



EXPERIMENTAL STUDY ON RETROFITTING OF URM HOUSES USING FERROCEMENT LAYERS WITH A BANDAGE SYSTEM

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ABSTRACT: The 2022 West Pasaman earthquake in Indonesia caused significant damage, particularly to Unreinforced Masonry (URM) houses. Generally, most URM houses in West Pasaman are constructed without essential structural components, such as columns and beams. Consequently, these houses lack resilience against earthquake loads due to the absence of proper load distribution from the roof to the base of the building. To prevent severe damage to URM houses during future earthquakes, an experimental study was conducted on retrofitting damaged URM houses. The proposed retrofitting method involves applying ferrocement layers with a bandage system. This study aims to investigate the seismic performance of URM houses reinforced with these ferrocement layers. The specimen was built at a 1:4 scale of the original house in West Pasaman. The experimental work was carried out in two phases: the first test was conducted on the Original House (OH) specimen, which was subsequently repaired and retrofitted with ferrocement layers. The second test was then conducted on the Retrofitted House (RH) specimen. The model specimen underwent shaking table tests under varying earthquake accelerations (input motions) of 0.3 g, 0.6 g, 1.0 g, and 1.5 g. The results showed that Specimen RH successfully withstood the earthquake loads. Incorporating woven wire within the plaster mortar layer markedly enhanced the seismic resistance of the URM house due to the ductile properties of the woven wire, which prevented the house from collapsing even at an earthquake acceleration of 1.5 g.

Keywords: Earthquake, URM House, Retrofit, Ferrocement Layers, Shaking Table Test

1. INTRODUCTION

Indonesia is a country located among the world's three active tectonic plates, namely the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. This geographical location renders Indonesia prone to major disasters, especially geological hazards [1–3]. Earthquakes are frequent natural phenomena in Indonesia due to the country's tectonic setting. A series of earthquakes has hit several regions in Indonesia, such as West Sumatra in 2009 [4], Central Sulawesi in 2018, West Pasaman and West Java in 2022, and East Java in 2024.

The magnitude 6.2 earthquake and its aftershocks that occurred on February 25, 2022, in West Pasaman Regency, West Sumatra, Indonesia, caused significant losses, including casualties and extensive infrastructure damage, particularly to unreinforced masonry (URM) houses [5]. As shown in Fig. 1, the area closest to the epicenter was Jorong Timbo Abu, Nagari Kajai, Talamau District, West Pasaman Regency, West Sumatra. In this area, widespread structural damage occurred to residential buildings.

Generally, URM houses in West Pasaman are constructed using half-brick ($\frac{1}{2}$ -brick) masonry walls

with a thickness of approximately 10 cm, as shown in Fig. 2. These structures lack sufficient seismic resistance because they do not incorporate structural elements, such as beams and columns, and their wall thickness does not meet the minimum standard of 20 cm [6–10]. To prevent sudden collapse or severe damage to URM houses during earthquakes, it is essential to conduct experimental research on strengthening post-earthquake damaged URM houses [11–13].

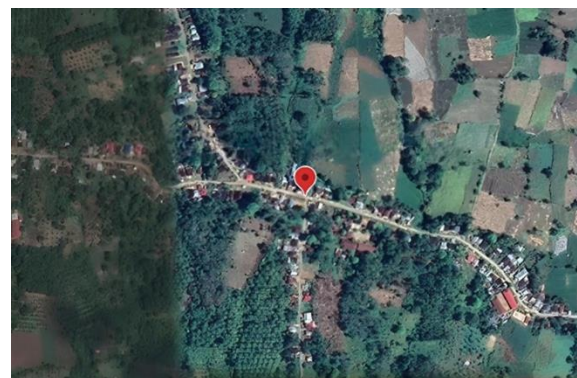


Fig.1 Areas Closest to the Epicenter of the 2022 West Pasaman Earthquake



Fig.2 URM hollow brick community house in West Pasaman

One alternative retrofitting method for URM houses involves applying ferrocement layers with a bandage system [14]. This study aims to experimentally evaluate a scaled model of a typical simple hollow brick house in West Pasaman, subsequently retrofit it with ferrocement layers, and subject it to shaking table tests to observe the building's structural behavior under dynamic earthquake loading.

2. RESEARCH SIGNIFICANCE

In this study, an experimental investigation was conducted on a residential house with hollow brick walls retrofitted with ferrocement layers. This strengthening method was applied to enhance the structural integrity of a simple brick block house lacking plaster and traditional reinforcement, as well as to serve as a construction alternative for new houses built without conventional structural elements like columns and beams. The findings of this study are significant as they provide a valuable reference and guidelines for constructing or retrofitting earthquake-resistant houses in seismic-prone regions, addressing both disaster mitigation and post-earthquake reconstruction efforts.

3. EXPERIMENTAL WORK

3.1 Specimen Characteristics

In this experimental study, the prototype house model represents a simple hollow brick house whose floor plan, layout, and dimensions were derived from a representative building surveyed in the earthquake-affected region of Nagari Kajai, Talamau District, West Pasaman Regency. The reference house measures 600 cm x 600 cm x 400 cm, consisting of two bedrooms measuring 300 cm x 300 cm and a living room measuring 600 cm x 300 cm. The scaled specimen was constructed at a 1:4 scale

relative to this prototype. Consequently, the dimensions of the scaled specimen plan were 150 cm x 150 cm x 100 cm, with the bedrooms partitioned at 75 cm x 75 cm and the living room at 150 cm x 75 cm, as shown in Fig. 3.

The experimental work was carried out in two phases. The first test was conducted on the unreinforced specimen, designated as the "Original House" (OH) specimen (Fig. 4), which was subsequently repaired and retrofitted with ferrocement layers. The second phase of testing was then conducted on the retrofitted structure, designated as the "Retrofitted House" (RH) specimen, as shown in Fig. 5.

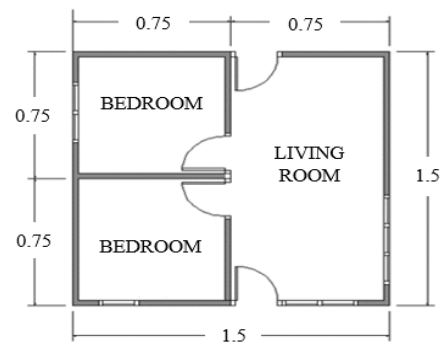


Fig.3 Plan view of the specimen

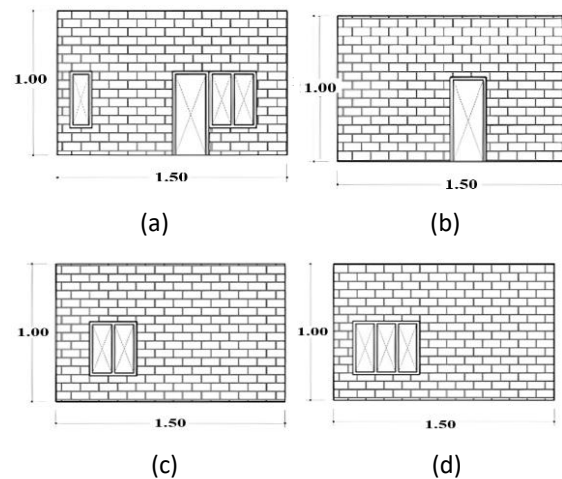


Fig.4 Elevation view of specimen OH; a) Front view, b) Back view, c) Left side view, and d) Right side view

The detailed drawings of the specimen walls, featuring a mortar layer thickness of 0.5 cm, are presented below. Fig. 6(a) shows the wall details of Specimen OH, while Fig. 6(b) illustrates the wall details of Specimen RH, which include woven wire installed at the wall corners. Following the installation of the woven wire, the plaster layer was applied to the retrofitted area. The plaster mortar was prepared with a cement-to-sand ratio of 1:4.

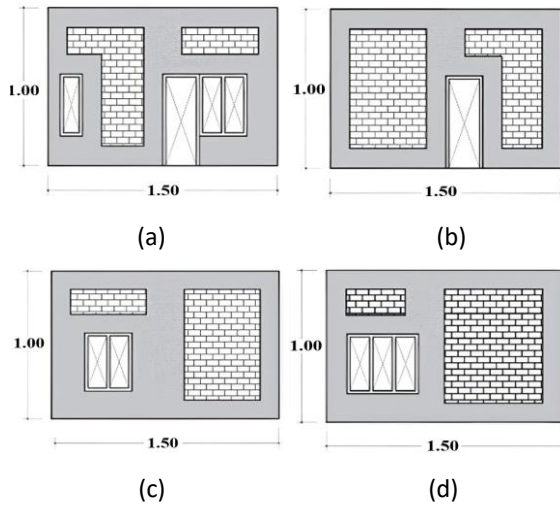


Fig.5 Elevation view of the specimen RH; a) Front view, b) Back view, c) Left side view, and d) Right side view

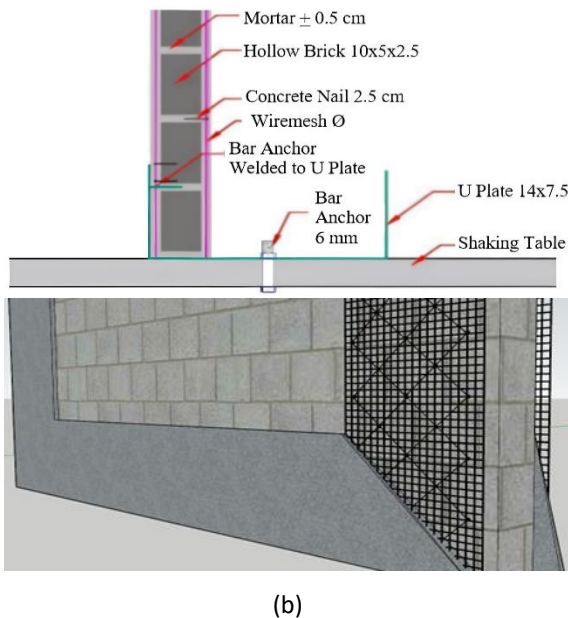
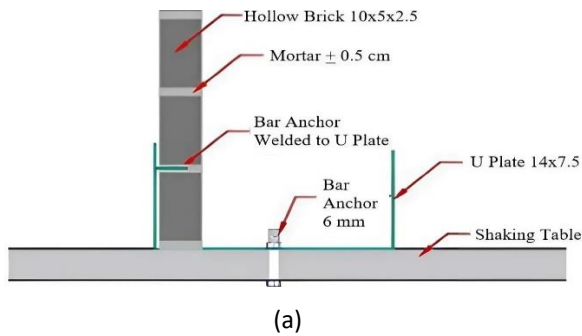


Fig.6 Wall details of the specimens: a) OH and b) RH

The process of making Specimen OH begins with the installation of the model house foundation as a model of sample house stands on a vibrating table made of a U plate with a thickness of 2 mm and its

shape that has been adjusted to the dimensions of the Specimen OH, as shown in Fig. 7. The U-plate will be anchored to the concrete plate of the vibrating table with a slope of 16° along the x-axis as seen in Fig. 8.

After the U plate is attached, the bricks will be arranged on the U plate with a specimen thickness of 0.5 cm. The process of installing a brick wall of the Specimen OH, as shown in Fig. 9. The roof frame was made of wood as the truss, while the roof covering used a zinc roof with a thickness of 0.25 mm. The process of making the roof frame of the model house is shown in Fig. 10.

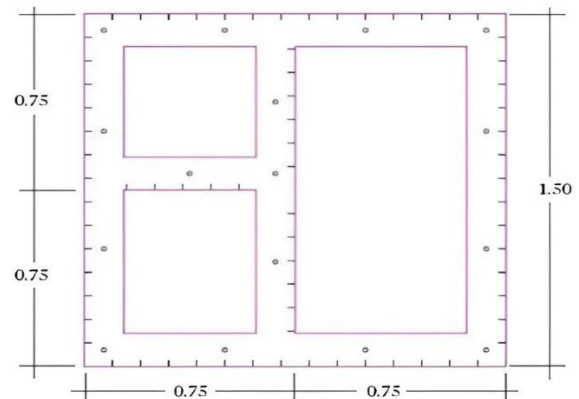


Fig.7 U-plate used as a specimen foundation for the shaking table test



Fig.8 Installation of the U-plate on the shaking table



Fig.9 Construction of the brick wall for Specimen OH



Fig.10 Fabrication of the roof frame and installation of the roof on the specimen

3.2 Loading Method

Table 1 Weight of the specimen OH

Material	Weight (kg)
Hollow brick	157
Mortar	246
Weight of the roof frame and the roof	68
Total weight of the model house	471

Table 2 Weight of the original house in West Pasaman

Material	Weight (kg)
Hollow brick	10606
Mortar	4172
Weight of the roof frame and the roof	718
Total weight of the original house	15496
qa: Dead load weight of the original house	430 kg/m ²

Loading was determined by scaling the weight of the original house to Specimen OH based on the area scale [15-18]. Specimen OH weighs 471 kg, as shown in Table 1. The full-scale original house in West Pasaman weighs 15,496 kg ($q_a = 430 \text{ kg/m}^2$), as presented in Table 2. Therefore, an additional load is required based on the weight scale of the model house, which is calculated using Eq. (1):

$$L_s \times q_a = q_s \quad (1)$$

Where, L_s : area of original house (m^2), q_a : dead load weight of the original house (kg/m^2), q_s : weight scale of Specimen OH (kg). so,

$$2.25 \text{ m}^2 \times 430 \text{ kg/m}^2 = 968 \text{ kg}$$

Therefore, an additional load of 500 kg was applied to Specimen OH. This value corresponds to the weight difference calculated from the area and weight scales of the original house. This additional load was applied using sandbags placed on top of the specimen.

3.3 Test Setup and Instrumentation

The G-Trace tools used to record earthquake acceleration values were installed at three points. First, a sensor labeled 'BASE' was placed on the shaking table platform to record the input acceleration. Second, a sensor labeled 'FRONT' was positioned on the front wall of the specimen. Third, a sensor labeled 'BACK' was attached to the rear wall. The FRONT and BACK sensors recorded the response acceleration of the specimen, as shown in Fig. 11. These three devices were connected to a computer.



Fig.11 G-Trace tool sensor locations

3.4 Test Procedures

Testing on the specimen was carried out in two phases. In the first phase, Specimen OH was tested on the shaking table by applying earthquake acceleration loads (input motions) of 0.3g and 0.6g, with a duration of 15 seconds for each load level, until failure occurred. Then, after Specimen OH was repaired and retrofitted using ferrocement layers with a bandage system, the retrofitted specimen (Specimen RH) was tested on the shaking table under sequential acceleration loads of 0.3g, 0.6g, and 1.0g for 15 seconds each, followed by 1.5g for 10 seconds.

4. RESULTS AND DISCUSSION

4.1 Testing of Specimen OH until Heavy Damage (0.3 g and 0.6 g)

Observation of Specimen OH revealed that no damage occurred during the 0.3g earthquake acceleration, as shown in Fig. 12. However, at an acceleration of 0.6g, the specimen experienced wall cracking and partial wall collapse, as shown in Fig. 13.

The earthquake acceleration responses of Specimen OH under 0.3g and 0.6g loads for 15 seconds are shown in Figs. 14 and 15. In these response graphs, the blue line represents the acceleration recorded by the shaking table instrument (BASE), the orange line represents the acceleration on the front wall (FRONT), and the green line represents the acceleration on the rear wall (BACK).



Fig.12 Specimen OH after testing under a 0.3g input motion



Fig.13 Specimen OH after testing under a 0.6g input motion

The maximum acceleration recorded under the application of a 0.3g earthquake load was 0.98g at the BASE, 1.64g at the FRONT, and 1.30g at the BACK.

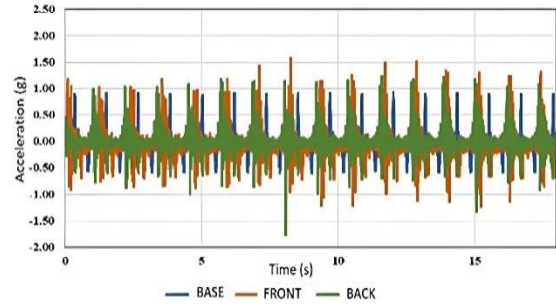


Fig.14 Acceleration response graph of Specimen OH under a 0.3g earthquake load (input motion)

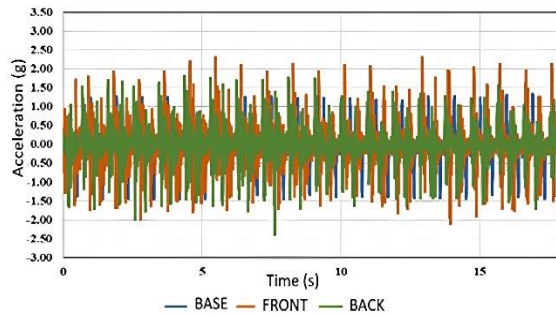


Fig.15 Acceleration response graph of Specimen OH under a 0.6g earthquake load (input motion)

When the applied earthquake acceleration was raised to 0.6g, the maximum acceleration values increased to 0.6g, the maximum acceleration values increased to 1.32g at the BASE, 2.22g at the FRONT, and 1.72g at the BACK. The crack patterns on the specimen under the 0.6g earthquake acceleration are illustrated in Fig. 16.

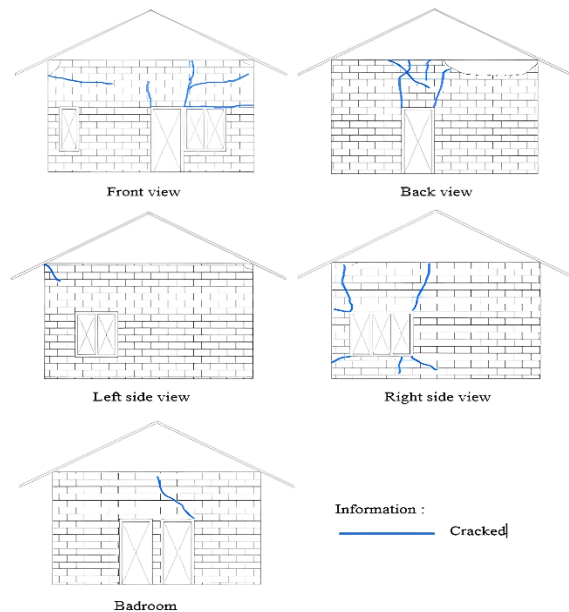


Fig.16 Schematic illustration of the crack pattern on Specimen OH under a 0.6g earthquake load

4.2 Repair and Retrofitting of Specimen

The damage to Specimen OH resulting from the first test was repaired and retrofitted using ferrocement layers with a bandage system, and this retrofitted structure was subsequently designated as Specimen RH. The procedure for repairing and retrofitting the specimen included patching the cracked sections (a), installing bricks (b), installing woven wire mesh (c), and applying plaster over the retrofitting area (d), as shown in Fig. 17.

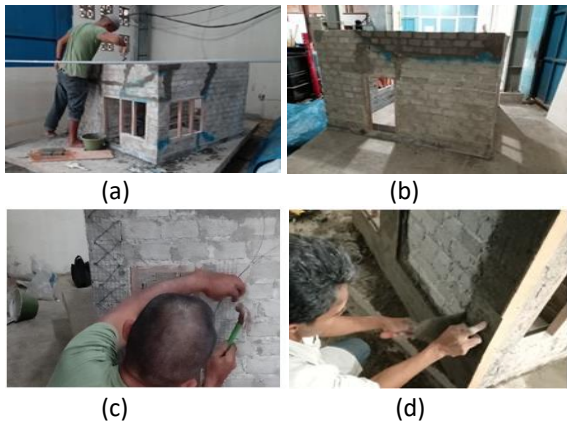


Fig.17 Repair and retrofitting process: a) patching cracked sections; b) installing bricks; c) installing woven wire mesh; d) plastering the retrofitted area



Fig.18 Specimen RH after completion of repair and retrofitting using the ferrocement layers method

After the specimen was repaired and retrofitted using the ferrocement layers method, it was subjected to a second shaking table test following the same procedure as the previous test. The final condition of Specimen RH, fully prepared for the second test, is shown in Fig. 18.

4.3 Testing Specimen OH (After Repair and Retrofitting)

Observation of Specimen RH revealed no damage after 15 seconds of testing under earthquake accelerations of 0.3g, 0.6g, and 1.0g, as well as after 10 seconds under a 1.5g acceleration, as shown in Figs. 19-22.



Fig.19 Specimen RH after testing under a 0.3g input



Fig.20 Specimen RH after testing under a 0.6g input motion

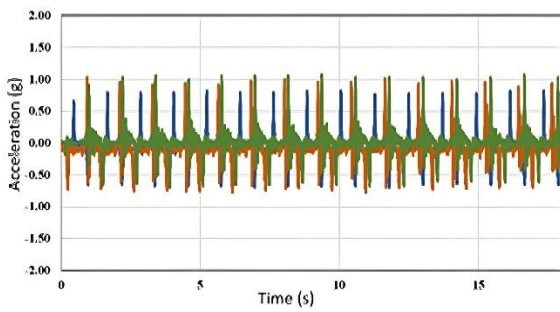
Fig. 23 shows the earthquake acceleration response graphs for the 0.3g, 0.6g, and 1.0g inputs (15-second duration) and the 1.5g input (10-second duration) from the shaking table testing of Specimen RH. As shown in the figure, under the 0.3g earthquake load, the maximum acceleration reached 0.92g at the BASE, 1.12g at the FRONT, and 1.06g at the BACK.



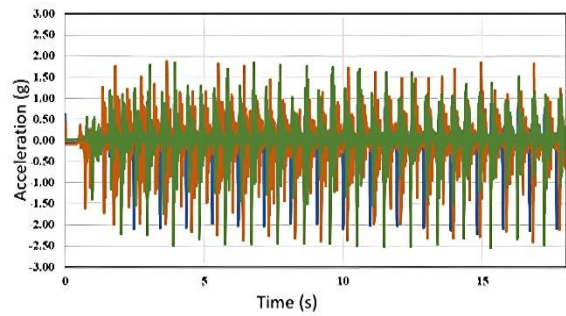
Fig.21 Specimen RH after testing under a 1.0g input motion



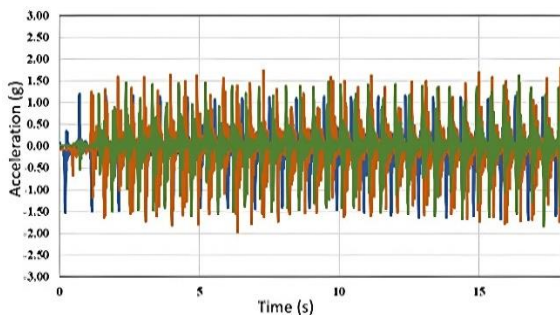
Fig.22 Specimen RH after testing under a 1.5g input motion



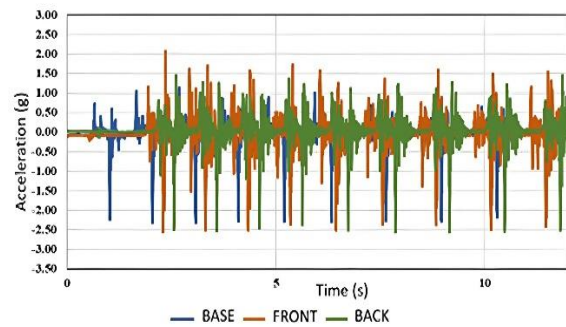
(a)



(c)



(b)



(d)

Fig.23 Acceleration response graphs of Specimen RH under earthquake loads of: a) 0.3g; b) 0.6g; c) 1.0g; and d) 1.5g

The maximum acceleration for the 0.6g load was 1.26g at the BASE, 1.88g at the FRONT, and 1.60g at the BACK. Under the 1.0g load, the maximum acceleration was 0.64g at the BASE, 1.66g at the FRONT, and 1.90g at the BACK. Finally, under the 1.5g load, the maximum acceleration reached 0.84g at the BASE, 1.86g at the FRONT, and 1.52g at the BACK.

5. CONCLUSION

Based on this study, it can be concluded that Specimen OH remained undamaged under an earthquake load of 0.3g but sustained damage to its walls at an acceleration of 0.6g. The cracks primarily occurred near the wall openings (doors and windows).

In contrast, Specimen RH, which was retrofitted using ferrocement layers with a bandage system, exhibited no damage under earthquake acceleration loads (input motions) of 0.3g, 0.6g, 1.0g, and 1.5g. This indicates that the ferrocement layers retrofitting method with a bandage system significantly enhances the structural integrity of URM houses, preventing collapse even under extreme earthquake conditions of up to a 1.5g acceleration.

6. ACKNOWLEDGEMENTS

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