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Analysis of the Effect of Column Dimension Variations on the Structure of a 12-Story Apartment Building

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ABSTRACT: High-rise buildings are building structures that are vulnerable to lateral forces so they must be designed to be able to withstand lateral loads, such as wind and earthquakes. Buildings in earthquake-prone areas must be planned to be able to withstand earthquakes. Basically, buildings that are designed to withstand earthquakes, the columns must be strong.

The purpose of this study is to determine the effect of column dimension variations on building structure and obtain effective and efficient column dimensions in the planned building. The research method is preceded by conducting a literature study. Furthermore, data collection was carried out, making preliminary design of the structure, and conducting structural analysis using the help of ETABS 19.1.0 software.

The results of analysis and comparison show that the smallest displacement value occurs in model 1 of 81.724 mm in the X direction and 83.776 mm in the Y direction. While the largest displacement occurs in model 3 of 95.222 mm in the X direction and 96.678 mm in the Y direction, but the displacement that occurs in model 3 is still within the permissible safe limit (100mm).

KEYWORDS: Apartment, column dimension, earthquake, story drift, displacement.

1. INTRODUCTION

High-rise buildings are building structures that are vulnerable to lateral forces so they must be designed to withstand lateral loads, such as wind and earthquakes. Earthquakes are one of the dynamic loads, namely loads that are large and whose direction changes according to time. One of the consequences of this dynamic load is that the building will experience horizontal deviation.

Building designs with strong columns are commonly used in multi-storey buildings, which is usually called the Strong Column Weak Beam concept, where the columns are designed to be stronger than the beams above them so that the structure has high ductility so that it is able to deform when an earthquake occurs.

Tall buildings usually use quite large column dimensions, while low-rise buildings use columns with quite small dimensions, but not all tall buildings have to use large columns and low buildings have small columns.

The aim of this research is to determine the effect of variations in column dimensions on the displacment values, floor drift and drift ratio of the planned building structure and to obtain effective and efficient column dimensions in the planned building structure.

2. THEORY

Columns are vertical compression members of the structural frame that carry the load from the beams. A column is a compressive structural element that plays an important role in a building, so that a collapse in a column is a critical location that can cause the floor in question to collapse and also total collapse of the entire structure (Sudarmoko, 1996).

2.1. Building Structures

Building structures are the parts of a building that make up the building. The structural parts of the building start from foundations, beams, frames (columns), arches, shear walls and others. These structures function to support other construction elements such as the interior and architecture of the building (Daniel L. Schodek, 2008).

The structural elements of a building frame do have different functions, but their purpose remains the same. Building frame structures have an important role in the world of construction. People's safety depends greatly on their strength. Weakness or damage can cause injury or death. Therefore, the structure should not be built haphazardly.

Judging from the height of the building and design specifications and requirements, multi-storey buildings are divided into 3 groups, namely:

1. Low rise building: has 3-4 floor levels or a height of ± 10m.
2. Mid Rise Building: has 5-10 floor levels or a height of ± 40m.
3. High rise building: has more than 10 floors and a height of more than 40m.

Multi-storey building structures are designed for structural and geotechnical development, especially if they are located in seismic areas or clay soils have geotechnical risk factors such as high pressure or muddy soil.

2.2. Types of Building Structures

Building structures can be divided into two main types, namely substructures and upper structures:

1. The upper structure of a building is all parts of the building structure that are above ground level (SNI 2002). This upper structure consists of columns, beams, floor plates, shear walls, stairs and roof plates, each of which has a very important role.
2. The substructure of a building is all parts of the building structure that are below ground level (SNI 2002). This substructure consists of foundations (stakes, bore piles, local foundations, etc.), soil excavation, pile cap and sloof, raft foundation (if any), retaining wall, waterproofing (generally membrane or integral waterproofing), backfill, and soil compaction, each of which has a very important role.

2.3. Column

Columns are vertical compression members of the structural frame that carry the load from the beams. A column is a compressive structural element that plays an important role in a building, so that a collapse in a column is a critical location that can cause the floor in question to collapse and also total collapse of the entire structure (Sudarmoko, 1996).

Columns transmit loads from the upper elevation to the elevation below until they finally reach the ground through the foundation. In column analysis and planning, the theoretical basics used in beam analysis can be applied in column analysis, but there are additional new factors (apart from bending moment) namely compressive normal forces which are included in the calculation. Therefore, it is necessary to make adjustments in compiling the balance equation by reviewing the combination of bending moment and compressive normal force. In bending beams, the amount of reinforcement installed can be planned so that the beam behaves ductilely, but in columns usually the compressive normal force is dominant so that compressive failure is difficult to avoid.

The basic principles used for column analysis are basically the same as beams, namely:

1. The stress distribution is linear throughout the cross-sectional height of the column.
2. The strain in the steel is the same as the strain of the concrete that covers it.
3. The compressive strain of concrete in the limit condition is 0.003/mm.
4. The tensile strength of concrete is ignored in strength calculations.

2.3.1. Column Behavior

Columns carry a combination of ultimate axial load and ultimate moment simultaneously. As a result of these conditions, the column must have strength and stiffness that is greater than the given load. So, columns must be planned according to the loads and moments received by the column and refer to existing regulations.

According to Bustamy (2011), in his research on flexural capacity and ductility in resisting lateral loads on various column shapes, it was found that columns with circular braces had the best performance in resisting load and ductility compared to square braces.

Krisnamurti (2013) also said that in his research regarding the influence of variations in column cross-sectional shape on the behavior of structural elements due to earthquake loads, he found that the capacity of circular columns to accept axial loads was greater than square and rectangular columns.

In square columns, square brace reinforcement has spaces between the reinforcement as support for the main longitudinal reinforcement. When a column is loaded until it collapses, the concrete outside the stirrups will be destroyed first. Columns with square stirrups will suddenly collapse if they are loaded until they collapse, causing the main longitudinal reinforcement to bend, then the braced reinforcement will bend outward because the concrete in the column experiences expansion until the column is destroyed.

In round columns, the begel reinforcement is in the form of a continuous spiral as support for the main longitudinal reinforcement. When a column is given an axial load until it collapses, the outer concrete will be destroyed first. The use of spiral reinforcement in round columns causes the column to collapse slowly because after the outer concrete is destroyed, the core column can be supported by the spiral reinforcement, which then deforms further until the main reinforcement bends and collapses.

2.3.2. Column capacity

In accordance with SNI 2847:2013 concerning "Structural Concrete Requirements for Buildings" for maximum axial load design on non-prestressed structural components with tie reinforcement (including braced columns), is:

$$\varphi Pn_{(max)} = 0{,}80\varphi\,[0{,}85\, f'c\,(A_g - A_{st}) + f_y\, A_{st}] \quad (2.1)$$

Which :

A_g = gross cross-sectional area of concrete (mm²)

A_{st} = total area of non-prestressed longitudinal reinforcement (mm²)

fy = yield strength of reinforcement (MPa)

$f'c$ = concrete quality (MPa)

2.4. Design Strength

In SNI 2847:2019 regulations for the strength reduction factor for compressive components in accordance with article

21.2 for moments and axial forces with transverse reinforcement type ties of 0.65

2.4.1. Principles of Earthquake Resistant Building Design

Earthquake resistant buildings are buildings that are able to withstand and not collapse if a small or large scale earthquake occurs. Earthquake-resistant buildings do not mean that they do not experience any damage at all, but earthquake-resistant buildings are allowed to experience damage as long as they are within the limits of applicable requirements.

High-rise buildings in a building structure must have a structure that is strong against lateral forces. Lateral force is a load that has a horizontal direction. A strong structure is a structure that will not be damaged and will not collapse due to lateral forces such as earthquake loads and wind loads, with planning that is appropriate to the area and soil conditions in the area where the building will be built.

According to Hoedajanto and Imran (2009), there are several principles for planning earthquake-resistant buildings that must be considered:

1. The structural system used must be appropriate to the level of vulnerability (seismic risk) where the building is being built.
2. Details of reinforcement, connections and building elements must be bonded effectively into one unit.
3. Concrete and steel materials must meet the requirements for earthquake-resistant buildings.
4. Architectural elements that have a large mass must be firmly attached to the main portal system.
5. Building characteristics greatly influence the earthquake forces that the building will receive.

2.4.2. Earthquake Load Resisting Structural Systems

Based on SNI 1726:2019, in article 7.2 concerning Seismic Force Resisting Structural Systems, the types of seismic force resisting structures are divided into 6 systems, namely:

1. *Bearing Wall System*.

structural system that does not have a complete gravity load-bearing space frame. The supporting wall or bracing system carries almost all the gravity load. Lateral loads are carried by shear walls or braced frames.

2. *Building Frame System*.

The existing structural system basically has space to bear complete gravity loads. Lateral loads are borne by structural walls or braced frames.

3. Moment Resisting Frame System.

A structural frame system that basically has a complete gravity load-bearing frame. The lateral load is borne by the moment-resisting frame mainly through a bending mechanism.

4. *Dual System*.

A dual system is a structural system with a space frame that carries the gravity load completely, while the lateral load caused by an earthquake is borne by a combination of a moment-bearing frame system and shear walls or by a moment-bearing frame and braced frame.

5. Sliding Frame Wall Interactive System.

This system is an interactive form of ordinary reinforced concrete moment-resisting frames and ordinary reinforced concrete shear walls.

6. Cantilever Column System.

A structural system that utilizes cantilever columns to carry lateral loads.

2.4.3. Equivalent Lateral Force Procedure

a) Seismic Base Shear

The base seismic force, *V*, in a specified direction should be determined according to the following equation:

$$V = C_S W \qquad (2.2)$$

Where:

C_S = seismic response coefficient

W = effective seismic weight

b) Vertical Distribution of Seismic Forces

The lateral seismic force, *Fx*, (kN) at any level must be determined from the following equation:

$$F_x = C_{vx}.V \qquad (2.5)$$

and

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \qquad (2.6)$$

Where:

C_{vx} = vertical distribution factor

V = total design lateral force or shear at the base of the structure (kN)

w_i dan w_x = the portion of the total effective seismic weight of the structure (W) placed or imposed at level *i* or *x*

h_i dan h_x = height from base to level *i* or *x* (m)

k = the exponent associated with the period of the structure with the following values:

for structures with T ≤ 0.5 seconds, k = 1

for structures with T ≥ 2.5 seconds, k = 2

for structures with 0.5 < T < 2.5 seconds, k = 2 or determined by linear interpolation between 1 and 2

c) Horizontal Distribution of Seismic Forces

The seismic design level shear at all levels, Vx (kN), should be determined from the following equation:

$$Vx = \sum_{i=x}^{n} Fi \qquad (2.7)$$

Where:

Fi = part of the seismic base shear (*V*) at the *i*-th level (kN).

i = level height.

The seismic design level shear, Vx (kN), should be distributed over the various vertical elements of the seismic force resisting system at the level under consideration based on the relative lateral stiffness of the vertical resisting elements and the diaphragm.

d) Determine the Design Response Spectrum

If a design response spectrum is required by this code and site-specific ground motion procedures are not used, then a design response spectrum curve shall be developed referring to Figure 2.6 and following the provisions below:

1. For periods smaller than T_0, the design acceleration response spectrum, S_a, should be taken from the equation:

$$S_a + S_{DS} = \left(0{,}4+0{,}6\frac{T}{To}\right) \qquad (2.8)$$

2. For periods greater than or equal to T_0 and less than or equal to T_s, he design acceleration response spectrum, S_a, is the same as $S_{DS;}$
3. For periods greater than T_s but less than or equal to T_L, the design acceleration spectral response, S_a, taken based on the equation:

$$S_a = \frac{S_{D1}}{T} \qquad (2.9)$$

4. For periods greater than T_L, the design acceleration spectral response, S_a, is taken based on the equation:

$$\frac{S_{D1}T_L}{T^2} \qquad (2.10)$$

Where:

S_{DS} = design spectrum acceleration parameters for short periods

S_{D1} = design spectrum acceleration parameters for a period of 1 second

T = period of fundamental vibration of the structure

By using T_0 and Ts as follows:

$$T_0 = 0{,}2\ .\ \frac{S_{D1}}{S_{DS}} \qquad (2.11)$$

$$Ts = \frac{S_{D1}}{S_{DS}} \qquad (2.12)$$

T_L = The long period transition map shown in Figure 1 whose values are taken from Figure 2

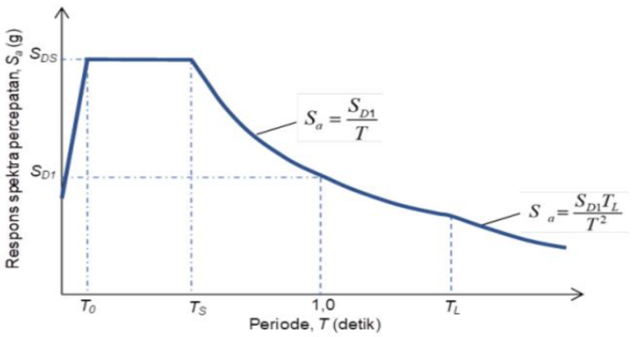


Figure 1. Design Response Spectrum

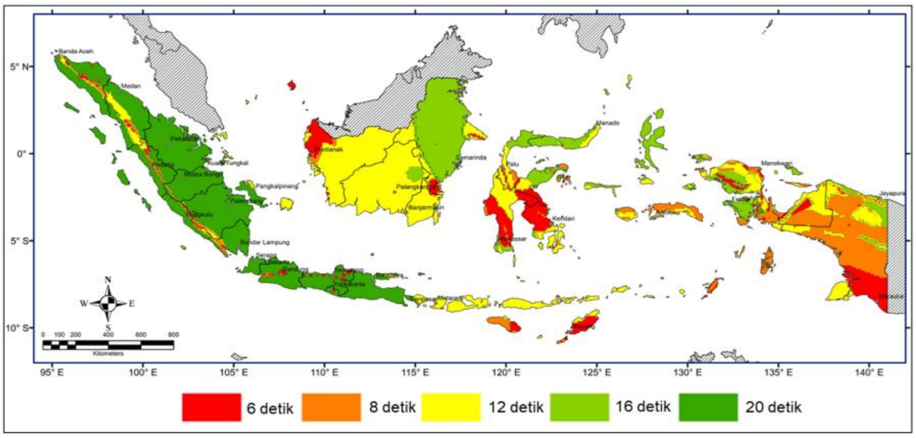


Figure 2. Long Period Transition Map

*(**Source:** SNI 1726:2019)*

e) Seismic Design Category

The seismic design category is something that is used to determine the seismic level in a building. The seismic design categories described in SNI 1726:2019 are differentiated based on previously determined S_{DS} and S_{D1}. To determine the seismic design category, see table 1 and table 2 below:

Table 1. Seismic Design Category Based on S_{DS} value

S_{DS} Value	Risk Category	
	I or II or III	IV
$S_{DS} < 0{,}167$	A	A
$0{,}167 \leq S_{DS} < 0{,}33$	B	C
$0{,}33 \leq S_{DS} < 0{,}50$	C	D
$0{,}5 \leq S_{DS}$	D	D

*(**Source:** SNI 1726:2019)*

Table 2. Seismic Design Category Based on S_{D1} value

S_{D1} Value	Risk Category	
	I or II or III	IV
$S_{D1} < 0{,}067$	A	A
$0{,}067 \leq S_{D1} < 0{,}133$	B	C
$0{,}133 \leq S_{D1} < 0{,}20$	C	D
$0{,}20 \leq S_{D1}$	D	D

*(**Source:** SNI 1726:2019)*

f) Inter-Story Drift

Drift is defined as relative lateral movement, or also commonly referred to as displacement. The deviation that occurs at each level in a building structure is a very important parameter to know, so that it is known how stiff or flexible the building structure is.

Based on SNI 1726:2019, determining the deviation between design levels (Δ) must be calculated as the difference in deviation at the center of mass above and below the level under consideration (see figure 3). If the center of mass is not aligned in the vertical direction, t is permitted to calculate the deviation at the base of the story based on the vertical projection of the center of mass of the story above. If design allowable stresses are used, (Δ) shall be calculated using the design seismic forces specified in clause 7.8. without reduction for design allowable stress.

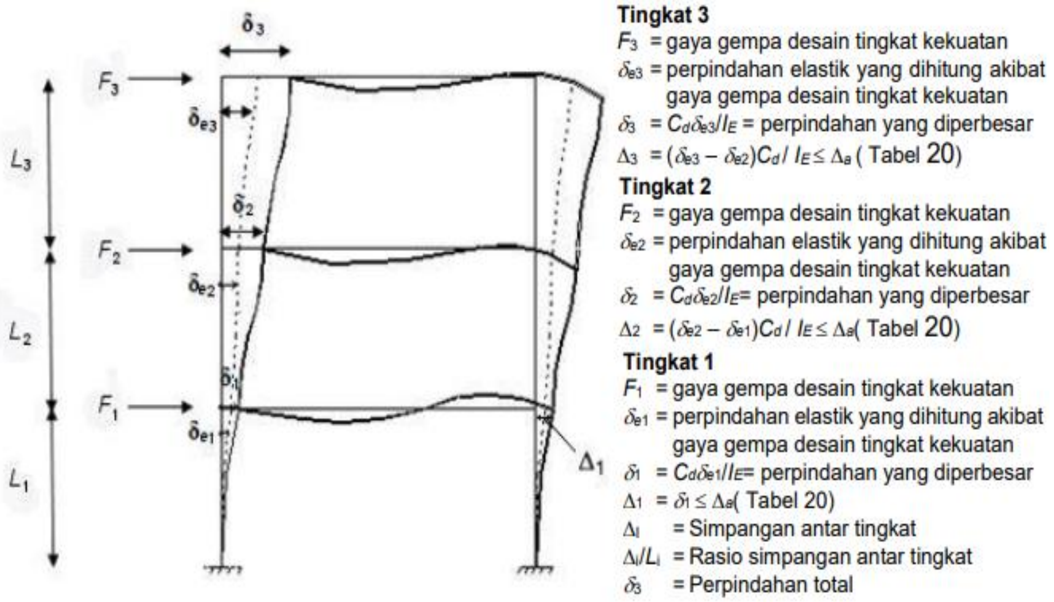


Figure 3. Determination of Inter-Floor Drift

*(**Source:** SNI 1726:2019)*

For structures designed for seismic design categories C, D, E or F which have horizontal irregularities of type 1a or 1b in table 13 in SNI 1726:2019, the drift between design levels, Δ, must be calculated as the largest difference from the drift of the points vertically along one edge of the structure, above and below the level under consideration.

Drift of the center of mass at x-level (δ_x) (mm), must be determined according to the following equation:

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \qquad (2.13)$$

Where:
C_d = deflection amplification factor in table 2.11
δ_{xe} = deviation at the required x-level
I_e = earthquake priority factors according to table 2.3

Pawirodikromo (2012) states that for multi-storey buildings, displacement can occur in ordinary beams or cantilever beams with long spans and in buildings with a very large number of levels (High Rise Building). Beam deflection is generally proportional to the span while story deviation is usually proportional to the story height in terms of drift ratio or drift index. Drift ratio is the ratio between the deviation between stories and the height of the stories, as shown in the following equation:

$$Drift\ ratio = \frac{\Delta}{h} \qquad (2.14)$$

Where:
Δ = Inter-floor drift
h = level height

g) Permit Drift Limit

In SNI 1726:2019 article 7.12.1 states that the deviation between design levels (Δ) must not exceed the deviation between permit levels (Δa) as in table 3 for all levels.

Table 3. Deviation Between Permit Levels, Δa [a,b]

Structure	Risk category		
	I or II	III	IV
Structures, other than masonry shear wall structures, of 4 stories or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate gaps between stories	0,025h_{sx} [c]	0,020h_{sx}	0,015h_{sx}
Brick cantilevered shear wall structure	0,010h_{sx}	0,010h_{sx}	0,010h_{sx}
Another brick shear wall structure	0,007h_{sx}	0,007h_{sx}	0,007h_{sx}
All other structures	0,020h_{sx}	0,015h_{sx}	0,010h_{sx}

*(**Source:** SNI 1726:2019)*

h) Dynamic Control

Dynamic control is a control used to determine the dynamic behavior of buildings. Dynamic control described in SNI 1726:2019. To determine dynamic control it can be explained as follows:

1. Control the Number of Variety

Analysis must be carried out to determine the natural vibration range for the structure. The analysis must include a sufficient number of variances to obtain combined variance mass participation of 100% of the structure mass. Alternatively, the analysis is permitted to include the minimum number of variances to achieve a combined variance mass of at least 90% of the actual mass in each orthogonal horizontal direction of the response considered by the model.

2. Control the Final Value of Spectrum Response

If the combined response for the basic shear force resulting from analysis of variance (*Vt*) is less than 100% of the shear force (*V*) calculated using the equivalent static method, then the force must be multiplied by *V/Vt*.

3. MATERIALS AND METHODS

A. Research Data

General planning data contains information or data related to the building model to be analyzed.

1. Building Plan : 12 Floor Apartment Building
2. Building function : Residential/Dwelling
3. Building Classification : High Rise Apartment, 1BR
4. Earthquake Location/Area : Palembang City/Earthquake Region II
5. Building area : 27m X 33m
6. Number of Floors : 12 Floors
7. Building height : 52 m (floors 1-2 = 5m, and floors 2-12 = 4m)
8. Type of Construction : Reinforced Concrete Structure

B. Planning Drawings

Before the structure is modeled in ETABS, the building drawing must be planned first, as follows:

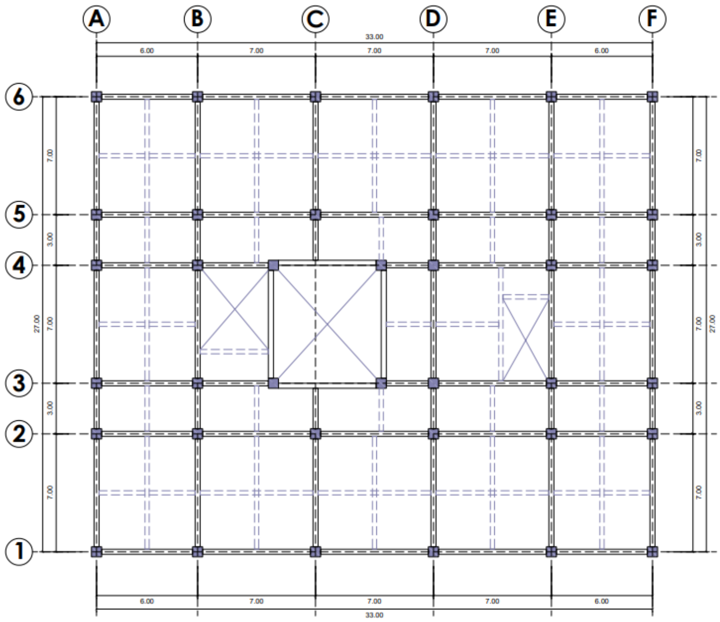


Figure 4. Apartment Structure Plan

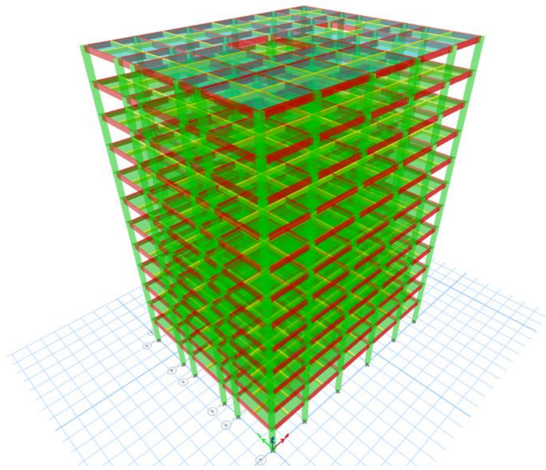


Figure 5. 3D Model of Apartment Structure

C. Material Quality Data

The quality of materials to be used in planning the structure of a 12-story apartment building is as follows:

1. Design quality of concrete for columns, beams and floor plates fc = 25 MPa with modulus of elasticity (E_c) = 4700√25 Mpa;
2. Design quality for main/longitudinal reinforcement using BjTS 420A with f_y = 420 Mpa and f_u = 525 Mpa;
3. Design quality for begel reinforcement using BjTS 280 with f_y = 280 Mpa and f_u = 350 Mpa.

D. Column Dimension

The column dimensions in the structural planning of this 12-story apartment building are varied in 3 combinations of column dimension models which can be seen in the following tables:

Table 4. Column Dimension Variations

Column variations	Column Position	Floor Height (m)	Column Dimension	
			Height (cm)	Wide (cm)
1	Floor 1	5	60	60
	Floor 2 - 12	4	60	60
2	Floor 1	5	60	60
	Floor 2 - 8	4	60	60
	Floor 9 - 12	4	50	50
3	Floor 1	4	60	60
	Floor 2 - 6	4	50	50

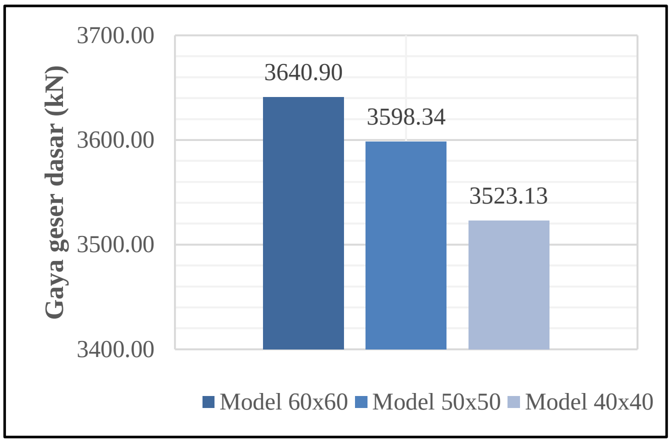
Column variations	Column Position	Floor Height (m)	Column Dimension	
			Height (cm)	Wide (cm)
	Floor 9 - 12	4	40	40

4. RESULT AND DISCUSSION

a. Base Shear Force Control

A comparison of the base shear control values of the three models can be seen in Figure 6 below:

Figure 6. Comparison of Base Shear Forces



b. Inter-Story Drift

The Inter-story drift is used to determine how rigid or flexible the structure of a building is. Inter-stories drift (Δ) must not exceed the permitted drift between floors (Δa), if the drift value between floors exceeds the permitted drift value then the building will collapse. The results of the analysis and calculation of the drift values between floors from the three models can be seen in Figure 7 and figure 8 below:

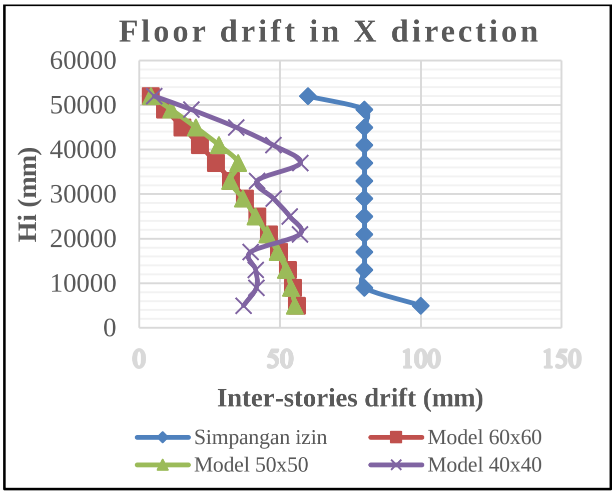


Figure 7. Comparison Chart of Inter-stories drift in X Direction

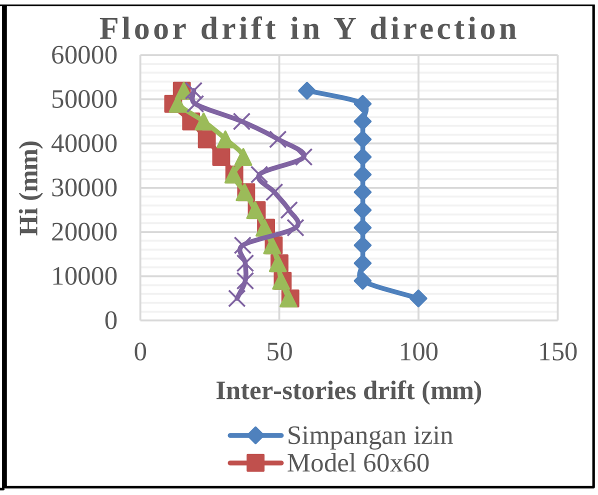


Figure 8.Comparison Chart of Inter-stories drift in Y Direction

Figure 7 and Figure 8 show the comparison results of the deviation between floors in the X direction and Y direction from the three compared models, It can be seen that the smallest deviation value is in the 60x60 model, namely 4,092 mm in the X direction and 11,919 mm in the Y direction, and the structure of this model is stiffer than the other models.

The largest deviation value between floors occurs in the 40x40 model on the 10th floor, amounting to 57.294 mm in the X direction and 58.828 mm in the Y direction, However, this value is still in a safe condition because it does not exceed the specified permit deviation limit. It is also known that this model has a more flexible structure than other models.

c. *Drift Ratio*

The drift ratio is a parameter of damage (deflection) that occurs in structural cross-sectional elements. A comparison of the drift ratio values of the three models can be seen in Figure 9 and Figure 10 below:

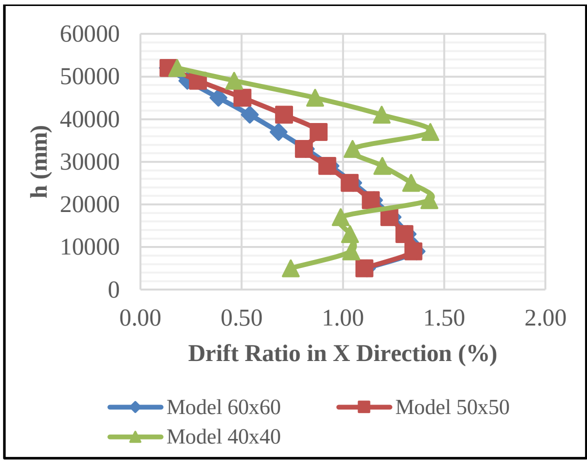


Figure 9. Comparison Chart of Drift Ratio in X Direction

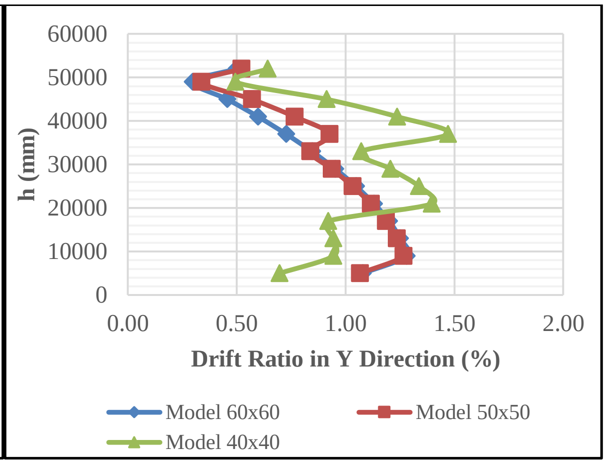


Figure 10. Comparison Chart of Drift Ratio in Y Direction

From Figure 9 and Figure 10, it is found that the largest drift ratio value occurs in the 40x40 model, amounting to 1.43% in the X direction and 1.47% in the Y direction, so it can be concluded that the 40x40 model has a greater risk of deflection of structural elements compared to other models.

d. Displacement

The displacement values for the three models were obtained from the results of analysis using the ETABS 19.1.0 program. The displacement value of the spectrum response analysis in the X direction and Y direction can be seen more informatively in Figure 11 and Figure 12 below:

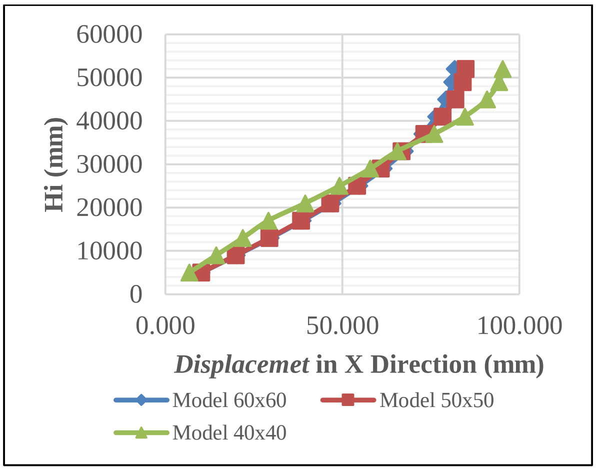


Figure 11. Comparison Chart of Displacement in X Direction

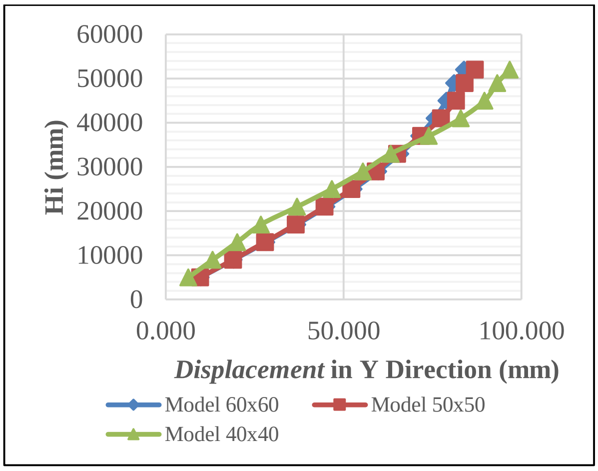


Figure 12 Comparison Chart of Displacement in Y Direction

Figure 11 and Figure 12 show the results of the comparison of displacement in the X direction and Y direction from the three models, It can be seen that the smallest displacement (deflection) occurs in the 60x60 model, amounting to 81.724 mm in the X direction and 83.776 mm in the Y direction. In the 50x50 model, the deflection that occurs is 84.754 mm in the X direction and 86.841 mm in the Y direction.

Meanwhile, the largest deflection occurred in the 40x40 model, amounting to 95,222 mm in the X direction and 96,678 mm in the Y direction, but this condition was still within the permitted safe limits.

e. Comparison of Column Concrete Volumes

A comparison of the volume of concrete columns from the three models can be seen in Figure 13 below:

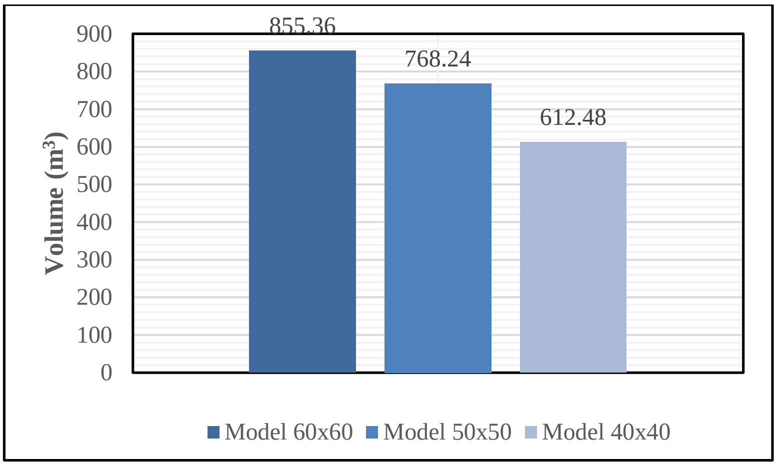


Figure 13. Comparison of Column Concrete Volumes

Figure 13 shows that in the 60x60 model the volume of concrete used for a total of 584 columns is 855.36 m3. In the 50x50 model the volume of concrete used for the same number of columns is 768.24 m3 or 10.19% more efficient than the 60x60 model. And in the 40x40 model the volume of concrete required for the same number of columns is 612.48 m3 or 28.40% more efficient than the 60x60 model.

f. Discussion result

Column dimensions have a big influence on the building structure in resisting earthquake forces, so choosing column dimensions is very important in planning a building. Columns must be designed to remain strong and safe, and have good efficiency values.

From the discussions that have been carried out, it is known that there are several significant differences between the three planned models. A comparison of all the discussions that have been carried out is summarized in table 5 below:

Table 5. Recapitulation of Discussion Results

No.	Variabel	Unit	Model 60x60	Model 50x50	Model 40x40	Permitted Limits
1.	Total Weight of Structure (*Wi*)	kg	13.320.598,36	13.164.895,96	12.889.731,16	-
2.	Seismic Base Shear (*V*)	kg	371.141,84	366.803,64	359.136,91	-
3.	Static Earthquake Force Distribution (*F*)	kg/m	68.096,09	66.478,86	64.989,12	-
4.	Base Shear Force	kN	3.640,90	3.598,34	3.523,13	-
5.	Inter-*Story Drift*	mm	55,996 (X) 53,961 (Y)	55,341 (X) 53,334 (Y)	57,294 (X) 58,828 (Y)	100
6.	*Drift Ratio*	%	1,36 (X) 1,28 (Y)	1,35 (X) 1,27 (Y)	1,43 (X) 1,47 (Y)	-
7.	*Displacement*	mm	81,724 (X) 83,776 (Y)	84,754 (X) 86,841 (Y)	95,222 (X) 96,678 (Y)	100
8.	Column Concrete Volume	m^3	855,36	768,24	612,48	-

Based on table 5 above, it can be seen that overall the 40x40 model is more efficient than other models, only if you look at the inter-story drift, drift ratio and displacement values in the model. It is indeed larger than other models, but this value is still within the permitted limits so it is still categorized as strong and safe in withstanding earthquake forces in the city of Palembang.

5. CONCLUSIONS

Based on the results of modeling analysis with variations in column dimensions of the structure of a 12-story apartment building carried out by the author, several conclusions can be drawn as follows, namely:

1. Column dimensions greatly influence the stiffness of a building in withstanding earthquake loads, so choosing column dimensions is very important in planning. The results of the analysis and comparison show that the

smallest displacement value occurred in the 60x60 model at 81.724 mm in the X direction and 83.776 mm in the Y direction. Meanwhile, the largest displacement occurred in the 40x40 model at 95.222 mm in the occurs in the 40x40 model which is still within the permitted safe limit (100mm).

2. The column dimensions chosen in planning a 12-story apartment building are the 40x40 model, this is because in the 60x60 model the volume of concrete used for a total of 584 columns is 855.36 m3. Meanwhile, in the 40x40 model, the volume of concrete required for the same number of columns is 612.48 m3 or 28.40% more efficient than the 60x60 model, and is still categorized as strong and safe because the value of the deviation between floors (Δ) is still far below the limit of deviation between floors. floor permit (Δa) has been determined, so that this model can be concluded as the most effective and efficient building structure model.

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