JURNAL MULTIDISIPLIN MADANI (MUDIMA)

(MUDIMA)

Homepage: https://journal.formosapublisher.org/index.php/mudima

ISSN: 2808-5639 (Online)

Research Article

Volume 5, No. 12, December (2025)	DOI: https://doi.org/10.55927/mudima.v5i12.798	Page: 1466-1476

Structural Performance Evaluation of the Sao Paulo Lospalos Parish Building Using Response Spectrum Analysis Based on Story Drift and Maximum Displacement

Fandel Maluw[1], Fardi Kalumata[2], Hendrie Joudie Palar[3], Ahmad Yani Abbas[4], Don Kabo[5*]

Manado State Polytechnic

Corresponding Author: Don Kabo donkabo74@gmail.com

ARTICLEINFO

Keywords: Structural Performance, Response Spectrum Analysis, Story Drift, Maximum Displacement, Life Safety.

Received : 3 October
Revised : 22 November
Accepted : 23 December

ABSTRACT

Southeast Asia, including Timor-Leste, is part of the Pacific Ring of Fire, which is known to be tectonically active. As a result, buildings in this region are highly vulnerable to earthquake loads. Therefore, the planning and evaluation of building structures against seismic forces are critical aspects in ensuring the safety and comfort of building occupants. The method used in this study involves calculations using ETABS software, starting from the modeling of a multi-story building structure, application of loads in accordance with applicable design standards, and response spectrum analysis to evaluate the structural performance under earthquake loading. This research employs dynamic response spectrum analysis, assisted by the ETABS program. The analysis is conducted in accordance with the calculation procedures stipulated in the Indonesian National Standards SNI 03-1726-2019 and SNI 03-2847-2019. The results of the dynamic response analysis based on ATC (Applied Technology Council–40) indicate that the building performance level in both the X and Y directions falls within the Life Safety category. This means that when subjected to an earthquake, the building structure remains safe and does not pose a risk to its occupants. From the displacement calculations due to earthquake loads, the maximum values obtained fromhe response spectrum analysis are 0.03964 m in the X direction and 0.02460 m in the Y direction. The Sao Paulo Lospalos Parish Building satisfies the allowable inter-story drift limits. Furthermore, based on the evaluation of the structural performance level, the maximum total inelastic drift is 0.05897 in the X direction and 0.04821 in the Y direction. Based on these values, the building performance category is classified as Life Safety (LS). In the event of an earthquake, the building does not experience severe damage; however, minor architectural repairs are still required for continued functional use, without affecting the structural performance.

INTRODUCTION

Southeast Asia, including Timor-Leste, is part of the Pacific Ring of Fire, a region characterized by high tectonic activity. As a result, buildings in this area are highly vulnerable to seismic loads. Therefore, structural planning and performance evaluation against seismic forces are critical aspects in ensuring the safety, comfort, and functional sustainability of buildings, particularly public service facilities.

The Sao Paulo Parish Building, located in Lospalos, Timor-Leste, is a public building with significant social and religious functions for the local community. With the increasing intensity of community activities and building utilization, a comprehensive structural evaluation is required to ensure that the building is capable of providing adequate protection against seismic loads in accordance with modern design standards (Purnomo, 2014). This evaluation is particularly important given that the building is situated in a region with a high seismic design category.

One of the most commonly applied methods for evaluating structural performance under seismic loading is response spectrum analysis, which allows the estimation of structural dynamic responses without the need for detailed time-history analysis, while still accounting for the characteristics of the local seismic response spectrum (Marwanto, 2014). In structural performance evaluation, the primary parameters analyzed include story drift and maximum displacement, as these parameters directly affect occupant comfort as well as the overall integrity and safety of the structure (Darmawan et al., 2021).

In this study, structural modeling and analysis are conducted using ETABS software, which has become an industry standard for analyzing and modeling multi-story buildings due to its high accuracy in simulating structural behavior and its compatibility with Building Information Modeling (BIM) systems to enhance modeling efficiency (Kalumata et al., 2024). By employing response spectrum analysis using ETABS, this research aims to evaluate the seismic response of the Sao Paulo Parish Building in Lospalos based on story drift and maximum displacement limits, as well as to determine the structural performance level according to seismic performance criteria. The findings are expected to provide technical recommendations for preventive and corrective measures, particularly minor architectural improvements that do not affect the main structural performance, while also contributing as a technical reference for the maintenance and seismic strengthening of existing public buildings in earthquake-prone regions.

METHODS

The method employed in this study involves calculations using ETABS software, beginning with the modeling of a multi-story building structure, the application of loads in accordance with applicable design standards, and response spectrum analysis to evaluate the structural performance under seismic loading. The results of this analysis can provide recommendations for improvements or enhancements to the structural design in order to increase the comfort and safety of building occupants (Prismastanto, 2019).

This research method adopts dynamic response spectrum analysis, assisted by the ETABS program. The analysis is carried out in accordance with the calculation procedures specified in the Indonesian National Standards SNI 03-1726-2019 (1726, 2019) and SNI 03-2847-2019 (BSN, 2019). The data collected in this study include shop drawings, structural calculation reports, and soil investigation results. The next step involves calculating and determining the types of loads acting on the structure, which consist of dead loads, live loads, and seismic loads.

Soil investigation data and the structural importance factor are used to generate the response spectrum curve according to the seismic zone of the study area, with the assistance of the ETABS program. Subsequently, the ETABS model is analyzed by running the program. The output results of this analysis include displacement, drift, and base shear. In addition, the structural calculation report is essential for assessing the strength and overall safety of the building.

Table 1. General Data of the Sao Paulo Lospalos Church Building

No.	Building Description	Specification
1	Building Function	Place of Worship
2	Seismic Design Category	D
3	Seismic Force-Resisting System	Special moment-resisting steel frame and composite concrete system
4	Number of Stories	2 Stories
5	Story Height	4.5 m
6	Total Building Area	4,702 m²

RESULTS AND DISCUSSION

The material properties, particularly the reinforcement used in this building, consist of main reinforcing steel with yield strengths of fy = 420 MPa and 280 MPa, while the type of reinforcing steel applied is BJp 41. The concrete compressive strength is f'c = 30 MPa for composite columns and f'c = 25 MPa for beams and floor slabs. The modulus of elasticity of steel is taken as Es = 200,000 MPa.

The total structural weight used for calculating the base seismic force is obtained from the ETABS software, as presented in the table below

Table 2. Structural Weight of Each Story

Stor / Elevation	Weight (kg)
Level 7	1,622.17
Level 6	65,005.64
Level 5	95,440.30
Level 4	259,826.80
Level 3	446,537.90
Level 2	55,329.86
Level 1	1,852,397.51
Base	263,884.25
Total Structural Weight	**2,776,160.18**

Subsequently, the response spectrum graph was obtained using the Design Spectra service provided by the Directorate General of Human Settlements (PUSKIM) through the following website: https://rsa.ciptakarya.pu.go.id/2021/. After obtaining the response spectrum parameters from the website, the values were recalculated manually in accordance with SNI 1726-2019 to ensure consistency between the web-based results and the manual calculations.

The seismic parameters obtained from the website are as follows: Ss = 0.969 g and S1 = 0.367 g. The site coefficients Fa = 1.112 and Fv = 1.933 were determined through interpolation based on Tables 4 and 5 of SNI 03-1726-2019. Using these parameters, the design spectral acceleration values were calculated using the following equations:

$$S_{DS} = \frac{2}{3} \times F_a \times S_S \quad (1)$$

$$S_{D1} = \frac{2}{3} \times F_v \times S_1 \quad (2)$$

Based on Equations (1) and (2), the resulting values are S_{DS} = 0.719 g and S_{D1} = 0.473 g. The charact eristic periods of the response spectrum were then calculated using:

$$T_0 = 0{,}2 \left(\frac{S_{D1}}{S_{D1}}\right) \quad (3)$$

$$T_0 = \frac{S_{D1}}{S_{DS}} \quad (4)$$

The spectral acceleration (Sa) values for different vibration periods were defined according to SNI 1726-2019 as follows:

$$S_a = 0.4_{DS}\text{ , for } T \quad (5)$$

$$S_a = S_{DS}\text{ , for } T_0 < T < T_S \quad (6)$$

$$S_a = S_{DS}\left(0.4 \div 0.6\,\frac{T}{T_0}\right) \quad (7)$$

$$S_a = \frac{S_{D1}}{T}\text{ , for } T > T_S \quad (8)$$

Based on the above equations, the seismic response spectrum curve was constructed. Figure X presents the comparison between the response spectrum obtained from the Design Spectra website and the response spectrum generated through manual calculations in accordance with SNI 1726-2019.

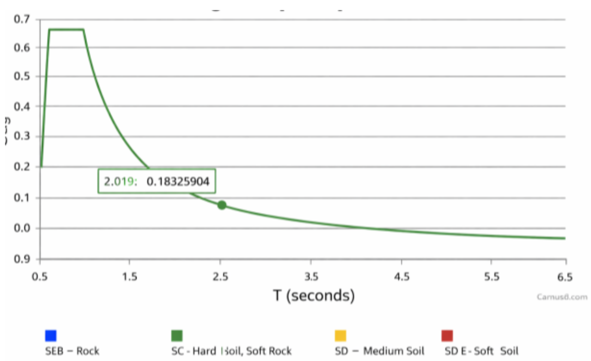


Figure 1. Response Spectrum Curve Graph from Website

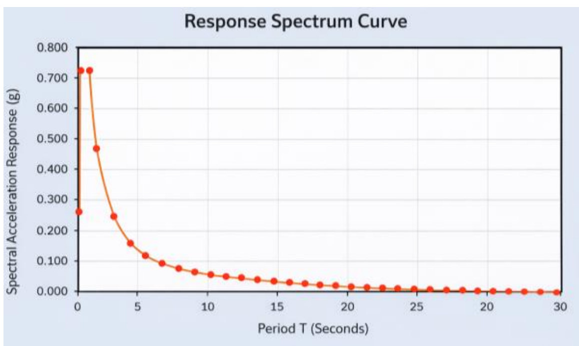


Figure 2. Response Spectrum Graph Based on Calculation Results

Fa	:	1.1124
Fv	:	1.9330
S_{MS}	:	1.0779
S_{M1}	:	0.7094
S_{DS}	:	0.7186
S_{D1}	:	0.4729
T_0	:	0.1316
T_S	:	0.6581
T_L	:	12.0000

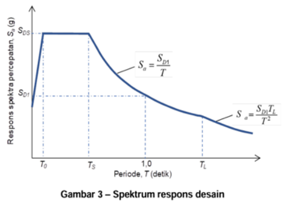


Figure 3. Response Spectrum Graph Parameters

Calculation of Structural Vibration Period

Referring to SNI 03-1726-2019 article 7.8.2, the fundamental period of the structure, T, in the direction under consideration must be obtained using the structural properties and deformation characteristics of the supporting elements in the tested analysis. The vibration time of the structure is limited by maximum and minimum values.

- X-Direction Vibration Period

Minimum Ta = $Ct.hn^x$ 9

Ct = 0.0488 (Table 18 of SNI 03-1726-2019) 10

X = 0.75 (Table 18 of SNI 03-1726-2019)

hn = 21.0 m (Building Height)

Based on equation 9, the minimum Ta value is 0.363 seconds.

Maximum Ta = Cu. Minimum Ta 11

Cu value = 1.4 (Table 17 SNI 03-1726-2019),

From equation 11, the maximum Ta value is 0.508 seconds.

The natural vibration period of the building from the ETABS program in the X direction is 1.531 seconds. Because the Ta in ETABS is greater than the maximum requirement, the maximum Ta value is used, namely 0.508 seconds.

- Vibration Period in the Y direction

The minimum and maximum Ta values in the y direction are the same as the value in the x direction.

Minimum Ta = 0.363 seconds

Maximum Ta = 0.508 seconds

Because the Ta in ETABS is greater than the maximum requirement, the maximum Ta value is used, namely 0.508 seconds.

Seismic Response Coefficient (Cs)

Based on SNI 03-1726-2019 Article 7.8, 7.8.1, the procedure for determining the seismic base shear value V in the specified direction must be determined using the following equation:

V = Cs x W 12

• Calculation of the Cs value in the X direction

Minimum Cs = 0.044 SDs Ie > 0.01 13

SDs = 0.719

Ie = 1.5 Earthquake priority factor for Places of Worship

Based on equation 13, the minimum Cs value is 0.0251

Maximum Cs $\frac{S_{D1}}{T\left(\frac{R}{I_e}\right)}$ 14

Sd1 = 0.4729

R = 8 (Modification factor coefficient value)

T = 0.508

Ie = 1.50

Based on the equation 14, the maximum Cs value is 0.185.

Calculate Cs = $\frac{S_{DS}}{\left(\frac{R}{I_e}\right)}$ 15

SDs = 0.4729

R = 8 (Modification factor coefficient value)

Ie = 1.5

Based on equation 15, the Cs value obtained is 0.1347. Because the Cs value is smaller than the Cs max and greater than the Cs min value, a Cs value of 0.1347 is used. From the results of equations 13, 14, and 15, the base shear force value is taken based on equation 12: V = Cs x W. The base shear force is 0.1347 x 2776160.18 kg = 3668.39 kN.

VERTICAL DISTRIBUTION OF EARTHQUAKE SHEAR FORCE (FX)

The calculated seismic base shear force is then distributed to all floors as a lateral earthquake force (Fx), the magnitude of which is determined as follows.

$$F_x = C_{vx} \, x \, V \quad (16)$$

$$C_{vx} = \frac{W_x \, h_x^{\,k}}{\sum_{i=1}^{n} W_i \, h_i^{\,k}} \quad (1)$$

Cvx = Vertical distribution factor of earthquake force
V = Lateral force or structural shear force
Wi and Wx = weight of structural level
Hi and hx = base height to level i

The results of the earthquake force distribution calculation can be seen in the following tabl

Table 1. Vertical Distribution of Earthquake Force

H	**H_i (m)**	**W_i (kN)**	**$W_i H_i^{\,k}$ (kN.m)**	**C_{VX}**	**F_x (kN)**	**V_x (kN)**	**W_i (kg)**
3.3	3.30	18166.46	59,949.3	0.38	1404.822	3660.557	1852397.51
3.25	6.55	542.62	3,554.2	0.02	83.286	2255.735	55329.86
1.25	7.80	4379.20	34,157.7	0.22	800.435	2172.448	446537.90
4.5	12.30	2548.12	31,341.9	0.20	734.450	1372.013	259826.80
4.5	16.80	935.98	15,724.5	0.10	368.480	637.563	95440.30
1.212	18.01	637.51	11,482.8	0.07	269.083	269.083	65005.64
3	21.01	15.91	334.3	0.00	7.833	7.833	1622.17
	21.012	27225.80	156,544.74		3668.39		2776160.18

The results of the distribution of lateral shear forces can be seen in the following image:

Story Shear Distribution		
St	Hi (m)	Vx (kN)
7	0.00	0.000
6	16.80	269.083
5	18.01	637.563
4	12.30	1372.013
3	7.80	2172.448
2	6.55	2255.735
1	3.30	3660.557
Base	0.00	0

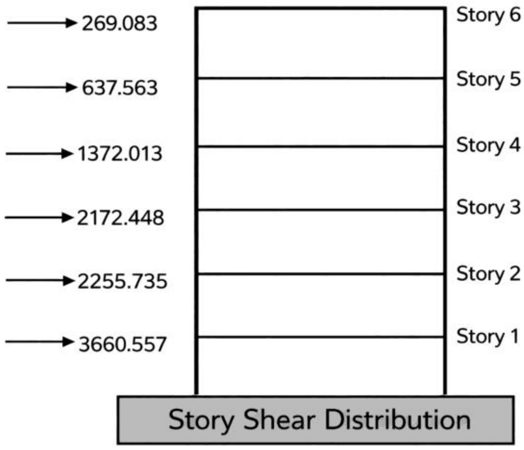
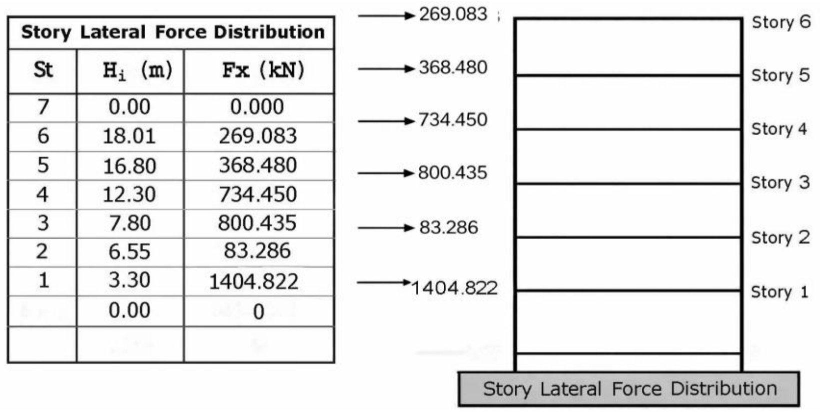


Figure 4. Distribution of Lateral Forces at Level



Story Lateral Force Distribution		
St	H_i (m)	Fx (kN)
7	0.00	0.000
6	18.01	269.083
5	16.80	368.480
4	12.30	734.450
3	7.80	800.435
2	6.55	83.286
1	3.30	1404.822
	0.00	0

Figure 5. Distribution of Shear Forces Level

Earthquake Base Shear Force (Fx)

Based on SNI 03-1726-2019, the base shear force obtained from dynamic response spectrum analysis shall be at least 85% of the base shear calculated from static analysis. If the resulting base shear from the dynamic analysis is less than 85% of the static base shear value, the response spectrum ordinates must be multiplied by a scaling factor.

$$FS = \frac{0.85.V\ Static}{V\ Dynamic} \qquad (18)$$

Fs = Scale factor

Table 4. Unscaled Basic Shear Forces

TABLE: Base Reactions			*Unscaled*	
Output Case	Case Type	Step Type	FX	FY
			kN	kN
EQX	Linstatic	Step By Step	3738.45	0.00
EQY	Linstatic	Step By Step	0.00	3639.18
RS-X	Linrespspec	Max	643.86	2.41
RS-Y	Linrespspec	Max	2.41	770.39

Table 5. Scaled Basic Shear Forces

TABLE: Base Reactions			*Unscaled*		Earthquake Force Scaling	
Output Case	Case Type	Step Type	FX	FY	Scale Factor	Scale Factor
			kN	kN	RS - X	RS - Y
EQX	Linstatic	Step By Step	3738.45	0.00		
EQY	Linstatic	Step By Step	0.00	3639.18		
RS-X	Linrespspec	Max	643.86	2.41	**5.8063**	
RS-Y	Linrespspec	Max	2.41	770.39		**4.7238**

Table 6. Scaled Basic Shear Forces

TABLE: Base Reactions			Fix Scaled	
Output Case	Case Type	Step Type	FX kN	**FY** kN
EQX	LinStatic	Step By Step	3738.45	0.00
EQY	LinStatic	Step By Step	0.00	3639.18
RS-X	LinRespSpec	Max	3738.42	
RS-Y	LinRespSpec	Max		3639.169

Displacement Analysis Results and Building Performance

After performing structural modeling, loading, and run analysis using ETABS software, the inter-story displacements for various load combinations were obtained. The largest value was then selected, and a displacement analysis was performed to verify the building's serviceability and ultimate performance.

Table 7. Load Combination Table

No	Load Combination	Load Combination Description
1	1.4 D	1.4 D + 1.4 SDL
2	1.2 D + 1.6 LL	1.2 D + 1.6 SDL + 1.6 LL
3	0.9 D + 1.0 E	0.9 D + 0.9 SDL + 1.0 EQx / RSPx
4		0.9 D + 0.9 SDL + 1.0 EQy / RSPy
5		0.9 D + 0.9 SDL - 1.0 EQx / RSPx
6		0.9 D + 0.9 SDL - 1.0 EQy / RSPy

Table 8. Story Drift in X Direction due to Static Earthquake

Story Drift Direction X due to Static Earthquake						
Level	Floor Height	Elastic	Story Drift	Amplified Drift	Allowable Story Drift	Info
	h_{sx} (mm)	δ_{xe} (mm)	Δ_x (mm)	δ_x (mm)	Δ_a (mm)	
4000	4000.00	0.0900	0.0900	0.33	80.00	Safe
8500	4500.00	5.1100	5.0200	18.41	90.00	Safe
13000	4500.00	11.9600	6.8500	25.12	90.00	Safe
16000	3000.00	7.3245	4.6355	17.00	60.00	Safe
20500	4500.00	29.109	21.7845	79.88	90.00	Safe

Table 9. Story Drift in Y Direction due to Static Earthquake

Story Drift Direction Y due to Static Earthquake						
Level	Floor Height	Elastic	Story Drift	Amplified Drift	Allowable Story Drift	Info
	h_{sx} (mm)	δ_{ye} (mm)	Δ_y (mm)	δ_x (mm)	Δ_a (mm)	
4000	4000	0.171	0.171	0.63	80.00	Safe
8500	4500	5.3	5.129	18.81	90.00	Safe
13000	4500	6.263	0.963	3.53	90.00	Safe
16000	3000	15.628	9.365	34.34	60.00	Safe
20500	4500	0	15.628	57.30	90.00	Safe

Table 10. Story Drift in X direction due to dynamic earthquake load

Level	Floor Height	Elastic	Story Drift	Allowable Story Drift	Info
	h_{sx} (mm)	δ_{xe} (mm)	Δ_x (mm)	Δ_a (mm)	
4000	4000	6.53	6.53	80.00	Safe
8500	4500	14.4	7.87	90.00	Safe
13000	4500	18.78	4.38	90.00	Safe
16000	3000	19.34	0.56	60.00	Safe
20500	4500	58.97	39.63	90.00	Safe

Table 11. Story Drift in Y direction due to dynamic earthquake load

Level	Floor Height	Elastic	Story Drift	Allowable Story Drift	Info
	h_{sx} (mm)	δ_{ye} (mm)	Δ_y (mm)	Δ_a (mm)	
4000	4000	7.22	7.22	80.00	Safe
8500	4500	16.01	8.79	90.00	Safe
13000	4500	22.82	6.81	90.00	Safe
16000	3000	23.61	0.79	60.00	Safe
20500	4500	48.21	24.6	90.00	Safe

Based on the table of results of the calculation of the inter-story deviation and the maximum permissible deviation, the Paraqouia Sao Paulo Lospalos Building is safe against earthquake loads.

Next, calculations were made on the structural performance value using ATC 40 (ATC-40, 1996).

Table 2. Performance Level ATC-40

Parameter	***Performance Level***			
	IO	***Damage Control***	**LS**	***Structural Stability***
Maksimum Total *Drift*	0,01	0,01 s.d 0,002	0,02	0,33 Vi/Pi
Maksimum Total Inelastik *Drift*	0,005	0,005 s.d 0,015	*No Limit*	*No Limit*

Based on table 12, an analysis is then carried out on the maximum deviation values in the X and Y directions due to dynamic earthquake loads. The results of this analysis are in the form of building performance parameters such as IO (immediate occupancy), LS (Life Safety), CP (collapse prevention). The results of the analysis are presented in the following table:

Table 13. Building Performance Levels Based on ATC-40

Parameter	Equivalent Static		Response Spectrum	
	X-Direction	Y-Direction	X-Direction	Y-Direction
Maksimum Total Drift	0.02178	0.015628	0.03964	0.02460
Performance level	*Life Safety (LS)*	*Life Safety (LS)*	*Life Safety (LS)*	*Life Safety (LS)*
Maximum Total Inelastic Drift	0.07988	0.07530	0.05897	0.04821
Performance level	*Life Safety (LS)*	*Life Safety (LS)*	*Life Safety (LS)*	*Life Safety (LS)*

The results of the dynamic response analysis based on ATC (Applied Technology Council–40) indicate that the building performance level in both the X and Y directions falls within the Life Safety category. This means that when subjected to an earthquake, the building structure remains safe and does not pose a risk to occupants. The building does not experience severe structural damage; however, minor architectural repairs are still required to restore its functional use, without affecting the structural performance.

CONCLUSION

Based on the results of structural modeling, load application, and response spectrum analysis in both the X and Y directions, the obtained base shear forces exceed 85% of the equivalent static base shear values. Therefore, it can be concluded that the final dynamic structural response of the building under nominal seismic loading satisfies the requirements of SNI 03-1726-2019. From the displacement analysis due to earthquake loading, the maximum response spectrum displacement is 0.03964 m in the X direction and 0.02460 m in the Y direction. The Sao Paulo Parish Building in Lospalos meets the allowable interstory drift limits and is considered safe. Furthermore, based on the evaluation of the structural performance level, the maximum total inelastic drift values are 0.05897 in the X direction and 0.04821 in the Y direction. Accordingly, the building performance category is classified as **Life Safety (LS)**. In the event of an earthquake, the building does not suffer severe damage; however, minor architectural repairs are still necessary to restore functionality, without affecting the structural performance.

REFERENCES

SNI 1726. (2019). *Development of science and technology, maintenance, and feasibility assessment of buildings and non-building structures as a revision of structural design provisions for buildings and non-building structures; State Gazette of the Republic of Indonesia*. National Standardization Agency of Indonesia (BSN).

ATC-40. (1996). *Seismic Evaluation and Retrofit of Concrete Buildings*. Redwood City, CA: Applied Technology Council.

BalaBalaji, Y., & Yesuratnam, G. (2022). *Analytical study on response spectrum analysis of different earthquake-resistant models using ETABS.*

BSN. (2019). *Indonesian National Standard (SNI) 2847:2019—Structural concrete requirements for buildings and explanatory provisions as a revision of SNI 2847:2013*. National Standardization Agency of Indonesia.

Bunitte, R. N. (2024). *Comparative analysis of seismic response of medium-rise reinforced concrete buildings subjected to earthquakes using the* *equivalent static method and response spectrum method based on SNI 1726-2019* (Doctoral dissertation, Indonesian Christian University).

Darmawan, R. R., Susanti, E., & Fitriyah, D. K. (2021). *Comparative study of response spectrum parameters between SNI 1726-2012 and SNI 1726-2019 with a case study of Building C, STIE Perbanas*. Proceedings of the Seminar on Planning, Design, Environment, and Infrastructure Technology, 139–145.

Kalumata, F., Palar, H. J., & Maluw, F. (2025). *Optimization of steel column design with Tekla Structures to minimize embodied carbon*. Jurnal Multidisiplin Madani, 5(4), 295–304.

Kalumata, F., Tanijaya, J., & Bungin, E. R. (2024). *Analysis of the implementation of Building Information Modeling (BIM) in accelerating the construction of the Manado Students' Dormitory*. Proceedings of the International Conference on Engineering & Applied Science and International Conference on Social Science (ICEA & ICSS), 1(1), 9–19.

Marwanto, A. (2014). *Performance evaluation of a 10-story building structure using pushover analysis on drift and displacement with ETABS software (Case study: Hotel in the Surakarta region)*.

Nair, S., Hemalatha, D. G., & Muthupriya, D. P. (2017). *Response spectrum analysis and design of a case study building*. International Journal of Civil Engineering and Technology, 8(8), 1227–1238.

Prismastanto, N. (2019). *Response spectrum analysis method for multi-story building structures*. MoDuluS: Media Komunikasi Dunia Ilmu Sipil, 1(1), 25. https://doi.org/10.32585/modulus.v1i1.378