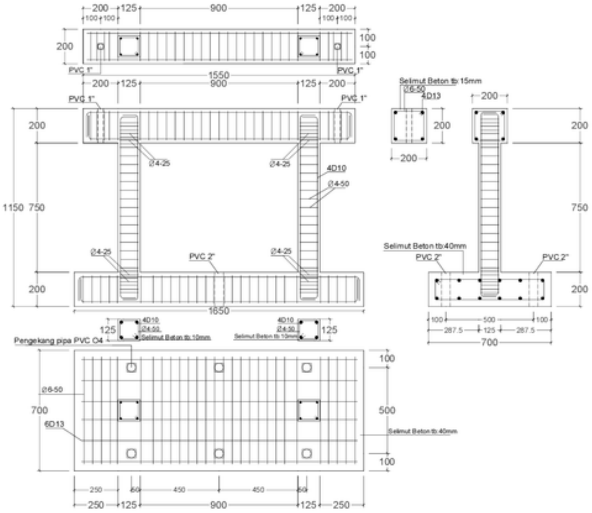
Large numbers of studies related to evaluating the brick masonry wall contribution on seismic performance of RC frames have been carried out (Choi et al., 2017; Maidiawati et al., 2011; Tanjung and Maidiawati, 2017; Zovkic et al., 2012; Dautaj et al., 2018). They mainly studied seismic behavior and performance of frames with solid masonry infill. The authors experimentally tested the RC frame infilled with brick infill for investigating its seismic behavior by comparing to those of bare frame (Maidiawati et al., 2011; Tanjung et al., 2017). Besides, an analytical model of infilled frame was developed and applied to calculate the seismic performance of RC building by considering the brick masonry infill as clearly stated in Reference (Maidiawati and Sanada, 2017). Nevertheless, these studies neglected the brick infills with openings by assuming that the infills with openings did not contribute to the seismic performance of frame structure (Choi et al., 2005). However, several references explained that infills with opening still contribute to the lateral strength of frame structure depended to type and size of opening (Maidiawati et al., 2017; Mohammadi and Nikfar, 2013; Mondal and Jain, 2008). The authors tested brick masonry infilled frames with door and window openings in infills by applying monotonic lateral loading (Maidiawati et al., 2017). It was found that openings in infill changed the failure mechanism of structure and decreased the seismic resistance and stiffness of overall infilled frame structures.

The current study experimentally investigated the seismic behavior RC frame infilled with brick infill having single and multi-window openings under cyclic lateral loading. The structure responses of failure modes, lateral strength, stiffness, and energy dissipation are discussed in this paper.

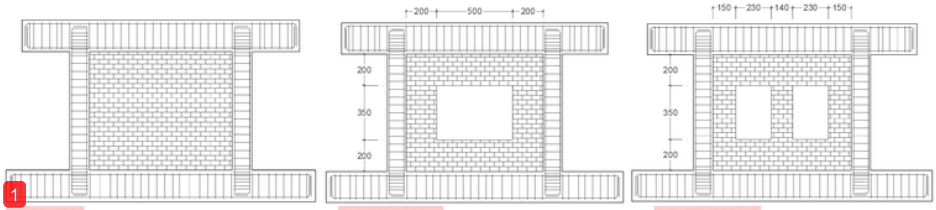
2 Experimental specimens

Four of 1/4-scaled single story and single bay RC frame specimens were prepared to experimentally clarify the effects of single and multi-openings in unreinforced brick infill on seismic response of RC frame structuregle bay RC frame specimens. They consisted of an RC bare frame (BF), an RC frame infilled with solid clay brick-masonry (IFSW) and one of brick masonry infilled RC frame with a central opening (IFOW-1) and one of infilled frame with two openings

(IFOW-2). The dimension and detailed structure of all specimens were all the same to RC frame elements. Figure 1(a) shows the detailed drawing of the RC frame elements. The columns clear height was 750 mm with their cross-sectional dimension of 125x125 mm, 4D10 longitudinal rebars and ϕ4-50 transverse hoops. The cross-sectional dimension of the upper beam was 200x200 mm with 4D13 longitudinal reinforcements and a hoop of ϕ8-50. The cross-sectional dimension of the footing beam was 700x200 mm with 16D13 for the longitudinal reinforcements and ϕ8-50 for the hoop.
The infill element used 1/4 scale clay bricks of dimensions of 60 mm in length, 30 mm in width and 13 mm in height. The scaled brick units were arranged with mortar beds in the interior clear height of frames. The ratio of cement:water for mortar was 1:0.5. Finishing mortar with 5.0 mm thickness used for plastering both wall surfaces. The average compressive strength of brick is 10.9 N/mm2. No shear connectors were used between infill and boundary columns. Figures 1(b), 1(b), and 1(c) show the RC frame with solid brick infill, RC frame with brick infill having a central opening, and RC frame with brick infill having two openings, respectively.



(a) Detailed drawing of the RC frame element



(b) IFSW (c) IFOW-1 (d) IFOW-2

Fig. 1: Detailed drawing of specimens.

3 Material properties

Table 1 shows the compressive strength of concrete (fc'), the compressive strength of brick masonry prism (fm'), yield strength (fy) and tensile strength (fu) of reinforcements as the material properties of specimens.

Table 1. Material properties of specimens

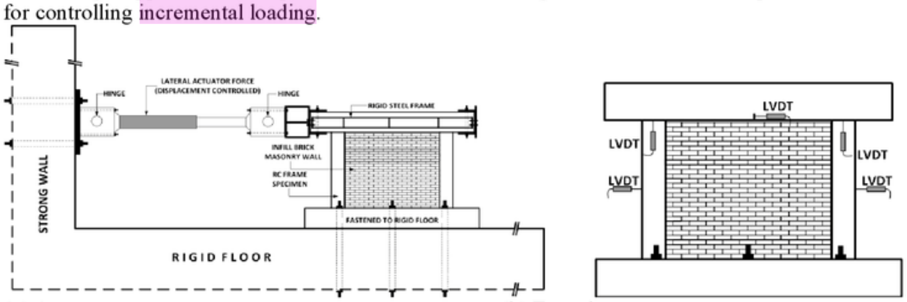
Specimen	f'_c (N/mm2)	f'_m (N/mm2)	f_y (N/mm2)	f_u (N/mm2)
BF	49.9	-	390.2 (for Ø4)	598.3 (for Ø4)
IFSW	49.9	13.0	346.8 (for Ø6)	448.6 (for Ø6)
IFOW-1	49.9	13.0	462.0 (for D10)	619.7 (for D10)
IFOW-2	49.9	13.0	421,1 (for D13)	582.4 (for D13)

4 Test method

4.1 Loading system

The test models were constructed and tested at the testing facility in Structural and Construction Material Laboratory of Civil Engineering Department, Syiah Kuala University. The specimens subjected by reversed cyclic lateral loads using a horizontal hydraulic jack with a capacity of 500 kN without axial load. Figure 2 demonstrates the schematic representation of the test setup and loading system.

The lateral reversed cyclic loading applied to the specimens referred to FEMA 461 standard (FEMA 461, 2007). The loading history of cyclic loading applied to specimens is shown in Figure 3. The lateral load with initial cycle to R=1/800 was applied to specimen and then followed by two cycles to R=1/400, 1/200, 1/100, 1/50, 1/25, 1/12.5, and 1/10, however, the loading stopped when the specimens failed. The drift angle R; ratio of lateral displacement to column height, is used for controlling incremental loading.



(a) Actuators set-up (b) Transducers set up

Fig. 2: Schematic representation of test setup

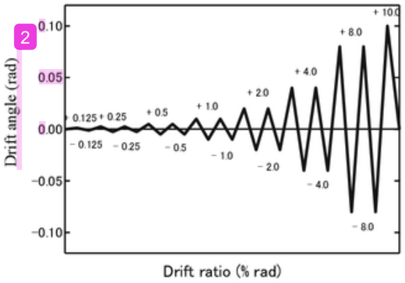


Fig. 3: Loading history

4.2 Measurement

Several measurement devices of LVDT were placed on the columns of specimen to quantify the horizontal and vertical displacements of both columns, as shown in Figure 2(b). During the test, the incremental applied cyclic lateral loads, as well as displacements, were recorded. Initiated cracks and crack propagation were marked in the columns and the infills at the peak and residual drifts to identify the failure process of specimens. Failure mode and the final cracking pattern of the specimen were noticed.

Test results and discussion

5.1 Failure process

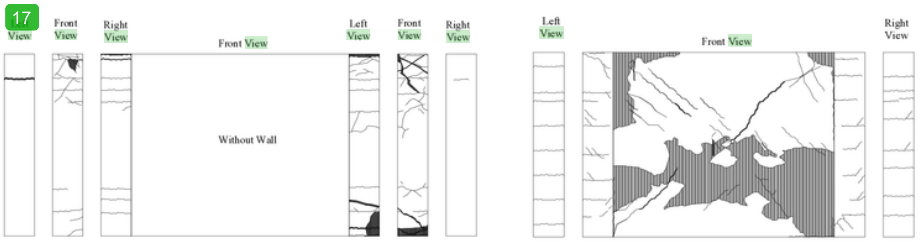
Table 2 summarizes the failure process of all specimens. Comparison of crack patterns of specimens at the final condition after testing are exhibited in Figure 4.

Table 2. Failure process of specimens

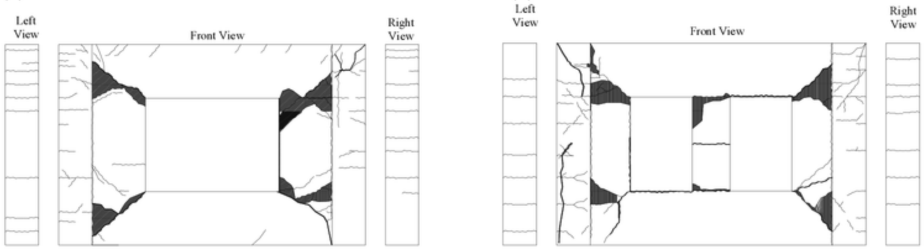
cycles	BF Specimen	IFSW specimen
1/800	No crack in this cycles	Separation cracks between column and wall at a drift ratio of 0.05.
1/400	Initial flexural crack at the top of the tensile column at 0.16 drift ratio.	Initial flexural crack at the tensile column at drift ratio 0.17. Initial shear crack at the tensile column at the drift ratio of 0.21.
1/200	Initial shear crack at the bottom of the compressive column at a drift ratio of 0.5.	Initial shear crack at the center of panel wall at a drift ratio 0.45.
1/100	Propagations of flexural cracks at the ends of both columns.	Propagation of shear cracks at the ends of both columns and peeling off of the wall plaster.

1/50	Development of flexural cracks to flexural-shear cracks.	Development of shear crack width at the ends of columns and spalling of wall plaster.
1/25	Propagation of shear crack at the ends of columns.	Shear failure of the brick wall in the in plane direction and then degradation of lateral strength.
1/25.5	Shear failure at the bottom of the compressive column at a drift ratio 7.85.	Failure of the wall in out of plane direction. Shear failure at the bottom of the compressive column.
1/10	Shear failure in both columns. Degradation of lateral strength	Shear failure of both columns.

cycles	IFOW-1 Specimen	IFOW-2 Specimen
1/800	Initial shear crack at the left top corner and at the right bottom corner of opening at the drift ratio 0.06.	Initial shear crack at the left top corner of the opening at the drift ratio 0.04. Initial flexural crack in the wall between two openings at drift ratio 0.06. Separation cracks between column and wall at a drift ratio of -0.06.
1/400	Separation cracks between columns and wall. Initial flexural crack at the tensile column at the drift ratio 0.25.	Initial flexural crack at the top of the tensile column at a drift ratio of 0.26.
1/200	Initial shear crack at the tensile column at a drift ratio 0.47. Propagation of flexural cracks at the middle height of both columns.	Initial shear crack at the top of the tensile column at a drift ratio of 0.51
1/100	Development of shear cracks at the corners of the opening. Propagation of shear cracks at the ends of both columns. And propagation of flexural cracks along both column height.	Development of shear cracks at the corners of the opening. Propagation of shear cracks at the ends of both columns. And propagation of flexural cracks along both column height.
1/50	Initial peeling off the plaster at the corner of the opening.	Development of shear cracks at the corners of the opening. Peeling off the plaster at the corner of the opening.
1/25	Spalling of plaster of the wall. further shear failure of the wall at the corner of the opening. Propagation of shear cracks at the top of the column. And then degradation of lateral strength	Spalling of plaster of the wall. Initial failure of the wall in out of plane direction. Degradation of lateral strength
1/12.5	Shear failure of the tensile column. Initial failure of the wall in out of plane direction	Shear failure of the tensile column. Initial failure of the wall in out of plane direction
1/10	Totally collapsed of the wall in out of plane direction	Totally collapsed of the wall in out of plane direction



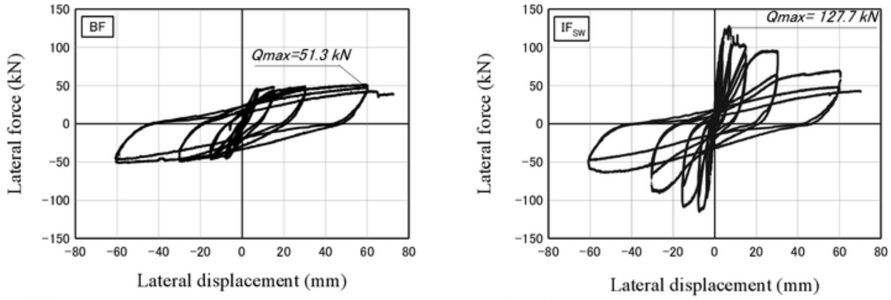
(a) BF (b) IFSW



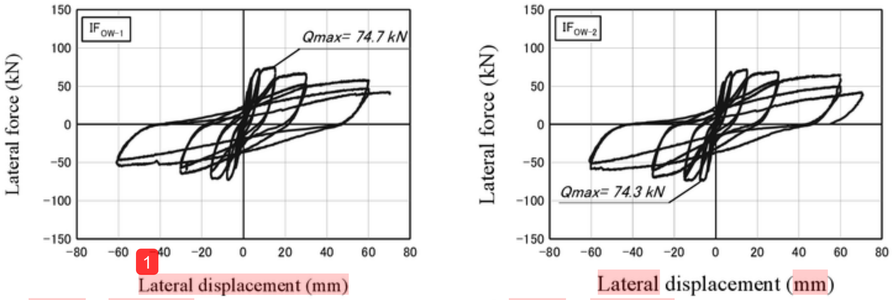
(c) IFOW-1 (d) IFOW-2
Fig. 4: Crack pattern of specimens

5.2 Lateral strength vs. lateral displacement

The relationship between lateral strength vs. Lateral displacement is shown in Figure 9 which indicates the seismic performance of specimens. The maximum lateral strength of 51.3 kN achieved at 57.8 mm lateral displacement. In the cases of the IFSW, IFOW-1 and IFOW-2 specimens attained to the maximum lateral strengths of 127.7 kN, 74.7 kN and 74.3 kN at the drift ratios of 0.93%, 1.86%, and 0.98%, respectively. These results revealed that the IFOW-1 and IFOW-2 specimens with the opening ratio of 25% are similar in lateral strength. It seems that reduction of lateral strength of infilled frame structure is influenced by the ratio of opening to panel area, even though the infill has single or multi openings. The deformation capacity was evaluated as the lateral strength degraded to 80% after the peak of lateral strength that it was obtained at drift ratios of 8.4% for BF, 1.9% for IFSW, 7.7% for IFOW-1 and 6.8% for IFOW-2. It indicates that the ductility performance of infilled frame with a single opening is higher than those of RC frames with solid infill and infill with two openings. The single and two openings with a ratio of 25% of panel decreased the lateral of infilled frame to 58%. The stiffness of infilled frame decreased to 30% and 60% as single and two openings appeared in infill, respectively. However, the seismic performance of infilled frames with single and two openings were better than those of bare frame.



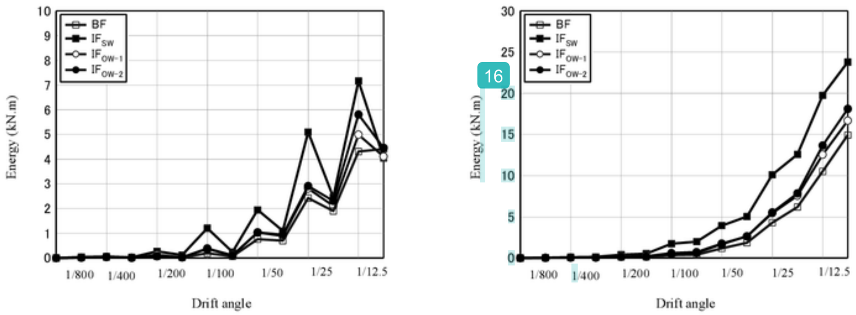
(a) BF specimen (b) IFSW specimen



(c) IFOW-1 specimen (d) IFOW-2 specimen
Fig. 5: Lateral force-Lateral displacement relationship

5.3 Dissipated energy

For elements of RC structure designed to resist seismic load which accommodate damage without collapse, the energy produced by the seismic event can be dissipated by hysteretic response of RC elements without a significant reduction in strength (Rodrigues et al., 2012). Therefore the amount of energy dissipated of structures may be evaluated by calculating the area enclosed by hysteresis loops curves indicated in Figure 5. Consequently, the dissipated energy in each loading cycle and the cumulative energy dissipation are presented in Figure 6. The energy dissipation of RC frame with solid infill is higher 1.6 times than those of the bare frame, 1.4 times than that of RC frame with a central opening and 1.3 times than those of RC frame with two openings infill. It indicates that energy dissipation of infilled frame was reduced as opening existed in infill. In the case of RC frames with infill with a central opening and infill with two openings, they were similar in energy dissipation. Significant reduction of energy dissipation in the second cycle was observed on the RC frame with solid infill. It reduced to 50% of the first cycle energy dissipation as shown in Figure 6(a). In the cases of bare frame (BF) and infilled frame with openings (IFOW-1 and IFOW-2), significant degradation of energy dissipation in the second cycle occurred at drift angels R=1/400 to R=1/100 that was about 70% of the first cycle energy dissipation, but reduction was only about 20% at drift angles R=1/50 to R=1/12.5.



(a) Dissipated energy in each loading cycle (b) Cumulative dissipated energy

Fig. 6: Dissipated energy of specimens

6 Conclusions

This paper reported the seismic responses of RC frames with a central opening infill and RC frame with two openings infill under the cyclic lateral loading tests which were compared to seismic responses of the solid infilled frame and the RC bare frame. The ratio of opening size to panel area was 25% for infill with central opening and infill with two openings. The following are the major findings:

Brick infilled frames with a central opening and two openings were similar in lateral strength and dissipated energy but they were little different in lateral stiffness.

The brick infill with a central opening and two openings of 25% of panel area decreased the lateral strength of the solid infilled frame to 58%. However, their lateral strengths were higher about 1.4 times than those of bare frame.

The stiffness of infilled frame structure dropped to 30% due to a central opening and 60% due to two openings appeared in infill.

The dissipated energy of the solid infilled frame was higher about 1.6 times than that of the bare frame. But, it decreased to 70% as openings of 25% appeared in infill.

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