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EXPERIMENTAL STUDY ON MASONRY BUILDING STRENGHTENED WITH FERROCEMENT LAYERS

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ABSTRACT: In the last ten years, Indonesia has suffered from moderate to severe building damages due to big earthquakes such as Yogyakarta and West Sumatra earthquakes in 2006 and 2009, respectively. Most of the damages are non-engineered buildings such as residential houses and schools, which are unreinforced masonry (URM) buildings made of brick without any reinforcements. These URM constructions are using a half clay thick brick method which is not compatible with the standards. In order to strengthen these URM buildings, a retrofitting method using ferrocement layers has been developed. An experimental study on URM building strengthened by ferrocement layers was conducted. Two specimens of a quarter scale house building models consisted of four walls with size 90cm x 110cm were constructed. The first model (M1) is the original unreinforced masonry structure with mortar plaster, and the second (M2) is the same masonry structure strengthened by providing full ferrocement layers on both sides of the walls which are acting as sandwich structures. Both specimens were tested by using a shaking table (304x190) cm^2 with input motions up to 1g. The test results show that the ferrocement layers can significantly improve the performance of the URM building model and effective in preventing the collapse of masonry walls when it is shaken by earthquakes. It is concluded that this retrofitting model is applicable to retrofit the URM houses in seismic regions.

Keywords: Earthquake, Unreinforced Masonry (URM) Building, Strengthening, Ferrocement Layers.

1. INTRODUCTION

Earthquakes that often occur in Indonesia, such as in Yogyakarta and West Sumatra, have caused severe damage to buildings, especially non-engineering buildings [1]. In general, the non-engineering buildings such as residential houses and schools are made of using unreinforced masonry (URM) building without any reinforcements [2].

Fig. 1 The collapse of unreinforced masonry building due to West Sumatra 2009 earthquake

This URM building made of a half clay thick brick method which is not compatible with the standards. In addition, a limitation on the resources available, including finance, skills, and building materials, results in the poor quality of the URM construction. Those buildings are very vulnerable and not strong against earthquake load, which will be severe damage even collapse when a big earthquake occurs, as shown in Figure 1.

In order to strengthen these URM buildings, some retrofitting methods have been proposed. Qaisar Ali, in the University of Engineering & Technology, Peshawar, Pakistan, studied and adapted steel mesh on masonry wall for avoiding the collapse in Pakistan [3]-[4]. This study was focused mostly on the strengthening of the non-structural masonry wall.

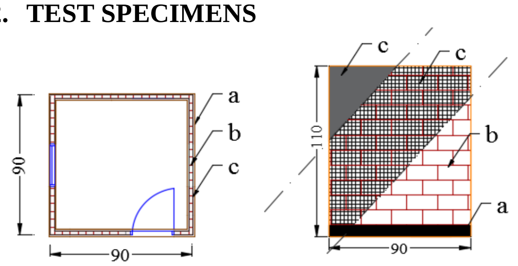
Kimiro Meguro proposed to use polypropylene band (PP-band) for strengthening method of the URM building in some developing countries [5]-[6]. In this method, masonry walls are wrapped by PP-band meshes on both sides as jacketing and the meshes are connected by PP-Strings or wires and embedded in cement or mud mortar overlay.

Boen introduced a retrofitting method for non-engineering building using ferrocement with wire mesh as strengthening layers and used sandwich construction analogy [7]-[8]. The ferrocement layers consist of mortar and wire mesh, in which the wire mesh was encased in the mortar. This retrofitting method uses ferrocement skin layers on walls as bandaging or jacketing.

Imai (2014) found that the significant effect of retrofitting on the URM buildings by using ferrocement overlay as bandaging with galvanized was successfully demonstrated by the shaking table test [9].

In this study, the behavior of two URM buildings with a quarter scale models made in full and without ferrocement layers on both sides of the walls under shaking table test was investigated.

2. TEST SPECIMENS



a : U Plate (14 x 7 x 14) cm
b : Masonry Brick (21 x 10 x 5) cm
c : Ferrocement layers, wiremesh Ø 1 mm, mesh spacing 25mm x 25mm, mortar 1 :4 (cement : sand)

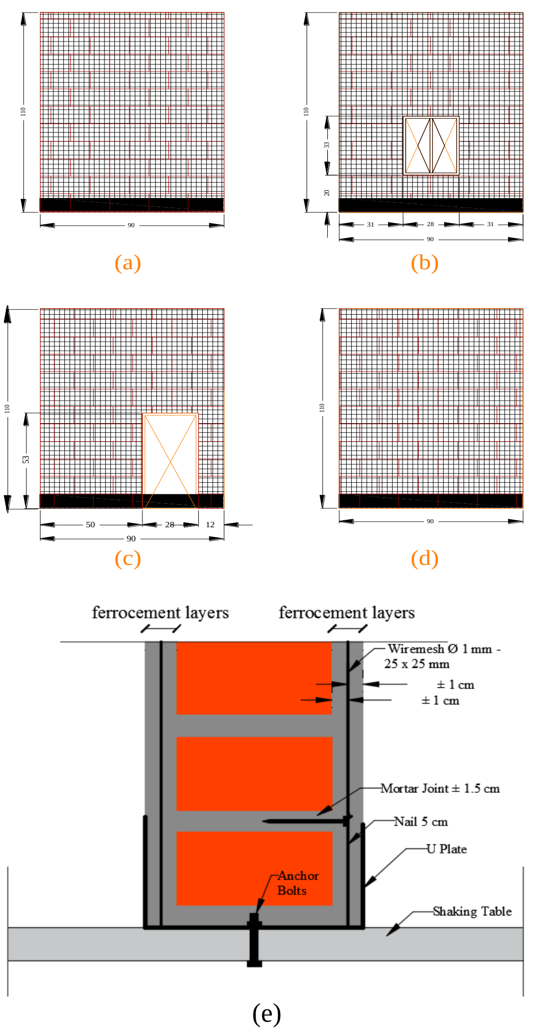


Fig. 2 Schematic drawings of test specimen for model M2, (a) back side wall, (b) left side wall, (c) front side wall, (d) right side wall and (e) detail section of clay brick wall with ferrocement layers

There are two URM models that built on the shaking table in soil mechanical laboratory of Andalas University. Both models have a 1:4 scale of the actual building due to the limitation of the shaking table area. The first model (M1) is the original of unreinforced masonry building covered with mortar plaster, and the second (M2) is the same masonry structure strengthened by providing full ferrocement layers on both walls which are acting as sandwich structures.

Each model consisted of four walls with size 0.9m x 1.1m. Figure 2 shows the schematic drawing of masonry walls for model M2. The masonry walls were made of brick (210x100x50) mm, bonded by using mortar joints with the ratio cement and sand was 1/4 by volume. The compressive strength of the brick was approximately 5 MPa and the compressive strength of mortar to construct the brick wall and ferrocement layer was 9.9 MPa. The construction process for installing ferrocement layers is shown in Figure 3.

Fig. 3 Construction process for installing wire mesh and plastering on specimen M2

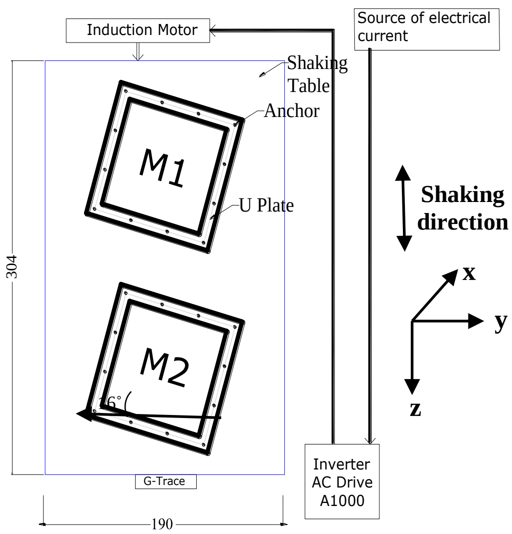


Fig. 4 Set-up of specimens on shaking table

According to National Standardization Agency of Indonesia for Design Method of Earthquake

Resistance for Buildings and Other Structures (SNI 1729–2012), clause 7.5.3, the load was applied separately in all two orthogonal directions. The most critical load effect due to the direction of earthquake forces application to the structure is considered to be fulfilled if the components and foundations are designed to carry the following set load combinations: 100 percent force for one direction plus 30 percent force for perpendicular directions [10]. Therefore, the slope of the specimens was set up on 16˚ in the direction of the positive x-axis, as shown in Figure 4.

3. TEST PROCEDURE

In this study, both specimens were tested by using a horizontal uniaxial movement type of shaking table in Soil Mechanic Laboratory of Andalas University [11]. The input motions with varying the frequency of earthquake, such as the Medium earthquake (ME), Strong earthquake (SE), and Very Strong Earthquake (VSE) (Table 1), were used as input motions for this test. The excitation increased gradually with a = 2.94 m/s^2, 5.88 m/s^2, and 9.81 m/s^2, respectively.

Table 1 Variation of the motions

Type of input motions	a (m/s^2)
ME (0.3g)	2.94
SE (0.6g)	5.88
VSE (1g)	9.81

The specimens were tested in three stages. The first stage (P1), both specimens were tested according to the above procedure. The second stage (P2), a uniform load was given on the top of the specimens, due to there is no crack on both specimens. The third stage (P3), the mortar plaster on the specimen M1 was removed with the test procedures the same as those on P2.

4. RESULTS AND DISCUSSION

The experimental results are presented in this section include the observed failure development and accelerations response of the shaking table that cause the crack on the specimens.

4.1 Test Specimens (P1)

The result of first stage test with 0.3g and 0.6g input motions shows that there is no crack was observed, as shown in Figure 5. From the analysis, it was found that the given input motion is not strong enough to damage the specimen. The required input motion to fail the specimen M1 will be 3.6g with maximum shear stress value is 1.166 MPa.

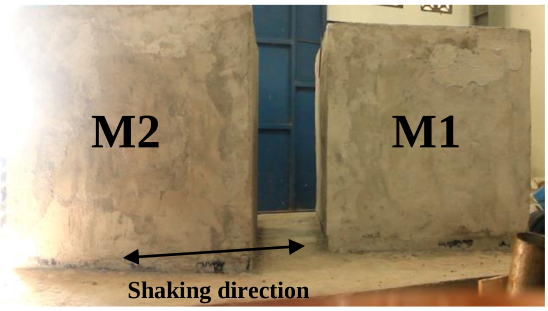


Fig. 5 The specimens without additional loads (P1) after testing

4.2 Test Specimens with Additional Uniform Load (P2)

Due to the limitation of the shaking table capacity, a uniform load 1479.29 kg/m^2 was given on top of the specimens by using sandbags as an additional load to make the damage on specimens with the given input motions.

In this test, there is also no crack occurred on both specimens at input motions 0.3g and 0.6g, while slightly crack was observed on the mortar plaster of specimen M1 at input motion 1g. Specimen M2 with ferrocement layers still survived without any damage, as shown in Figure 6. Due to the capacity limitations, the higher input motion could not be applied.

Fig. 6 The specimens with additional uniform loads (P2) after testing

4.3 Test Specimen by Removing Mortar Plaster on Specimen M1 with Additional Uniform Load (P3)

In order to know the effect of ferrocement layer on original URM building, the plaster of specimen M1 was removed and the test was continued with the additional load on the top of the specimen with the input motion from 0.3g up to 1g.

Similar to the result of specimens on P1 and P2 tests, there is no crack was observed on both specimens with the input motion 0.3g. The slightly crack was observed on specimen M1 at input motion 0.6g. As the input motion increased to 1g, many new cracks occurred in both of sides (outside and inside) of the wall on specimen M1, as shown in Figure 7. The three sides (left, right and front) of the wall had almost failed, whereas the back side of the wall was slightly damaged. Most of the cracks on specimen M1 were found on near the opening to the corner on the left and front sides of the specimen, as shown in Figure 8.

On specimen M2, there was no crack in all sides of the wall. A little damage was found at the bottom of the specimen connection, especially on the connection between the building and the plate U (without apparent cracks) due to the slightly uplift of the specimen. The higher stiffness of the specimen due to the presence of ferrocement layer caused the weaker the joint between the wall of specimen and plate U. The wire mesh on the ferrocement layer may contribute to the increase of wall stiffness and the ductile material behavior of the specimen M2.

Fig. 7 Specimens M1 (without plastering) and M2 (with ferrocement layers) after the P3 test

Fig. 8 The crack near the opening wall on specimens

4.4 Acceleration Responses to Cracks Pattern

The pattern of the cracks on the specimen was observed based on video camera recording. The acceleration response is obtained from the G-trace in the form of an acceleration graph over time.

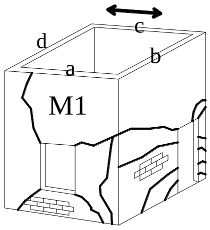


Fig. 9 Failure mechanism of specimen M1

Failure mechanism of the specimen M1 for the P3 test with a very strong earthquake (input motion of 1g) can be seen in Figure 9. Figure 10 shows the collapse process of the specimen in the P3 test. The initial crack occurs on 5 seconds (Figure 10), and then the pattern of the crack is observed every 5 seconds until 30 seconds.

Fracture of the left side wall occurs when t = 5s (see Figure 10a) with a 1.4g acceleration, as shown in Figure 11a. This crack begins at the corner between the left and the front side wall (Figure 10b), and then the crack extends to the opening section of the window. This opening is a part that has a high concentration of stress. The fracture pattern occurring at t = 15s (see Figure 10a) in which the specimen will be moderately damaged.

In addition, due to additional uniform loads on the top of the specimen, cracks also occur from above specimen at t = 25s and propagate toward the openings, where the acceleration 1.44g (Figure 11f). In the front side specimen, there is an opening, as shown in Figure 10b. As a result of an earthquake force perpendicular to the front side wall plane, the wall experiences the first crack on the left and right sides.

At t = 15s, a large crack occurs on the front of the specimen (Figure 10b) with an acceleration 1.56g, as shown in Figure 11c. Meanwhile, horizontal crack was observed on the right side of the wall. The fracture pattern of the right side wall of the specimen M1 is slightly different from the other sides of the wall, as shown in Figure 10c. The shear force causes the horizontal crack at the bottom of the walls and they are slightly uplifted. Horizontal fracture occurs at t = 10s with a large acceleration 1.54g (Figure 11b), then a large crack was observed. The horizontal crack is elongated. The load received during this maximum horizontal crack ranges from t = 16s to t = 25s with the accelerations from 1.56g to 1.44g (Figure 11(c-e)). At 1.36g, there is no continuous crack observed on the right side of the wall (Figure 11f).

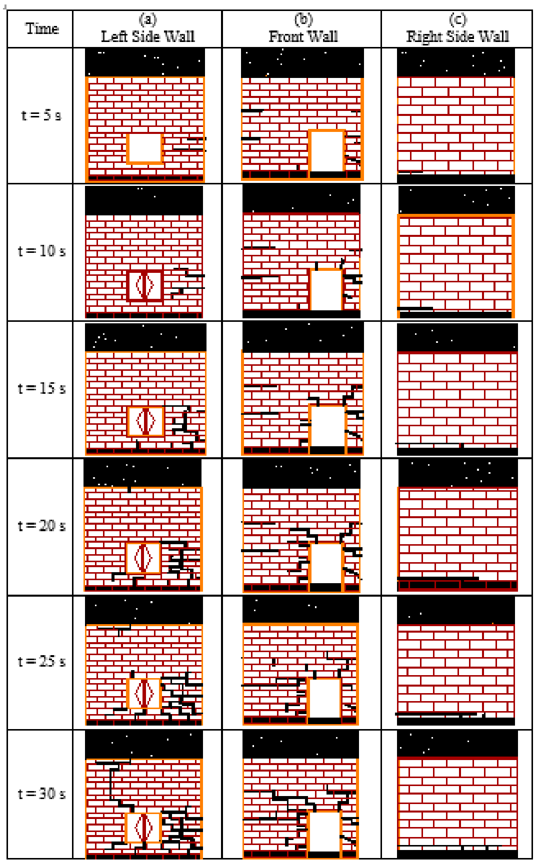


Fig. 10 Schematic of cracks pattern on specimen M1 (without ferrocement layers)

a. Right side wall

b. Left side wall

c. Front side wall

d. Back side wall

Fig. 12 Failure pattern of specimen M1 on advanced test

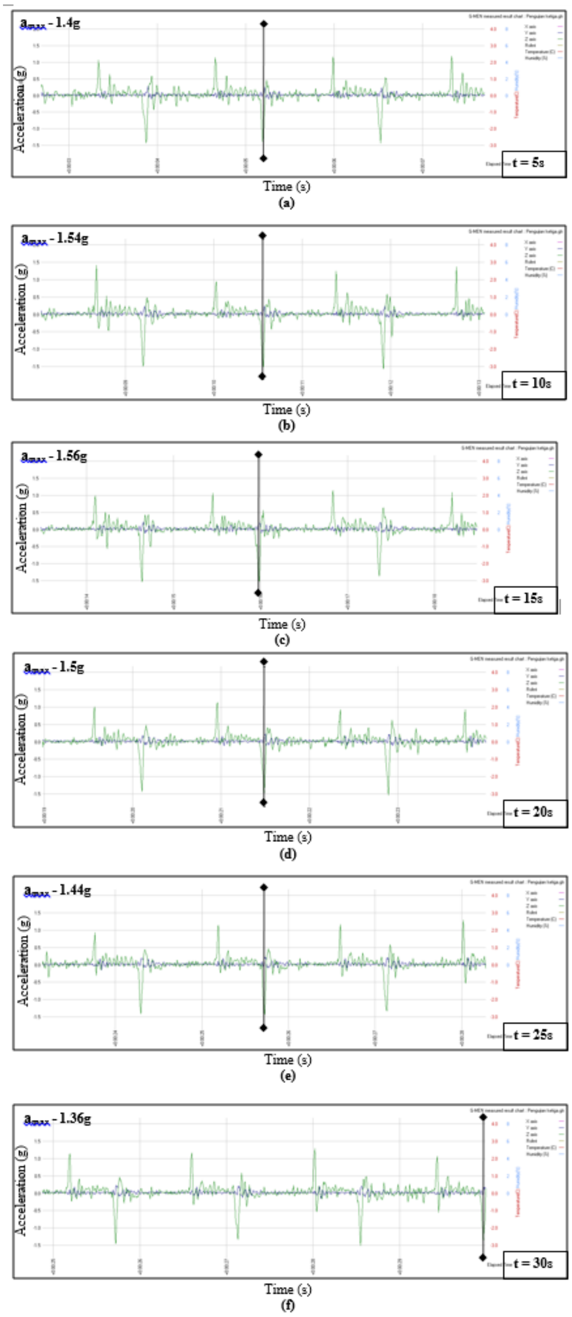
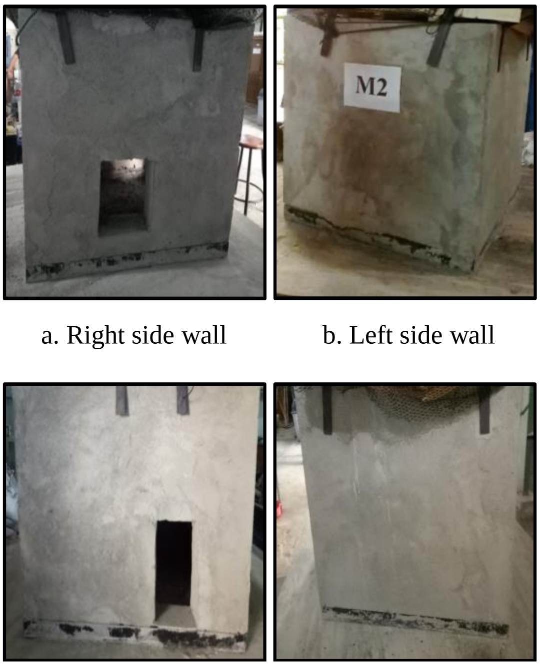


Fig. 11 The graph of acceleration vs. crack time with very strong earthquake load on testing (P3)

On the back side of the wall, at t = 5s to t = 25s, there was no crack due to no opening on the back side of the specimen. Only slightly damaged was found on the back side of the wall, at t = 30s.

In order to know the final failure pattern of both specimens, the test was continued by using very strong earthquake input motion (1g) for another 30 seconds. Figures 12 and 13 show the final failure pattern of specimens M1 and M2, respectively. As shown in Figure 12, the specimen M1 has been seriously damaged, especially on the corner of the wall between the left and right sides, while a wide diagonal crack was observed on the back side of the specimen M1.

For specimen M2, there was no crack appears on all of the specimen walls, as shown in Figure 13; however they are slightly uplifted on the bottom of the specimen. This indicates that the presence of ferrocement layer on the original URM building had improved the stiffness of the wall, prevented the cracks and collapsed the masonry walls during the earthquake.



a. Right side wall b. Left side wall

c. Front wall d. Back wall

Fig. 13 Failure pattern of specimen M2 on advanced test

5. CONCLUSION

Based on the experimental result, it can be concluded that:

1. No crack was observed for both specimens on P1 and P2 tests because the input motion is not strong enough to cause the crack of the specimen.
2. By removing the mortar plaster on specimen M1 and being tested with additional load (P3), there was a large crack in the wall with the opening at t = 15s with acceleration 1.56g, then the horizontal crack on the wall occurred at t = 10s with acceleration 1.54g.
3. The specimen with ferrocement layers (M2), is resistant to earthquake loads in each variation of P1 to P3 testing up to very strong input motion (1g). There is no crack due to the contribution of ferrocement layer in confining the clay brick wall. The wire mesh on ferrocement layer contributes to minimizing the brittle behavior of plaster mortar and clay brick wall.
4. The ferrocement layers are very effective to strengthen original URM that made of brick, which can improve the performance of the brick wall of URM. So, it can be applied easily by local construction workers, at an affordable cost. The ductile properties of ferrocement layers make the URM resistant to the earthquake load without having collapsed and saved the occupant.

6. ACKNOWLEDGEMENTS

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