Equivalency of the diagonal shear strength of plastered and non-plastered lightweight brick walls to the strength of red brick walls

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Abstract. Simple (non-engineered) house buildings are so popular in Indonesia. However, the vast majority of these buildings were damaged in the past earthquake events. In such building type, the masonry walls contribute as structural elements to withstand the load. Currently, the innovation that is emerged to be favoured by the community is lightweight brick walls, therefore, such kinds of walls need to be deeply and widely explored by a series of research. The purposes of this study are to compare the maximum shear loads between plastered and non-plastered brick walls as well as lightweight brick walls with various thicknesses through laboratory tests and to find the equality of maximum shear loads lightweight brick walls against red brick walls. This study used laboratory test and literature study. This study concludes that, the addition of plaster on a lightweight brick wall provides additional maximum load to the wall in the amount of 74.6336%. Maximum load of non-plastered red brick walls is equivalent to the strength of a non-plastered light brick wall with a thickness of 47.26 mm. For plastered red brick walls, maximum load to carry is equivalent to plastered lightweight brick walls with a thickness of 168.76 mm.

1. Introduction

Earthquakes are one of the most common natural disaster threats in Indonesia. The position of Indonesia's territory which is located at three confluence of the world's tectonic plates is the cause of its high seismicity which covers about 2/3 of Indonesia's territory [1].

Basically, an earthquake does not directly cause loss of life. It is rarely, if not never, found that someone died as a result of the direct impact of an earthquake. Spence [2] stated that based on data collected from 1950-1990, more than 75% of the fatalities in earthquake cases were caused by building collapse. Strong earthquake shocks can damage buildings and then the debris cause injuries or fatalities to the people in the buildings.

In the case of the 2006 Yogyakarta Earthquake, as many as 358,693 housing units were reported damaged, 5,716 people died, and 37,927 people were injured [3]. The majority of the damaged houses were classified as non-engineered houses [4]. Non-engineered masonry wall buildings are highly vulnerable to damages subjected to earthquake shocks because they do not have sufficient shear strength of walls and are not equipped with adequate reinforced concrete confinement [5]. Ironically, this type of building is the most popular and liked by the communities. In fact, if it is built with earthquake-resistant building concept, building damage can be avoided, as was the case in the 2006 Yogyakarta Earthquake [6].

As an effort to reduce the risk of earthquakes, innovations in earthquake-resistant houses, especially the type of walls, need to be encouraged. One of the main structural components in a one-story non-
engineered building is the wall. In technical buildings such as multi-story buildings, the role of walls in terms of structure is not so significant. The main function of the walls in these buildings is as a divider between spaces. Whereas in non-engineered house buildings, masonry walls contribute as structural elements to withstand the load borne by the building, and even red brick walls have been standardized by the government for earthquake-safe house buildings, for example in the Minister of PUPR Regulation No. 2016. Therefore, wall innovation as a structural component in a walled house is necessary. The goal is to obtain a wall composition that is strong, easy to work with, and requires low costs. In other words, walled houses that can meet increasingly optimal Cost, Quality, and Time (BMW) criteria are needed through technological and engineering innovations.

Currently, there are innovations masonry wall materials such as research carried out by Teguh [7] and Teguh et al., [8]. In addition, currently the innovation that is starting to be favored by the community is lightweight brick. Lightweight bricks are bricks that have a lighter weight volume compared to bricks in general. In the market, this lightweight brick has been produced by various manufacturers with various specifications and has been applied by the community in simple buildings with various wall thicknesses. Light brick strength tests have also generally been carried out by lightweight brick manufacturers, but only at the unit brick form, not at the unit wall element.

Unlike quite a number of tests of red brick walls that have been carried out, one of the most important issues is that tests of walls made of lightweight bricks of various thicknesses are still rarely carried out for various regions. Thus, research through laboratory tests on the equivalence of the strength of lightweight brick walls with various thicknesses against the strength of red brick walls, which is still the standard, needs to be done. Tests and assessments carried out include shear test loads. The results of laboratory testing and assessment of lightweight masonry walls will then be compared with the red masonry which has been used by the people of Indonesia and around the world for hundreds of years.

Based on the description of the background and problems mentioned above, the purpose of this study is to compare maximum shear test loads between red brick walls and lightweight brick walls of various thicknesses through laboratory tests to find the equivalency of shear strength of various thicknesses of plastered and non-plastered lightweight brick walls against red brick walls.

2. Literature Reviews
In engineered buildings (multi-story building), walls have a different role when compared to simple (non-engineered) buildings. Although it also contributes to providing strength [9], in engineered buildings the role is not so significant. For example, in an open frame reinforced concrete building, if the walls of the building are removed, the building will remain standing because the main support is reinforced concrete frames (columns and beams). On the other hand, in simple residential buildings, such principles do not apply. This is because the contribution of walls to support simple building structures is highly significant. Therefore, if the walls are removed, the building can collapse.

Structural components in a simple one-story building are at least columns, beams, tie beam, and walls. For this type of building, generally the dimensions of columns, beams, and tie beam are not so large. This results in the difference in strength and stiffness of the portal not much different from that of a brick wall [10]. The components are considered to act as wall confinements [6]. Therefore, strength and stiffness in non-engineered buildings need to be supported by walls. This study focuses on the role of masonry walls in non-engineered buildings.

2.1. Wall Test
Wall testing has been carried out in several previous studies, one of which was carried out by Yardim and Lalaj [11]. In this study, we compared the shear strength performance of several types of reinforcement in brick walls. The reinforcement in question is reinforcement due to the addition of wall plastering materials, namely textile reinforced mortars (TRM), polypropylene fiber reinforced mortar plastering (PP-FRM), and ferrocement reinforced mortar plastering. The results of the study showed that the walls reinforced with ferrocement and polypropylene mortar plaster experienced a significant increase in shear performance compared to standard brick walls.
Another study was conducted by Milosevic et al. [12]. The wall tested in this study is a wall composed of rubble stone. Rubble stone walls are often found in traditional Portuguese buildings. The test is carried out in two stages, the finite element model and direct testing (load test). As a result, load-displacement diagrams and failure modes from the numerical approach (finite element) and direct testing (load test) show similar results.

The two studies above have some differences and similarities. The difference can be seen from the side of the material making up the walls. One study tested walls made of masonry with a certain reinforcement while the other tested walls made of rubble stone. However, both have one thing in common, namely the dependent variable. Both tests review the shear performance of the tested walls. The test method also refers to the same source, namely ASTM E519 as can be seen in Figure 1 and Figure 2. Therefore, this study more or less refers to the two previous studies but with different wall building materials.

**Figure 1.** Diagonal Compression (Shear) Test on Brick Wall [11]

**Figure 2.** Diagonal Compression (Shear) Test on Rubble Stone Wall [13]

### 3. Materials and Methods

#### 3.1. Data Collection

Data collection was carried out by conducting direct testing of test objects at the Laboratory of Engineering Construction Materials and literatures of relevant studies. The data used in the analysis consists of primary data and secondary data.

1. **Primary data**
   Primary data is data obtained directly from laboratory testing conducted by the authors. Primary data are in the form of maximum shear load data.

2. **Secondary Data**
   Secondary data are data that obtained from other sources that are relevant to this paper. Secondary data includes material specifications (study by Sugiharto [14]), and literatures of relevant previous studies.

#### 3.2. Research Variables

In this study there are two variables as follows.

1. The independent variables include variations in the thickness of the light brick walls
2. The dependent variable constitutes the maximum shear loads of the specimens.

The specimens are plastered and non-plastered red brick walls as well as light brick walls with various thicknesses. The plasters for red brick wall and lightweight brick wall use different compositions. For
red brick wall plaster, the mix ratio for each component is 1 PC (Portland Cement), 5 sand (fine aggregate), 0.5 water. 1, 5, and 0.5 are mix proportion by mass. For lightweight brick wall, the plaster used instant mix. The mix ratio is 1 PC and 0.2 water (mix proportion by mass).

3.3. Research Equipment and Materials
The equipment used in this earthquake-resistant wall research is a set of wall test equipment, concrete mixer, mortar ladle, saw, scales, knife, scissors and tub. While the materials used for this research are brick, lightweight brick, Portland cement, sand, water, and nails.

One very important element in this test is a set of wall test kits. Specifically, the criteria for this tool are set out in ASTM E519. The regulation states that the test equipment used must have an adequate compression load capacity.

3.4. Specimens
The specimens are in the form of masonry walls in 9 (nine) variations as follows.
1. Standard red masonry wall (non-plastered)
2. Lightweight masonry wall with a thickness of 6 cm (non-plastered)
3. Lightweight masonry wall with a thickness of 8 cm (non-plastered)
4. Lightweight masonry wall with a thickness of 10 cm (non-plastered)
5. Standard red masonry wall (plastered)
6. Lightweight masonry wall with a thickness of 7.5 cm (plastered)
7. Lightweight masonry wall with a thickness of 10 cm (plastered)
8. Lightweight masonry wall with a thickness of 12.5 cm (plastered)
9. Lightweight masonry wall with a thickness of 15 cm (plastered)

3.5. Constructing and curing the specimens
The specimens were made in the warehouse. The process of making specimens can be seen in Figure 3. In ASTM E519 (2010), the dimensions of wall specimens for diagonal shear testing are specifically regulated. The size of the test object (specimens) should not be less than 1.2 x 1.2 meters (4 x 4 ft). The number of test objects for each variation is also required not less than 3 (three) pieces. That is, if there are 9 variations, the total number of test specimens is 27. The curing procedure of test specimens is also regulated in ASTM E519. Once made, the test object may not be moved before 7 days-old. During the curing period, the specimens must be placed in room temperature ranging from 24±8°C with humidity levels between 25 and 75% for approximately 28 days.

![Figure 3. The Process of making specimens in the warehouse](image)

3.6. Testing
Diagonal compression testing was carried out at the Laboratory of the Civil Engineering Department, Islamic University of Indonesia. The test method refers to SNI 4166:1996 which is also in accordance
with ASTM E519, as shown in Figure 4. Figure 4a (left) is the example of a specimen before testing and Figure 4b (right) is the example of a specimen after reaching maximum load.

4. Result and Discussion

In this research, 27 samples of wall were tested using diagonal tension test method. The samples consist of light-weight brick masonry wall and brick masonry wall. Both types of masonry are plastered and non-plastered. The result of the test is shown in Figure 5. The scatter, as shown in Figure 5, represents the relationship between the maximum loads recorded during test versus the wall thickness. There are several scatter markers in Figure 5. The red square marker represents a non-plastered red brick wall. The blue circle markers represent non-plastered lightweight brick walls where these primary data are obtained from the laboratory testing done by the authors. The blue triangle markers represent plastered lightweight brick walls where these secondary data are obtained from the laboratory research by Sugiharto [14]. The laboratory tests by the authors and Sugiharto used the same wall materials and were carried out at almost the same time. The red diamond markers represent red plaster brick walls. In general, it can be seen that the plastered walls, both red bricks and light bricks, are able to carry higher loads than those that are not plastered.

![Figure 4. The test specimens](image)

In non-plastered lightweight brick masonry wall sample, a point in the coordinates (0,0) is added (see Figure 6). This point is added based on the assumption when the wall thickness is equal to zero, the load that can be carried by the wall is also zero. This point is needed to help creating a regression line to describe the equation of the relationship between wall thickness and the maximum load. In plastered lightweight brick masonry walls, a (0,0) point is not added like in non-plastered lightweight brick masonry walls because wall plaster also plays a role in carrying the load. Therefore, at a thickness of 0.0 mm the wall still has the strength to carry the load.
Figure 5. The result of Diagonal Compression Test

Figure 6. The result of Diagonal Compression Test of Lightweight Masonry Wall

After adding a point on the scatter graph, a regression equation is made to obtain an equation of the relationship between the thickness versus maximum load for plastered and non-plastered lightweight brick masonry walls. This regression equation is then used to predict the maximum load that can be carried by the wall with a certain thickness beyond the thickness tested in the laboratory. In this study, the wall thickness tested between plastered and non-plastered masonry wall was not the same. Therefore, this regression equation is used to add the additional points in order to obtain the same number of plots between plastered and non-plastered lightweight masonry wall. The regressions are shown in Figure 7. Both regressions, as shown in Figure 7, indicate positive relation. It means, the higher the thickness of the wall, the higher the maximum load.

In Figure 8, additional points based on regression equations have been added. To distinguish the points obtained from regression equations and laboratory testing, the data presented in different markers. The blue triangle symbol with a red border is an additional point obtained from the results of interpolation and extrapolation based on the linear regression equation obtained previously. After adding the points based on regression equation, now the number of points between plastered and non-plastered light brick walls is the same to become comparable. (See Figure 8).
Furthermore, the average maximum load is calculated between plaster and non-plaster light brick walls. The maximum average load for non-plaster light brick walls is 69,14385 kN, while for plastered lightweight brick walls, the average maximum load is 120,7484 kN. From these results it can be seen that the difference in the average maximum load between plaster and non-plaster lightweight brick walls is 51.60455 kN (see Figure 9). In conclusion, the addition of plaster on a lightweight brick wall provides additional strength to the wall. The increase in the strength of the addition of plaster on a light brick wall is 74.6336%.

Figure 7. Regression Lines of plastered and non-plastered lightweight masonry wall

Figure 8. Additional points based on regression equation
Figure 9. Average Loads of Plastered and non-plastered lightweight brick masonry wall

Figure 10. The equivalence of plastered and non-plastered lightweight brick walls with red brick walls

To get mathematical relationship between the thickness of the walls and the maximum load, linear equations are developed as seen in Figure 3.5 and Figure 3.6. Based on the figures, it can be seen that the strength of a non-plastered red brick wall is equivalent to the strength of a non-plastered light brick wall with a thickness of 47.26 mm. For plastered red brick walls, the strength is equivalent to plastered light brick walls with a thickness of 168.76 mm.
5. Conclusion
By referring to maximum shear test load, the strength of non-plastered red brick walls is equivalent to the strength of a non-plastered lightweight brick wall with a thickness of 47.26 mm. In addition, for plastered red brick walls, the strength is equivalent to the strength of plastered lightweight brick walls with a thickness of 168.76 mm.

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