Analysis of Base Shear and Story Drift in the Low-Rise RC Structure

Phil Benson Bong, Ika Bali*

Department of Civil Engineering, President University, Cikarang, Indonesia

Received 16 April 2024; received in revised form 26 April 2024; accepted 27 April 2024

Abstract

Earthquakes frequently occur in Indonesia because it is an earthquake-prone area. Due to lateral load from an earthquake can cause a weakly constructed building to collapse. Designers often only consider tall buildings in designing earthquake-resistant building structures but ignore earthquake-resistant designing for low-rise buildings. This study focuses on the analysis of earthquake resistant structures with a case study of low-rise buildings in the form of a 3-story reinforced concrete (RC) building in the South Jakarta area. The objective of the study is to analyze the base shear and story drift of the structure due to lateral or earthquake loads. The structure is a reinforced concrete with the concrete compressive strength of $\boldsymbol{f'_c}$ = 30 MPa and longitudinal reinforcement of $\boldsymbol{f_y}$ = 420 MPa and stirrups of $\boldsymbol{f_y}$ = 280 MPa. This study uses Equivalent Static analysis manually and using ETABS 20.1.0 application. The results showed that three story buildings analyzed using Equivalent Static analysis method and using ETABS 20.1.0 application had almost the same results on horizontal forces with manual result of 1680.97 kN and ETABS of 1648.46 kN. The elastic story deflection and inelastic story drift in this study are still within safe limits because it is below the drift limit.

Keywords: low-rise, RC structure, earthquake load, base shear, drift ratio

1. Introduction

Indonesia is a country that geographically has unique conditions because it is located on three of the seven large tectonic plates that make up the earth. Indonesia is a country that is prone to earthquakes, both tectonic and volcanic. This is because Indonesia is located on the Pacific Ring of Fire, which means there are many volcanoes, and Indonesia is located at the meeting point of three plates, namely the Indonesia-Australian plate, the Eurasian plate, and the Pacific plate. That is why Indonesia often experiences earthquakes with great frequency [1].

The earthquake transfers energy to the building structure, causing it to shake or sway. During such short periods, the structure of the building will accept both vertical and horizontal forces. Building structures may still be able to withstand vertical forces, but they tend to be weak against horizontal forces. As a result, while designing small structures like residential houses and other simple buildings, structural engineers must count for earthquake loads. Typically, structural engineers only look at tall buildings and disregard residential buildings where the majority of residents live in modest houses [2-5]. Based on available literature reports, most of the buildings damaged or even collapsed due to the earthquake were low-rise buildings, including residential buildings. This needs to be the attention of structural engineers in designing low-rise building structures so that it can reduce casualties due to damage or collapse of the building [6-8].

In 2019, the Indonesia National Standardization Agency revised SNI-1726-2019 [9] concerning the procedures for earthquake resistance designing for building and non-building structures. Designing the earthquake load can be calculated

* Corresponding author. E-mail address: ika.bali@president.ac.id
Tel.: +62(0)21 89109763

using the Equivalent Static analysis, Dynamic Time History, Performance-based, and others. Dynamic Time History analysis is an analysis using earthquake records of certain areas or coordinates, but this method is more intended for high-rise buildings or more than 10 floors. Equivalent Static analysis is an analysis that assumes lateral loads at the working point of each floor. Despite its static nature, the basic value of the shear load is obtained from the principle of pure static, but already considering the principles of dynamics [10]. In this study, the building used as a case study was the low-rise building with 3 stories in Kebayoran Lama, Jakarta. The purpose of this study was to determine the resistance of the structure to the lateral load of the earthquake from the building using Equivalent Static analysis. Specifically, to analyze the base shear and drift ratio of the building structure [11-12]. This study was conducted using the application of ETABS software [13] to make a model of the building structure.

2. Material and Method

In this study, the building structure is a model of an earthquake-resistant concrete frame structure. The structure model, which is located in the Kebayoran Lama, South Jakarta with the soil condition as stiff soil (SD). The Location is about 4 m from the Baribis fault which crossing from Tangerang to Purwakarta as shown in Fig. 1. The Baribis fault is one of the reversal faults that runs around 100 kilometers from Purwakarta regency to the Baribis highlands in Majalengka regency. This fault line, on the other hand, is split into multiple pieces of varying length. One of these fault segments, known as the Jakarta section, also runs south of Jakarta.

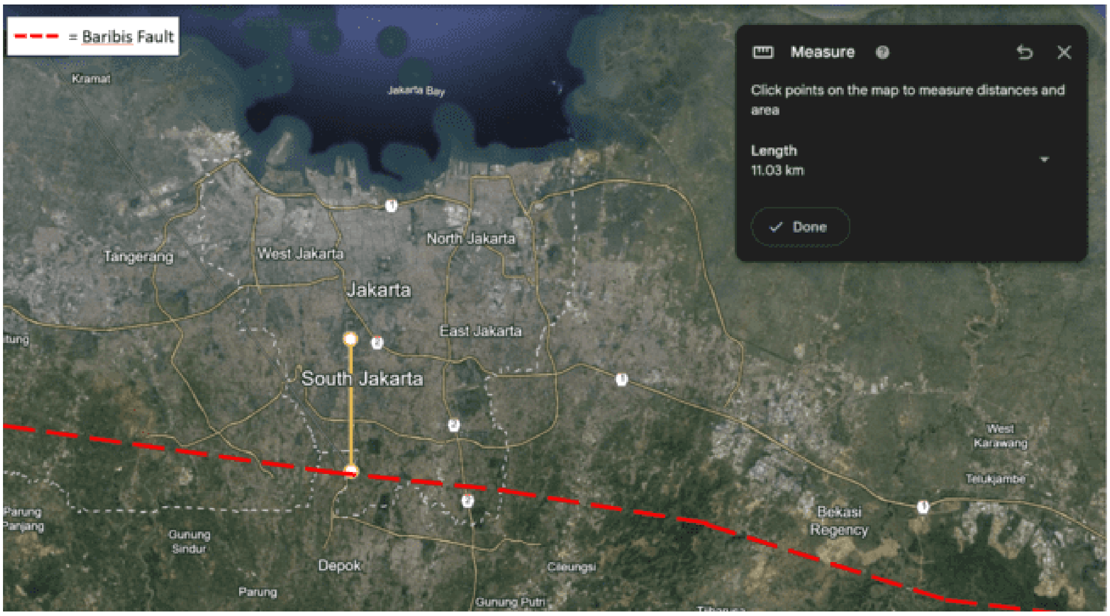


Fig. 1 Location of the building

The structure plan, beam and column section details are shown in Fig. 2, Fig. 3, and Fig. 4, respectively. The 3-dimensional model of structure geometry (Fig. 5) with details as follows. This structure has an elevation from the base or the 1st floor to the 2nd floor of 3.3 m, the 2nd floor to the 3rd floor is 4.5 m, and the 3rd floor to the roof is 3.9 m. The Material properties that use for the structure modelling is concrete quality f'_c = 30 MPa and for the longitudinal rebar f_y is 420 MPa and the transverse rebar f_y is 280 MPa. For structural analysis in this study the ETABS program, version 20.1.0 was used to model the three-story structure of the building. The structure is a reinforced concrete frame with varying elevations for each floor served as the study's structural model.

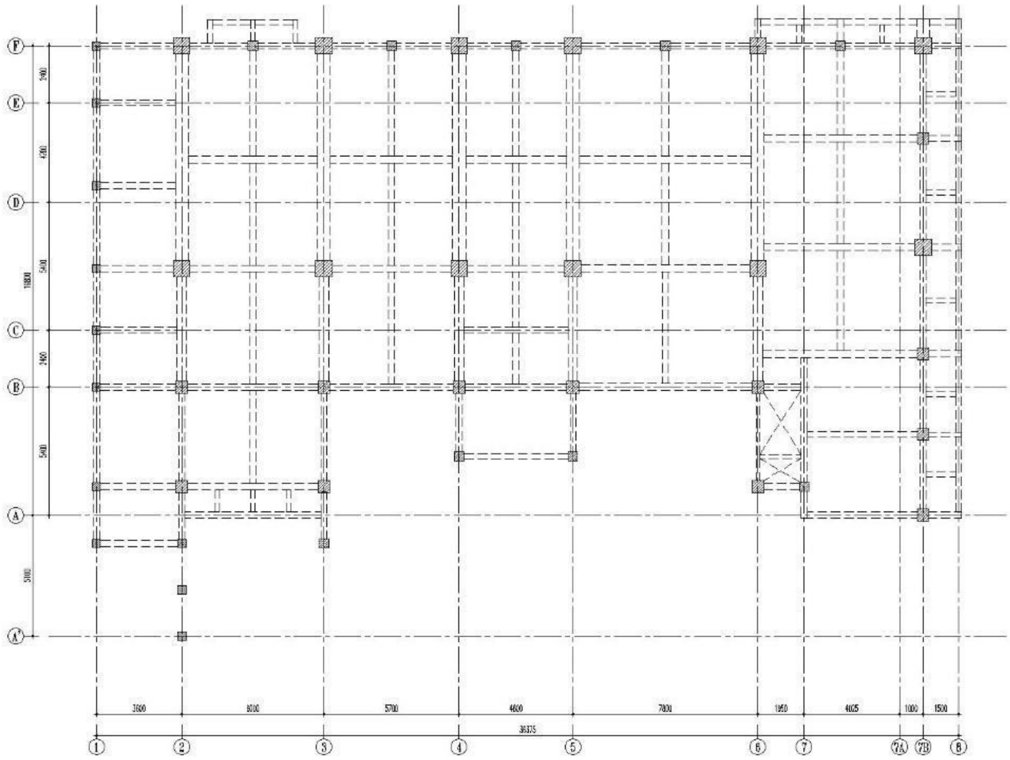
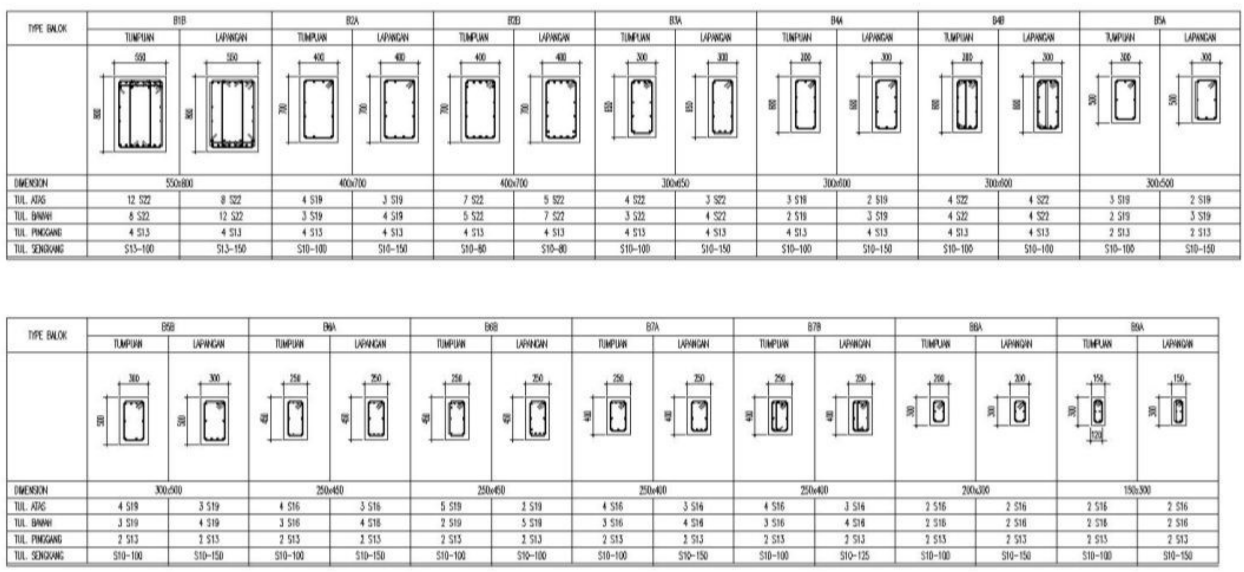


Fig. 2 Structure plan view



TYPE BALOK	B1B		B2A		B2B		B3A		B4A		B4B		B5A	
	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN
DIMENSION	550x800		400x700		400x700		300x650		300x600		300x600		300x500	
TUL. ATAS	12 S22	8 S22	4 S19	3 S19	7 S22	5 S22	4 S22	3 S22	3 S19	2 S19	4 S22	4 S22	3 S19	2 S19
TUL. BAWAH	8 S22	12 S22	3 S19	4 S19	5 S22	7 S22	3 S22	4 S22	2 S19	3 S19	4 S22	4 S22	2 S19	3 S19
TUL. PINGGANG	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	4 S13	2 S13	2 S13
TUL. SENGKANG	S13-100	S13-150	S10-100	S10-150	S10-80	S10-80	S10-100	S10-150	S10-100	S10-150	S10-100	S10-100	S10-100	S10-150

TYPE BALOK	B5B		B6A		B6B		B7A		B7B		B8A		B9A	
	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN
DIMENSION	300x500		250x450		250x450		250x400		250x400		200x300		150x300	
TUL. ATAS	4 S19	3 S19	4 S16	3 S16	5 S19	2 S19	4 S16	3 S16	4 S16	3 S16	2 S16	2 S16	2 S16	2 S16
TUL. BAWAH	3 S19	4 S19	3 S16	4 S18	2 S19	5 S19	3 S16	4 S16	3 S16	4 S16	2 S16	2 S16	2 S16	2 S16
TUL. PINGGANG	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13	2 S13
TUL. SENGKANG	S10-100	S10-150	S10-100	S10-150	S10-100	S10-100	S10-100	S10-150	S10-100	S10-125	S10-100	S10-150	S10-100	S10-150

Fig. 3 Beam section details

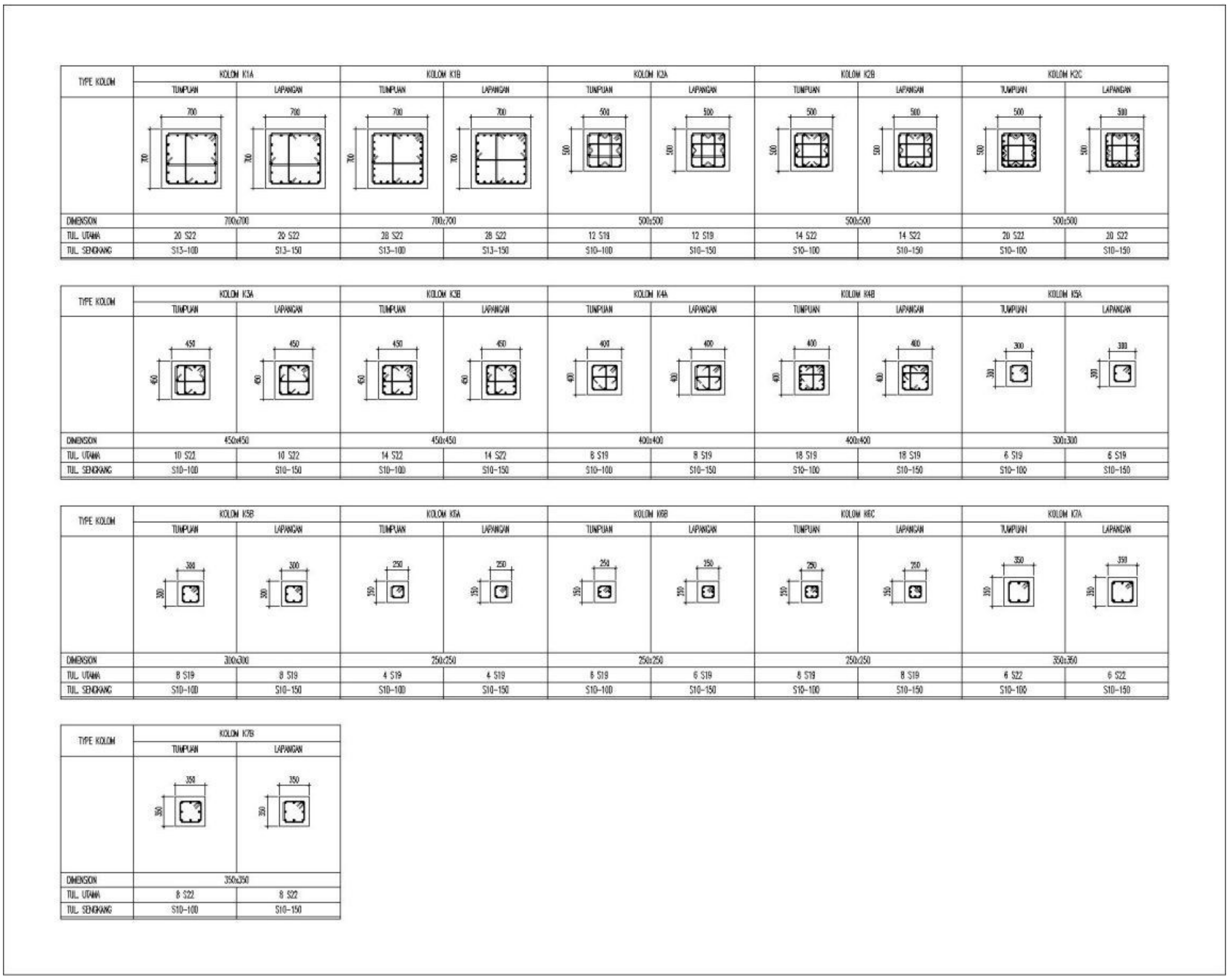


Fig. 4 Column section details

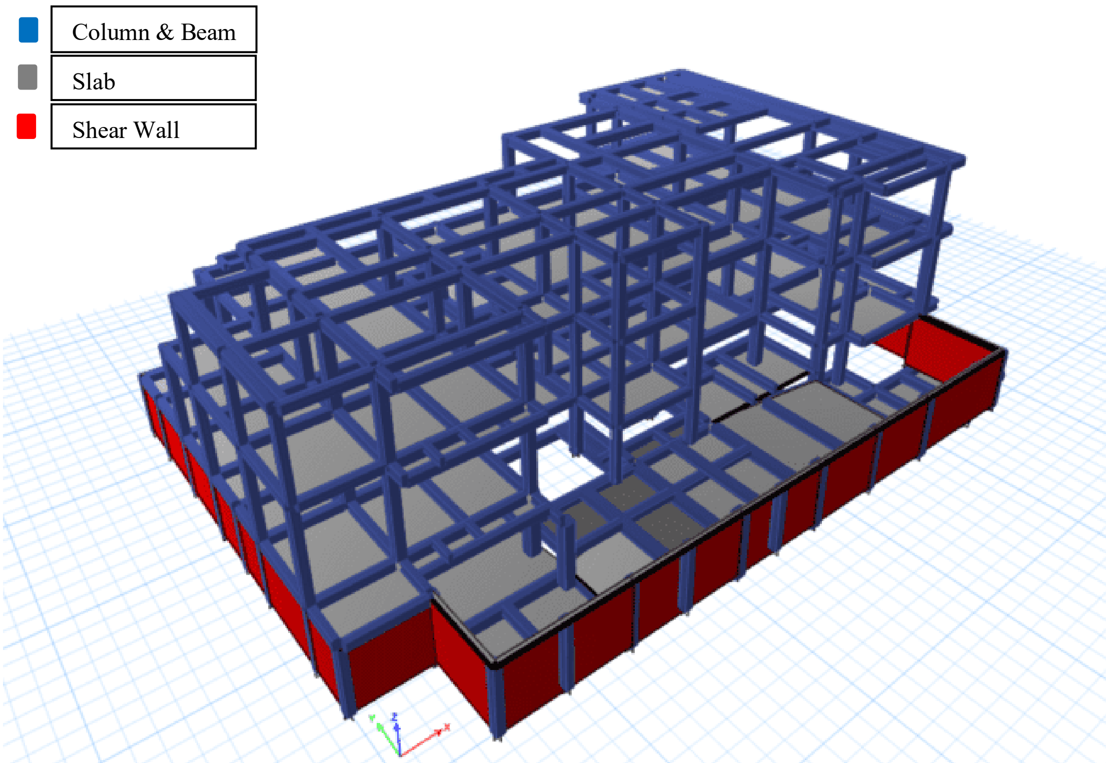


Fig. 5 Structure 3D modelling

The Equivalent Static analysis method is used to obtain base shear and deflection of the structure. To design response spectrum data using Indonesia Spectra Design and response spectrum graphs which are available online [14] as shown in Fig. 6 and Fig. 7. The base shear force, denoted as V, in the designated direction will be calculated by the equation 1. Where Cs is the coefficient for seismic response and $W$is the effective seismic weight (in kg).

$$V = Cs\,.W \tag{1}$$

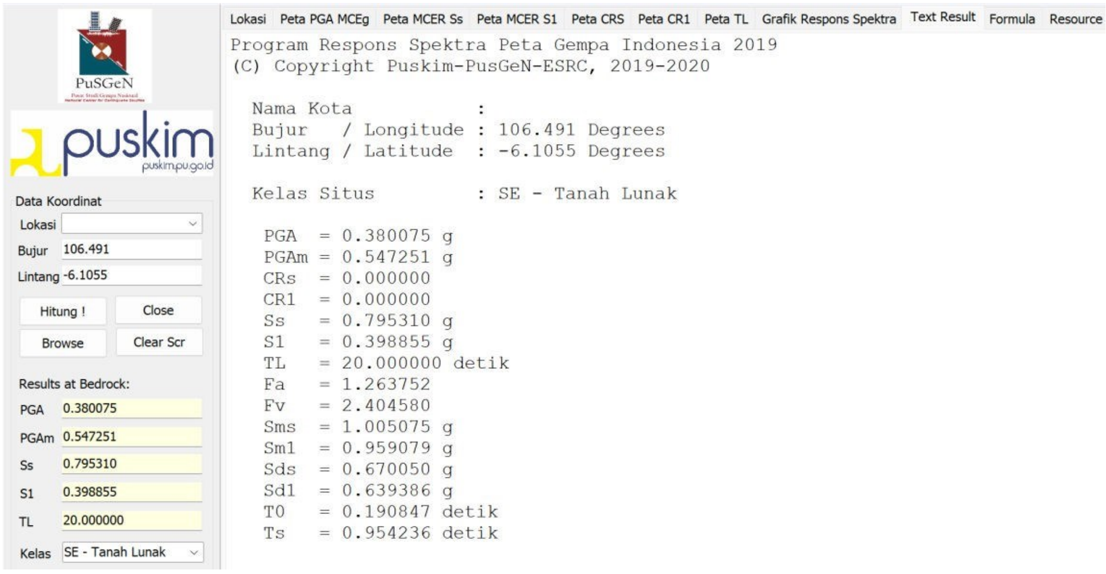


Fig. 6 Design response spectrum data

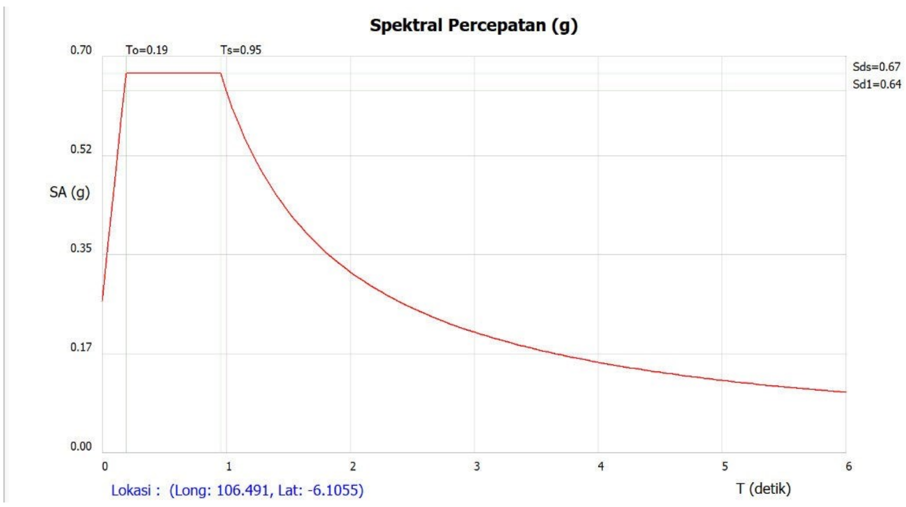


Fig. 7 Design response spectrum

The horizontal seismic force, denoted as Fx, at any given level is to be calculated using the equation 2 and 3. Where Fx is the horizontal seismic forces (in kN), C_{Vx} is the vertical distribution factor, V is the base shear or lateral forces (in kN), w_i and w_x are the percentage of the structure's overall effective seismic weight (W) that is imposed at level i or x, respectively, h_i and h_x are the vertical distance from the base to level i or x (in m), respectively, and k is the power linked to the structure's period, having the subsequent values. For structures with T ≤ 0.5 seconds, is equal to 1, for structures with T ≥ 2.5 seconds, is equal to 2, for structures with 0.5 < T < 2.5 seconds, is equal to 2 or determined by interpolating linearly between 1 and 2.

$$Fx = C_{Vx}.V \tag{2}$$

$$C_{Vx} = \frac{Wx\,.{h_x}^k}{\sum_{i=1}^{n} Wi.{h_i}^k} \tag{3}$$

The seismic design shear at all base levels Vx is calculated using the equation 4. Where Vx is the base shear (in kN) and Fi is the horizontal forces (in kN).

$$Vx = \sum_{i=x}^{n} Fi \tag{4}$$

The following equation is used to calculate the center of mass's deflection at the x-level (δ_x). Where C_d is the deflection amplification factor, δ_{xe} is the deflection at the required location and determined by the elastic analysis (in mm), and I_e is the earthquake priority factor.

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \tag{5}$$

3. Results and Discussion

The structural design check was carried out with ETABS software. The dimensions of the columns and beams that have been determined, then given loading which includes live loads, dead loads, then carried out design checks with ETABS software. The results of the design check are shown with Interactive concrete frame design which illustrates the strength of structural elements in bearing live and dead loads. Unqualified columns or beams will be shown in red in Interactive concrete frame design. The results obtained in the form of interactive concrete frame design figures show that the structure is safe, as shown in Fig. 8.

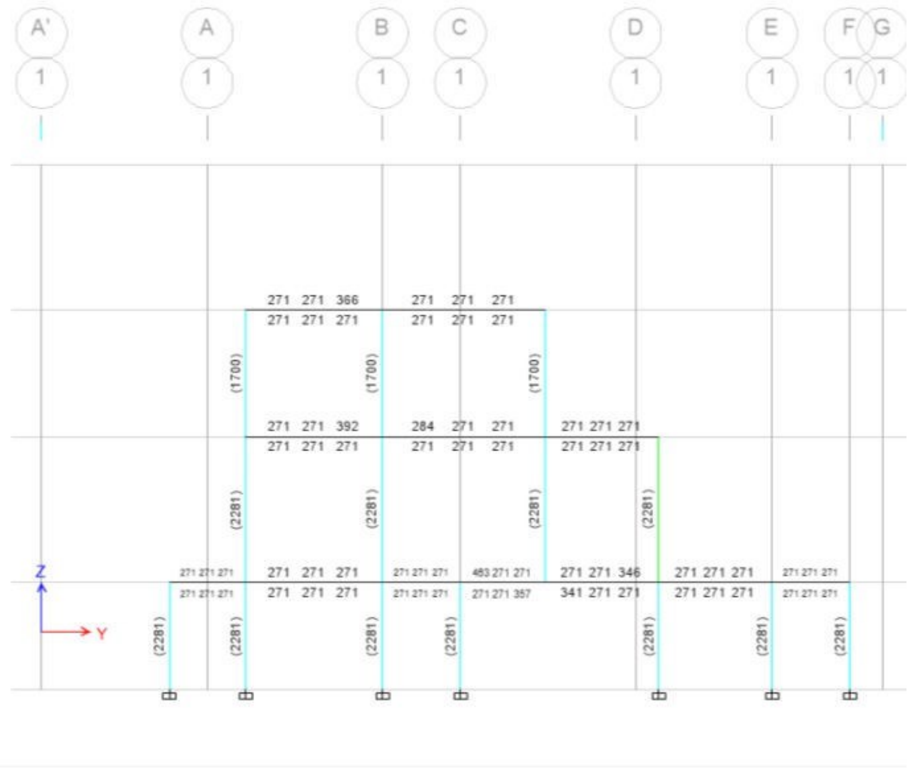


Fig. 8 Interactive concrete frame design

Calculating the weight and mass of the structure is a crucial step in static equivalent analysis. The masses and weight of the structure obtain by sum of dead load + live load + superimposed dead load. Calculation of the weight and mass of the structure can be obtained directly from the analysis using ETABS and can be seen in Table 1. The base shear of structure analyzed using ETABS obtained a result of 1648.46 kN as shown in Table 2. Meanwhile, the result of manual Static Equivalent method analysis is 1680.97 kN (Table 3). This means that the results obtained from ETABS and manually are almost the same. The story deflection is showed in Table 4 with the elastic deflection 18.6 mm at 3rd story and 8.4 mm at 2nd story. The elastic story deflection and the inelastic drift (Fig. 9) show that it is still within safe limits because it is still below the limit of drift.

Table 1 The weight of structure

Story	Elevation (m)	*Wx* (kg)	*Wy* (kg)
3	11.70	153938.2	153938.2
2	7.80	533437.3	533437.3
1 (Semi-basement)	3.30	797579.1	797579.1
Road	1.80	146771.3	146771.3
Ramp	0.90	124376.5	124376.5
Base	0.00	169312.3	169312.3
Total		1756102	1756102

Table 2 Base shear of structure by ETABS

Earthquake Load		*Fx* (kN)	*Fy* (kN)
Static	EQSX	1648.46	0
	EQSY	0	1648.46

Table 3 Horizontal forces per level/story

Story	Elevation (m)	*W* (kg)	H^k	$W.H^k$	CV_x	*F* (kN)
3	11.70	1539.38	13.17	20267.74	0.21	348.03
2	7.80	5334.37	8.61	45919.64	0.47	788.52
1 (Semi-basement)	3.30	7975.79	3.49	27872.53	0.28	478.62
Road	1.80	1467.71	1.85	2717.48	0.03	46.66
Ramp	0.90	1243.77	0.90	1113.74	0.01	19.12
Base	0.00	0.00	0.00	0.00	0.00	0.00
Total		17561.02		97891.13		1680.97

Table 4 Deflection and story drift

Story	Diplacement (mm)		Elastic drift (kg)		*h* (mm)	Inelastic drift (mm)		Drift limit (mm)	Check
	δeX	δeY	δeX	δeY		ΔX	ΔY		
3	18.567	11.060	10.203	5.963	3900	56.117	32.797	60.000	OK
2	8.364	5.097	8.321	5.070	4500	45.766	27.885	69.231	OK
1	0.043	0.027	0.043	0.027	3300	0.237	0.149	50.769	OK

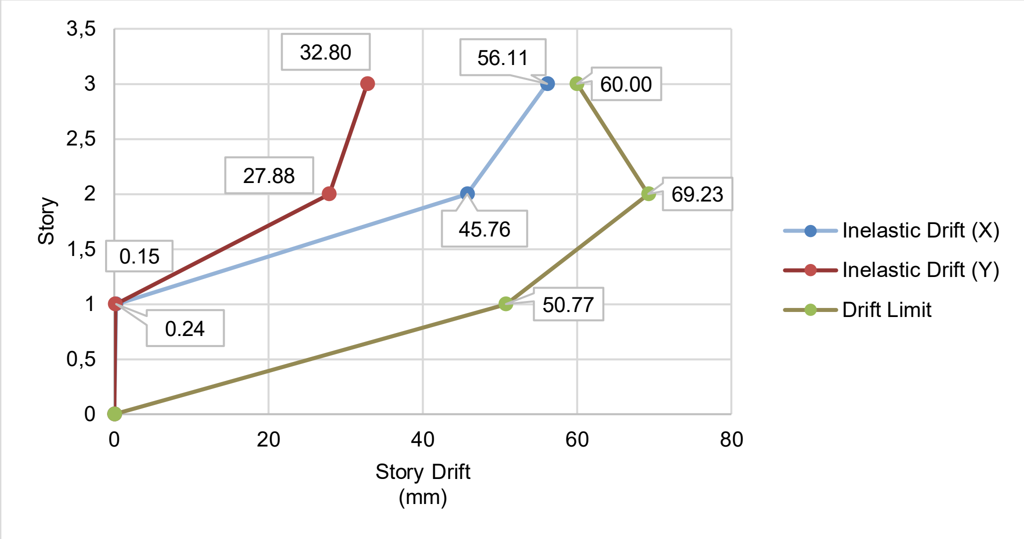


Fig. 9 Inelastic story drifts and drift limits of the building

The first three mode forms that occur in the structure in this study are depicted in Fig. 10 to Fig. 12. The direction of the building's vibration response owing to loads and seismic loads that occur in the building may be identified from the form of the building vibration pattern.

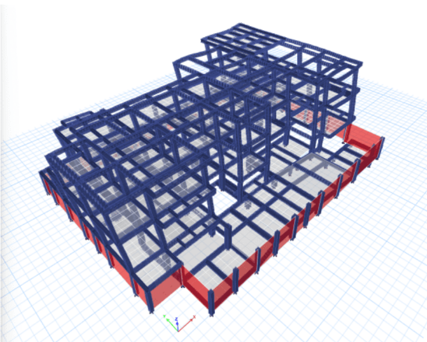


Fig. 10 Mode 1 of the structure

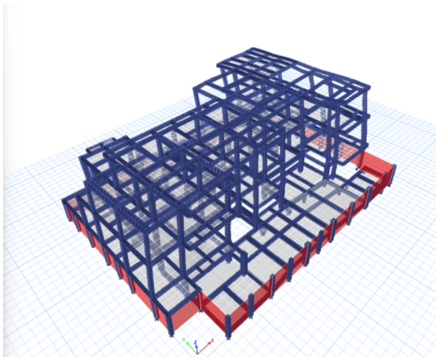


Fig. 11 Mode 2 of the structure

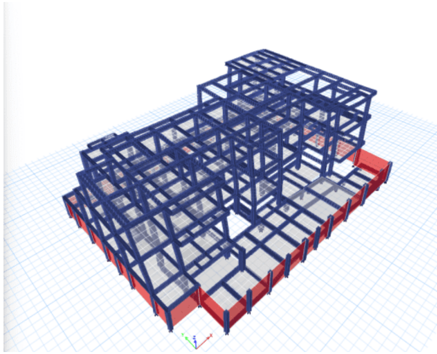


Fig. 12 Mode 3 of the structure

Fig. 10 indicates the first mode shape; the building experienced a translation towards to x-axis with the period is 0.6894 s. The second mode shape is shown in Fig. 11, which the building experienced a translation towards to y-axis with the period is 0.5681 s. While the third mode shape as seen in Fig. 12, the building experienced a translation towards to x-axis and y-axis with the period is 0.5315 s, that means the third mode shape experienced rotation.

Center of mass (*CM*) is the location on a building structure where the mass of the entire structure may be considered concentrated. Meanwhile, center of rigidity (*CR*) is the point on the building structure where lateral displacement occurs without rotation. The position of *CR* has a big impact to the structure drift ratio, if the position of *CR* farther from the *CM*, then the drift ratio value is also greater. Table 5 shows the location of *CM* & *CR* and the eccentricity (*e*). The biggest eccentricity in x-direction is 1.5 m and in y-direction is 6.2 m. According to the Indonesian standard of SNI-1726-2019 [9], eccentricity should not over 10% of the diaphragm length or the center of masses. Based on this analysis, the eccentricity in the x-direction still meets the requirements, and the y-direction does not meet the requirements, but in this case the drift ratio can still be reduced by adding structural components such as shear walls.

Table 5 Center of mass, center of rigidity, and eccentricity

Story	*X-CM* (m)	*Y-CM* (m)	*X-CR* (m)	*X-CR* (m)	e_x (m)	e_y (m)
3	31.8	21.7	30.4	19.2	-1.4	-2.5
2	20.5	16.3	20.3	15.4	-0.2	-0.9
1	18.7	16.3	17.2	22.5	-1.5	6.2

4. Conclusions

Based on the results of the analysis of the earthquake load building structure using the Static Equivalent analysis method manually and the ETABS application, the following conclusions can be drawn. Due to the similarity in the period (T) value between manual and ETABS analysis, the horizontal force value in the Static Equivalent analysis for both methods are almost the same with the manual analysis is 1680.97 kN and ETABS analysis 1648.46 kN. The implications of the structure being subjected to horizontal earthquake force loads from the Static Equivalent analysis were shown to give rise to deflection or story drift, with the limit of drift 50.77 mm for 1st story, 69.23 mm for 2nd story, and 60.00 mm for 3rd story. The story deflection also showed with the elastic deflection 18.6 mm at 3rd story and 8.4 mm at 2nd story. Based on the elastic story deflection and inelastic story drift, this shows that the story deflection due to earthquake loads is still within safe limits because it is still below the limit of drift.

References

[1] N. Maharani, “Sosialisasi dan Mitigasi Gempa Bumi Menggunakan Media Berbasis Virtual Reality pada Panti Asuhan Adzkiyah Alkhair Kecamatan Denpasar Barat, Provinsi Bali,” Jurnal Bakti Saraswati (JBS): Media Publikasi Penelitian dan Penerapan Ipteks, vol. 10, no. 1, 2021. (In Indonesian)

[2] G. F. Waworuntu, M. D. J. Sumanouw, and R. S. Windah, “Evaluasi Kemampuan Struktur Rumah Tinggal Sederhana Akibat Gempa,” Jurnal Sipil Statik, vol. 2, pp. 191–200, 2014. (In Indonesian)

[3] I. Bali, W.W. Kuo, C. Lesmana, B. Suswanto, K.T. Lin, C.C. Chen, J.W. Ko, and S.J. Hwang, “Structural Damage Observation and Case Study of 2006 Yogyakarta Earthquake,” Proc., International Seminar and Symposium on Earthquake Engineering and Infrastructure & Building Retrofitting (EE&IBR), Yogyakarta, Indonesia, Aug. 28, 2006.

[4] I. Bali, An Analytical Study of the Lateral Load-Deflection Curves of Low-Rise RC Shear Walls and Its Application, Ph. D. Dissertation, Dept. of Constr. Engrg., Nat. Taiwan Univ. of Sci. and Technol., Taipei, Taiwan, 2007.

[5] C.C. Chen, K.T. Lin, B. Suswanto, I. Bali, W.W. Kuo, S.J. Hwang, J.W. Ko, “Experiences of 1999 Chichi Earthquake and Observation of 2006 Yogyakarta Earthquake,” International Seminar and Symposium on Earthquake Engineering and Infrastructure & Building Retrofitting (EE & IBR), Yogyakarta, Indonesia Aug. 28, 2006.

[6] I. Bali and S. J. Hwang, “Strength and Deflection Prediction of Double-Curvature Reinforced Concrete Squat Walls,” Structural Engineering and Mechanics: An International Journal, vol. 27, no. 4, pp. 501-521, 2007.

[7] I. Bali and S. J. Hwang, “Prediction of Ultimate Strength and Deflection of Double-Curvature Low Rise Shear Walls,” The 8th Korea-Taiwan-Japan Joint Seminar on Earthquake Engineering for Building Structures (SEEBUS 2006), Nagoya, Japan, 2006.

[8] I. Bali, Low-Rise RC Shear Walls: An Analytical Study of Lateral Load-Deflection Curves and Its Application, Saarbrücken: VDM Verlag Dr. Müller, 2008.

[9] Badan Standardisasi Nasional, Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung, SNI 1726:2019, BSN, 2019. (In Indonesian)

[10] I. Rifandi and E. Walujodjati, “Analisis Beban Gempa dengan Metode Statik Ekuivalen Berdasarkan SNI 1726-2019 pada Gedung Ipal,” Jurnal Konstruksi, vol. 18, no. 2, pp. 72–82, 2021. https://doi.org/10.33364/konstruksi/v.18-2.811 (In Indonesian)

[11] A. B. Siswanto and M. Salim, “Basic Criteria Design of Earthquake Resistant Building Structures,” International Journal of Civil Engineering and Technology, vol. 9, 2018.

[12] H.Pahur, D. Sulistyrini, I. Yasin, and A. Priyanto, "Analisis Struktur Gedung Perkantoran Tiga Lantai di Kabupaten Sleman terhadap Beban Gempa SNI 1726:2019," RENOVASI: Rekayasa dan Inovasi Teknik Sipil vol. 6, no. 2, pp.63-69, 2021.
[13] Computers and Structures, Inc., ETABS v20.1.0, 2022.
[14] Ministry of Public Works and Housing, "Indonesia Spectra Design," 2021. https://rsa.ciptakarya.pu.go.id/2021/