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Cyclic behavior of the R/C frames with reinforced masonry infills

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Abstract. This study focuses on the experimental works to define the behavior of the reinforced concrete (R/C) frame model with the strengthening of the brick masonry infill by using the embedded reinforcement bars subjected to lateral reversed cyclic loads. A previous study by applying the lateral monotonic static loads showed that the embedded reinforcement bars increased the lateral capacity of the R/C frame and also delayed the failure of the brick masonry infill and R/C frame structure as well. However, in order to define its seismic capacity, a lateral reversed cyclic loading is required. The experimental works in this study were conducted by preparing and testing the 1/4 scaled-down R/C frame specimens represented the first story of the middle multi-story commonly constructed in the earthquake-prone area such as West Sumatera, Indonesia. The R/C frame specimens were two R/C frames with brick masonry infills where one of them strengthened by the embedded reinforced bars. All specimens were tested for applying the lateral reversed cyclic loads. The applied lateral load, the lateral displacement, the progressive cracks, and the failure mode of the specimens were observed and recorded during experimental works. As it was expected, the presence of the embedded reinforced bars in the brick masonry infills increases the seismic capacity and stiffness of the R/C specimens and also delayed the failure of the specimens. The experimental results in this study imply the simple strengthening method for the brick masonry infills.

1 Introduction

The low-rise multi-story buildings which are constructed by the Reinforced-Concrete (R/C) frame structures with unreinforced brick masonry infill walls are frequently used in developing countries with the earthquake-prone area such as Indonesia. Due to difficulty in defining the final distribution of the masonry infill walls to the R/C frame, the structural engineers mostly not consider these brick masonry infill walls as the structural components in the design process. The masonry infill walls are generally treated as non-structural components and their interaction with R/C frame structures have been ignored. Hence, the actual response of the R/C frame structures will deviate radically from what is expected in the design. [1]

The post-earthquake investigation results showed beneficial as well as the adverse effects of the presence of the masonry infill walls in the R/C frame structures. They demonstrated excellent performance during shaken by the moderate earthquake. Unfortunately, they also cause several undesirable effects such as short columns, soft-story, torsion, and out of plane collapse when suffering the strong ground motion. [2, 3]

Several researchers have proposed the strengthening technique and advanced material to overcome the weakness of the brick masonry infilled in the R/C frame structures. For example, Ismail [4] uses wire mesh banded to strengthen the unconfined brick masonry housing in Pariaman, West Sumatera. Leeanansaksiri [5] also used the Ferro-cement for straightening the brick masonry infilled in RC frame structures. More advanced researches were carried out by many researchers; such are well summarized in the article [6]-[11]. They proposed the strengthening methods by using modern materials such as textile-reinforced mortar, welded wire mesh, and Carbon Fiber Reinforced Polymer (CFRP).

Previously, Tanjung [12] has proposed an tested a simple strengthening technique to improve the seismic performance of the R/C. He also used the embedded plain steel bars on the bed mortar join of the brick masonry infills. Unfortunately, due to the limitation of the structural testing facilities, the RC frame specimens were only loaded by the static monotonic loading. As a result, seismic performance, including seismic behavior, of the RC frame specimens could not be accurately obtained. In order to evaluate the seismic performance of its strengthening technique more realistic, in the current study, the identical RC frame specimens were tested subjected to lateral static reversed cyclic loads.

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2 Experimental Program

The experimental works were performed at Structure and Construction Material Laboratory of Syiah Kuala University, Banda Aceh, Indonesia. We have prepared and tested two RC frame specimens. These specimens were the 1/4 reduce-scaled one-bay and one-story RC frame. The specimens included one of the RC frame infilled with brick masonry and one the RC frames infilled with strengthened brick masonry by using embedded plain steel bars. The specimens were tested for the lateral static reversed cyclic loading.

2.1 The Detail of the RC Frame Specimen

The geometrical and the detail of the reinforcements of the RC frame specimens are shown in Fig. 1. The reinforcement design of the columns of the RC frame was yield in flexure prior to the shear failure. The columns with a dimension of 125 mm x 125 mm were used in this study. The columns were reinforced by 4D10 longitudinal bars and ϕ4@50 transverse hoops. The clear height of the columns was 750 mm. The top-beam had a dimension of 200 mm wide, 200 mm deep, and 1550 mm long. It has reinforced with 4D13 longitudinal bars and ϕ6@50 transverse stirrups. The columns were then connected by the lower-beam. The dimension of its beam was 700 mm wide, 150 mm deep, and 1650 mm long and reinforced with 12D16 longitudinal bars and ϕ6@50 transverse stirrups. The beam was fastened to the strong-floor by using six post-tensioning rods.

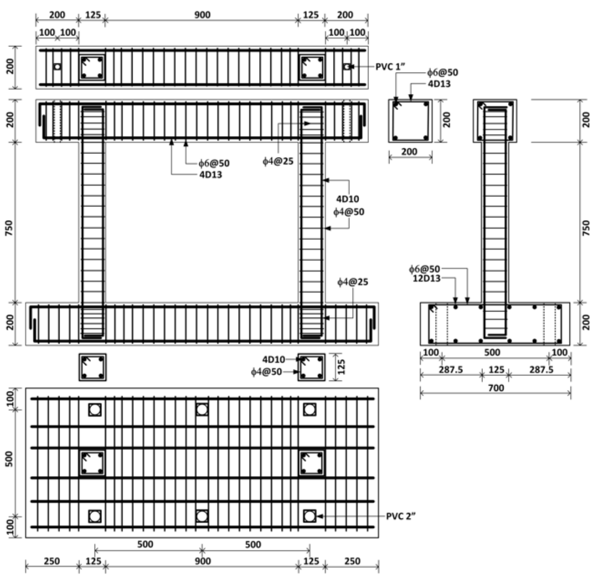
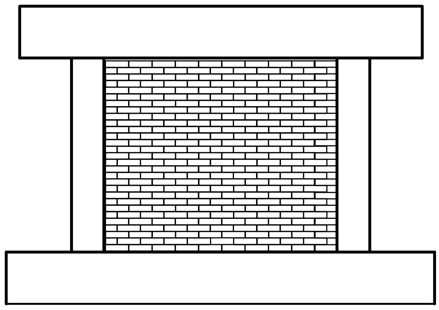


Fig. 1. Reinforcements Detail of the RC Frame Specimen.

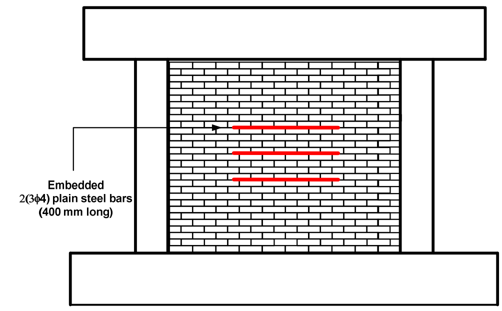
In this study, we have prepared two of 1/4 reduced-scale singe-bay and single-story RC frame specimens, i.e., RC frame infilled with brick masonry (IF-SW) and RC frames infilled with strengthened brick masonry by using the embedded reinforcement steel bars (IF-2C). The steel bars were embedded on the brick masonry infill by using chemical epoxy adhesive. The schematic of these specimens is shown in Fig. 2.

2.2 Experimental Setup

Fig. 3.a shows the schematically image of the experimental setup for the current study. The specimen was placed on the rigid-floor during testing and was fastened to the rigid-floor by using six post-tensioning rods to keep the specimen remain in its position during the test. A double-action lateral actuator force equipment was attached and fastened to the strong wall by using four post-tensioning rods. Two horizontal steel beams were used to restrain the top-beam of the specimen from preventing the applied force on its top-beam causes out-of-plane deformation occurs during testing. These two horizontal steel beams were connected to the actuator force, which mounted on the strong wall. The displacement transducers (LVDTs) were installed at several points to measure the deformation of the RC frame specimen, as is shown in Fig. 3.b. A displacement transducer which was placed in the middle of top-beam was used as a displacement-control point.



(a) RC Frame with Brick Masonry Infill

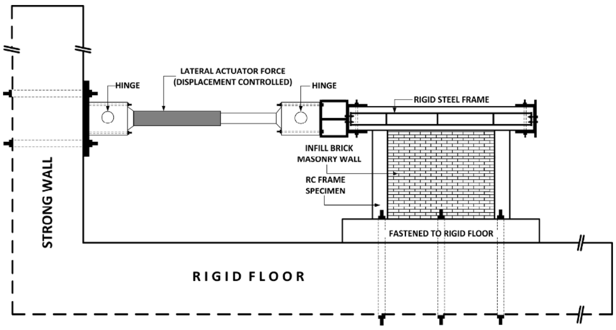


(b) RC Frame with Strengthened Brick Masonry Infill

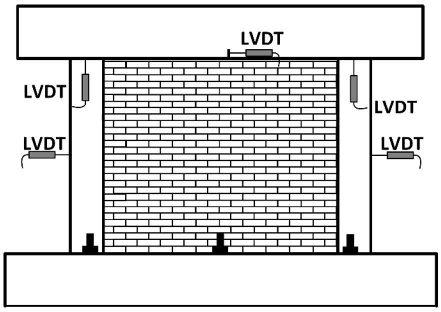
Fig. 2. Design of the RC Frame Specimen.

The lateral static reversed cyclic loading applied in current experimental works was conducted by control the lateral displacement of the top-beam with the loading speed of approximately 0.05 mm/s. The procedure follows FEMA461 [13]. The amount of lateral movement of the top-beam was defined based on the drift ratio of the column R=δ/H, where δ is the lateral displacement at a tip of the top-beam measured by the displacement transducer and H is the distance between the transducer and the bottom of the column. The loading program was R=1/800, R=1/400, R=1/200, R=1/100, R=1/50, R=1/25, R=1/12.5 rad., and followed by a pushover to R=+1/10. Except for the first drift ratio

R=+1/800, two cycles were applied for each drift ratio. Incremental of the applied lateral static load and the deformation of the specimen were monitored and recorded throughout the tests. An initial crack and its crack propagation were drawn on the RC frame and brick masonry infill in every loading cycle for identifying the failure mechanism of the specimen.



(a) The Experimental Setup



(b) A Position of the LVDTs

Fig. 3. The Experimental Setup and Instrumentation.

3 Results and Discussion

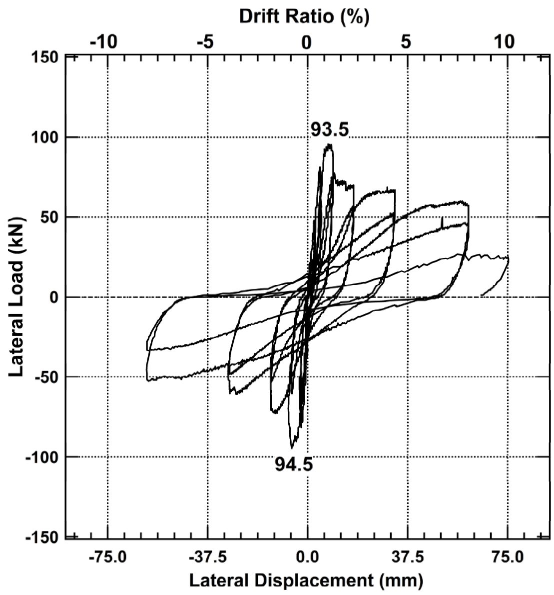
3.1 Material Properties

The material properties used for constructing RC frame specimens, including their brick masonry infills, were obtained by standard material testing procedures. The compressive strength of the concrete cylinder at 28 days after casting was 30.6 MPa, i.e., the sample of the concrete was cast to the RC frame specimens. The compressive strength of the brick masonry cube was 9.4 MPa. The nominal yield (tensile) strengths of the reinforcements, respectively for Ø4, Ø6, D10, and D13, were 390.2 (574.9) MPa, 346.8 (446.3) MPa, 324.6 (449.5) MPa, and 374.3 (535.4) MPa.

3.2 Seismic Performances and Failure Mode

Fig. 4. shows the test results of the IF-SW specimen. The ultimate lateral strength was obtained about 93.5 kN at the first cycle of R =+1/100 and 94.5 kN at R=-1/100. An initial crack on the interface between columns and brick masonry infill firstly appeared at R = +1/400 at a load of 30 kN, and the initial flexural crack in the column has also been seen at it R= +1/400 due to the lateral load of 47.6 kN. Meanwhile, the brick masonry infill started to crack on its diagonal at the first cycle of R =+1/200 caused by the lateral loading of 78 kN.

Furthermore, the diagonal crack on the brick masonry infill spreads and widens when the specimen was loaded to 92 kN at cyclic R = +1/100. At the same time, the flexural cracks in the left column also increased. The shear crack on the upper of the left column occurred at the first cycle of R = +1/50, and the diagonal cracks on the brick masonry infill increased become wider than 5 mm. The surface plastering on the brick masonry infill started to peel off at R = +1/50, as it is shown in Fig. 4.b., then the diagonal crack on the brick masonry infill increased more than 10 mm wide when R = +1/25. Finally, the brick masonry infill collapsed at the second cycle of R = +1/12.5, and the transverse hoop in the left column ruptured when the specimen has been subjected to a pushover loading to R = +1/10.

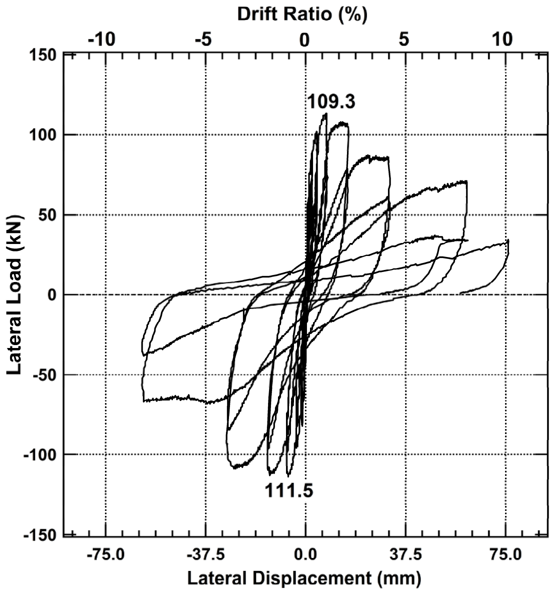


(a) Load-Displacement Hysteresis Curve

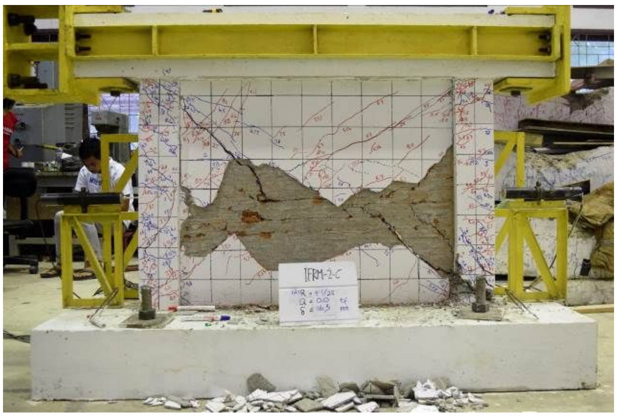
(b) Crack Pattern at R=+1/12.5

Fig. 4. The Experimental Results of the IF-SW Specimen.

The test results of the IF-2C specimen is shown in Fig. 5. The comparison of the experimental results on the load-displacement hysterical curves of both specimens shows that the strengthening of the brick masonry infill does not significantly contribute to the response of the R/C frame specimen. These load-displacement hysteresis curves are almost the same as each other. Thus, the energy absorption and ductility of these specimens may be stated to be almost identical.



(a) Load-Displacement Hysteresis Curve



(b) Crack Pattern at R=+1/12.5

Fig. 5. The Experimental Results of the IF-2C Specimen.

The maximum of the ultimate lateral load for the IF-2C specimen was also reached at the first cyclic R = + 1/100, where an increase in lateral strength increased by about 18% compared to IF-SW specimen. The advantage of the strengthening technique applied in this study is mainly in the failure model of the specimen. By strengthening the brick masonry infill delayed the cracking that occurs, both in the masonry infill and in the R/C frame as well and the crack significantly reduced. The cracked path on the diagonal brick masonry infill was cut off by the plain bars embedded in the middle area of the masonry infill.

4 Conclusion

A specimen to define the simple strengthening technique which is applied for the brick masonry infilled in the RC frame structure by using the embedded reinforced bars on the bed mortal join (IF-2C), has been tested subjected to lateral static reversed cyclic loads. Compared to an IF-SW specimen, the lateral strength of the strengthened specimen has increased about 17% and delayed the failure of the RC frame and collapse of the brick masonry infill. The strengthening technique is easy to apply by unskill local labor. Therefore, this method will be useful and applicable in the seismic-prone area, such as West Sumatera, Indonesia.

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