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GRADUAL STRENGTHENING OF EXISTING MASONRY HOUSES WITH FERROCEMENT BANDAGING IN INDONESIA FOR EDUCATING THE COMMON PEOPLE TO BE SELF-RELIANT AND SELF-SUPPORTING

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ABSTRAK

There are approximately 85 million people's houses scattered all over Indonesia and almost all are in strong earthquake area. Every time there is an earthquake, people's houses are damaged or collapse. Therefore, it is urgent that those houses be strengthened to make them earthquake resistant. This paper discusses a gradual strengthening of existing houses using ferrocement bandaging. The gradual strengthening is introduced due to limited funding of the people. It also serves as an educational tool to educate people to be self-reliant and self-sufficient in building their earthquake resistant houses. The first time, maybe the sleeping room shall be strengthened so that if there is an earthquake during night-time, people will be safe and if there is an earthquake during daytime, people can immediately run to that particular room. A global analysis is made of West Sumatra earthquake 2009, with one room strengthened to show that the strengthened room can survive the earthquakes. Then the analysis is continued gradually to the other rooms until the masonry house is fully strengthened by ferrocement bandaging.

Kata kunci : Gradual strengthening, Existing house, Ferrocement bandaging

1. INTRODUCTION

On the average, every two years, there is a strong earthquake in Indonesia and every time most of the people's houses were damaged or collapse, causing the loss of property and human life. From past earthquakes, it is evident that the damage and or collapse of people's houses were caused by the unavailability of standard building materials and poor workmanship. Among others, poor quality mortar, poor quality mix, and poor-quality detailing of reinforcing bars (Buana, 2012). The majority of the existing people's houses are of poor quality (see **Figure. 1** to **Figure. 4**) and the most sensible measure to take is to strengthen all those existing people's houses using a simple and economical method that

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can be done by local masons. So far, people's houses damaged by earthquakes are dependent on government funding for the repair of their buildings. Therefore, people must be educated to be self-reliant and self-supporting in building earthquake resistant houses (Boen, 2004a), (Boen, 2004c), (Boen, 2004b) (Boen, 2008), (Boen, 2018), (Boen, 2014). People should be encouraged to be independent and not dependent on the government. However, it is the government's obligation to provide technical assistance. Technical assistance must be carried out comprehensively at all levels of society to increase understanding of earthquake disaster, and the steps that must be taken so that people can be independent in building earthquake resistant houses to prevent casualties in the future. A multi-sectoral approach is needed to make a vulnerability reduction program effective. Training must be action oriented, and demand driven and should focus on vulnerability reduction (Teddy Boen, Juniawan Priyono, 2004).

Reconstruction of masonry houses after the earthquake so far has not been running well. Many permanent houses promised by the government were not fulfilled and even 3-4 years after the disaster so that the problem became unclear. With self-reliant and self-supporting, assisted by NGOs with proven reputations and clear accountability, people can quickly recover to build earthquake resistant houses. Therefore, the problem becomes clear, resolved, and not protracted.

Since several years ago, a strengthening method using ferrocement bandaging was introduced and already practiced in several places in Indonesia (Teddy Boen, Hiroshi Imai, Lenny, 2014). The most simple and affordable strengthening method is bandaging with ferrocement layers. Beside ferrocement layers, if available, Fiber Reinforced Cementitious (FRC) layers or Textile Fiber Composite (TRC) can be used (Teddy Boen, Hiroshi Imai, Lenny, Sarah E. Suryanto, 2021). The method is simple and does not need demolition or reconstruction. Because of financial problem, people are reluctant to build earthquake resistant houses. In their opinion, it is too costly, therefore this paper proposes gradual strengthening to make the funding of earthquake resistant houses affordable, namely, to strengthen one room at a time so that in case of an earthquake that can occur any time, especially at night-time, people can stay in that room and be safe from collapsed walls. For the purpose, the authors perform structural dynamic analysis of a simple masonry house with gradual strengthening started from stage 1 (one room strengthened by ferrocement bandaging). Then strengthening is continued to stage 2 and stage 3. Gradual strengthening does not mean that retrofitting can be delayed for years, but rather that reinforcement must be carried out as soon as possible to prevent collapse due to an upcoming earthquake. It is preferable that 3 stages be finished within one year, meaning the masonry house is fully strengthened by ferrocement bandaging (see **Figure. 5**).

Figure. 1 Examples of poorly built houses from the West Sulawesi Earthquake in January 15, 2021

Figure. 2 Examples of poorly built houses from the Palu (Central Sulawesi) Earthquake in September 28, 2018

Figure. 3 Examples of poorly built houses from the Selat Sunda Earthquake and Tsunami in December 22, 2018

Figure. 4 Examples of poorly built houses from the Lombok Earthquake in July 29, 2018

2. RESEARCH METHODOLOGY

2.1. Structural model

The analysis model of sample house bandaged by ferrocement layers follow the same method as indicated in reference (Teddy Boen, Hiroshi Imai, Febrin Ismail, Toshikazu Hanazato, and Lenny, 2014). The gradual strengthening analysis is started from the first stage, one bedroom. Then it is continued to the next bedroom for the second stage and subsequently completed for the last stage which is bandaging the entire masonry house as can be seen in **Figure. 5.**

The modelling of an existing masonry house is using practical columns and beams with poor quality as is the reality found in actual practice. Practical columns and beams do not need to be dismantled. Just restored and directly bandage with ferrocement layers. **Figure. 6** shows the model of sample masonry house for the analysis and **Figure. 7** depicts the installation sketch of ferrocement layers.

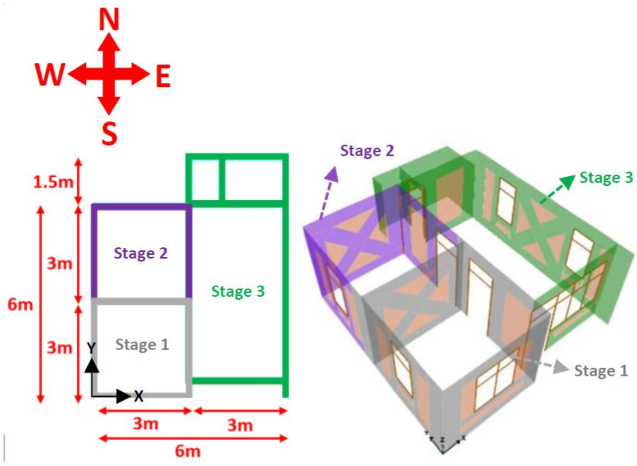
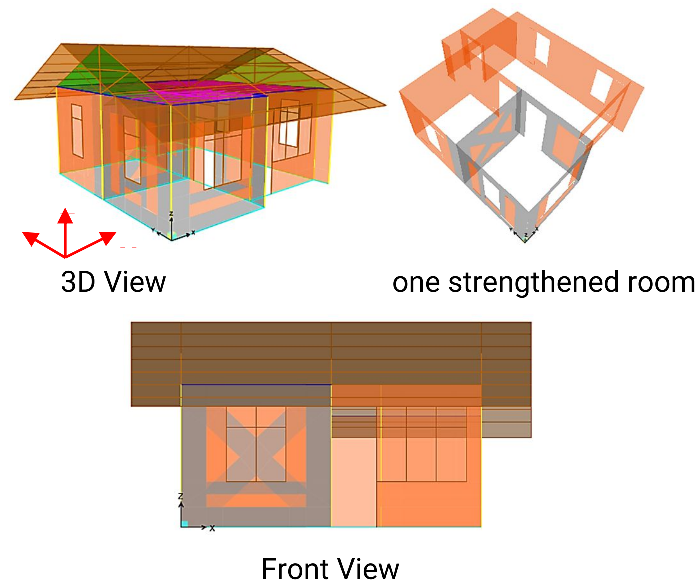
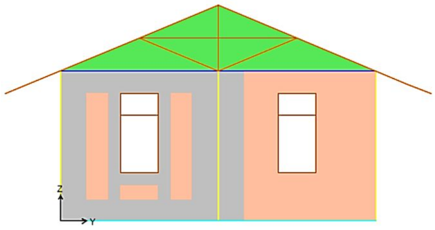
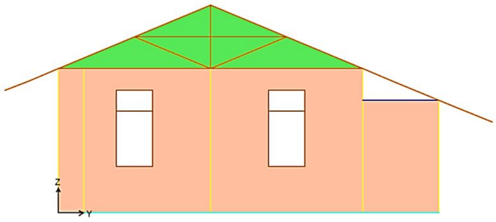


Figure. 5 Sample layout of gradual strengthening masonry house





Left View



Right View

Figure. 6 Model of sample house with one strengthened room

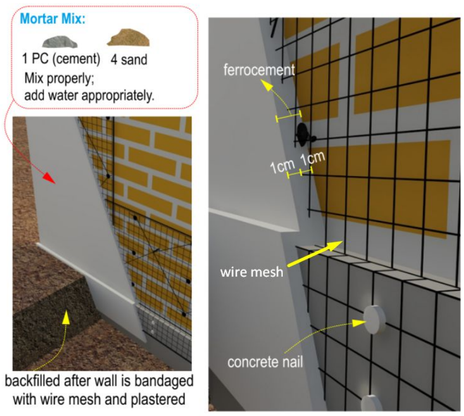


Figure. 7 Sketch of ferrocement layer installation (Boen, Constructing Earthquake Resistant Masonry Houses - Bandaged using Ferrocement Layers, 2015)

2.2. material properties

Material properties of masonry wall used for the analysis are taken from reference of previous shaking table test in Tsukuba, 2014 (Teddy Boen, Hiroshi Imai, Lenny, 2014). The modulus elasticity of masonry wall is 5,885kgf/cm^2 with adhesion tensile strength of mortar (1pc:6sand) used for the masonry wall is 3.5kgf/cm^2 as cited in the reference. The compressive strength of mortar (1pc:4sand) for ferrocement layer is 275.8kgf/cm^2, and the modulus elasticity is 211,950kgf/cm^2 as mentioned in the reference. For practical columns and beams, the compressive strength of concrete used in the analysis is K-150 (150 kgf/cm^2). According to SNI 7973-2013, wooden for window frames, door frames, truss, and purlins used are second grade wood that has 740kgf/m^3 density and 112,168 kgf/cm^2 modulus of elasticity (E11), (Standar Nasional Indonesia (SNI) 7973-2013, 2013).

2.3. input motion

The earthquake records used in the analysis are the September 28, 2018 Palu (Central Sulawesi) earthquake (0.33g), and the September 30, 2009 Padang (West Sumatra) earthquake (0.3g) (Prof. Dr. Ir. Masyhur Irsyam, M.S.E. and Andhika Sahadewa, S.T., M.S.E., Ph.D., 2018; Rusnardi, 2009). The Palu earthquake record represent a single pulse type earthquake dominant in U-D direction (see **Figure. 8**). Meanwhile, the Padang earthquake record represent a multiple pulse type earthquake dominant in N-S direction (see **Figure. 9**). The analysis of the model for both earthquake records is conducted by running earthquake loads in 3 directions simultaneously, namely the X, Y, and Z directions of the building as can be seen in **Figure. 6**. The X direction of the building is given an E-W direction of earthquake load, the Y direction of the building is given an N-S direction of earthquake load, and the Z direction of the building is given a U-D direction of earthquake load.

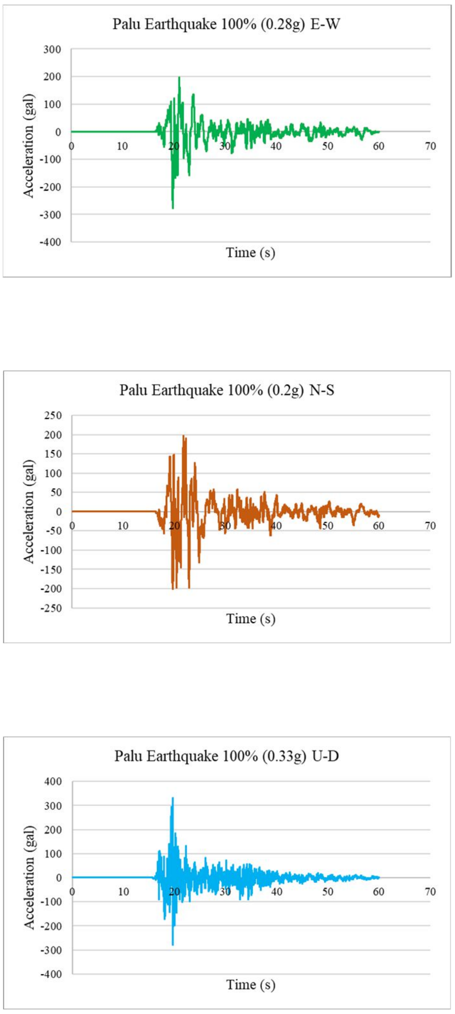


Figure. 8 Palu (Central Sulawesi) earthquake records (Masyhur Irsyam, 2015)

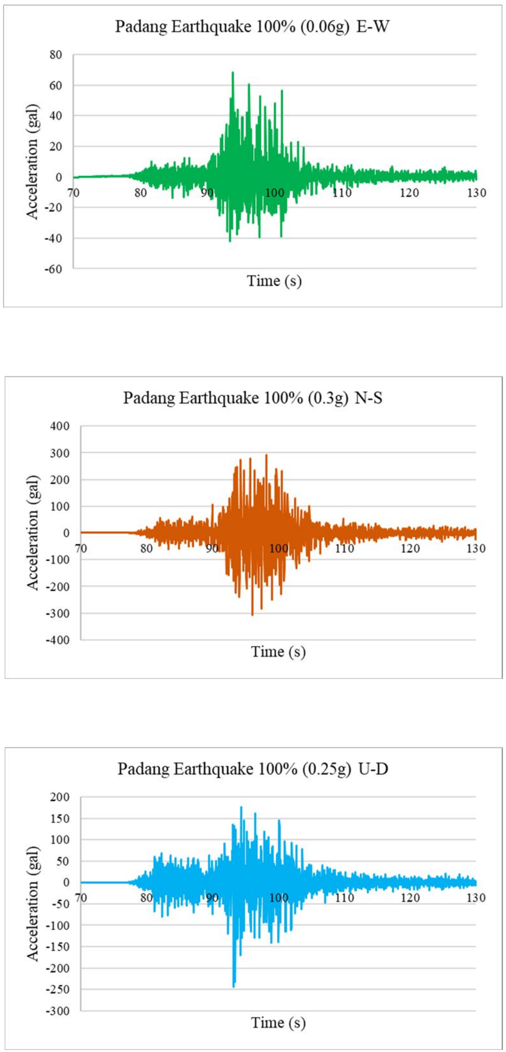


Figure. 9 Padang (West Sumatra) earthquake records (Rusnardi, 2009)

3. RESULTS

The results of gradual strengthening analysis started from stage 1 to stage 3 show that there is a significant impact in the strength of masonry houses when bandaged using ferrocement layers. Below are the graphs as summary of the maximum tensile stress resulted from the Palu and Padang earthquake shaking (see **Figure. 10** until **Figure. 12**). The result of each stage is elaborated deeply in part 5.1. until 5.4.

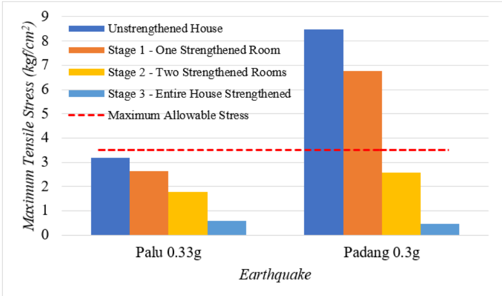


Figure. 10 Maximum tensile stress of masonry wall

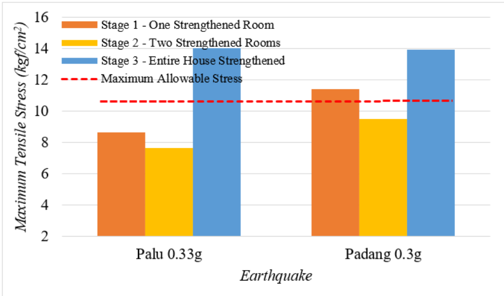


Figure. 11 Maximum tensile stress of outer ferrocement layers

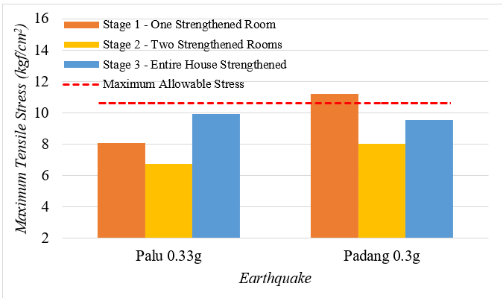


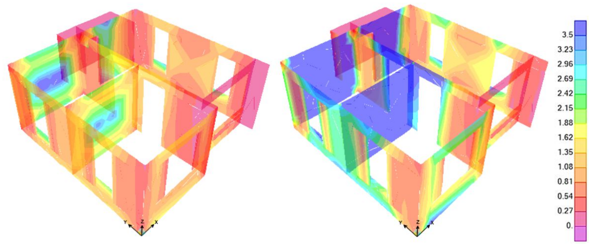
Figure. 12 Maximum tensile stress of inner ferrocement layers

3.1. Analysis Results of Unstrengthened House

a. The results of the analysis of unreinforced masonry house when shaken by Palu and Padang earthquakes provide a significant difference due to the characteristics of the Padang earthquake which is a multiple pulse type, while Palu earthquake is a single pulse type. It proves that the masonry walls were quite strong when shaken by Palu earthquake, while when they were shaken by Padang earthquake, most of the wall tensile stress had exceeded the allowable stress limit (3.5kgf/cm^2) as indicated in blue color. As can be seen in **Figure. 10**, the tensile stress that occurs in the walls reaches 8.48kgf/cm^2. It could be said that the walls were heavily damaged and might even collapse.

b. The damaged walls indicated in blue color is the result of the large out-of-plane load caused by the N-S direction earthquake. Since Padang earthquake records in N-S direction is larger than E-W direction (see **Figure. 9**), the damaged masonry walls in **Figure. 13** are perpendicular in N-S direction.

c. Based on the above finding, it is suggested strengthening of masonry houses should be prioritized and implemented immediately.



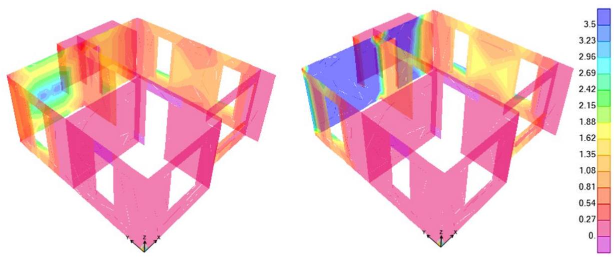
(a) (b)

Figure. 13 Maximum tensile stress pattern of masonry wall (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)

3.2. Analysis Results of Stage 1 – one strengthened room

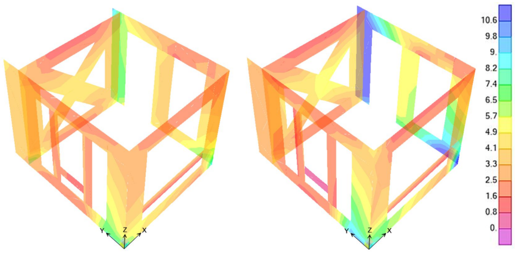
From the analysis, when shaken by Palu earthquake, the tensile stress at a small part of the unstrengthened masonry wall (**Figure. 14**) exceed the allowable stress limit (3.5kgf/cm^2), whereas for strengthened masonry wall, the tensile stress occurred is very small. The unstrengthened masonry wall when shaken by Padang earthquake suffered severe damage, which was marked by blue color in some parts. From **Figure. 10**, the maximum stress at the masonry wall that occurs is 6.77kgf/cm^2.

For one room strengthened by ferrocement layers, when shaken by Padang earthquake, the tensile stress in the ferrocement layers are slightly exceed the allowable stress (the maximum stress that occurred was 11.4kgf/cm^2 as can be seen in **Figure. 11** and **Figure. 12**). This indicates that the ferrocement layers may experience a slight crack but not collapse (see **Figure. 15** and **Figure. 16**).



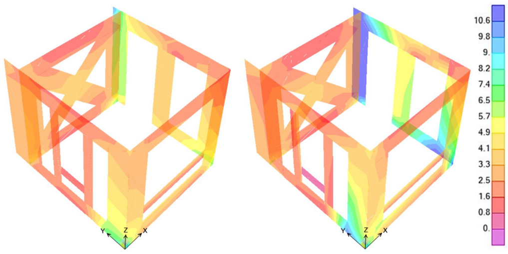
(a) (b)

Figure. 14 Maximum tensile stress pattern of masonry wall (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)



(a) (b)

Figure. 15 Maximum tensile stress pattern of outer ferrocement layers (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)



(a) (b)

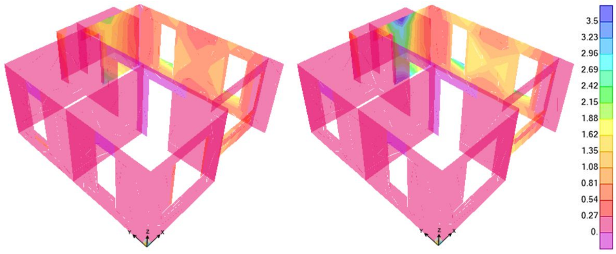
Figure. 16 Maximum tensile stress pattern of inner ferrocement layers (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)

3.3. Analysis Results of Stage 2 – two strengthened rooms

In the second stage, the strengthening is applied to 2 bedrooms. For the unreinforced masonry wall, the analysis results show that the maximum stress in the North wall did exceed the allowable stress limit when shaken by Padang earthquake (see **Figure. 17**). This is influenced by the out-of-plane load from Padang earthquake which is much larger in the Y direction (0.3g) than in the X direction (0.25g) of the house.

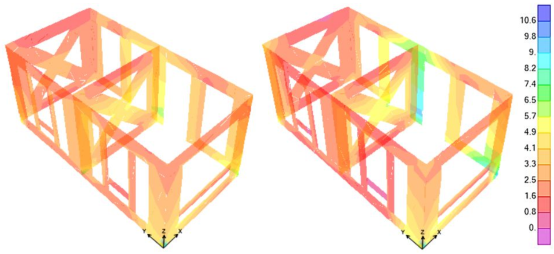
Compared to the prior analysis of one strengthened room (see **Figure. 14**), the previously unstrengthened second room is now earthquake resistant due to the ferrocement bandaging.

Earthquake can occur any time. Therefore, it is better to strengthen the masonry house completely up to stage 3. For both the inner and outer ferrocement layers, it can be seen clearly that the tensile stress occurred in ferrocement layers is only around 3-6kgf/cm^2 (see **Figure. 18** and **Figure. 19**), below the allowable tensile stress limit (10.63kgf/cm^2).



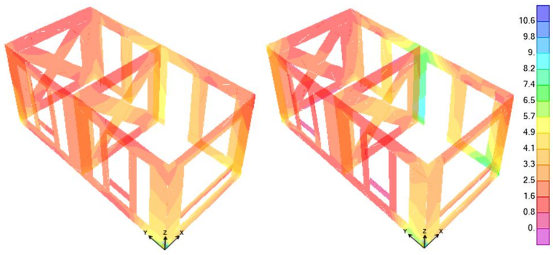
(a) (b)

Figure. 17 Maximum tensile stress pattern of masonry wall (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)



(a) (b)

Figure. 18 Maximum tensile stress pattern of outer ferrocement layers (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)

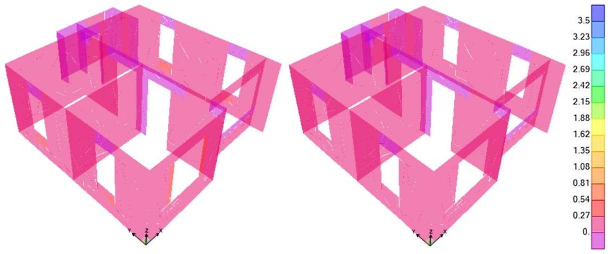


(a) (b)

Figure. 19 Maximum tensile stress pattern of inner ferrocement layers (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)

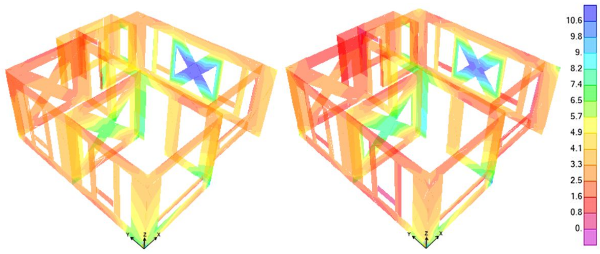
3.4. Analysis Results of Stage 3 – entire house strengthened

When all masonry walls are strengthened by ferrocement bandaging, the tensile stresses occurred are very small as can be seen in **Figure. 20**. In general, the tensile stress of ferrocement layers when shaken by Palu and Padang earthquakes were below the allowable stress (10.63kgf/cm^2) as can be seen in **Figure. 21** and **Figure. 22**. For the right wall, where there is no room partition, the tensile stress of outer ferrocement layers slightly exceed the allowable stress (see **Figure. 11**) which indicates the possibility of cracks. The analysis results of stage 3 shows that the masonry house strengthened by ferrocement layers is earthquake resistance.



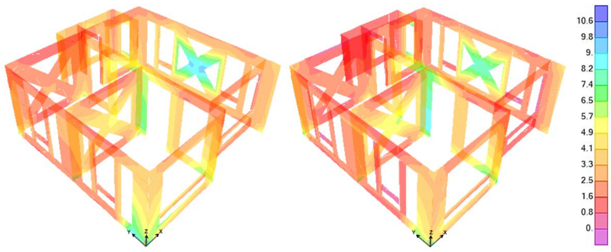
(a) (b)

Figure. 20 Maximum tensile stress pattern of masonry wall (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)



(a) (b)

Figure. 21 Maximum tensile stress pattern of outer ferrocement layers (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)



(a) (b)

Figure. 22 Maximum tensile stress pattern of inner ferrocement layers (kgf/cm^2) due to Palu earthquake (a) and Padang earthquake (b)

4. CONCLUSION

1. Gradual strengthening with ferrocement bandaging significantly improves the earthquake resistance of masonry house. It is proven by the analysis results using Padang earthquake which is multiple pulse type and Palu earthquake which is a single pulse type.
2. The gradual strengthening should serve as an educational tool to encourage people to be self-reliant and self-sufficient in building their earthquake resistant houses to prevent collapse in the future.
3. People should not depend on the government funding to strengthen their houses.
4. It is recommended to strengthen masonry houses by bandaging with ferrocement layers up to stage 3; if available, FRC and TRC layers can be used (Dr. Teddy Boen,

Dr. Hiroshi Imai, Lenny, M.T., Sarah E. Suryanto, M.Eng., 2021). However, due to limited funding, gradual retrofitting can be applied immediately, and all stages shall be completed within one year. Therefore, the masonry houses become earthquake resistance.

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