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A SIMPLE METHOD FOR STRENGTHENING THE BRICK MASONRY INFILLED IN THE REINFORCED CONCRETE FRAME STRUCTURE

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ABSTRACT: The collapse of the brick masonry infill in the Reinforced Concrete (RC) structures has been known as one of the causes of the many casualties during the earthquake. This clay brick masonry has been commonly used as partitions in the RC frame structures in earthquake-prone areas such as West Sumatera, Indonesia. Strengthening the brick masonry infill is expected to be able to increase the performance of the brick masonry against the earthquake motions, which also may improve the seismic performance of RC structures. In this study, four of 1/4 reduced-scale singe-bay and single-story RC frame specimens were prepared and tested under lateral static reversed cyclic loading. The specimens include one specimen of RC frame infilled with brick masonry and three specimens of RC frames infilled with strengthened brick masonry. Strengthening of the brick masonry infill has used three types of wire mesh, namely plastic wire mesh, steel wire mesh, and chicken wire mesh. The wire mesh was tacked on both sides of the diagonal area of the brick masonry infill. The wire mesh was then fastened to columns and beams of the RC frame by using chemical epoxy adhesive. The purpose of this experimental study is to define an effective, inexpensive, and easy to apply the strengthening of the brick masonry infill such that it may be applied by the local labors in West Sumatera, Indonesia. The structural test results have shown that all the strengthening methods increase the lateral strength of the RC frame and can delay the failure of the brick masonry infill. Even though the strengthening by using the steel wire mesh produced a higher increase in stiffness of the specimen compares to others, however strengthening by using chicken wire mesh performed the most effective strengthening method. The presence of the chicken wire mesh maintains the ductility of brick masonry infill and the RC frame as well.

Keywords: RC building, strengthening brick masonry, seismic performance, reversed cyclic loading

1. INTRODUCTION

The presence of brick masonry as infill in the reinforced concrete (RC) structure has commonly in the earthquake-prone area such as West Sumatera, Indonesia. Based on the results of the post-earthquake investigation after the earthquake and the experimental results of the RC frame subjected to static lateral loading showed that the presence of infilled brick masonry in RC frame structures influence the performance of its structures. The presence of brick masonry infill, on one side, increasing the lateral strength and the stiffness of the structure, however, decreases its ductility. On the other hand, the existence of this brick masonry infill may endanger the occupants.

In many cases, the brick masonry infill often collapses during the earthquake shaken and results in a loss of human life [1]-[2]. The studies for investigating the influence of brick masonry infill to seismic capacity and behavior of the RC frame structures have been conducted by many researchers covering various aspects. Tanjung [3]-[4] has examined the use of various types of brick masonry materials commonly used in West Sumatra, Indonesia, for evaluating the seismic performance of the RC frame structures with infilled by the brick masonry. The RC specimens were subjected to the lateral static pushover loading only. More detail and complex studied have been carried out by Madiawati [5] Cavaleri [6] and Dautaj [7], where the brick masonry infilled of RC frame specimens were tested under the lateral static reversed cyclic loading. They concluded that the brick masonry infill plays an essential role in the damaged on the RC frame structure during cyclic loading.

One effort to reduce the vulnerability of this brick masonry infill is by strengthening its brick masonry infill with such ductile materials. Obviously, the research on the strengthening of the brick masonry has also been carried out by several researchers. Tanjung [8], for instance, has used the embedded plain steel on the bed mortar joint to strengthen the brick masonry infill in the RC frame structure, while Ismail [9] uses wire mesh banded to strengthen the unconfined brick masonry housing in Pariaman, West Sumatera. Leeanansaksiri [10] also used the Ferro-cement for straightening the brick masonry infilled in RC frame structures. More advanced research is carried out by researchers that have been well summarized in the article [11]-[16]. The strengthening methods by using modern materials such as textile-reinforced mortar, welded wire mesh, and Carbon Fiber Reinforced Polymer (CFRP) have also been conducted and proposed by the researchers. Although their test results show that the strengthening materials and methods gave better RC frame construction, unfortunately, the strengthening methods require the relative expensive materials and specialized labor for applying the strengthening. Therefore, these methods are not suitable to apply in the West Sumatra area, since there is no available strengthening material and skilled labors as well.

In this study, the simple method based on the experimental works for strengthening the brick masonry infilled in the RC frame structure is proposed. For this purpose, four of 1/4 reduced-scale singe-bay and single-story RC frame specimens were prepared and tested under lateral static reversed cyclic loading. The purpose of this experimental study is to define an effective, inexpensive, and easy to apply the strengthening of the brick masonry infill such that it may be applied by the local labors in West Sumatera, Indonesia.

2. EXPERIMENTAL PROGRAM

The experimental study explains in this paper was conducted by utilizing the structural testing facilities at Structure and Construction Material Laboratory of Syiah Kuala University, Banda Aceh, Indonesia. Four of 1/4 reduce-scaled one-bay and one-story RC frame specimens were prepared, i.e., one specimen of RC frame infilled with brick masonry and three specimens of RC frames infilled with strengthened brick masonry. The specimens represent the first story of the typical construction of low-rise RC frame structures in West Sumatra, Indonesia. Strengthening of the brick masonry has used three types of wire mesh, namely plastic wire mesh, steel wire mesh, and chicken wire mesh. The materials for constructing these specimens were collected from local markets in Banda Aceh, Indonesia. All the specimens were subjected to lateral static reversed cyclic loading.

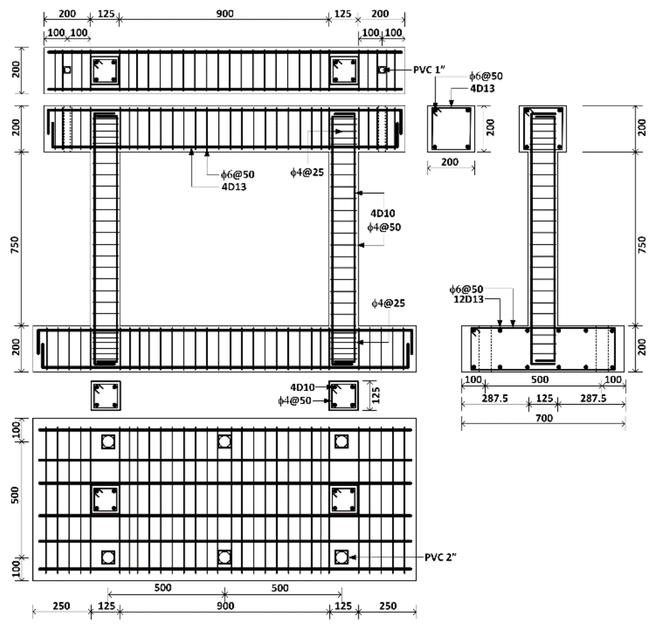
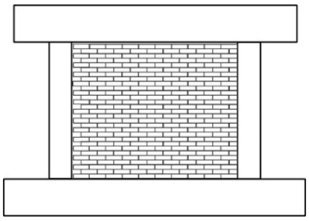


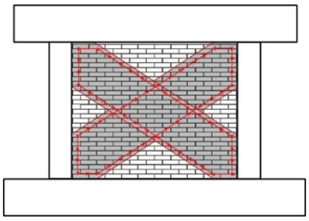
Fig. 1 Reinforcements Details of the RC Frame.

2.1 The RC Frame Specimens

Figure 1. shows the details of the geometry and reinforcement applied for all RC frame specimens. The columns of the RC frame were detailed to yield in flexure before shear failure. The dimension of the cross-section of columns was 125 mm x 125 mm and reinforced with 4D10 longitudinal bars and ϕ4@50 transverse hoops. We designed the cross-section of the columns by considering the scale reduction. The clear height of the columns was 750 mm. The dimension of top-beam was 200 mm wide, 200 mm deep, and 1550 mm long and reinforced with 4D13 longitudinal bars and ϕ6@50 transverse stirrups. The columns were then supported by the lower-beam, which was fastened to the strong-floor by using six post-tensioning rods. The dimension of the lower-beam was 700 mm wide, 150 mm deep, and 1650 mm long and reinforced with 12D16 longitudinal bars and ϕ6@50 transverse stirrups.



(a) RC Frame with Brick Masonry Infill Specimen



(b) RC Frame with Strengthened Brick Masonry Infill Specimen

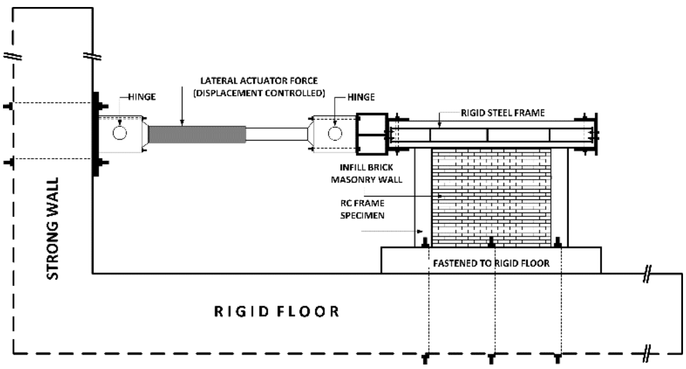
Fig. 2 Design of the RC Frame Specimens.

Four of 1/4 reduced-scale singe-bay and single-story RC frame specimens were constructed in this study. The specimens include one specimen of RC frame infilled with brick masonry (IF-SW) and three specimens of RC frames infilled with strengthened brick masonry. Strengthening of the brick masonry has used three types of wire mesh, namely plastic wire mesh (IF-SM-P), steel wire mesh (IF-SM-S), and chicken wire mesh (IF-SM-A). The wire mesh was tacked on both sides of the diagonal area of the brick masonry wall. The wire mesh was then fastened to columns and beams of the RC frame by using chemical epoxy adhesive. The RC frame specimen with brick masonry infill is schematically shown in Fig. 2a while the RC frame with strengthened brick masonry infill is presented in Fig. 2.b.

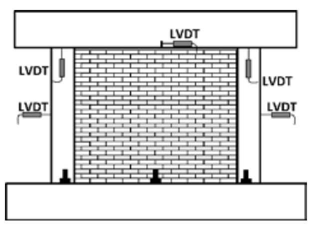
2.2 Experimental Setup and Instrumentation

As was mentioned above, during experimental works, the prepared RC frame specimens were subjected to static lateral reversed cyclic loading. A schematically image of the experimental setup for the current study is shown in Fig 3.a. For testing the specimen, at first, its specimen was placed on the rigid-floor. The lower-beam of the specimen 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.

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 [17]. The amount of lateral movement of the top-beam was defined based on the drift ratio of the column $R=\delta/H$, 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) The Position of the LVDTs

Fig. 3 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 Performance and Failure Mechanism

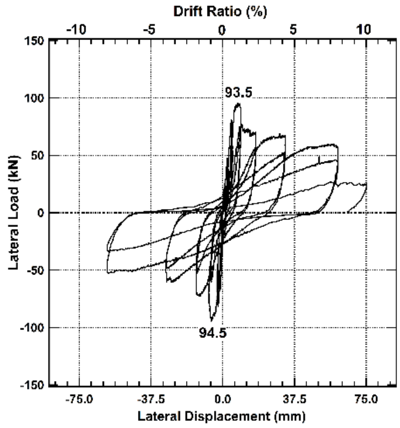
3.2.1 RC Frame with Brick Masonry Infill

Figure 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.

3.2.2 RC Frame with Strengthened Brick Masonry Infill

The comparison of the load-displacement hysteresis curves based on the experimental results for all three strengthened brick masonry infill specimens is shown in Fig. 5. Compare to the test results of the IF-SW specimen, increasing the lateral strength due to the strengthening of brick masonry infill in IF-SM-P, IF-SM-S, and IF-SM-A specimens are 12.4%, 5.3%, and 22.6%, respectively. Although the increase in its lateral strength is not significant, however, the presence of the strengthened brick masonry infill in the RC frame significantly changed the deformation behavior, crack pattern, and the progressive failure of the RC frame specimens.



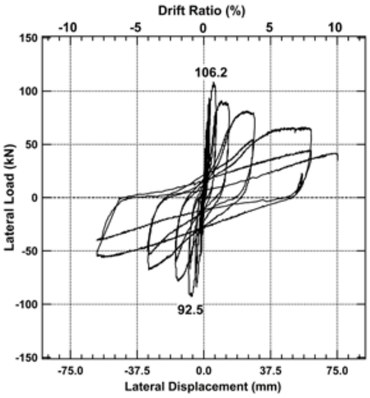
(a) Load-Displacement Hysteresis Curve

(b) Crack Pattern at R=1/12.5

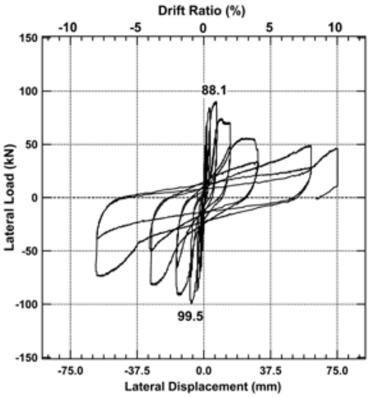
Fig. 4 Experimental Setup and Instrumentation.

In the IF-SM-P specimen, the plastic wire mesh could not perfectly bond to brick masonry and surface plastering as well. Therefore, the strengthening of the brick masonry infill became imperfect. The initial crack on the wall has seen at the first cycle of R = + 1/400, and the surface plastering of the brick masonry infill has begun to release at the second cycle of R = + 1/200. The interface between the column and the brick masonry infill connected by wire plastic was also the weak area of this strengthening method. The cracks in this area have already appeared at the beginning of loading. The advantage of this method is that the use of wire mesh plastic may delay the collapse of the RC frame specimen and the brick masonry infill.

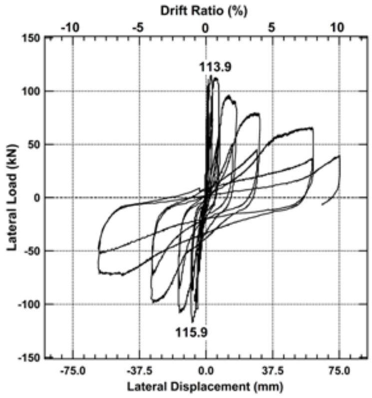
The material of the steel wire mesh has better tensile strength compared to plastic wire mesh and chicken wire mesh. Its material may bond to the brick masonry infill as well as to the surface plastering of the brick masonry infill. Strengthening



(a) IF-SM-P Specimen

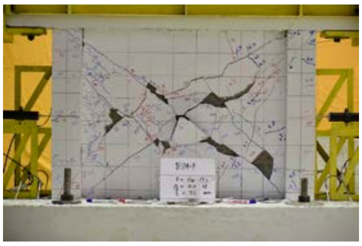


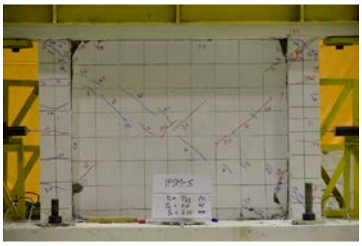
(b) IF-SM-S Specimen



(c) IF-SM-A Specimen

Fig. 5 Comparison of the Load-Displacement Hysteresis Curves


(a) IF-SM-P Specimen


(b) IF-SM-S Specimen

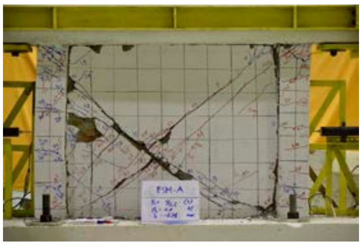

(c) IF-SM-A Specimen

Fig. 6 Comparison of the Crack Pattern of the Specimens at R=1/12.5

using this steel wire mesh (IF-SM-S specimen) gave an excellent strengthening on brick masonry infill. The cracks that occur on the brick masonry wall were significantly reduced. The strengthening causes increase the stiffness of the brick masonry infill. Unfortunately, increasing the brick masonry stiffness produced the high force on the diagonal brick masonry infill that compresses the column such that the column damaged relatively faster than other test specimens.

When comparing these three types of strengthening materials shows that the strengthening by using chicken wire mesh (IF-SM-A specimen) provided the most optimal result. Although the cracks occurred on its brick masonry infill was more than those of the IF-SM-S specimen, the strengthening using chicken wire mesh can delay the collapse of the brick masonry infill. We noted that the cracks on the brick masonry infill generally occurred outside the area where the chicken wire mesh was installed. The cracks that appeared in the columns were dominated by the flexure cracks. This result contrasts with the experimental results of the IF-SM-S specimen, where the column damage was caused by shear failure. The experimental results were also indicated that the ductility of the IF-SM-A specimen better than other specimens. The images of the crack pattern of the RC frame specimen infilled by the brick masonry are shown in Fig. 6.

4. CONCLUSION

The simple method for strengthening the brick masonry infilled in the RC frame structures has been proposed. A proposed method is defined based on experimental works on several RC frame specimens. Comparing the experimental results of these specimens concluded that the strengthening by using the chicken wire mesh gave the optimal result. The strengthening increase in the lateral strength about 22,6% and delayed the failure of the RC frame and collapse of the brick masonry infill. This proposed strengthening method by using the chicken wire mesh also has good ductility compare to other materials. The strengthening material is easy to find in the local markets and 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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