DESIGN OF DORMITORY STRUCTURE WITH STEEL SPECIAL MOMENT FRAMES

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ABSTRACT

Colomadu District is one of the districts located in Karanganyar Regency, Central Java Province. It is projected that the economy in this area will grow through business sectors such as goods and services, tourism, and industry, thus the construction of a Dormitory Building is planned in the area. Considering its proximity to Yogyakarta Province, which frequently experiences earthquakes, earthquake-resistant buildings are necessary to reduce the risk of casualties and material losses. Therefore, the design of this building utilizes a Special Moment Resisting Frame (SRPMK) system. The building with SRPMK is designed with the concept of SCWC (Strong Column and Weak Beam), where the column elements are stronger than the beam elements. This design aims to create a structural system that can withstand seismic forces, in accordance with SNI 2847:2019 requirements. Seismic force loading is analyzed using the response spectrum method, and the structural calculations are performed using ETABS V9.7.4 software. From the planning results, the dimensions obtained include a Bondek floor slab thickness of 130 mm, beam dimensions B1A 150x400 mm, B2A 200x400 mm, B2B 200x400 mm, B2C 200x400 mm, B2D 200x400 mm, B2E 200x400 mm, B3A 200x500 mm, B3B 200x500 mm, B4A 300x150 mm, B5A 300x150 mm, BS 150x300 mm, and column dimensions KP 150x150 mm, K1A 200x300 mm, K2A 400x550 mm, K3A 450x650 mm, and K4 350x500 mm.

Keywords: Karanganyar, SRPMK, earthquake-resistant, ETABS V9.7.4.

1. INTRODUCTION

Colomadu District is a district in Karanganyar Regency, Central Java Province, which is rapidly developing like a metropolitan city. The streets in downtown Colomadu are now adorned with star hotels, luxurious restaurants, and official residences. The renovated former sugar factory, now a tourist destination, has also played a role in advancing this district, despite being an exclave from the Karanganyar Regency government center. Colomadu's proximity to Surakarta (Solo) compared to the Karanganyar Regency government center has positively impacted its development. This can be seen in the growth of hotel areas, restaurants, and residential areas in Baturan, Blulukan, Bolon, Klodran, and Tohudan.

The economy in Colomadu District has flourished through various business activities, prompting plans for constructing a Dormitory Building in the area. Given Colomadu's proximity to Yogyakarta Province, which experiences frequent earthquakes, earthquake-resistant buildings are necessary to reduce the risk of human casualties and material losses. Therefore, the design of this Dormitory utilizes a Special Moment Resisting Frame (SRPMK) system. SRPMK is a reinforced concrete structure designed to achieve high ductility. This ductility allows the structure to undergo repeated deformations without collapsing, even during strong earthquakes, thereby minimizing human casualties and material damage.

In the planning of buildings with SRPMK, a concept of strong columns and weak beams is applied. With this concept, the frame system is expected to have full ductility and withstand high earthquake risk areas (Almufid and Santoso, E.). The main goal is to ensure the structure remains standing even at the point of ultimate collapse.

2. DESIGN PROCEDURES

The planned structure for this project is a Special Moment Resisting Steel Frame (SRPMK) structure, intended for a Dormitory building located in Colomadu, Karanganyar, Central Java. Structural analysis is conducted using ETABS V9.7.4 software. Based on the analysis results, the reinforcement requirements for beams, columns, and floor slabs will be calculated, along with checking the steel profiles and foundations to be used.

Reference

The references used in the planning include,

a. SNI 2847:2019 : *Persyaratan Beton Beton Struktural Untuk Bangunan Gedung dan Penjelasannya*
b. SNI 1727:2018 : *Beban Desain Minimum Dan Kriteria Terkait Untuk Bangunan Gedung dan Struktur lain*
c. SNI 1726:2019 : *Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung*

d. SNI 1729:2015 : *Spesifikasi Untuk Bangunan Gedung Baja Struktural*
e. SNI 2052:2017 : *Baja Tulangan Beton*

Materials

The specifications of the materials used are as follows,

a. Concrete	: Fc' 20 MPa
b. Rebar	: Ø < 10, BJTP 280 (F_y = 280 MPa)
	: D ≥ 10, BJTS 420B (F_y = 420 MPa)
c. Steel Shape	: ASTM A36/SS400/BJ37 (Fy = 240 MPa)
d. Wire Mesh	: Fy 500 MPa (U-50)
e. Light Steel	: G550 MPa
f. Baut	: HTB A325
g. Weld	: E70XX
h. $\Upsilon_{concrete}$	: 2400 Kg/m^3
i. Υ_{steel}	: 7850 Kg/m^3

Design loads and combination

The planned working loads are as follows,
a. Dead Load (DL)
b. Live Load (LL)
c. Earthquake Load (E)

The load combinations used refer to LRFD as follows,
a. 1,4 DL
b. 1,2 DL + 1,6 LL + 0,5 L_r
c. 1,2 DL + 1,6 L_r + 1,0 LL
d. (1,2 + 0,2 Sd_s) DL + E + LL
e. (0,9 – 0,2 Sd_s) DL + E

The foundation bearing capacity check combinations used refer to ASD as follows,
a. DL
b. DL + LL
c. DL + Lr
d. DL + 0,75 LL + 0,75 Lr
e. (1,0 + 0,14 Sd_s) DL + 0,7 E
f. (1,0 + 0,1 Sd_s) D + 0,525 E + 0,75 L
g. (0,6 – 0,14 Sd_s) D + 0,7 E

3. RESULTS

Preliminary design

Preliminary design is the stage of planning dimensions and materials, where structural modeling is done in two or three dimensions. Preliminary design also includes modeling structural specifications and other elements within software. Planned structural elements include beams, columns, and slabs according to SNI 03-2847-2019 standards.

Structure modeling

The main structure modeling uses ETABS V9.7.4. Beams, columns, and floor slabs are represented in 3D. The structural data used is based on the initial design results. The structure's fixity is assumed at the building's base as pinned support.

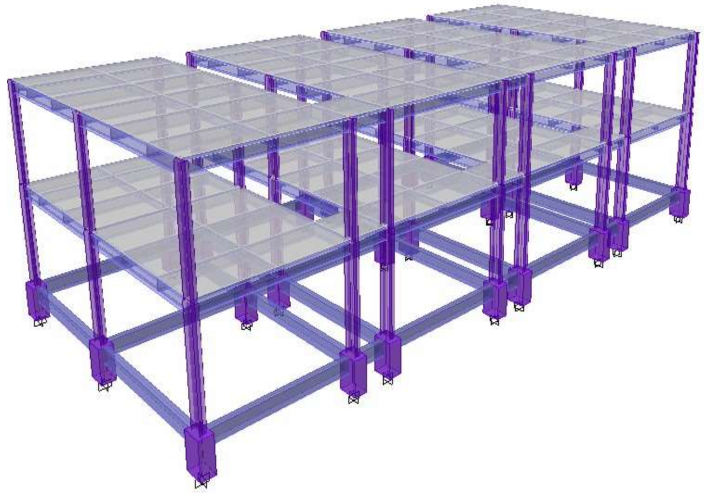


Figure 1. 3D View of the structure

Loads analysis

1. Dead Load (DL)

Dead Load is the dead weight of structural elements, typically including the weight of concrete, steel, mortar, walls, and other materials. The weight of these structural elements will be automatically calculated by ETABS V9.7.4 software as self-weight.

Table 9. Dead load data

No.	Load	Value	Unit
1	Self Weight	Automatic ETABS	
2	SDL Wall	1,6	kN/m^2
3	SDL Floor	1,35	kN/m^2
4	Roof	0,2	kN/m^2

(*Source: Software ETABS V9.7.4.)*

2. Live Load (LL)

Live Load is the dynamic load that occurs on a building as follows.

Table 10. Live loads data

No	Load	Value	Unit
1	*Hunian*	2,0	kN/m^2
2	Roof	1,0	kN/m^2

(*Source: Software ETABS V9.7.4.)*

3. Earthquake Load (EL)

In seismic load analysis using response spectrum, this analysis is designed based on the response values to ground acceleration recorded during earthquakes (Mahendrayu, B and Kalrtini, K.). Spectrum design is an estimation of the ground motion curve influenced by previous earthquakes in the area around the planning location. For the Dormitory Building planning, response spectrum parameter data is obtained from the Puskim PU site. These parameter data are obtained based on the soil characteristics and the region to be designed. After obtaining the response spectrum parameters, a response spectrum graph according to SNI 1726:2019 (Badan Standarisasi Nasional) can be created, and this data is inputted into the previously created ETABS V9.7.4 modeling.

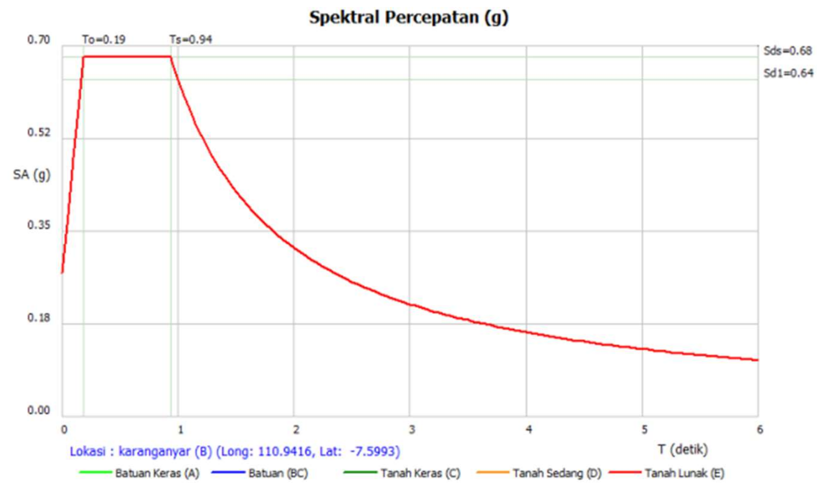


Figure 2. Response spectrum of earthquake location planning, karanganyar

Table 11. Base shear output

Direction	Base Shear Static V	Base Shear Dynamic V
X	294	263
Y	294	261

(*Source: ETABS V9.7.4.*)

Final design and verifications

1. Verification of Vertical Irregularity in Interstory Drift

Table 4. X-Direction

Floor	H_x m	δ_{xe} mm	δ_x mm	Δ_x mm	h_{sx} m	$0.02h_{sx}/\rho$ mm	Rasio	Rasio < 1
RF	6	21.10	116.05	58.3	3	60.000	0.972	OK
2	3	10.50	57.75	57.8	3	60.000	0.963	OK

Table 5. Y-Direction

Floor	H_x m	Δ_{ye} mm	Δ_y mm	Δ_y mm	h_{sy} mm	$0.02h_{sy}/\rho$ mm	Rasio	Rasio < 1
RF	6	5.700	31.35	17.6	3	60.000	0.293	OK
2	3	2.500	13.75	13.8	3	60.000	0.229	OK

2. Verification of Vertical Irregularity in Stiffness Between Floors

It is necessary to conduct stiffness verification because the greater the stiffness of the building, the smaller the deflection (Ramadhani, S.F. et all).

Table 6. X-Direction

Floor	V_x kN	δ_{xe} mm	Δ mm	K_x kN/mm	K_x / K_{x+1} ≥ 60%	$K_x / K_{avg\ 3lt}$ ≥ 70%	V_x / V_{x+1} ≥ 65%
RF	183.70	21.10	10.60	17.33			
2	290.20	10.50	10.50	27.64	OK	OK	OK

Table 7. Y-Direction

Floor	V_y kN	δ_{ye} mm	Δ mm	K_y kN/mm	K_y / K_{y+1} > 60%	$K_y / K_{avg\ 3lt}$ > 70%	V_y / V_{y+1} ≥ 65%
RF	186.07	5.70	3.20	58.1469			
2	288.51	2.50	2.50	115.404	OK	OK	OK

3. Verification of Horizontal Torsional Irregularity

It is necessary to check the effects of torsional forces because they can cause issues with the lateral force-resisting elements at the building edges and increase building displacement (M. Lumban et all).

Tabel 8. Torsion x-direction

Floor	H_n (m)	Load	Point		δ Point		δ_{max} (mm)	δ_{min} (mm)	$\Delta_{average}$ (mm)	X-direction δ_{max} / $\delta_{average}$	Torsion Check	A_x
RF	6	RSX	679	687	0.023	0.022	0.023	0.022	0.022	1.02	No Torsion	1.00
2	3	RSX	679	687	0.011	0.010	0.011	0.010	0.011	1.02	No Torsion	1.00

Tabel 9. Torsion y--direction

Floor	H_n (m)	Load	Point		δ Point		δmax (mm)	δmin (mm)	δrata^2 (mm)	Y-direction δmax / δrata^2	Torsion Check	Ax
RF	6	RSY	687	694	0.006	0.006	0.006	0.006	0.006	1.00	No Torsion	1.00
2	3	RSY	687	694	0.002	0.002	0.002	0.002	0.002	1.00	No Torsion	1.00

4. Reinforcement of Floor Slabs with Steel Deck

The reinforcement analysis of the floor slabs is performed using Excel, considering the dead load and live load of the building floors according to their respective functions, based on the technical guidelines of SNI 1729 (Surat Edaran 50/SE/M/2015). Below is the analysis of the reinforcement of the floor slabs.

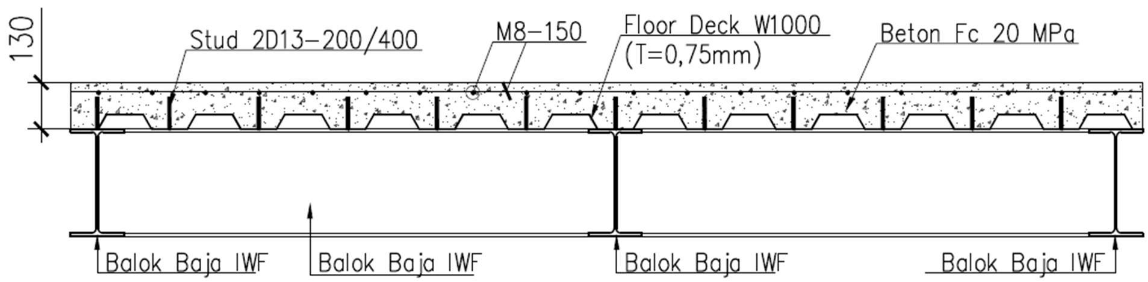


Figure 3. Reinforcement of floor slabs with steel deck

Table 9. Slab reinforcement design

Type	Fuction	Concrete Data					Steel Deck Data			Loads (kPa)			Length
		T_p	C_v	f'c	f_y	β_1	F_{ys}	A_s	h_r	DL	LL	DL+SW	
		mm	mm	Mpa	Mpa		Mpa	mm/m^2	mm				m
DC13	Hunian	130	40	20	500	0.92	500	857	50	1.35	2.00	4.47	2.0

Type	Fuction	Support								Span						ρ_{min}	$A_{s,min}$	Shrinkage Bar			
		Dia.	S	M_u	d'	a	M_n	ΦM_n	ΦM_n	Mu	d	a	M_n	ΦM_n	ΦM_n			Dia.	Jarak		CEK
		mm	mm	kN.m	mm	mm	kN.m	kN.m	> M_u	kN.m	mm	mm	kN.m	kN.m	> M_u			X	max	pas.	
DC13	Hunian	8	150	2.85	65	9.86	10	9.06	OK	4.28	105	25.2	39.6	35.63	OK	0.0018	189	8	266	150	OK

5. Reinforcement of Concrete Beams

The reinforcement analysis of the floor beams is based on the concept of SRPMK beams, specifically Capacity Design of Beams, so that the beams are designed to form plastic hinges during earthquakes. Analysis of beam shear reinforcement is conducted after inputting the area of longitudinal reinforcement used into ETABS (according to the Capacity Design concept). Below is the analysis of beam reinforcement.

Table 10. Concrete beam reinforcement analysis

Type	Beam Data						Output Element				Long. Reinforcement ETABS + 0.35Alt				Etabs Shear Reinf	
	Dimention			Materials			V_u		T_u		Top		Bottom		$A_{v/s}$ (mm^2/mm)	
	B	H	C_v	F_c'	F_y	F_{ys}	Supp.	Span	Supp.	Span	Supp.	Span	Supp.	Span		
	mm	mm	mm	MPa	MPa	MPa	kN	kN	kN.m	kN.m	cm^2	cm^2	cm^2	cm^2	Tump.	Lap.
B2A.20.40	200	400	40	20	420	420	23.75	12.93	0.03	0.03	3.16	1.67	2.16	2.41	0.08	0.06
B2B.20.40	200	400	40	20	420	420	25.8	21.79	0.014	0.014	2.33	1.46	2.06	1.46	0.41	0.38

Type	Long. Reinforcement Required						Long. Rebar			Shear Reinforcement										
	Dia.	n max	Top		Bottom					V_c	Support					Span				
			Supp.	Span	Supp.	Span	Dia.	Supp.	Span		V_s	A_{vS}	d_s	n	S	V_s	A_{vS}	d_s	n	S
	mm		bh	bh	bh	bh	mm	bh	bh	kN	kN	mm^2/mm	mm	bh	mm	kN	mm^2/mm	mm	bh	mm
B2A.20.40	13	3	3	3	3	3	10	1	1	55	0	0.16	10	2	990	0	0.16	10	2	990
B2B.20.40	13	3	3	3	3	3	10	1	1	55	0	0.41	10	2	381	0	0.38	10	2	418

Beam Data	Torsion Reinforcement Analysis															
Type	Properties Torsi							Torsion Reinf.		Support						
	A_{oh}	A_o	A_{cp}	P_{cp}	P_h	ΦT_{cr}	$\Phi T_{cr}/4$			T_n	$A_{t/s}$	Alt	A_{v+t}/S	$A_{v+t}/S_{,min}$	$A_{v+t}/S_{,use}$	S
	mm^2	mm^2	mm^2	mm	mm	kN.m	kN.m	Tump.	Lap.	kN.m	mm^2/mm	mm^2	mm^2/mm	mm^2/mm	mm^2/mm	mm
B2A.20.40	38400	32640	80000	1200	880	5.90	1.48	Tcr	Tcr	8	0.38	337	0.46	0.17	0.46	170
B2B.20.40	38400	32640	80000	1200	880	5.90	1.48	Tcr	Tcr	8	0.38	337	0.59	0.17	0.59	133

Type	Torsion Reinforcement Analysis							Shear Reinforcement							
	Span							Supp. Spcng.			Span Spcng.			Used	
	T_n	$A_{t/s}$	Alt	A_{v+t}/S	A_{v+t}/S, min	$A_{v+t}/S_{,use}$	S	Dia.	leg	S	Dia.	leg	S	Supp.	Span
	kN.m	mm^2/mm	mm^2	mm^2/mm	mm^2/mm	mm^2/mm	mm	mm	bh	mm	mm	bh	mm	mm	mm
														0	0
B2A.20.40	8	0.38	337	0.46	0.17	0.46	170	10	2	170	10	2	170	100	150
B2B.20.40	8	0.38	337	0.57	0.17	0.57	138	10	2	133	10	2	138	100	150

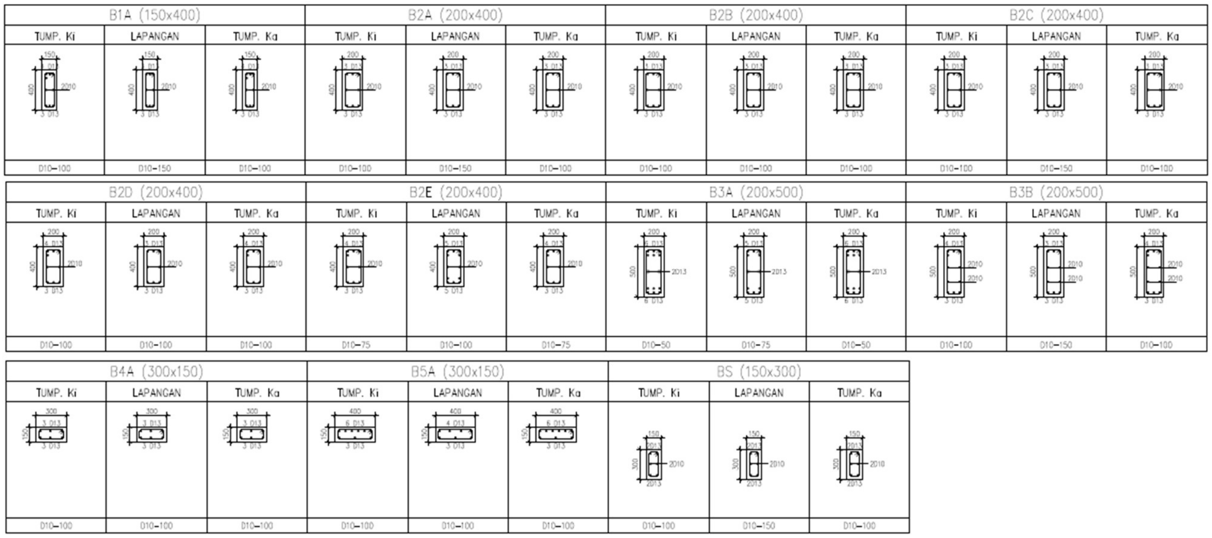


Figure 4. Concrete beams design

6. Reinforcement of Concrete Columns

The reinforcement analysis of columns is conducted using Excel and the output results from ETABS. The ETABS output results are processed and then re-input into ETABS to determine shear reinforcement and column capacity ratios. Column Reinforcement Analysis is based on SNI 2847:2019 (Badan Standarisasi Nasional). Below is the analysis of column reinforcement.

Table 11. Concrete column reinforcement analysis

DATA							LONGITUDINAL REINFORCEMENT											SHEAR REINFORCEMENT								
Sec. ID	Section (mm)		F_c'	F_y	F_{ys}	C_v	$A_{s,u}$	dia.	N – Req.	Max. Ps		Long. Ps		CHEK	LONGIT. REINF.	D/C < 1	%	Av/s (mm²/mm)		Dia.	Spakai (mm)		n -		pakai	
	BxH		MPa		MPa	mm	(cm²)	(mm)		B_x	H_y	B_x	H_y		Used			Bx (MAJ)	Hy (MIN)	(mm)	Bx	Hy	Bx	Hy	Bx	Hy
K3A.45.65.WF400	450	650	20	420	420	30	29.25	16	15 D 16	7	11	4	6	OK	16 D16	0.16	1.10	0.20	0.38	10	150	150	2	2	3	3

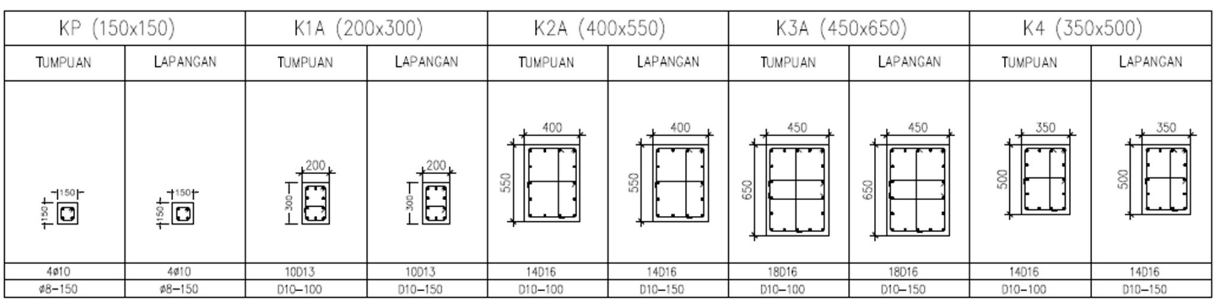


Figure 5. Concrete columns design

7. Verification of Column & Steel Beam Capacity Ratio

Analysis of axial-moment capacity ratio D/C for steel structure using LRFD method is automatically performed by ETABS. The requirement for axial-moment capacity ratio D/C must be < 1.0 to be considered safe. Below are the results of axial-moment capacity ratio analysis for steel structure from ETABS.

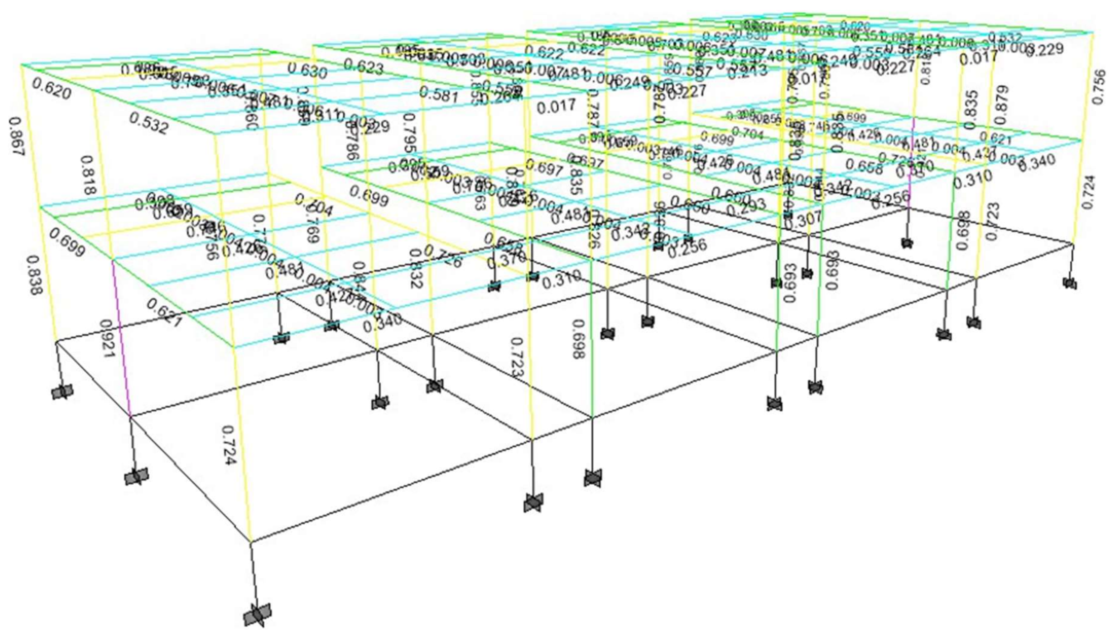


Figure 6. Steel beam & columns analysis

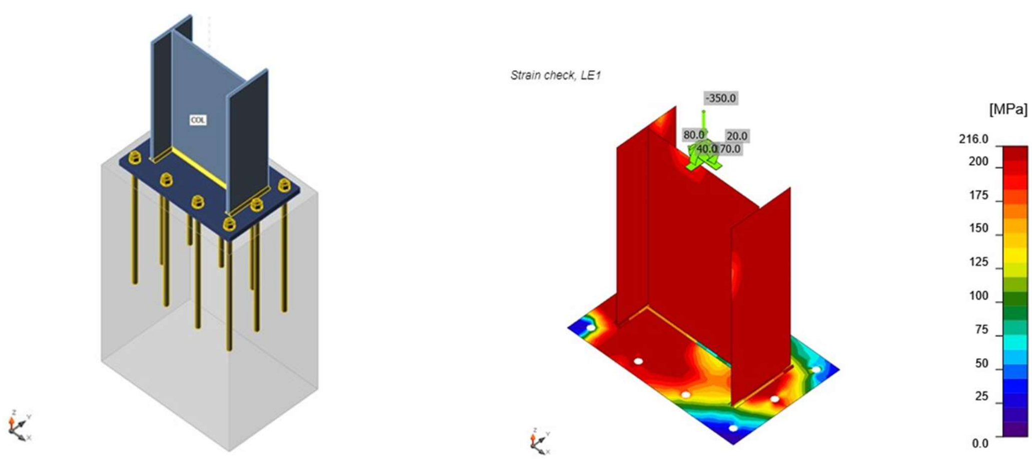
8. Base Plate Connection Design

The analysis of base plate connections is conducted using IDEA Statica software. An example analysis of base plate connection for WF 400 column is described as follows.

Summary

Name	Value	Check status
Analysis	100.0%	OK
Plates	4.2 < 5%	OK
Anchors	78.4 < 100%	OK
Welds	97.3 < 100%	OK
Concrete block	44.4 < 100%	OK
Buckling	Not calculated	

Figure 7. Summary analysis base plate from idea statica

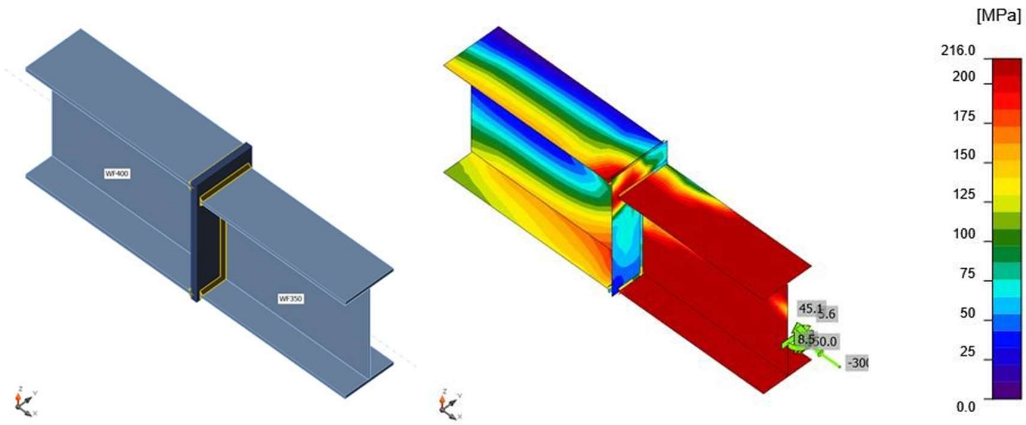


(a) (b)

Figure 8. Summary Analysis Base Plate, a. 3D model b. strain check

9. Steel Column Connection Design

The analysis of steel column connections between columns is performed using IDEA Statica software. An example analysis of connection between WF 400 column and WF 350 column is described as follows.



(a) (b)

Figure 9. Summary Analysis Column Joint, a. 3D model b. strain check

10. Pile Bearing Capacity

The foundation analysis for this project uses bored pile foundations with a diameter of 30 cm and a depth of 6 m. The bearing capacity used is 34 tons for compression and 14 tons for tension. A summary of the bearing capacity of the 30 cm diameter bored pile with a depth of 6 m can be seen in the following table.

Table 12. Recap of bored piles

Sondir	Depth	Type	Dimension	Q_{all} (ton)	Tall (ton)
S1	6	Bored	30	34.37	14.74
S2	6	Bored	30	45.46	18.04
S3	6	Bored	30	34.84	15.14
		Used		34	14

11. Analysis of Pile Quantity Requirement

The load used in the analysis of pile quantity is based on the joint reactions generated from ETABS output. Below is an example analysis of the requirement for the number of bored piles.

Red *LL*	: 1	Point Column	: 694	D/C Comp. max	: 0.33	(OK)
Pile grup factor	: 1,0 (axial)	Pile	: 1	D/C Tension max	: 0.31	(OK)
S_{DS}	: 0,670	N	: 2,0	$P_{u\ ultimate}$	: 243.71	
ρ	: 1,3	$x\text{-}max/x^2$	: 1,1111	$T_{u\ ultimate}$	: 92.66	
Ω	: 3	$y\text{-}max/y^2$	: 0,0000			
Daya dukung tiang tekan	: 340 kN	$x\text{-}max/(x^2+y^2)$	: 1,1111			
Daya dukung tiang tarik	: 140 kN	$y\text{-}max/(x^2+y^2)$	: 0,0000			

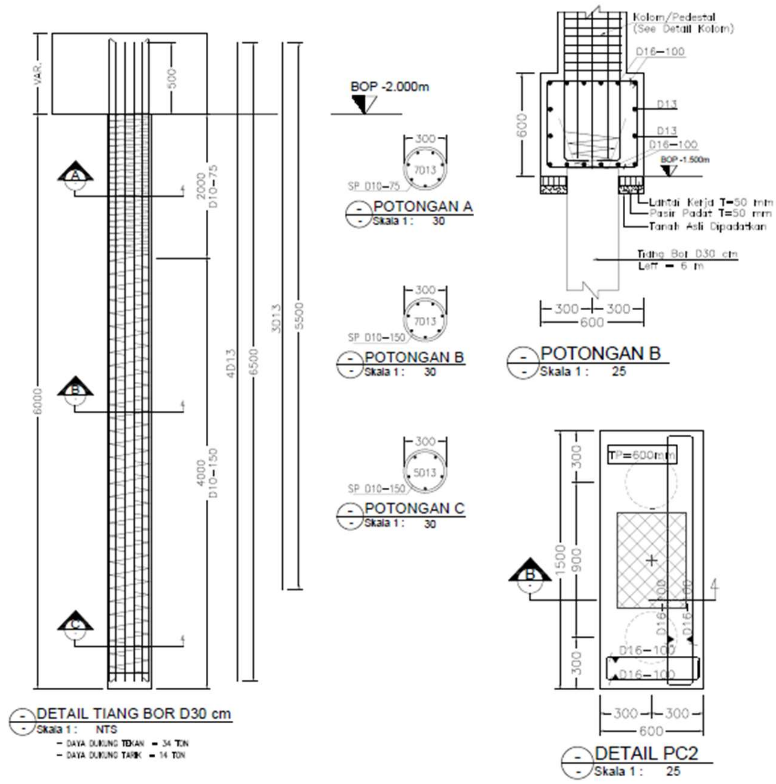


Figure 10. Summary analysis bored piles foundation

4. CONCLUSION

Based on the analysis and discussion, it can be concluded that the Dormitory building has a risk category II and utilizes Special Moment Resisting Frame (SRPMK) to withstand earthquakes. Puskim provides response spectra and data obtained using SE soil site classification and seismic design category B. For SRPMK building design, the values R = 8 and Cd = 5.5 are established, with an earthquake importance factor of 1.0. Design spectrum acceleration parameters Sds = 0.68 and Sd1 = 0.637 are also considered. The final spectrum response scale values are Vdynamic in the x direction at 1.367 and in the y direction at 1.378. Based on structural analysis, it is found that the calculated structure meets all regulatory requirements. Reinforcement of Bondek floor slabs, floor beams, columns, and pile cap foundations is in accordance with the specified tables.

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