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EXPERIMENTAL STUDY ON THE RETROFITTING OF DAMAGED HOLLOW BRICK MASONRY HOUSES USING A FERROCEMENT LAYER

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ABSTRACT: An experimental study on a hollow brick masonry house with and without a ferrocement layer was conducted to investigate the effects of retrofit on damaged houses using the ferrocement layer. Two specimens of the hollow brick masonry house with a scale 1/4 of the actual size (104 cm x 104 cm x 110 cm) were prepared. The first specimen (B1) is a hollow brick house without retrofitting and mortar plastering tested to suffer heavy damage. In contrast, the second specimen (B2) is a brick wall house retrofitted using a ferrocement layer with a bandage system on both sides of the specimen wall. Both specimens were tested on a shaking table of 304 cm x 190 cm with a load variation of 0.3 g – 1 g. The first test aims to make the B1 specimen severely damaged, in which the heavy damage occurs when the input load is 0.6 g with an additional evenly distributed load of 200 kg. After testing, the cracked B1 specimen was repaired and retrofitted using a ferrocement layer with a bandage system. The second test was carried out on the retrofitted B1 and B2 specimens. The test result shows that no visible damage was observed on both specimens up to a variation of the input load of 1 g with an additional uniform load of 500 kg. This result proves that the retrofitting method using the ferrocement layer with a bandage system significantly improves the seismic behavior of hollow brick houses such that this method can be applied for retrofitting the damaged hollow brick houses after an earthquake.

Keywords: URM House, Hollow Brick, Earthquake, Shaking Table, Ferrocement Layer

1. INTRODUCTION

Indonesia is one of the most earthquake-prone countries in the world. For the last two decades, major earthquakes have occurred in Indonesia, such as the Aceh earthquake in 2004, the West Sumatra earthquake in 2009, the Lombok and Palu earthquake in 2018, the Mamuju earthquake in 2021, the West Pasaman Earthquake in 2022, and the recent is the Cianjur earthquake in November 21st, 2022. These earthquakes caused enormous losses, claimed many lives, and damaged infrastructure and buildings, especially simple houses/community houses, ranging from minor to major damage.

Community houses are generally built using unreinforced masonry (URM) buildings. These houses cannot resist earthquake loads because the buildings do not have structural elements such as beams and columns, and the thickness of the walls does not comply with earthquake-resistant house standards [1]. The houses were usually built without involving construction experts such as Architects and Civil Engineers [2].

The characteristics of the brick/hollow brick material make this house brittle and have almost no ductility, which makes the brick walls do not have sufficient resistance to horizontal loads or earthquake loads. These simple unreinforced hollow brick buildings can suffer light and heavy damage when an earthquake occurs, as shown in Fig.1.

Fig.1 Damage to brick wall houses due to the 2022 West Pasaman earthquake [3]

Many methods have been published to retrofit the damaged houses, including the ferrocement layer method. Ferrocement is a type of plaster (mortar) that is reinforced with woven wire. Many studies have been conducted on using the Ferrocement layer as a retrofitting method for damaged non-engineering buildings such as houses [4,5]. Testing results of the brick house retrofitted with a ferrocement layer showed that the retrofitting method improves the house's capacity and effectively prevents wall collapse during an earthquake [6]. In addition, many experimental studies have been done to strengthen existing building structures including houses, for example, a study on cement clay interlocking brick masonry structures strengthened with CFRP and cement-sand mortar [7], load-bearing performance of non-prismatic RC beams wrapped with carbon FRP composites[8], experimental and analytical studies on low-cost glass-fiber-reinforced-polymer-composite-strengthened reinforced concrete beams: a comparison with carbon/sisal fiber-reinforced polymers [9], and behavior of non-prismatic RC beams with conventional steel and green GFRP rebars for sustainable infrastructure [10].

In this research, an experimental study on hollow brick masonry houses was carried out to investigate the effect of the retrofit on damaged houses using a ferrocement layer with a bandage system. The house specimens were tested on a shaking table test by applying earthquake load to these specimens.

2. RESEARCH SIGNIFICANCE

One way to anticipate earthquakes is to design buildings and houses that are resistant to earthquakes. Earthquake-resistant houses should be considered in constructing community houses in earthquake-prone areas. However, many URM houses in Indonesia do not meet the building standard, especially in terms of the thickness, which is less than the requirement of the building standard [11]. These houses are not strong enough against earthquake load and should be retrofitted to prevent damage or collapse. Therefore, this research focused on investigating the effects of retrofitting on a damaged hollow brick URM house using a ferrocement layer with a bandage system [12]. The results and findings of this study will be useful and applicable for the design and analysis of the retrofitting of the damaged URM houses after the earthquake.

3. TEST SPECIMENS

Two specimens with the size of 1.04 m x 1.04 m x 1.1 m were constructed, as shown in Figs.2-4. Both specimens have a 1:4 reduced-scale model of the actual housing due to the limitation of the shaking table capacity.

The hollow brick material used was 100 x 50 x 25 mm, which is the scale of the actual material size. The composition of the cement and sand mixture to make the material is 1:5 in volume. The hollow brick has a compressive strength (fc') of 2.5 MPa and an elastic modulus of 7431.35 MPa. The mortar used for spacing and plaster is a 1:4 mixture of cement and sand by volume. The mortar has a compressive strength (fc') of 9.9 MPa and a modulus of elasticity of 14788.2 MPa. The thickness of the spacing is 5 mm, the width of the ferrocement layer is 125 mm, and the thickness of plaster for coating the woven wire is 5 mm. Woven wire with a yield tensile strength (fy) of 275 MPa, ultimate tensile strength (fu) of 620 MPa, and shear modulus of 187500 MPa are installed inside of the mortar.

The material properties were tested using ASTM C1314-21 [13] at the materials and structures laboratory, Department of Civil Engineering, Andalas University. The process of making B1 and B2 specimens is shown in Figs.5 and 6.

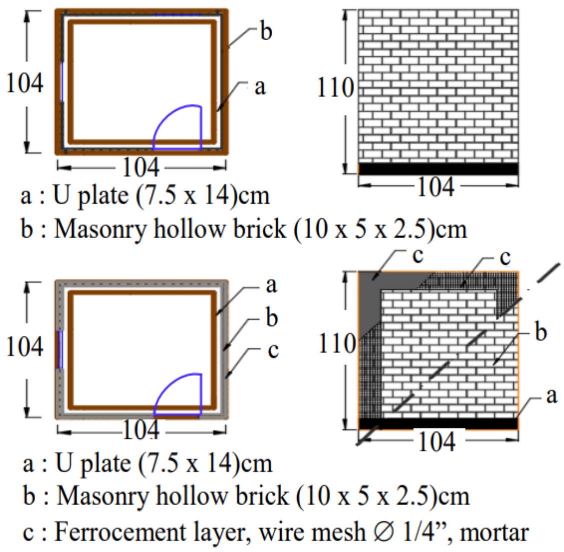

Fig.2 Plans and sections of B1 and B2 specimens

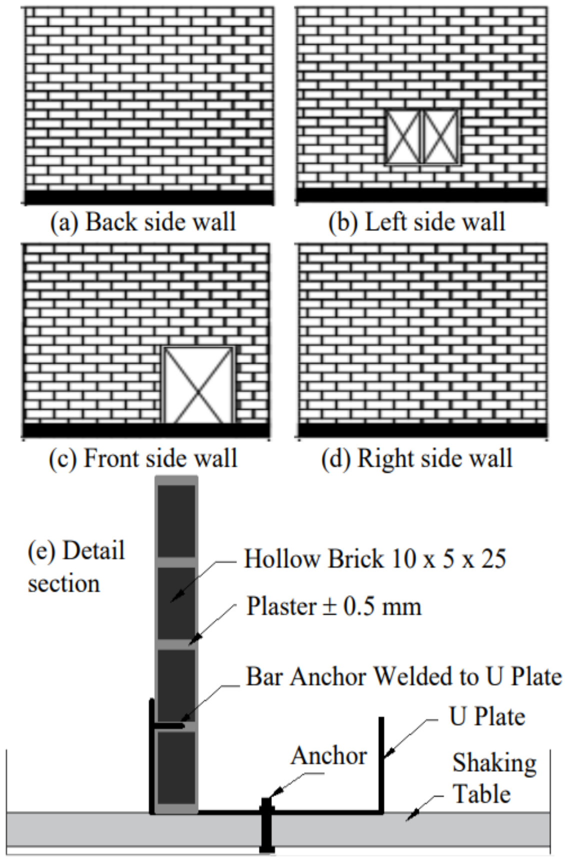

Fig.3 Views and details of B1 specimen

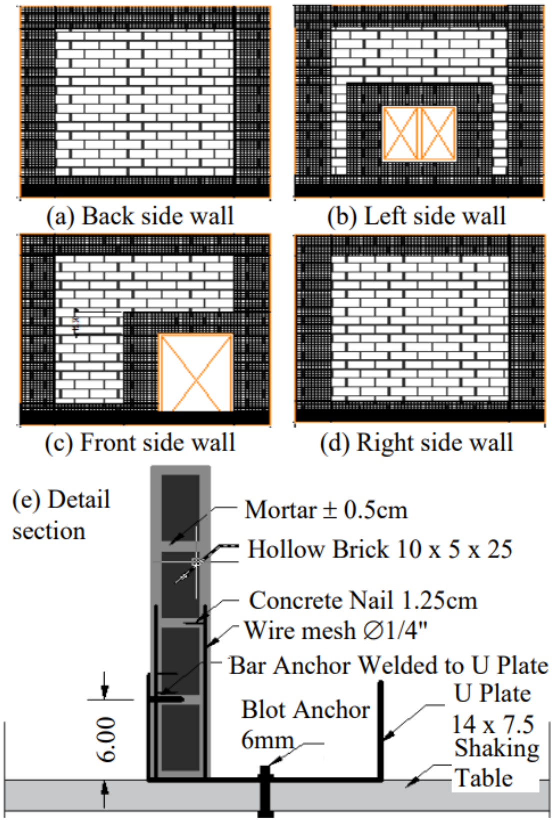

Fig.4 Views and details of B2 specimen

Fig.5 Construction process of B1 specimen

According to the Indonesian seismic standard (SNI 1729:2019), clause 7.5.3 states that the load is applied separately in all two orthogonal directions. The effect of the most critical load due to the direction of application of earthquake forces on the structure is considered fulfilled if the components and foundations are designed to carry the load combination specified as follows: 100 percent of the force for one direction plus 30 percent of the force for the perpendicular direction [14]. Therefore, the slope of the specimen was set at 16° towards the positive X-axis, as shown in Fig.7.

Fig.6 Construction process of B2 specimen

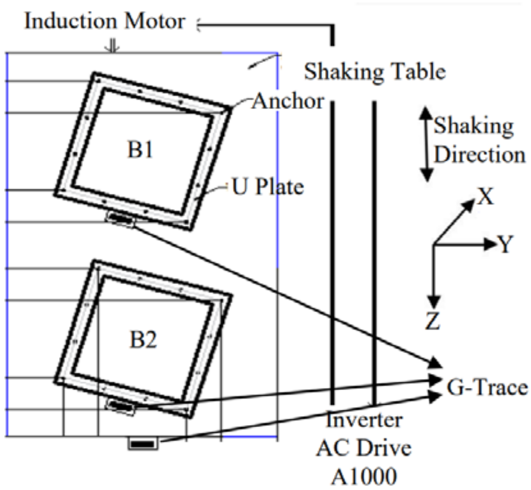

Fig.7 Set-up of specimens on shaking table

4. TEST PROCEDURES

In this study, both specimens were tested using a horizontal uniaxial motion shaking table at the soil mechanics laboratory at Andalas University [15]. Table 1 shows the input motions of this test with variations in earthquake frequency, such as moderate earthquake (ME), strong earthquake (SE), and very strong earthquake (VSE) [10]. The input motion of 0.6 g is the peak ground acceleration (PGA) of Padang City based on the 2019 Indonesia Earthquake Map (Fig.8). The excitation is given to the test object: a = 2.94 m/s^2, 5.88 m/s^2, and 9.81 m/s^2.

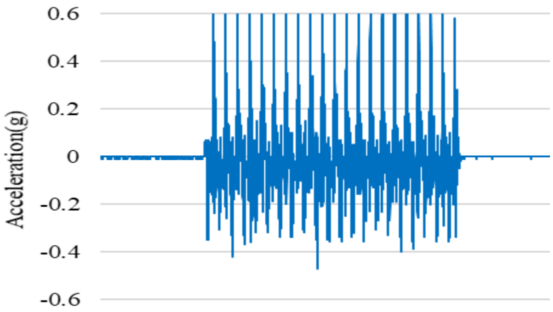

Fig.8 Input motion of 0.6 g is the peak ground acceleration (PGA) of Padang City, Indonesia

Table 1 Variation of input earthquake load

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

B1 and B2 specimens were tested on a shaking table, in which the test was stopped when the B1 specimen was severely damaged. This test (P1) consists of three loading stages: 0.3 g – no additional uniform load, 0.3 g – 200 kg additional uniform load, and 0.6 g – 200 kg additional uniform load.

After the B1 specimen was severely damaged, the specimen was repaired and strengthened using a ferrocement layer with a bandage system.

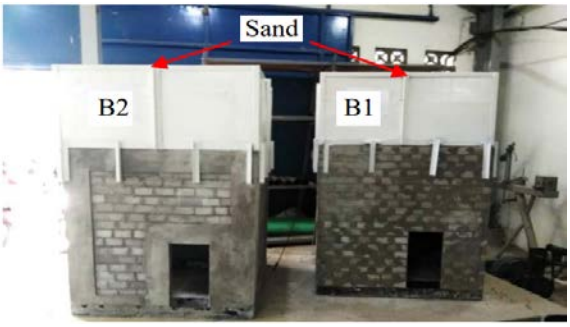

Fig.9 Specimens with additional uniform load using sand-filled sacks (sandbags)

Both specimens were tested again on the shaking table. This retesting (P2) consists of four loading stages: 0.3 g – 400 kg additional dead load, 0.6 g – 400 kg additional dead load, 0.6 g – 500 kg additional dead load, and 1 g – 500 kg additional dead load. The additional dead load referred to is the load using a sand-filled sack placed on top of the specimen, as shown in Fig.9.

5. RESULTS AND DISCUSSION

The test results from this experimental study include failures such as crack patterns that occur in the specimen and the maximum acceleration obtained from the readings of the G-Trace vibration reader. This experimental study was divided into two tests: testing the B1 specimen until severely damaged (P1) and another testing after the B1 specimen was strengthened using a ferrocement layer with a bandage system.

5.1 Testing B1 Specimen until Heavily Damaged

In this stage, both specimens were tested until the B1 specimen was severely damaged to observe its damage and the possibility of retrofitting the damaged specimen.

5.1.1 Tests with input motion of 0.3 g and no additional uniform load (P1-A)

In this test, both specimens were subjected to an earthquake load of 0.3 g and no additional load. From the test result, it appears that the two specimens did not suffer any damage as the earthquake's magnitude was insufficient to damage the building, as shown in Fig.10.

5.1.2 Tests with an input motion of 0.3 g and an additional uniform load of 200 kg (P1-B)

Both specimens in this test were given an earthquake load of 0.3 g with an additional uniform load of 200 kg. The test result shows that the two specimens also did not suffer damage, and there was no crack appeared.

5.1.3 Tests with an input motion of 0.6 g and an additional uniform load of 200 kg (P1-C)

In this test, both specimens were given an earthquake load of 0.6 g with an additional uniform load of 200 kg. The results of this test show that the B1 specimen suffered heavy damage on all sides of the specimen wall, as shown in Figs.11 and 12. The result shows that cracks started to appear in the door openings at the front walls on specimen B1 (red marker). In contrast, the B2 specimen did not suffer any damage. The condition of damage in the B1 specimen is classified as the condition of the specimen experiencing severe damage.

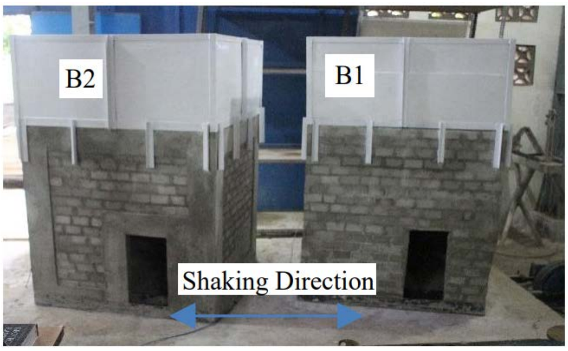

Fig.10 Tested specimens with 0.3 g input motion and without applied additional load

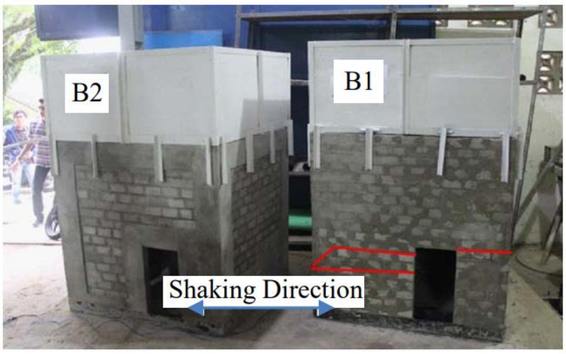

Fig.11 Tested specimens with the input of 0.6 g and an additional uniform load of 200 kg

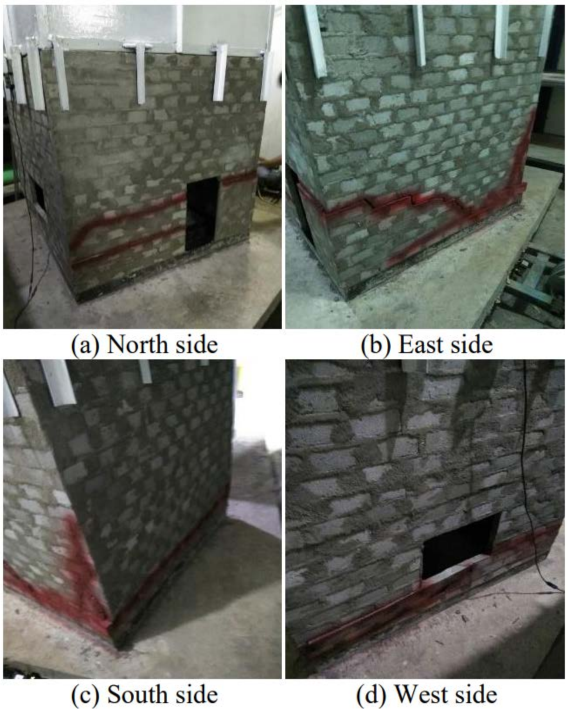

Fig.12 Damages to specimen B1 after testing (input motion of 0.6 g and an additional uniform load of 200 kg)

5.1.4 Displacement of specimens B1

Table 2 shows the displacement of specimen B1 for each loading stage.

Table 2 Displacement of B1 specimen

Load Variation	Input Motion and Uniform Load	Displacement Value (cm)
P1-A	0.3 g and 0 kg	5
P1-B	0.3 g and 200 kg	5.5
P1-C	0.6 g and 200 kg	6.5

The figure shows that the displacement of specimen B1 increases with the addition of a uniform load of 200 kg for input motion 0.3 g. The displacement continues to increase with the increase of the input motion from 0.3 g to 0.6 g. The largest displacement value of 6.5 cm was observed at input motion 0.6 g and the additional uniform load of 200 kg.

5.2 Testing B1 Specimen After Retrofitting

After testing, the heavily damaged B1 specimen was repaired and retrofitted by a ferrocement layer with a bandage system. The repair and retrofitting process of the heavily damaged specimen is shown in Figs.13 and 14.

Fig.13 Repair of the concrete crack and installment of woven wire in the damaged B1 specimen

Fig.14 Plastered the woven wire on the damaged B1 specimen

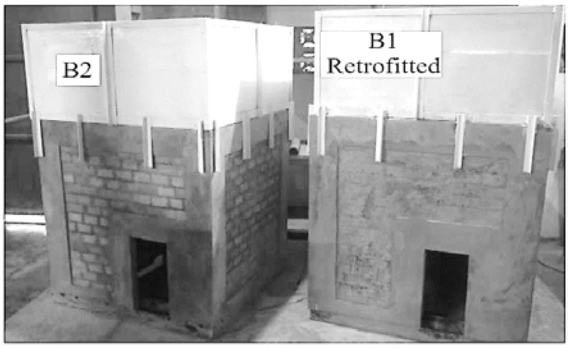

Fig.15 Retrofitted B1 specimen

Due to the B1 specimen severely damaged condition, the B1 specimen was repaired and retrofitted using a ferrocement layer with a bandage system, which later was tested again on the shaking table (Fig.15).

Both specimens were subjected to an earthquake load of 0.3 g with an additional uniform load of 200 kg (P2-A), 0.6 g with an additional uniform load of 400 kg (P2-B), and 500 kg (P2-C), 1 g with an additional uniform load of 500 kg (P2-D). The test results show that no damage was observed on both specimens after each test until the P2-D test, as shown in Fig.16. The test was only carried out until this stage due to the limitations of the shaking table equipment.

The addition of ferrocement layers contributes to improving the specimen capacity to withstand earthquake load. These retrofitted houses can be safe without damage and cause no casualties when another earthquake occurs. This study result also proves that retrofitting using a ferrocement layer can be applied to damaged houses due to earthquakes.

Fig.16 Tested specimens with an input motion of 1 g and an additional uniform load of 500 kg

5.2.1 Displacement of specimens B1 after retrofitting

Table 3 shows the displacement value of each loading variation. As seen in the figure, the retrofitted B1 specimen slightly increases with the increase of input motions and additional uniform loads. The maximum value of the displacement (7 cm) was observed at the last loading stage with input motion 1 g and the additional uniform load of 500 kg.

Table 3 Displacement of the retrofitted specimen B1

Load Variation	Input Motion and Uniform Load	Displacement Value (cm)
P2-A	0.3 g and 200 kg	6
P2-B	0.6 g and 400 kg	6.3
P2-C	0.6 g and 500 kg	6.5
P2-D	1 g and 500 kg	7

5.3 Comparison of Cracks Pattern Occurring During Testing

Figs. 17 and 18 show the crack pattern on the B1 specimen tested until it is severely damaged. The figure shows that the cracks occurred at an earthquake load of 0.6 g with an additional evenly distributed load of 200 kg. The acceleration reading obtained using G-Trace shown in Fig.19 indicates that the maximum acceleration (a_{max}) of the B1 specimen when the cracks occur is 2.5 g at t = 2.5 seconds.

After retrofitting the B1 specimen, the test was proceeded until the input motion of 1g and an additional uniform load of 500 kg. For this test, neither the reinforced B1 specimen nor the B2 specimen experienced cracks, as shown in Fig.20. In the PS-B test, both specimens (B1 and B2) almost had similar acceleration response behavior. The a_{max} of the B1 and B2 specimens at this test were 2.52 g and 1.27 g, respectively, as shown in Fig.21. The test was carried out for 30 seconds, but there was no damage to both specimens, although the acceleration of the shaking that occurred in both specimens was considerably high.

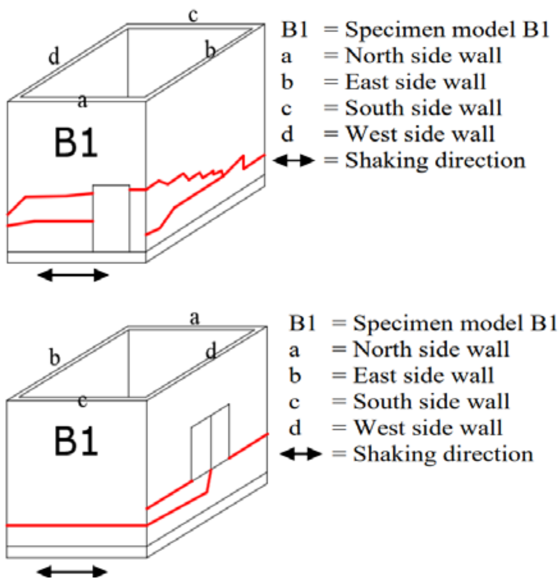

Fig.17 Schematic drawing of crack specimens at different sides of specimen walls

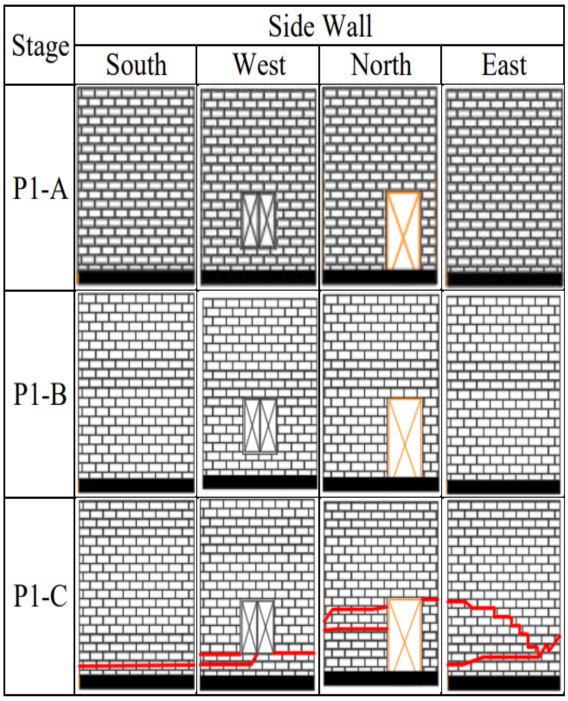

Fig.18 Schematic illustration of crack patterns on B1 specimen until it is severely damaged

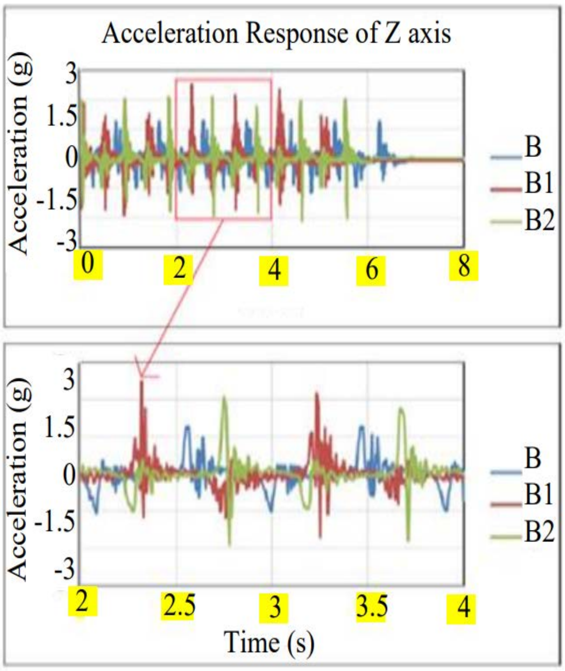

Fig.19 Acceleration response for B1 and B2 specimens with input motion 0.6 g and an additional uniform load of 200 kg on the shaking table test

Based on Figs.20 and 21, it is seen that the retrofitted building using a ferrocement layer with the bandage system can withstand a high acceleration of the given earthquake load on the house specimens without any damage.

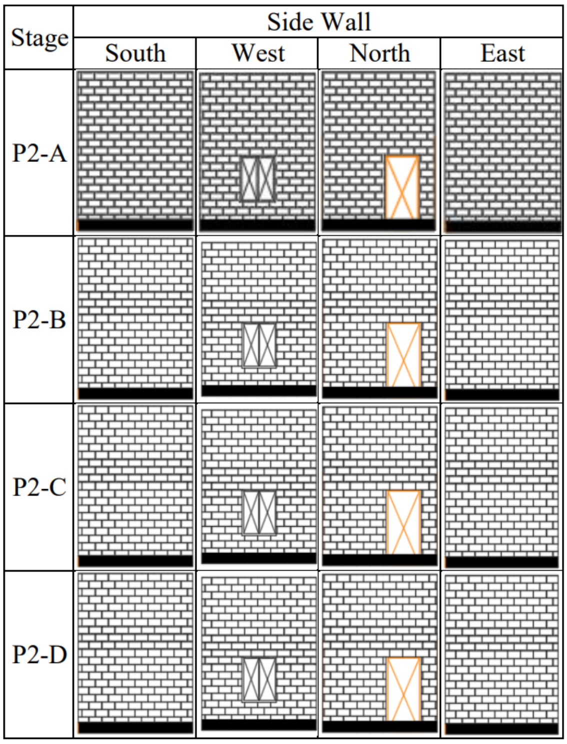

Fig.20 Schematic illustration of crack patterns of the retrofitted B1 specimen until the end of the test

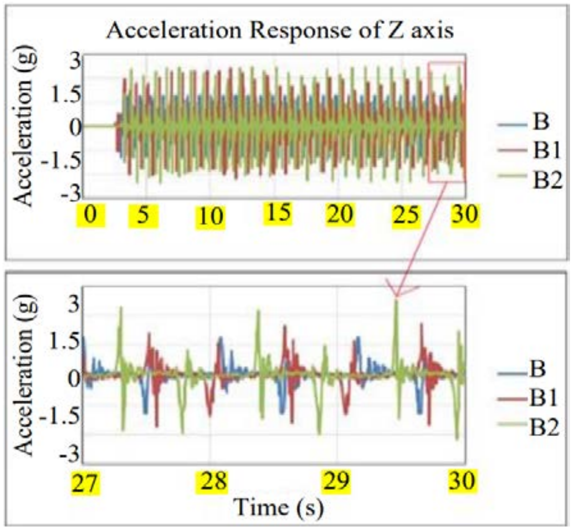

Fig.21 Acceleration response for the B1 and B2 specimens with an earthquake load of 1g and an additional load of 500 kg on the shaking table test

6. CONCLUSION

Based on the experimental results carried out on retrofitting the damaged hollow brick houses using a ferrocement layer, the following conclusions can be drawn:

1. B1 Specimen suffered heavy damage at the input motion of 0.6 g and an additional evenly distributed load of 200 kg because the damage

occurred on all sides of the hollow brick walls of the specimen.

2. No damage or cracking was observed in both specimens until the input motion of 1g and an additional uniform load of 500 kg when the testing was conducted after retrofitting the B1 specimen.
3. The maximum acceleration (a_{max}) of the B1 specimen when the cracks occurred was 2.5 g at t = 2.5 seconds, while the a_{max} of the retrofitted B1 specimen at the end of the test was 2.52 g without any crack appearing on the specimen.
4. The results of this study prove that the ferrocement layer with a bandage system significantly increases the seismic behavior of hollow brick houses. Therefore, this method is possible to be applied for retrofitting the damaged hollow brick houses after an earthquake.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] Gumilang A. A., and Rusli M., Seismic Performance of earthquake resistant simple residential confined masonry house structure based on permen PUPR No. 5 of 2016 specification, IOP Conf. Series: Earth and Environmental Science Vol. 708, No. 012085, 2021, pp.1-13.

[2] Boen T., Imai H., Lenny, and Suryanto S. E., Earthquake Resistant Non-Engineered Construction in Developing Countries Utilizing Appropriate Technology, European Journal of Adv. in Eng. and Tech., Vol. 7, No. 8, 2020, pp.49-63.

[3] CNN Indonesia, 8 Died as a Result of the West Pasaman Earthquake, 103 Houses Heavily Damaged, Retrieved from: https://www.cnnindonesia.com/nasional/20220226122239-20-764392/8-meninggal-akibat-gempa-pasaman-barat-103-rumah-rusak-berat. [Access sed December 09, 2022].

[4] Sandeep K., Ferrocement Material for Construction, International Journal of Engineering Research and Applications, Vol. 8, No. 3, 2018, pp.53-55.

[5] Al-Rifaie W.N., and Mohammad K., Load Carrying Capacity of Clay Brick Masonry Wall Encased by Ferrocement, International Journal of Emerging Engineering Research and Technology, Vol. 5, No. 4, 2017, pp.26-35.

[6] Fauzan, Ismail F.A., Hakam A., Zaidir, and Amalia S.H., Experimental Study on Masonry Building Strengthened with Ferrocement Layers, International Journal of GEOMATE, Vol. 14, Issue 45, 2018, pp.84-90.

[7] Joyklad, P., Waqas, H. A., Hafeez, A., Ali, N., Ejaz, A., Hussain, Q., and Saingam, P., Experimental Investigations of Cement Clay Interlocking Brick Masonry Structures Strengthened with CFRP and Cement-Sand Mortar, Infrastructures, Vol. 8, Issue 3, No. 59, 2023, pp. 1-15.

[8] Suparp, S., Ejaz, A., Khan, K., Hussain, Q., Joyklad, P., and Saingam, P., Load-Bearing Performance of Non-Prismatic RC Beams Wrapped with Carbon FRP Composites, Sensors, Vol. 23, Issue 12, No. 5409, 2023, pp. 1-22.

[9] Rodsin, K., Ejaz, A., Hussain, Q., & Parichatprecha, R., Experimental and Analytical Studies on Low-Cost Glass-Fiber-Reinforced-Polymer Composite-Strengthened Reinforced Concrete Beams: A Comparison with Carbon/Sisal Fiber-Reinforced Polymers, Polymers, Vol. 15, Issue 19, No. 4027, 2023, pp. 1-28.

[10] Suparp, S., Khan, I., Ejaz, A., Khan, K., Weesakul, U., Hussain, Q., and Saingam, P., Behavior of non-prismatic RC beams with conventional steel and green GFRP rebars for sustainable infrastructure, Scientific Reports, Vol. 13, Issue 1, No. 15733, 2023, pp. 1-25.

[11] Imai H., A Study of Disaster Mitigation for Non-Engineered Construction in Developing Countries: Bridging the Gap between Experiment and Practice, Doctoral Dissertation in Mie University, Japan, 2014, pp.1-3.

[12] Meguro K., Sorimachi N., and Numada M., Development of Promotion Systems for PP-Band Retrofitting of Non-Engineered Masonry Houses, in Proc. 15th World Conf. on Earthquake Engineering (15WCEE), No. 2188, 2012, pp.1-9.

[13] ASTM International, Standard Test Method for Compressive Strength of Masonry Prisms (ASTM C1314-21), ASTM International, United States, 2021, pp.1-10.

[14] National Standardization Agency, Earthquake Resistance Planning Procedures for Building Structure and Non-Building Structure (SNI 1726:2019), BSN, Jakarta, 2019, pp.1-238.

[15] Hakam A., Ismail F. A., and Fauzan, Liquefaction Potential Assessment Based on Laboratory Test, International Journal of GEOMATE, Vol. 11, Issue 26, 2016, pp.2553-2557.