Study on Non-Engineered Building Vulnerability with Red Brick Masonry Wall through Finite Element Analysis

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Abstract. In this study comparing two types of simple house forms that were built without using count analysis. The building uses beams and columns that are usually used in a simple house in Indonesia. The modeled building consists of a square cross section and L cross section, also the modeled wall consists of a full wall, a wall with door openings, walls with door and window openings. Modeling using STERA 3D software to model non-engineered building comprise beams and columns and STERA FEM software for modeling walls. Modeling was carried out to analyze building shear stiffness, earthquake acceleration, and wall deflection when receiving loads. The loading in this study uses dead loads and earthquake loads using the time history method. The results of the modeling are the largest shear stiffness of a simple house building with a square cross-section of 35 kN/cm. The maximum land acceleration resulting is 8.72 m/s². The largest wall deflection occurs at a load of 20 kN with a deflection value of 58.83 mm on the wall with door and window openings. The high deflection value is caused by the influence of the width openings on the wall and the load go down to the wall.

1. Introduction

Bricks are a type of material that is often used for various types of construction in various countries, even used for several historic buildings [1]. In addition, bricks are one of the structural materials for building construction in most developing countries [2]. Indonesia is one of the archipelagos countries which is squeezed by three very active plates namely Eurasian, Pacific and Indian Australia [3]. Geographically, the Indonesian archipelago has two main earthquake pathways known as the Trans-Asiatic Circum-Pacific tan [4]. With these conditions, it certainly makes Indonesia one of the countries prone to various natural disasters, especially earthquakes. The irregularity of the building system and there are still many building systems that are not calculated by meeting the standards of earthquake resistant buildings will certainly be very dangerous.

Most of the non-engineered buildings in Indonesia are one-story buildings that were built by the community as residents. In several regions in Indonesia, they have built non-engineered buildings equipped with structural components such as beams and columns. However, there are still many buildings that do not use structural components that only rely on the wall system as a load restraint.

Research that has been done on building systems and building resilience in Indonesia after an earthquake is not a new thing. However, Indonesia has a large area coverage so that knowledge of earthquake resistant buildings has not been well spread. In addition, the economic level of the community is one of the factors that determine whether the development system can be done well or not. Several studies on wall damage have also been carried out, including using the laboratory method Tes [5] [6] [7], numerical simulation [8] [9] [10] [11], and identifying the level of damage to buildings after an earthquake [12] [13] [14]. In this study there are several building structural elements that are reviewed, including beams, columns, and walls to analyze the comparison between square cross section
and L cross section, and the deflection value of wall type in modeling. The method used is the finite element method (FEM) with STERA 3D software and STERA FEM.

2. Non-Engineered Building

Simple non-engineered building houses were built by builders, building materials obtained from the local area, and without the help of architects or structural experts. Planning simple building houses are generally based on [3]:

1. Study building damage from past earthquakes,
2. Use trained engineering judgment, and
3. Use hardware and software.

2.1. Wall Stiffness

Elastic stiffness is defined as the slope of the deviation load curve at the current load 0,4 \( P_{\text{peak}} \) which is used to determine and know the elastic part of the curve, also to determine parameters such as ductility, \( P_{\text{yield}} \), and \( \Delta P_{\text{yield}} \). Elastic rigidity uses the following equation.

\[
K_e = \frac{0.4 P_{\text{peak}}}{\Delta 0.4 P_{\text{peak}}}
\]  

(1)

which are:

- \( K_e \) = elastic stiffness (kN/mm),
- \( P_{\text{peak}} \) = load at 0,4 \( P_{\text{peak}} \), and
- \( \Delta P_{\text{peak}} \) = deviation during load 0,4 \( P_{\text{peak}} \).

2.2. Earthquake Acceleration

Every earthquake that occurs will cause one value of ground acceleration. The greater the acceleration value, the greater the risk that occurs. Measuring the value of ground acceleration is done empirically with the approach of several formulas derived from earthquake magnitude or data intensity. Maximum ground acceleration is the largest acceleration value of the surface that has occurred in an area in a certain period.

3. Finite Element Analysis

Beams are structural elements that accept the main load of shear force and bending moment, with the result that the main displacement is a deflection which is perpendicular to the beam axis and angular displacement that is equal to the bending moment, as in Figure 1 [15].

![Figure 1. Beam elements with nodal points [15]](image)

The stiffness matrix that relates the displacement vector and force vector is as follows.

\[
\begin{bmatrix}
Q_1 \\
M_1 \\
Q_2 \\
M_2 \\
\end{bmatrix} =
\begin{bmatrix}
k_1 & k_1 & k_1 & k_1 \\
k_2 & k_2 & k_2 & k_2 \\
k_3 & k_3 & k_3 & k_3 \\
k_4 & k_4 & k_4 & k_4 \\
\end{bmatrix}
\begin{bmatrix}
\theta_1 \\
\theta_2 \\
\theta_3 \\
\theta_4 \\
\end{bmatrix}
\begin{bmatrix}
v_1 \\
v_2 \\
v_3 \\
v_4 \\
\end{bmatrix}
\]  

(2)
4. Research Method

The material of this study is a simple house building with a square cross section and an L shaped cross-section with an area of 36 m² with the structure being reviewed namely beams, columns, and walls. The walls use full wall types, walls with door openings, and walls with door and window openings. Modeling in this study uses STERA 3D software to analyze beams and columns, as well as STERA FEM software for analyzing walls. Aspects reviewed include building shear stiffness, earthquake acceleration, and wall deflection. Loading on this model is dead load and earthquake load. The test object used is a simple house building with a square cross section and an L-shaped cross-section that has a plan as shown in Figure 2.

![Figure 2: Building plan (a) square cross-section; (b) L-shape cross section, in units of cm](image1)

The type of wall modeled is in Figure 3 to Figure 4. The dimensions of the structure used can be seen in Table 1. The dimensions of the beams and columns include b×h, while the wall dimensions include wall thickness, height, and width of each structure adjusting the shape of the cross-section building or building plan. Concrete compressive strength of beam and column are 24 MPa. Material properties used in modeling can be seen in Table 2.

![Figure 3: Square cross-section, in units of cm](image2)

![Figure 4: L-shape cross section, in units of cm](image3)
Table 1. Structure Dimensions

| Structure | Dimensions (mm) |
|-----------|----------------|
| Beam      | 150×150        |
| Column*   | 150×150        |
| Wall      | 100            |

*e.g. column height 4 m

Table 2. Material properties of bricks [16]

| Parameter                      | Value  |
|--------------------------------|--------|
| Modulus of elasticity (MPa)    | 2237.50|
| Poisson ratio                  | 0.15   |
| Density (kg/m$^3$)             | 1700   |

The earthquake data used was the Kobe earthquake that occurred in Kobe, Japan in 1995 with a magnitude of 6.9 SR magnitude with a depth of 7.1 km from the epicenter with an earthquake period of 20 seconds and the building was located 30 km from the epicenter.

5. Result and Discussion

5.1. Non-Engineered Building Analysis

The magnitude of the basic shear force that occurs in buildings is directly proportional to the stiffness of the building. The maximum building shear stiffness in buildings with a square cross-section reaches 35 kN/cm, while the maximum building shear stiffness in buildings with an L-shaped cross-section reaches 25 kN/cm in Figure 8 (b). Through these results it can be concluded that buildings with square shapes have a greater stiffness value than buildings that are not square, it should be done more in-depth research on the level of rigidity with various types of building plans.

Based on the graph of the relationship of time with acceleration, it can be seen that the earthquake acceleration per unit time in direction X and direction Y, can also find out the maximum earthquake acceleration that can be seen in Table 3. Based on the results obtained indicate that the acceleration of Y direction is greater than the acceleration of X direction shown in Table 3.

Table 3. The maximum acceleration value for each building cross section

| Time (s) | Acceleration (gal) | Square cross section | Cross Section L |
|----------|--------------------|----------------------|-----------------|
|          |                    | X        | Y        | X        | Y        |
| 4.48     | 746.30             |          |          |          |          |
| 6.52     | 887.20             |          |          |          |          |
| 7.82     | 745.50             |          |          |          |          |
| 6.54     | 835.90             |          |          |          |          |

5.2. Masonry Walls Analysis

Wall analysis produces deflection values and collapse patterns. Table 4 describes the deflection of the wall at the time of the first crack and the load received by the wall. The condition with openings cracks faster with a smaller load, this indicates that openings in the wall can reduce the strength on the wall. In the Y direction, each wall tends to crack longer than in the X direction with a greater deflection value. Thus it can be concluded that the wall is stronger to accept Y direction load compared to the X direction.

Figure 5 through Figure 7 is the result of stress distribution and the location of damage with maximum load. In Figure 5, the condition of a wall with a full shape is used in a square building. With
the direction of load X indicates that the damage is greatest at the bottom of the support. Whereas with directional loads Y the level of damage occurs distributing to the bottom to the middle of the building, including the upper part near the end of the load position. From the results of the analysis in Figure 6 it can be seen that with the direction of the horizontal load there is more damage, namely by checking the red dot lines on each model. The red dotted line illustrates the amount of displacement of the wall due to the load given until it is blue.

In Figure 5 a wall collapse pattern with door openings. In the results of this analysis, it can be seen that lateral loads show significant damage to the support area, while models with vertical directional loads occur near the opening area due to the door. The use of doors in building walls shows a significant change compared to not using a door, so certain reinforcement needs to be done for the wall that will use the door.

### Table 4. Deflection value when first cracked

| Load (kN) | Full wall | Wall with Door Openings | Walls with Door and Window Openings |
|-----------|-----------|-------------------------|-----------------------------------|
|           | X         | Y                       | X       | Y               | X       | Y               |
| 0.30      | 0.17      |                         |         |                 |         |                 |
| 2.75      | 1.90      |                         |         |                 |         |                 |
| 0.20      |           | 0.23                    |         | 0.57            |         |                 |
| 1.00      |           |                         |         |                 |         | 0.35            |
| 0.05      |           |                         |         |                 |         |                 |
| 1.10      |           |                         |         |                 |         | 0.69            |

**Figure 5.** Wall collapse pattern with load 2.5 kN (a, b) direction X; (c, d) direction Y

**Figure 6.** Wall collapse pattern with load 5 kN (a, b) direction X; (c, d) direction Y

Figure 7 is a wall model that uses door and window openings. The damage has the same pattern. The first damage occurred in the area of the door and window which was not reinforced at all. With the load direction Y will experience faster collapse due to the influence of the shape of the wall that is not stable because there are many openings.
Figure 8 is the result of the relationship of the load given to the deflection that is generated both in the X direction and Y direction. The results obtained are still in linear analysis so that in-depth analysis of non-linear simulations needs to be done. The results show that the full wall has a smaller deflection with the same load which is 20 kN, while the other models have a greater deflection result, especially the wall with door openings and windows in the X direction. There is no significant difference between the Y direction wall with door openings with door and window openings.

![Figure 7: Wall collapse pattern with load 7.5 kN (a, b) direction X; (c, d) direction Y](image)

![Figure 8: The relationship between load and deflection (a) direction X; (b) direction Y](image)

Inspections were also carried out for models with L-shaped buildings. Basically, there were not many differences in the type of wall model for the building. Table 5 is the result of deflection and the resulting load when the model experiences the first crack and the resulting deflection value.

| Load (kN) | Full wall X | Wall with Door Openings X | Walls with Door and Window Openings X | Full wall Y | Wall with Door Openings Y | Walls with Door and Window Openings Y |
|-----------|-------------|--------------------------|-------------------------------------|-------------|--------------------------|-------------------------------------|
| 0.30      | 0.14        | 1.83                     | 0.26                                | 0.41        | 0.49                     | 0.26                                |
| 0.41      | 1.83        | 0.18                     | 0.26                                | 0.49        | 0.26                     | 0.23                                |

In Figure 9 through Figure 11 is the result of the distribution of damage or crack patterns that occur with each model. While in Figure 12 is the result of the relation of the load given with the resulting deflection. The inspection is carried out by gradual testing up to a load of 20 kN. The pattern of damage that occurs on the wall does not affect the shape of the building so that both buildings with square plan and plan L do not affect the damage that occurs to one wall component. However, the shape of the house plan greatly influences the rigidity of the building as a whole.
In Figure 11 shows that with the Y direction load on the wall model with door openings and windows will experience considerable deflection compared to other models, so it can be concluded also that openings greatly affect the condition of the wall, the more openings the smaller the moment of inertia and will reduce wall stiffness.

![Figure 9](image1.png)

**Figure 9.** Wall collapse pattern with load 2.5 kN (a, b) direction X; (c, d) direction Y

![Figure 10](image2.png)

**Figure 10.** Wall collapse pattern with load 5 kN (a, b) direction X; (c, d) direction Y

![Figure 11](image3.png)

**Figure 11.** Wall collapse pattern with load 7.5 kN (a, b) direction X; (c, d) direction Y

![Figure 12](image4.png)

**Figure 12.** The relationship between load and deflection (a) direction X; (b) direction Y

6. Conclusion

Based on the results of modeling with finite element methods can be summarized as follows:

1. The shear stiffness of a simple house building with a square cross section and L cross section in a row reaches 35 kN/cm and 25 kN/cm.
2. The maximum ground acceleration during an earthquake is 87.27 gal or 8.7227 m/s². The maximum acceleration of an earthquake against a building occurs in the direction of Y including a square cross section reaching 887.2 gal or 8.872 m/s² in seconds to 6.52 and for a cross-section L reaches 835.9 gal or 8,359 m/s² in seconds to 6.54.

3. The largest wall deflection occurs at a load of 20 kN, including for buildings with square crossings occurring on walls with door and window openings; and for buildings with cross-sections L occurs on the walls with door openings.

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