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The Comparison of Brick as a Load and a Structure with Non-Linear Analysis of Soft Storey Behaviour in Multi-storey Buildings

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Abstract. The design of earthquake resistant buildings is built with strong columns and weak beams. One of the reasons that building collapses is due to the selection of soft storey structures. The research objective was to determine the increase in stiffness, the maximum load capacity regarding to brick as a load and brick as a structure. The method used is numerical simulation with the finite element method. From the results of data analysis, it can be concluded that the maximum base shear force of brick X direction is 147.88 kN (as load), 148.59 kN (as a structure). The basic shear force of the brick with the maximum direction of Y direction is 156.10 kN (as a load), 158.32 kN (as a structure). From the results of data analysis, the maximum stiffness of bricks in X direction is 11.73 kN / mm (as a load), 11.28 kN / mm (as a structure). In terms of the maximum stiffness of the brick from the Y direction, it is = 8.68 kN / mm (as load), 9.01 kN / mm (as a structure). The basic shear force increases by 1.01 times (brick as a structure), 1.015 times (brick as a load). When compared to brick as a load, the maximum stiffness increases by 0.96 times (brick as a structure) and 1,044 times (brick as a load).

Key words: Brick as a load, Brick as a Structure, Basic shear force, stiffness

1. Introduction

An earthquake occurred in West Sumatra with a magnitude of 7.6 on the Richter scale off the coast of West Sumatra in 2009. This earthquake occurred off the coast of Sumatra, about 50 km northwest of Padang City. Hence, it is likely that earthquake could happen in the City of Padangsidimpuan. A visual survey showed that the buildings in the City of Padangsidimpuan are built with a strong beam and a weak column. Meanwhile, the principle in designing earthquake-resistant buildings is strong columns and weak beams. The cause of high amount of damaged buildings cannot be omitted from the type of structure of the building itself. Basically, a column that experiences soft storey can be categorized as a column that receives a relatively strong load from the structure above it. Structures with soft storey will increase the lateral deformation and shear forces in the column. The building collapsed due to the earthquake and the selection of soft storey structures for building construction.

The research objective was to determine the increase in stiffness, the maximum load capacity due to brick as a load and structure to the houses that were reviewed in the city of Padangsidimpuan with earthquake resistance.

2. Literature Review

2.1 Earthquake

An earthquake is a natural disaster in which a vibration occurs on the earth's surface due to a sudden release of energy from the epicentre. The energy released propagates through the ground in the form of vibrational waves. Based on the hypocentre of the earthquake, it can be divided into 3, namely shallow earthquakes, intermediate earthquakes and deep earthquakes. There are 3 types of earthquake waves, namely: primary / longitudinal waves, secondary / transverse waves and long waves.

Based on the events, it can be divided into 3, namely: volcanic earthquake, tectonic earthquake and collapse earthquake. [1-2]

2.2 Ground Motion Characteristics

Ground motion due to the earthquake is mostly shown in the acceleration of the ground, which is also the main parameter. Ground motions are often referred to as ground acceleration, ground velocity and ground displacement. In order to discuss the ground motions parameters, it will be linked to the understanding of earthquake's character itself and its relationship with the resulting damage. [3-4]

Figure 1 shows one of the unfavourable effects on the structure due to the behaviour of brick walls, whereby the soft-storey collapsed because of the earthquake that occurred in Padang in 2009. This soft-storey collapse occurred due to the minimal use of infill walls at the base of the building.



Figure 1. The soft storey collapse that occurred in the city of Padang in 2009

2.3. Infill Wall

The infill wall used in this study is a red brick wall, because it is very widely used in almost all buildings all over Indonesia. This is due to the fact that red bricks are affordable, easy to obtain and resistant to weather. This infill wall is brittle, besides it can also be destroyed much earlier, the weight of the structure increases and the base shear of the design increases. In non-linear analysis, the infill wall element is modelled by means of a line element called a compressional member (strut). This element has brittle strength and deviation properties [4].

The behaviour of portals with brick walls against lateral loading has long been investigated, [3-4-5]. From several existing studies, modelling brick walls as press bracing [6] is considered the simplest but representative. This method has taken into account the elastic and plastic behaviour of the fill portal considering the limited ductility of the infill wall material [7-8]. This method is better known as the Equivalent Diagonal Strut method [9].

2.4 Soft Storey

Soft storey which is also known as a weak storey, is defined as a level in a building that has most of the rigidity or capacity to absorb minimum energy to resist pressure induction due to earthquake against the building. As a result of the earthquake, the soft storey building at the lowest level will have the character of a base insulator where an earthquake occurs the top part of the building will behave as a rigid body and only the lower column is deformed (its function as a base insulator). Buildings with soft storey behaviour do not meet the rule of "strong column weak beam" [3-4-5]. The building structure must meet this requirement of "weak beam strong column" so that when the structure is subjected to the effects of the earthquake force, the plastic hinges in the structure may only occur at the ends of the beam and at the column feet.

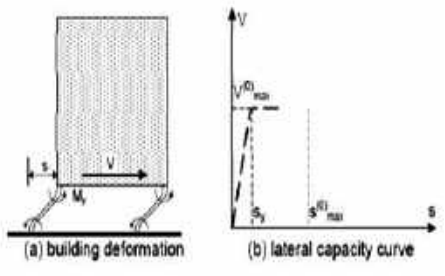

FIGURE 2. Building with soft storey

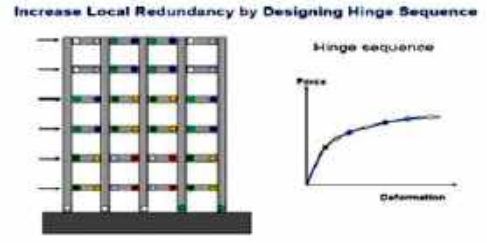

FIGURE 3. The structure of the Ductile

When the plastic hinge occurs at both ends of the column, demand rotation (θ^o_{max}) and the shear force (V^o_{max}) occurs, i.e.:

$$\theta^o_{max} = \frac{s^0_{max}}{H} \quad (1)$$

$$V^o_{max} = \sum \frac{\frac{My}{H}}{2} \quad (2)$$

If the strength capacity and column rotation are smaller than demand, a soft storey mechanism will be formed. In planning the effect of soft storey, it should be checked by carrying out dynamic analysis such as static or dynamic push over analysis, so that the sequence of plastic hinges can be checked before the soft storey mechanism is formed which can cause the building collapse. By designing the sequence of plastic hinges, a ductile building can be obtained. In addition, to increase the rotation capacity of the column, adequate confinement is required. Confinement will increase the ductility of the column section.

2.5 Stiffness

A structure must have sufficient rigidity so that its motion can be limited. The stiffness of the K structure can be measured from the amount of deviation between the floors of the building, the smaller the deviation of the structure, the more rigid the building will be. There is a difference between displacement and drift, displacement is the deviation of a floor measured from the floor while drift is the deviation of a floor measured from the floor below. So that the stiffness formula becomes:

$$K = \frac{P}{D}(N/mm) \quad (3)$$

K = stiffness
P = force (N)
d = motion (mm)

The analysis procedure will explain how to identify the parts of the building that will fail first. As the load increases, other elements will experience melting and inelastic deformation [6-7].

2.6 Non Linear Static Analysis (Pushover Analysis)

The non-linear pushover static analysis (ATC 40, 1997) is a component of performance based design which is a means of finding the structure's capacity. The basis of analysis is carried out by increasing certain static loads in the lateral direction whose value is increased gradually (incrementally) proportionally to the structure until it reaches the target displacement or reaches a mechanism on the verge of collapse [1- 15].

Pushover analysis is a non-linear static analysis method in which the effect of the planned earthquake on the building structure is considered as static loads that capture the mass centre of each floor, the value of which is increased gradually until it exceeds the load causing melting (plastic joints) first in the building structure. Afterwards, further load increase undergoes a large post-elastic deformation until it reaches a plastic condition.

3. Research Method

In this study, Pushover Analysis is implemented as an analysis method to obtain a good result. The method used is the numerical approach method with the assistance of numeric programs. Nonlinear static analysis is an analytical procedure to determine the collapse behaviour of a building against earthquakes, which is known as pushover analysis or static thrust load analysis.

3.1 Structural Modelling

In this research, linear static analysis and non-linear static analysis will be carried out on a building structure that is modelled as a 3-dimensional portal and consists of 2 models, namely: brick as a load and brick as a structure. The static analysis used is the Equivalent Static Analysis and the Variety Response Spectrum Analysis, while the Static Pushover Analysis was applied for the non-linear behaviour analysis.

All structural models consist of 3 floors and 3 spans, according to the actual field. The height for the first floor for all models is 4m, while for the other floors it is 3.5m. Each has a span length of 4.5m. Positioning is assumed to be fixed. The structure is assumed to be located on medium ground and in a moderate and high earthquake zone. The building is assumed to be designated as a shop.
For the preliminary design, the beam dimensions are 30 x 50 cm, the column is 30 x 30 cm, and the floor plate thickness is 12 cm.

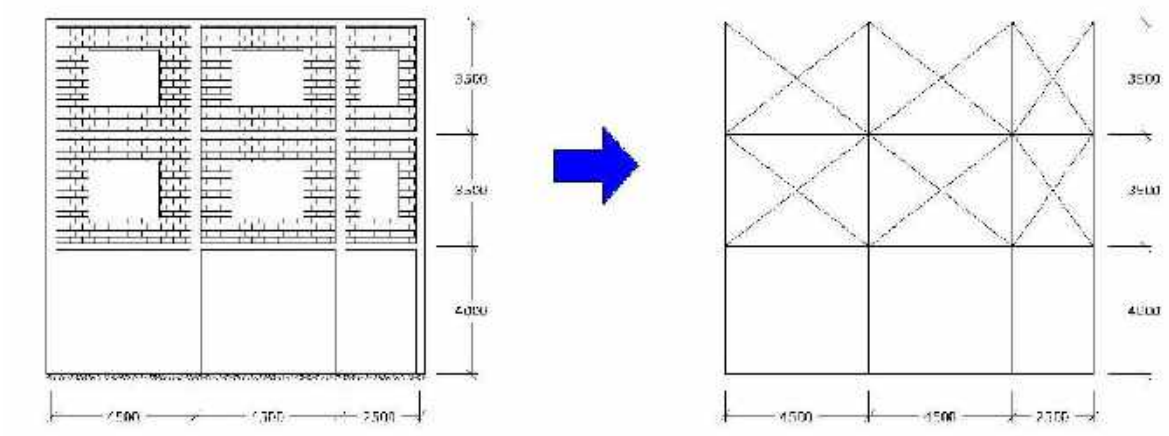

Figure 5. Brick wall model with openings as a strut element

There are 4 buildings models. In the four structural models, the same load combination is carried out. The loads on the structure consist of gravity loads (dead and live loads) and earthquake loads. The gravity load is obtained based on PPIUG 1987, while the earthquake load is based on SNI 03-1726-2012 [10].

The structural data required in this study are in accordance with the actual results of the field survey, namely:

1. The function of the building under review is: shop houses as shown in Figure 6
2. Reinforced concrete structure with column beams which are reviewed in 3 dimensions
3. The number of floors, which is 3 floors (Figure 6)
4. Thickness of the concrete slab = 12 cm
5. Column Dimensions = 30 x 30 cm
6. Dimension of beam = 30 x 50 cm and 10 x 50 cm for level beam

The material specifications of the shop building under review are adjusted based on the actual data obtained from the field. The material specifications of the shop building being reviewed are:

1. The quality of the steel consists of 2 types, namely:
   a. Steel quality (fy) = 400 MPa (BJTD 40), for Ø > 10 mm.
   b. Steel quality (fy) = 240 MPa (BJTP 24), for Ø < 10 mm.
2. Quality of Concrete Plates, Beams, Columns = K-225 (fc'=18.67 MPa).

3. Concrete elasticity modulus, Ec = 4700· $\sqrt{18.67}$ = 20310 Mpa
4. Quality of bricks, namely:
   a. Density = 1.70 kN/m^3
   b. Compressive strength (f_c') = 10 MPa)
   c. Elasticity (E) = 14000 Mpa.

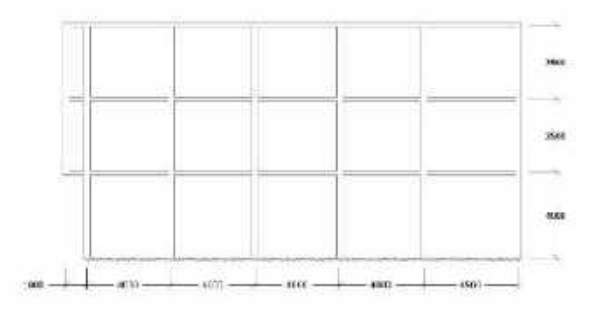

Figure 6. Side view of the actual conditions in the field

Main portal structure analysis: modeled by 3-dimensional finite element method with the aid of numerical programs. The results of the analysis method obtained are as shown in Figure 7.

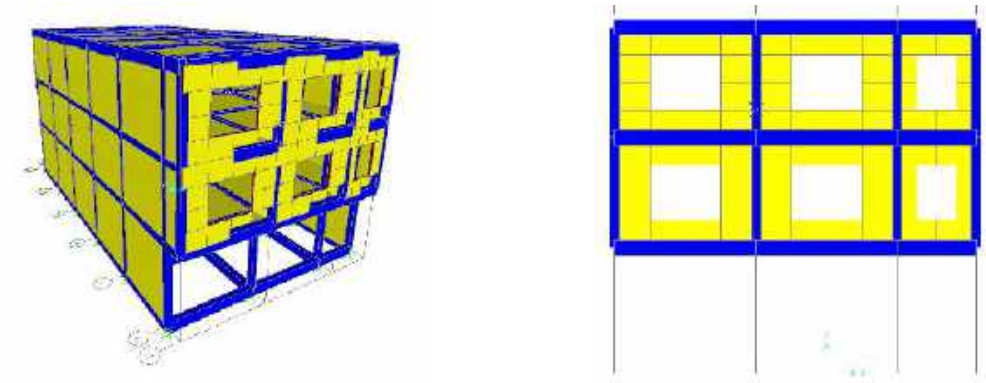

Figure 7. Numerical simulation modelling in 3 dimensions and front view

4. Result

In this research, the structural modelling in question is the 3-dimensional reinforced concrete building structure modelling as a comparison with the existing (actual) building and with the design model based on SNI 2012, both building structures are modelled with soft storey effect.

After the run analysis is completed, the next step is to control the analysis results, which include the period of natural shear, shear force (base shear) and displacement. After obtaining the results of the linear analysis that the building structure is still safe, then the pushover analysis is continued. The non-linear static load analysis will be carried out following the FEMA 356 instructions and by using the ETABS program.

After the structural program is completed, the results of the analysis or the output generated from this numerical program are obtained in the form of forces and displacements as well as deviation between levels through pushover analysis. In this case, the analysis result is displayed in graphs, i.e.: the maximum curve of deviation between floors according to SNI 1726-2012 and actual & capacity curve of the relationship between force, displacement, deviation and stiffness of each floor.

Comparison of the performance point and ductility of all structural models can be seen in Figure 8 and Figure 9.

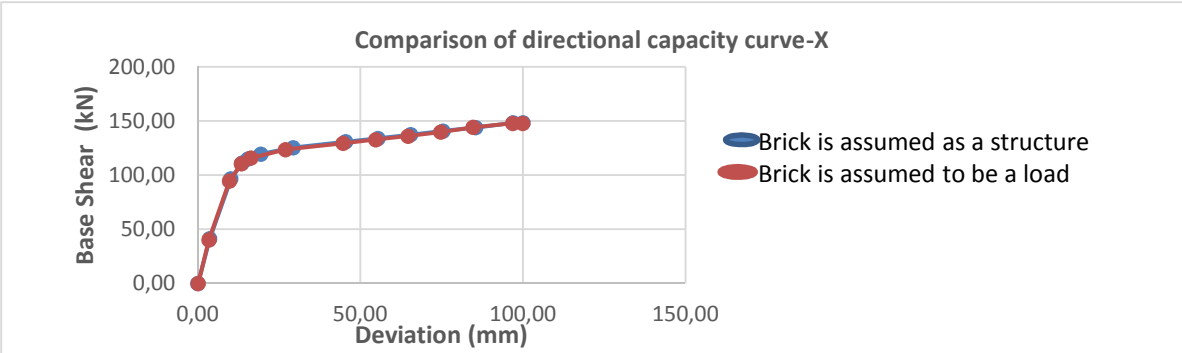

Figure 8. Directional capacity curve comparison-*x*

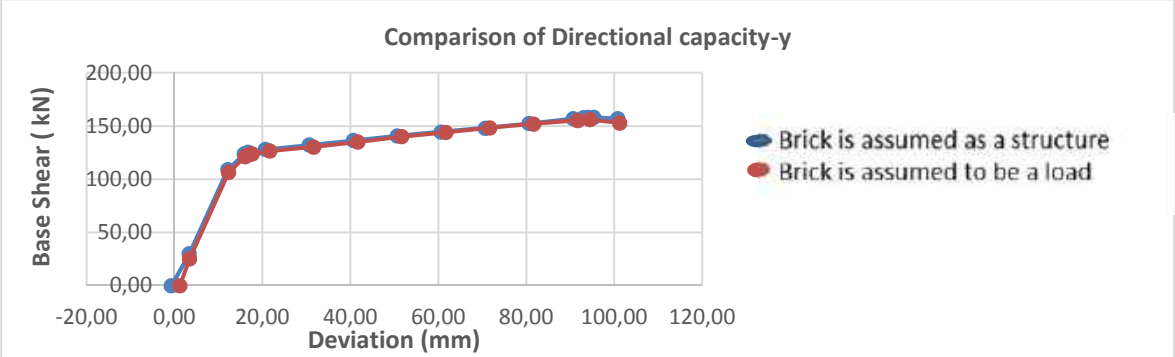

Figure 9. Directional capacity curve comparison -*y*

From the graph above, the basic shear force, ductility and maximum stiffness of the x-direction of each type can be seen in the table below.

Table 3. Basic shear force, ductility and *x*-direction maximum stiffness

No	Simulation Type	Maximum shear force (kN)	Ductility	Maximum stiffness (kN/mm)
1	Brick is assumed to be a load	147.88	1.48	11.28
2	Brick is assumed as a structure	148.59	1.49	11.73

Table 4. Basic shear force, ductility and *y*-direction maximum stiffness

No	Simulation Type	Maximum shear force (kN)	Ductility	Maximum stiffness (kN/mm)
1	Brick is assumed to be a load	156.10	1.65	8.68
2	Brick is assumed as a structure	158.32	1.70	9.01

5. Conclusion

Based on the results of the beam connection analysis using bolts and connecting plates, several conclusions were made, namely:

1. From the graph of the basic shear force (V) against the deviation (Δ) the maximum shear force ($V_{\max}$) of the brick is obtained, i.e.:
   a. In terms of X-direction, $V_{\max\ I}$ = 147.88 kg (as a load), $V_{\max\ II}$ = 148.59 kg (as a structure),
   b. In terms of Y-direction, $V_{\max\ I}$ = 156.10 kg (as a load), $V_{\max\ II}$ = 158.32 kg (as a structure),
2. From the graph of the basic shear force (V) to the deviation, the maximum deviation of brick is obtained, i.e.:
   a. In terms of X-direction, V_{max} I = 12.60mm (as a load), V_{max} II = 13.17mm (as a structure)
   b. In terms of Y-direction, V_{max} I = 17.98mm (as a load), V_{max} II = 17.57mm (as a structure)
3. From the data analysis results, the maximum stiffness of the brick is obtained, i.e.:
   a. In terms of X-direction, max = 11.73 kN/mm (as a load), max =11.28 kN/mm (as a structure)
   b. In terms of Y-direction, max I = 8.68 kN/mm (as a load), max II =9.01 kN/mm (as a structure)
4. If we compare it to brick as a load with brick as a structure, the maximum base shear force (V_{max}), increases by 1.005 times in terms of x-direction and 1.014 times in terms of y-direction.
5. If we compare the brick as the load with the brick as the structure, the maximum stiffness increases by: 1.039 times in terms of x-direction and 1.038 times in terms of y-direction.

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