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THE EXPERIMENTAL INVESTIGATION ON BENEFICIAL EFFECTS OF THE LOCAL BRICK MASONRY INFILLS TO SEISMIC PERFORMANCE OF R/C FRAME STRUCTURES IN WEST SUMATERA

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ABSTRACT

The field observation of damage caused by past Sumatera earthquakes clearly indicates that the response of reinforced concrete (R/C) structures may significantly be affected by the contribution of the masonry infill walls. The effect of infill walls on the seismic performance of R/C frame structures can be significant, even if masonry infill walls are usually considered as nonstructural elements. This paper presents some laboratory experimental results on the lateral monotonic tests of R/C frame structures with were infilled by brick masonry wall. The experimental works were conducted to investigate the beneficial of the several types of brick masonries which are commonly used as infill wall in West Sumatera, Indonesia, on seismic performance of the R/C frame structures. All types of the bricks used in this study, are locally produced in West Sumatera. The 1:4 reduce-scale singe-bay single-story R/C frame specimens were tested in this study. Three types of 1:4 reduce-scale brick masonries were placed as infills, i.e. burnt clay brick, hollow concrete brick and lightweight brick. It was seen that the brick masonry infills contribute significantly to the lateral stiffness, lateral strength, and overall ductility of the R/C frame specimens. Usage of the burnt clay brick masonry as infill wall has been given better seismic performance of R/C frame structure than other brick masonries. Considering that such brick masonry infill in R/C frame are most common type structures used for low-rise building construction and landed unreinforced brick masonry residential in West Sumatera, there is need to develop satisfy seismic design procedures for such buildings.

Keyword head: Earthquake Engineering, Seismic Performance, Reinforced Concrete Structure, Brick Masonry Infill.

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1. INTRODUCTION

Reinforced-concrete (R/C) frame structures with unreinforced brick masonry infill walls are commonly used in regions of high seismicity, such as West Sumatera, Indonesia. In many cases, the engineers do not consider brick masonry infill walls in the design process of R/C frame structures, therefore the brick masonry infill walls are usually treated as non-structural elements and their interaction with R/C frame structures have been not taken into account. Since the final distribution forces of the brick masonry infill walls to the R/C frame structure have been not clearly known, as a consequence, the actual response of the R/C structures may be deviate radically from what is expected in the design [1,2,3,4].

During the last few decades, a lot of research activities have been devoted for both of experimental and numerical works for investigating the seismic performance of the R/C frames structures with brick masonry infills, as were well-documented in [5,6,7,8,9,10]. The field investigation of after Sumatera earthquake 2007 on two identical R/C frame building in Padang city, has shown the significant contribution of the clay brick masonry infill walls to the R/C frame structures against the lateral seismic forces [11]. Since one of these building was occupied as company's office, the building used clay brick masonry as infill in the R/C frame structure. On the other hand, another building was occupied as car's shown room, therefore, the tempered-glass was used as infill in the R/C frame, instead of the brick masonry wall. The first building was surviving, while another one collapse. The field observation indicated that infilled clay brick masonry walls in the R/C frame structures of the first building, helped the building to survive during its Sumatera earthquake 2007. The photograph of the survival building is shown in Figure 1.

This field observation results mentioned above has exhibited that the excellent performance of R/C frame structures with clay brick masonry infills when suffers the moderate earthquakes, i.e. the earthquake of approximately in magnitude 6.0 to 6.5 and/or maximum intensity VIII on MMI scale. On the contrary, the presence of the masonry infill often negatively modified the response of the R/C frame structures and results undesired structural performance such as soft-storey, torsion and out of plane collapse. Figure 2. shows an example of the suffered R/C frame structure due to soft-story effect.

Figure 1 Surviving R/C frame building suffered sumatera earthquake 2007 [6]

Figure 2 Soft-story effect on R/C frame structure

This paper presents the results of experimental works of the infilled R/C frames with brick masonry wall specimens which were subjected to applied lateral monotonic loading. In this experimental study, three type of brick masonries were used as the infill walls, i.e. burnt clay brick, hollow concrete brick and lightweight brick. These bricks are produced and commonly used in West Sumatera region. All the masonry-infills consist of unreinforced bricks in cement mortar. The cement mortar is a blend of pozzolan cement and graded sand. Furthermore, four types of 1:4 scale-reduce of R/C frame specimens have been built, tested and evaluated, i.e. the bare R/C frame, infilled R/C frame with unreinforced burnt clay brick masonry wall, infilled R/C frame with unreinforced hollow concrete brick masonry wall and infilled R/C frame with unreinforced lightweight brick masonry wall. These specimens were laterally loaded until collapse (pushed-over). The seismic performance of infilled masonry R/C frames specimens were compared with that of the bare frame specimen. The applied lateral loading, obtained lateral displacement, failure mechanism as well as crack pattern of the specimens were recorded and observed during experimental works. This paper will explore the beneficial effects of these local brick masonry infill walls on seismic performance of R/C frame structures based-on these experimental results.

2. EXPERIMENTAL MODEL

Four of the 1:4 reduce-scale singe-bay single-storey R/C frame specimens were designed and built in the Material and Structural Laboratory (LMS) of Civil Engineering Department, Andalas University, Padang, i.e. one bare R/C frame (BF), one infilled R/C frame with unreinforced clay brick masonry wall (IFBM), one infilled R/C frame with unreinforced hollow concrete brick masonry wall (IFCM) and one infilled R/C frame with unreinforced lightweight brick masonry wall specimens (IFLM). The experimental matrix for current works is tabulated in Table 1.

Table 1 Experimental matrix

specimen's name	codes
bare frame	BF
clay brick infill	IFBM
concrete brick infill	IFCM
lightweight brick infill	IFLM

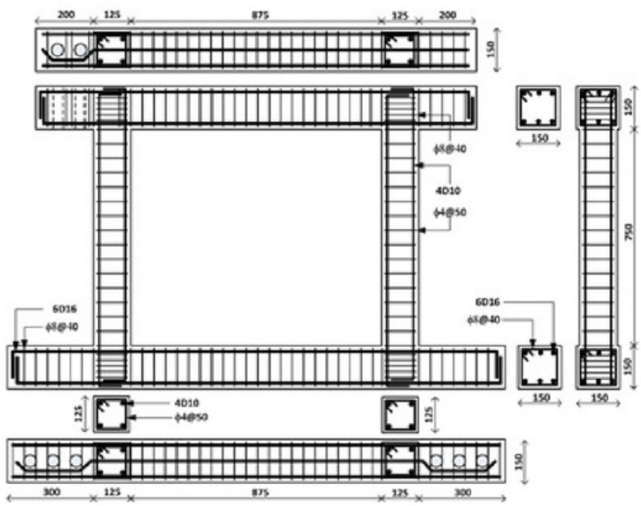

Figure 3 Geometry and reinforcement detail of the R/C frame specimen

Figure 3 illustrates the typical geometry and reinforcement details use for all R/C frame specimens. The columns of the R/C frames were detailed to yield in flexure before shear failure. The dimension of cross-section of columns were 125 mm x 125 mm and reinforced with 4-D10 longitudinal bars with a yield stress 417 MPa and ϕ4@50 transverse hoops with a yield stress 235 MPa. The dimension of cross-section of the columns and their reinforcements were designed considering the scale reduction. The clear high of the columns were 750 mm. An over-reinforced concrete top-beam was constructed on the top of columns for the purpose of applying the lateral loads, while also representing the rigid floor system. The dimension of top-beam was 150 mm wide, 150 mm deep and 1525 mm long and reinforced with 6-D16 longitudinal bars with a yield stress 488 MPa and ϕ8@40 transverse hoops with a yield stress 333 MPa. The columns were supported by the over-reinforced foundation-beam which was fastened to the Loading-Frame by using six post-tensioning rods as is schematically shown in Figure 3. The dimension of the foundation-beam was 150 mm wide, 150 mm deep and 1725 mm long and reinforced with 6-D16 longitudinal bars with a yield stress 488 MPa and ϕ8@40 transverse hoops with a yield stress 333 MPa. The compressive strength of concrete cylinder at 28 days after casting was 23.1 MPa, i.e. the sample of the concrete was casted to the R/C frame specimens.

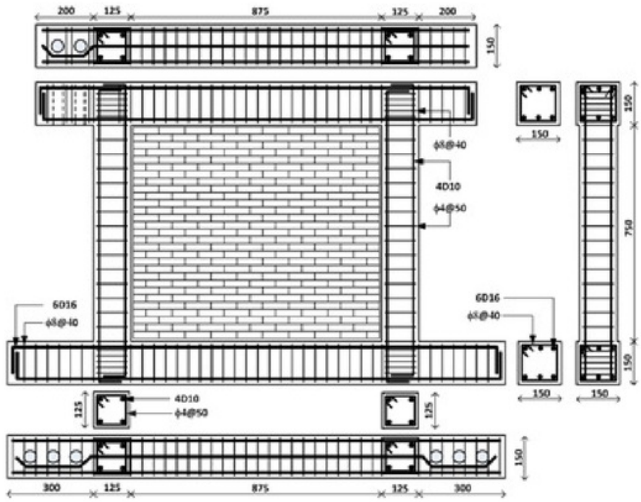

Figure 4 Geometry and reinforcement detail of the infilled R/C frame specimen

Except for the bare R/C frame BF three remain R/C frame specimens were infilled by 1:4 reduce-scale masonries of burnt clay brick with dimension 22.5 mm wide, 12.5 mm deep, 45 mm long, hollow concrete brick with dimension 40 mm wide, 25 mm deep, 100 mm long and lightweight brick with dimension 45 mm wide, 25 mm deep and 150 mm long, respectively. The dimension of wall was 875 mm width and 750 mm height as schematically shown in Figure 4. For the specimens IFBM and IFCM, the cement mortar was used to place the brick masonry infill walls. Further, both sides of infill wall were plastered by using the same mortar covering the entire of the wall's surfaces. For the specimen IFLM, the lightweight brick was placed by using special mortar, called 'mortar utama 380'. Both side of the wall's surfaces were also plastered with special mortar, namely 'mortar utama 301'.

3. TEST SETUP AND INSTRUMENTATION

Figure 5. illustrates how the experimental works were conducted. The specimen was placed on the Loading-Frame and the foundation beam was fastened to the Loading-Frame by using 6 post-tensioning rods. The lateral monotonic forces were applied to the left side of the top-beam until the specimen collapse (pushed-over). The lateral forces will result the lateral displacements of the R/C specimen. These lateral forces and the existing lateral displacements were further measured by a load-cell and a displacement transducer, respectively and were directly recorded by the portable data logger. The load-cell was positioned between hydraulic jack and the left side surface of the top-beam, whereas the displacement transduced was installed at mid-height of right side surface, i.e. opposite to the load-cell position. During testing, the top-beam was not allowed to deform in upper direction. To do this, the rollers equipment's were placed between top surface of the top-beam and the Loading-Frame. In addition, during experimental works, the failure mechanism and the crack pattern of the R/C frame specimens were also observed.

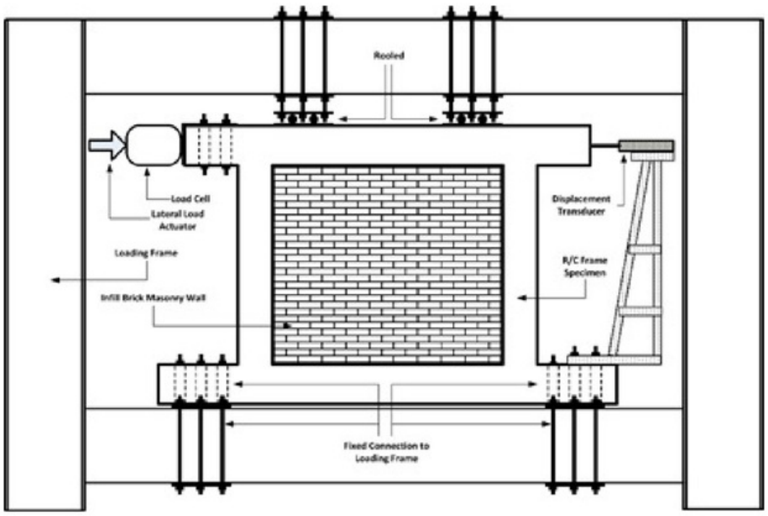

Figure 5 Experimental setup and its instrumentation for in-plane test

4. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 6. Presents the comparison experimental results as curves of the applied lateral forces versus lateral displacement for all tested R/C frame specimens. Indeed, in the experimental works, the specimens were pushed-over until reach the lateral displacement about 70 mm or 80 mm. However, in order to clearly displaying the experimental results, these curves were cropped and shows in 45 mm of lateral displacement. The separately experimental results of tested BF, IFBM, IFCM and IFLM specimens are shown in Figure 7. To Figure 10, respectively. The photographs in these figures are the crack patterns of the R/C specimens at the end of loading test.

For infilled R/C specimens, since the brick masonry wall contact with its confining frame on all four sides of R/C frame, made the initial stiffness significantly increase compare to bare R/C frame. The initial stiffness of the IFBM specimen increases more than five times that of the bare R/C frame specimen BF, while the initial stiffness of the IFCM and IFLM are average about four times that of BF specimen. In all cases, the lateral forces-displacement curves of the R/C frames with brick masonry infills wall tend to return to the bare R/C frame curve at drifts values relevant to a collapse of the brick infills walls. Compare to the BF specimen, the presence of the brick masonry infills wall in specimens IFBM, IFCM and IFLM, increase the lateral strength of these R/C frames about 98%, 53% and 55%, respectively. The R/C frame specimen with burnt clay brick masonry infill wall showed better performance than the companion IFCM and IFLM specimens.

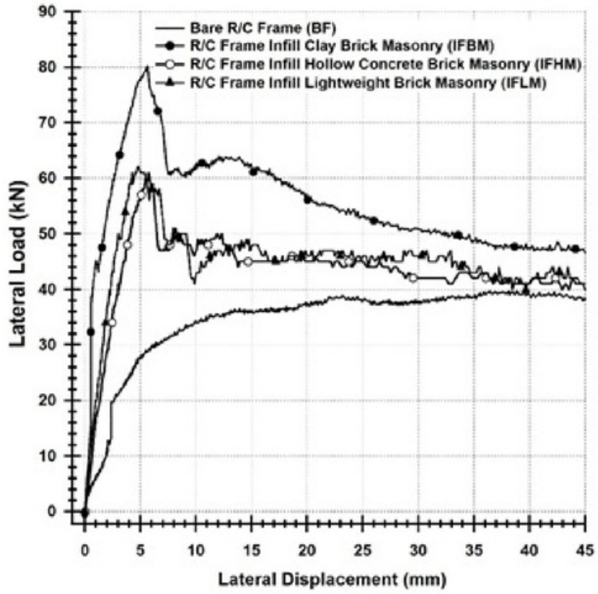

Figure 6 Comparison of the experimental results

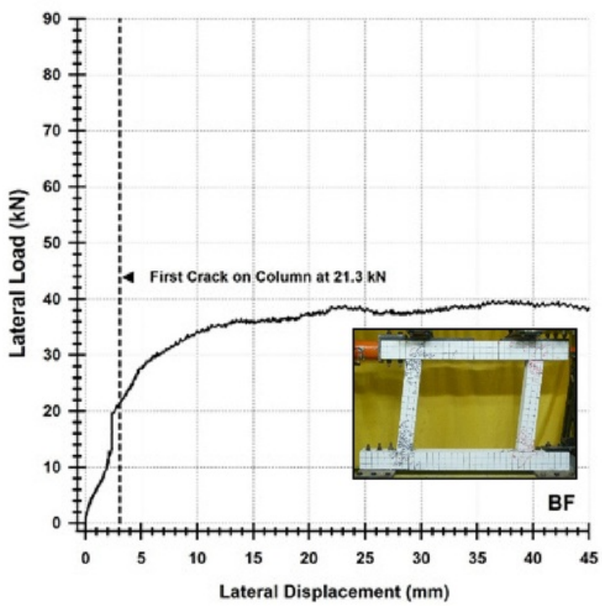

Figure 7 Experimental results of bf specimen

The observations during experimental works showed that the brick masonry infill wall interfere with the lateral deformation of the R/C frame. The separation of the R/C frame and the brick masonry infill takes along one diagonal and the compression strut forms takes place along the other. As a consequence, the brick masonry infill will add the lateral stiffness of the R/C frame specimen. The load transfers in the specimens were changed from frame action to predominant truss action, thus, the columns will experience increased axial forces and reduced the bending moments and shear forces.

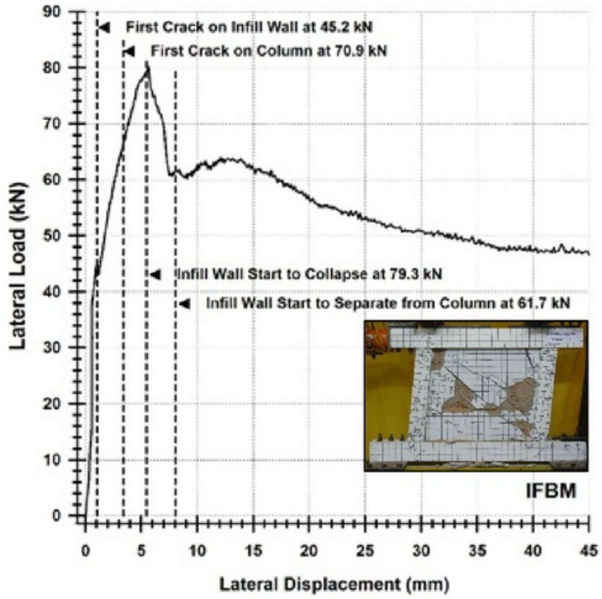

Figure 8 Experimental results of IFBM specimen

The presence of the brick masonry infill in the R/C frame increases the lateral strength, stiffness and overall ductility of the specimens as are shown in Figure 6. The brick masonry infill help in drastically reducing the deformation and ductility demand on the R/C frame specimens. These experimental results explain about fact of the excellent performance of the infilled R/C structures with the brick masonry infill in moderate earthquake even when the structures were not designed or detailed for earthquake forces.

The due to relatively less stiffness of infilled of hollow concrete brick in IFCM specimen and the lightweight brick in IFLM specimen, the initial crack on their diagonal infill occurred in the lower level of the lateral displacement compare to the clay brick infill IFBM. As the results, the crack on the column for specimen IFBM was also delayed compare to IFCM and IFLM specimens. However, for all infilled specimens, the separation of the infill from the R/C frames took place in almost the same level of lateral deformation.

Indeed, the brick masonry infill possess the large lateral stiffness and hence draw a significant of the lateral force. The brick infills made the infilled R/C frame stronger than bare R/C frame. The failure mechanism of the specimens now depends on the relative strength of the bare R/C frame and brick infill. All infilled R/C frame specimens have identical failure mechanism. The failure mechanism was started by diagonal cracking of the brick infill wall, implying the formation of the compression strut in the brick masonry, then followed by plastic hinges in the column. Finally, the specimen failed by the shear failure in the column. The diagonal crack on the infill occurred before first crack on column.

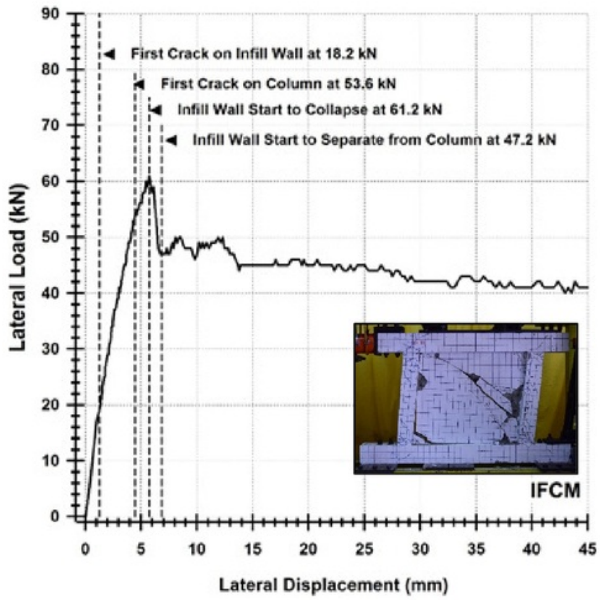

Figure 9 Experimental results of IFCM specimen

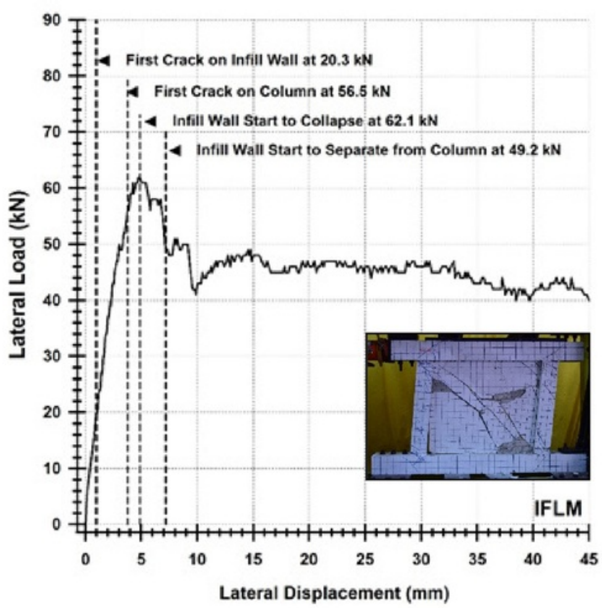

Figure 10 Experimental results of IFLM specimen

5. CONCLUSION

Based on test results which have been presented and discussed throughout this paper, the following main conclusions may be drawn:

1. The initial stiffness of the IFBM specimen increases more than five times that of BF specimen and the average of initial stiffness of the IFCM and IFLM are about four times that of BF specimen.
2. Compared to BF specimen, the increasing the lateral strength of the specimens of IFBM, IFCM and IFLM, were about 98%, 53% and 55%, respectively.
3. The IFBM specimen showed better performance than the companion IFCM and IFLM specimens.
4. The failure mechanism of the specimens was started by diagonal cracking of the brick infill wall, then followed by plastic hinges in the column and finally, failed by the shear failure in the column.

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