Analysis of Column Cross-Section Shape on Structural Performance of Building Under Seismic Loads: Case Study of Building A, Rusun Jagakarsa, Jakarta

Ariefin Galuh Akbar Permana[1*], Istiqomah[1], Ben Novarro Batubara[1]
[1]Civil Engineering Study Program, Indonesia University of Education
*Corresponding Author: Ariefin Galuh Akbar Permana. Email: ariefin.glh@upi.edu

Abstract

Columns are vertical structural elements that function to resist axial loads and moments resulting from gravity and lateral loads acting on the structure. Therefore, columns play a crucial role in the integrity of the structure; failure of a column can lead to the collapse of the building structure. Structural performance is essential for determining the performance level of a structure against the design earthquake, based on the level of damage sustained during an earthquake with a specific return period. This study aims to determine the structural performance level based on variations in column cross-sectional shapes, with the case study of Building A, Rusun Jagakarsa, Jakarta.The structural performance analysis was conducted using three structural models: a structure with rectangular column cross-sections (Type I structure) representing the existing condition, a structure with circular column cross-sections (Type II structure), and a structure with square column cross-sections (Type III structure). Performance levels were determined based on ATC-40, using earthquake load analysis through response spectrum. Internal force calculations were performed using ETABS version 18.The results showed that Type II structure had the smallest displacement among the three models, with displacement values of 45.584 mm in the X direction and 26.763 mm in the Y direction, and maximum displacements of 91.782 mm (X direction) and 62.966 mm (Y direction), compared to the other two models. The structural performance of all three models based on ATC-40 indicated the same performance level, Immediate Occupancy (IO), meaning that after the earthquake, only minor damage occurred, and the structure's strength and stiffness remained approximately the same as before the earthquake.gempa.

Keywords: Rectangular Columns, Circular Columns, Square Columns, Structural Performance, Interstory Drift

1. INTRODUCTION

Columns are vertical structural elements that function to resist axial loads and moments resulting from gravity loads and lateral forces acting on the structure. Therefore, columns play a crucial role in the integrity of the structure; failure of a column can lead to the collapse of the superstructure. Generally, in the design of buildings or residential structures in Indonesia, rectangular columns are predominantly used as the main structural elements to support beams. The use of circular and square columns as primary columns in high-rise buildings is rare. However, in certain conditions, some buildings utilize circular and square columns as their main structural components.

In column design, various cross-sectional shapes can be used. The most common cross-section shapes are square, rectangular, and circular columns. The differences between rectangular, square, and circular columns are fundamental. Regarding reinforcement and stirrups, circular columns with spiral reinforcement have closer stirrup spacing compared to rectangular and square columns, which use single stirrups with relatively larger spacing. This difference significantly influences the comparative behavior of these columns. According to SNI 1726:2019, dynamic analysis methods are used for structural performance evaluation. In dynamic analysis, response spectrum analysis, time history analysis, and design response spectrum analysis are required to obtain the maximum response from each vibration mode that occurs (Silaban et al., 2023). There are two dynamic analysis methods: response spectrum analysis and time history analysis.

Response spectrum analysis is a technique used to determine the dynamic response of a three-dimensional building structure that behaves elastically under seismic loads. This method is known as the response spectrum method, where the total dynamic response of the building is obtained by superimposing the maximum dynamic responses of each vibration mode, calculated based on the design earthquake response spectrum. Response spectrum analysis is often applied to elastic responses of irregular multi-degree-of-freedom building structures, based on the principle that the structural response is the sum of the responses of its individual vibration modes. Each vibration mode reacts with unique characteristics such as mode shape and frequency.

Time history analysis is a method to determine the time-dependent dynamic response history of a nonlinear building structure subjected to seismic ground motion as input data, where the dynamic response at each time interval is calculated using step-by-step integration methods. Earthquake loads are time-dependent, so the structural response depends on the loading duration(Safitri, 2023)

Column cross-section capacity analysis is a fundamental aspect of structural performance evaluation. Typically, structural design only considers safety factors and the building's capacity to withstand applied loads without assessing or defining the performance level of the structure. Structural performance is used to determine the performance level of a structure against a design earthquake, viewed from the damage level when subjected to an earthquake with a specific return period. This study presents the influence of column shape variations on structural performance under seismic loads by analyzing base shear, displacement, and the effect of P-Delta. The evaluation is conducted through simulation using the structural analysis software ETABS v18, employing dynamic analysis via response spectrum on the case study of the Jagakarsa Rusunawa Building in Jakarta.

2. RESEARCH METHODOLOGY

The method used in this study is a quantitative analysis approach employing linear dynamic analysis, specifically response spectrum analysis, on the Jagakarsa Rusunawa Building located in Jagakarsa, South Jakarta, utilizing ETABS version 18 software.

2.1 Structural Data

Table 1 Building Description

Building Description	Details
Building Name	Rusun Jagakarsa Building
Building Location	Jalan Raya Margasatwa, Jagakarsa Subdistrict, Jagakarsa District, South Jakarta, Special Capital Region of Jakarta
Structural System	Dual System: Special Moment-Resisting Reinforced Concrete Frame + Shear Walls
Building Function	Apartment / Rusun
Number of Floors	16 floors + 1 Roof
Concrete Strength	fc' = 30 MPa and fc' = 35 MPa
Steel Reinforcement Grade	BJ 420B: Yield Strength (Fy) = 420 MPa, Ultimate Strength (Fu) = 525 MPa
Soil Site Class	Medium Soil (SD)
Seismic Risk Category	Category II

2.2 Structural Model Variations

In this analysis study, three variations were conducted. The variations differ in shape, with each variation having the same column cross-sectional area of 700 cm². These variations are detailed in Figures 1 to 3 below

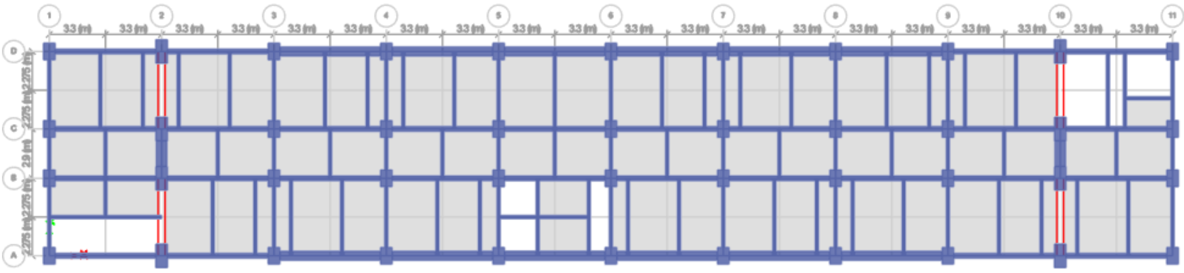

Figure 1 Variation 1: Rectangular Column

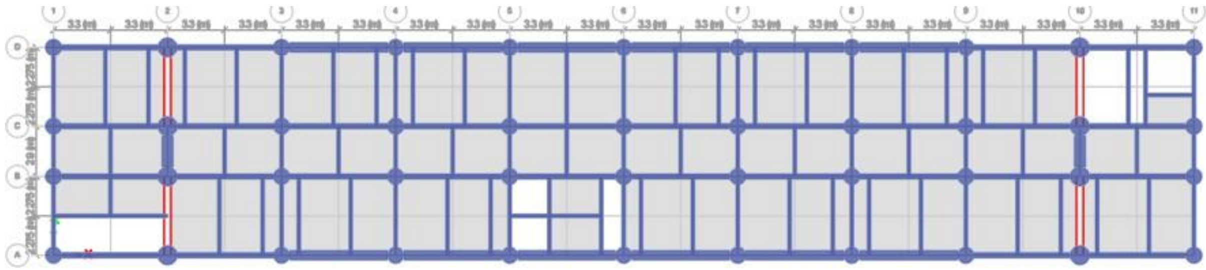

Figure 2 Variation 2: Circular Column

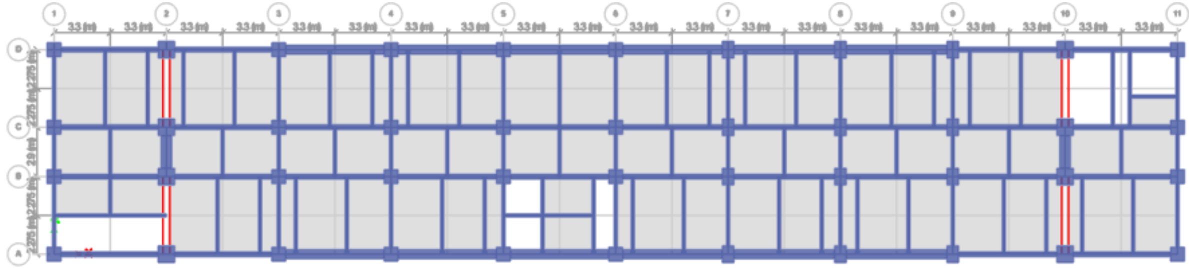

Figure 3 Variation 3: Square Column

Typical floor plans of beams, slabs, and shear walls from the ground floor up to the 16th floor for all variations can be seen in Figure 3.

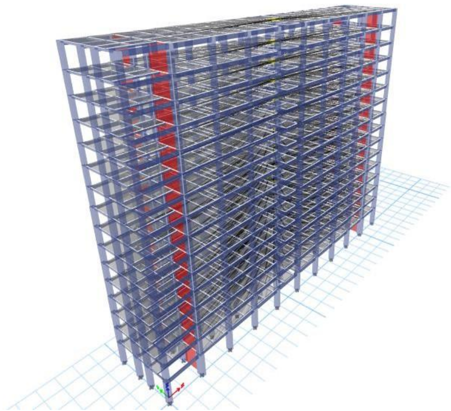

Figure 43D Modeling of Building A Rusun Jagakarsa Structure Using ETABS 18

2.3 Load Input

a) Dead Load,

The dead load of the structure consists of loads from permanent structural elements such as columns, beams, slabs, and shear walls.

b) *Additional Dead Load (SIDL)*

1. Floor Slab SIDL(SNI, 2020)
   - Additional Dead Load / Superimposed Dead Load (SIDL)
   - Cement mortar, 1 cm thickness = 0,63 kN/m2
   - Ceramic tiles = 0,24 kN/m2
   - Ceiling + Suspended system = 0,18 kN/m2
   - Mechanical Electrical = 0,25 kN/m2
   - Total Dead Load = 1,3 kN/m2
2. Roof Slab SIDL
   - Ceiling + Suspended system = 0,18 kN/m2
   - Mechanical Electrical = 0,25 kN/m2
   - Total Dead Load = 0,43 kN/m2

c) *Live Load*

- Floor Slab = 2.25 kN/m^2
- Roof Slab = 1 kN/m^2

d) *Rainwater Load*

For the Unjani Rectorate Building, the rainwater accumulation on the roof is planned to have a maximum depth of 5 cm. Rainwater Load (R) = 10 kN/m^2 x 0.05 m
= 0.5 kN/m^2

e) *Response Spectrum Earthquake Load*

Based on the soil investigation results at the construction site of Building A, Jagakarsa Rusunawa Jakarta, the soil type is classified as Site Class SD (medium soil) according to the classification in SNI 1726:2019. This building falls under Seismic Risk Category II as it is an Apartment/Flat Building, with an earthquake importance factor (Ie) of 1. The bedrock acceleration values for the South Jakarta location are SS = 0.7806 and S1 = 0.3823, obtained from the official national seismic information system website. Based on amplification coefficients Fa = 1.28 and Fv = 2.47, the spectral response parameters SMS = 1 and SM1 = 0.94 are derived. Subsequently, the design acceleration parameters are determined as SDS = 0.67 g and SD1 = 0.63 g. Since SDS ≥ 0.50 and SD1 ≥ 0.20, the structure is classified under Seismic Design Category D. The structural system used is a Special Moment Resisting Frame (SMRF) combined with shear walls, forming a dual structural system with values of R = 8, Cd = 5.5, and Ω_0 = 3. The characteristic design response spectrum curve parameters include T_0 = 0.19 seconds, Ts = 0.94 seconds, and TL = 20 seconds. (SNI, 2019)

f) *Load Combinations*

According to SNI 1726:2019 Article 7.4, load combinations must consider the effects of both horizontal and vertical earthquake forces. The load combinations are described as follows:

- 1.4D
- 1.2D + 1.6L + 0.5(Lr atau R)
- 1.2D + L + 1.6(Lr atau R)
- 1.2D + Ev + Eh + L
- 0.9D - Ev + Eh

For load combinations 5 and 7 involving earthquake loads, the provisions are regulated by SNI 1726:2019, Article 7.4. The factors and load combinations for nominal dead load, nominal live load, and nominal earthquake load are as follows:

- (1,2 + 0,2Sds) D + L ± 0,3 ρ EX ± 1 ρ EY
- (1,2 + 0,2Sds) D + L ± 1 ρ EX ± 0,3 ρ EY
- (0,9 – 0,2 Sds) D ± 0,3 ρ EX ± 1 ρ EY
- (0,9 – 0,2 Sds) D ± 1 ρ EX ± 0,3 ρ EY

2.4 Structural Performance Evaluation

Structural performance is defined as the limit of a structure's capacity to resist loads in the inelastic range, or beyond the elastic limit of the structural material components. Performance level analysis is conducted by assuming that the magnitude of lateral loads, particularly the design earthquake loads, is exceeded. In this study, the performance level determination is carried out using the ATC-40 and FEMA 440 methods, where the plastic hinges formed in beams and columns are observed until reaching the target capacity or specified target displacement (Chopra and Goel, 2002).

The capacity spectrum method based on ATC-40 (Applied Technology Council-40) is a structural performance analysis approach using the capacity spectrum derived from the actual structural displacement. In this method, the performance is represented by the performance point, which is determined from the maximum drift calculated by Equation 1 and the maximum inelastic drift calculated by Equation 2.

$$D = \frac{D_t}{H} \quad (1)$$

$$MID = \frac{D_t - D_1}{H} \quad (2)$$

Maximum drift (D) is defined as the ratio of the maximum displacement (Dt) to the building height, while the maximum inelastic drift (MID) is the ratio between the difference of the maximum displacement (Dt) and the displacement at a 1-second period (D1) to the building height. There are four performance point categories according to ATC-40, calculated from the maximum drift and maximum inelastic drift values, as shown in Table 1. These performance point categories include Immediate Occupancy (IO), Damage Control (DC), Life Safety (LS), and Structural Stability (SS). The performance point determination involves plotting the demand spectrum with 5% damping, based on soil conditions and seismic zone, onto the capacity spectrum to obtain the performance point.

Table 2 Performance Point Categories Based on ATC-40

Parameter	IO	Performance Levels		SB
		DC	LS	
Maximum total drift	0,01	0,01 s.d. 0,02	0,02	0,33vi/pi
Maximum inelastic drift	0,005	0,005 s.d. 0,015	No limit	No limit

3. Results and Discussion

3.1 Effective Seismic Weight

According to SNI 1726:2019, the calculation of effective seismic weight is obtained from the dead load (DL) as well as the additional dead load (SIDL).

Table 3. Effective Seismic Weight

Floor	Mass (kg)		
	Rectangular Column	Circular Column	Square Column
Roof	589346.94	584675.09	587095.28
Lt16	731876.76	727839.47	730045.31
Lt15	722912.65	718879.45	721081.19
Lt14	722912.65	718879.45	721081.19
Lt13	722912.65	718879.45	721081.19
Lt12	722912.65	718879.45	721081.19
Lt11	722912.65	718879.45	721081.19
Lt10	753608.9	748521.05	751219.82
Lt9	787439.89	782330.95	785051.59
Lt8	787439.89	782330.95	785051.59
Lt7	787439.89	782330.95	785051.59
Lt6	787439.89	782330.95	785051.59
Lt5	802293.82	797414.99	800353.79
Lt4	819209.31	814318.93	817268.41
Lt3	819209.31	814318.93	817268.41
Lt2	889930.67	884934.41	888771.62

3.2 Response Spectrum Modal Analysis

The seismic base shear calculation is performed to obtain a comparison between the resulting shear forces. This comparison serves as the basis for scaling dynamic earthquake loads, ensuring that the analysis results meet consistency and validation requirements with the static approach, as stipulated in SNI 1726:2019. An example of the calculation using Variation I is as follows:

Seismic Response Coefficient (Cs), $C_s = S_{DS}/(R/I_e)$
$= 0.6638/(8/1)$
$= 0.0830$

Upper Limit (X Direction), $C_{s\,max} = S_{D1}/T \times (R/I_e)$
$C_{s\,max}, x = 0.0340$
$C_{s\,max}, y = 0.0508$

Lower Limit $C_{s\,min} = 0.044 \times S_{DS} \times I_e$ (C_{smin} harus ≥ 0.01)
$= 0.0292$

Provision for the seismic response coefficient value if $C_s > C_{smax}$, maka $C_s = C_{smax}$

The seismic response coefficient used in the X direction is Cs, = 0.0340
The seismic response coefficient used in the Y direction is Cs, = 0.0508

Base Shear Calculation

Effective Seismic Weight (W)	= 119345 kN
Seismic Base Shear in X Direction (Vx)	= Cs x W
	= 3878.6758 kN
Seismic Base Shear in Y Direction (Vy)	= Cs x W
	= 6055.9974 kN
Static Base Shear Output from ETABS Vx	= 3878.7154 kN
Static Base Shear Output from ETABS Vy	= 6056.0482 kN
Unscaled Response Spectrum Base Shear $V_{i,X}$	= 4054.90 kN
Unscaled Response Spectrum Base Shear $V_{i,Y}$	= 6056.93 kN

Table 4. Base Shear Force from Response Spectrum

Output Case	Step Type	Tipe I (Rectangular Column)		Tipe II (Circular Column)		Tipe III (Square Column)	
		V_X kN	V_Y kN	V_X kN	V_Y kN	V_X kN	V_Y kN
Statik Ex	1	-3878.676	0	-3855.074	0	-3868.425	0
Statik Ex	2	-3878.676	0	-3855.074	0	-3868.425	0
Statik Ex	3	-3878.676	0	-3855.074	0	-3868.425	0
Statik Ey	1	0	-6056.0	0	-6010.057	0	-6024.494
Statik Ey	2	0	-6056.0	0	-6010.057	0	-6024.494
Statik Ey	3	0	-6056.0	0	-6010.057	0	-6024.494
Unscale Ex		2895.8546	1.4021	2949.5283	1.4336	2959.2966	1.4366
Unscale Ey		1.4021	4419.1761	1.4336	4392.5564	1.4366	4401.6382
scale X		3878.7154	1.878	3855.0821	1.8738	3868.4288	1.8779
scale Y		1.9214	6056.0482	1.9616	6010.0727	1.9662	6024.5096

3.3 Inter-Story Drift

Inter-story drift is defined as the difference in horizontal displacement between the centers of mass of two adjacent floors. In this study, the Jagakarsa Rusunawa Building in Jakarta utilizes a Special Moment Resisting Frame (SMRF) system combined with shear walls, forming a dual structural system. The drift analysis was conducted using ETABS v18 software to accurately calculate the inter-story displacements. The analysis parameters were systematically defined to precisely capture the structural response under seismic loading.

Allowable Inter-Story Drift, Δa	= 0.02 h
Redundancy Factor, ρ	= 1.3
Allowable Inelastic Story Drift, Δmax	= Δ / ρ
	= 0.0154 h
Deflection Amplification Factor, Cd	= 5.5
Seismic Importance Factor, Ie	= 1.5
Inelastic Story Drift, Δ	= δ * Cd / Ie

Table 5. Displacement in X-Direction from Response Spectrum Analysis

Story	h	Δh	Perpindahan arah X (mm)		
			Tipe I	Tipe II	Tipe III
	(mm)	(mm)	(mm)	(mm)	(mm)
16	52800	3500	97.575	91.782	91.946
15	49300	3200	96.089	90.257	90.41
14	46100	3200	93.803	88.038	88.187
13	42900	3200	90.549	84.931	85.082
12	39700	3200	86.381	80.964	81.121
11	36500	3200	81.379	76.193	76.357
10	33300	3200	75.599	70.658	70.829
9	30100	3200	69.043	64.338	64.514
8	26900	3200	62.288	57.701	57.871
7	23700	3200	55.003	50.592	50.759
6	20500	3200	47.15	42.998	43.167
5	17300	3200	38.759	34.978	35.153
4	14100	3200	29.951	26.69	26.873
3	10900	3200	21.22	18.523	18.708
2	7700	3200	12.792	10.837	11.008
1	4500	4500	5.444	4.422	4.526

Table 6. Displacement in Y-Direction from Response Spectrum Analysis

Story	h	Δh	Perpindahan arah Y (mm)		
			Tipe I	Tipe II	Tipe III
	(mm)	(mm)	(mm)	(mm)	(mm)
16	52800	3500	63.005	62.966	63.052
15	49300	3200	58.175	58.157	58.234
14	46100	3200	53.629	53.629	53.697
13	42900	3200	48.967	48.983	49.043
12	39700	3200	44.197	44.227	44.278
11	36500	3200	39.35	39.392	39.435
10	33300	3200	34.474	34.526	34.56
9	30100	3200	29.632	29.689	29.715
8	26900	3200	24.887	24.946	24.964
7	23700	3200	20.292	20.348	20.36
6	20500	3200	15.927	15.98	15.986
5	17300	3200	11.887	11.935	11.936
4	14100	3200	8.282	8.325	8.322

Story	*h*	Δ*h*	*Perpindahan arah Y (mm)*		
			Tipe I	*Tipe II*	*Tipe III*
	(mm)	(mm)	(mm)	(mm)	(mm)
3	10900	3200	5.199	5.237	5.231
2	7700	3200	2.733	2.763	2.756
1	4500	4500	1.019	1.039	1.034
Base	0	0	0	0	0

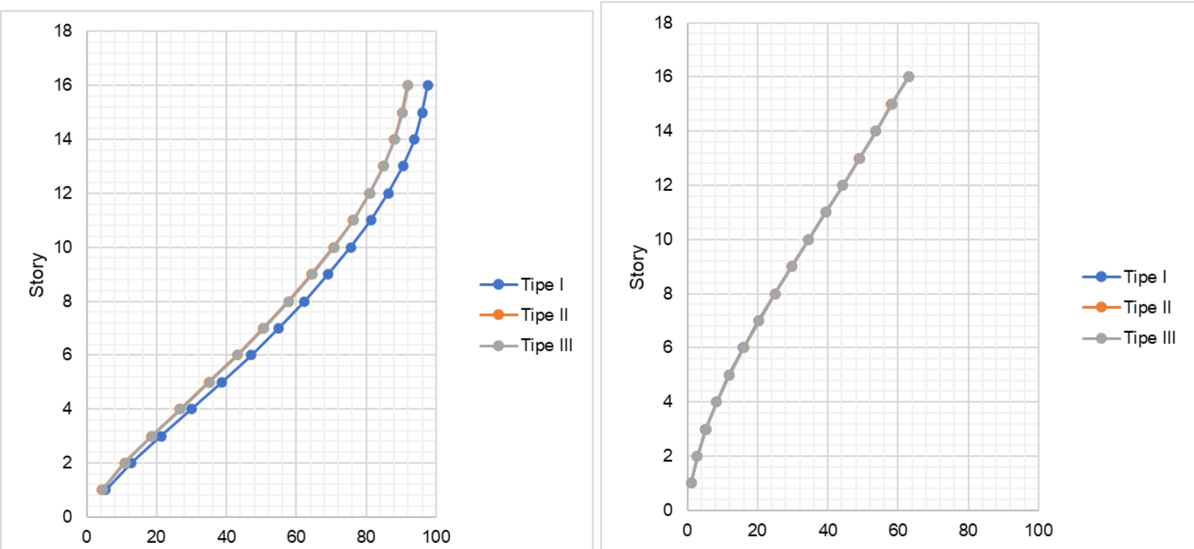

Figure 5 Displacement in X-Direction (Left) and Displacement in Y-Direction (Right)

Based on the structural modeling results, Type I structure with rectangular column cross-section exhibits the largest maximum displacement in the X-direction, reaching 97.575 mm. Meanwhile, the largest maximum displacement in the Y-direction is observed in the Type III structure, which uses square column cross-sections, with a value of 63.052 mm. In contrast, the Type II structure, which utilizes circular column cross-sections, shows the smallest maximum displacements in both X and Y directions, with values of 91.782 mm and 62.966 mm, respectively.

Table 7. Inter-Story Drift in the X-Direction Using Response Spectrum Methods

Story	*h*	Δ*h*	Inter-Story Drift in the X-Direction			Drift Limit
			Tipe I	*Tipe II*	*Tipe III*	
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
16	52800	3500	8.173	8.387	8.448	53.846
15	49300	3200	12.573	12.205	12.227	49.231
14	46100	3200	17.897	17.089	17.078	49.231
13	42900	3200	22.924	21.819	21.786	49.231
12	39700	3200	27.511	26.241	26.202	49.231
11	36500	3200	31.790	30.443	30.404	49.231
10	33300	3200	36.058	34.760	34.733	49.231
9	30100	3200	37.153	36.504	36.537	49.231
8	26900	3200	40.068	39.100	39.116	49.231
7	23700	3200	43.192	41.767	41.756	49.231

Story	***h***	**Δ*h***	**Inter-Story Drift in the X-Direction**			**Drift Limit**
			Tipe I	***Tipe II***	***Tipe III***	
	(mm)	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
6	20500	3200	46.151	44.110	44.077	49.231
5	17300	3200	48.444	45.584	45.540	49.231
4	14100	3200	48.021	44.919	44.908	49.231
3	10900	3200	46.354	42.273	42.350	49.231
2	7700	3200	40.414	35.283	35.651	49.231
1	4500	4500	29.942	24.321	24.893	69.231
Base	0	0	0	0	0	0

Table 8. Inter-Story Drift in the X-Direction Using Response Spectrum Methods

Story	***h***	**Δ*h***	**Inter-Story Drift in the Y-Direction**			**Drift Limit**
			Tipe I	***Tipe II***	***Tipe III***	
	(mm)	**(mm)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
16	52800	3500	26.565	26.450	26.499	53.846
15	49300	3200	25.003	24.904	24.954	49.231
14	46100	3200	25.641	25.553	25.597	49.231
13	42900	3200	26.235	26.158	26.208	49.231
12	39700	3200	26.659	26.593	26.637	49.231
11	36500	3200	26.818	26.763	26.813	49.231
10	33300	3200	26.631	26.604	26.648	49.231
9	30100	3200	26.098	26.087	26.131	49.231
8	26900	3200	25.273	25.289	25.322	49.231
7	23700	3200	24.008	24.024	24.057	49.231
6	20500	3200	22.220	22.248	22.275	49.231
5	17300	3200	19.828	19.855	19.877	49.231
4	14100	3200	16.957	16.984	17.001	49.231
3	10900	3200	13.563	13.607	13.613	49.231
2	7700	3200	9.427	9.482	9.471	49.231
1	4500	4500	5.605	5.715	5.687	69.231
Base	0	0	0	0	0	0

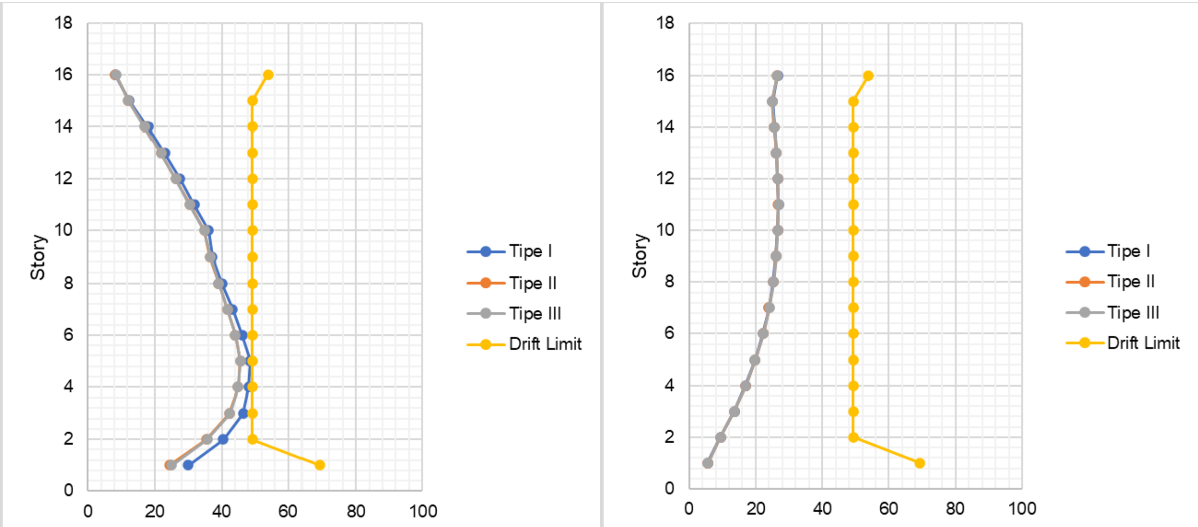

Figure 6 Inter-Story Drift in the X-Direction (left) and Inter-Story Drift in the Y-Direction (right)

The difference in displacement values among the three structural types is caused by the stiffness of the building structure itself. Structural stiffness is a function of the lateral deformation (Δ) resulting from an applied force (P), where stiffness and displacement are inversely related—the smaller the structural displacement, the stiffer the building.

Structural Performance Levels According to ATC-40

The structural performance level in this analysis refers to the criteria established by the Applied Technology Council-40 (ATC-40). The following is an example of determining the structural performance level for a structure using rectangular columns.

Level Kineja Struktur Arah X

Displacement Target	Dt	= 97.575 mm	= 0.0976 m
Displacement Pertama	D1	= 5.444 mm	= 0.0054 m
Tinggi Total Struktur	H	= 52.8m	= 52800 mm
Simpangan Total Maksimum	Dt/H	= 0.0976 /52.8	= 0.001848
Simpangan Inelastik Maksimum	(Dt – D1)/H	= (0.0976-0.0054) /52.8	
		= 0.001745 mm	

Level Kineja Struktur Arah Y

Displacement Pertama	D1	= 1.019 mm	= 0.0010
Tinggi Total Struktur	H	= 52.8 m	= 52800 mm
Simpangan Total Maksimum	Dt/H	= 63.005/52.8	= 0.001193
Simpangan Inelastik Maksimum	(Dt – D1)/H	= (0.0630-0.0010) /52.8	
		= 0.001174	

Table 9. Recapitulation of Structural Performance Level Determination in the X-Direction

Column Type	Roof Floor Drift (m)	D1 (m)	Building Height	Maksimum total drift	Maksimum Inelastic Drift	Structural Performance Level
Persegi Panjang	0.097575	0.005444		0.001848011	0.001744905	IO
Bulat	0.091782	0.004422	52.8	0.001738295	0.001654545	IO
Persegi	0.091946	0.004526		0.001741402	0.001655682	IO

Table 10. Recapitulation of Structural Performance Level Determination in the Y-Direction

Column Type	Roof Floor Drift (m)	D1 (m)	Building Height	Maksimum total drift	Maksimum Inelastic Drift	Structural Performance Level
Persegi Panjang	0.063005	0.001019	52.8	0.001193277	0.001173977	IO

Column Type	Roof Floor Drift (m)	D1 (m)	Building Height	Maksimum total drift	Maksimum Inelastic Drift	Structural Performance Level
Bulat	0.062966	0.001039		0.001192538	0.00117286	IO
Persegi	0.063052	0.001034		0.001194167	0.001174583	IO

Based on the results of the structural performance level analysis under earthquake loads using the response spectrum method for the three column variations, the maximum drift ratios in both the X and Y directions were recorded to be below 0.01, while the maximum inelastic drift ratios were below 0.005. Therefore, the structure of the Jagakarsa Rusunawa Building in Jakarta is classified under the Immediate Occupancy (IO) performance level, indicating that the structure remains protected, sustains only minor damage, and can be reoccupied immediately after an earthquake.

4. CONCLUSIONS

Based on the results of the structural performance level analysis due to earthquake loads using the response spectrum method with various column cross-sectional shapes, the following conclusions can be drawn:

1. The performance level of the Rectangular Column Structure, using a rectangular column cross-section, shows a maximum roof displacement based on response spectrum analysis of 48.444 mm in the X-direction and 26.818 mm in the Y-direction, with maximum lateral displacements of 97.575 mm in the X-direction and 63.005 mm in the Y-direction. Therefore, it falls into the Immediate Occupancy (IO) performance level, where only minor damage occurs during an earthquake, and the structure retains nearly the same strength and stiffness as before the earthquake.
2. The performance level of the Circular Column Structure, using a circular column cross-section, shows a maximum roof displacement of 45.584 mm in the X-direction and 26.763 mm in the Y-direction, with maximum lateral displacements of 91.782 mm in the X-direction and 62.966 mm in the Y-direction. This also falls into the Immediate Occupancy (IO) level, indicating minor damage and that the structure maintains nearly its original strength and stiffness post-earthquake.
3. The performance level of the Square Column Structure, using a square column cross-section, shows a maximum roof displacement of 45.540 mm in the X-direction and 26.813 mm in the Y-direction, with maximum lateral displacements of 91.946 mm in the X-direction and 63.052 mm in the Y-direction. This structure is also categorized under the Immediate Occupancy (IO) performance level, with minimal damage and strength/stiffness retention similar to its pre-earthquake condition.
4. The structural performance levels of all three types—Rectangular, Circular, and Square Columns—fall under the same category, Immediate Occupancy (IO). However, when comparing the roof displacement values, the structure with the Circular Column (Type II) exhibits the smallest displacements—91.782 mm in the X-direction and 62.966 mm in the Y-direction—indicating that this configuration results in the stiffest structural system among the three

REFERENCES

1. Silaban, G. T. N., Tampubolon, S. P., Sri Mulyani, A., & Felestin. (2023). Performance Evaluation of High-rise Buildings with Respons Spectrum Analysis and Time History Analysis. *Science Tech: Jurnal Ilmu Pengetahuan Dan Teknologi*, *9*(1), 84–95. https://jurnal.ustjogja.ac.id/index.php/sciencetech/article/view/14295
2. Safitri, R. A. (2023). Analisis Penentuan Kebutuhan Shear Wall Terhadap Kekakuan Struktur Menggunakan Time History dan Respon Spektrum Pada Gedung Perkuliahan di Tangerang. *Jurnal Teknik*, Vol. 12 No. 01, 48-56.
3. SNI, 1726-2019. (2019). Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung. *Badan Standarisasi Nasional 1726:2019*, *8*.
4. SNI, 1727-2020. (2020). Penetapan Standar Nasional Indonesia 1727 : 2020 Beban Desain Minimum dan Kriteria Terkait Untuk Bangunan Gedung dan Struktur. *Badan Standarisasi Nasional 1727:2020*, *8*, 1–336.