Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

Structural Design of a 10-Story Office Building using the Special Moment Frame System (SMFS) in Padang, West Sumatra

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Received 18th August 2024; Revision 10th September 2024; Accepted 30th September 2024

ABSTRACT

Indonesia is located at the convergence of the Eurasian, Pacific, and Indo-Australian tectonic plates, making it prone to significant earthquakes, such as the Aceh earthquake and tsunami in 2004 with a magnitude of 9.1, and the Padang earthquake in 2009 with a magnitude of 7.6, both known for their severe impacts. According to the Central Statistics Agency (BPS), there were 10,843 earthquakes in 2022. Given this high level of risk, all buildings, especially offices, must be designed to be earthquake-resistant due to high activity and user numbers. The city of Padang is categorized in Seismic Design Category D, indicating a high level of earthquake risk. The construction of a ten-story reinforced concrete building for office use is planned, referring to SNI 1726-2019 on earthquake resistance and SNI 1727-2020 on minimum loads, along with the Special Moment Resisting Frame System (SMRF). Structural analysis and modeling are conducted using ETABS software, with element dimensions based on the initial design. This analysis aims to ensure the building meets earthquake resistance requirements through response spectrum evaluation, including natural periods, inter-story drift, P-Delta effects, and checks for irregularities. Based on internal forces from ETABS V.18, reinforcement designs are prepared for structural elements such as columns, beams, slabs, and shear walls. A design capacity evaluation ensures the safety and optimal performance of the structure during an earthquake.

Keywords: *Earthquake Resistance; Seismic Design Category; Special Moment Resisting Frame (SMRF); Response Spectrum Analysis; ETABS.*

INTRODUCTION

Indonesia is witnessing an annual increase in high-rise building projects. According to Wunarlan and Syaf, this increase is driven by population growth and rising land use. This growth contradicts the availability of existing land, making high-rise construction a viable solution. By constructing tall buildings, the challenges posed by limited land and the need for infrastructure due to population growth can be fully addressed. However, comprehensive and in-depth analysis is necessary to plan high-rise construction due to Indonesia's location and geographic conditions, which are highly susceptible to disasters [1].

According to [2], the archipelagic and maritime regions of Indonesia are situated in a critical and complex area with active tectonic zones. This is due to the convergence of the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate in this region. Furthermore, as noted by [3], the Pacific Ring of Fire runs along the Indonesian archipelago, leading to frequent earthquakes and volcanic eruptions in the area. These natural disasters can cause damage to all aspects of life, particularly infrastructure. Therefore, to construct disaster-resistant high-rise buildings, it is essential to meet the necessary standards and quality requirements.

In this final project, the structural planning of an earthquake-resistant reinforced concrete office building is presented. This planning is based on a design layout for a ten-story building. The office building is designed using the Special Moment Frame System (SMFS). All structural components are designed to be robust to prevent collapse. Additionally, the structure must be strong enough to ensure that its ductility can withstand lateral earthquake loads and prevent failure.

METHOD

Planning Stage

The planning stages in this final project are as follows:

1. Literature Study Stage: Conduct a literature review on theories related to the final project study to analyze and use them as references in this project. Structural System
2. Determination Stage: Determine the structural system to be used in this project, which consists of a dual system comprising the Special Moment Frame System (SMFS).
3. Preliminary Design Stage: This stage involves the initial design of the structure by determining the properties of structural elements, such as cross-sectional dimensions, material types, and material quality, in accordance with the applicable regulations for reinforced concrete and prestressed concrete structures.
4. Structural Modeling Stage: Model the building structure, which consists of 10 floors with a height of 40 meters, adding shear walls to the sides of the building using the ETABS V.18 software.
5. Loading Input Stage: Input the loads acting on the structure, including gravitational loads that consist of dead loads and live loads, as well as earthquake loads and response spectra.
6. First Running Stage: Perform the first run to check the natural period requirements with a minimum participation mass ratio of 90% and verify the dual system requirements, ensuring that shear walls carry a maximum of 75% of the lateral forces.
7. Static and Dynamic Earthquake Load Input Stage: Input static and dynamic earthquake loads with scaled earthquake factors.
8. Second Running Stage: Conduct a second run to re-examine the earthquake safety parameters of the building, including the scaled earthquake factors, story drift, and P-Delta effects.
9. Loading Combination Input Stage: Input load combinations affected by the modified scaled earthquake factors.
10. Third Running Stage: Perform a third run to obtain the internal forces in the structure due to the combined earthquake load effects.
11. Internal Force Calculation Stage: Calculate the internal forces within the structure.
12. Structural Design Stage: Design the structure using reinforced concrete.
13. Upper Structural Element Design Stage: Design structural elements including beams, columns, floor slabs, and shear walls.
14. Strong Column-Weak Beam Check Stage: Verify the strong column-weak beam configuration of the earthquake-resistant structure.

Structural Planning Data

The final project uses ETABS software for structural analysis calculations and adheres to SNI 1726-2019 regarding the design guidelines for earthquake resistance in buildings and non-building structures to design earthquake-resistant high-rise buildings. The following are the technical data for this final project:

Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

1. Building Function : Office
2. Number of Floors : 10 Floors
3. Building Height : 40 m
4. Structural Type : Reinforced Concrete
5. Concrete Quality (fc’) : 30 Mpa
6. Concrete Density : 24 kN/m³
7. Concrete Elastic Modulus : 4700√fc’ Mpa
8. Yield Strength (fy) : BJTS 420B and BJTP 280
9. Steel Elastic Modulus : 200,000 MPa

Structural Figure

The following structural figure used in this project can be seen in the floor plans for Levels 1 to 10.

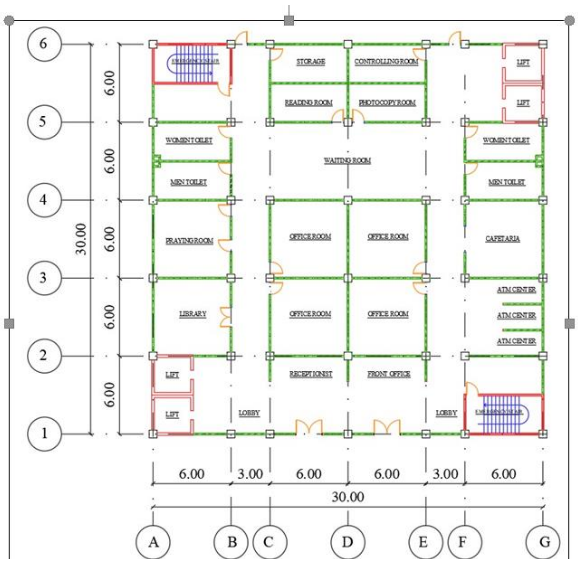

Figure 1. Floor Plan Level 1

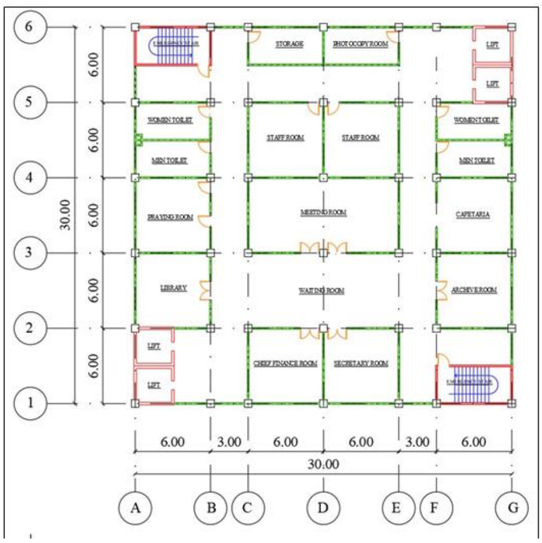

Figure 2. Floor Plan Level 2

Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

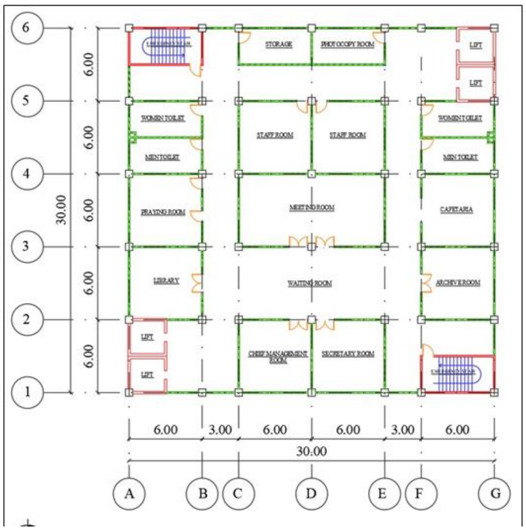

Figure 3. Floor Plan Level 3

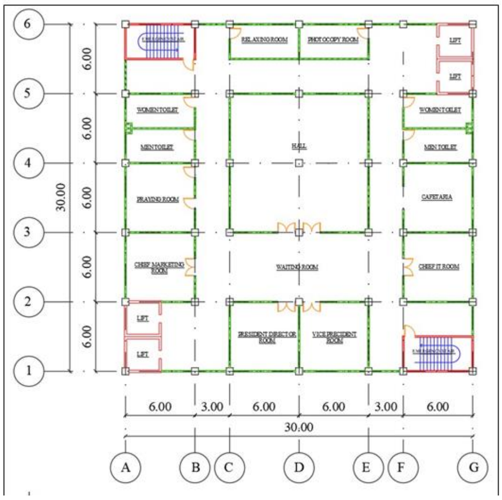

Figure 4. Floor Plan Level 4

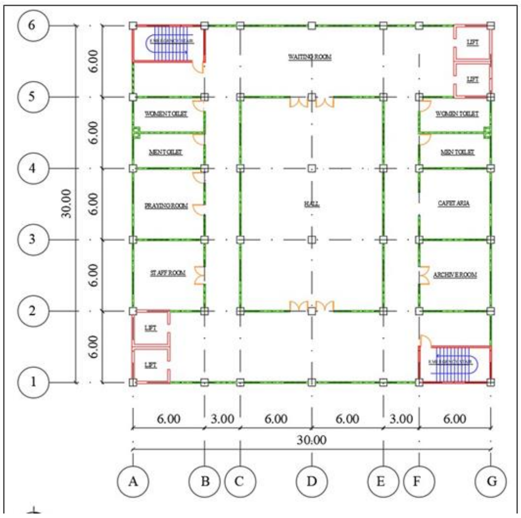

Figure 5. Floor Plan Level 5-10

RESULTS AND DISCUSSION

Determination of the Structural System

Before selecting the structural system to be used, it is essential to understand the Seismic Design

Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

Category (KDS) of the area where the construction will take place, as this will determine the methods to be applied in the structural design, tailored to the construction conditions. The city of Padang is the location for the construction in this final project. Data regarding the determination of the KDS for the Padang area can be found in

Table 1. Determination of KDS for the City of Padang.

No	Data	Variable	Value
1	**Risk Category for Office Buildings**	K =	II
2	**Earthquake Importance Factor**	I =	1
3	**Ground Acceleration Parameters (Ss, S1)**		
	a. MCE Spectral Response Acceleration from the Earthquake Map for Short Periods	SS =	1,125
	b. MCE Spectral Response Acceleration from the Earthquake Map for a 1-Second Period	S1 =	0,5737
4	**Site Class / Site Classification**	SD =	Medium
5	**Site Coefficient Factor (Fa,Fv)**		
	a. Site Coefficient for Short Periods	Fa =	1,0502
	b. Site Coefficient for Long Periods	Fv =	1,7263
6	**Acceleration Response Spectrum Parameters (SMS and SM1)**		
	a. MCE Spectral Response Acceleration for Short Periods Adjusted for Site Class (SMS = Fa. Ss)	SMS =	1,1809
	b. MCE Spectral Response Acceleration for a 1-Second Period Adjusted for Site Class (SMS = Fv. S1)	SM1 =	0,9903
7	**Design Spectrum Acceleration Parameters (SDS,SD1)**		
	a. Spectral Response Acceleration for Short Periods (SDS = 2/3 SMS)	SDS =	0,7873
	b. Spectral Response Acceleration for a 1-Second Period (SD1 = 2/3 SM1)	SD1 =	0,66
8	**Design Response Spectrum**		
	a. To = 0,2 SD1/SDS	T_0 =	0,168
	b. Ts = SD1/SDS	T_S =	0,839
9	**Seismic Design Category (KDS)**		
	a. Based on the SDS Parameter	KDS=	D
	b. Based on the SD1 Parameter	KDS=	D

Here's the translation for your text: After obtaining the KDS D value, the structural system can be identified based on Table 1 in the Indonesian National Standard (SNI) 1726:2019. Therefore, the structural system to be used is a dual system, which is a combination of the Special Moment Frame System (SMFS).

Preliminary Structural Design

The purpose of the preliminary design is to determine the dimensions of columns, beams, floor slabs, shear walls, and foundations, following the Indonesian National Standard (SNI) 2847:2019 for the Special Moment Resisting Frame (SMRF) system.

Preliminary Design of Columns

The column dimensions are calculated based on the impact of dead loads and live loads on the structure. Both live and dead loads must comply with the following requirements:

$$Pu \leq 0,3.Ag.fc' \quad (4.1)$$

Description:

Pu : Total axial load carried by the column (kg) :

Ag : Cross-sectional area of the column (mm^2)
fc' : Compressive strength of concrete (kg/mm^2)

The results of the preliminary column design calculations are presented in Table 4.2 below. The complete calculations for the preliminary column design can be found in the appendix.

Table 2 Preliminary Column Design

No.	Column	Beam (b) mm	Hight (h) mm	Floor
1	K1	1000	1000	1 - 4
2	K2	800	800	5 - 8
3	K3	700	700	9 - 10

Preliminary Design of Beams

SNI 2847:2019 specifies dimensional limits for beam elements. The initial design dimensions outlined in SNI 2847:2019 establish restrictions for the height and width of beam cross-sections. The following table presents the minimum height requirements for non-prestressed beams.

Table 3 Minimum Height of Non-Prestressed Beams

Support Conditions	Minimum Height (h)
Simple Support	L/16
Continuous on One	L/18,5
Side Continuous on	L/21
Both Sides Cantilever	L/8

In this final project, the beam design distinguishes between primary beams and secondary beams. The minimum height for the primary beam is calculated using the following formula:

$$h \geq l/18{,}5 \qquad (4.2)$$

Meanwhile, the minimum height for secondary beams is calculated with the following formula:

$$h \geq l/21 \qquad (4.3)$$

The beam web width must satisfy the following condition:

$$\tfrac{1}{2}\, h \leq bw \leq 2/3\, h \qquad (4.4)$$

Description:
h : Beam Height
bw: Beam Web Width

The results of the preliminary design for the beam elements are obtained with the dimensions shown in Table 4 The complete calculations can be found in the appendix.

Table 4. Preliminary Beam Design

Preliminary Beam Design			
Beam	Width (b)	Height (h)	Long (l)
	(mm)	(mm)	(mm)
Primary Beam	400	600	6000
Primary Beam	400	600	3000
Secondary Beam	300	500	6000

EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

Preliminary Design of Floor

Slabs Based on SNI 2847:2019, the preliminary design for slabs is regulated in Article 8.3.1.2. The calculations can be found in the appendix. The results of the preliminary design for the slab elements are obtained with the dimensions shown in Table 5 as follows:

Table 5. Preliminary Design of Slabs

No.	Type of Shear Wall	Thickness (mm)
1	Shear Wall P1	250
2	Shear Wall P2	250

Structural Modeling

The structural modeling is performed using ETABS V.18 based on the floor plan and the results of the previous preliminary design calculations. The steps are as follows:

Edit Story and Grid

System Creating the story and grid according to the planned building layout is the first step in the structural modeling process using ETABS V.18.0.1. The building planned for this final project has dimensions of 30 m x 30 m with a height of 10 stories.

Define Material Properties

The purpose of defining material properties is to determine the type of material to be used in the structural modeling. In this project, concrete with a quality of 30 MPa will be used. Input the concrete material property data, such as name, material type, specific gravity, and modulus of elasticity.

Define Section Properties

Based on the preliminary design conducted in the previous stage, the structural elements to be used in the structural modeling are defined in the Section Properties Definition.

a. Frame Section

This is used to define the cross-sections of beams and columns.
Based on Article 6.6.3.1.1 in SNI 2847:2019, data on the moment of inertia and the allowable cross-sectional area for elastic analysis under factored loads can be seen in the following table 6:

Table 6. Allowable Moment of Inertia for Cross-Sections

Section and Condition		Inersia Moment	Cross-Section Area
Column		0,70 lg	1,0Ag
Wall	Crack-Free	0,70 lg	
	Crack	0,35 lg	
Beam		0,35 lg	
Flat Plate and Flat Slab		0,25 lg	

The above moment of inertia is inputted into the property/stiffness modification factor in the ETABS

Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

Structural Modeling

After defining the grid, story, material, and section properties in ETABS V.18.0.1, the next step is to model the structure according to the planned layout. The results of the structural modeling for this final project are shown in Figures, which illustrate the structural layout and the 3D structural model.

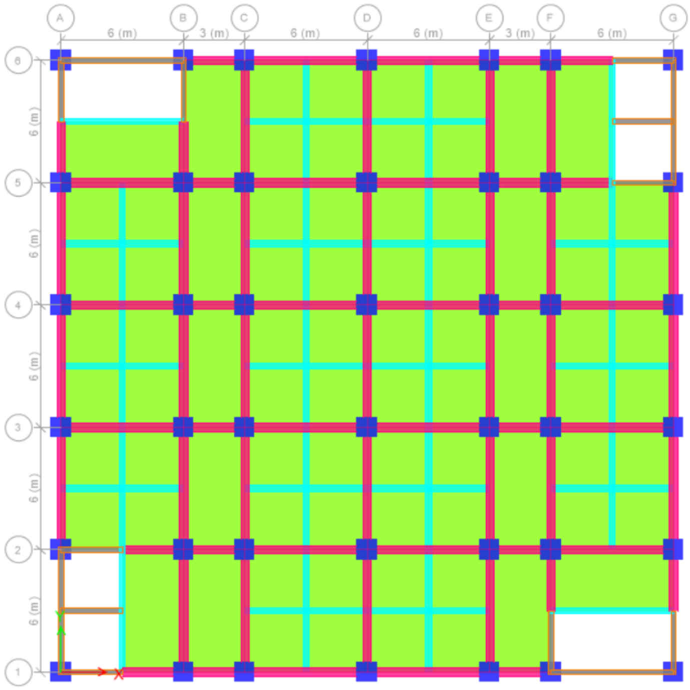

Figure 6. Structural Layou

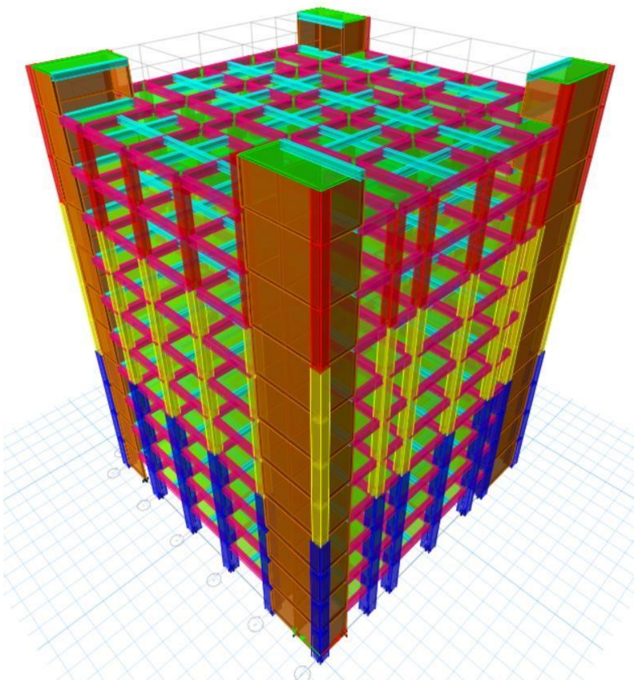

Figure 7. 3D Structural Model

EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

Load Analysis

a. Live Load

Based on the provisions of Table 4.3-1 from SNI 1727:2020, the uniformly distributed live load for office buildings can be seen in Table 7 below:

Table 7. Live Load for Office Buildings

Live Load			
Based on SNI 1727:2019 Tabel 4.3-1			
No	**Room**	**Load**	**Unit**
1	Lobby and first-floor corridor	4,79	kN/m²
2	Office	2,40	kN/m²
4	Corridor above the first floor	3,83	kN/m²

b. Dead Load

The structural dead load has been automatically calculated by the ETABS V.18 program based on the dimensional data and material characteristics inputted during the design process.

Table 8. Dead Load on Primary Beams

Dead Load On Beams				
Primary Beam 400 x 600 mm				
No	**Name**	**Dimentions(m)**	**Unit Weight**	**qu (kN/m)**
1	Floor Height	4		
2	Beam Height	0.6		
3	Wall Height	3.4	250	8.50
Total				8.50

Table 9. Dead Load on Secondary Beams

Dead Load On Beams				
Secondary Beam 300 x 500 mm				
No	**Name**	**Dimentions(m)**	**Unit Weight**	qu (kN/m)
1	Floor Height	4		
2	Beam Height	0.5		
3	Wall Height	3.5	250	8.75
Total				8.75

Dead Load on Floor Slabs

The dead load on the floor slabs arises from the weight of finishes, mechanical electrical plumbing (MEP) installations, ceilings, and ceramics.

Table 10. Dead Load on Floor Slabs

Dead load on slabs				
Floor Plate				
No	**Type of Load**	**Unit Weight**	**Thickness (m)**	**qut (kN/m²)**
1	Mortar Weight	2200	0.02	0.44
2	Ceilings Weight	20	1	0.2
3	MEP weight	25	-	0.25
4	Ceramic Weight	2400	0.01	0.24
TOTAL				1.13

Dead Load on Concrete Roof Slabs

The dead load on the concrete roof slabs arises from the weight of mortar, mechanical electrical plumbing (MEP) installations, and ceilings. The calculation of the dead load on the roof slabs is shown in Table 11.

Table 11. Dead Load on Concrete Roof Slabs

Dead Load On Slabs				
Concrete Roof Slab				
No	Type of Load	Unit Weight	Thickness (m)	qut (kN/m²)
1	Mortar/spasi	2200	0.02	0.44
2	Plafond/Ceiling	20	1	0.2
3	MEP	25	-	0.25
TOTAL				0.89

Earthquake Load

The results of the dynamic earthquake calculations, in accordance with the equations in Section 6.4 of SNI 1726:2019, yield the response spectrum recorded in Table 12.

Table 12. Response Spectrum Parameters for Padang, West Sumatera

No	Description	Variable	Value
1	**Building Risk Category for Office Buildings**	K	II
2.	**Building Location**	Padang	
3.	**Earthquake Importance Factor**	Le	1
4.	**Ground Acceleration Parameters (Ss, S1)**		
	a. Spectral response acceleration parameter (MCE) from the seismic map for a short period	Ss	1,1245
	b. Spectral response acceleration parameter (MCE) from the seismic map for a 1-second period	S1	0,5737
5.	**Site Class / Classification**	Sedang (SD)	
6.	**Site Coefficient Factors (Fa, Fv)**		
	a. Amplification factor for short-period vibration	Fa	1,0502
	b. Amplification factor for 1-second period vibration	Fv	1,7263
7.	**Spectral Response Acceleration (SMSdan SM1)**		
	a. Adjusted spectral response acceleration for a short period (SMS=Fa.Ss)	SMS	1,1809
	b. Adjusted spectral response acceleration for a 1-second period (SM1=Fv.S1)	SM1	0,9904
8	Design Spectral Acceleration Parameters (SDS, SD1)		
	a. Spectral response acceleration at a short period (SDS = 2/3 × SMS)	SDS	0,7873
	b. Spectral response acceleration at a 1-second period (SD1 = 2/3 × SM1)	SD1	0,6603
9	Design Response Spectrum		
	a. $T_0 = 0.2 \times SD1 / SDS$	T0	0,168
	b. Ts = SD1 / SDS	Ts	0,839
	c. TL	TL	20

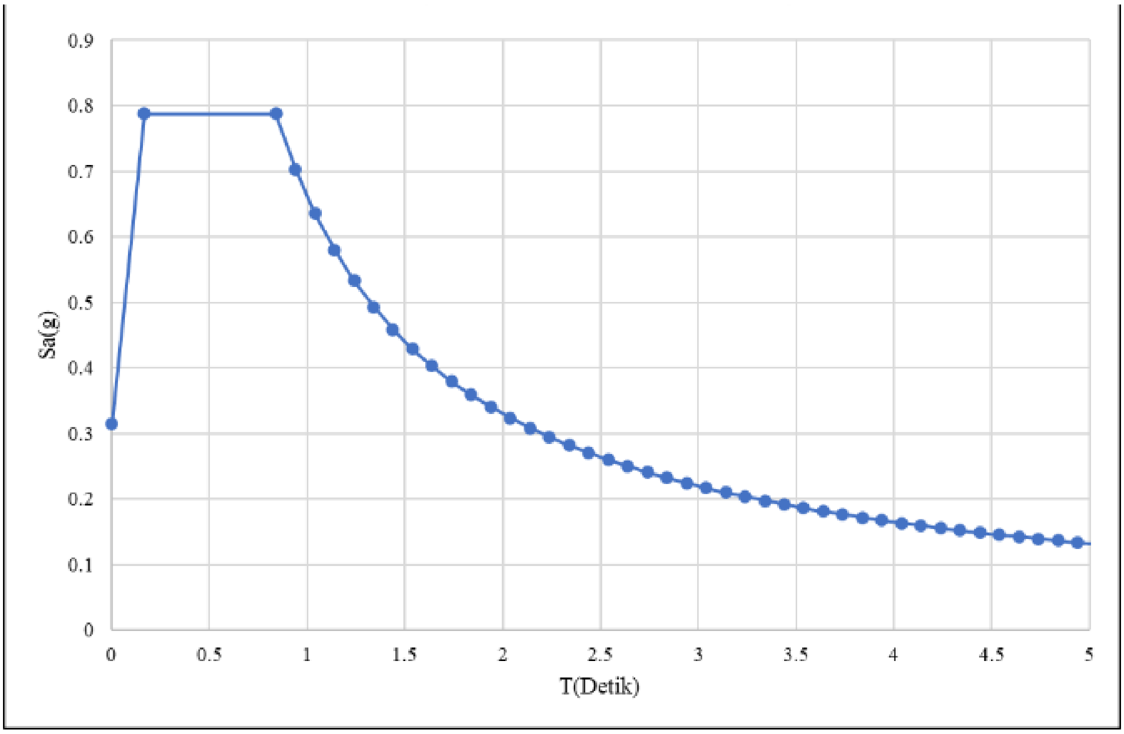

Figure 8. Spectral Response Graph for Padang City

Structural Dynamic Characteristics Examination

1. First Check

a. Mode Shape Check

The mode shape check is performed by observing the direction of structural deformation that occurs

Table 13. Structural Mass Participation for Mode Shapes

Mode	Period	UX	UY	UZ	RX	RY	RZ
1	1.010	0%	69%	0%	36%	0%	0%
2	0.943	69%	0%	0%	0%	35%	0%
3	0.707	0%	0%	0%	0%	0%	68%

1) *Mode shape 1 undergoes translation in the y-axis direction with a period of 1.010 seconds.*

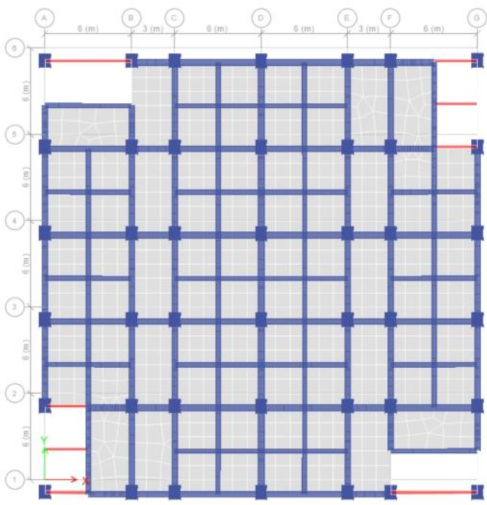

Figure 9. Mode Shape 1

Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.3 September 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

2) Mode shape 2 translates towards the x-axis with a period of 0,943 detik

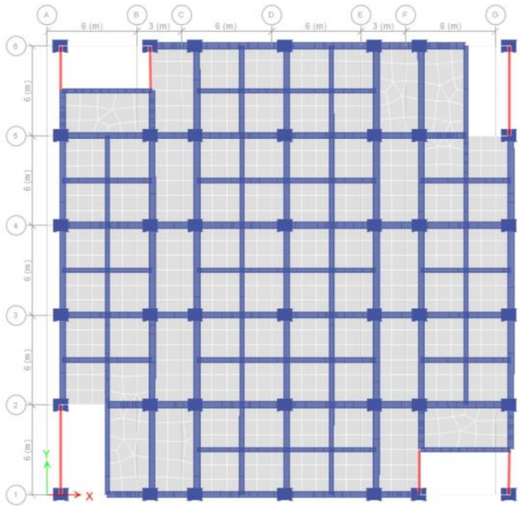

Figure10. Mode Shape 2

3) Mode shape 3 undergoes translation in the z-axis direction with a period of 0.707 second

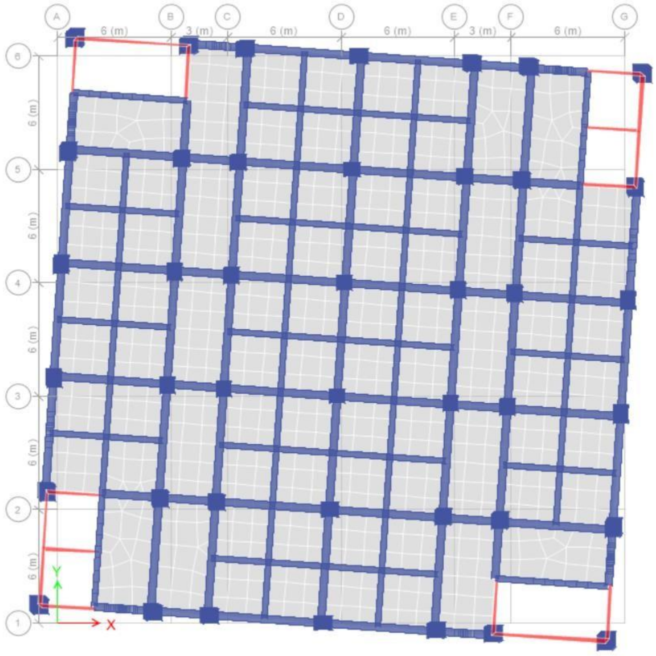

Figure 11. Mode Shape 3

b. Structural Mass Participation Check

Table 14. Structural Mass Participation

Mode	Period	SumUX	SumUY	SumRZ
1	1.01	0.02%	68.75%	0.00%
2	0.943	69.39%	68.77%	0.00%
3	0.707	69.39%	68.77%	68.42%
4	0.298	69.39%	86.31%	68.42%
5	0.284	86.32%	86.31%	68.42%
6	0.206	86.32%	86.31%	87.20%
7	0.163	86.33%	91.45%	87.20%
8	0.155	91.53%	91.46%	87.20%

Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
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http://cived.ppj.unp.ac.id/index.php/CIVED

9	0.113	91.54%	94.10%	87.20%
10	0.11	91.54%	94.10%	92.54%
98	0.034	99.46%	99.55%	98.76%
99	0.034	99.46%	99.55%	98.76%
100	0.033	99.46%	99.55%	98.76%

c. Frame Contribution Check: Minimum 25% Lateral Force

Table 15. Lateral Forces Supported by the Frame

Direction	**Location**	**Supported Forces**	**Shear Wall Persentage**	**Frame Persentage**
x	Shearwall	4710.082	72.47%	27.53%
	Total	6499.00		
y	Shearwall	4415.595	72.56%	27.44%

d. Second Check
Earthquake Scale Factor Check
Static Earthquake Load in the X Direction

Tabel 15. Scale Factor Check

Earthquake Force	**Vx**	**Vy**
	(kN)	**(kN)**
STATIC(Vs)	8614.046	9167.741
DYNAMIC (Vd)	8618.369	9168.768
Multiplication Coefficient	0.999	1.000
Comparison	1.001	1.000
Check of Dynamic Shear Force against Static Shear Force.		
Cek Vd ≥ Vs	**OKE**	**OKE**
Scale Factor	1401.43	1401.43
Scale Factor correction	1400.73	1401.43

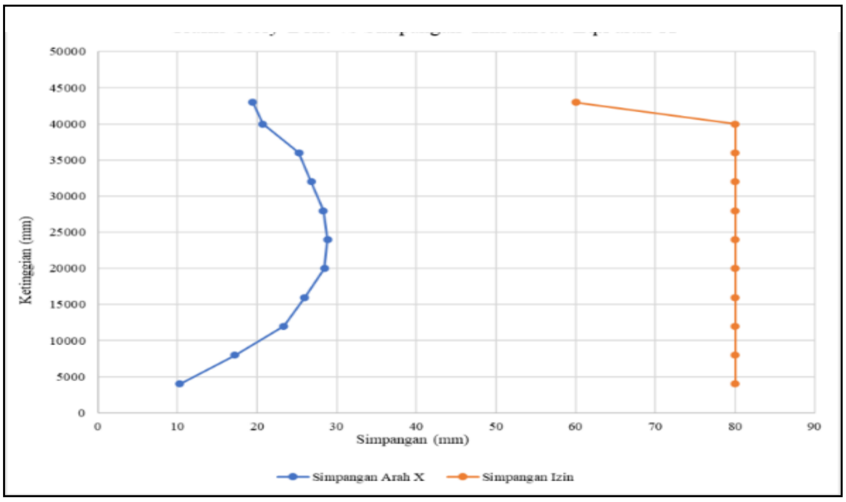

Figure 12. Graph of Inter-Story Drift in the X Direction

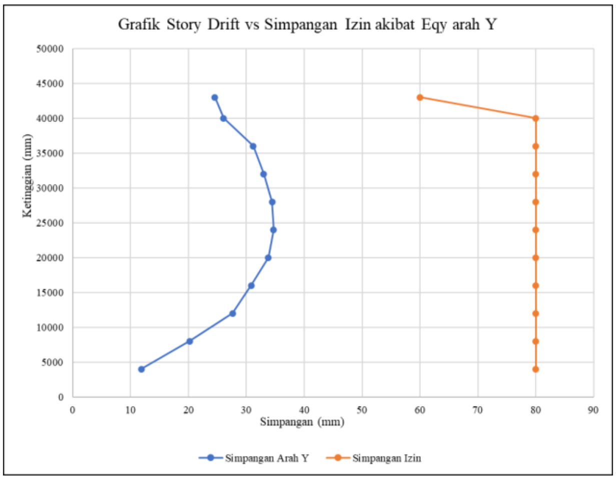

Figure 13. Graph of Inter-Story Drift in the Y Direction

c. Effect of P-**Delta**

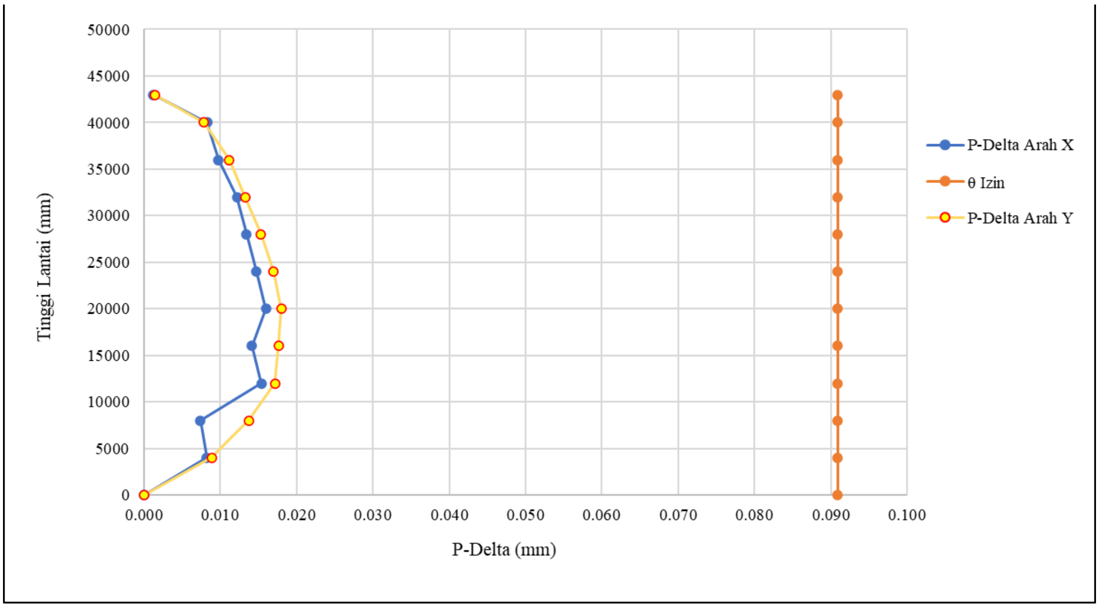

Figure 14. Graph of the P-Delta Effect

Based on the results in the table and figure above, it can be concluded that the P-Delta effect in the X and Y directions complies with the requirements of SNI 1726:2019. a. Horizontal Irregularity Check Based on Table 13 of SNI 1726:2019, horizontal irregularity includes several types, namely: Torsional Irregularity (Type 1a and Type 1b) The results of the torsional irregularity check in the X and Y directions can be seen in, The results of the torsional irregularity check in the X and Y directions can be seen in Table 27 below:

Tabel 16. Torsional Irregularity Check.

Story	**Arah X**		**Arah Y**	
	Δmax/Δavg	**Control Chek**	**Δmax/Δavg**	**Control Chek**
	mm	**(Δmax/Δavg) < 1.2**	**mm**	**(Δmax/Δavg) < 1.2**
Rooftop	1.149	OK	1.157	OK
FLOOR 10	1.113	OK	1.099	OK

FLOOR 9	1.053	OK	1.042	OK
FLOOR 8	1.029	OK	1.023	OK
FLOOR 7	1.026	OK	1.021	OK
FLOOR 6	1.029	OK	1.024	OK
FLOOR 5	1.039	OK	1.032	OK
FLOOR 4	1.051	OK	1.042	OK
FLOOR 3	1.055	OK	1.051	OK
FLOOR 2	1.053	OK	1.051	OK
FLOOR 1	1.179	OK	1.148	OK

CONCLUSION

Based on the calculations performed in the previous chapter, several conclusions were obtained, including: a). The dynamic characteristics of the structure have met the requirements, with translation occurring in mode shapes 1 and 2, while mode shape 3 involves rotation. Mass participation reaches nearly 100% by the 100th mode shape. b) The percentage of frame contribution meets the requirements, as it can carry at least 25% of the lateral forces. In the X direction, the frame contributes 27.53%, and the shear wall contributes 72.47%. In the Y direction, the frame contributes 27.53%, and the shear wall contributes 72.56%. c) The inter-story drift of the building meets the requirements, not exceeding 2% per floor for a risk category II building. The P-Delta effect is within the allowable range, with $\theta \leq \theta max \leq 0.25$, ensuring the building's stability. d) No horizontal or vertical irregularities were found in the building structure. e) The design of both the superstructure and substructure complies with the applicable standards in SNI 2847:2019. f) The beam and column elements comply with the Strong Column-Weak Beam requirement

REFERENCE

[1] T. Apryanto and H. Hartopo, "Kajian Hubungan Antara Dimensi Penampang, Mutu Baja Dan Mutu Beton Terhadap Nilai Daktilitas Beton Bertulang," *Teknika*, vol. 17, no. 2, p. 127, 2022. doi: 10.26623/teknika.v17i2.5423.

[2] Badan Standardisasi Indonesia, *SNI 1727:2020 Beban Desain Minimum dan Kriteria Terkait untuk Bangunan Gedung dan Struktur Lain*, Jakarta, 2020, pp. 1–336.

[3] Badan Standardisasi Nasional, *Persyaratan Beton Struktural untuk Bangunan Gedung. SNI 2847-2019*, 2019, pp. 1–720.

[4] E. R. Boyoh, R. S. Windah, and S. O. Dapas, "Perencanaan Hotel Konstruksi Beton Bertulang 12 Lantai di Jln. Ahmad Yani Kota Manado," *Jurnal Sipil Statik*, vol. 7, no. 8, pp. 913–922, 2019.

[5] T. Joko, *Rencana Anggaran Biaya (RAB)*, Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018, pp. 1–72.

[6] R. Nursani and D. E. Noor, "Analisis Pengaruh Penambahan Dinding Geser terhadap Perilaku Struktur Gedung Sistem Ganda," *Jurnal Teknik Sipil dan Lingkungan*, vol. 8, no. 2, pp. 105–114, 2023. doi: 10.29244/jsil.8.02.105-114.

[7] R. Thamrin, R. Kurniawan, B. Yunas, and I. Arifky, "Flexural behavior of reinforced concrete beams with high strength material layer in compression zone," *IOP Conference*

Series: Earth and Environmental Science, vol. 708, no. 1, p. 012083, Apr. 2021. doi: 10.1088/1755-1315/708/1/012083

[8] P. H. Karisoh, S. O. Dupas, and R. P. Dapas, *Perencanaan Struktur Gedung Beton Bertulang dengan Sistem Rangka Pemikul Momen Khusus (SRPMK) dan Sistem Rangka Pemikul Momen Menengah (SRPMM)*, Universitas Sam Ratulangi Manado, 2018, pp. 1–260.

[9] A. D. S. Purwantoro et al., "Studi Perbandingan Pengaruh Letak Dinding Geser pada Bangunan Bertingkat Akibat Beban Gempa," *Jurnal Teknik Sipil*, vol. 15, pp. 35–45, 2023.

[10] J. O. Simanjuntak and H. P. Harefa, "Analisis Perbandingan Kolom Persegi dan Kolom Bulat dengan Mutu Beton, Luas Penampang, dan Luas Tulangan yang Sama," *Jurnal Teknik Sipil*, vol. 1, no. 1, pp. 11–24, 2021.

[11] J. O. Simanjuntak, T. E. Saragi, and B. T. L. Gaol, "Beton Bermutu dan Ramah Lingkungan dengan Memanfaatkan Limbah Tongkol Jagung (Penelitian Laboratorium)," *Jurnal Visi Eksakta*, vol. 1, no. 1, pp. 79–98, 2020. doi: 10.51622/eksakta.v1i1.53.

[12] D. Sistem and P. Standar, *Penerapan Standar Nasional Indonesia*, 2020.

[13] F. R. Tambingon, D. Martin, S. E. Sumajouw, and Wallah, "Kuat Tekan Beton Geopolymer dengan Perawatan Temperatur Ruangan," *Sipil Statik*, vol. 6, no. 9, pp. 641–648, 2018.

[14] F. M. Van Gobel, "Nilai Kuat Tekan Beton pada Slump Beton Tertentu," *RADIAL – Jurnal Peradaban Sains, Rekayasa dan Teknologi Sekolah Tinggi Teknik (STITEK) Bina Taruna Gorontalo*, vol. 5, no. 1, pp. 22–33, 2019.