Behaviour of Reinforced Concrete Frames with Central Opening Masonry Infill under Lateral Reversed Cyclic Loading.

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Abstract. This paper will describe the seismic behaviour of masonry infilled RC frame with a central opening structure under reversed cyclic lateral loading. To achieve the purpose of this study, four 1/4-scale single story and single bay RC frame specimens were tested, i.e. one bare frame, one clay brick masonry infilled RC frame without opening and two clay brick masonry infills with a central opening in infills. The ratios of opening size to panel area were 25% and 40%. Through reversed cyclic lateral loading tests, the seismic performance of RC frames with a central opening brick masonry infills was investigated. As the results, significant distinctions of failure mechanism, lateral strength, stiffness, and ductility were observed between these specimens. In the case of infills with a central opening, the cracks sprouted and developed at the corners of the opening. Although the presence of the opening in infill reduces the lateral strength and stiffness overall structure, the brick infilled frames with a central opening of 25% and 40% of panel area show better seismic performance as compared to the bare frame.

1 Introduction

Brick masonry walls are widely used as infill in open reinforced concrete (RC) frame buildings. For designing seismic-resistance of those buildings, the contributions of the brick masonry wall are usually excluded. This issue is caused by the shortage of the knowledge of the performance of brick wall under seismic loads. Several experimental and analytical studies have been reported that masonry infills strongly affected seismic performance of RC buildings [1-5]. Nevertheless, most of them concentrated to study the seismic behaviour of RC frame buildings using the solid masonry wall. In the previous study, the first author also has calculated the seismic capacity of RC buildings including the contribution of brick masonry infill by applying a developed analytical model of infill frame [3]. But, the presence of brick infills with openings was excluded in evaluation which guessed that no contribution from the infills with openings on the earthquake resistance of RC frame structures as reported on the Reference [6].

A number of research results have stated that openings in masonry infill incline to reduce the seismic performance of infilled frame structure. They discussed that the effect of openings infill depends on the ratio of the area of openings to the area of masonry wall [7-9]. Based on these contrary observation results, evaluation of the effect of opening to the seismic resistance of brick infilled frames need to be studied more. Therefore, in the current study, a series structural test was performed on brick infilled RC frame structures with and without opening in the panel.

2 Experimental programs

2.1 Description of specimens.

Four of specimens that were the 1/4-scaled RC frame structures were constructed. The specimens were the single story and single bay RC frame consisting of an RC bare frame (BF), an RC frame infilled with solid clay brick-masonry (IF_{sw}) and two of brick masonry infilled RC frame with a central opening (IF_{o1}) and (IF_{o2}). The RC frame elements of specimens were built with similar in cross-sectional dimensions and reinforcements arrangement. The detailing structure for the RC frame elements were 750 mm of the column height with their cross-sectional area of 125x125 mm, 4D10 longitudinal rebars and ϕ4-50 transverse hoop. The cross-sectional dimension of the upper beam was 200x200 mm with 4D13 longitudinal reinforcement and a hoop of ϕ8-50. For the footing beam, the cross-sectional dimension was 700x200 mm with 16D13 and ϕ8-50 of longitudinal reinforcement and hoop, respectively. Figure 1(a) shows the detailed drawing of dimension and reinforcement arrangement for BF specimen.

The infill walls were built using 1/4 scaled clay bricks of dimensions of 60 mm in length, 30 mm in width and 13 mm in height. The scaled brick units were laid up in the interior clear height of frames with mortar

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beds. The mortar composed with a ratio of cement: water = 1: 0.5. The wall surfaces were plastered with mortar of 5.0 mm in thickness. The average compressive strength of brick was 10.9 N/mm^2. There was no shear connectors installed between infill and frame elements. The parameters studied in this experimental evaluation were the influence of opening size to the seismic behaviour of RC frame structure. In this case, the ratio of the opening size to the panel area were 25% and 40% for IF_{o1} and IF_{o2} specimens, respectively. The figures 1(b), 1(c) and 1(d) present the structural detailed of IF_{sw}, IF_{o1}, and IF_{o2}, respectively.

2.2 Material properties

Material properties of the tested specimens are shown in Table 1 for the compressive strengths of concrete and brick masonry prism and Table 2 for the yield and tensile strengths of reinforcing bars.

Table 1. Compressive strength of concrete and brick masonry

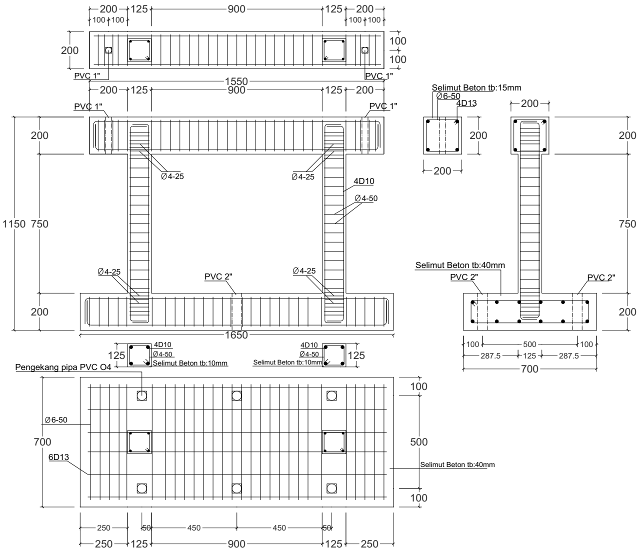
Specimen	Concrete	Brick masonry prism
	Compressive strength (N/mm^2)	Compressive strength (N/mm^2)
BF	49.9	-
IF_{sw}	49.9	13.0
IF_{o1}	49.9	13.0
IF_{o2}	49.9	13.0

Table 2. Material properties of reinforcing bars

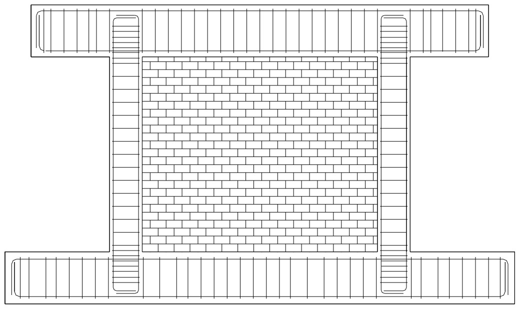
Bar number	Yield strength	Tensile strength
	(N/mm^2)	(N/mm^2)
Ø4	390.2	598.3
Ø6	346.8	448.6
D10	462.0	619.7
D13	421,1	582.4

2.3 Loading method

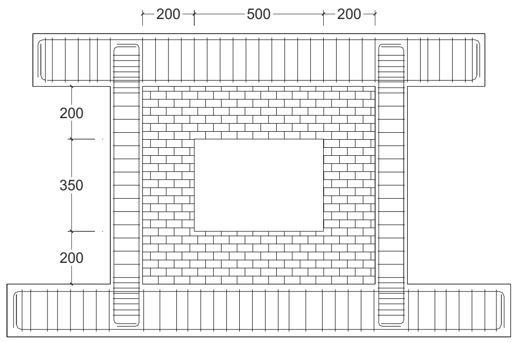
The constructed specimens were tested at the testing facility in Structural and Construction Material Laboratory of Civil Engineering Department, Syiah Kuala University. The loading system was applying reversed cyclic lateral loads to the tested specimens based on the FEMA 461 standard [10]. The lateral load was implemented through a horizontal hydraulic jack as shown in Figure 2(a). In this case, no axial load was applied to columns of specimens during the test due to limited available equipment.



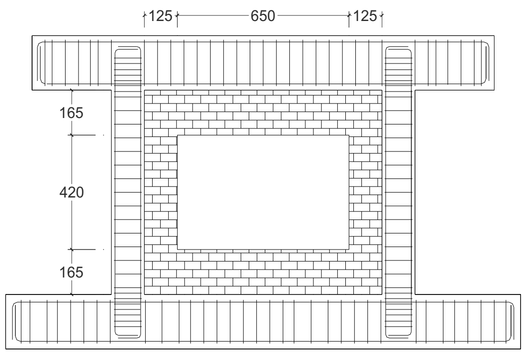
(a) Detailed drawing of BF specimen



(b) IF_{sw} specimen

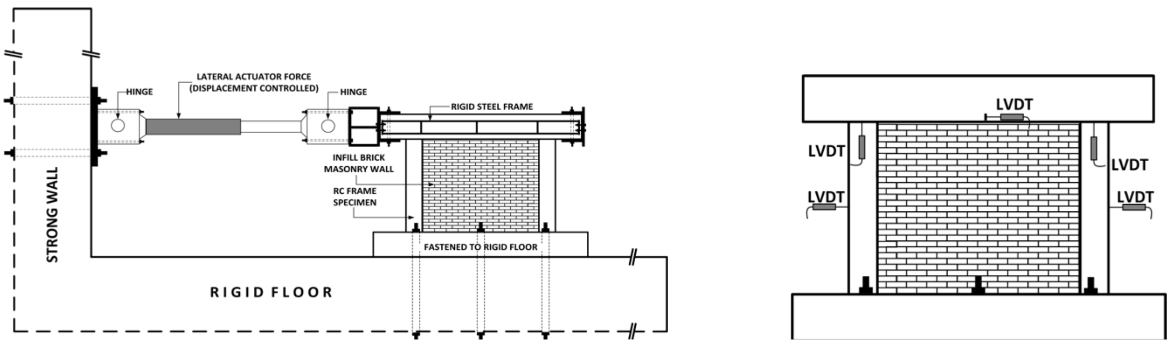


(c) IF_{o1} specimen



(b) IF_{o2} specimen

Fig. 1. Detailed drawing of specimens.



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

Fig.2. Schematic view of the test setup

The history of cyclic lateral loading program applied to specimens is shown in Figure 3. The loading was started with one cycle to R=1/800 and then it was continued by two cycles to R=1/400, 1/200, 1/100, 1/50, 1/25, 1/12.5, and 1/10. Where, R (rad) was the drift angle that was the ratio of lateral displacement to column height. In the test method, the drift angle R was used for controlling the increased load. The loading was stopped if the specimens failed prior to the end cycles.

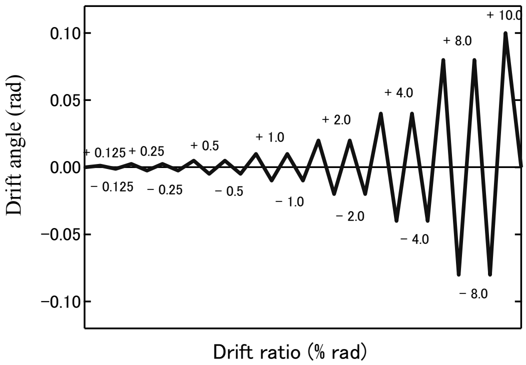


Fig.3. Loading history

2.4 Measurement

Some transducers were placed on the columns of the specimen, as shown in Figure 2(b), to measure the horizontal and vertical displacements of both columns. During testing, the applied cyclic lateral loads were monitored as well as displacements. The initial flexural and shear cracks which were appeared was on the specimens were noticed. The crack propagation was investigated since the loading cycle of R=1/800 to R= 1/10 to recognize the failure process of specimens.

3 Experimental results and discussion

3.1 Failure process

Significant distinctions of failure mechanism were noted among the specimens as described below.

3.1.1 BF specimen

An initial flexural crack appeared while the cycle of 1/400 at the top of the tensile column at the drift ratio of 0.16. In the next cyclic loading of 1/200, first shear crack was observed at the base of the compressive column at the drift ratio of 0.5. Flexural cracks significantly appeared during the cycle of 1/100 at the ends of both columns. Moreover at the subsequent cycles loading the flexural cracks grew become flexural-shear cracks and shear cracks propagated at the ends of columns. During the cycle of 1/12.5, the compressive column failed in shear at the drift ratio of 7.85. At the next cycle of 1/10, after the shear failure of both columns, the lateral strength significantly degraded. Photo 1(a) shows the condition of BF specimen by cycles -1/25 rad. Figure 4(a) shows the crack pattern of BF specimen.

3.1.2 IF$_{SW}$ specimen

During cycle 1/800, a separation crack occurred between column and wall at the drift ratio of 0.05. Initial flexural and shear cracks were detected at tensile column during the cycle of 1/400 at drift ratios of 0.17 and 0.21, respectively. Initial diagonal shear crack at the centre of panel wall came out during cycle 1/200 at the drift ratio of 0.45. During the next cycle loads, shear cracks developed at the ends of columns and then followed by peeling off the wall plaster. After the shear failure of the brick wall during the cycle 1/25, the lateral strength degraded significantly. Shear failure of the boundary column happened at the cycle 1/12.5 after the failure of the infill wall in out of plane direction. Photo 1(b) shows the condition of the IF$_{sw}$ specimen by cycles -1/25 rad. The crack pattern of IF$_{sw}$ specimen is exhibited in Figure 4(b).

3.1.3 IF$_{O-1}$ specimen

Initial shear cracks existed at the top left corner and at the bottom right corner of opening at drift ratio 0.06 during the cycle 1/800. Separation crack between columns and infill wall was detected during the cycle 1/400. At this cycle, the earliest flexural crack was observed at the tensile column at drift ratio 0.25. The first shear crack at the tensile column occurred during the cycle 1/200 at drift ratio 0.47. At this cycle, flexural cracks grew at the middle height of both columns. In further cycles, flexural cracks appeared along columns height and shear cracks increased at the corners of the opening. Peeling off the plaster took place at the corners

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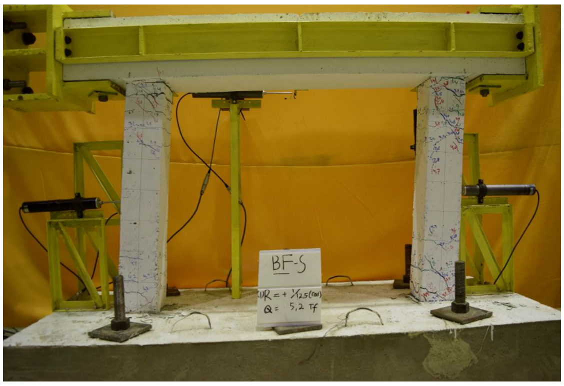
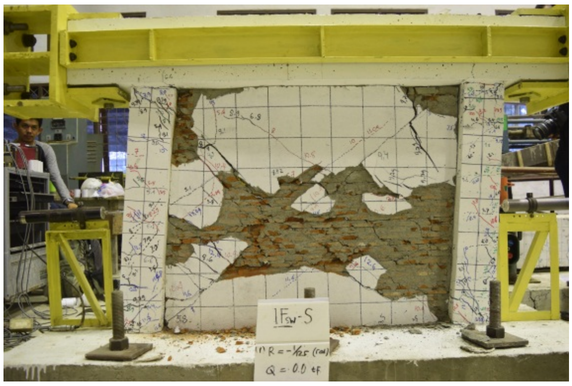
of opening and then the infill wall failed in shear at the corner of opening during the cycle 1/25 followed by degradation of lateral strength. Shear failure of tensile column happened during the cycle 1/12.5. Photo 1(c) shows the condition of IF$_{o1}$ specimen by cycles-1/25 rad. The crack pattern of IF$_{o1}$ specimen is demonstrated in Figure 4(c).



(a) BF specimen

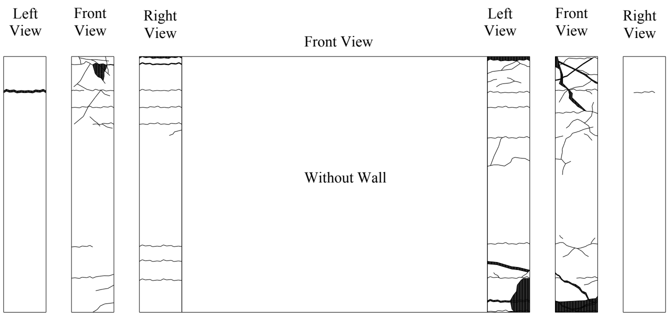


(b) IF$_{sw}$ specimen

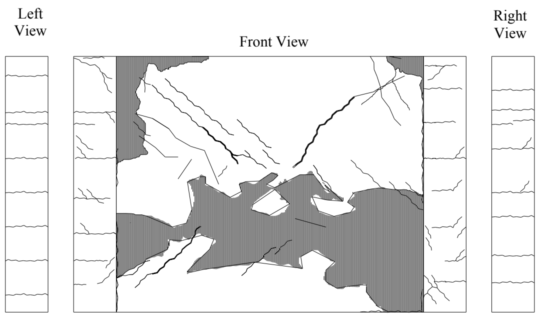
(c) IF$_{o1}$ specimen

(d) IF$_{o2}$ specimen

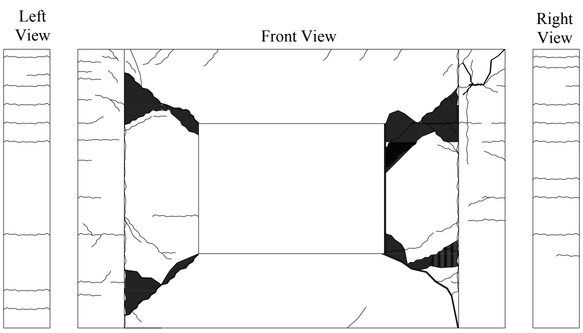
Photo 1. Typical damage of specimens under lateral load at the cycles 1/12.5



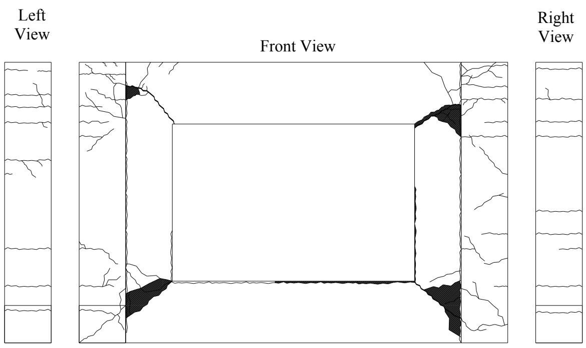
(a) BF specimen



(b) IF$_{sw}$ specimen



(c) IF$_{o1}$ specimen



(c) IF$_{o2}$ specimen

Fig. 4. Crack patterns of specimens at the *R*=1/12.5

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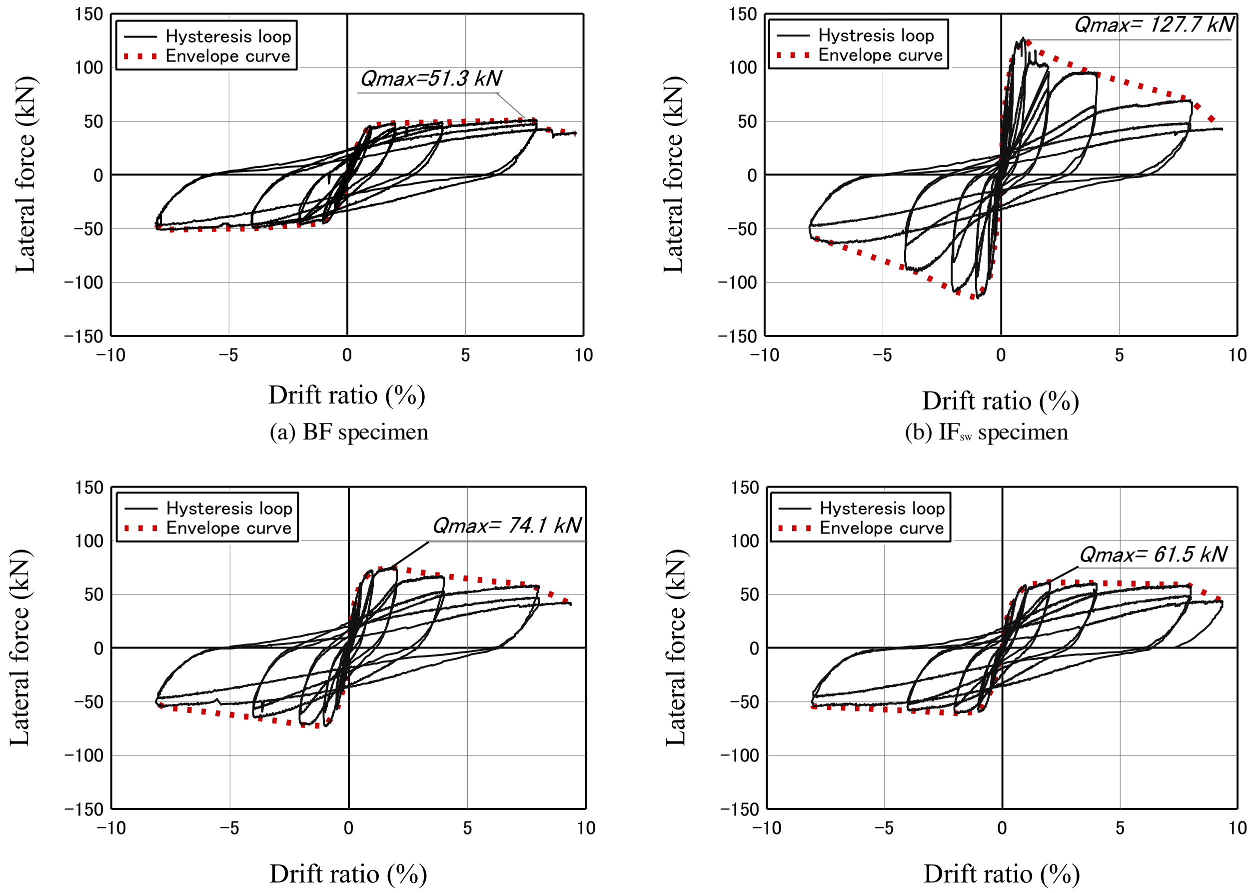
3.1.4 IF_{O-2} specimen

During the cycle 1/800, explored events were an initial flexural crack at the tensile column at drift ratio 0.05, separation crack between column and wall at the drift ratio of 0.06, initial shear crack at the left top corner of opening at the drift ratio of 0.11. Initial shear crack at the top of the tensile column was detected at the drift ratio of 0.32 during the cycle 1/200. The shear cracks on both columns and at the corners of opening propagated during the subsequent cycles. Shear failure of the bottom compressive column occurred during the cycle 1/12.5 followed by failure of the wall in out of plane direction. Photo 1(d) shows the condition of IF_{o2} specimen by cycles -1/25 rad. The crack pattern of IF_{o2} specimen is shown in Figure 4(d).

3.2 Lateral force-drift ratio relationship

Seismic performance of tested specimens is shown in Figure 5 that are in the relationship between lateral force and drift ratio. The bare frame specimen achieved the highest lateral strength of 51.3 kN at the 7.9% drift ratio. However, the IF_{sw}, IF_{o1} and IF_{o2} specimens reached the greatest lateral strengths of 127.7 kN, 74.1 kN and 81.5 kN at the drift ratios of 0.93%, 1.86%, and 1.99%, respectively. Comparison of envelope curves of the seismic performance of the specimens are described in Figure 5 and Figure 6. These figures state that both brick infills with and without openings increased the lateral strength of the RC frames. The RC frame with solid brick infill had lateral strength about 2.5 times higher than the bare frame. However, a centre opening in infill with ratio of 25% and 40% to panel area decreased the lateral strength to about 0.42 times and 0.52, respectively. It was described that the lateral strength of the infilled frames with a central opening of 25% and 40% were 1.4 times and 1.2 times higher than that of the bare frame, respectively. The deformation capacities of the overall structure that was a deformation as the lateral force degraded to 80% after the maximum of the force were reached at drift ratios of 8.4% for BF, 1.9% for IF_{sw}, 7.7% for IF_{o1} and 8.02% for IF_{o2}. It indicates that the infilled frames with a central opening more ductile when compared to RC frame with full infill, as shown in comparison envelope curves in Figure 6.



(a) BF specimen
(b) IF_{sw} specimen
(c) IF_{o1} specimen
(d) IF_{o2} specimen

Fig. 5. Lateral force-drift ratio relationship and envelope curve

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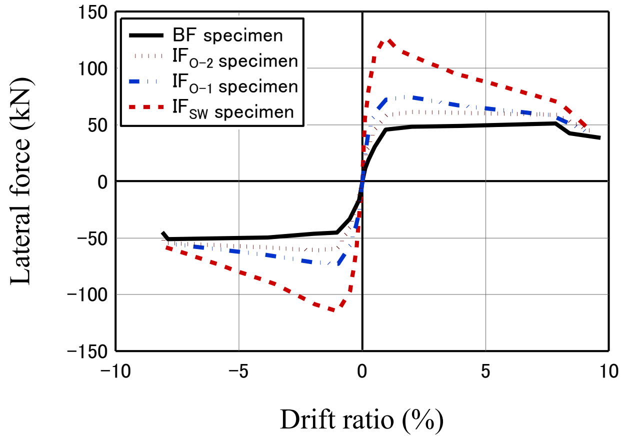

Fig. 6. Comparison of envelope curves

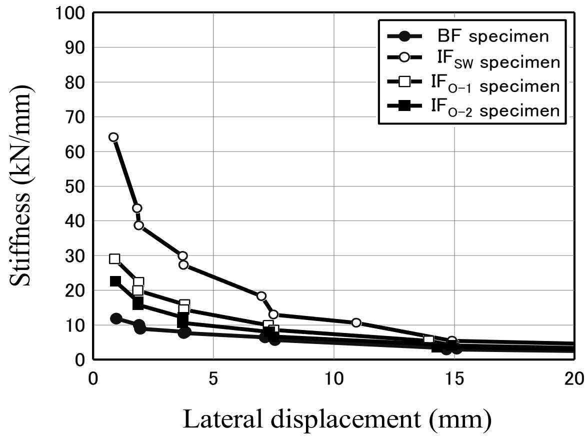

Fig. 7. Comparison of lateral stiffness

3.3 Lateral stiffness

The stiffness was obtained from the initial tangent modulus of the slopes of the load-drift curves. The presence of infill with/without opening improved the initial stiffness of overall structures. The brick infill without opening increased the lateral stiffness of RC frame structure by about 5.4 times compared to the RC frame without infill, and the other hand the brick infill with openings size of 25% and 40% increased the initial stiffness about 2.5 and 1.9 times as compared to those of the RC frame with no infill, respectively. It means that the presence of an opening in the infill lost the initial stiffness of solid brick infilled frame structure near 55% and 65% due to opening sizes of 25% and 40%, respectively. The lateral stiffness of structure gradually degraded as the cracks became big under the cyclic lateral loads in inelastic range. Comparison of the lateral stiffness of specimens on each cyclic loading is shown in Figure 7.

4 Conclusions

RC frame structure specimens of 1/4-scaled single bay and single story structure infilled with brick walls having a centre opening were tested under cyclic lateral load for evaluating the effect of central opening to the seismic behaviour of RC frame structure. Finally, the test results are summarized as the following.

1. The solid brick infill increases the lateral strength of entire structure about 2.5 times compared to the lateral of RC frame with no infill. However, the presence of opening reduced the lateral strength of the overall structure about 0.42 times and 0,52 time for infills with the opening size of 25% and 40%, respectively
2. The ductility of RC frame was reduced by installing the brick infill. However, the presence of a central opening affected the ductility structure.
3. Different failure mechanism was observed among the specimens. In the case of infilled frame specimens, the infill failed in shear prior to shear failure of the column. Shear cracks in solid infill came across in the central part of the panel, whereas the shear cracks in infill with opening were dominated at the corners of the opening. It was assumed that the corners of an opening are the weakest part in infill.
4. Opening on infill reduced the in-plane stiffness of overall RC frame structure.

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