Height and width effect on brick masonry wall to defection through finite element analysis

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Abstract. The wall is an important structure to protect the inside of a house or building. The wall also functions to carry and forward loads from the roof. Wall collapse can be a structural failure that can make people die. Therefore, it is necessary to do an analysis in the form of modelling to the wall that will be built to review the damage that can be occur. There are 3 types of the wall, which is 3 meters, 3.5 meters and 4 meters of width wall with variation of height and load direction. The walls are modelled using software STERA FEM. This research was conducted to see the pattern of wall damage and to determine the high effect on wall stiffness. The result from this research shows that the pattern of damage to the wall, press on the bottom right and drag on the bottom left to the load direction X, then press on the upper right and left angles to the load direction Y. The walls were tested using variations in height and width produce the same pattern of damage. However, the deflection value for each wall is different.

1. Introduction
Research on wall analysis has been carried out. Behavioral experiments on cyclic in-planes on brick walls with composite material reinforcement show shear failure on walls with CTRC and GTRC reinforcement [1]. Research on the out-of-plane response of brick walls with textile-reinforced mortar (TRM) reinforcement shows the failure of single and double wall [2]. Research on out-of-plane behavior in brick walls reinforced with mortar coating techniques using GFRP reinforcement shows sudden damage that begins at the front of the wall followed by a horizontal direction [3]. Research on calculating the stiffness of a brick wall portal in multi-storey buildings with pushover analysis shows that the contribution of infill walls made of brick walls affects the lateral stiffness of the building structure [4]. Research on the effect of explosions on brick infill walls reinforced with GFRP shows that lamination using GFRP increases the flexibility of out-of-plane URM fill wall walls to withstand blast loads [5]. Zhang, et al conducted a study of numerical models of FRP reinforcement of brick walls with in-plane earthquake loads using ABAQUS software showing that a wall model with FRP reinforcement results in a wider and distributed damage pattern [6]. Comparison between experimental results and numerical results shows the match between stiffness degradation and peak strength. Research on out-of-plane test
of brick walls without reinforcement with ECC added materials shows that the use of ECC can increase the capacity of out-of-plane walls [7].

The wall is an important structure to protect the inside of a building. The wall has several functions, namely to hold the load, give weight to the whole building, as a silencer and noise, and to provide a boundary area as a space separated [8]. Walls in buildings that function as an outer covering or as partitions related to architectural requirements and building use [9]. Based on applicable regulations, walls are non-structural components of buildings and do not affect the strength of construction, so walls are often ignored in the process of structural calculation.

Stiffness is a resilience to deformation. Stiffness and strength of a brick wall had a significant effect on the performance of low-rise buildings [10]. The red brick building is the element used in the manufacture of building construction made of soil with or without impurities, which burned quite high, so cannot be destroyed when soaked in water [11]. The collapse of the wall there are two types based on the direction of forces acting on the wall that is out-of-plane failure is the collapse due to forces acting perpendicular to the plane of the wall and In-plane failure is collapse resulting from the force parallel to the plane of the wall [12,13].

Modeling in this study using STERA FEM software. The walls were modeled is a full wall with a rectangular brick building block. The width of the wall that is modeled based on the size that is often used for the wall of the house are 3 meters, 3.5 meters and 4 meters with variations in height and direction of the load. The purpose of this study was to compare the effect of height and width variations of the wall on the pattern of wall damage.

2. Research method

In this study using the STERA FEM application which still uses linear static analysis to detect displacement values that occur due to lateral and vertical load falls. STERA FEM is a software for analyzing walls created in 2015 by Taiki Saito from Toyohashi University of Technology, Japan. STERA FEM stands for Structure Earthquake Response Analysis. STERA FEM is a 2-dimensional software for analyzing walls using horizontal and vertical static loads. The output generated from this software is the value of the wall's main stress and the wall's main stress distribution pattern. In Table 1 is the ratio of width and height used in this study.

Table 1. Wall width and height ratio.

| A | Width | Height | Ratio |
|---|---|---|---|
| 3 | 2.5 | 1.2 |
| 3 | 3 | 1 |
| 3 | 3.5 | 3.5 |
| 3 | 4 | 0.8 |

Material data used in modeling in this study can be seen in Table 2. In the STERA FEM application only requires the value of density, modulus of elasticity and poisson ratio of the material used. This application is designed to analyze walls so that it is more specific and does not require a lot of supporting material properties.

In this study using the modulus of elasticity in red brick of 2237.5 MPa with a poisson ratio of 0.2 and a density of 1700 kg/m³. This data is taken from secondary data that has been collected previously.

Table 2. Material properties of Red brick [10,13].

| Parameters | Value |
|---|---|
| Modulus of elasticity (MPa) | 2237.5 |
| Poisson ratio | 0.2 |
| Density (Kg/m³) | 1700 |
3. Results and discussion

3.1. Variation in width of 3 meters

In this study an analysis was carried out on a wall with a width of 3 meters with a variation in height of 2.5 meters to 4 meters. The load used is 2 kN to 15 kN. The first crack of a wall with a height of 2.5 meters in the horizontal load direction occurs when a wall is given a 4 kN load, while a wall with a height of 3 to 4 meters has a crack since the initial load was given 2 kN. In the vertical direction there is no cracking. In Table 3 is the result of the deformation value on the wall both due to the load direction X and Y direction with the results obtained load varies on each test object.

The wall can accept the load direction X greater than the Y direction so that the deformation that can be received by the X direction becomes greater than the wall with the Y direction. The higher the wall in the X direction can increase the value of the deformation which means it can receive greater deformation while in the Y direction will produce a smaller deformation value if the height of the wall is higher. In Figure 1 is the deformation and stress patterns that occur with each model with different height and type of load.

Using lateral load direction Y shows that the greatest damage occurred in the area of support to the right, it is influenced by the load, all kinds of wall experiencing similar types of damage. Based on Figure 1 show blue color is tensile stress and orange color is compressive stress, that while using the vertical load and damages tend to be at the top of the wall closest to the load position. In Figure 1 are consecutive.

![Figure 1](image)

_Figure 1. Damage pattern for high wall and different load direction (a) 2.5 m; (b) 3 m; (c) 3.5 m; (d) 4 m (width 3m)._ 

In Figure 2 is the relationship of the deformation value obtained with the amount of load received, in which in this study the load is limited to 15 kN. In Figure 2 (a) shows the results with high variations with the load given in the Y direction, resulting in a higher deformation value that can be received by the wall. While in Figure 2 (b) which is a high variation model with load direction Y indicates that the value of the received deformation smaller the higher the test object will result in deformation of the smaller value. This indicates that the height of the test specimen is good enough to load the X direction, but not good to load the Y direction because it will wear down more quickly in the event of overload in the Y direction, especially on the walls without structural components.

| Table 3. Wall Deformation value width 3 m. |
|-------------------------------------------|
| Wall Height (m) | Load Direction (15 kN) | X(mm) | Y(mm) |
|-----------------|------------------------|-------|-------|
| 2.5             | 3.50                   | 1.11  |
| 3               | 3.99                   | 1.09  |
| 3.5             | 4.48                   | 1.06  |
| 4               | 4.97                   | 1.04  |
Figure 2. The relationship between the value of wall deformation and load (a) Load direction X; (b) Load direction Y (width 3 m).

3.2. Variation in width of 3.5 meters
In modeling with a width of 3.5 meters, but the height of the test specimen is varied the same as the previous model. The results in Table 4 show the same pattern of results as the previous model. It's just that the deformation value generated is smaller. In the model using X direction load, the largest deformation is 3.8 m with a high condition of the test object about 4 meters. Whereas in the Y direction produces the greatest deformation in the wall with a height of 2.5 m that is equal to 0.97 mm. While the stress distribution patterns that occur also have similarities with the previous modeling with a wall width of 3 meters.

The level of damage to the wall occurs more in the wall with the load direction X. In Figure 3 shows the results that the level of damage occurs more than the load with the direction of the load Y. The stress distribution that occurs in the Y direction load is more evenly distributed than the load distribution with the load direction X From the results of this modeling it can be concluded that the higher the model, the greater the deformation of the received X direction while the deformation of the Y direction received will decrease.

Figure 3. Damage pattern for high wall and the different load direction (a) 2.5 m; (b) 3 m; (c) 3.5 m; (d) 4 m (width 3.5m).

Table 4. Wall Deformation value width 3.5 m.

| Wall Height (m) | Load Direction (15 kN) | X (mm) | Y (mm) |
|----------------|------------------------|--------|--------|
| 2.5            | 2.71                   | 0.97   |
| 3              | 3.07                   | 0.95   |
| 3.5            | 3.43                   | 0.93   |
| 4              | 3.80                   | 0.91   |
In Figure 4 explains the relationship between wall deformation and load, where the deformation of the wall that occurs in the X direction and Y direction. The difference in the X direction deformation produced is more than the Y direction deformation, which has a fairly small yield per variation of its height. In this study still produces a linear pattern because the analysis is still using a static linear pattern with a specified load maximum of 15 kN. Thus, it is necessary to further examine the direction of load X because it will produce greater deformation.

**Figure 4.** The relationship between the value of wall deformation and load (a) Load direction X; (b) Load direction Y (width 3.5 m).

### 3.3. Variation in width of 4 meters

In modeling the width of 4 meters results in smaller deformation values compared to the walls with widths of 3 and 3.5 meters. This shows that the wider the wall, the smaller the deformation produced and the load that can be received by the wall will be even greater. In the X direction with a width of 2.5 meters the wall height produces a deformation of 2.19 mm as shown in Table 5, while in Table 4 with the same height but a wall width of 3.5 meters produces a deformation of 2.71 mm. This proves a significant decrease which is influenced by the width of the wall.

**Table 5.** Wall Deformation value width 4 m.

| Wall Height (m) | Load Direction (15 kN) | Load Direction (15 kN) |
|----------------|------------------------|------------------------|
|                | X (mm)                 | Y (mm)                 |
| 2.5            | 2.19                   | 0.86                   |
| 3              | 2.46                   | 0.85                   |
| 3.5            | 2.74                   | 0.83                   |
| 4              | 3.02                   | 0.82                   |

**Figure 5.** The relationship between the value of wall deformation and load (a) Load direction X; (b) Load direction Y (width 4 m).
The highest deformation in the X direction is 3.02 mm with a wall height of 4 meters (figure 5). Increasing the height of the wall will result in higher deformation as well, this is similar to the two variations previously described. In loading the Y direction produces a deformation value that decreases with increasing wall height of the model. So it can be concluded that the addition of wall height serves to add strength in the Y direction while the addition of wall width is good for loading the X direction (figure 6).

Figure 6. The relationship between the value of wall deformation and load (a) Load direction X; (b) Load direction Y (width 4 m).

4. Conclusion
Based on the results of modeling using STERA FEM software, it can be concluded that the pattern of damage to the wall, press on the bottom right and drag on the bottom left to the load direction X, then press on the upper right and left angles to the load direction Y. The walls were tested using variations in height and width produce the same pattern of damage. However, the deflection value for each wall is different. For the load direction X, the wider and higher the wall, the smaller the deformation value. For the load direction Y, the wider the wall, the smaller the deformation value, while the higher the wall, the greater the deformation value.

References
[1] Nadege R, Zyed M, Amir S L and Emmanuel F 2018 Experimental study of the in-plane cyclic behavior of masonry walls strengthened by composite materials Constructional and Building Materials p70-83
[2] Kariou F A, Triantafyllou S F, Bouronas D A and Koutas L N 2018 Out-of-plane response of masonry walls strengthened using textile-mortar system Construction and Building Materials p769-781
[3] Gattesco N and Boem I 2017 Out-of-plane behavior of reinforced masonry walls: Experimental and numerical study Composite Part B p39-52
[4] Frapanti S 2018 Studi pengaruh kekakuan portal dinding bata pada bangunan bertingkat dari beberapa negara dengan pushover Jurnal Education Building p1-10
[5] Alsayed S H, Elsanadedy H M, Al-Zaheri Z H, Al-Salloum Y A, Abbas H 2016 Blast response of GFRP-strengthened infill masonry walls Construction and Building Materials p438-451
[6] Zhang S, Yang D, Sheng Y, Garrity S W and Xu L 2017 Numerical modelling of FRP-reinforced masonry walls under in-plane seismic
[7] Lin Y, Lawley D, Wotherspoon L and Ingham J M 2016 Out-of-plane Testing of Unreinforced Masonry Walls Strengthened Using ECC Shotcrete Structures p33-42
[8] Wisnumurti, Soehardjono A and Palupi K A 2007 Optimalisasi penggunaan komposisi campuran mortar terhadap kuat tekan dinding pasangan bata merah Jurnal Rekayasa Sipil p1-8
[9] Prayuda H 2015 Gaya Lateral In-Plane Struktur Portal Dinding PASangan Bata ½ Batu Melalui Analisis Numerik Jurnal Ilmiah Semesta Teknika 18(2) p130-139
[10] Leksono R S, Iranata G and Kristijanto H 2012 Studi pengaruh kekuatan dan kekakuan dinding bata pada bangunan bertingkat Jurnal Teknik ITS p1-4
[11] Handayani S 2010 Kualitas batu bata merah dengan penambahan serbuk gergaji Jurnal Teknik Sipil dna Perencanaan p41-50
[12] Prayuda H and Cahyati M D 2016 Gaya lateral in plane struktur dinding pasangan bata ½ batu melalui beban statik Prosiding Seminar Nasional Teknik Sipil 370-377
[13] Prayuda H, Zega B C and Priyosulisty H 2017 Prediction of Allowable Lateral Ground Acceleration (In-Plane Direction) of Confined Masonry Walls using Ambient Vibration (Microtremor) Analysis Procedia Engineering 171 pp1194-1203