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Structural Design of a Six-Story Reinforced Concrete Apartment Building Using a Special Moment Frame (SMF) System

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A B S T R A C T

The limited land around the campus area encourages the application of vertical solutions in the form of student flats as a comfortable and efficient residential alternative. This research aims to design an earthquake-resistant multi-story flat structure by applying the principles of a special moment bearing frame system (SMF). Planning refers to earthquake loading according to SNI and other loading theories. The structure has a size of 38.25 m × 17.85 m with a height of 24 m, using concrete f'c = 30 MPa, steel fy = 420 MPa, and fyt = 280 MPa. Based on the soil investigation, the site belongs to SD soil class and Seismic Design Category D and the structural design and analysis process is assisted using *software*. The design results show that all structural elements are able to withstand vertical and horizontal loads, and the reinforcement has been controlled against moments and shear forces, and the structure meets SMF standards.

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INTRODUCTION

The development of multi-story buildings in Indonesia, particularly in Tomohon City, has accelerated in response to ongoing urbanization and the growing demand for residential facilities, especially within university environments. This trend necessitates the provision of adequate student accommodations to meet the increasing population in higher education institutions. The spatial limitations within campus areas have prompted the need for alternative housing solutions that are not only efficient and strategically located but also conducive to academic and social activities.

The scarcity of available land surrounding educational zones has led to the adoption of vertical housing solutions, such as student apartment buildings, which offer an effective and comfortable alternative. However, Tomohon is situated in a seismically active region, as it lies at the convergence of three tectonic plates and forms part of the Pacific Ring of Fire. This geotechnic condition elevates the importance of seismic resilience in the structural design of buildings within the area.

Consequently, structural systems must be designed to resist lateral forces generated by seismic activity. One of the recommended approaches is the implementation of the Special Moment Resisting Frame (SMRF) system, in accordance with the guidelines specified in SNI 2847:2019 and SNI 1726:2019. This system offers high ductility and is capable of sustaining both gravitational and seismic loads simultaneously, thereby ensuring the development of structures that are robust, safe, and suitable for long-term residential use.

LITERATURE REVIEW

Loading

The structural elements to be designed must be able to withstand the service load of the building in order to provide safety to the structure. (Berry Koloy, 2023) The following are the types of loading:

1. Live Load
   Loads caused by users and occupants of buildings or other structures that do not include construction loads and environmental loads, such as wind loads, rain loads, earthquake loads, flood loads, or dead loads. (SNI 1727:2020 Article 4.1)
2. Dead Load
   Dead load is the weight of all installed building construction materials, including walls, floors, roofs, ceilings, stairs, fixed partition walls, finishing, building cladding and other architectural and structural components and other installed service equipment including the weight of cranes and material transport systems. (SNI 1727:2020 Article 3.1)
3. Earthquake Load
   Earthquake loads are all equivalent static loads acting on buildings or parts of buildings that mimic the effects of ground motion due to the earthquake. (Rivaldo, 2019)
4. Load Combination
   - 1,4 DL
   - 1,2 DL + 1,6 LL + 0,5 (Lr or R)

- 1,2 DL + 1,6 (Lr or R) + (L or 0,5 W)

Load combination with seismic load effect based on SNI 1726-2019 article 4.2.2.3:

- 1,2 DL + Ev + Eh + LL
- 0,9 DL + Eh - Ev

Dimana:

DL = Dead Load
LL = Live Load
R = Rain Load
W = Wind Load
E = Earthquake Load
S = Snow Load
Lr = Roof Load
Eh = pQE (SNI 1726:2019 article 7.4.2.1)
Ev = 0.2SDSD (SNI 1726:2019 article 7.4.2.2)

Special Momen Frame

The definition of a moment-reinforcing frame system is an inner space frame system in which the structural components and joins can withstand forces acting through bending, shear and axial actions. Special Moment Bearing Frame System (SMF) is used for areas with high earthquake risk (earthquake regions 5 and 6). (Betania Mahendrayu, 2019).

METHODOLOGY

Building Data

Building Function	: Flat building
Number of Story	: 6 floor
Structure Height	: 24 meters
Height Between Floor	: Story 1 = 3,6 meters
	Story 2-6 typical = 3,4 meters
Span length	: 38,25 meters (X), 17,85 meters (Y)
Construction	: Reinforced concrete

Data Material

Concrete Material Spesification:	
Concrete Quality (f'c)	= 30 MPa
Spesific Gravity	= 2400 kg/m3
Modulus Elasticity of Concrete	= 4700√(f'c) = 25742,9602 MPa
Poison Number	= 0,2
Steel Material Spesification:	
Main Reinforcement Steel (fy)	= 420 MPa (BjTS 420A)
Stirrup Reinforcement Steel (fys)	= 280 MPa (BjTP 280)
Modulus Elasticity of Steel	= 200000 Mpa

Load Data

The planned load is reviewed from sni 1727: 2020 which consists of live load (based on the type of function of each room based on area per m2) and dead load (own weight of the structure and additional dead load). For earthquake loads are reviewed from sni 1726: 2019

Soil Data

Soil data investigation is used for site class review, calculation of earthquake loads and planning of the building's lower structure and N-SPT data is used at a depth of 15 m (N-SPT value is above 60).

Flow Chart Planning

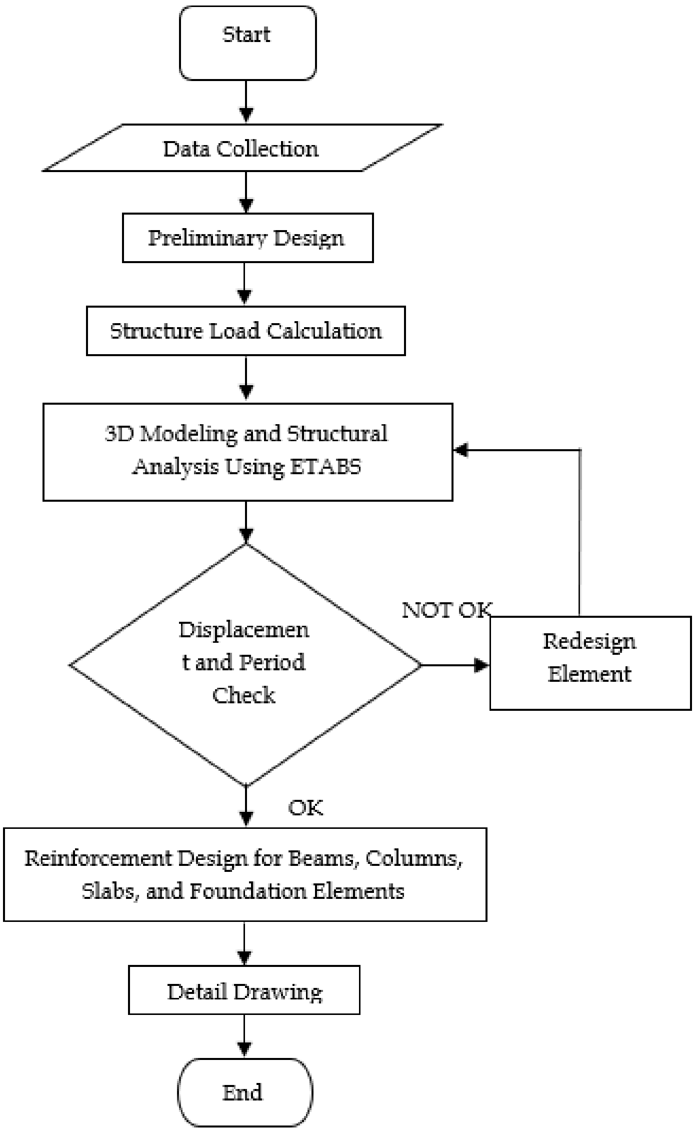

Figure 1. Flow Chart Planning

RESEARCH RESULT AND DISCUSSION

Structure Geometry

The following is the geometry of the planned structure:

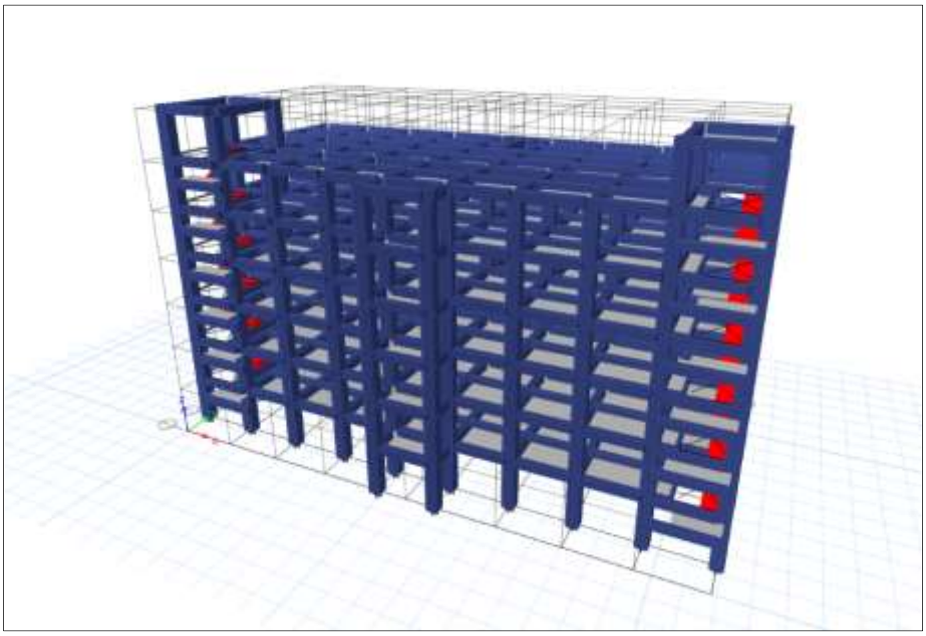

Figure 2. 3D Building Geometry

Dead Load

- Self weight structure (calculated by E-TABS)
- Reinforced concrete = 24 kN/m^3
- Specific gravity of steel = 7850 kg/m^3
- Additional dead load:
-

Table 1. Additional Dead Load

Additional Dead Load						
No	Component	Weight		Thickness	Q	Unit
		Value	Unit			
1	Partition				0,720	kN/m^2
2	Ceramic	17	kg/m^2		0,167	kN/m^2
3	3 cm specimen	2100	kg/m^3	0,03	0,618	kN/m^2
4	5 cm sand	1600	kg/m^3	0,05	0,785	kN/m^2
5	MEP				0,300	kN/m^2
6	Ceiling	9	kg/m^2		0,088	kN/m^2
7	Ceiling Frame	5	kg/m^2		0,049	kN/m^2
Total Dead Load on Floor Plate, QSIDL1 =					2,727	kN/m^2
Total Dead Load on Floor Plate, QSIDL2 =					2,007	kN/m^2

Live Load

The room functions obtained in SNI 1727: 2020 are as follows:

Table 2. Type of Loading for Each Function:

Loading			
Live Load			
Lobby	=	4,79	kN/m²
Corridor Room	=	4,79	kN/m²
Corridor Room Upside From 1st Story	=	3,83	kN/m²
Public Room	=	4,79	kN/m²
Private Room	=	1,92	kN/m²
Roof Slab	=	0,96	kN/m²
Pantry	=	4,79	kN/m²
Stairs and Stair Land	=	4,79	kN/m²

In article 4.3.2 for function spaces with live load ≥ 3,83 kN/m2, partition load does not need to be included

Earthquake Load

For earthquake loads that are reviewed in the city of Tomohon, North Sulawesi with reference to SNI 1726: 2019, the following parameters are obtained:

- Ss = 1,0489 g
- S1 = 0,4704 g
- Risk Category = II
- Earthquake Primacy Factor = 1.0
- Site Class = Medium Soil (SD)
- Response Spectrum Parameter:
- SDS = 0,7555 g
- SD1 = 0,5738 g
- Seismic Desain Category = D

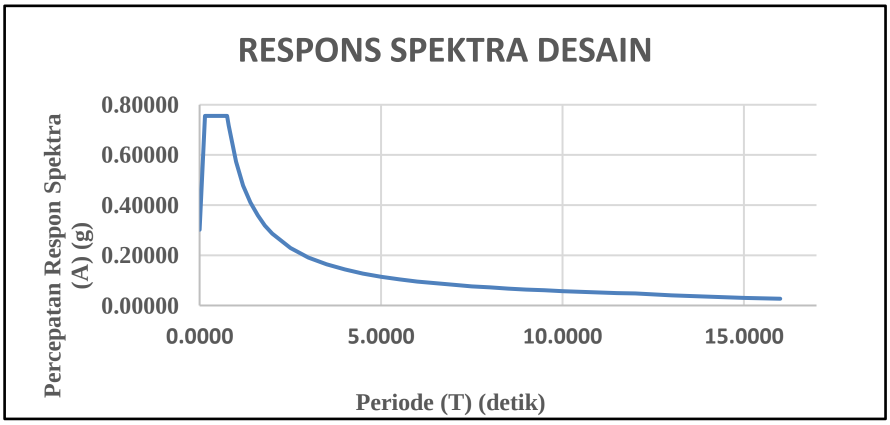

Figure 3. Design Response Spectrum Graph

Load Combination

For the design of the upper structure design a combination of LRFD (Load Resistance Factor Design) is used while for the lower structure a combination of ASD (Allowable Stress Design) is used which refers to SNI 1726: 2019.

Structure Design

a. Beam Element

Table 3. Beam Design

Beam	b	h
B1	350	550
B2	400	600
B3	450	700
B4	450	600
BA	300	400
BV	350	500
BL	450	600
BB	350	500
B5	300	400

b. Column Element
Column K1 = 750 x 750 mm

c. Plate Element
- Story 1-5 = 130 mm
- Story 6-7 = 140 mm

Analysis Result

The following are the result of the E-TABS program analysis of axial forces, moment, and shear forces:

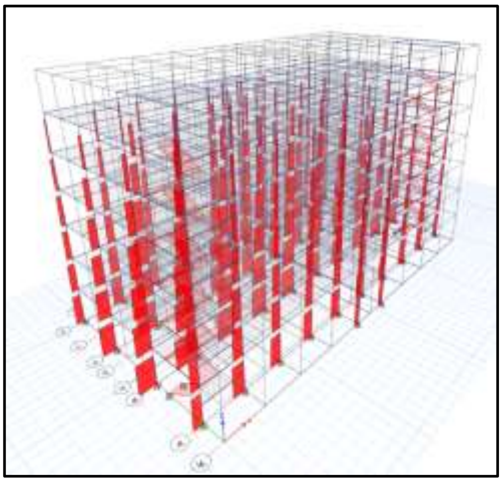

Figure 4. Internal Force Due to Maximum Axial Load

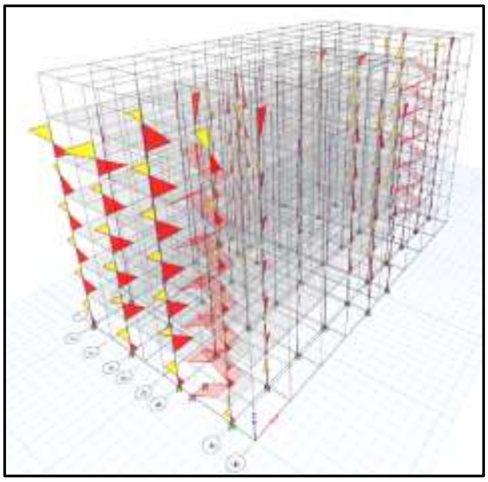

Figure 5. Maximum Inside Force Due to Shear in X Direction

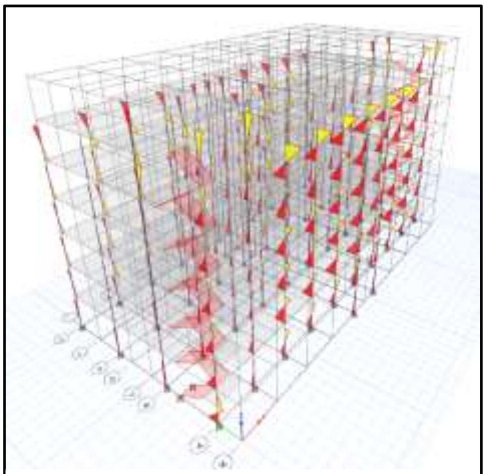

Figure 7. Maximum Inside Force Due to Shear in Y Direction

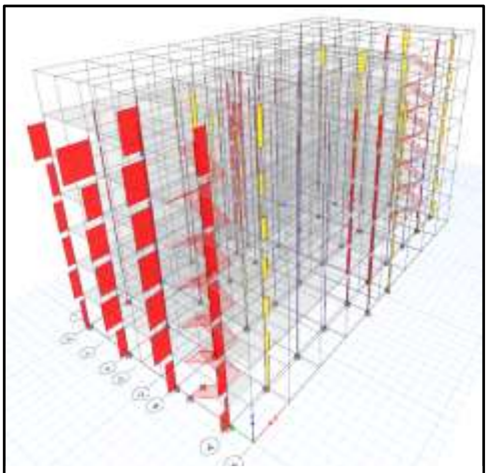

Figure 6. Maximum Inside Force Due to Moment in X Direction

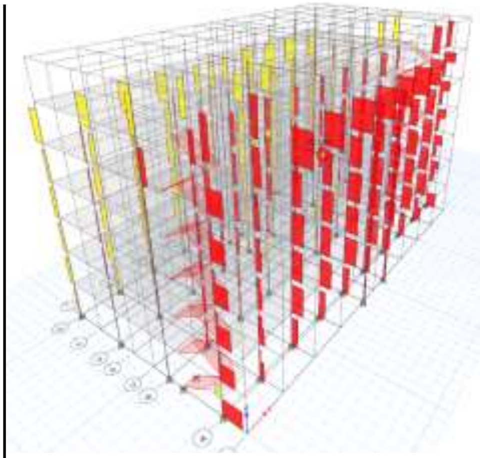

Figure 8 Maximum Inside Force Due to Moment in X Direction

Upper Structure Reinforcement Planning

After obtaining the results of the internal forces, we can proceed to the calculation process of the reinforcement requirements for beams, columns and plates.

Beam Reinforcement

The following is the result of the beam reinforcement recap:

Table 4. Recap of Main Beam Reinforcement

Story		Beam B1			Beam B2			Beam B3			Beam B4			Beam Bv
		Joint	Midspan	Joint	Joint	Midspan	Joint	Joint	Midspan	Joint	Joint	Midspan	Joint	All
1	DImensions	350x550			400x600			450x700			450x600			350x550
	Reinforcement Top	5S16	3S16	5S16	8S16	3S16	8S16	8S16	3S16	8S16	5S16	3S16	5S16	3S16
	Reinforcement Bottom	3S16	5S16	3S16	3S16	4S16	3S16	4S16	5S16	4S16	3S16	5S16	3S16	2S16

	Shear	2S13-80	2S13-150	2S13-80	3S13-80	3S13-150	3S13-80	3S13-80	2S13-150	3S13-80	2S13-80	2S13-150	2S13-80	2S13-80
	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13
2	DImensions	350x550			400x600			450x700			450x600			350x550
	Reinforcement Top	6S16	3S16	6S16	8S16	3S16	8S16	9S16	3S16	9S16	5S16	3S16	5S16	3S16
	Reinforcement Bottom	3S16	6S16	3S16	3S16	4S16	3S16	4S16	5S16	4S16	3S16	5S16	3S16	2S16
	Shear	2S13-80	2S13-150	2S13-80	3S13-80	3S13-150	3S13-80	4S13-80	2S13-150	4S13-80	2S13-80	3S13-150	2S13-80	2S13-80
	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13
3	DImensions	350x550			400x600			450x700			450x600			
	Reinforcement Top	6S16	3S16	6S16	7S16	3S16	7S16	8S16	3S16	8S16	5S16	3S16	5S16	
	Reinforcement Bottom	3S16	6S16	3S16	4S16	4S16	4S16	4S16	5S16	4S16	3S16	5S16	3S16	
	Shear	2S13-80	2S13-150	2S13-80	2S13-80	3S13-110	2S13-80	3S13-80	2S13-150	3S13-80	2S13-80	3S13-110	2S13-80	
	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	
4	DImensions	350x550			400x600			450x700			450x600			
	Reinforcement Top	5S16	2S16	5S16	6S16	3S16	6S16	7S16	3S16	7S16	5S16	3S16	5S16	
	Reinforcement Bottom	2S16	5S16	2S16	3S16	4S16	3S16	4S16	5S16	4S16	3S16	5S16	3S16	
	Shear	2S13-80	2S13-150	2S13-80	2S13-80	3S13-150	2S13-80	2S13-80	2S13-150	2S13-80	2S13-80	4S13-150	2S13-80	
	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	

Table 4. (continued) Recap of Main Beam Reinforcement

Story		Beam B1			Beam B2			Beam B3			Beam B4			Beam Bv
		Joint	Midspan	Joint	Joint	Midspan	Joint	Joint	Midspan	Joint	Joint	Midspan	Joint	All
5	DImensions	350x550			400x600			450x700			450x600			
	Reinforcement Top	3S16	2S16	3S16	6S16	2S16	6S16	6S16	3S16	6S16	5S16	3S16	5S16	
	Reinforcement Bottom	2S16	3S16	2S16	3S16	4S16	3S16	4S16	5S16	4S16	3S16	5S16	3S16	
	Shear	2S13-80	2S13-150	2S13-80	2S13-80	2S13-150	2S13-80	2S13-80	2S13-150	2S13-80	2S13-80	3S13-150	2S13-80	

	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13
6	DImensions	350x550			400x600			450x700			450x600		
	Reinforcement Top	4S16	2S16	4S16	5S16	2S16	5S16	5S16	3S16	5S16	5S16	3S16	5S16
	Reinforcement Bottom	2S16	4S16	2S16	3S16	4S16	3S16	3S16	5S16	3S16	3S16	5S16	3S16
	Shear	2S13-80	2S13-150	2S13-80	2S13-80	2S13-150	2S13-80	2S13-80	2S13-150	2S13-80	2S13-80	3S13-150	2S13-80
	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13	2S13
7	DImensions	350x550			400x600								
	Reinforcement Top	3S16	2S16	3S16	4S16	2S16	4S16						
	Reinforcement Bottom	2S16	3S16	2S16	2S16	4S16	2S16						
	Shear	2S13-80	3S13-150	2S13-80	2S13-80	2S13-150	2S13-80						
	Reinforcement Waistband	2S13	2S13	2S13	2S13	2S13	2S13						

Table 5. Recap of Beam Outside the Main Beam

Section	Story		Beam As 1-2		
			Joint	Midspan	Joint
Secondary Beam	1	DImensions	300x400		
		Reinforcement Top	3S16	2S16	3S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-110	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13
	2	DImensions	300x400		
		Reinforcement Top	3S16	2S16	3S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-110	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13
	3	DImensions	300x400		
		Reinforcement Top	3S16	2S16	3S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-110	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13

Table 5. (continued) Recap of Beam Outside the Main Beam

Section	Story		Beam As 1-2		
			Joint	Midspan	Joint
Secondary Beam	4	DImensions	300x400		
		Reinforcement Top	3S16	2S16	3S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-150	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13

	5	DImensions	300x400		
		Reinforcement Top	3S16	2S16	3S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-150	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13
	6	DImensions	300x400		
		Reinforcement Top	3S16	2S16	3S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-150	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13
Beam B5	Max (Story 6)	DImensions	300x400		
		Reinforcement Top	2S16	2S16	2S16
		Reinforcement Bottom	2S16	2S16	2S16
		Shear	2S13-80	2S13-150	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13
Elevator Beam	6	DImensions	250x450		
		Reinforcement Top	5S16	3S16	5S16
		Reinforcement Bottom	3S16	5S16	3S16
		Shear	2S13-80	2S13-150	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13
Stair Landing Beam	Max (Story 3)	DImensions	450x600		
		Reinforcement Top	4S16	2S16	4S16
		Reinforcement Bottom	2S16	3S16	2S16
		Shear	2S13-80	2S13-150	2S13-80
		Reinforcement Waistband	2S13	2S13	2S13

Column Reinforcement

Columns are made 1 type and then divided evenly at all points of the planned building. The results of the K1 column reinforcement recapture are obtained as follows:

- Longitudinal Reinforcement = 16S22
- Transvers Reinforcement
  - Plastic Joint Area (725 mm) = 5S13 – 100
  - Outside Plastic Joint = 5S13 – 125

Plate Reinforcement

The plate reinforcement is divided into 2 types of lane recapitulated with the following results:

Table 6. Recap of 2 Lanes Plate Reinforcement

Story	Lane	Plate Thickness (mm)	Main Reinforcement		Shrinkage
			X	Y	
7	Center (Field)	140	S10-250	S10-250	S10-300
	Column (Support)		S10-250	S10-250	
6	Center (Field)	140	S10-250	S10-250	
	Column (Support)		S10-250	S10-250	

5	Center (Field)	130	S10-250	S10-250	
	Column (Support)		S10-250	S10-250	
4	Center (Field)	130	S10-250	S10-250	
	Column (Support)		S10-250	S10-250	
3	Center (Field)	130	S10-250	S10-250	
	Column (Support)		S10-250	S10-250	
2	Center (Field)	130	S10-200	S10-200	
	Column (Support)		S10-200	S10-200	
1	Center (Field)	130	S10-200	S10-200	
	Column (Support)		S10-200	S10-200	

For stairs and Stairs Landing Reinforcement:

Table 7. Recap of Stairs and Stairs Landing

Story	Lane	Plate Thickness (mm)	Main Reinforcement	Shrinkage
Stairs	Field	140	S13-150	S13-300
	Support	140	S13-150	
Stairs Landing	Field	140	S13-150	
	Support	140	S13-150	

Bearing Capacity of Foundation Piles

The bearing capacity of a single pile is taken at a depth of 15 m with the following data:

Table 8. Bearing Capacity of Single Pile with Reese O' Neil Method

Depth	Thickness	Qu	Qall
1,5	1,50	98,394682	61,398282
3	1,50	163,70839	102,15404
4,5	1,50	471,61589	294,28831
6	1,50	611,57384	381,62208
7,5	1,50	899,12382	561,05326
9	1,50	1104,3955	689,14278
10,5	1,50	1986,3851	1239,5043
12	1,50	2385,3925	1488,4849
13,5	1,50	2738,5954	1708,8835
15	1,50	3253,98	2030,4835

The bearing capacity of group piles is taken at a depth of 15 m with the following data:

Table 9. Bearing Capacity of Group Pile with Reese O' Neil Method

S1 Point								
Depth (m)	Qu (kN)	Qa (kN)	Qg					
			Eg	Qg (2 Pile) kN	Eg	Qg (3 Pile) kN	Eg	Qg (4 Pile) kN
0	-	-	-	-	-	-	-	-
1,5	98,4	61,4	0,879	107,924	0,717	132,139	0,758	186,101
3	163,7	102,2	0,879	179,562	0,717	219,853	0,758	309,634
4,5	471,6	294,3	0,879	517,289	0,717	633,358	0,758	892,002
6	611,6	381,6	0,879	670,801	0,717	821,315	0,758	1156,715
7,5	899,1	561,1	0,879	986,198	0,717	1207,481	0,758	1700,580
9	1104,4	689,1	0,879	1211,349	0,717	1483,151	0,758	2088,825
10,5	1986,4	1239,5	0,879	2178,754	0,717	2667,621	0,758	3756,998
12	2385,4	1488,5	0,879	2616,402	0,717	3203,469	0,758	4511,670
13,5	2738,6	1708,9	0,879	3003,811	0,717	3677,803	0,758	5179,709
15	3254,0	2030,5	0,879	3569,107	0,717	4369,940	0,758	6154,494

From the above results, 2 types of bearing capacity are obtained to withstand the load of the structure and then 2 types of pile cap (Single pile and group pile) are made by considering the fz load.

For loads (Fz) above 2000 kN a group pile foundation is used while for below it a single pile foundation is used.

Lower Structure Reinforcement Planning

Pile Reinforcement

For foundation reinforcement at a depth of 15 m, the following results were obtained:

- Longitudinal Reinforcement = 19D16
- Transverse Reinforcement:

1. Confinement Zone (Support)
   Length = 1800 mm
   Selected based on min 3 maximum values:
   - D/4 = 150 mm
   - 6db = 114 mm
   - 100 ≤ 100+ ((350-hx))/3 ≤150
   - 100 ≤ 150 ≤ 150

   S max = 114
   S used = 100
   S used ≤ S max
   D13 - 100
2. Outside Confinement Zone (Field)
   Length = 13200 m
   Selected based on min 3 maximum values:

- D/2 = 300 mm
- 12db = 228 mm
- 300 mm

S max = 300
S used = 200
S used ≤ S max
D13 – 200

Pile Cap Reinforcement

For Pile Cap Reinforcement with 2 types of dimensions, the following result are obtained:

Table 10. Pile Cap Type 1

PC 1				
DIRECTION	CONDITION	TOTAL NUMBER	DIAMETER	DISTANCE
x	Tension	23,00	19,00	70,00
	Compression	12,00	19,00	150,00
y	Tension	32,00	19,00	100,00
	Compression	16,00	19,00	210

Table 11. Pile Cap Type 2

PC 2				
DIRECTION	CONDITION	TOTAL NUMBER	DIAMETER	DISTANCE
x	Tension	33,00	19,00	50,00
	Compression	16,00	19,00	110,00
y	Tension	33,00	19,00	50,00
	Compression	16,00	19,00	110

CONCLUSION AND RECOMMENDATION

The results of the analysis and structural planning of the 6 Story Flat House Building in Tomohon city designed using the Special Moment Bearing Frame System (SMF) method for earthquake resistance, it can be concluded that:

1. Design of beam dimension:
   Main Beam (B1, BV, Sloof) = 350 x 550 mm
   Main Beam (B2, B5) = 400 x 600 mm
   Main Beam (B3) = 450 x 700 mm
   Main Beam (B4) = 450 x 600 mm
   Secondary Beam (BA) = 300 x 400 mm
   For reinforcement planning for each type of beam, it is adjusted to the factored force on each floor
2. Design of column dimensions:
   Column (K1) = 750 x 750 mm
   And divided into 4 types (Corner Column, Center Column, X Edge Column, dan Y Edge Column) with all typical dimensions from story 1 to 7.

3. Design of Plaet dimensiond :
   For floor slab design, 2-way type slab is planned but for stair and stair land section, 1-way slab is designed
   - Story 1-5 (Floor Plate) = 130 mm
   - Story 6-7 (Dak Plate) = 140 mm
   - Stairs and Stair Land = 140 mm
4. The building structure shows horizontal irregularities as examined and evaluated in reference to the provisions of SNI 1726:2019 on Earthquake Resistance Planning Procedures for Building and Non-Building Structures, with the following details:
   Diaphragm Discontinuity Irregularity, because the opening area on the roof floor reaches 92.7% and has exceeded 50% of the required limit, then repairs are made, namely by using Spectrum Response Analysis in conducting earthquake force analysis.
5. The building structure does not exhibit any vertical structural irregularities.
6. The results of fundamental period of the structural approach carried out using E-TABS software, show that:
   - Mode 1 in X Direction = 0.793 detik
   - Mode 2 in Y Direction = 0.751 detik

   If the structure is made smaller (especially in the Y direction beam), it will experience torsion in mode 1 in the X direction so that the designed structure is not safe, so the dimensions are enlarged for the Y direction beams so that the structure in the X direction is more rigid.
7. The planned reinforcement and structural elements are able to withstand the forces acting, with the fulfillment of the design requirements of Plan Strength ≥ Necessary Strength, according to SNI 2847: 2019.
8. The "Strong Column Weak Beam" requirement in the Special Moment Bearing Frame System (SMF) according to SNI 2847: 2019 concerning the Planning Procedure for Structural Concrete Requirements for Building and Explanation, has been controlled with the results:
   - The relation between beam and column (joint) meets the condition $\Sigma M_{nc} \geq 1{,}2\ \Sigma M_{nb}$, this shows that the nominal bending strength of the column is greater than the nominal bending strength of the beam.
   - The structural components have been designed to withstand the shear forces due to the applied loads, by ensuring that the nominal shear capacity (Vn) is greater than the observed shear force (Vu) of each structural element.
9. Design of the Lower Structure Elements:
   - Pile cap (PC 1) = 1800 x 3300 mm
   - Pile cap (PC 2) = 1800 x 1800 mm
   - Diameter of bore pile = 600 mm
10. For planning pile cap is made with 2 types according to the type of load on each column point as follows:
    - For Fz ≥ 2000 kN Load using PC type 1 (Group Pile)
    - For Fz ≤ 2000 kN Load using PC type 2 (Single Pile)

ADVANCED RESEARCH

For future research, variations of the structural system can be carried out by applying a dual system using shear walls or bracing, and also considering the use of piles as a foundation system, as well as trying to change the type of building to a high rise building to evaluate its effect on overall structural performance.

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