

BAB II

PERANCANGAN STRUKTUR ATAS

2.1 *Layout Struktur*

2.1.1 Data Jumlah dan Fungsi Lantai

Tabel 2. 1 Data Jumlah dan Fungsi Lantai

Lantai	Fungsi Lantai
Lantai 1	Lahan parkir mobil
Lantai 2	Lahan parkir sepeda motor
Lantai 3	Lab komputer
Lantai 4	Aula

2.1.2 Data Material Struktur

Mutu bahan yang digunakan sebagai berikut :

Beton : $f_c' = 30$ MPa untuk Kolom & Balok

Baja : $f_y = 420$ MPa untuk baja ulir (BJTS 420)

: $f_y = 280$ MPa untuk baja ulir (BJTS 280)

2.2 Perencanaan Pelat Atap

- Material Pelat

Ukuran pelat = 5500 x 4000 mm

Ukuran balok = 600 x 350 mm

Ukuran kolom = 600 x 600 mm

LL = 0,96 kN/m²

SIDL = 2,52 kN/m²

$$\begin{aligned}
 F'_c &= 30 \text{ Mpa} \\
 F_y &= 420 \text{ Mpa} \\
 \phi \text{ tulangan atas} &= 10 \text{ mm} \\
 \phi \text{ tulangan bawah} &= 10 \text{ mm} \\
 \text{Tebal pelat} &= 100 \text{ mm} = 0,1 \text{ m}
 \end{aligned}$$

- Beban Terfaktor

$$\begin{aligned}
 QD &= \text{SIDL} + \left(\left(\frac{\text{tebal pelat}}{1000} \right) \times 24 \right) \\
 &= 2,52 + \left(\left(\frac{100}{1000} \right) \times 24 \right) \\
 &= 4,92 \text{ kN/m}
 \end{aligned}$$

$$\begin{aligned}
 QU &= 1,2 \times Qd + 1,6 \times LL \\
 &= 1,2 \times 4,92 + 1,6 \times 0,96 \\
 &= 7,44 \text{ kN/m}
 \end{aligned}$$

- Perhitungan Momen Statik

Arah memanjang

$$\begin{aligned}
 \text{MoL} &= Q_u + \frac{\left(\frac{L_x}{1000} \right) \times \left(\left(\frac{L_y}{1000} \right) - \left(\frac{uk \text{ kolom}}{1000} \right) \right)^2}{8} \\
 &= 7,44 + \frac{\left(\frac{5500}{1000} \right) \times \left(\left(\frac{4000}{1000} \right) - \left(\frac{600}{1000} \right) \right)^2}{8} \\
 &= 59,1294 \text{ kN/m}
 \end{aligned}$$

Arah memendek

$$\begin{aligned}
 \text{Mos} &= Q_u + \frac{\left(\frac{L_y}{1000} \right) \times \left(\left(\frac{L_x}{1000} \right) - \left(\frac{uk \text{ kolom}}{1000} \right) \right)^2}{8} \\
 &= 7,44 + \frac{\left(\frac{4000}{1000} \right) \times \left(\left(\frac{5500}{1000} \right) - \left(\frac{600}{1000} \right) \right)^2}{8} \\
 &= 89,3172 \text{ kN/m}
 \end{aligned}$$

- Arah Memanjang

687,5	1375	687,5	
-24,5017	13,19324738	-24,5017	0,5
-13,9324		-13,9324	
	7,502042625		1
-24,5017	13,19324738	-24,5017	0,5

$$M_{ol} = 59,1294 \text{ kN/m}$$

$$M^+ = 0,35 \times 59,1294$$

$$= 20,6953 \text{ kN/m}$$

$$M^- = 0,65 \times 59,1294$$

$$= 38,4341 \text{ kN/m}$$

	Negatif	Positif
Momen Balok	20,82648	11,21426
Momen Pelat	3,675262	1,978987
Jumlah Balok + Pelat	24,50175	13,19325
Momen Lajur Tengah	13,93236	7,502043

- Arah Memendek

687,5	1375	687,5	
-37,0108		19,9289	-37,0108
			0,5
19,9289	11,33212	19,9289	
			1
-37,0108		19,9289	-37,0108
			0,5

$$M_{ol} = 89,3172 \text{ kN/m}$$

$$M^+ = 0,35 \times 89,3172$$

$$= 31,2610 \text{ kN/m}$$

$$M^- = 0,65 \times 89,3172$$

$$= 58,0562 \text{ kN/m}$$

	Negatif	Positif
Momen Balok	31,45919	16,93957
Momen Pelat	5,551622	2,989335
Jumlah Balok + Pelat	37,01081	19,9289
Momen Lajur Tengah	21,04537	11,33212

- Tulangan Pelat

$$\text{Lebar pelat} = 1000 \text{ mm}$$

$$D_s = \text{tebal pelat} - 20 - \left(\frac{\phi \text{ tul atas}}{2} \right)$$

$$= 100 - 20 - \left(\frac{10}{2} \right)$$

$$= 75 \text{ mm}$$

$$Mu = 13,9324 \text{ kN/m}$$

$$\rho = \frac{0,85 f'c}{f_y} \left[1 - \sqrt{1 - \frac{4 Mu}{1,7 \phi f'c b d^2}} \right]$$

$$= 0,00695$$

$$As = 0,00695 \times 1000 \times 75$$

$$= 521,2786 \text{ mm}^2$$

$$As_{\min} = \frac{0,0018 \times 420}{420 \times 100 \times 1000}$$

$$= 180 \text{ mm}^2$$

$$S = \frac{0,25 \pi d^2 b}{As}$$

$$= \frac{0,25 \times 3,14 \times 10^2 \times 1000}{521,2786}$$

$$= 150,6676 \text{ mm} < 200 \text{ mm} \rightarrow \text{OK}$$

Digunakan D10-200

- Rekap

Tabel 2. 2 Rekap Penulangan Pelat Atap

	Arah Memanjang				Arah Memendek			
	Lajur Kolom		Lajur Tengah		Lajur Kolom		Lajur Tengah	
	Momen Negatif	Momen Positif	Momen Negatif	Momen Positif	Momen Negatif	Momen Positif	Momen Negatif	Momen Positif
Mu	24,5018	13,19333	13,9324	7,502043	37,01081	19,9289	21,04537	11,33212
β	0,0129	0,0066	0,0070	0,003637	0,021059	0,010236	0,010871	0,005587
As	966,9181	491,9438	521,2786	272,7935	1579,404	767,6685	815,3355	418,9993
As min	200	200	200	200	200	200	200	200
S	81,2270	159,652	150,6676	287,9094	49,72751	102,3095	96,32822	187,4462
	D10-50	D10 - 150	D10 - 150	D10 - 250	D10-50	D10 - 100	D10 - 50	D10- 150
Digunakan	24,5018	13,1933	13,93236	7,502043	37,01081	19,9289	21,04537	11,33212

2.3 Perencanaan Tangga

Lebar lantai (L1) = 3700 mm

Lebar bordes = 2750 mm

Optrede (O) = 210 mm

Antrede (A) = 138 mm

Tinggi lantai (Het) = 4000 mm

Tebal pelat tangga = 130 mm = 0,13 m

Berat volume beton = 24 kN/m³

Berat jenis spesi = 21 kN/m³

Beban hidup = 4,79 kN/m²

Jumlah anak tangga (n) = $\frac{Het}{O} = \frac{4000}{210} = 19,0476 = 20$ buah

Lebar tangga (Ltg) = $(1/2 \times (n-1)A = 1245,286$ mm

$\alpha = 57^\circ$

Rencana beban merata pada tangga

Berat sendiri tangga = $\frac{Htg}{\cos \alpha} \times bj \text{ beton} = \frac{0,13}{\cos 57^\circ} \times 24 = 5,681$ kN/m²

Berat anak tangga = $1/2 \times O \times bj \text{ beton} = 1/2 \times 210 \times 24 = 2,52$ kN/m²

Berat ubin dan spesi = $0,05 \times bj \text{ spesi} = 0,05 \times 22 = 1,1$ kN/m²

Berat railing = 1 kN/m² (asumsi)

Beban qtg = 10,301 kN/m²

Rencana beban merata pada bordes

Berat sendiri tangga = $Htg \times bj \text{ beton} = 0,13 \times 24 = 3,12$ kN/m²

Berat ubin dan spesi = $0,05 \times bj \text{ spesi} = 0,05 \times 22 = 1,1$ kN/m²

Berat railing = 1 kN/m² (asumsi)

$$\text{Beban qbd} = 5,22 \text{ kN/m}^2$$

$$\text{Beban hidup} = 4,79 \text{ kN/m}^2$$

$$\text{MDL} = 13,7689 \text{ kN/m} \quad \text{MLL} = 6,8789 \text{ kN/m}$$

$$\text{VDL} = 16,5361 \text{ kN} \quad \text{VLL} = 8,1182 \text{ kN}$$

Kombinasi

$$\text{MU1} = 1,4 \text{ MDL} = 19,27646 \text{ kN/m}$$

$$\text{MU2} = 1,2 \text{ MDL} + 1,6 \text{ MLL} = 27,52892 \text{ kN/m}$$

$$\text{VU1} = 1,4 \text{ VDL} = 23,15054 \text{ kN}$$

$$\text{VU2} = 1,2 \text{ VDL} + 1,6 \text{ VLL} = 32,83244 \text{ kN}$$

Dipilih

$$\text{Mur} = 27,52892 \text{ kN/m}$$

$$\text{Vur} = 32,83244 \text{ kN}$$

Rencana penulangan tangga tumpuan

$$\text{Mux} = \text{Mur} = 27,52892 \text{ kN/m}$$

Direncanakan

$$\text{Tulangan pokok} = 10$$

$$\text{As} = 78,53982 \text{ mm}^2$$

$$\text{Tulangan susut} = 10$$

$$\text{As} = 78,53982 \text{ mm}^2$$

$$\text{Fy tulangan pokok} = 420 \text{ Mpa}$$

$$\text{Fy tulangan susut} = 280 \text{ Mpa}$$

$$\text{Fc'} = 30 \text{ Mpa}$$

$$\text{B} = 1000 \text{ mm}$$

Selimut beton = 20 mm

Htg = 130 mm

$\beta_1 = 0,85$

$d_s = \text{htg} - \text{selimut beton} - \frac{D_{tul}}{2} = 130 - 20 - \frac{10}{2} = 105 \text{ mm}$

$$\rho = \frac{0,85 f_{c'}}{f_y} \times \left[1 - \sqrt{1 - \frac{4Mu}{1,7 \phi f_{c'} x b x d^2}} \right]$$

$$= \frac{0,85 \times 30}{380} \times \left[1 - \sqrt{1 - \frac{4 \times 27,52892}{1,7 \times 0,9 \times 30 \times 1000 \times 105^2}} \right]$$

$$= 0,00701$$

$A_{s \text{ min}} = \frac{0,0018 \times 420}{f_y \text{ tul pokok} \times b \times \text{htg}} = \frac{0,0018 \times 420}{420 \times 1000 \times 130} = 234 \text{ mm}^2$

$A_{s \text{ perlu}} = \rho \times b \times d = 0,00701 \times 1000 \times 105 = 736,095 \text{ mm}^2$

$S = \frac{0,25 \times \pi \times d^2 \times b}{A_s} = \frac{0,25 \times \pi \times 10^2 \times 1000}{736,095} = 106,698 \text{ mm}$

Digunakan D10-100

Cek gaya geser

$V_c = 0,17 \times \sqrt{f_{c'} \times b \times d} = 0,17 \times \sqrt{30 \times 1000 \times 105} = 97,768 \text{ kN}$

$\phi V_c = 0,75 \times V_c = 0,75 \times 97,768 = 73,326 \text{ kN}$

Syarat :

$\phi V_c > V_{ur} \rightarrow \text{OK}$

$73,326 > 32,83244 \rightarrow \text{OK}$

Tulangan susut

$A_{s \text{ min}} = 234 \text{ mm}^2$

$S = \frac{A_{tulangan \text{ susut}} \times b}{A_{s \text{ min}}} = \frac{50,2655 \times 1500}{450} = 335,640 \text{ mm}$

Digunakan P10-300

Rencana penulangan tangga lapangan

$$M_{ux} = M_{ur} = 27,5289 \text{ kN/m}$$

Direncanakan

$$\text{Tulangan pokok} = 10$$

$$A_s = 78,5398 \text{ mm}^2$$

$$\text{Tulangan susut} = 10$$

$$A_s = 78,5398 \text{ mm}^2$$

$$f_y \text{ tulangan pokok} = 420 \text{ Mpa}$$

$$f_y \text{ tulangan susut} = 280 \text{ Mpa}$$

$$f_c' = 30 \text{ Mpa}$$

$$B = 1000 \text{ mm}$$

$$\text{Selimut beton} = 20 \text{ mm}$$

$$H_{tg} = 130 \text{ mm}$$

$$\beta_1 = 0,85$$

$$d_s = h_{tg} - \text{selimut beton} - \frac{D_{tul}}{2} = 130 - 20 - \frac{10}{2} = 105 \text{ mm}$$

$$\begin{aligned} \rho &= \frac{0,85 f_c'}{f_y} \times \left[1 - \sqrt{1 - \frac{4M_u}{1,7 \phi f_c' x b x d^2}} \right] \\ &= \frac{0,85 \times 30}{380} \times \left[1 - \sqrt{1 - \frac{4 \times 27,5289}{1,7 \times 0,9 \times 30 \times 1000 \times 105^2}} \right] \\ &= 0,00701 \end{aligned}$$

$$A_{s \text{ min}} = \frac{0,0018 \times 420}{f_y \text{ tul pokok} \times b \times h_{tg}} = \frac{0,0018 \times 420}{420 \times 1000 \times 130} = 234 \text{ mm}^2$$

$$A_{s \text{ perlu}} = \rho \times b \times d = 0,00701 \times 1000 \times 105 = 736,0954 \text{ mm}^2$$

$$S = \frac{0,25 \times \pi \times d^2 \times b}{A_s} = \frac{0,25 \times \pi \times 10^2 \times 1000}{736,0954} = 106,6979 \text{ mm}$$

Digunakan D10-100

Cek gaya geser

$$V_c = 0,17 \times \sqrt{f_c'} \times b \times d = 0,17 \times \sqrt{30 \times 1000 \times 105} = 100,975 \text{ kN}$$

$$\phi V_c = 0,75 \times V_c = 0,75 \times 100,975 = 73,326 \text{ kN}$$

Syarat :

$$\phi V_c > V_{ur} \rightarrow \text{OK}$$

$$73,326 > 32,832 \rightarrow \text{OK}$$

Tulangan susut

$$A_{s \text{ min}} = 234 \text{ mm}^2$$

$$S = \frac{A_{\text{tulangan susut}} \times b}{A_{s \text{ min}}} = \frac{78,53982 \times 1000}{234} = 335,6402 \text{ mm}$$

Digunakan P10-300

Perencanaan pondasi tangga

$$\text{Beban mati tangga} = 41,20 \text{ kN/m}$$

$$\text{Beban hidup tangga} = 19,16 \text{ kN/m}$$

$$\text{Beban dinding} = 9,6 \text{ kN/m}$$

$$\text{Beban qtg} = 69,96 \text{ kN/m}$$

$$\gamma \text{ tanah} = 17 \text{ kN/m}^3$$

$$\sigma = 200 \text{ kN/m}^2$$

$$\text{tebal pondasi} = 200 \text{ mm}$$

$$d = 2000 \text{ mm}$$

$$\sigma_{\text{netto}} = 188,4 \text{ kN/m}^2$$

$$b = 1000 \text{ mm (asumsi)}$$

$$e = \frac{M_{\text{tulangan tumpuan}}}{\text{beban qtg}} = \frac{27,52892}{69,96} = 0,393 \text{ m}$$

$$\text{Cek tegangan} = \frac{\text{beban } qtg}{\frac{b}{1000}} = \frac{69,96}{\frac{1000}{1000}} = 69,965$$

$$\text{Syarat} = 69,965 < 188,40 \rightarrow \mathbf{OK}$$

Menghitung tegangan terfaktor

$$\text{Beban mati tangga} = 49,446 \text{ kN/m}$$

$$\text{Beban hidup tangga} = 30,656 \text{ kN/m}$$

$$\text{Beban dinding} = 11,52 \text{ kN/m}$$

$$\text{Beban } qtg = 91,6219 \text{ kN/m}$$

$$e = \frac{\text{Mu tulangan tumpuan}}{\text{beban } qtg} = \frac{27,52892}{91,6219} = 0,3 \text{ m}$$

$$\text{Cek tegangan} = \frac{\text{beban } qtg}{\frac{b}{1000}} = \frac{91,6219}{\frac{1000}{1000}} = 91,6219$$

$$\text{Syarat} = 91,6219 < 188,40 \rightarrow \mathbf{OK}$$

Rencana penulangan tangga

$$Mu = 22,905 \text{ kN/m}$$

$$Vu = 45,811 \text{ kN}$$

$$\begin{aligned} Ds &= \text{tebal pondasi} - \text{selimut beton} - \text{diameter tulangan pokok} \\ &= 200 - 40 - \frac{10}{2} = 155 \end{aligned}$$

$$\begin{aligned} \rho &= \frac{0,85 f'c'}{f_y} \times \left[1 - \sqrt{1 - \frac{4Mu}{1,7 \phi f'c' x b x d^2}} \right] \\ &= \frac{0,85 \times 30}{380} \times \left[1 - \sqrt{1 - \frac{4 \times 22,905}{1,7 \times 0,9 \times 30 \times 1000 \times 105^2}} \right] \\ &= 0,005771 \end{aligned}$$

$$As_{\min} = 0,002 \times b \times h$$

$$= 0,002 \times 1000 \times 150$$

$$= 360$$

$$\begin{aligned}
 A_s \text{ perlu} &= \rho \times b \times d \\
 &= 0,005771 \times 1000 \times 105 \\
 &= 894,4279 \text{ mm}^2
 \end{aligned}$$

$$\begin{aligned}
 S &= \frac{0,25 \times \pi \times d^2 \times b}{A_s \text{ min}} \\
 &= \frac{0,25 \times \pi \times 10^2 \times 1000}{360} \\
 &= 218,1662 \text{ mm}^2
 \end{aligned}$$

Digunakan D10-200

Cek gaya geser

$$\begin{aligned}
 V_c &= 0,17 \times \sqrt{f_c'} \times b \times d \\
 &= 0,17 \times \sqrt{30} \times 1000 \times 105 \\
 &= 144,325 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 \phi V_c &= 0,75 \times V_c \\
 &= 0,75 \times 144,325 \\
 &= 108,24 \text{ kN}
 \end{aligned}$$

Syarat

$$\phi V_c > V_{ur} \rightarrow \text{OK}$$

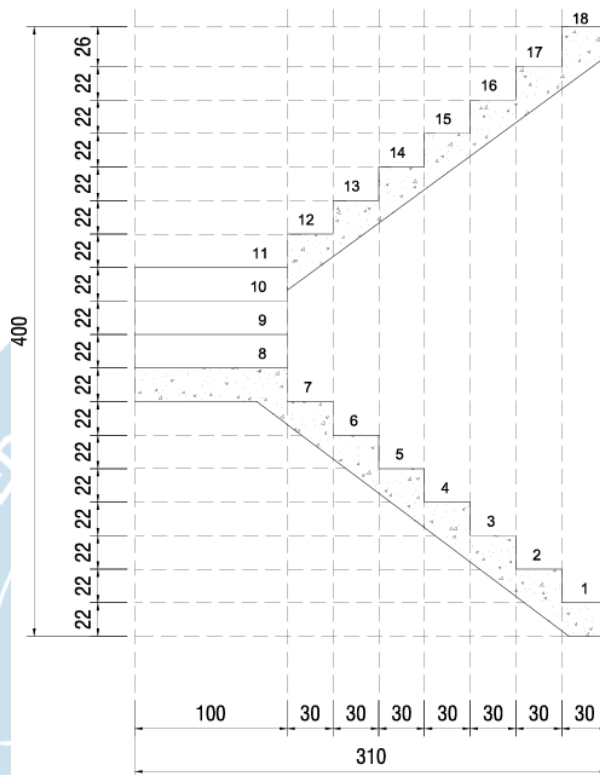
$$108,24 > 32,83244 \rightarrow \text{OK}$$

Tulangan susut

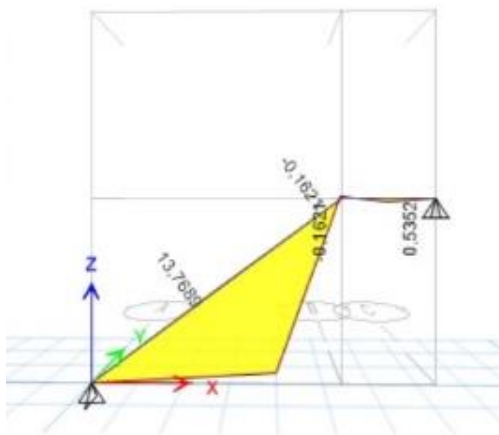
$$A_s \text{ min} = 360 \text{ mm}^2$$

$$S = \frac{A_{\text{tulangan susut}} \times b}{A_s \text{ min}} = \frac{360 \times 1000}{360} = 218,166 \text{ mm}$$

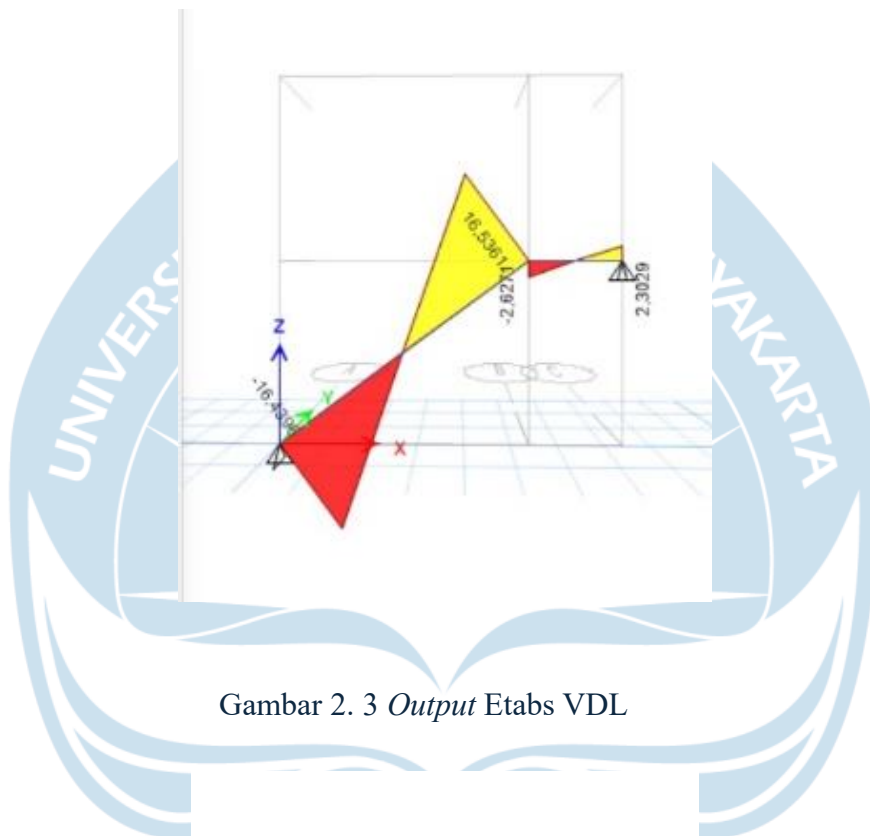
Digunakan P10-200



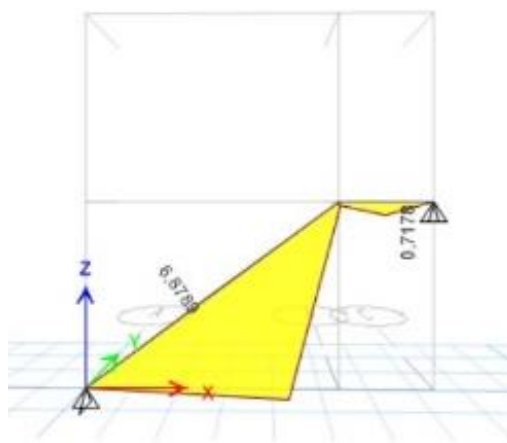
Gambar 2. 1 Denah Tangga

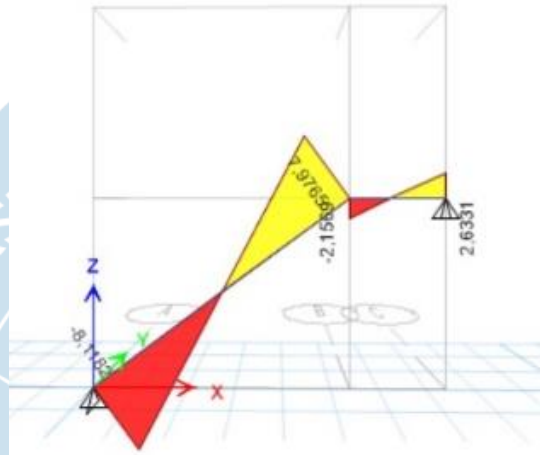


Gambar 2. 2 *Output* Etabs MDL



Gambar 2. 3 *Output* Etabs VDL



Gambar 2. 4 *Output* Etabs MLLGambar 2. 5 *Output* Etabs VLL

2.4 Preliminary Design

Merupakan tahap awal dalam yang harus dilakukan dalam merancang struktur bangunan yang bertujuan untuk memberikan gambaran umum mengenai dimensi dan sistem struktur yang akan digunakan. Perhitungan awal elemen struktural dilakukan pada tahap ini, dengan mempertimbangkan berbagai jenis beban, termasuk beban mati, beban hidup, dan beban lain yang relevan. Perkiraan dimensi yang akan direncanakan pada balok, kolom, dan pelat sebagai berikut :

2.4.1 Balok

1. Balok Induk Melintang

Bentang antar kolom = 5500 mm

$$H = \frac{5500}{16} = 343,75 \text{ mm}$$

$$\begin{aligned}
 H \text{ digunakan} &= 650 \text{ mm} \\
 B &= 2 \times \frac{h \text{ digunakan}}{3} \\
 &= 2 \times \frac{650}{3} \\
 &= 433,33 \text{ mm}
 \end{aligned}$$

$$B \text{ digunakan} = 350 \text{ mm}$$

Pengecekan Syarat SPRMK Balok Induk

$$B = 350 \text{ mm}$$

$$H = 650 \text{ mm}$$

$$\text{Selimut beton} = 40 \text{ mm}$$

$$\text{Diameter sengkang} = 10 \text{ mm}$$

$$\text{Diameter tul utama} = 22 \text{ mm}$$

$$\text{Dimensi kolom} = 600 \times 600 \text{ mm}$$

Jika $L_n > 4d$ maka aman

$$L_n = 5500 - 600 = 4900$$

$$\begin{aligned}
 d &= 650 - 40 - 10 - \frac{22}{2} \\
 &= 589
 \end{aligned}$$

$$\begin{aligned}
 4d &= 4 \times 589 \\
 &= 2356
 \end{aligned}$$

Jika $B_w > 0,3h$ atau 250 mm maka aman

$$B_w = 350$$

$$\begin{aligned}
 0,3h &= 0,3 \times 650 \\
 &= 195
 \end{aligned}$$

2. Balok Induk Memanjang

$$\text{Bentang antar kolom} = 4000 \text{ mm}$$

$$H = \frac{4000}{16} = 250 \text{ mm}$$

$$H \text{ digunakan} = 500 \text{ mm}$$

$$B = 2 \times \frac{h \text{ digunakan}}{3}$$

$$= 2 \times \frac{444,44}{3}$$

$$= 333,33 \text{ mm}$$

B digunakan = 300 mm

Pengecekan Syarat SPRMK Balok Induk

B = 300 mm

H = 500 mm

Selimut beton = 40 mm

Diameter sengkang = 10 mm

Diameter tul utama = 22 mm

Dimensi kolom = 600 x 600 mm

Jika $L_n > 4d$ maka aman

$L_n = 4000 - 600$
 $= 3400$

$d = 500 - 40 - 10 - \frac{22}{2}$
 $= 439$

$4d = 4 \times 439$
 $= 1756$

Jika $B_w > 0,3h$ atau 250 mm maka aman

$B_w : 300$

$0,3h = 0,3 \times 500$
 $= 150$

3 Balok Anak

Bentang antar kolom = 5500 mm

$H = \frac{5500}{18} = 305,5 \text{ mm}$

H digunakan = 400 mm

$B = 2 \times \frac{h \text{ digunakan}}{3}$

$$= 2 \times \frac{400}{3}$$

$$= 266,67 \text{ mm}$$

B digunakan = 200 mm

Pengecekan Syarat SPRMK Balok Induk

B = 200 mm

H = 400 mm

Selimut beton = 40 mm

Diameter sengkang = 10 mm

Diameter tul utama = 22 mm

Dimensi kolom = 600 x 600 mm

Jika $L_n > 4d$ maka aman

$L_n = 4000 - 600$

$= 4900$

$d = 400 - 40 - 10 - 22/2$

$= 339$

$4d = 4 \times 339$

$= 1356$

Jika $B_w > 0,3h$ atau 250 mm maka aman

$B_w = 200$

$0,3h = 0,3 \times 400$

$= 120$

2.5.2 Kolom

$$\frac{5500}{12} = 458,3 \text{ mm, digunakan} \rightarrow 600 \text{ mm}$$

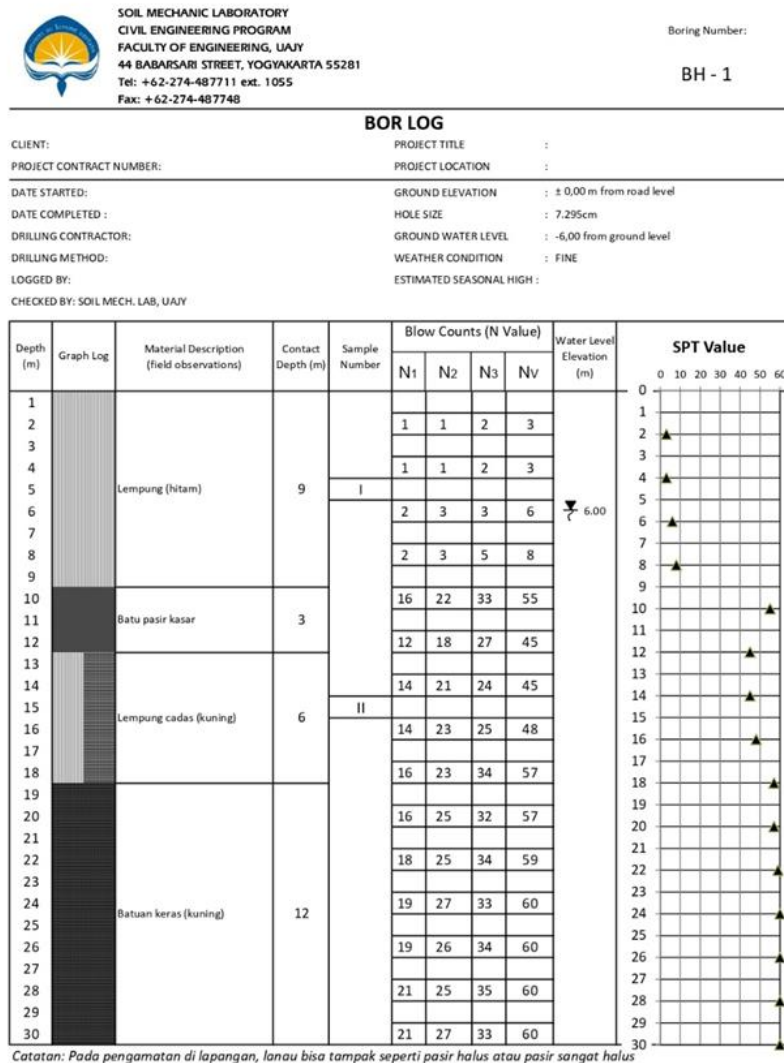
$$\frac{4000}{12} = 333,3 \text{ mm, digunakan} \rightarrow 600 \text{ mm}$$

Digunakan dimensi kolom 600 mm x 600 mm

2.6 Interpretasi Data Tanah dan Penentuan Klasifikasi Situs

1. Interpretasi Data Tanah

Data bor log tanah yang telah di survei lalu dianalisis untuk memperoleh interpretasi data tanah. Berdasarkan hasil analisis tersebut, dilakukan penentuan kelas situs tanah sebagai berikut :



Gambar 2. 6 Data Bor Log

Tabel 2. 3 Interpretasi Data Tanah

No	Kedalaman (m)	T (m)	N (SPT)	N' = T/N
1	0 – 2	2	3	0,67
2	2 – 4	2	3	0,67
3	4 – 6	2	6	0,34
4	6 – 8	2	8	0,25
5	8 – 10	2	55	0,04
6	10 – 12	2	45	0,04
7	12 – 14	2	45	0,04
8	14 – 16	2	48	0,04
9	16 – 18	2	57	0,04
10	18 – 20	2	57	0,04
11	20 – 22	2	59	0,03
12	22 -24	2	60	0,03
13	24 – 26	2	60	0,03
14	26 – 28	2	60	0,03
15	28 – 30	2	60	0,03
	Jumlah =	30		2,32
	N rerata =	12,93		

Dengan N rata-rata = 12,93. Sehingga dapat dikategorikan ke dalam golongan Tanah Lunak (SE).

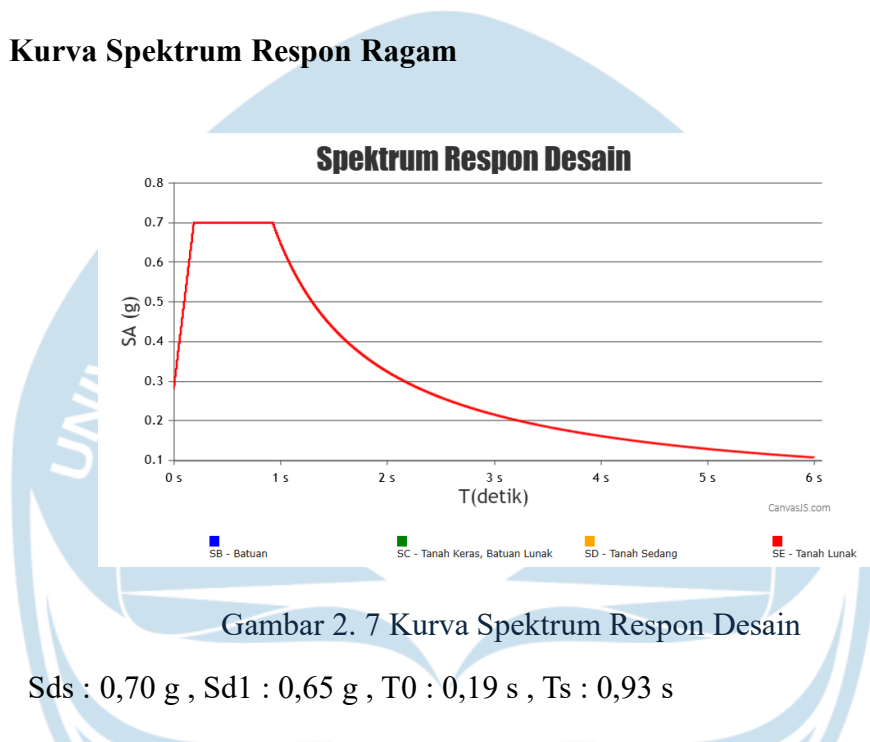
2. Penentuan Klasifikasi Situs

Tabel 2. 4 Penentuan Klasifikasi Situs

Kelas situs	$\bar{V}_s$ (m/detik)	$\bar{N}$ atau $\bar{N}_{ch}$	$\bar{s}_u$ (kPa)
SA (batuan keras)	>1500	N/A	N/A
SB (batuan)	750 sampai 1500	N/A	N/A
SC (tanah keras, sangat padat dan batuan lunak)	350 sampai 750	>50	≥ 100
SD (tanah sedang)	175 sampai 350	15 sampai 50	50 sampai 100
SE (tanah lunak)	< 175	<15	< 50
	Atau setiap profil tanah yang mengandung lebih dari 3 m tanah dengan karakteristik sebagai berikut : 1. Indeks plastisitas, $PI > 20$, 2. Kadar air, $w \geq 40\%$, 3. Kuat geser niralir, $\bar{s}_u < 25$ kPa		
SF (tanah khusus, yang membutuhkan investigasi geoteknik spesifik dan analisis respons spesifik-situs yang mengikuti 0)	Setiap profil lapisan tanah yang memiliki salah satu atau lebih dari karakteristik berikut: - Rawan dan berpotensi gagal atau runtuh akibat beban gempa seperti mudah likuifaksi, lempung sangat sensitif, tanah tersementasi lemah - Lempung sangat organik dan/atau gambut (ketebalan $H > 3$ m)		

Sesuai dengan data yang telah diperoleh dan diolah, bangunan Gedung *Workshop* SMK Muhammadiyah 01 Boyolali merupakan situs SE (Tanah Lunak).

3. Kurva Spektrum Respon Ragam



Results: Tabel dibawah ini merupakan Parameter untuk membuat Grafik Desain Spektra Indonesia:

Kelas	T0(detik)	Ts(detik)	Sds(g)	Sd1(g)
SE - Tanah Lunak	0.19	0.93	0.70	0.65

Rentang T(s) Value: 6

PGA MCEG 0.3743 (g) bedrock

SS MCEr 0.8712 (g) bedrock

S1 MCEr 0.4146 (g) bedrock

TL 20 Detik

Save

Gambar 2. 8 Hasil Kurva Spektrum Respon Desain

2.7 Pelat Lantai

2.6.1 Perencanaan Pelat Lantai

Pada struktur bangunan bertingkat, pelat lantai berperan sebagai elemen struktural utama yang menyalurkan beban ke balok dan kolom. Perancangan pada pelat lantai harus dapat menahan beban mati, beban hidup, serta beban tambahan lainnya seperti beban gempa dan angin. Pemilihan jenis pelat satu arah maupun dua arah harus disesuaikan dengan rasio bentang dan kondisi tumpuan. Berikut merupakan tebal pelat yang digunakan dalam perencanaan :

Tabel 2. 5 Tipe Pelat

Pelat	Ly	Lx	Ly / Lx	Jenis Pelat
P1	5500	4000	1,38	Dua arah
P2	5500	2800	1,96	Dua arah

Tebal pelat

$$\frac{L_{\text{terpendek}}}{28} = \frac{2800}{28} = 100 \rightarrow \text{digunakan } 120 \text{ mm}$$

Sesuai dengan ketentuan dalam SNI 2847:2019, pelat dua arah direncanakan dengan ketebalan minimum 12 cm.

Tabel 2. 6 Tebal Pelat

Pelat	Tebal Pelat
Pelat Lantai	120 mm
Pelat Tangga	130 mm

2.6.2 Tulangan Pelat Lantai

- Material Pelat

Ukuran pelat = 5500 x 4000 mm

Ukuran balok = 600 x 350 mm

Ukuran kolom = 600 x 600 mm

LL = 4,79 kN/m²

SIDL = 2,52 kN/m²

F'c = 30 Mpa

Fy = 420 Mpa

φ tulangan atas = 13 mm

φ tulangan bawah = 13 mm

Tebal pelat = 120 mm = 0,12 m

- Beban Terfaktor

$$QD = SIDL + \left(\left(\frac{tebal\ pelat}{1000} \right) \times 24 \right)$$

$$= 2,52 + \left(\left(\frac{120}{1000} \right) \times 24 \right)$$

$$= 5,4 \text{ kN/m}$$

$$QU = 1,2 \times Qd + 1,6 \times LL$$

$$= 1,2 \times 5,4 + 1,6 \times 4,79$$

$$= 14,144 \text{ kN/m}$$

- Perhitungan Momen Statik

Arah memanjang

$$MoL = Qu + \frac{\left(\frac{Lx}{1000} \right) \times \left(\left(\frac{Ly}{1000} \right) - \left(\frac{uk\ kolom}{1000} \right) \right)^2}{8}$$

$$= Qu + \frac{\left(\frac{5500}{1000} \right) \times \left(\left(\frac{4000}{1000} \right) - \left(\frac{600}{1000} \right) \right)^2}{8}$$

$$= 112,4094 \text{ kN/m}$$

Arah memendek

$$\begin{aligned}
 \text{Mos} &= Q_u + \frac{\left(\frac{Ly}{1000}\right) \times \left(\left(\frac{Lx}{1000}\right) - \left(\frac{uk \text{ kolom}}{1000}\right)\right)^2}{8} \\
 &= Q_u + \frac{\left(\frac{4000}{1000}\right) \times \left(\left(\frac{5500}{1000}\right) - \left(\frac{600}{1000}\right)\right)^2}{8} \\
 &= 169,7987 \text{ kN/m}
 \end{aligned}$$

- Arah Memanjang

687,5	1375	687,5	
46,579662	25,0813563	-46,579662	0,5
26,486474		-26,486474	
	14,2619477		1
46,579662	25,0813563	-46,579662	0,5

$$M_{ol} = 112,4094 \text{ kN/m}$$

$$\begin{aligned}
 M^+ &= 0,35 \times 112,4904 \\
 &= 39,3433 \text{ kN/m}
 \end{aligned}$$

$$\begin{aligned}
 M^- &= 0,65 \times 112,49044 \\
 &= 73,0661 \text{ kN/m}
 \end{aligned}$$

	Negatif	Positif
Momen Balok	39,592712	21,3191529
Momen Pelat	6,9869493	3,76220345
Jumlah Balok + Pelat	46,579662	25,0813563
Momen Lajur Tengah	26,486474	14,2619477

- Arah Memendek

1,125 m	2,25 m	1,125 m	
-70,360345		37,886339	-70,360345
			0,75 m
37,886339	21,5432126		37,8863394
			1,5 m
-70,360345		37,886339	-70,360345
			0,75 m

$$M_{ol} = 169,7987 \text{ kN/m}$$

$$M^+ = 0,35 \times 169,7987$$

$$= 59,4296 \text{ kN/m}$$

$$M^- = 0,65 \times 169,7987$$

$$= 110,3692 \text{ kN/m}$$

	Negatif	Positif
Momen Balok	59,806293	32,2033885
Momen Pelat	10,554052	5,68295091
Jumlah Balok + Pelat	70,360345	37,8863394
Momen Lajur Tengah	40,008823	21,5432126

- Tulangan Pelat

$$\text{Lebar pelat} = 1000 \text{ mm}$$

$$D_s = \text{tebal pelat} - 20 - \left(\frac{\phi \text{ tul atas}}{2} \right)$$

$$= 120 - 20 - \left(\frac{13}{2} \right)$$

$$= 93,5 \text{ mm}$$

$$M_u = 26,4865 \text{ kN/m}$$

$$\rho = \frac{0,85 f'c}{f_y} \left[1 - \sqrt{1 - \frac{4 Mu}{1,7 \phi f'c b d^2}} \right]$$

$$= 0,008628185$$

$$A_s = 0,008628185 \times 1000 \times 93,5$$

$$= 806,7352 \text{ mm}^2$$

$$A_{s \text{ min}} = \frac{0,0018 \times 420}{420 \times 120 \times 1000}$$

$$= 216 \text{ mm}^2$$

$$S = \frac{0,25 \pi d^2 b}{A_s}$$

$$= \frac{0,25 \times 3,14 \times 13^2 \times 1000}{806,7352}$$

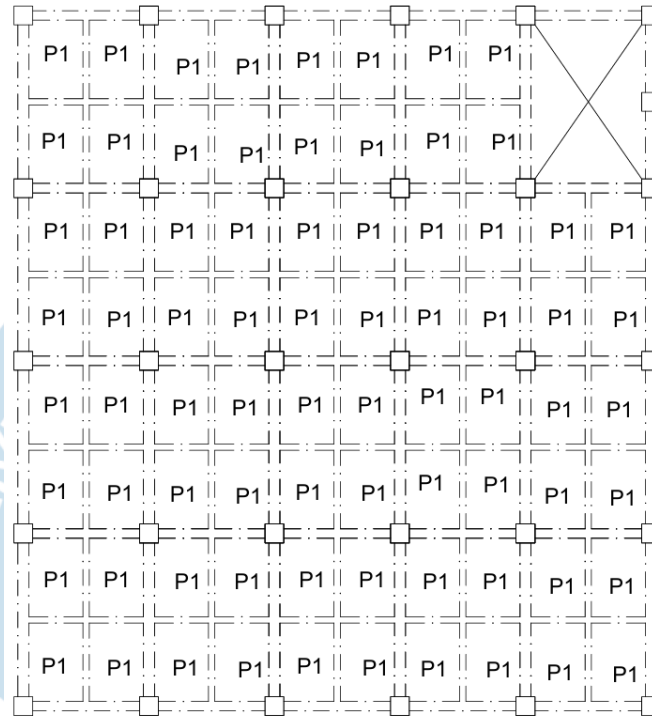
$$= 164,53017 \text{ mm} < 260 \text{ mm} \rightarrow \text{OK}$$

Digunakan D10-200

- Rekap

Tabel 2. 7 Rekap Penulangan Pelat Lantai

	Arah Memanjang				Arah Memendek			
	Lajur Kolom		Lajur Tengah		Lajur Kolom		Lajur Tengah	
	Momen Negatif	Momen Positif	Momen Negatif	Momen Positif	Momen Negatif	Momen Positif	Momen Negatif	Momen Positif
Mu	46,5796	25,0813	26,4864	14,2619	70,3603	37,8863	40,0088	21,5432
β	0,0162	0,0081	0,0086	0,0044	0,0275	0,0128	0,0136	0,0069
As	1521,9495	760,6112	806,7352	418,9921	2574,631	1198,471	1275,254	646,3421
As min	240	240	240	240	240	240	240	240
S	87,2120	174,5073	164,5301	316,7895	51,5539	110,7514	104,083	205,3592
Digunakan	D13-100	D13 - 200	D13 - 200	D13 - 400	D13-50	D13 - 150	D13 - 100	D13- 250



Gambar 2. 9 Denah Pelat Lantai

2.7 Perhitungan Beban Rencana

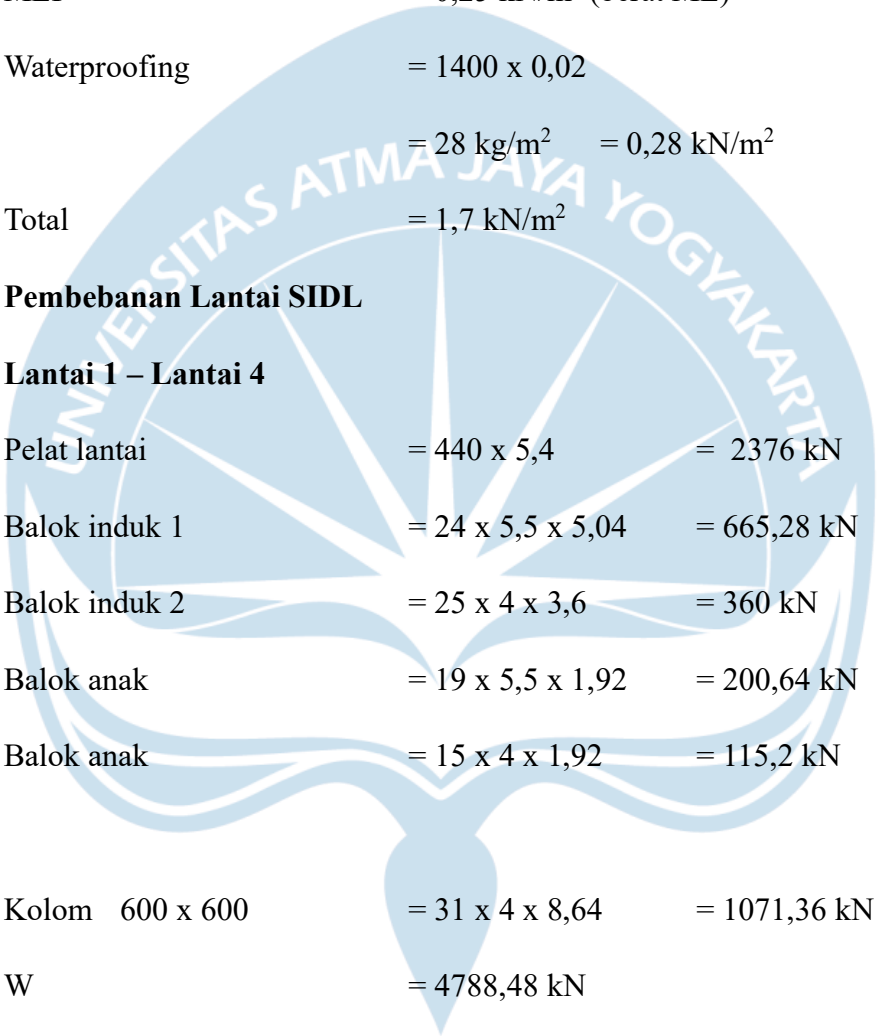
2.7.1 Beban Gravitasi

1. Beban Sendiri (SIDL)

Dak

$$\begin{aligned} \text{Berat sendiri pelat} &= 2400 \text{ kg/m}^3 \times 0,14 \text{ m} \\ &= 336 \text{ kg/m}^2 = 3,36 \text{ kN/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Beban pasir} &= 1800 \times 0,05 \\ &= 90 \text{ kg/m}^2 = 0,9 \text{ kN/m}^2 \end{aligned}$$



Beban spesi $= 2300 \times 0,03$
 $= 69 \text{ kg/m}^2 = 0,69 \text{ kN/m}^2$
 MEP $= 0,25 \text{ kN/m}^2$ (berat ME)
 Waterproofing $= 1400 \times 0,02$
 $= 28 \text{ kg/m}^2 = 0,28 \text{ kN/m}^2$
 Total $= 1,7 \text{ kN/m}^2$

Pembebanan Lantai SIDL

Lantai 1 – Lantai 4

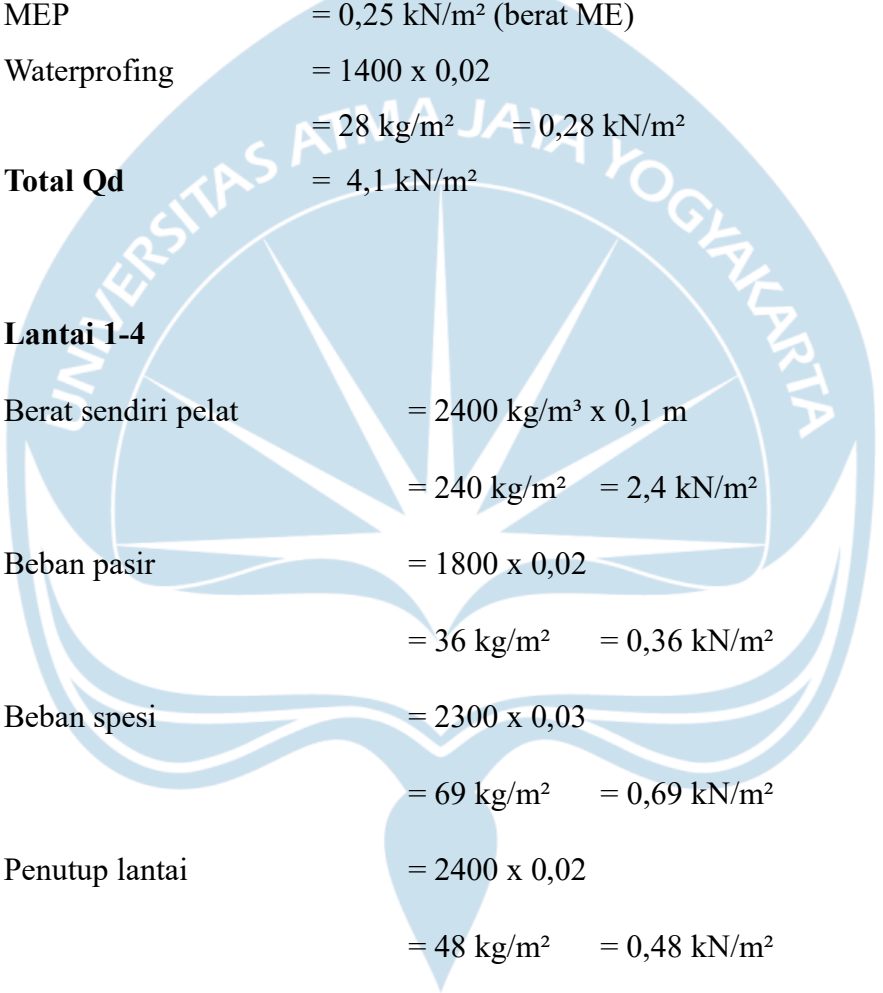
Pelat lantai $= 440 \times 5,4 = 2376 \text{ kN}$
 Balok induk 1 $= 24 \times 5,5 \times 5,04 = 665,28 \text{ kN}$
 Balok induk 2 $= 25 \times 4 \times 3,6 = 360 \text{ kN}$
 Balok anak $= 19 \times 5,5 \times 1,92 = 200,64 \text{ kN}$
 Balok anak $= 15 \times 4 \times 1,92 = 115,2 \text{ kN}$

 Kolom 600 x 600 $= 31 \times 4 \times 8,64 = 1071,36 \text{ kN}$
 W $= 4788,48 \text{ kN}$

2. Beban Mati (QD)

Dak

Berat sendiri pelat $= 2400 \text{ kg/m}^3 \times 0,1 \text{ m}$
 $= 240 \text{ kg/m}^2 = 2,4 \text{ kN/m}^2$



Beban pasir $= 1800 \times 0,02$
 $= 36 \text{ kg/m}^2 = 0,36 \text{ kN/m}^2$
 Beban spesi $= 2300 \times 0,03$
 $= 69 \text{ kg/m}^2 = 0,69 \text{ kN/m}^2$
 MEP $= 0,25 \text{ kN/m}^2$ (berat ME)
 Waterprofing $= 1400 \times 0,02$
 $= 28 \text{ kg/m}^2 = 0,28 \text{ kN/m}^2$
Total Qd $= 4,1 \text{ kN/m}^2$

Lantai 1-4

Berat sendiri pelat $= 2400 \text{ kg/m}^3 \times 0,1 \text{ m}$
 $= 240 \text{ kg/m}^2 = 2,4 \text{ kN/m}^2$
 Beban pasir $= 1800 \times 0,02$
 $= 36 \text{ kg/m}^2 = 0,36 \text{ kN/m}^2$
 Beban spesi $= 2300 \times 0,03$
 $= 69 \text{ kg/m}^2 = 0,69 \text{ kN/m}^2$
 Penutup lantai $= 2400 \times 0,02$
 $= 48 \text{ kg/m}^2 = 0,48 \text{ kN/m}^2$
 Plafond $= 0,20 \text{ kN/m}^2$
 MEP $= 0,25 \text{ kN/m}^2$ (berat ME)
Total Qd $= 5,4 \text{ kN/m}^2$

Nilai T

$$T_a = 0,0466 \times 16^{0,9} = 0,565 \text{ s}$$

Nilai K

$$0,5 T_a + 0,75 = 1,03253$$

Nilai V

$$V_x = V_y$$

$$C_s \times W = 23960,64 \times 5,36 = 128429 \text{ kN}$$

Tabel 2. 8 Base Shear

Lantai	W _x	H _x	W _x x H _x	C _v	F _x
Atap	4806,72	21,6	151175,26	0,34	43186,66
4	4788,48	17,4	120452,74	0,27	34410,07
3	4788,48	13,2	90560,46	0,20	25870,66
2	4788,48	9	60981,28	0,14	17420,69
1	4788,48	4	26397,19	0,06	7540,96
Σ	23960,64	-	449566,9358	-	128429,03

3. Beban Hidup (QL)

Beban hidup lantai 1 dan 2 = 4,79 kN/m²

Beban hidup lantai 3

Beban koridor = 3,83 kN/m²

Beban lab komputer = 4,79 kN/m²

Beban hidup lantai 4

Beban koridor = $3,83 \text{ kN/m}^2$

Beban aula = $4,79 \text{ kN/m}^2$

Beban hidup atap = $0,96 \text{ kN/m}^2$

2.7.2 Beban Gempa

Beban gempa merupakan salah satu beban yang harus diperhitungkan dalam perencanaan struktur bangunan, terutama di wilayah yang rawan terhadap aktivitas seismik seperti Indonesia. Beban ini timbul akibat percepatan tanah yang terjadi selama gempa bumi, yang menghasilkan gaya inersia pada massa bangunan. Gaya inersia ini bekerja secara horizontal dan dapat menyebabkan deformasi atau bahkan keruntuhan struktur apabila tidak diperhitungkan dengan baik. Oleh karena itu, perencanaan struktur harus mengikuti ketentuan dalam peraturan yang berlaku, seperti SNI 1726:2019 tentang Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung.

1. Penentuan Sistem Struktur

Sistem struktur yang ada pada bangunan yang diatur pada SNI 2847:2019 dibedakan menjadi beberapa sistem, seperti berikut:

- a. Sistem pemikul gaya seismik (Seismic-force-resisting system). Sistem ini merupakan bagian dari struktur yang dirancang khusus untuk menahan beban gempa. Sistem ini digunakan dalam pembangunan gedung dengan mengikuti ketentuan perencanaan beban kombinasi yang telah ditetapkan secara legal.
- b. Sistem ini terdiri dari elemen struktural seperti balok, pelat, kolom, dan sambungan (joint) yang secara bersama-sama menahan momen lentur, gaya geser, dan gaya aksial.

- c. Sistem rangka pemikul momen biasa atau (Ordinary Moment Frame) merupakan sistem rangka sederhana berupa sambungan balok dan kolom yang dicor di tempat, dan digunakan pada struktur dengan persyaratan seismik rendah. Untuk kategori wilayah dengan risiko gempa sedang hingga tinggi, seperti yang termasuk dalam Kategori Desain Seismik (KDS) D, sistem ini tidak direkomendasikan tanpa penguatan tambahan.
 - d. Sistem rangka pemikul momen khusus atau (Special Moment Frame) digunakan pada bangunan yang berada di wilayah dengan risiko gempa sedang hingga tinggi (KDS C, D, dan E). Sistem ini menuntut tingkat daktilitas tinggi, serta desain dan detail elemen struktur yang lebih ketat agar mampu menahan deformasi inelastik selama peristiwa seismik.
 - e. Sistem ini diterapkan pada struktur balok-kolom atau sistem pelat dua arah tanpa balok yang dicor di tempat. Sistem ini umumnya digunakan untuk bangunan di wilayah dengan tingkat risiko gempa sedang.
- Pada Gedung Workshop SMK Muhammadiyah 01 Boyolali, digunakan Sistem Rangka Pemikul Momen Khusus (Special Moment Frame). Pemilihan sistem ini didasarkan pada kebutuhan struktur untuk mampu menahan gaya lentur dan geser yang timbul akibat beban gempa. Oleh karena itu, diperlukan penetapan parameter tambahan dalam perhitungan struktur, termasuk parameter gempa serta faktor-faktor lain yang relevan. Maka dari itu, diperlukan penetapan parameter tambahan untuk melengkapi data beban gempa serta parameter lain yang terkait, dengan rincian sebagai berikut:

Tabel 2. 9 Kategori Resiko Gedung

Jenis pemanfaatan	Kategori risiko
Gedung dan nongedung yang memiliki risiko rendah terhadap jiwa manusia pada saat terjadi kegagalan, termasuk, tapi tidak dibatasi untuk, antara lain: - Fasilitas pertanian, perkebunan, perternakan, dan perikanan - Fasilitas sementara - Gudang penyimpanan - Rumah jaga dan struktur kecil lainnya	I
Semua gedung dan struktur lain, kecuali yang termasuk dalam kategori risiko I,III,IV, termasuk, tapi tidak dibatasi untuk: - Perumahan - Rumah toko dan rumah kantor - Pasar - Gedung perkantoran - Gedung apartemen/ rumah susun - Pusat perbelanjaan/ mall - Bangunan industri - Fasilitas manufaktur - Pabrik	II

Dengan menggunakan data tersebut, faktor keutamaan gempa Gedung *Workshop* SMK Muhammadiyah sebesar 1,0. Seperti pada Tabel berikut :

Tabel 2. 10 Faktor Keutamaan Gempa

Kategori risiko	Faktor keutamaan gempa, I_e
I atau II	1,0
III	1,25
IV	1,50

Sumber dari SNI 1726 : 2019

2. Penentuan Periode Fundamental Gedung

Gedung *Workshop* SMK Muhammadiyah 01 Boyolali dengan tinggi 16 meter menggunakan sistem pemikul gaya seismik dengan rangka beton bertulang momen khusus. Pada Tabel 2.7 menunjukkan bahwa nilai $C_t = 0,0466$ dan nilai $x = 0,9$.

Tabel 2. 11 Nilai Parameter Periode Pendekatan C_t dan x

Tipe struktur	C_t	x
Sistem rangka pemikul momen di mana rangka memikul 100 % gaya seismik yang disyaratkan dan tidak dilingkupi atau dihubungkan dengan komponen yang lebih kaku dan akan mencegah rangka dari defleksi jika dikenai gaya seismik:		
• Rangka baja pemikul momen	0,0724	0,8
• Rangka beton pemikul momen	0,0466	0,9
Rangka baja dengan bresing eksentris	0,0731	0,75
Rangka baja dengan bresing terkekang terhadap tekuk	0,0731	0,75
Semua sistem struktur lainnya	0,0488	0,75

Berdasarkan SNI 1726:2019, periode fundamental dapat ditentukan dengan persamaan :

$$T_a = C_t h_n^x$$

h_n = tinggi bangunan (m)

C_t = koefisien sesuai pada tabel

3. Kategori Desain Seismik

Menentukan klasifikasi desain seismik menggunakan spektrum respon desain yang diakses melalui google Desain Spektra Indonesia. Selanjutnya akan didapatkan data SDS dan SDI. Dari data diperoleh $SDS = 0,67$ dan $SDI = 0,52$, sehingga jika dimasukkan ke dalam kategori risiko SNI 1726:2019 masuk dalam kategori risiko D dan kategori risiko IV.

Tabel 2. 12 Kategori Desain Seismik

Nilai S_{DS}	Kategori risiko	
	I atau II atau III	IV
$S_{DS} < 0,167$	A	A
$0,167 \leq S_{DS} < 0,33$	B	C
$0,33 \leq S_{DS} < 0,50$	C	D
$0,50 \leq S_{DS}$	D	D

4. Penentuan Koefisien Modifikasi Respons (R)

Tabel 2. 13 Koefisien Modifikasi Respons

Sistem pemikul gaya seismik	Koefisien modifikasi respons, R^a	Faktor kuat lebih sistem, Ω_0^b	Faktor pembesaran defleksi, C_d^c	Batasan sistem struktur dan batasan tinggi struktur, h_s (m) ^d				
				Kategori desain seismik				
				B	C	D ^e	E ^e	F ^f
19. Dinding geser batu bata polos didetail	2	2½	2	TB	TI	TI	TI	TI
20. Dinding geser batu bata polos biasa	1½	2½	1½	TB	TI	TI	TI	TI
21. Dinding geser batu bata prategang	1½	2½	1½	TB	TI	TI	TI	TI
22. Dinding rangka ringan (kayu) yang dilapisi dengan panel struktur kayu yang dimaksudkan untuk tahanan geser	7	2½	4½	TB	TB	22	22	22
23. Dinding rangka ringan (baja canal dingin) yang dilapisi dengan panel struktur kayu yang dimaksudkan untuk tahanan geser, atau dengan lembaran baja	7	2½	4½	TB	TB	22	22	22
24. Dinding rangka ringan dengan panel geser dari semua material lainnya	2½	2½	2½	TB	TB	10	TB	TB
25. Rangka baja dengan bresing terkekang terhadap tekuk	8	2½	5	TB	TB	48	48	30
26. Dinding geser pelat baja khusus	7	2	6	TB	TB	48	48	30
C. Sistem rangka pemikul momen								
1. Rangka baja pemikul momen khusus	8	3	5½	TB	TB	TB	TB	TB
2. Rangka batang baja pemikul momen khusus	7	3	5½	TB	TB	48	30	TI
3. Rangka baja pemikul momen menengah	4½	3	4	TB	TB	10 ^g	TI ^h	TI ^h
4. Rangka baja pemikul momen biasa	3½	3	3	TB	TB	TI ⁱ	TI ⁱ	TI ⁱ
5. Rangka beton bertulang pemikul momen khusus ^m	8	3	5½	TB	TB	TB	TB	TB
6. Rangka beton bertulang pemikul momen menengah	5	3	4½	TB	TB	TI	TI	TI
7. Rangka beton bertulang pemikul momen biasa	3	3	2½	TB	TI	TI	TI	TI
8. Rangka baja dan beton komposit pemikul momen khusus	8	3	5½	TB	TB	TB	TB	TB
9. Rangka baja dan beton komposit pemikul momen menengah	5	3	4½	TB	TB	TI	TI	TI
10. Rangka baja dan beton komposit terkekang parsial pemikul momen	6	3	5½	48	48	30	TI	TI
11. Rangka baja dan beton komposit pemikul momen biasa	3	3	2½	TB	TI	TI	TI	TI
12. Rangka baja canal dingin pemikul momen khusus dengan pembautan ⁿ	3½	3 ⁿ	3½	10	10	10	10	10

Berdasarkan Tabel 2.9, sistem pemikul gaya seismik pada Gedung Workshop SMK Muhammadiyah 01 Boyolali yaitu rangka baja pemikul momen khusus dengan nilai $R = 8$, $\Omega_0 = 3$, $C_d = 5,5$.

2.8 Pemeriksaan Ketidakberaturan Struktur

2.8.1 Ketidakberaturan Horizontal

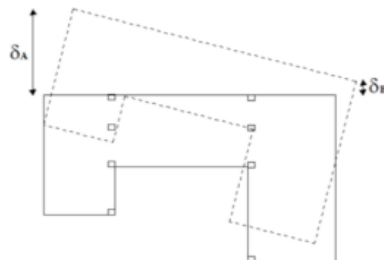
Ketidakberaturan horizontal dalam struktur bangunan merujuk pada kondisi di mana distribusi massa, kekakuan, atau sistem penahan gaya lateral tidak merata dalam arah horizontal. Hal ini dapat menyebabkan perilaku struktur yang tidak seimbang saat menerima beban lateral seperti gempa dan angin. SNI 1726:2019 mengatur berbagai jenis ketidakberaturan horizontal yang harus diperhitungkan dalam desain struktur untuk memastikan kinerja yang aman dan stabil.

Tabel 2. 14 Ketidakberaturan Horizontal

	Tipe dan penjelasan ketidakberaturan	Pasal referensi	Penerapan kategori desain seismik
1a.	Ketidakberaturan torsi didefinisikan ada jika simpangan antar tingkat maksimum, yang dihitung termasuk torsi tak terduga dengan $A_s = 1,0$, di salah satu ujung struktur melintang terhadap suatu sumbu adalah lebih dari 1,2 kali simpangan antar tingkat rata-rata di kedua ujung struktur. Persyaratan ketidakberaturan torsi dalam pasal-pasal referensi berlaku hanya untuk struktur di mana diafragma kaku atau setengah kaku.	0 0 0 0 Tabel 16 0	D, E, dan F B, C, D, E, dan F C, D, E, dan F C, D, E, dan F D, E, dan F B, C, D, E, dan F
1b.	Ketidakberaturan torsi berlebihan didefinisikan ada jika simpangan antar tingkat maksimum yang dihitung termasuk akibat torsi tak terduga dengan $A_s = 1,0$, di salah satu ujung struktur melintang terhadap suatu sumbu adalah lebih dari 1,4 kali simpangan antar tingkat rata-rata di kedua ujung struktur. Persyaratan ketidakberaturan torsi berlebihan dalam pasal-pasal referensi berlaku hanya untuk struktur di mana diafragma kaku atau setengah kaku.	0 0 0 0 0 0 Tabel 16 0	E dan F D B, C, dan D C dan D C dan D D B, C, dan D
2.	Ketidakberaturan sudut dalam didefinisikan ada jika kedua dimensi proyeksi denah struktur dari lokasi sudut dalam lebih besar dari 15 % dimensi denah struktur dalam arah yang ditinjau.	0 Tabel 16	D, E, dan F D, E, dan F
3.	Ketidakberaturan diskontinuitas diafragma didefinisikan ada jika terdapat suatu diafragma yang memiliki diskontinuitas atau variasi kekakuan mendadak, termasuk yang mempunyai daerah terpotong atau terbuka lebih besar dari 50 % daerah diafragma bruto yang tertutup, atau perubahan kekakuan diafragma efektif lebih dari 50 % dari suatu tingkat ke tingkat selanjutnya.	0 Tabel 16	D, E, dan F D, E, dan F
4.	Ketidakberaturan akibat pergeseran tegak lurus terhadap bidang didefinisikan ada jika terdapat diskontinuitas dalam lintasan tahanan gaya lateral, seperti pergeseran tegak lurus terhadap bidang pada setidaknya satu elemen vertikal pemikul gaya lateral.	0 0 0 0 Tabel 16 0	B, C, D, E, dan F D, E, dan F B, C, D, E, dan F D, E, dan F B, C, D, E, dan F
5.	Ketidakberaturan sistem nonparalel didefinisikan ada jika elemen vertikal pemikul gaya lateral tidak paralel terhadap sumbu-sumbu ortogonal utama sistem pemikul gaya seismik.	0 0 0 Tabel 16 0	C, D, E, dan F B, C, D, E, dan F D, E, dan F B, C, D, E, dan F

- Ketidakberaturan Torsi

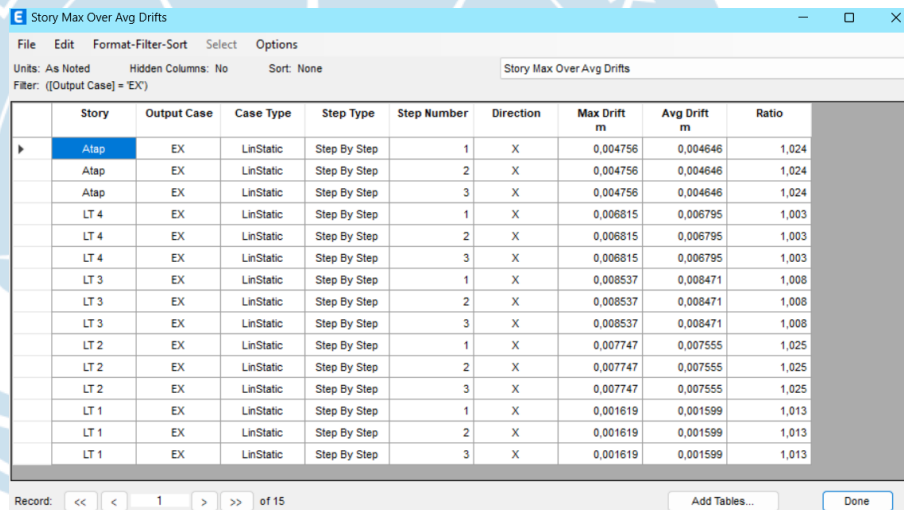
Terjadi ketika pusat massa dan pusat kekakuan bangunan tidak berimpit, sehingga menyebabkan rotasi saat bangunan menerima beban lateral. Berikut perhitungan dan data dari ketidakberaturan torsi :



Gambar 2. 10 Ketidakberaturan Horizontal Tingkat 1a dan 1b

Tabel 2. 15 Ketidakberaturan Torsi

Lantai	Arah X		Arah Y	
	$\Delta_{max} / \Delta_{avg}$	Cek	$\Delta_{max} / \Delta_{avg}$	Cek
4	1,024	OK	1,058	OK
3	1,003	OK	1,058	OK
2	1,008	OK	1,061	OK
1	1,025	OK	1,061	OK
Base	1,013	OK	1,063	OK



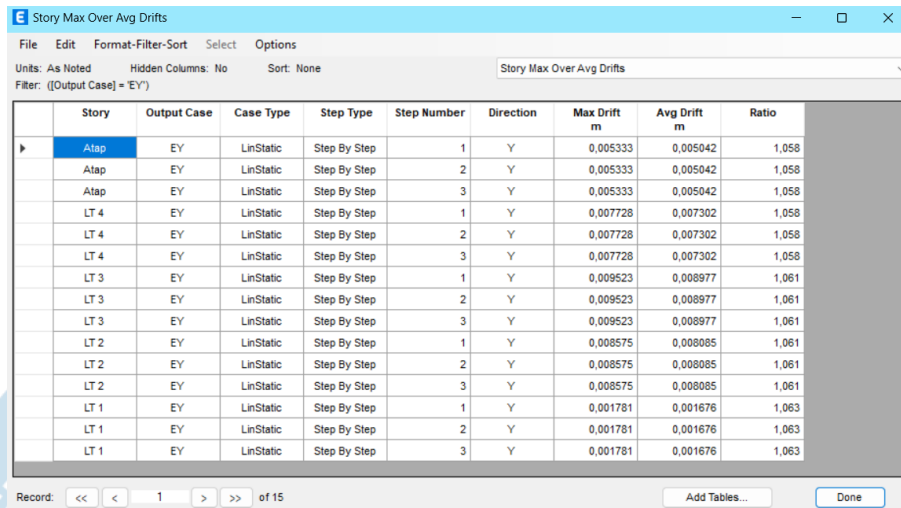
Story Max Over Avg Drifts

Units: As Noted Hidden Columns: No Sort: None Filter: ([Output Case] = 'EX')

Story	Output Case	Case Type	Step Type	Step Number	Direction	Max Drift m	Avg Drift m	Ratio
Atap	EX	LinStatic	Step By Step	1	X	0,004756	0,004646	1,024
Atap	EX	LinStatic	Step By Step	2	X	0,004756	0,004646	1,024
Atap	EX	LinStatic	Step By Step	3	X	0,004756	0,004646	1,024
LT 4	EX	LinStatic	Step By Step	1	X	0,006815	0,006795	1,003
LT 4	EX	LinStatic	Step By Step	2	X	0,006815	0,006795	1,003
LT 4	EX	LinStatic	Step By Step	3	X	0,006815	0,006795	1,003
LT 3	EX	LinStatic	Step By Step	1	X	0,008537	0,008471	1,008
LT 3	EX	LinStatic	Step By Step	2	X	0,008537	0,008471	1,008
LT 3	EX	LinStatic	Step By Step	3	X	0,008537	0,008471	1,008
LT 2	EX	LinStatic	Step By Step	1	X	0,007747	0,007555	1,025
LT 2	EX	LinStatic	Step By Step	2	X	0,007747	0,007555	1,025
LT 2	EX	LinStatic	Step By Step	3	X	0,007747	0,007555	1,025
LT 1	EX	LinStatic	Step By Step	1	X	0,001619	0,001599	1,013
LT 1	EX	LinStatic	Step By Step	2	X	0,001619	0,001599	1,013
LT 1	EX	LinStatic	Step By Step	3	X	0,001619	0,001599	1,013

Record: << < 1 > >> of 15 Add Tables... Done

Gambar 2. 11 Output Etabs Ketidakberaturan Torsi Arah X



The screenshot shows a software window titled "Story Max Over Avg Drifts". It contains a table with the following columns: Story, Output Case, Case Type, Step Type, Step Number, Direction, Max Drift m, Avg Drift m, and Ratio. The table lists data for stories Atap, LT 4, LT 3, LT 2, and LT 1, each with three output cases (EY) and three step types (Step By Step). The Max Drift values are consistently low across all entries, and the Ratio values are all 1.058 or 1.061, indicating no significant torsional irregularity.

Story	Output Case	Case Type	Step Type	Step Number	Direction	Max Drift m	Avg Drift m	Ratio
Atap	EY	LinStatic	Step By Step	1	Y	0,005333	0,005042	1,058
Atap	EY	LinStatic	Step By Step	2	Y	0,005333	0,005042	1,058
Atap	EY	LinStatic	Step By Step	3	Y	0,005333	0,005042	1,058
LT 4	EY	LinStatic	Step By Step	1	Y	0,007728	0,007302	1,058
LT 4	EY	LinStatic	Step By Step	2	Y	0,007728	0,007302	1,058
LT 4	EY	LinStatic	Step By Step	3	Y	0,007728	0,007302	1,058
LT 3	EY	LinStatic	Step By Step	1	Y	0,009523	0,008977	1,061
LT 3	EY	LinStatic	Step By Step	2	Y	0,009523	0,008977	1,061
LT 3	EY	LinStatic	Step By Step	3	Y	0,009523	0,008977	1,061
LT 2	EY	LinStatic	Step By Step	1	Y	0,008575	0,008085	1,061
LT 2	EY	LinStatic	Step By Step	2	Y	0,008575	0,008085	1,061
LT 2	EY	LinStatic	Step By Step	3	Y	0,008575	0,008085	1,061
LT 1	EY	LinStatic	Step By Step	1	Y	0,001781	0,001676	1,063
LT 1	EY	LinStatic	Step By Step	2	Y	0,001781	0,001676	1,063
LT 1	EY	LinStatic	Step By Step	3	Y	0,001781	0,001676	1,063

Gambar 2. 12 *Output* Etabs Ketidakberaturan Torsi Arah Y

Dari hasil pada perhitungan pada Tabel 2.15 menunjukkan bahwa tidak ada ketidakberaturan torsi sehingga gedung dinyatakan aman.

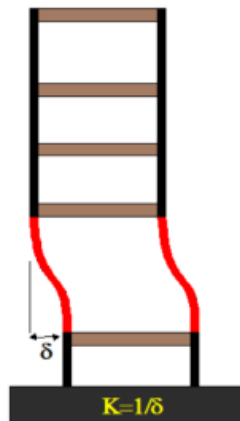
2.8.2 Ketidakberaturan Vertikal

Ketidakberaturan vertikal dalam struktur bangunan merujuk pada kondisi di mana perubahan geometri, kekakuan, atau distribusi massa antar lantai tidak merata dalam arah vertikal. Ketidakberaturan ini dapat menyebabkan perilaku struktur yang tidak diinginkan saat menerima beban vertikal maupun lateral, seperti gempa dan angin. SNI 1726:2019 mengatur berbagai jenis ketidakberaturan vertikal yang harus diperhitungkan dalam desain bangunan agar tetap aman dan stabil.

Tabel 2. 16 Ketidakberaturan Vertikal

	Tipe dan penjelasan ketidakberaturan	Pasal referensi	Penerapan kategori desain seismik
1a.	Ketidakberaturan Kekakuan Tingkat Lunak didefinisikan ada jika terdapat suatu tingkat yang kekakuan lateralnya kurang dari 70 % kekakuan lateral tingkat di atasnya atau kurang dari 80 % kekakuan rata-rata tiga tingkat di atasnya.	Tabel 16	D, E, dan F
1b.	Ketidakberaturan Kekakuan Tingkat Lunak Berlebihan didefinisikan ada jika terdapat suatu tingkat yang kekakuan lateralnya kurang dari 60 % kekakuan lateral tingkat di atasnya atau kurang dari 70 % kekakuan rata-rata tiga tingkat di atasnya.	0 Tabel 16	E dan F D, E, dan F
2.	Ketidakberaturan Berat (Massa) didefinisikan ada jika massa efektif di sebarang tingkat lebih dari 150 % massa efektif tingkat di dekatnya. Atap yang lebih ringan dari lantai di bawahnya tidak perlu ditinjau.	Tabel 16	D, E, dan F
3.	Ketidakberaturan Geometri Vertikal didefinisikan ada jika dimensi horizontal sistem pemikul gaya seismik di sebarang tingkat lebih dari 130 % dimensi horizontal sistem pemikul gaya seismik tingkat didekatnya.	Tabel 16	D, E, dan F
4.	Ketidakberaturan Akibat Diskontinuitas Bidang pada Elemen Vertikal Pemikul Gaya Lateral didefinisikan ada jika pergeseran arah bidang elemen pemikul gaya lateral lebih besar dari panjang elemen itu atau terdapat reduksi kekakuan elemen pemikul di tingkat di bawahnya.	0 0 Tabel 16	B, C, D, E, dan F D, E, dan F D, E, dan F
5a.	Ketidakberaturan Tingkat Lemah Akibat Diskontinuitas pada Kekuatan Lateral Tingkat didefinisikan ada jika kekuatan lateral suatu tingkat kurang dari 80 % kekuatan lateral tingkat di atasnya. Kekuatan lateral tingkat adalah kekuatan total semua elemen pemikul seismik yang berbagi geser tingkat pada arah yang ditinjau.	0 Tabel 16	E dan F D, E, dan F
5b.	Ketidakberaturan Tingkat Lemah Berlebihan Akibat Diskontinuitas pada Kekuatan Lateral Tingkat didefinisikan ada jika kekuatan lateral suatu tingkat kurang dari 65 % kekuatan lateral tingkat di atasnya. Kekuatan lateral tingkat adalah kekuatan total semua elemen pemikul seismik yang berbagi geser tingkat pada arah yang ditinjau.	0 0 Tabel 16	D, E, dan F B dan C D, E, dan F

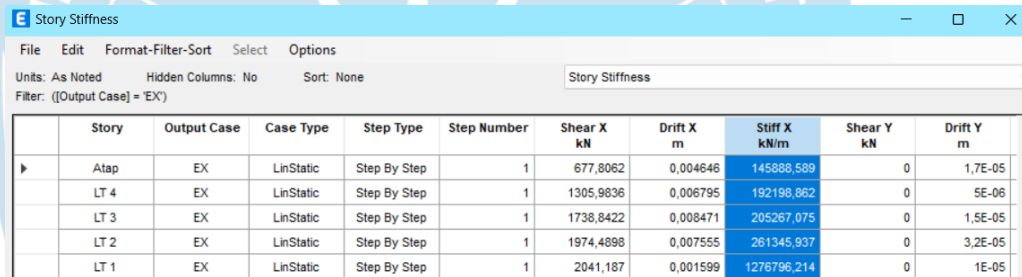
- **Ketidakberaturan Kekakuan Tingkat Lunak**



Gambar 2. 13 Ketidakberaturan Vertikal Tingkat 1a dan 1b

Tabel 2. 17 Ketidakberaturan Vertikal Tingkat 1

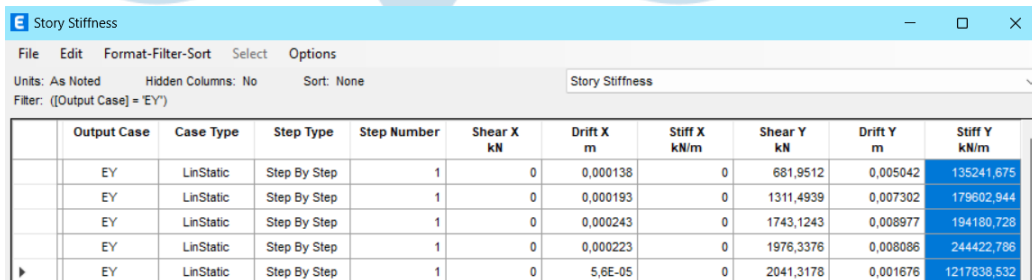
Lantai	Arah X		Arah Y	
	Kekakuan kN/m	Cek	Kekakuan kN/m	Cek
4	145888,589	OK	135241,675	OK
3	192198,862	OK	179602,944	OK
2	205267,075	OK	194180,728	OK
1	261345,937	OK	244422,786	OK
Base	1276796,21	OK	1217836,53	OK



Etabs Story Stiffness window showing vertical irregularity data for Level 1 in the X direction. The table lists Story, Output Case, Case Type, Step Type, Step Number, Shear X (kN), Drift X (m), Stiff X (kN/m), Shear Y (kN), Drift Y (m), and Stiff Y (kN/m).

Story	Output Case	Case Type	Step Type	Step Number	Shear X kN	Drift X m	Stiff X kN/m	Shear Y kN	Drift Y m	Stiff Y kN/m
Atap	EX	LinStatic	Step By Step	1	677,8062	0,004646	145888,589	0	1,7E-05	
LT 4	EX	LinStatic	Step By Step	1	1305,9836	0,006795	192198,862	0	5E-06	
LT 3	EX	LinStatic	Step By Step	1	1738,8422	0,008471	205267,075	0	1,5E-05	
LT 2	EX	LinStatic	Step By Step	1	1974,4898	0,007555	261345,937	0	3,2E-05	
LT 1	EX	LinStatic	Step By Step	1	2041,187	0,001599	1276796,214	0	1E-05	

Gambar 2. 14 Output Etabs Ketidakberaturan Vertikal Tingkat 1 Arah X

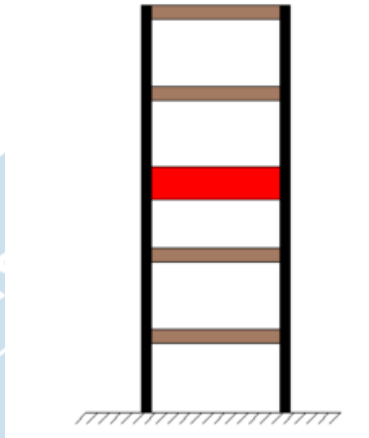


Etabs Story Stiffness window showing vertical irregularity data for Level 1 in the Y direction. The table lists Output Case, Case Type, Step Type, Step Number, Shear X (kN), Drift X (m), Stiff X (kN/m), Shear Y (kN), Drift Y (m), and Stiff Y (kN/m).

Output Case	Case Type	Step Type	Step Number	Shear X kN	Drift X m	Stiff X kN/m	Shear Y kN	Drift Y m	Stiff Y kN/m
EY	LinStatic	Step By Step	1	0	0,000138	0	681,9512	0,005042	135241,675
EY	LinStatic	Step By Step	1	0	0,000193	0	1311,4939	0,007302	179602,944
EY	LinStatic	Step By Step	1	0	0,000243	0	1743,1243	0,008977	194180,728
EY	LinStatic	Step By Step	1	0	0,000223	0	1976,3376	0,008086	244422,786
EY	LinStatic	Step By Step	1	0	5,6E-05	0	2041,3178	0,001678	1217838,532

Gambar 2. 15 Output Etabs Ketidakberaturan Vertikal Tingkat 1 Arah Y

- **Ketidakberaturan Berat (Massa)**



Gambar 2. 16 Ketidakberaturan Vertikal Tingkat 2

Tabel 2. 18 Ketidakberaturan Berat (Massa)

Lantai	Massa (kg)	Cek
Atap	412,3061	V.2
4	519,8056	OK
3	530,5843	OK
2	521,7342	V.2
1	505,4694	OK
Base	29,4964	OK

E Mass Summary by Story

File Edit Format-Filter-Sort Select Options

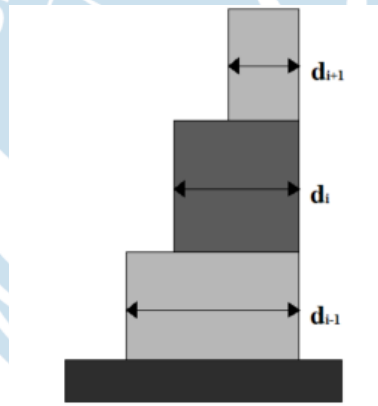
Units: As Noted Hidden Columns: No Sort: None

Filter: None

	Story	UX ton	UY ton	UZ ton
	Atap	412,3061	412,3061	0
	LT 4	519,8056	519,8056	0
	LT 3	530,5843	530,5843	0
	LT 2	521,7342	521,7342	0
	LT 1	505,4694	505,4694	0
▶	Base	29,4964	29,4964	0

Gambar 2. 17 Output Etabs Ketidakberaturan Vertikal Tingkat 2

- Ketidakberaturan Geometri Vertikal**

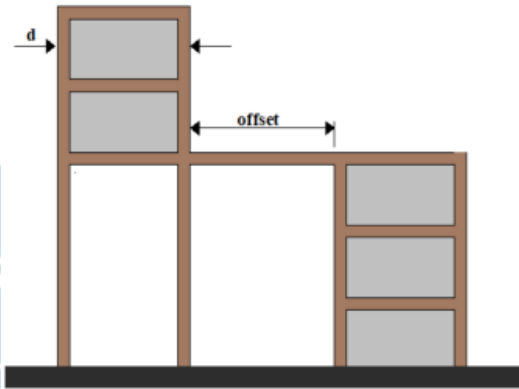


Gambar 2. 18 Ketidakberaturan Vertikal Tingkat 3

Tabel 2. 19 Ketidakberaturan Geometri Vertikal

Lantai	L (mm)	Cek
4	600	OK
3	600	OK
2	600	OK
1	600	OK

- **Diskontinuitas Arah Bidang dalam Ketidakberaturan Elemen Penahan Gaya Lateral Vertikal**



Gambar 2. 19 Ketidakberaturan Vertikal Tingkat 4

Ketidakberaturan elemen penahan gaya lateral tidak terjadi pada gedung ini, karena tidak terdapat shear wall pada bangunan dan kolom menerus pada lantai dasar ke lantai atas.

- **Diskontinuitas dalam Ketidakberaturan Kuat Lateral Tingkat**

Tabel 2. 20 Diskontinuitas dalam Ketidakberaturan Kuat Lateral

Lantai	Arah X	Cek	Arah Y	Cek
	Kekuatan (kN)		Kekuatan (kN)	
Atap	677,8062	OK	681,9512	OK
4	1305,9836	OK	1311,4939	OK
3	1738,8422	OK	1743,1243	OK
2	1974,4898	OK	1976,3376	OK
1	2041,187	OK	2041,3178	OK

Story Forces

File Edit Format-Filter-Sort Select Options

Units: As Noted Hidden Columns: No Sort: None

Filter: ([Output Case] = 'EX') AND ([Location] = 'Top')

	Story	Output Case	Case Type	Step Type	Step Number	Location	P kN	VX kN	VY kN	T kN-m
▶	Atap	EX	LinStatic	Step By Step	1	Top	0	-677,8062	0	6754,931
	Atap	EX	LinStatic	Step By Step	2	Top	0	-677,8062	0	6754,931
	Atap	EX	LinStatic	Step By Step	3	Top	0	-677,8062	0	6754,931
	LT 4	EX	LinStatic	Step By Step	1	Top	0	-1305,9836	0	13075,9027
	LT 4	EX	LinStatic	Step By Step	2	Top	0	-1305,9836	0	13075,9027
	LT 4	EX	LinStatic	Step By Step	3	Top	0	-1305,9836	0	13075,9027
	LT 3	EX	LinStatic	Step By Step	1	Top	0	-1738,8422	0	17431,5143
	LT 3	EX	LinStatic	Step By Step	2	Top	0	-1738,8422	0	17431,5143
	LT 3	EX	LinStatic	Step By Step	3	Top	0	-1738,8422	0	17431,5143
	LT 2	EX	LinStatic	Step By Step	1	Top	0	-1974,4898	0	19804,1288
	LT 2	EX	LinStatic	Step By Step	2	Top	0	-1974,4898	0	19804,1288
	LT 2	EX	LinStatic	Step By Step	3	Top	0	-1974,4898	0	19804,1288
	LT 1	EX	LinStatic	Step By Step	1	Top	0	-2041,187	0	20468,3311
	LT 1	EX	LinStatic	Step By Step	2	Top	0	-2041,187	0	20468,3311
	LT 1	EX	LinStatic	Step By Step	3	Top	0	-2041,187	0	20468,3311

Record: << < 1 > >> of 15 Add Tables... Done

Gambar 2. 20 Output Etabs Ketidakberaturan Vertikal Tingkat 5 Arah X

Story Forces

File Edit Format-Filter-Sort Select Options

Units: As Noted Hidden Columns: No Sort: None

Filter: ([Output Case] = 'EY') AND ([Location] = 'Top')

	Story	Output Case	Case Type	Step Type	Step Number	Location	P kN	VX kN	VY kN	T kN-m
	Atap	EY	LinStatic	Step By Step	1	Top	0	0	-681,9512	-7469,3325
	Atap	EY	LinStatic	Step By Step	2	Top	0	0	-681,9512	-7469,3325
	Atap	EY	LinStatic	Step By Step	3	Top	0	0	-681,9512	-7469,3325
	LT 4	EY	LinStatic	Step By Step	1	Top	0	0	-1311,4939	-14462,5568
	LT 4	EY	LinStatic	Step By Step	2	Top	0	0	-1311,4939	-14462,5568
	LT 4	EY	LinStatic	Step By Step	3	Top	0	0	-1311,4939	-14462,5568
	LT 3	EY	LinStatic	Step By Step	1	Top	0	0	-1743,1243	-19287,2233
	LT 3	EY	LinStatic	Step By Step	2	Top	0	0	-1743,1243	-19287,2233
	LT 3	EY	LinStatic	Step By Step	3	Top	0	0	-1743,1243	-19287,2233
	LT 2	EY	LinStatic	Step By Step	1	Top	0	0	-1976,3376	-21869,6589
	LT 2	EY	LinStatic	Step By Step	2	Top	0	0	-1976,3376	-21869,6589
	LT 2	EY	LinStatic	Step By Step	3	Top	0	0	-1976,3376	-21869,6589
▶	LT 1	EY	LinStatic	Step By Step	1	Top	0	0	-2041,3178	-22580,7199
	LT 1	EY	LinStatic	Step By Step	2	Top	0	0	-2041,3178	-22580,7199
	LT 1	EY	LinStatic	Step By Step	3	Top	0	0	-2041,3178	-22580,7199

Record: << < 13 > >> of 15 Add Tables... Done

Gambar 2. 21 Output Etabs Ketidakberaturan Vertikal Tingkat 5 Arah Y

2.9 Konsekuensi Ketidakberaturan Vertikal

Pada gedung ini hanya terjadi ketidakberaturan berat (massa) sehingga akan menggunakan Tabel 16 pada SNI 1726:2019 berikut :

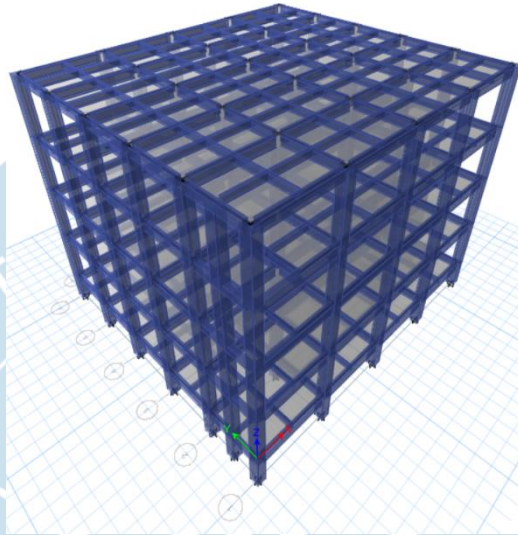
Tabel 2. 21 Prosedur Analisis yang Diizinkan

Kategori desain seismik	Karakteristik struktur	Analisis gaya lateral ekuivalen pasal 0	Analisis spektrum respons ragam pasal 0	Prosedur respons riwayat waktu seismik pasal 0
B, C	Semua struktur	I	I	I
D, E, F	Bangunan dengan kategori risiko I atau II yang tidak melebihi 2 tingkat diatas dasar	I	I	I
	Struktur tanpa ketidakberaturan struktural dan ketinggiannya tidak melebihi 48,8 m	I	I	I
	Struktur tanpa ketidakberaturan struktural dengan ketinggian melebihi 48,8 m dan $T < 3,5 T_c$	I	I	I
	Struktur dengan ketinggian tidak melebihi 48,8 m dan hanya memiliki ketidakberaturan horizontal tipe 2,3,4 atau 5 atau ketidakberaturan vertikal tipe 4, 5a atau 5b	I	I	I
	Semua struktur lainnya	Ti	I	I

CATATAN I: Diizinkan, Ti: Tidak Diizinkan

2.10 Pemodelan Struktur

2.10.1 Pemodelan 3D



Gambar 2. 22 Pemodelan 3D

2.10.2 Material Fc Beton = 30 MPa

E Material Property Data

General Data

Material Name	beton fc 30
Material Type	Concrete
Directional Symmetry Type	Isotropic
Material Display Color	 Change...
Material Notes	Modify/Show Notes...

Material Weight and Mass

☒ Specify Weight Density ☐ Specify Mass Density

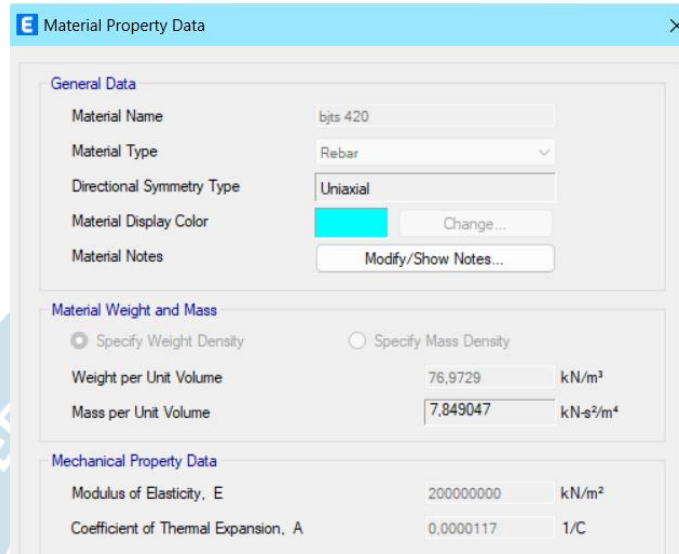
Weight per Unit Volume	23,5631	kN/m ³
Mass per Unit Volume	2,40277	kN-s ³ /m ⁴

Mechanical Property Data

Modulus of Elasticity, E	25742960,2	kN/m ²
Poisson's Ratio, U	0,2	
Coefficient of Thermal Expansion, A	0,0000099	1/C
Shear Modulus, G	10726233,42	kN/m ²

Gambar 2. 23 Material Fc Beton = 30 MPa

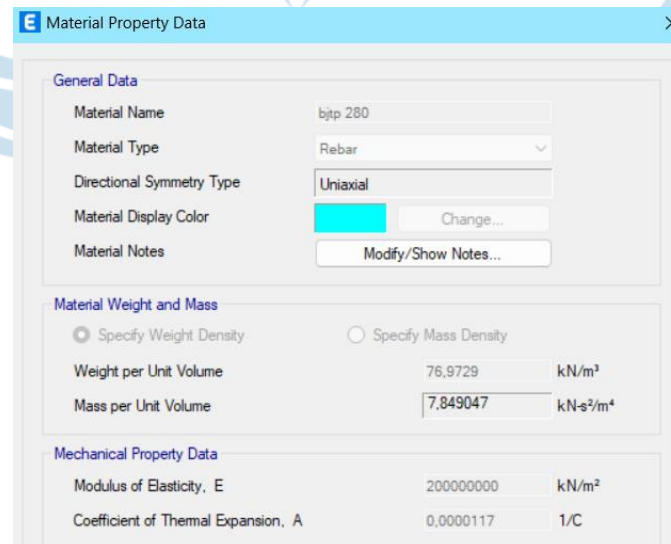
2.10.3 Material Baja Tulangan Sirip (BJTS) = 420 MPa



Material Property Data		
General Data		
Material Name	bjts 420	
Material Type	Rebar	
Directional Symmetry Type	Uniaxial	
Material Display Color	 Change...	
Material Notes	Modify/Show Notes...	
Material Weight and Mass		
☒ Specify Weight Density	☐ Specify Mass Density	
Weight per Unit Volume	76,9729	kN/m³
Mass per Unit Volume	7,849047	kN-s²/m⁴
Mechanical Property Data		
Modulus of Elasticity, E	200000000	kN/m²
Coefficient of Thermal Expansion, A	0,0000117	1/C

Gambar 2. 24 Material Baja Tulangan Sirip (BJTS) = 420 Mpa

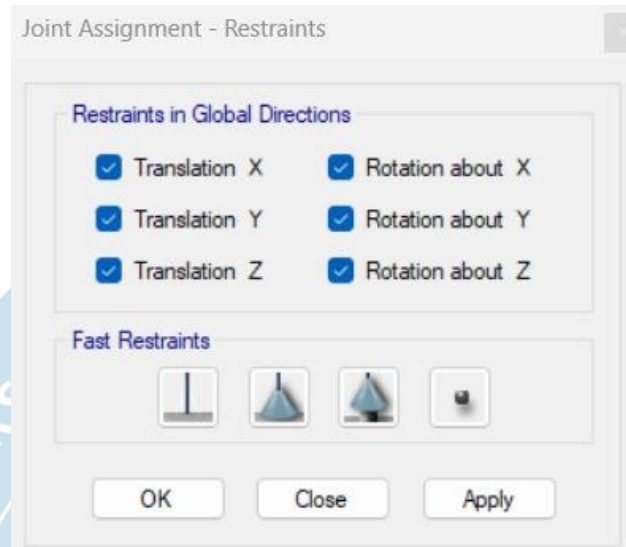
2.10.4 Material Baja Tulangan Polos (BJTP) = 280 MPa



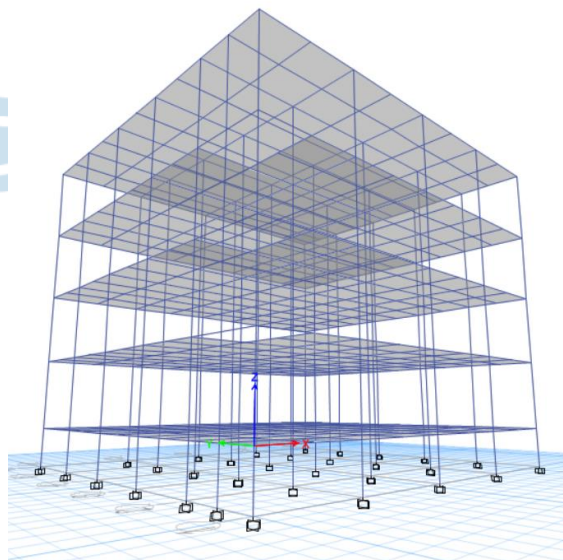
Material Property Data		
General Data		
Material Name	bjtp 280	
Material Type	Rebar	
Directional Symmetry Type	Uniaxial	
Material Display Color	 Change...	
Material Notes	Modify/Show Notes...	
Material Weight and Mass		
☒ Specify Weight Density	☐ Specify Mass Density	
Weight per Unit Volume	76,9729	kN/m³
Mass per Unit Volume	7,849047	kN-s²/m⁴
Mechanical Property Data		
Modulus of Elasticity, E	200000000	kN/m²
Coefficient of Thermal Expansion, A	0,0000117	1/C

Gambar 2. 25 Material Baja Tulangan Polos (BJTP) = 280 Mpa

2.10.5 Tumpuan Bangunan

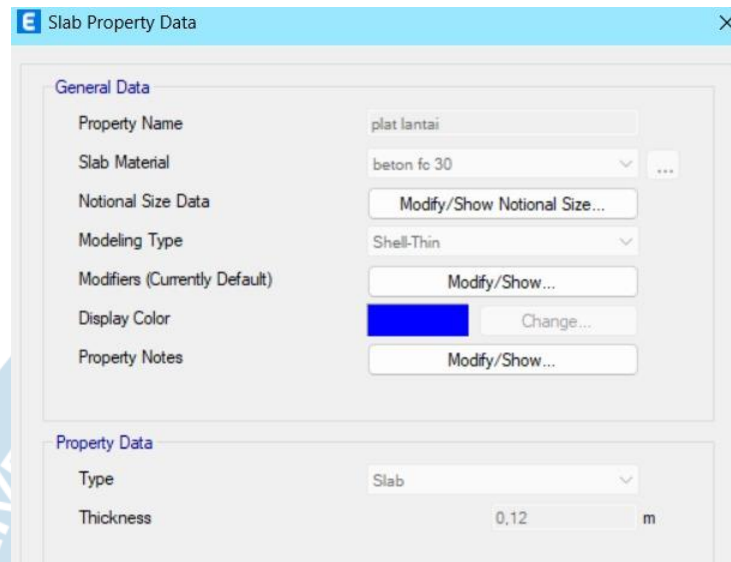


Gambar 2. 26 Tumpuan Bangunan



Gambar 2. 27 Tumpuan Bangunan 3D

2.10.6 Tebal Pelat Lantai



Slab Property Data

General Data

Property Name: plat lantai

Slab Material: beton fc 30

Notional Size Data: Modify/Show Notional Size...

Modeling Type: Shell-Thin

Modifiers (Currently Default): Modify/Show...

Display Color: [Blue] Change...

Property Notes: Modify/Show...

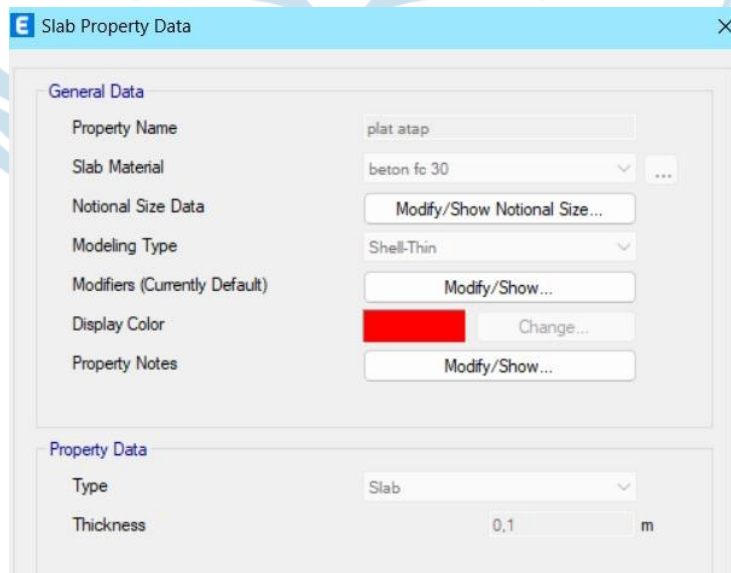
Property Data

Type: Slab

Thickness: 0,12 m

Gambar 2. 28 Tebal Plat Lantai

2.10.7 Tebal Pelat Atap



Slab Property Data

General Data

Property Name: plat atap

Slab Material: beton fc 30

Notional Size Data: Modify/Show Notional Size...

Modeling Type: Shell-Thin

Modifiers (Currently Default): Modify/Show...

Display Color: [Red] Change...

Property Notes: Modify/Show...

Property Data

Type: Slab

Thickness: 0,1 m

Gambar 2. 29 Tebal Plat Atap

2.10.8 Tebal Pelat Tangga

Slab Property Data

General Data

Property Name: Slab1

Slab Material: 4000Psi

Notional Size Data: Modify/Show Notional Size...

Modeling Type: Shell-Thin

Modifiers (Currently Default): Modify/Show...

Display Color: Change...

Property Notes: Modify/Show...

Property Data

Type: Slab

Thickness: 200 mm

Gambar 2. 30 Tebal Pelat Tangga

2.10.9 Dimensi Balok Induk 1

Frame Section Property Data

General Data

Property Name: BI 1

Material: beton fc 30

Notional Size Data: Modify/Show Notional Size...

Display Color: Change...

Notes: Modify/Show Notes...

Shape

Section Shape: Concrete Rectangular

Section Property Source

Source: User Defined

Section Dimensions

Depth: 0,6 m

Width: 0,35 m

Property Modifiers

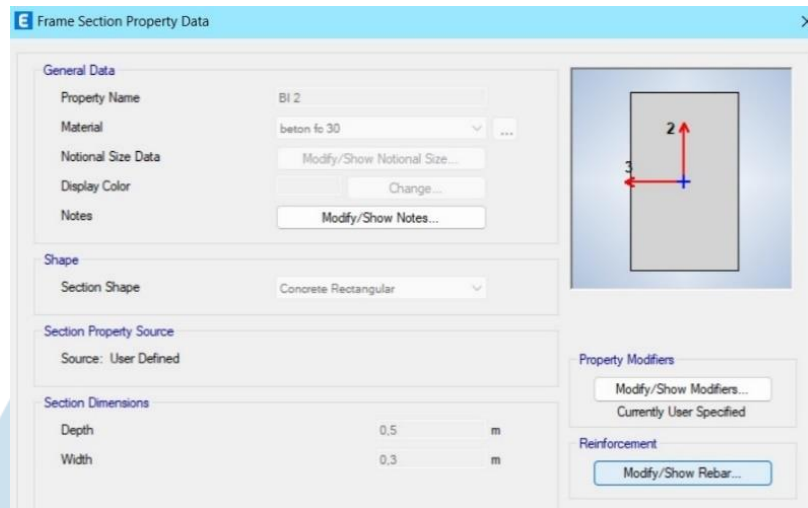
Modify/Show Modifiers...
Currently User Specified

Reinforcement

Modify/Show Rebar...

Gambar 2. 31 Dimensi Balok Induk 1

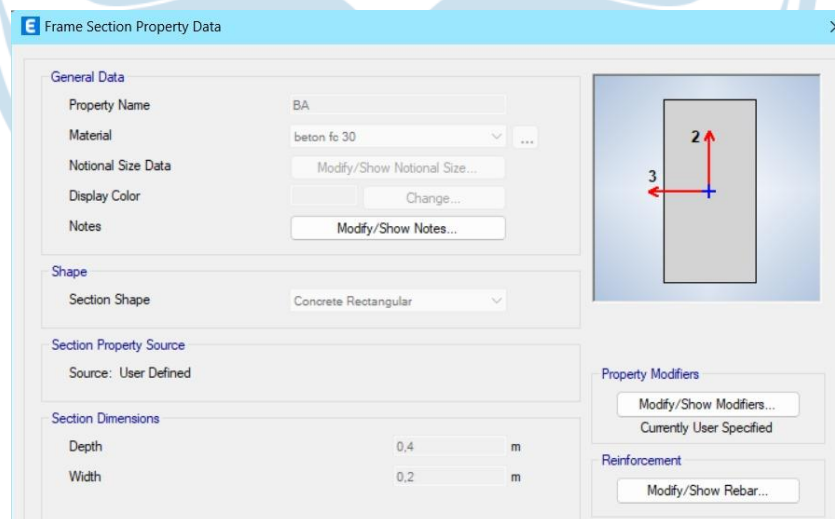
2.10.10 Dimensi Balok Induk 2



The screenshot shows the 'Frame Section Property Data' dialog box for 'Balok Induk 2'. The 'General Data' section includes 'Property Name' (BI 2), 'Material' (beton fc 30), 'Notional Size Data' (Modify/Show Notional Size...), 'Display Color' (Change...), and 'Notes' (Modify/Show Notes...). The 'Shape' section shows 'Section Shape' as 'Concrete Rectangular'. The 'Section Property Source' is 'User Defined'. The 'Section Dimensions' section shows 'Depth' as 0.5 m and 'Width' as 0.3 m. The 'Property Modifiers' section shows 'Modify/Show Modifiers...' and 'Currently User Specified'. The 'Reinforcement' section shows 'Modify/Show Rebar...'. A diagram on the right shows a rectangular cross-section with dimensions 2 (width) and 3 (depth).

Gambar 2. 32 Dimensi Balok Induk 2

2.10.11 Dimensi Balok Anak



The screenshot shows the 'Frame Section Property Data' dialog box for 'Balok Anak'. The 'General Data' section includes 'Property Name' (BA), 'Material' (beton fc 30), 'Notional Size Data' (Modify/Show Notional Size...), 'Display Color' (Change...), and 'Notes' (Modify/Show Notes...). The 'Shape' section shows 'Section Shape' as 'Concrete Rectangular'. The 'Section Property Source' is 'User Defined'. The 'Section Dimensions' section shows 'Depth' as 0.4 m and 'Width' as 0.2 m. The 'Property Modifiers' section shows 'Modify/Show Modifiers...' and 'Currently User Specified'. The 'Reinforcement' section shows 'Modify/Show Rebar...'. A diagram on the right shows a rectangular cross-section with dimensions 2 (width) and 3 (depth).

Gambar 2. 33 Dimensi Balok Anak

2.10.12 Dimensi Kolom

Frame Section Property Data

General Data

Property Name: K 1

Material: beton fc 30

Notional Size Data: Modify/Show Notional Size...

Display Color: Change...

Notes: Modify/Show Notes...

Shape

Section Shape: Concrete Rectangular

Section Property Source

Source: User Defined

Section Dimensions

Depth: 0,6 m

Width: 0,6 m

Property Modifiers

Modify/Show Modifiers...
Currently User Specified

Reinforcement

Modify/Show Rebar...

Gambar 2. 34 Dimensi Kolom

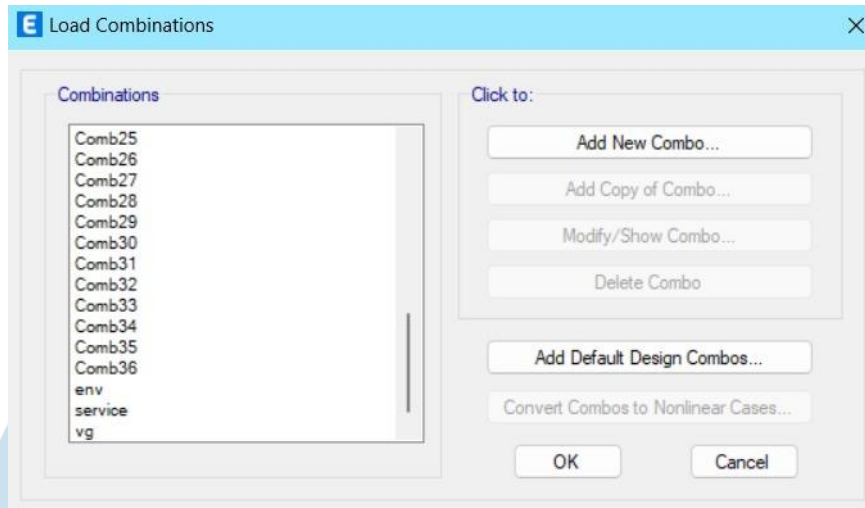
2.10.13 Load Case Gedung

Load Cases

Load Case Name	Load Case Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
SIDL	Linear Static
LL	Linear Static
EX	Linear Static
EY	Linear Static
RSX	Response Spectrum
RSY	Response Spectrum

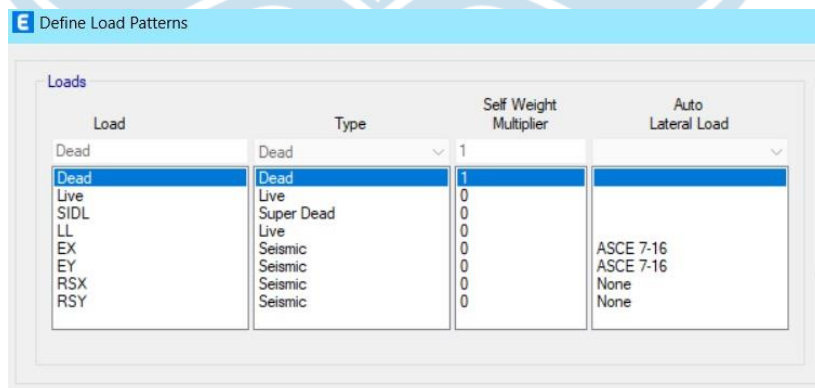
Gambar 2. 35 Load Case Gedung

2.10.14 Load Combination Gedung



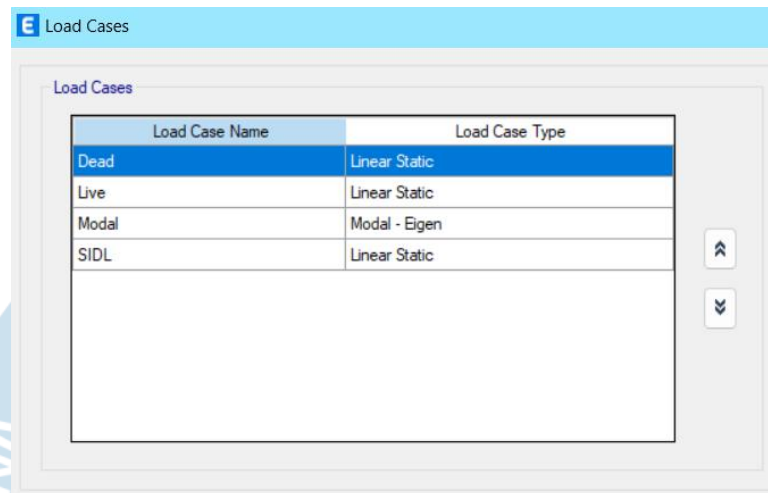
Gambar 2. 36 Load Combination Gedung

2.10.15 Load Pattern Gedung



Gambar 2. 37 Load Pattern Gedung

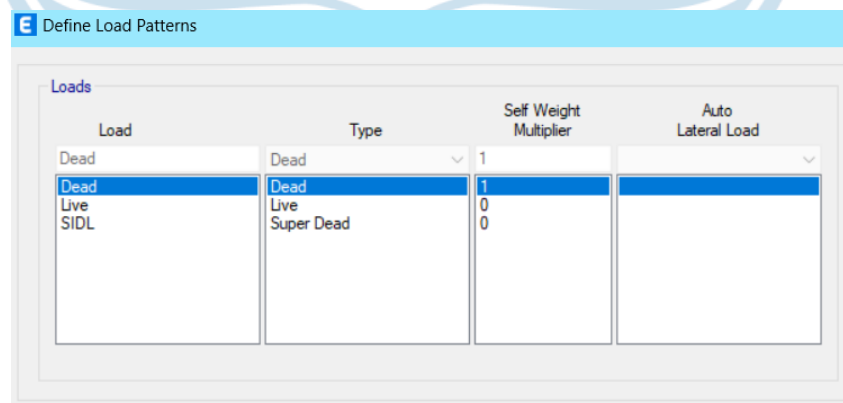
2.10.16 Load Case Tangga



Load Case Name	Load Case Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
SIDL	Linear Static

Gambar 2. 38 Load Case Tangga

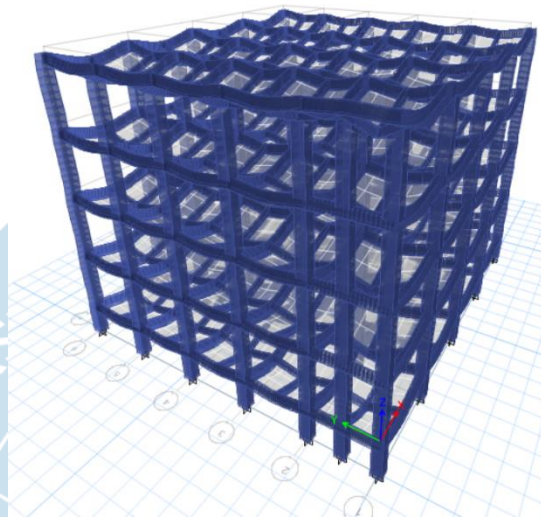
2.10.17 Load Pattern Tangga



Load	Type	Self Weight Multiplier	Auto Lateral Load
Dead	Dead	1	
Live	Live	0	
SIDL	Super Dead	0	

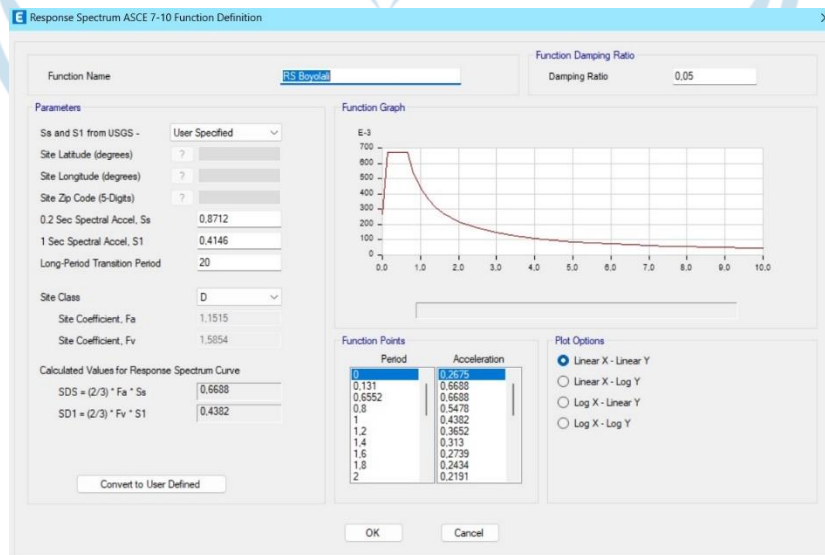
Gambar 2. 39 Load Pattern Tangga

2.10.18 Pembebanan Balok dan Pelat



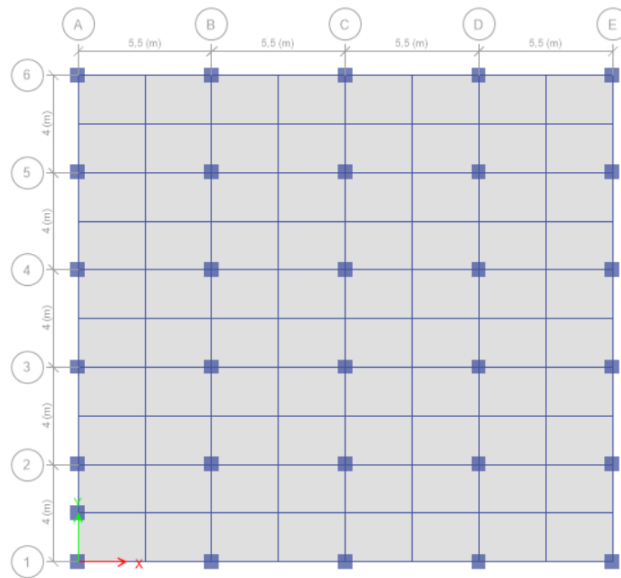
Gambar 2. 40 Pembebanan 3D Balok dan Pelat

2.10.19 Respon Spektrum



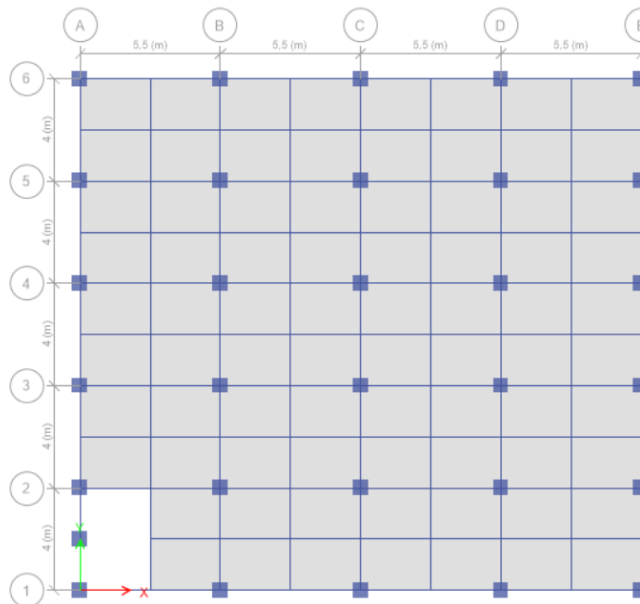
Gambar 2. 41 Respon Spektrum

2.10.20 Denah Balok dan Kolom Lantai 1



Gambar 2. 42 Denah Balok dan Kolom Lantai 1

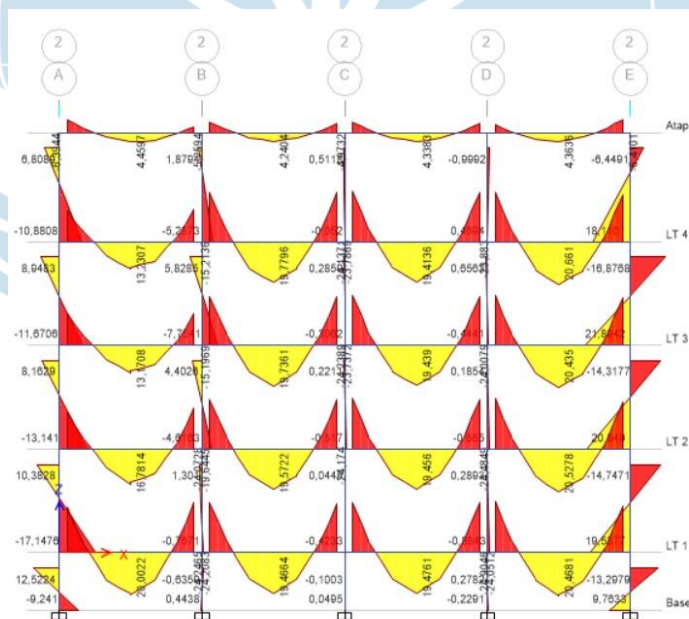
2.10.21 Denah Balok dan Kolom Lantai 2,3,4



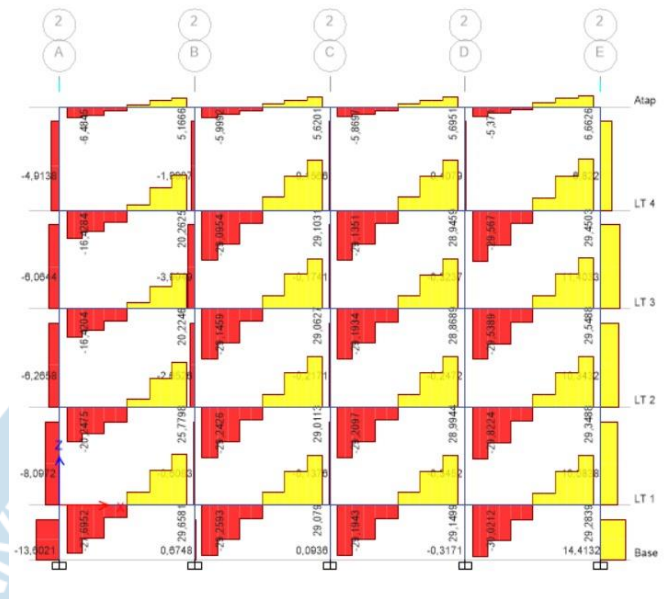
Gambar 2. 43 Denah Balok dan Kolom Lantai 2,3,4

2.10.22 Interpretasi *Output* Pemodelan

Setelah dilakukan pemodelan struktur menggunakan perangkat lunak ETABS, tahapan selanjutnya adalah menginterpretasikan hasil analisis atau *output* yang dihasilkan. Output analisis struktur mencakup berbagai hal, salah satunya adalah gaya dalam yang mempengaruhi balok dan kolom sebagai elemen utama struktur. ETABS menyediakan diagram gaya geser (*Shear Force Diagram* / SFD) dan diagram momen lentur (*Bending Moment Diagram* / BMD) yang menunjukkan nilai maksimum, minimum, dan lokasi terjadinya gaya-gaya kritis. Dengan menganalisis SFD dan BMD, perencana dapat mengidentifikasi bagian-bagian struktur yang memerlukan perhatian khusus dalam proses perancangan, seperti penempatan tulangan utama pada balok atau pengecekan kapasitas elemen terhadap gaya geser. Berikut merupakan diagram SFD, BMD, dan gaya dalam pada etabs :



Gambar 2. 44 Diagram BMD



Gambar 2. 45 Diagram SFD

Tabel 2. 22 Gaya Dalam Balok Induk 1 dan 2

Kondisi	Balok Induk 1	Balok Induk 2
$M_{u,tumpuan} (-)$	-196,867 kN/m	-118,080 kN/m
$M_{u,tumpuan} (+)$	115,8121 kN/m	104,0676 kN/m
$M_{u,lapangan} (-)$	-46,4309 kN/m	-146,032 kN/m
$M_{u,lapangan} (+)$	87,9916 kN/m	136,2527 kN/m
P_u	25,3831 kN	37,867 kN
$V_{u,tumpuan}$	154,419 kN	144,7097 kN
$V_{u,lapangan}$	111,231 kN	148,7175 kN
T_u	51,0152 kN/m	26,3342 kN/m

Tabel 2. 23 Gaya Dalam Balok Anak 1 dan 2

Kondisi	Balok Anak 1	Balok Anak 2
$M_{u,tumpuan} (-)$	-17,3404 kN/m	-17,3404 kN/m
$M_{u,tumpuan} (+)$	16,4552 kN/m	16,5176 kN/m
$M_{u,lapangan} (-)$	-17,3316 kN/m	-9,3534 kN/m
$M_{u,lapangan} (+)$	16,5176 kN/m	13,8592 kN/m
P_u	6,8415 kN	6,8415 kN
$V_{u,tumpuan}$	16,6905 kN	18,2099 kN
$V_{u,lapangan}$	18,6934 kN	18,6934 kN
T_u	4,7049 kN/m	4,7049 kN/m

Tabel 2. 24 Gaya Dalam pada Kolom

Kondisi	P	M2	M3
$P_u \text{ Max (kN)}$	316,3929	85,4912	121,1428
$P_u \text{ Min (kN)}$	-1636,8703	-235,5191	-218,864
$M2 \text{ Max (kN/m)}$	-246,6778	249,72	227,3498
$M2 \text{ Min (kN/m)}$	-1130,6502	-249,6847	-191,8143
$M3 \text{ Max (kN/m)}$	-244,6827	249,2342	232,5078
$M3 \text{ Min (kN/m)}$	-1128,2872	-183,2189	-232,4543

2.11 Pemeriksaan Simpangan Antar Lantai

- Input data percepatan gempa

$$S_s = 0,8712 \text{ g}$$

$$S_1 = 0.4146 \text{ g}$$

$$F_a = 1,1515$$

$$F_v = 1,8854$$

$$S_{DS} = 0,6688 \text{ g}$$

$$\begin{aligned}
 S_{D1} &= 0,5211 \text{ g} \\
 T_0 &= 0,1558 \text{ detik} \\
 T_s &= 0,7792 \text{ detik}
 \end{aligned}$$

- Input parameter gempa

$$\begin{aligned}
 I_e &= 1,00 \\
 R &= 8 \\
 \Omega_0 &= 3 \\
 C_d &= 5,5
 \end{aligned}$$

- Periode struktur

$$\begin{aligned}
 S_{D1} &= 0,5211 \text{ g} \\
 C_U &= 1,4 \\
 C_1 &= 0,0466 \\
 x &= 0,9 \\
 h &= 16 \text{ m} \\
 T_a &= 0,5651 \text{ detik} \\
 T_{\max} &= 0,791 \text{ detik} \\
 T_{c,x} &= 0,845 \text{ detik} \\
 T_{c,y} &= 0,874 \text{ detik} \\
 T_x &= 0,791 \text{ detik} \\
 T_y &= 0,791 \text{ detik}
 \end{aligned}$$

- Bentuk dan jumlah ragam

Case	Mode	Period sec	UX	UY	UZ	SumUX	SumUY	SumUZ	RX
Modal	1	0,874	0,0001	0,7116	0	0,0001	0,7116	0	0,2785
Modal	2	0,845	0,7331	0,0001	0	0,7332	0,7117	0	3,214E-05
Modal	3	0,735	0,0001	0,0189	0	0,7333	0,7305	0	0,003
Modal	4	0,267	0,0001	0,1016	0	0,7333	0,8321	0	0,3482
Modal	5	0,259	0,1027	0,0001	0	0,8361	0,8322	0	0,0003
Modal	6	0,226	0,0001	0,003	0	0,8361	0,8353	0	0,0104
Modal	7	0,136	0,0002	0,0463	0	0,8364	0,8616	0	0,0723
Modal	8	0,133	0,0463	0,0003	0	0,8827	0,8619	0	0,0005
Modal	9	0,117	0,0002	0,0012	0	0,8828	0,883	0	0,0018
Modal	10	0,084	0,0006	0,0224	0	0,8834	0,9055	0	0,0546
Modal	11	0,084	0,0221	0,0006	0	0,9055	0,9061	0	0,0015
Modal	12	0,073	0,0001	0,0005	0	0,9055	0,9066	0	0,0012

Gambar 2. 46 Output Bentuk dan Jumlah Ragam

- Gaya dasar seismik

$$\begin{aligned}
 C_s &= 0,0836 \\
 C_{s,max,X} &= 0,0823 \\
 C_{s,max,Y} &= 0,0823 \\
 C_{s,min,1} &= 0,0294 \\
 C_{s,min,2} &= 0,0259 \\
 C_{s,pakai,X} &= 0,0823 \\
 C_{s,pakai,Y} &= 0,0823 \\
 W &= 22291 \text{ kN}
 \end{aligned}$$

- Penskalaan gaya

$$\begin{aligned}
 \text{Gaya geser statik manual (V}_x\text{)} &= 1835,55 \text{ kN} \\
 \text{Gaya geser statik manual (V}_y\text{)} &= 1835,55 \text{ kN} \\
 \text{Gaya geser statik etabs (V}_x\text{)} &= 1863,45 \text{ kN} \\
 \text{Gaya geser statik etabs (V}_y\text{)} &= 1863,57 \text{ kN} \\
 \text{Faktor skala awal (SF)} &= 1225,83 \text{ mm/s}^2
 \end{aligned}$$

$$\begin{aligned}
 V_{i,x} &= 1771,512 \text{ kN} \\
 V_{i,y} &= 1787,167 \text{ kN} \\
 F_x &= 1,036 \\
 F_y &= 1,027 \\
 \text{Faktor skala baru (SFX)} &= 1270,15 \text{ mm/s}^2 \\
 \text{Faktor skala baru (SFY)} &= 1259,02 \text{ mm/s}^2
 \end{aligned}$$

- Penskalaan simpangan

$$\begin{aligned}
 C_s &= 0,0259 \\
 V &= 577,63 \text{ kN} \\
 SF &= 1225,83 \text{ mm/s}^2 \\
 V_{i,x} &= 1771,512 \text{ kN} \\
 V_{i,y} &= 1787,167 \text{ kN} \\
 F_x &= 1 \\
 F_y &= 1 \\
 \text{Faktor skala baru (SFX)} &= 1225,83 \text{ mm/s}^2 \\
 \text{Faktor skala baru (SFY)} &= 1225,83 \text{ mm/s}^2
 \end{aligned}$$

- Simpangan antar tingkat

Tabel 2. 25 Kategori Risiko simpangan

Struktur	Kategori risiko		
	I atau II	III	IV
Struktur, selain dari struktur dinding geser batu bata, 4 tingkat atau kurang dengan dinding interior, partisi, langit-langit dan sistem dinding eksterior yang telah didesain untuk mengakomodasi simpangan antar tingkat.	$0,025h_{xx}^c$	$0,020h_{xx}$	$0,015h_{xx}$
Struktur dinding geser kantilever batu bata ^d	$0,010h_{xx}$	$0,010h_{xx}$	$0,010h_{xx}$
Struktur dinding geser batu bata lainnya	$0,007h_{xx}$	$0,007h_{xx}$	$0,007h_{xx}$
Semua struktur lainnya	$0,020h_{xx}$	$0,015h_{xx}$	$0,010h_{xx}$

$$\begin{aligned}
 \text{Simpangan antar tingkat izin } (\Delta_a) &= 0,02 h \\
 \text{Faktor redundansi } (\rho) &= 1,3 \\
 \text{Story drift inelastik izin } (\Delta_{\max}) &= 0,0154 h \\
 \text{Faktor pembesaran defleksi } (C_d) &= 5,5 \\
 \text{Faktor keutamaan gempa } (I_e) &= 1
 \end{aligned}$$

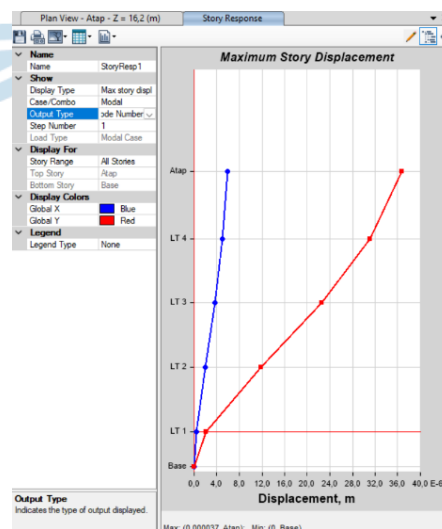
Tabel 2. 26 Story drift

Story	Displacement		Elastic Drift		h	Inelastic Drift		Drift Limit	Cek
	δe_x	δe_y	δe_x	δe_y		Δ_x	Δ_y		
	(mm)	(mm)	(mm)	(mm)		(mm)	(mm)		
5	25,768	27,751	3,866	4,194	4000	21,263	23,067	61,538	OK
4	21,902	23,557	5,897	6,410	4000	32,434	35,255	61,538	OK
3	16,005	17,147	7,530	8,135	4000	41,415	44,743	61,538	OK
2	8,475	9,012	7,009	7,463	4000	38,550	41,047	61,538	OK
1	1,466	1,549	1,466	1,549	4000	8,063	8,520	61,538	OK

E Story Response

	Story	Elevation m	Location	X-Dir m	Y-Dir m
▶	Atap	16,2	Top	0,026013	0,000479
	LT 4	12	Top	0,022141	0,000432
	LT 3	8	Top	0,01621	0,00034
	LT 2	4	Top	0,008602	0,000198
	LT 1	0	Top	0,001494	3,9E-05
	Base	-2,2	Top	0	0

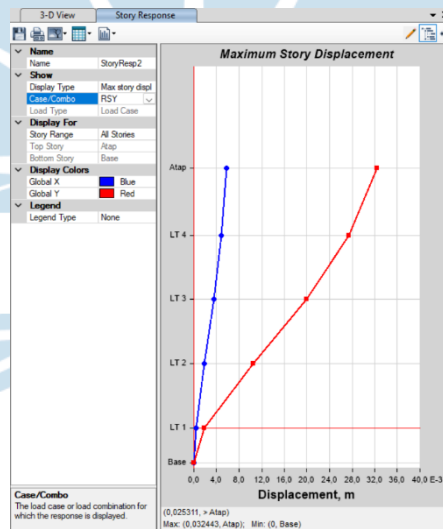
Gambar 2. 47 Output Etabs Simpangan Arah Ex



Gambar 2. 48 Grafik Simpangan Arah Ex

E Story Response					
	Story	Elevation m	Location	X-Dir m	Y-Dir m
▶	Atap	16,2	Top	0,005737	0,032443
	LT 4	12	Top	0,004864	0,027426
	LT 3	8	Top	0,00355	0,019964
	LT 2	4	Top	0,001878	0,010514
	LT 1	0	Top	0,000329	0,00182
	Base	-2,2	Top	0	0

Gambar 2. 49 Output Etabs Simpangan Arah Ey



Gambar 2. 50 Grafik Simpangan Arah Ey

2.12 Perencanaan Balok Induk

2.12.1 Balok Induk 1

- Desain lentur
- Data material dan penampang

Panjang balok (L)	= 5500 mm
Lebar balok (b)	= 350 mm
Tinggi balok (h)	= 600 mm
Panjang tumpuan	= 2 x h
	= 2 x 600
	= 1200 mm
db	= 19
dbt	= 10
ds	= 10
selimut bersih (cc)	= 30
tinggi efektif balok	= $h - cc - ds - db/2$
	= $1200 - 30 - 10 - 19/2$
	= 550,5 mm
fc'	= 30 Mpa
fy	= 420 Mpa
fyv	= 280 Mpa
β_1	= 0,8357
Panjang kolom (c1)	= 600 mm
Lebar kolom (c2)	= 600 mm
Ln	= panjang balok – panjang kolom
	= 5500 – 600
	= 4900 MM
λ	= 1

- Gaya dalam

Tabel 2. 27 Gaya Dalam Balok Induk 1

Mu tumpuan (-)	-196,867 kN/m
Mu tumpuan (+)	115,8121 kN/m
Mu lapangan (-)	-46,4309 kN/m
Mu lapangan (+)	87,9916 kN/m
Pu	25,3831 kN

- Syarat gaya dan geometri

$$\begin{aligned}\text{Syarat gaya aksial} &= P_u \leq 0,1 \times A_g \times f_c' \\ &= 25,3831 \leq 0,1 \times 350 \times 600 \times 30 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat tinggi efektif} &= L_n \geq 4d \\ &= 4900 \geq 4 \times 550,5 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 1} &= b \geq \min(0,3 \times h, 250 \text{ mm}) \\ &= 350 \geq \min(0,3 \times 600, 250 \text{ mm}) \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 2} &= b \leq \text{lebar kolom} + 2 \times \min(c_2, 0,75 \text{ ci}) \\ &= 350 \leq 600 + 2 \times \min(600, 0,75 \text{ ci}) \rightarrow \mathbf{OK}\end{aligned}$$

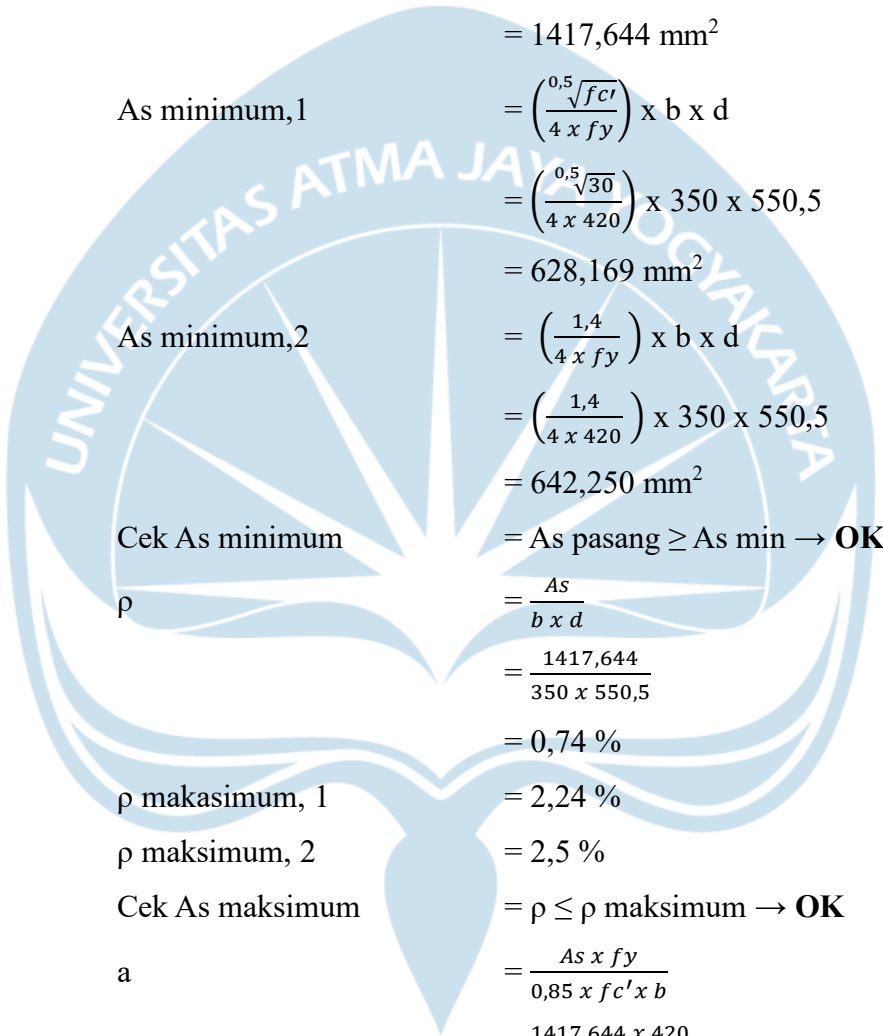
- Penulangan lentur

Tumpuan negatif

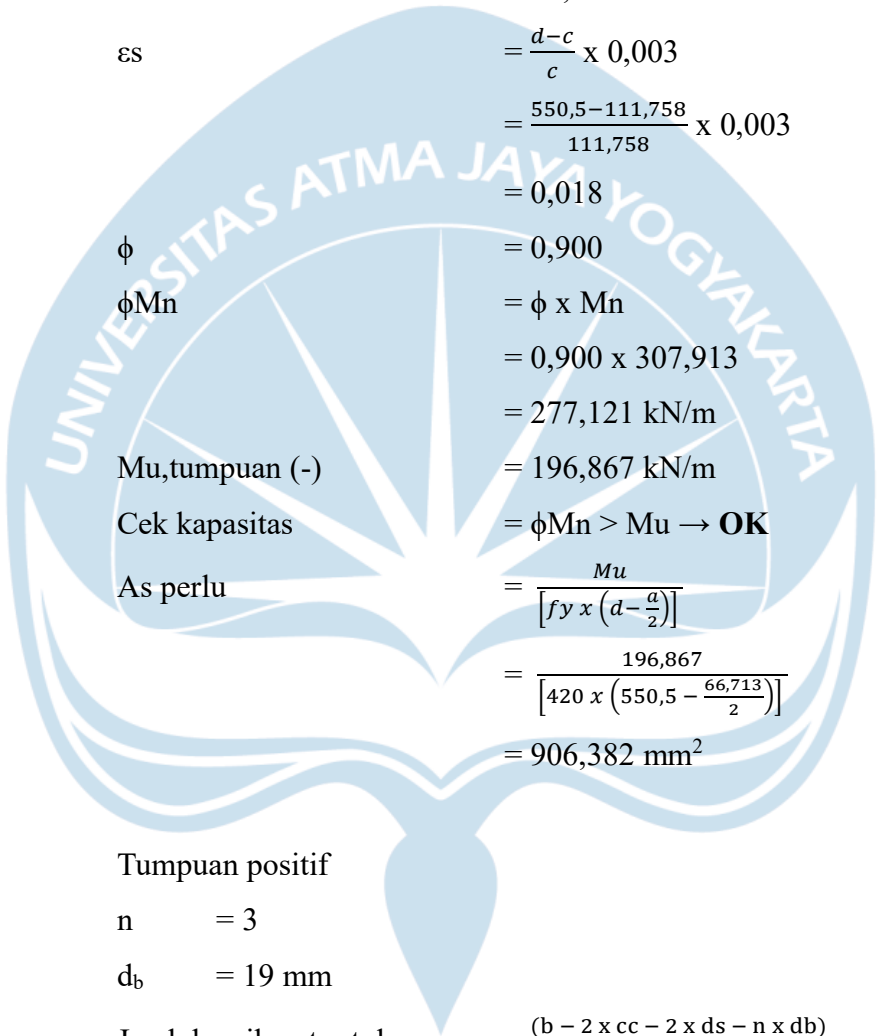
$$n = 5$$

$$d_b = 19 \text{ mm}$$

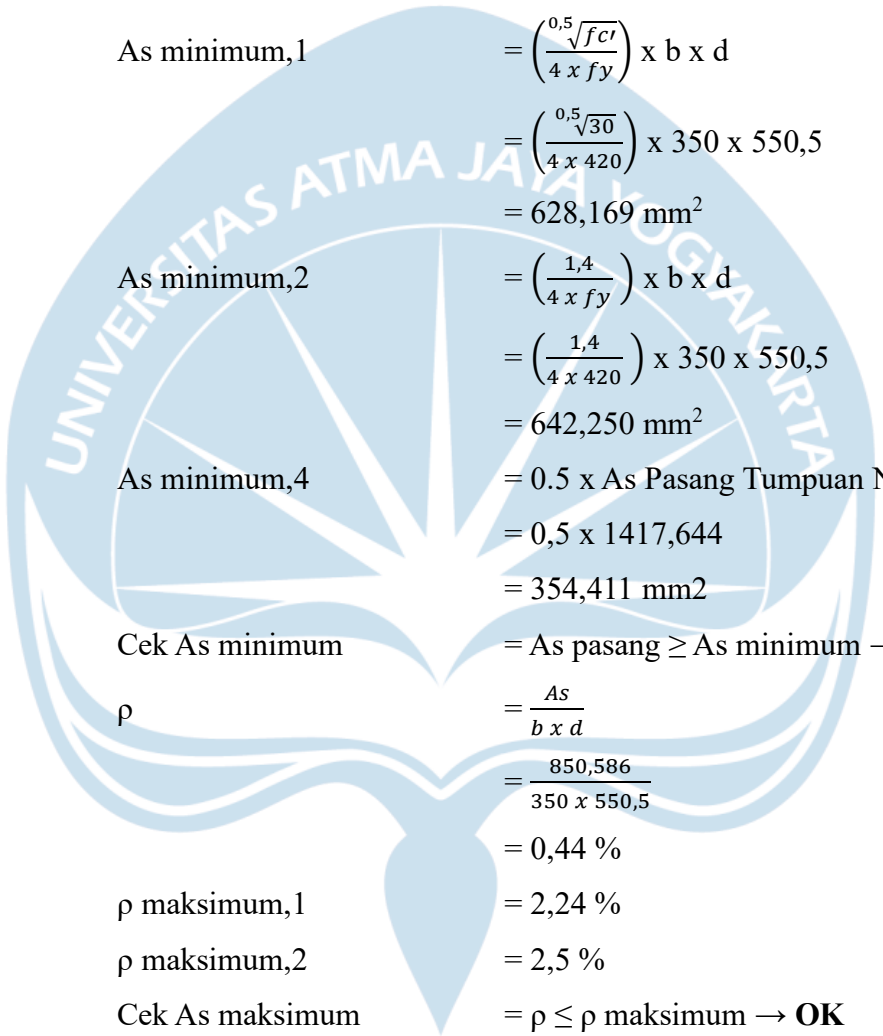
$$\begin{aligned}\text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\ &= \frac{(350 - 2 \times 30 - 2 \times 10 - 5 \times 19)}{5-1} \\ &= 43,750 \text{ mm}\end{aligned}$$



Jumlah lapis	$= 1$
As pasang	$= n \times \frac{\pi}{4} \times db^2$ $= 5 \times \frac{3,14}{4} \times 19^2$ $= 1417,644 \text{ mm}^2$
As minimum,1	$= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d$ $= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 350 \times 550,5$ $= 628,169 \text{ mm}^2$
As minimum,2	$= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d$ $= \left(\frac{1,4}{4 \times 420} \right) \times 350 \times 550,5$ $= 642,250 \text{ mm}^2$
Cek As minimum	$= \text{As pasang} \geq \text{As min} \rightarrow \text{OK}$
ρ	$= \frac{As}{b \times d}$ $= \frac{1417,644}{350 \times 550,5}$ $= 0,74 \%$
ρ maksimum, 1	$= 2,24 \%$
ρ maksimum, 2	$= 2,5 \%$
Cek As maksimum	$= \rho \leq \rho \text{ maksimum} \rightarrow \text{OK}$
a	$= \frac{As \times f_y}{0,85 \times f_c' \times b}$ $= \frac{1417,644 \times 420}{0,85 \times 30 \times 350}$ $= 66,713 \text{ mm}$
Mn	$= As \times f_y \times \left(d - \frac{a}{2} \right)$ $= 1417,644 \times 30 \times \left(550,5 - \frac{66,713}{2} \right)$ $= 307,913 \text{ kN/m}$



$$\begin{aligned}
 c &= \frac{a}{\beta_1} \\
 &= \frac{66,713}{0,8357} \\
 &= 79,827 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{550,5-111,758}{111,758} \times 0,003 \\
 &= 0,018 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 307,913 \\
 &= 277,121 \text{ kN/m} \\
 \mu_{\text{tumpuan (-)}} &= 196,867 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > \mu \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{\mu}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{196,867}{\left[420 \times \left(550,5 - \frac{66,713}{2} \right) \right]} \\
 &= 906,382 \text{ mm}^2 \\
 \text{Tumpuan positif} & \\
 n &= 3 \\
 d_b &= 19 \text{ mm} \\
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(350 - 2 \times 30 - 2 \times 10 - 3 \times 19)}{19-1} \\
 &= 106,500 \text{ mm} \\
 \text{Jumlah lapis} &= 1
 \end{aligned}$$



As pasang $= n \times \frac{\pi}{4} \times db^2$

$= 3 \times \frac{\pi}{4} \times 19^2$

$= 850,586 \text{ mm}^2$

As minimum,1 $= \left(\frac{0,5 \sqrt{f'c'}}{4 \times f_y} \right) \times b \times d$

$= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 350 \times 550,5$

$= 628,169 \text{ mm}^2$

As minimum,2 $= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d$

$= \left(\frac{1,4}{4 \times 420} \right) \times 350 \times 550,5$

$= 642,250 \text{ mm}^2$

As minimum,4 $= 0,5 \times \text{As Pasang Tumpuan Negatif}$

$= 0,5 \times 1417,644$

$= 354,411 \text{ mm}^2$

Cek As minimum $= \text{As pasang} \geq \text{As minimum} \rightarrow \text{OK}$

$\rho = \frac{As}{b \times d}$

$= \frac{850,586}{350 \times 550,5}$

$= 0,44 \%$

ρ maksimum,1 $= 2,24 \%$

ρ maksimum,2 $= 2,5 \%$

Cek As maksimum $= \rho \leq \rho \text{ maksimum} \rightarrow \text{OK}$

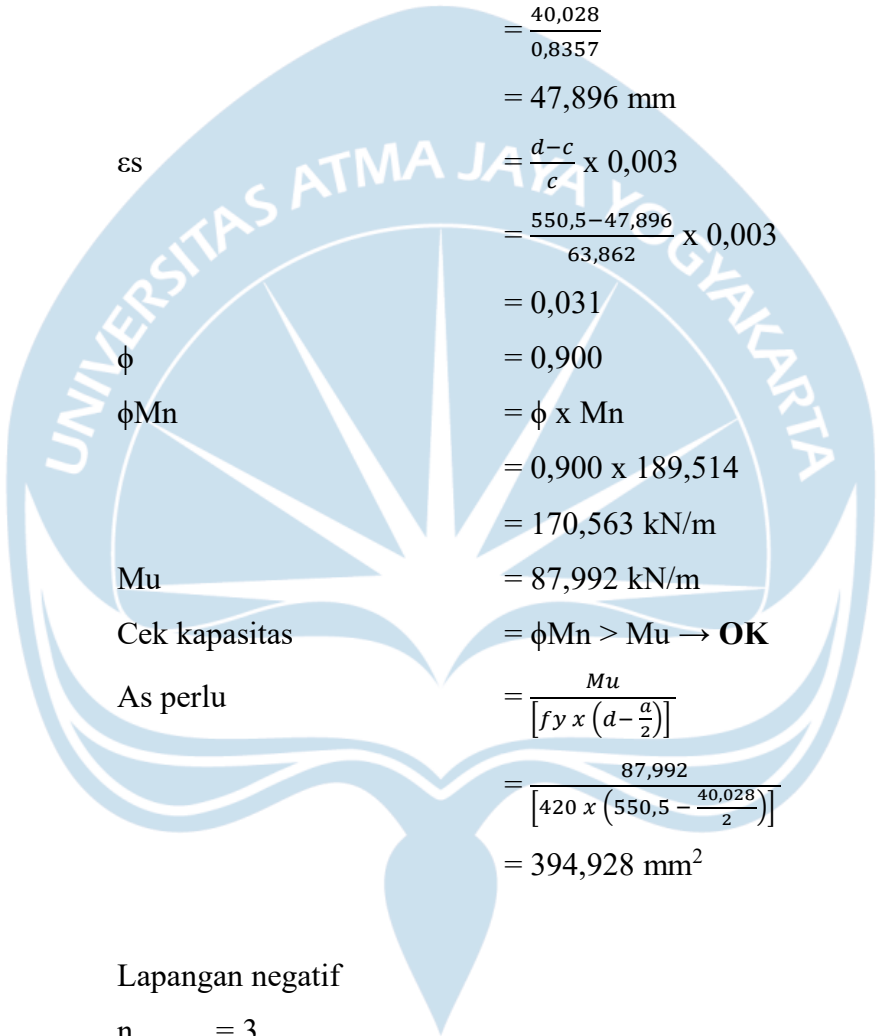
$a = \frac{As \times f_y}{0,85 \times f'c' \times b}$

$= \frac{850,586 \times 420}{0,85 \times 30 \times 350}$

$= 40,028 \text{ mm}$

$M_n = As \times f_y \times \left(d - \frac{a}{2} \right)$

$= 850,586 \times 30 \times \left(550,5 - \frac{40,028}{2} \right)$



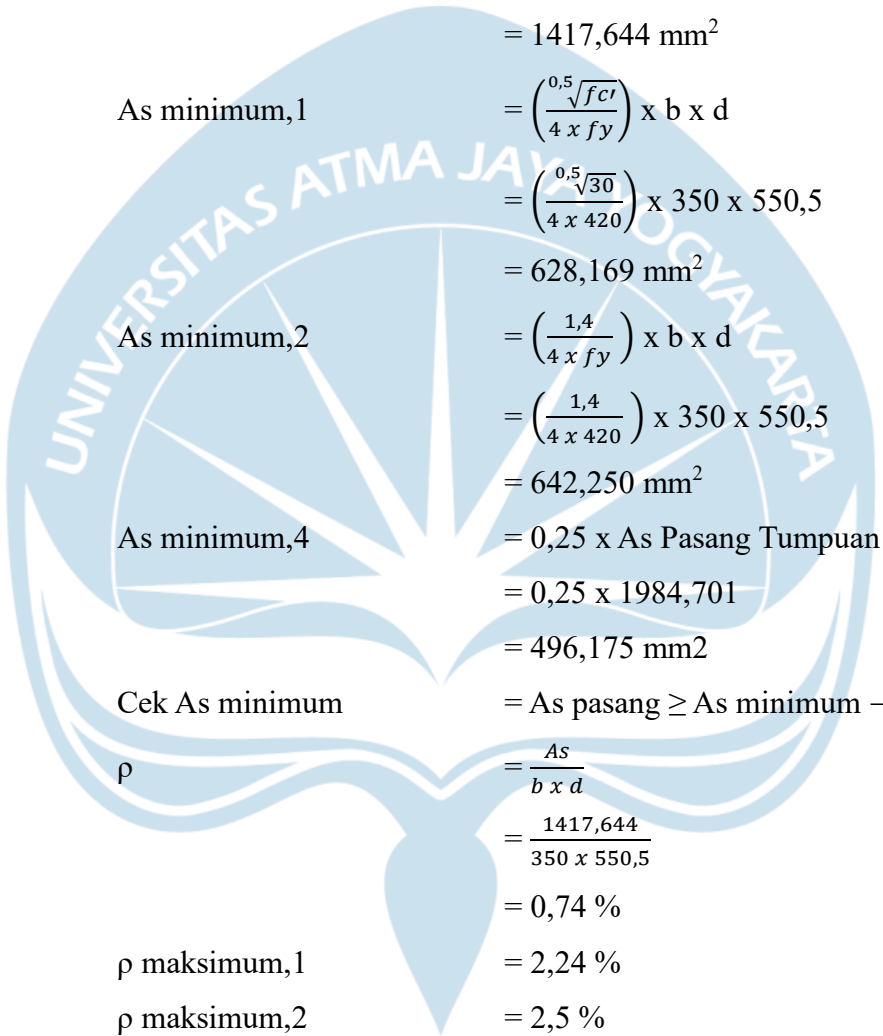
$$\begin{aligned}
 &= 189,514 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{40,028}{0,8357} \\
 &= 47,896 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{550,5-47,896}{63,862} \times 0,003 \\
 &= 0,031 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 189,514 \\
 &= 170,563 \text{ kN/m} \\
 M_u &= 87,992 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{87,992}{\left[420 \times \left(550,5 - \frac{40,028}{2} \right) \right]} \\
 &= 394,928 \text{ mm}^2
 \end{aligned}$$

Lapangan negatif

$$n = 3$$

$$d_b = 19 \text{ mm}$$

$$\begin{aligned}
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(350 - 2 \times 30 - 2 \times 10 - 5 \times 19)}{19-1} \\
 &= 43,750 \text{ mm}
 \end{aligned}$$



Jumlah lapis	$= 1$
As pasang	$= n \times \frac{\pi}{4} \times db^2$ $= 5 \times \frac{3,14}{4} \times 19^2$ $= 1417,644 \text{ mm}^2$
As minimum,1	$= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d$ $= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 350 \times 550,5$ $= 628,169 \text{ mm}^2$
As minimum,2	$= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d$ $= \left(\frac{1,4}{4 \times 420} \right) \times 350 \times 550,5$ $= 642,250 \text{ mm}^2$
As minimum,4	$= 0,25 \times \text{As Pasang Tumpuan Negatif}$ $= 0,25 \times 1984,701$ $= 496,175 \text{ mm}^2$
Cek As minimum	$= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK}$
ρ	$= \frac{As}{b \times d}$ $= \frac{1417,644}{350 \times 550,5}$ $= 0,74 \%$
ρ maksimum,1	$= 2,24 \%$
ρ maksimum,2	$= 2,5 \%$
Cek As maksimum	$= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK}$
a	$= \frac{As \times f_y}{0,85 \times f_c' \times b}$ $= \frac{1417,644 \times 420}{0,85 \times 30 \times 350}$ $= 66,713 \text{ mm}$

$$\begin{aligned}
 M_n &= A_s \times f_y \times \left(d - \frac{a}{2}\right) \\
 &= 1417,644 \times 30 \times \left(550,5 - \frac{66,713}{2}\right) \\
 &= 307,913 \text{ kN/m}
 \end{aligned}$$

$$\begin{aligned}
 c &= \frac{a}{\beta_1} \\
 &= \frac{66,713}{0,8357} \\
 &= 79,827 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{550,5-79,827}{79,827} \times 0,003 \\
 &= 0,018
 \end{aligned}$$

$$\begin{aligned}
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 307,913 \\
 &= 277,121 \text{ kN/m}
 \end{aligned}$$

$$M_u = 46,431 \text{ kN/m}$$

$$\text{Cek kapasitas} = \phi M_n > M_u \rightarrow \mathbf{OK}$$

$$\begin{aligned}
 A_s \text{ perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2}\right)\right]} \\
 &= \frac{46,431}{\left[420 \times \left(550,5 - \frac{66,713}{2}\right)\right]} \\
 &= 213,770 \text{ mm}^2
 \end{aligned}$$

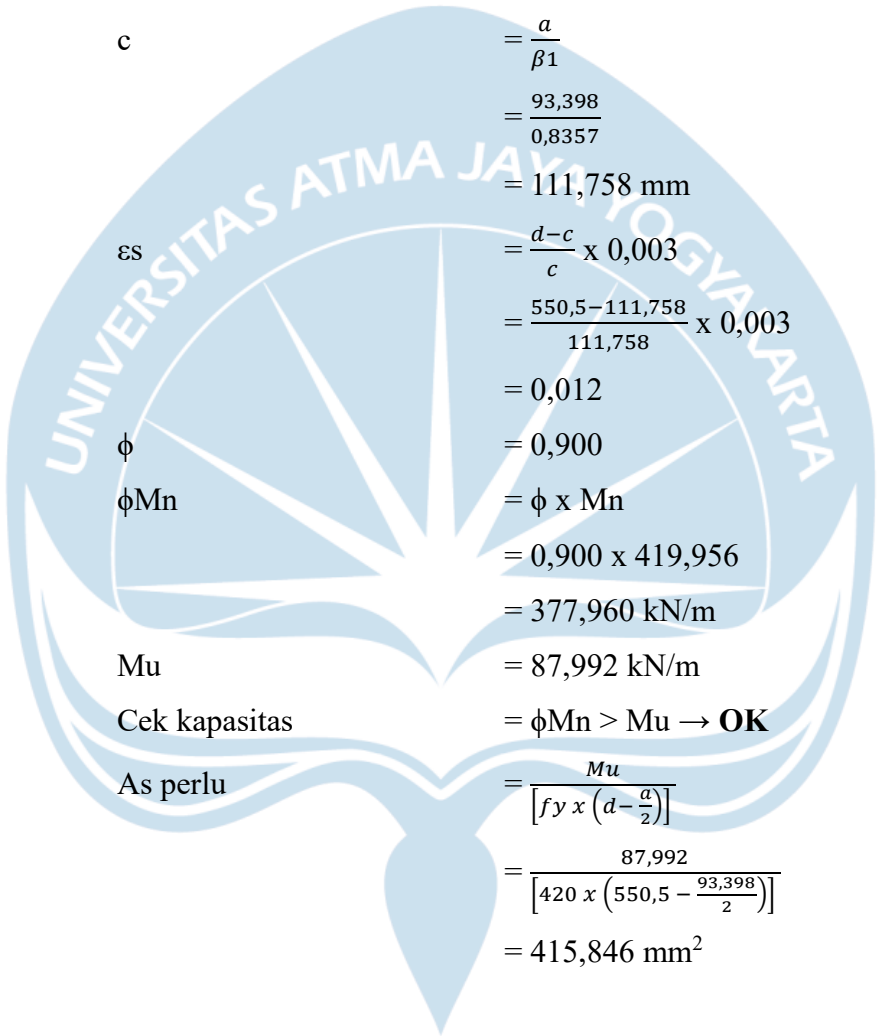
Lapangan positif

$$n = 3$$

$$d_b = 19 \text{ mm}$$

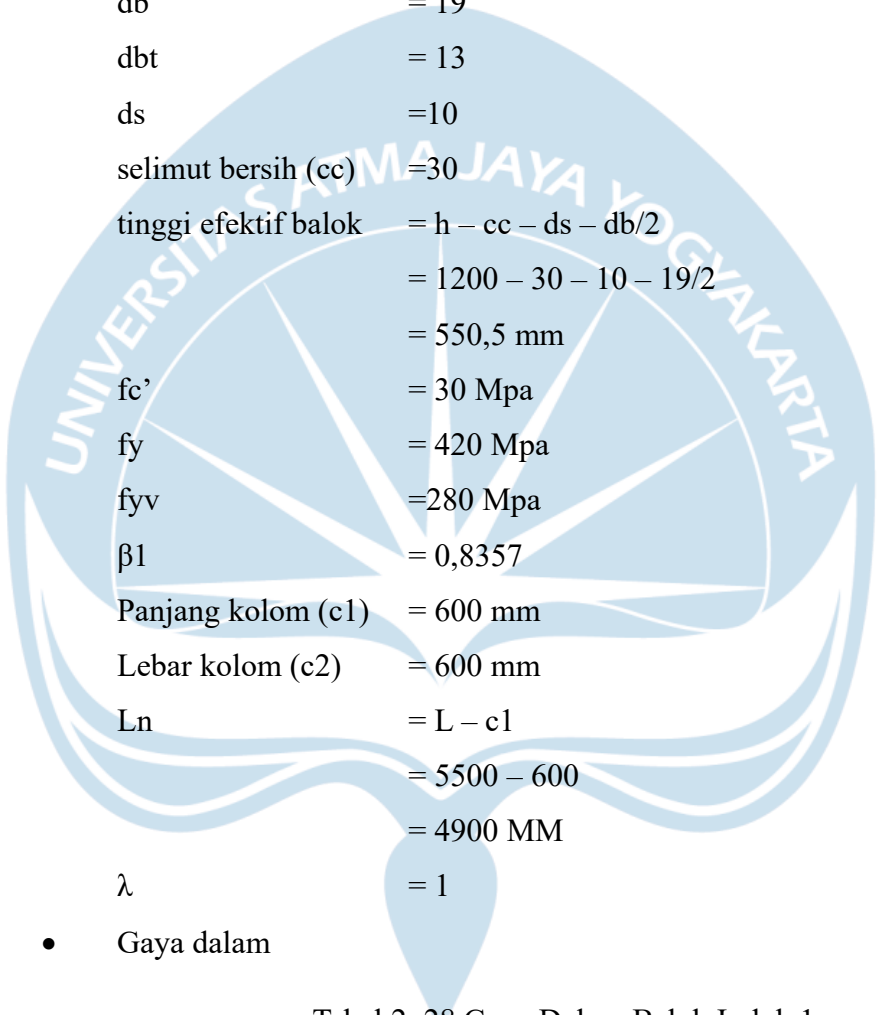
$$\begin{aligned}
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(350 - 2 \times 30 - 2 \times 10 - 7 \times 19)}{19-1}
 \end{aligned}$$

$$\begin{aligned}
 &= 22,833 \text{ mm} \\
 \text{Jumlah lapis} &= 2 \\
 \text{As pasang} &= n \times \frac{\pi}{4} \times db^2 \\
 &= 7 \times \frac{3,14}{4} \times 19^2 \\
 &= 1984,701 \text{ mm}^2 \\
 \text{As minimum,1} &= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 350 \times 550,5 \\
 &= 628,169 \text{ mm}^2 \\
 \text{As minimum,2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 350 \times 550,5 \\
 &= 642,250 \text{ mm}^2 \\
 \text{As minimum,4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1984,701 \\
 &= 496,175 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1984,701}{350 \times 550,5} \\
 &= 1,03 \% \\
 \rho \text{ maksimum,1} &= 2,24 \% \\
 \rho \text{ maksimum,2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1984,701 \times 420}{0,85 \times 30 \times 350} \\
 &= 93,398 \text{ mm}
 \end{aligned}$$



$$\begin{aligned}
 M_n &= A_s \times f_y \times \left(d - \frac{a}{2}\right) \\
 &= 1984,701 \times 30 \times \left(550,5 - \frac{93,398}{2}\right) \\
 &= 419,956 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{550,5-111,758}{111,758} \times 0,003 \\
 &= 0,012 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 419,956 \\
 &= 377,960 \text{ kN/m} \\
 M_u &= 87,992 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 A_s \text{ perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2}\right)\right]} \\
 &= \frac{87,992}{\left[420 \times \left(550,5 - \frac{93,398}{2}\right)\right]} \\
 &= 415,846 \text{ mm}^2
 \end{aligned}$$

- **Desain Geser**
- Data material dan penampang
 - Panjang balok (L) = 5500 mm
 - Lebar balok (b) = 350 mm
 - Tinggi balok (h) = 600 mm



Panjang tumpuan $= 2 \times h$
 $= 2 \times 600$
 $= 1200 \text{ mm}$
 $d_b = 19$
 $d_{bt} = 13$
 $d_s = 10$
 selimut bersih (cc) $= 30$
 tinggi efektif balok $= h - cc - d_s - d_b/2$
 $= 1200 - 30 - 10 - 19/2$
 $= 550,5 \text{ mm}$
 $f_c' = 30 \text{ Mpa}$
 $f_y = 420 \text{ Mpa}$
 $f_{yv} = 280 \text{ Mpa}$
 $\beta_1 = 0,8357$
 Panjang kolom (c1) $= 600 \text{ mm}$
 Lebar kolom (c2) $= 600 \text{ mm}$
 $L_n = L - c_1$
 $= 5500 - 600$
 $= 4900 \text{ MM}$
 $\lambda = 1$

- Gaya dalam

Tabel 2. 28 Gaya Dalam Balok Induk 1

$V_{u,tumpuan}$	154,419 kN
$V_{u,lapangan}$	111,231 kN

- Tumpuan

Gaya desain

$$V_{g,tumpuan} = 92,2231 \text{ kN}$$

$$A_s + tumpuan = 850,586 \text{ mm}^2$$

$$A_s - tumpuan = 1417,644 \text{ mm}^2$$

$$A_{pr+} = 50,034 \text{ mm}$$

$$A_{pr-} = 83,391 \text{ mm}$$

$$M_{pr+} = 234658404 \text{ N/mm}$$

$$M_{pr-} = 378684403 \text{ N/mm}$$

$$V_{sway}/V_{pr} = 125172 \text{ N}$$

$$V_e = 217395 \text{ N}$$

Tahanan geser beton

$$V_{pr} = 167488 \text{ N}$$

$$\frac{1}{2} V_e = 129856 \text{ N}$$

$$P_u = 25383,1 \text{ N}$$

$$\frac{A_g f_c'}{20} = 315000 \text{ N}$$

Penulangan geser

$$n = 4$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 4 \times \frac{3,14}{4} \times 10^2 \\ &= 314,159 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 100 \text{ mm}$$

$$\text{Spasi maksimum 1} = \frac{d}{4} = \frac{550,5}{4} = 137,63 \text{ mm}$$

$$\begin{aligned} \text{Spasi maksimum 2} &= 6 \times d_b \\ &= 6 \times 19 \end{aligned}$$

$$= 114 \text{ mm}$$

$$\text{Spasi maksimum } 3 = 150 \text{ mm}$$

Cek spasi $\rightarrow$ **OK**

$$\begin{aligned} V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 314,159 \times 280 \times \frac{550,5}{100} \\ &= 484245 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 350 \times 550,5 \\ &= 696514 \text{ N} \end{aligned}$$

$$\begin{aligned} \phi &= 0,75 \\ V_n &= V_c + V_s \\ &= 0 + 484245 \\ &= 484245 \text{ N} \end{aligned}$$

$$V_u = 217395 \text{ N}$$

$$\begin{aligned} \phi V_n / V_u &= 0,75 \times \frac{484245}{217395} \\ &= 1,671 \end{aligned}$$

Cek kapasitas $= \phi V_n / V_u \geq 1 \rightarrow$ **OK**

- Lapangan

Penulangan geser

$$n = 2$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 2 \times \frac{3,14}{4} \times 10^2 \\ &= 157,080 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 150 \text{ mm}$$

$$\text{Spasi maksimum} = \frac{d}{2} = \frac{550,5}{2} = 275,25 \text{ mm}$$

Cek spasi $\rightarrow$ **OK**

$$\begin{aligned}
 V_s &= A_v \times f_{yv} \times \frac{d}{s} \\
 &= 157,080 \times 280 \times \frac{550,5}{150} \\
 &= 161415 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\
 &= 0,66 \times 30^{0,5} \times 350 \times 550,5 \\
 &= 696514 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\
 &= 0,17 \times 30^{0,5} \times 350 \times 550,5 \\
 &= 179405 \text{ N}
 \end{aligned}$$

$$\phi = 0,75$$

$$\begin{aligned}
 V_n &= V_c + V_s \\
 &= 179405 + 161415 \\
 &= 340820
 \end{aligned}$$

$$V_u = 111231 \text{ N}$$

$$\begin{aligned}
 \phi V_n / V_u &= 0,75 \times \frac{340820}{111231} \\
 &= 2,298
 \end{aligned}$$

$$\text{Cek kapasitas} = \phi V_n / V_u \geq 1 \rightarrow \text{OK}$$

- **Desain Torsi**
- Data materail dan penampang

$$\text{Panjang balok (L)} = 5500 \text{ mm}$$

$$\text{Lebar balok (b)} = 350 \text{ mm}$$

$$\text{Tinggi balok (h)} = 600 \text{ mm}$$

$$\text{Panjang tumpuan} = 2 \times h$$

$$= 2 \times 600$$

$$= 1200 \text{ mm}$$

$$d_b = 19$$

$$d_{bt} = 13$$

$$\begin{aligned}
 d_s &= 10 \\
 \text{selimut bersih (cc)} &= 30 \\
 \text{tinggi efektif balok} &= h - cc - d_s - d_b/2 \\
 &= 1200 - 30 - 10 - 19/2 \\
 &= 550,5 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 f_c' &= 30 \text{ Mpa} \\
 f_y &= 420 \text{ Mpa} \\
 f_{yv} &= 280 \text{ Mpa}
 \end{aligned}$$

$$\begin{aligned}
 \beta_1 &= 0,8357 \\
 \text{Panjang kolom (c1)} &= 600 \text{ mm} \\
 \text{Lebar kolom (c2)} &= 600 \text{ mm} \\
 L_n &= L - c_1 \\
 &= 5500 - 600 \\
 &= 4900 \text{ MM} \\
 \lambda &= 1
 \end{aligned}$$

- Parameter geometri penampang untuk perhitungan torsi

$$\begin{aligned}
 A_{cp} &= b \times h \\
 &= 350 \times 600 \\
 &= 210000 \text{ mm}^2
 \end{aligned}$$

$$\begin{aligned}
 P_{cp} &= 2 \times (b + h) \\
 &= 2 \times (350 + 600) \\
 &= 1900 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 X_0 &= b - 2 C_c - d_s \\
 &= 350 - 2 \times 30 - 10 \\
 &= 280 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 Y_0 &= h - 2 cc - d_s \\
 &= 600 - 2 \times 30 - 10 \\
 &= 530 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 A_{oh} &= X_0 \times Y_0 \\
 &= 280 \times 530 \\
 &= 148400 \text{ mm}^2 \\
 A_0 &= 0,85 \times A_{oh} \\
 &= 126140 \text{ mm}^2 \\
 P_h &= 2 \times (X_0 + Y_0) \\
 &= 1620 \text{ mm}
 \end{aligned}$$

- Gaya dalam

Tabel 2. 29 Gaya Dalam Balok Induk 1

Tu	51,0152 Kn/m
----	--------------

- Pengecekan kebutuhan tulangan torsi

$$\begin{aligned}
 T_{cr} &= 0,33 \times f_c'^{0,5} \times \frac{A_{cp}^2}{P_{cp}} \\
 &= 0,33 \times 30^{0,5} \times \frac{210000^2}{1900} \\
 &= 41952665 \text{ N/mm}
 \end{aligned}$$

$$\phi = 0,75$$

$$\frac{\phi T_{cr}}{4} = \frac{0,75 \times 41952665}{4} = 7866125 \text{ N/mm}$$

$$\text{Syarat } Tu > \frac{\phi T_{cr}}{4} \rightarrow \text{MEMERLUKAN TULANGAN TORSI}$$

- Pengecekan kecukupan dimensi penampang

$$Tu \text{ pakai} = 31464499 \text{ N/mm}$$

$$V_u = 259711 \text{ N}$$

$$\begin{aligned}
 V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\
 &= 0,17 \times 30^{0,5} \times 350 \times 550,5 \\
 &= 179405 \text{ N}
 \end{aligned}$$

$$\begin{aligned}\text{Tegangan ultimate geser + torsi} &= \left\{ \left(\frac{Vu}{b \times d} \right)^2 + \left(\frac{Tu \times Ph}{1,7 \times Ao h^2} \right)^2 \right\}^{0,5} \\ &= \left\{ \left(\frac{259711}{350 \times 550,5} \right)^2 + \left(\frac{31464499 \times 1620}{1,7 \times 148400^2} \right)^2 \right\}^{0,5} \\ &= 1,916 \text{ Mpa}\end{aligned}$$

$$\begin{aligned}\text{Kapasitas tegangan beton} &= \phi \times \left\{ \left(\frac{Vu}{b \times d} \right) + 0,66 \times (fc')^{0,5} \right\} \\ &= 0,75 \times \left\{ \left(\frac{179405}{350 \times 550,5} \right) + 0,66 \times (30)^{0,5} \right\} \\ &= 3,410 \text{ Mpa}\end{aligned}$$

$$\text{Cek dimensi penampang} = \text{ruas kiri} \leq \text{ruas kanan} \rightarrow \text{OK}$$

• Penulangan transversal torsi

$$\text{n kaki tumpuan} = 4$$

$$\text{n kaki lapangan} = 2$$

$$\text{s tumpuan} = 100 \text{ mm}$$

$$\text{s lapangan} = 150 \text{ mm}$$

$$\text{s max 1} = \frac{Ph}{8} = \frac{1620}{8} = 203 \text{ mm}$$

$$\text{s max 2} = 300 \text{ mm}$$

$$\text{Cek spasi tumpuan} = \text{s tumpuan} \geq \text{s max} \rightarrow \text{OK}$$

$$\text{Cek spasi lapangan} = \text{s lapangan} \geq \text{s max} \rightarrow \text{OK}$$

$$\begin{aligned}\frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 6 \times \frac{3,14}{4} \times \frac{10^2}{100} \\ &= 4,712 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 2 \times \frac{3,14}{4} \times \frac{10^2}{150} \\ &= 1,047 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{At}{s} &= \frac{Tu}{(2 \times \phi \times Ao \times fyv)} \\ &= \frac{31464499}{(2 \times 0,75 \times 126140 \times 280)}\end{aligned}$$

$$\frac{A_v}{s \text{ tumpuan perlu}} = \frac{0,594 \text{ mm}^2/\text{mm}}{\left(\frac{V_u \text{ tumpuan}}{\phi - V_c} \right) / f_{yv} \times d} = 2,247 \text{ mm}^2/\text{mm}$$

$$\frac{A_v}{s \text{ lapangan perlu}} = \frac{2,247 \text{ mm}^2/\text{mm}}{\left(\frac{V_u \text{ lapangan}}{\phi - V_c} \right) / f_{yv} \times d} = -0,202 \text{ mm}^2/\text{mm}$$

$$\frac{A_v + s}{s \text{ tumpuan perlu}} = 2 \times \frac{A_t}{s} + \frac{A_v}{s} = 2 \times \frac{0,594}{s} + \frac{2,247}{s}$$

$$= 2 \times \frac{0,594}{s} + \frac{2,247}{s}$$

$$= 2 \times 0,594 + 2,247$$

$$= 3,434$$

$$\frac{A_v + s}{s \text{ tumpuan perlu}} = 2 \times \frac{A_t}{s} + \frac{A_v}{s} = 2 \times \frac{0,594}{s} + \frac{-0,202}{s}$$

$$= 2 \times 0,594 + (-0,202)$$

$$= 0,986$$

$$\frac{A_v + t}{s \text{ min } 1} = 0,062 \times f_c'^{0,5} \times \frac{b}{f_{yv}}$$

$$= 0,062 \times 30^{0,5} \times \frac{350}{280}$$

$$= 0,424$$

$$\frac{A_v + t}{s \text{ min } 2} = \frac{0,35 \times b}{f_{yv}}$$

$$= \frac{0,35 \times 350}{280}$$

$$= 0,438$$

$$\text{Cek geser + torsi tumpuan} = \frac{A_v + t}{s \text{ pasang}} \geq \frac{A_v + t}{s \text{ perlu}} \rightarrow \text{OK}$$

$$\text{Cek geser + torsi lapangan} = \frac{A_v + t}{s \text{ pasang}} \geq \frac{A_v + t}{s \text{ perlu}} \rightarrow \text{OK}$$

- Penulangan longitudinal torsi

$$db \text{ atau } dbt = 10 \text{ mm}$$

$$db, \text{min} = 0,042 \times s = 6,3 \text{ mm}$$

$$\text{Cek db} = db \geq db \text{ min} \rightarrow \mathbf{OK}$$

$$\text{Kebutuhan As tumpuan atas} = 906,382 \text{ mm}^2$$

$$\text{Kebutuhan As tumpuan bawah} = 519,793 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan atas} = 208,393 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan bawah} = 394,928 \text{ mm}^2$$

$$\begin{aligned} A_1 &= \frac{At}{s} \times Ph \\ &= 0,594 \times 1620 \\ &= 962,130 \text{ mm}^2 \end{aligned}$$

$$\begin{aligned} A_1 \text{ min} &= \frac{0,42 \times f_c r^{0,5} \times Acp}{f_y - \frac{At}{s} \times ph} \\ &= \frac{0,42 \times 30^{0,5} \times 210000}{30 - 0,594 \times 1620} \\ &= 188,087 \text{ mm}^2 \end{aligned}$$

$$\text{As} + A_1 \text{ perlu tumpuan} = 2388,305 \text{ mm}^2$$

$$\text{As} + A_1 \text{ perlu lapangan} = 1565,451 \text{ mm}^2$$

$$n \text{ tumpuan atas} = 5$$

$$n \text{ tumpuan tengah} = 2$$

$$n \text{ tumpuan bawah} =$$

$$n \text{ tumpuan vertikal} = 2 + \frac{n \text{ tengah}}{2} = 3$$

$$n \text{ lapangan atas} = 3$$

$$n \text{ lapangan tengah} = 2$$

$$n \text{ lapangan atas} = 3$$

$$n \text{ tumpuan vertikal} = 2 + \frac{n \text{ tengah}}{2} = 3$$

$$\text{Spasi horizontal tumpuan} = 126 \text{ mm}$$

$$\text{Spasi vertikal tumpuan} = 251 \text{ mm}$$

$$\text{Spasi horizontal lapangan} = 126 \text{ mm}$$

$$\text{Spasi vertikal lapangan} = 251 \text{ mm}$$

$$\text{Spasi tulangan longitudinal tumpuan} = \text{spasi} \geq 300 \text{ mm} \rightarrow \mathbf{OK}$$

Spasi tulangan longitudinal lapangan = spasi ≥ 300 mm $\rightarrow$ **OK**

As + A1 pasang tumpuan = 2425,310 mm²

As + A1 pasang lapangan = 1858,252 mm²

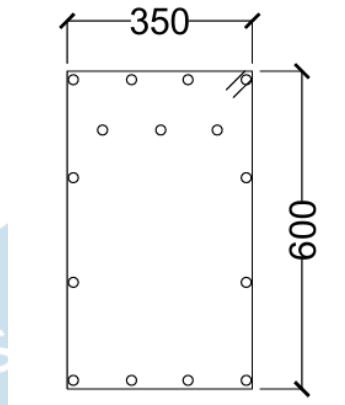
Cek lentur + torsi tumpuan = As+A1 pasang $\geq$ As + A1 perlu $\rightarrow$ **OK**

Cek lentur + torsi lapangan = As+A1 pasang $\geq$ As + A1 perlu $\rightarrow$ **OK**

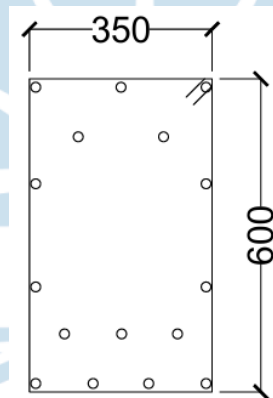
- **Rekap**

Tabel 2. 30 Rekap Balok Induk 1

Kesimpulan	
Syarat Gaya dan Geometri	OK
Kapasitas Lentur	OK
Kapasitas Geser	OK
Kapasitas Torsi	OK
Tulangan Longitudinal	
Longitudinal Tumpuan Atas	5 D19
Longitudinal Tumpuan Tengah	2 D10
Longitudinal Tumpuan Bawah	3 D19
Longitudinal Lapangan Atas	3 D19
Longitudinal Lapangan Tengah	2 D10
Longitudinal Lapangan Bawah	3 D19
Tulangan Transversal/Sengkang	
Sengkang Tumpuan	4D10-100
Sengkang Lapangan	2D10-150



Gambar 2. 51 Penulangan Tumpuan Balok Induk 1



Gambar 2. 52 Penulangan Lapangan Balok Induk 2

2.12.2 Balok Induk 2

- **Desain Lentur**
- Data material dan penampang

Panjang balok (L)	= 4000 mm
Lebar balok (b)	= 300 mm
Tinggi balok (h)	= 500 mm
Panjang tumpuan	= 2 x h

$$\begin{aligned}
 &= 2 \times 500 \\
 &= 1000 \text{ mm} \\
 db &= 19 \\
 dbt &= 13 \\
 ds &= 10 \\
 \text{selimut bersih (cc)} &= 30 \\
 \text{tinggi efektif balok} &= h - cc - ds - db/2 \\
 &= 500 - 30 - 10 - 19/2 \\
 &= 450,5 \text{ mm} \\
 f_c' &= 30 \text{ Mpa} \\
 f_y &= 420 \text{ Mpa} \\
 f_{yv} &= 280 \text{ Mpa} \\
 \beta_1 &= 0,8357 \\
 \text{Panjang kolom (c1)} &= 600 \text{ mm} \\
 \text{Lebar kolom (c2)} &= 600 \text{ mm} \\
 L_n &= L - c1 \\
 &= 4000 - 600 \\
 &= 3400 \text{ MM} \\
 \lambda &= 1
 \end{aligned}$$

- Gaya dalam

Tabel 2. 31 Gaya Dalam Balok Induk 2

Mu tumpuan (-)	-118,081 kN/m
Mu tumpuan (+)	104,0676 kN/m
Mu lapangan (-)	-146,032 kN/m
Mu lapangan (+)	136,2527 kN/m
Pu	37,867 kN

- Syarat gaya dan geometri

$$\begin{aligned}\text{Syarat gaya aksial} &= P_u \leq 0,1 \times A_g \times f_c' \\ &= 37,867 \leq 0,1 \times 300 \times 500 \times 30 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat tinggi efektif} &= L_n \geq 4d \\ &= 3400 \geq 4 \times 450,5 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 1} &= b \geq \min(0,3 \times h, 250 \text{ mm}) \\ &= 300 \geq \min(0,3 \times 500, 250 \text{ mm}) \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 2} &= b \leq c_2 + 2 \times \min(c_2, 0,75 c_i) \\ &= 300 \leq 600 + 2 \times \min(500, 0,75 c_i) \rightarrow \mathbf{OK}\end{aligned}$$

- Penulangan lentur
Tumpuan negatif

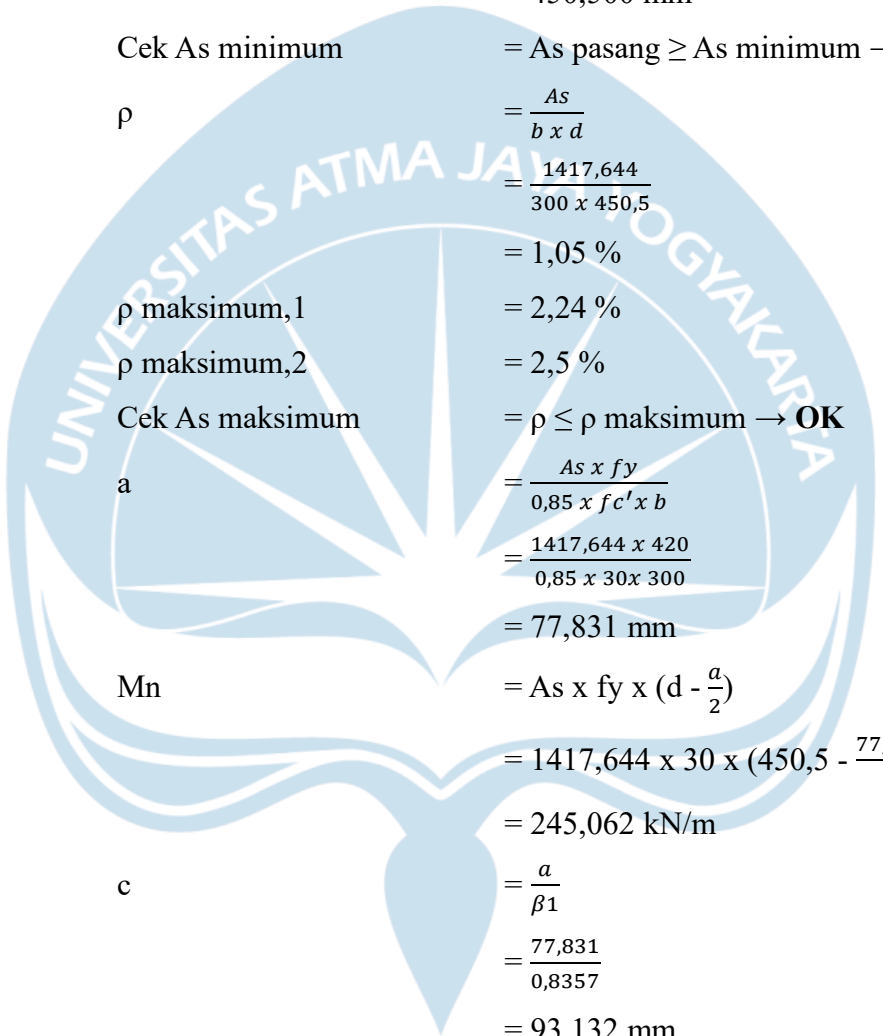
$$\begin{aligned}n &= 5 \\ d_b &= 19 \text{ mm}\end{aligned}$$

$$\begin{aligned}\text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\ &= \frac{(300 - 2 \times 30 - 2 \times 10 - 5 \times 19)}{5-1} \\ &= 31,250 \text{ mm}\end{aligned}$$

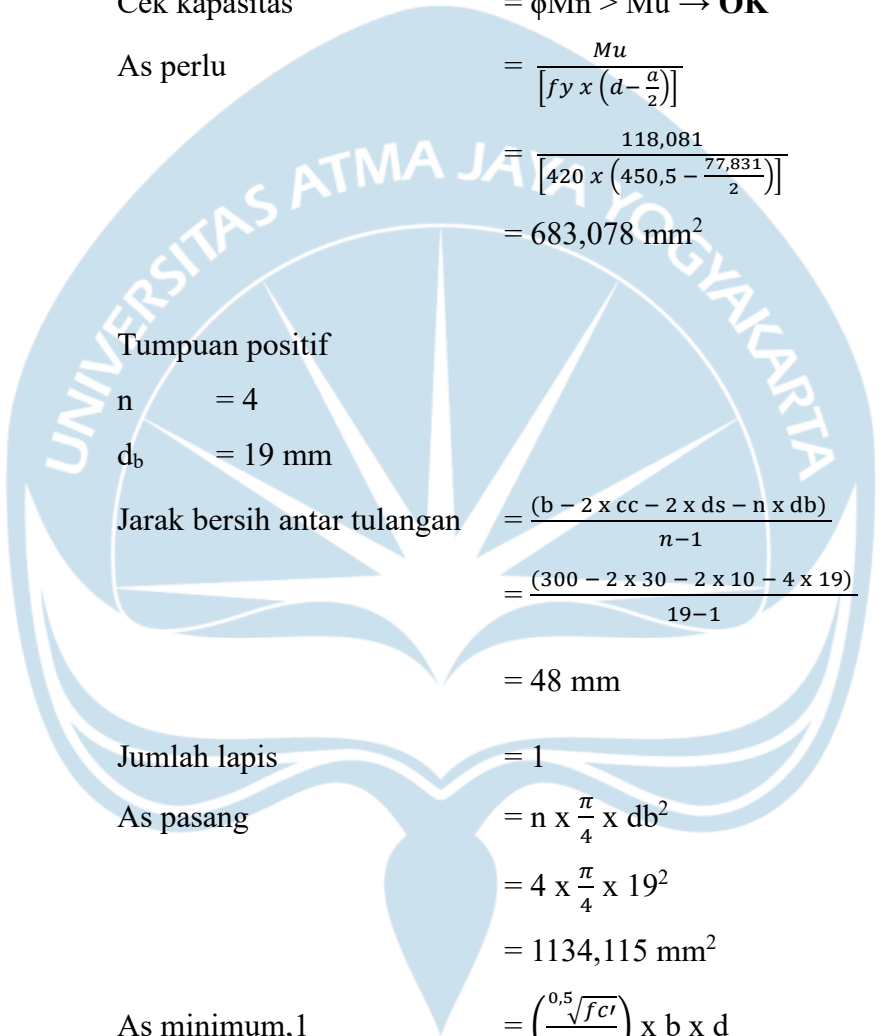
$$\text{Jumlah lapis} = 1$$

$$\begin{aligned}\text{As pasang} &= n \times \frac{\pi}{4} \times d_b^2 \\ &= 5 \times \frac{3,14}{4} \times 19^2 \\ &= 1417,644 \text{ mm}^2\end{aligned}$$

$$\begin{aligned}\text{As minimum,1} &= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d \\ &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 300 \times 450,5 \\ &= 440,623 \text{ mm}^2\end{aligned}$$



$$\begin{aligned}
 \text{As minimum,2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 300 \times 450,5 \\
 &= 450,500 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{\text{As}}{b \times d} \\
 &= \frac{1417,644}{300 \times 450,5} \\
 &= 1,05 \% \\
 \rho \text{ maksimum,1} &= 2,24 \% \\
 \rho \text{ maksimum,2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{\text{As} \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1417,644 \times 420}{0,85 \times 30 \times 300} \\
 &= 77,831 \text{ mm} \\
 \text{Mn} &= \text{As} \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1417,644 \times 30 \times \left(450,5 - \frac{77,831}{2} \right) \\
 &= 245,062 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{77,831}{0,8357} \\
 &= 93,132 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{450,5-93,132}{93,132} \times 0,003 \\
 &= 0,012 \\
 \phi &= 0,900 \\
 \phi \text{Mn} &= \phi \times \text{Mn}
 \end{aligned}$$



$$= 0,900 \times 245,062$$

$$= 220,555 \text{ kN/m}$$

Mu,tumpuan (-) $= 118,081 \text{ kN/m}$

Cek kapasitas $= \phi M_n > M_u \rightarrow \mathbf{OK}$

As perlu $= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]}$

$$= \frac{118,081}{\left[420 \times \left(450,5 - \frac{77,831}{2} \right) \right]}$$

$$= 683,078 \text{ mm}^2$$

Tumpuan positif
 $n = 4$
 $d_b = 19 \text{ mm}$

Jarak bersih antar tulangan $= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1}$

$$= \frac{(300 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{19-1}$$

$$= 48 \text{ mm}$$

Jumlah lapis $= 1$

As pasang $= n \times \frac{\pi}{4} \times d_b^2$

$$= 4 \times \frac{\pi}{4} \times 19^2$$

$$= 1134,115 \text{ mm}^2$$

As minimum,1 $= \left(\frac{0,5 \sqrt{f'c'}}{4 \times f_y} \right) \times b \times d$

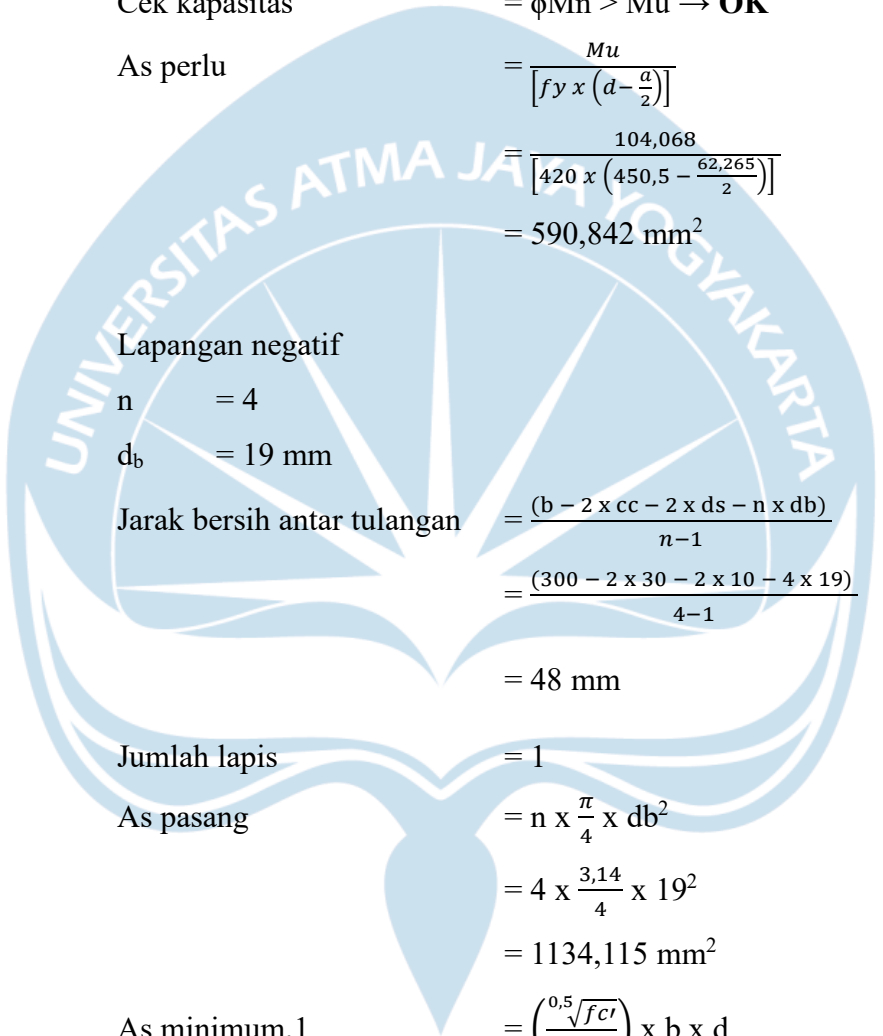
$$= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 300 \times 450,5$$

$$= 440,623 \text{ mm}^2$$

As minimum,2 $= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d$

$$= \left(\frac{1,4}{4 \times 420} \right) \times 300 \times 450,5$$

$$\begin{aligned}
 &= 450,500 \text{ mm}^2 \\
 \text{As minimum, 4} &= 0.5 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,5 \times 1984,701 \\
 &= 992,351 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1134,115}{300 \times 450,5} \\
 &= 0,84 \% \\
 \rho \text{ maksimum, 1} &= 2,24 \% \\
 \rho \text{ maksimum, 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 300} \\
 &= 62,265 \text{ mm} \\
 M_n &= As \times f_y \times (d - \frac{a}{2}) \\
 &= 1134,115 \times 30 \times (450,5 - \frac{62,265}{2}) \\
 &= 199,757 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{62,265}{0,8357} \\
 &= 74,505 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{450,5-74,505}{74,505} \times 0,003 \\
 &= 0,015 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n
 \end{aligned}$$



$$\begin{aligned}
 &= 0,900 \times 199,757 \\
 &= 179,781 \text{ kN/m} \\
 \text{Mu} &= 104,068 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > \text{Mu} \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{Mu}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{104,068}{\left[420 \times \left(450,5 - \frac{62,265}{2} \right) \right]} \\
 &= 590,842 \text{ mm}^2 \\
 \text{Lapangan negatif} & \\
 n &= 4 \\
 d_b &= 19 \text{ mm} \\
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times cc - 2 \times ds - n \times db)}{n-1} \\
 &= \frac{(300 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{4-1} \\
 &= 48 \text{ mm} \\
 \text{Jumlah lapis} &= 1 \\
 \text{As pasang} &= n \times \frac{\pi}{4} \times db^2 \\
 &= 4 \times \frac{3,14}{4} \times 19^2 \\
 &= 1134,115 \text{ mm}^2 \\
 \text{As minimum,1} &= \left(\frac{\sqrt[0,5]{f_c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{\sqrt[0,5]{30}}{4 \times 420} \right) \times 300 \times 450,5 \\
 &= 440,623 \text{ mm}^2 \\
 \text{As minimum,2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 300 \times 450,5
 \end{aligned}$$

$$\begin{aligned}
 &= 450,500 \text{ mm}^2 \\
 \text{As minimum,4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1134,112 \\
 &= 354,411 \text{ mm}^2 \\
 \text{Cek As min} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1134,115}{300 \times 450,5} \\
 &= 0,84 \% \\
 \rho \text{ maksimum,1} &= 2,24 \% \\
 \rho \text{ maksimum,2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times fy}{0,85 \times f'c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 350} \\
 &= 62,265 \text{ mm} \\
 Mn &= As \times fy \times (d - \frac{a}{2}) \\
 &= 1034,115 \times 30 \times (450,5 - \frac{77,831}{2}) \\
 &= 245,062 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{77,831}{0,8357} \\
 &= 93,132 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{450,5-93,132}{93,132} \times 0,003 \\
 &= 0,012 \\
 \phi &= 0,900 \\
 \phi Mn &= \phi \times Mn
 \end{aligned}$$

$$\begin{aligned}
 &= 0,900 \times 245,062 \\
 &= 220,555 \text{ kN/m} \\
 \text{Mu} &= 146,032 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{146,032}{\left[420 \times \left(450,5 - \frac{62,265}{2} \right) \right]} \\
 &= 829,096 \text{ mm}^2 \\
 \text{Lapangan positif} & \\
 n &= 4 \\
 d_b &= 19 \text{ mm} \\
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(300 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{4-1} \\
 &= 48 \text{ mm} \\
 \text{Jumlah lapis} &= 1 \\
 \text{As pasang} &= n \times \frac{\pi}{4} \times d_b^2 \\
 &= 4 \times \frac{3,14}{4} \times 19^2 \\
 &= 1134,115 \text{ mm}^2 \\
 \text{As minimum,1} &= \left(\frac{\sqrt[0,5]{f_c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{\sqrt[0,5]{30}}{4 \times 420} \right) \times 300 \times 450,5 \\
 &= 440,623 \text{ mm}^2 \\
 \text{As minimum,2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 300 \times 450,5
 \end{aligned}$$

$$\begin{aligned}
 &= 450,500 \text{ mm}^2 \\
 \text{As minimum,4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1134,115 \\
 &= 354,411 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1134,115}{300 \times 450,5} \\
 &= 0,84 \% \\
 \rho \text{ maksimum,1} &= 2,24 \% \\
 \rho \text{ maksimum,2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ max} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times fy}{0,85 \times f'c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 300} \\
 &= 62,265 \text{ mm} \\
 Mn &= As \times fy \times (d - \frac{a}{2}) \\
 &= 1134,115 \times 30 \times (450,5 - \frac{62,265}{2}) \\
 &= 199,757 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{62,265}{0,8357} \\
 &= 74,505 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{450,5-74,505}{130} \times 0,003 \\
 &= 0,015 \\
 \phi &= 0,900 \\
 \phi Mn &= \phi \times Mn
 \end{aligned}$$

$$\begin{aligned}
 &= 0,900 \times 199,757 \\
 &= 179,781 \text{ kN/m} \\
 \text{Mu} &= 136,253 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > \text{Mu} \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{Mu}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{136,253}{\left[420 \times \left(450,5 - \frac{62,265}{2} \right) \right]} \\
 &= 773,573 \text{ mm}^2
 \end{aligned}$$

- **Desain Geser**

- Data material dan penampang

Panjang balok (L) = 4000 mm

Lebar balok (b) = 300 mm

Tinggi balok (h) = 500 mm

Panjang tumpuan = 2 x h
 = 2 x 500
 = 1000 mm

db = 19

dbt = 13

ds = 10

selimut bersih (cc) = 30

tinggi efektif balok = h - cc - ds - db/2
 = 500 - 30 - 10 - 19/2
 = 450,5 mm

fc' = 30 Mpa

fy = 420 Mpa

fyv = 280 Mpa

β_1 = 0,8357

Panjang kolom (c1) = 600 mm

$$\begin{aligned}
 \text{Lebar kolom (c2)} &= 600 \text{ mm} \\
 L_n &= L - c1 \\
 &= 4000 - 600 \\
 &= 3400 \text{ MM}
 \end{aligned}$$

- Gaya dalam

Tabel 2. 32 Gaya Dalam Balok Induk 2

Vu,tumpuan	144,7097 kN
Vu,lapangan	148,7175 kN

- Tumpuan
 Gaya desain
 $V_{g,tumpuan} = 52,5336 \text{ kN}$
 $A_s + tumpuan = 1134,115 \text{ mm}^2$
 $A_s - tumpuan = 1984,701 \text{ mm}^2$
 $A_{pr+} = 77,831 \text{ mm}$
 $A_{pr-} = 136,205 \text{ mm}$
 $M_{pr+} = 245061546 \text{ N/mm}$
 $M_{pr-} = 398446009 \text{ N/mm}$
 $V_{sway} / V_{pr} = 189267 \text{ N}$
 $V_e = 241801 \text{ N}$

Tahanan geser beton

$$\begin{aligned}
 V_{pr} &= 189267 \text{ N} \\
 \frac{1}{2} V_e &= 120900 \text{ N} \\
 P_u &= 37867 \text{ N} \\
 \frac{A_g f_c'}{20} &= 225000 \text{ N}
 \end{aligned}$$

Penulangan geser

$$n = 5$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 5 \times \frac{3,14}{4} \times 10^2 \\ &= 392,699 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 100 \text{ mm}$$

$$\text{Spasi maksimum 1} = \frac{d}{4} = \frac{450,5}{4} = 112,63 \text{ mm}$$

$$\begin{aligned} \text{Spasi maksimum 2} &= 6 \times d_b \\ &= 6 \times 19 \\ &= 114 \text{ mm} \end{aligned}$$

$$\text{Spasi maksimum 3} = 150 \text{ mm}$$

Cek spasi $\rightarrow$ **OK**

$$\begin{aligned} V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 392,699 \times 280 \times \frac{450,5}{100} \\ &= 495351 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 300 \times 450,5 \\ &= 488563 \text{ N} \end{aligned}$$

$$\phi = 0,75$$

$$\begin{aligned} V_n &= V_c + V_s \\ &= 0 + 488563 \\ &= 488563 \text{ N} \end{aligned}$$

$$V_u = 212577 \text{ N}$$

$$\begin{aligned} \phi V_n / V_u &= 0,75 \times \frac{488563}{212577} \\ &= 1,724 \end{aligned}$$

Cek kapasitas $= \phi V_n / V_u \geq 1 \rightarrow$ **OK**

- Lapangan

Penulangan geser

$$n = 2$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 2 \times \frac{3,14}{4} \times 10^2 \\ &= 157,080 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 150 \text{ mm}$$

$$\text{Spasi maksimum} = \frac{d}{2} = \frac{450,5}{2} = 225,25 \text{ mm}$$

Cek spasi $\rightarrow$ **OK**

$$\begin{aligned} V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 157,080 \times 280 \times \frac{450,5}{150} \\ &= 132093 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 300 \times 450,5 \\ &= 488563 \text{ N} \end{aligned}$$

$$\begin{aligned} V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\ &= 0,17 \times 30^{0,5} \times 300 \times 450,5 \\ &= 125842 \text{ N} \end{aligned}$$

$$\phi = 0,75$$

$$V_n = 257935$$

$$V_u = 148717,5 \text{ N}$$

$$\begin{aligned} \phi V_n / V_u &= 0,75 \times \frac{257935}{148717,5} \\ &= 1,301 \end{aligned}$$

Cek kapasitas $= \phi V_n / V_u \geq 1 \rightarrow$ **OK**

- **Desain Torsi**

- Data materail dan penampang

Panjang balok (L) = 4000 mm

Lebar balok (b) = 300 mm

Tinggi balok (h) = 500 mm

Panjang tumpuan = 2 x h

= 2 x 500

= 1000 mm

db = 19

dbt = 13

ds = 10

selimut bersih (cc) = 30

tinggi efektif balok = $h - cc - ds - db/2$

= $500 - 30 - 10 - 19/2$

= 450,5 mm

fc' = 30 Mpa

fy = 420 Mpa

fyv = 280 Mpa

β_1 = 0,8357

Panjang kolom (c1) = 600 mm

Lebar kolom (c2) = 600 mm

Ln = L - c1

= 4000 - 600

= 3400 MM

- Parameter geometri penampang untuk perhitungan torsi

Acp = b x h

= 300 x 500

= 150000 mm²

$$\begin{aligned}
 P_{cp} &= 2 \times (b + h) \\
 &= 2 \times (300 + 500) \\
 &= 1600 \text{ mm} \\
 X_0 &= b - 2 C_c - d_s \\
 &= 300 - 2 \times 30 - 10 \\
 &= 230 \text{ mm} \\
 Y_0 &= h - 2 c_c - d_s \\
 &= 500 - 2 \times 30 - 10 \\
 &= 430 \text{ mm} \\
 A_{oh} &= X_0 \times Y_0 \\
 &= 230 \times 430 \\
 &= 98900 \text{ mm}^2 \\
 A_0 &= 0,85 \times A_{oh} \\
 &= 84065 \text{ mm}^2 \\
 P_h &= 2 \times (X_0 + Y_0) \\
 &= 1320 \text{ mm}
 \end{aligned}$$

- Gaya dalam

Tabel 2. 33 Gaya Dalam Balok Induk 2

Tu	26,3342 kN/m
----	--------------

- Pengecekan kebutuhan tulangan torsi

$$\begin{aligned}
 T_{cr} &= 0,33 \times f_c'^{0,5} \times \frac{A_{cp}^2}{P_{cp}} \\
 &= 0,33 \times 30^{0,5} \times \frac{150000^2}{1600} \\
 &= 25417750 \text{ N/mm}
 \end{aligned}$$

$$\phi = 0,75$$

$$\frac{\phi T_{cr}}{4} = \frac{0,75 \times 25417750}{4} = 4765828 \text{ N/mm}$$

$$\text{Syarat } Tu > \frac{\phi T_{cr}}{4} \rightarrow \text{MEMERLUKAN TULANGAN TORSI}$$

- Pengecekan kecukupan dimensi penampang

$$Tu \text{ pakai} = 19063312 \text{ N/mm}$$

$$Vu = 241801 \text{ N}$$

$$\begin{aligned} Vc &= 0,17 \times f'c^{0,5} \times b \times d \\ &= 0,17 \times 30^{0,5} \times 300 \times 450,5 \\ &= 125842 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Tegangan ultimate geser + torsi} &= \left\{ \left(\frac{Vu}{b \times d} \right)^2 + \left(\frac{Tu \times Ph}{1,7 \times A_o h^2} \right)^2 \right\}^{0,5} \\ &= \left\{ \left(\frac{240801}{300 \times 450,5} \right)^2 + \left(\frac{190633 \times 1320}{1,7 \times 98900^2} \right)^2 \right\}^{0,5} \\ &= 2,343 \text{ Mpa} \end{aligned}$$

$$\begin{aligned} \text{Kapasitas tegangan beton} &= \phi \times \left\{ \left(\frac{Vu}{b \times d} \right) + 0,66 \times (f'c)^{0,5} \right\} \\ &= 0,75 \times \left\{ \left(\frac{240801}{350 \times 550,5} \right) + 0,66 \times (30)^{0,5} \right\} \\ &= 3,410 \text{ Mpa} \end{aligned}$$

$$\text{Cek dimensi penampang} = \text{ruas kiri} \leq \text{ruas kanan} \rightarrow \mathbf{OK}$$

- Penulangan transversal torsi

$$n \text{ kaki tumpuan} = 5$$

$$n \text{ kaki lapangan} = 6$$

$$s \text{ tumpuan} = 100 \text{ mm}$$

$$s \text{ lapangan} = 150 \text{ mm}$$

$$s \text{ max 1} = \frac{Ph}{8} = \frac{1320}{8} = 165 \text{ mm}$$

$$s \text{ max 2} = 300 \text{ mm}$$

$$\text{Cek spasi tumpuan} = s \text{ tumpuan} \geq s \text{ max} \rightarrow \mathbf{OK}$$

$$\text{Cek spasi lapangan} = s \text{ lapangan} \geq s \text{ max} \rightarrow \mathbf{OK}$$

$$\begin{aligned} \frac{Av + t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 5 \times \frac{3,14}{4} \times \frac{10^2}{100} \\ &= 3,927 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 6 \times \frac{3,14}{4} \times \frac{10^2}{150} \\ &= 3,142 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{At}{s} &= \frac{Tu}{(2 \times \phi \times Ao \times fyv)} \\ &= \frac{19063312}{(2 \times 0,75 \times 84065 \times 280)} \\ &= 0,540 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av}{s \text{ tumpuan perlu}} &= \frac{\left(\frac{Vu \text{ tumpuan}}{\phi - Vc}\right)}{fyv \times d} \\ &= 2,247 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av}{s \text{ lapangan perlu}} &= \frac{\left(\frac{Vu \text{ lapangan}}{\phi - Vc}\right)}{fyv \times d} \\ &= 0,574 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av+s}{s \text{ tumpuan perlu}} &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times 0,540 + 2,247 \\ &= 3,327 \end{aligned}$$

$$\begin{aligned} \frac{Av+s}{s \text{ tumpuan perlu}} &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times 0,540 + 0,574 \\ &= 1,654 \end{aligned}$$

$$\begin{aligned} \frac{Av+t}{s \text{ min } 1} &= 0,062 \times fc'^{0,5} \times \frac{b}{fyv} \\ &= 0,062 \times 30^{0,5} \times \frac{300}{280} \\ &= 0,364 \end{aligned}$$

$$\begin{aligned} \frac{Av+t}{s \text{ min } 2} &= \frac{0,35 \times b}{fyv} \\ &= \frac{0,35 \times 300}{280} \\ &= 0,375 \end{aligned}$$

$$\text{Cek geser + torsi tumpuan} = \frac{Av+t}{s \text{ pasang}} \geq \frac{Av+t}{s \text{ perlu}} \rightarrow \mathbf{OK}$$

$$\text{Cek geser + torsi lapangan} = \frac{Av+t}{s \text{ pasang}} \geq \frac{Av+t}{s \text{ perlu}} \rightarrow \mathbf{OK}$$

- Penulangan longitudinal torsi

$$\text{db atau dbt} = 13 \text{ mm}$$

$$\text{db,min} = 0,042 \times s = 6,3 \text{ mm}$$

$$\text{Cek db} = \text{db} \geq \text{db min} \rightarrow \mathbf{OK}$$

$$\text{Kebutuhan As tumpuan atas} = 683,078 \text{ mm}^2$$

$$\text{Kebutuhan As tumpuan bawah} = 590,842 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan atas} = 829,096 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan bawah} = 773,573 \text{ mm}^2$$

$$A_1 = \frac{At}{s} \times Ph$$

$$= 0,540 \times 1320$$

$$= 712,702 \text{ mm}^2$$

$$A_1 \text{ min} = \frac{0,42 \times f_c'^{0,5} \times A_{cp}}{f_y - \frac{At}{s} \times ph}$$

$$= \frac{0,42 \times 30^{0,5} \times 150000}{30 - 0,540 \times 1630}$$

$$= 108,882 \text{ mm}^2$$

$$\text{As + A1 perlu tumpuan} = 1986,622 \text{ mm}^2$$

$$\text{As + A1 perlu lapangan} = 2315,371 \text{ mm}^2$$

$$n \text{ tumpuan atas} = 5$$

$$n \text{ tumpuan tengah} = 2$$

$$n \text{ tumpuan bawah} = 4$$

$$n \text{ tumpuan vertikal} = 2 + \frac{n \text{ tengah}}{2} = 3$$

$$n \text{ lapangan atas} = 4$$

$$n \text{ lapangan tengah} = 2$$

$$n \text{ lapangan atas} = 4$$

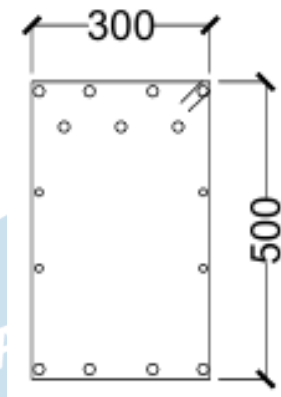
$$n \text{ tumpuan vertikal} = 2 + \frac{n \text{ tengah}}{2} = 3$$

Spasi horizontal tumpuan = 67 mm
 Spasi vertikal tumpuan = 201 mm
 Spasi horizontal lapangan = 67 mm
 Spasi vertikal lapangan = 201 mm
 Spasi tulangan longitudinal tumpuan = spasi $\geq$ 300 mm → **OK**
 Spasi tulangan longitudinal lapangan = spasi $\geq$ 300 mm → **OK**
 As + A1 pasang tumpuan = 2817,223 mm²
 As + A1 pasang lapangan = 2533,694 mm²
 Cek lentur + torsi tumpuan = As+A1 pasang $\geq$ As + A1 perlu → **OK**
 Cek lentur + torsi lapangan = As+A1 pasang $\geq$ As + A1 perlu → **OK**

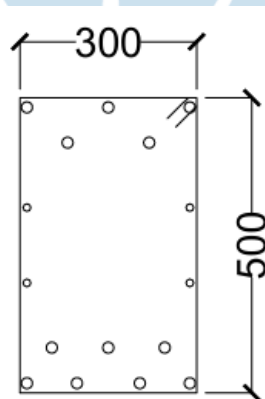
• **Rekap**

Tabel 2. 34 Rekap Balok Induk 2

Kesimpulan	
Syarat Gaya dan Geometri	OK
Kapasitas Lentur	OK
Kapasitas Geser	OK
Kapasitas Torsi	OK
Tulangan Longitudinal	
Longitudinal Tumpuan Atas	5 D19
Longitudinal Tumpuan Tengah	2 D13
Longitudinal Tumpuan Bawah	4 D19
Longitudinal Lapangan Atas	4 D19
Longitudinal Lapangan Tengah	2 D13
Longitudinal Lapangan Bawah	4 D19
Tulangan Transversal/Sengkang	
Sengkang Tumpuan	5D10-100
Sengkang Lapangan	6D10-150



Gambar 2. 53 Penulangan Tumpuan Balok Induk 2



Gambar 2. 54 Penulangan Lapangan Balok Induk 2

2.12.3 Balok Anak 1 Melintang

- **Desain Lentur**
- Data material dan penampang

Panjang balok (L)	= 5500 mm
Lebar balok (b)	= 200 mm
Tinggi balok (h)	= 400 mm
Panjang tumpuan	= 2 x h

$$\begin{aligned}
 &= 2 \times 400 \\
 &= 800 \text{ mm} \\
 db &= 19 \\
 dbt &= 13 \\
 ds &= 10 \\
 \text{selimut bersih (cc)} &= 30 \\
 \text{tinggi efektif balok} &= h - cc - ds - db/2 \\
 &= 400 - 30 - 10 - 19/2 \\
 &= 350,5 \text{ mm} \\
 f_c' &= 30 \text{ Mpa} \\
 f_y &= 420 \text{ Mpa} \\
 f_{yv} &= 280 \text{ Mpa} \\
 \beta_1 &= 0,8357 \\
 \text{Panjang kolom (c1)} &= 600 \text{ mm} \\
 \text{Lebar kolom (c2)} &= 600 \text{ mm} \\
 L_n &= L - c1 \\
 &= 5500 - 600 \\
 &= 4900 \text{ MM} \\
 \lambda &= 1
 \end{aligned}$$

- Gaya dalam

Tabel 2. 35 Gaya Dalam Balok Anak Melintang

Mu tumpuan (-)	-17,3404 kN/m
Mu tumpuan (+)	16,4552 kN/m
Mu lapangan (-)	-17,3316 kN/m
Mu lapangan (+)	16,5176 kN/m
Pu	6,8415 kN

- Syarat gaya dan geometri

$$\begin{aligned}\text{Syarat gaya aksial} &= P_u \leq 0,1 \times A_g \times f_c' \\ &= 6,8415 \leq 0,1 \times 200 \times 400 \times 30 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat tinggi efektif} &= L_n \geq 4d \\ &= 4900 \geq 4 \times 350,5 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 1} &= b \geq \min(0,3 \times h, 250 \text{ mm}) \\ &= 200 \geq \min(0,3 \times 400, 250 \text{ mm}) \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 2} &= b \leq c_2 + 2 \times \min(c_2, 0,75 c_i) \\ &= 200 \leq 600 + 2 \times \min(600, 0,75 c_i) \rightarrow \mathbf{OK}\end{aligned}$$

- Penulangan lentur

Tumpuan negatif

$$n = 4$$

$$d_b = 19 \text{ mm}$$

$$\begin{aligned}\text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\ &= \frac{(200 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{4-1} \\ &= 14,667 \text{ mm}\end{aligned}$$

$$\text{Jumlah lapis} = 2$$

$$\text{As pasang} = n \times \frac{\pi}{4} \times d_b^2$$

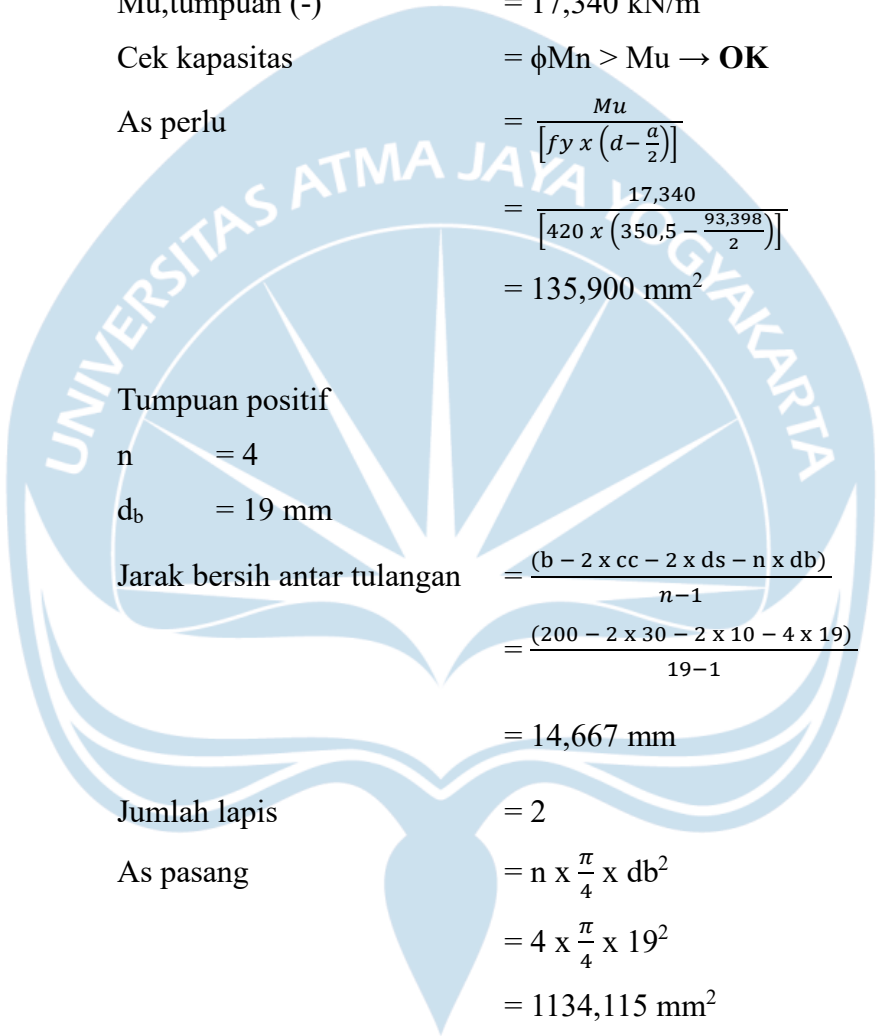
$$= 4 \times \frac{3,14}{4} \times 19^2$$

$$= 1134,115 \text{ mm}^2$$

$$\text{As minimum,1} = \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d$$

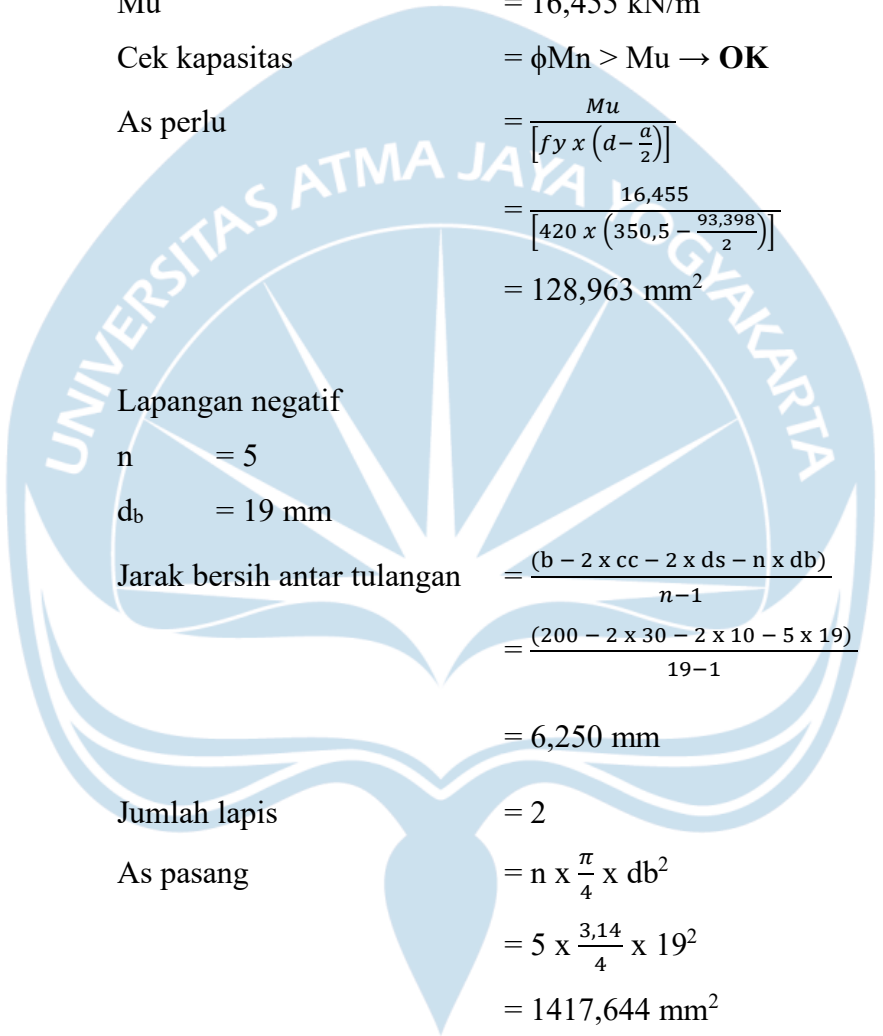
$$= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5$$

$$\begin{aligned}
 &= 228,544 \text{ mm}^2 \\
 \text{As minimum,2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 233,667 \text{ mm}^2 \\
 \text{Cek As min} &= \text{As pasang} \geq \text{As min} \rightarrow \mathbf{OK} \\
 \rho &= \frac{\text{As}}{b \times d} \\
 &= \frac{1134,115}{200 \times 350,5} \\
 &= 1,62 \% \\
 \rho \text{ maksimum,1} &= 2,24 \% \\
 \rho \text{ maksimum,2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{\text{As} \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 200} \\
 &= 93,398 \text{ mm} \\
 \text{Mn} &= \text{As} \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1134,115 \times 30 \times \left(350,5 - \frac{93,398}{2} \right) \\
 &= 144,709 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5-111,758}{111,758} \times 0,003 \\
 &= 0,006 \\
 \phi &= 0,900
 \end{aligned}$$



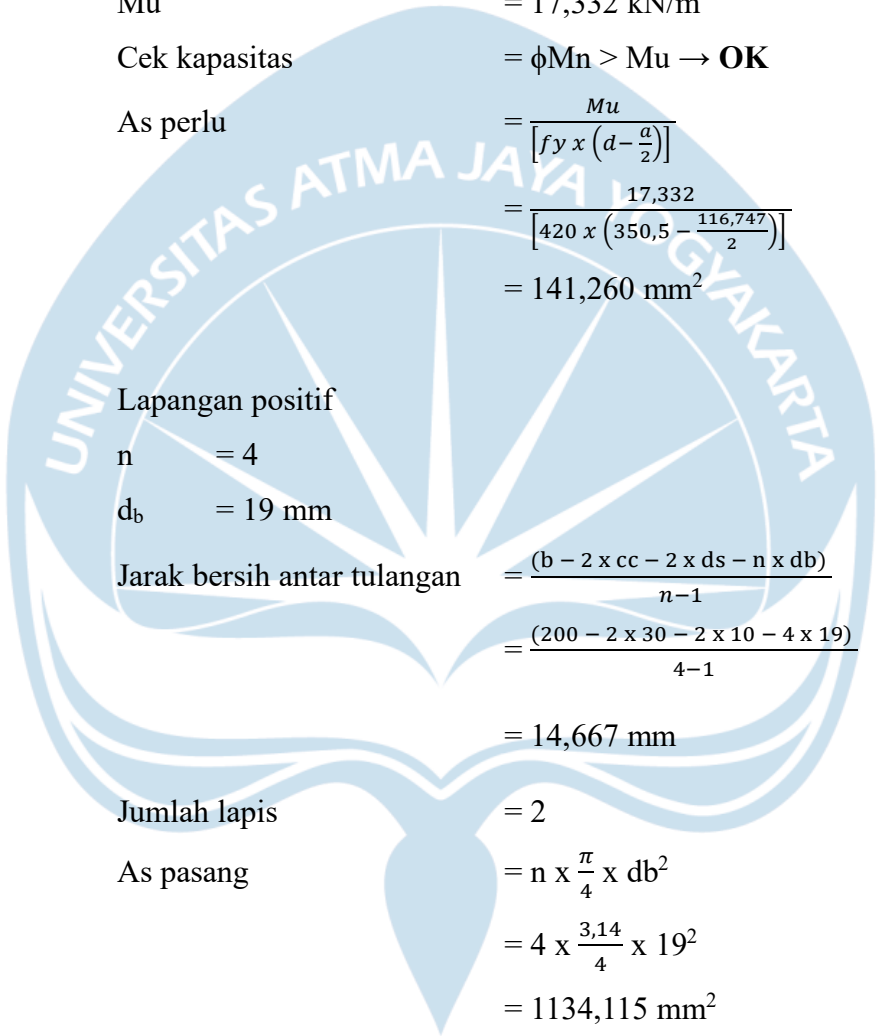
$$\begin{aligned}
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 144,709 \\
 &= 130,238 \text{ kN/m} \\
 M_{u,\text{tumpuan (-)}} &= 17,340 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{17,340}{\left[420 \times \left(350,5 - \frac{93,398}{2} \right) \right]} \\
 &= 135,900 \text{ mm}^2 \\
 \text{Tumpuan positif} \\
 n &= 4 \\
 d_b &= 19 \text{ mm} \\
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(200 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{19-1} \\
 &= 14,667 \text{ mm} \\
 \text{Jumlah lapis} &= 2 \\
 \text{As pasang} &= n \times \frac{\pi}{4} \times d_b^2 \\
 &= 4 \times \frac{\pi}{4} \times 19^2 \\
 &= 1134,115 \text{ mm}^2 \\
 \text{As minimum 1} &= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 258,544 \text{ mm}^2 \\
 \text{As minimum 2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d
 \end{aligned}$$

$$\begin{aligned}
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 223,667 \text{ mm}^2 \\
 \text{As minimum 4} &= 0,5 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,5 \times 1134,115 \\
 &= 567,057 \text{ mm}^2 \\
 \text{Cek As min} &= \text{As pasang} \geq \text{As min} \rightarrow \mathbf{OK} \\
 \rho &= \frac{\text{As}}{b \times d} \\
 &= \frac{1134,115}{200 \times 350,5} \\
 &= 1,62 \% \\
 \rho \text{ maksimum 1} &= 2,24 \% \\
 \rho \text{ maksimum 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{\text{As} \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 200} \\
 &= 93,398 \text{ mm} \\
 M_n &= \text{As} \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1134,115 \times 30 \times \left(350,5 - \frac{93,398}{2} \right) \\
 &= 144,709 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5 - 111,758}{111,758} \times 0,003 \\
 &= 0,006 \\
 \phi &= 0,900
 \end{aligned}$$

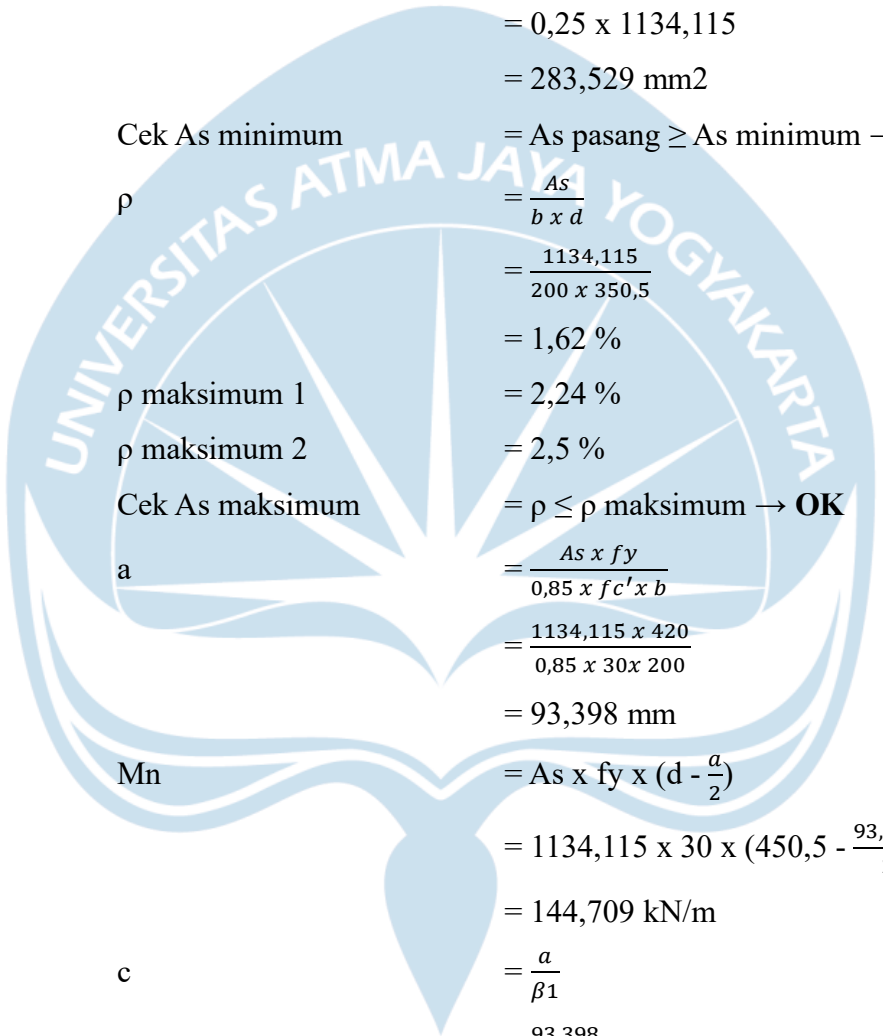


$$\begin{aligned}
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 144,709 \\
 &= 130,238 \text{ kN/m} \\
 M_u &= 16,455 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{16,455}{\left[420 \times \left(350,5 - \frac{93,398}{2} \right) \right]} \\
 &= 128,963 \text{ mm}^2 \\
 \text{Lapangan negatif} \\
 n &= 5 \\
 d_b &= 19 \text{ mm} \\
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(200 - 2 \times 30 - 2 \times 10 - 5 \times 19)}{19-1} \\
 &= 6,250 \text{ mm} \\
 \text{Jumlah lapis} &= 2 \\
 \text{As pasang} &= n \times \frac{\pi}{4} \times d_b^2 \\
 &= 5 \times \frac{3,14}{4} \times 19^2 \\
 &= 1417,644 \text{ mm}^2 \\
 \text{As minimum 1} &= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 228,544 \text{ mm}^2 \\
 \text{As minimum 2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d
 \end{aligned}$$

$$\begin{aligned}
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 233,667 \text{ mm}^2 \\
 \text{As minimum 4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1134,115 \\
 &= 283,529 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1417,644}{200 \times 350,5} \\
 &= 2,02 \% \\
 \rho \text{ maksimum 1} &= 2,24 \% \\
 \rho \text{ maksimum 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1417,644 \times 420}{0,85 \times 30 \times 200} \\
 &= 116,747 \text{ mm} \\
 M_n &= As \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1417,644 \times 30 \times \left(350,5 - \frac{116,747}{2} \right) \\
 &= 173,935 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{116,747}{0,8357} \\
 &= 139,697 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5 - 139,697}{139,697} \times 0,003 \\
 &= 0,005 \\
 \phi &= 0,861
 \end{aligned}$$



$$\begin{aligned}
 \phi M_n &= \phi \times M_n \\
 &= 0,861 \times 173,935 \\
 &= 149,685 \text{ kN/m} \\
 M_u &= 17,332 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{17,332}{\left[420 \times \left(350,5 - \frac{116,747}{2} \right) \right]} \\
 &= 141,260 \text{ mm}^2 \\
 \text{Lapangan positif} \\
 n &= 4 \\
 d_b &= 19 \text{ mm} \\
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(200 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{4-1} \\
 &= 14,667 \text{ mm} \\
 \text{Jumlah lapis} &= 2 \\
 \text{As pasang} &= n \times \frac{\pi}{4} \times d_b^2 \\
 &= 4 \times \frac{3,14}{4} \times 19^2 \\
 &= 1134,115 \text{ mm}^2 \\
 \text{As minimum 1} &= \left(\frac{0,5 \sqrt{f_c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 228,544 \text{ mm}^2 \\
 \text{As minimum 2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d
 \end{aligned}$$



$$\begin{aligned}
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 233,667 \text{ mm}^2 \\
 \text{As minimum 4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1134,115 \\
 &= 283,529 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1134,115}{200 \times 350,5} \\
 &= 1,62 \% \\
 \rho \text{ maksimum 1} &= 2,24 \% \\
 \rho \text{ maksimum 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f_c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 200} \\
 &= 93,398 \text{ mm} \\
 Mn &= As \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1134,115 \times 30 \times \left(450,5 - \frac{93,398}{2} \right) \\
 &= 144,709 \text{ kN/m} \\
 c &= \frac{a}{\beta_1} \\
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5 - 111,758}{111,758} \times 0,003 \\
 &= 0,006 \\
 \phi &= 0,900
 \end{aligned}$$

$$\begin{aligned}
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 144,709 \\
 &= 130,238 \text{ kN/m} \\
 M_u &= 16,518 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{16,518}{\left[420 \times \left(350,5 - \frac{93,398}{2} \right) \right]} \\
 &= 129,452 \text{ mm}^2
 \end{aligned}$$

- **Desain Geser**

- Data material dan penampang

Panjang balok (L) = 5500 mm

Lebar balok (b) = 200 mm

Tinggi balok (h) = 400 mm

Panjang tumpuan = 2 x h
 = 2 x 400
 = 800 mm

db = 19

dbt = 13

ds = 10

selimut bersih (cc) = 30

tinggi efektif balok = h - cc - ds - db/2
 = 400 - 30 - 10 - 19/2
 = 350,5 mm

fc' = 30 Mpa

fy = 420 Mpa

fyv = 280 Mpa

$$\begin{aligned}\beta_1 &= 0,8357 \\ \text{Panjang kolom (c1)} &= 600 \text{ mm} \\ \text{Lebar kolom (c2)} &= 600 \text{ mm} \\ L_n &= L - c1 \\ &= 5500 - 600 \\ &= 4900 \text{ mm}\end{aligned}$$

- Gaya dalam

Tabel 2. 36 Gaya Dalam Balok Anak Melintang

Vu,tumpuan	16,6905 kN
Vu,lapangan	18,6934 kN

- Tumpuan

Gaya desain

$$\begin{aligned}V_{g,tumpuan} &= 13,5889 \text{ kN} \\ A_s + \text{tumpuan} &= 1134,115 \text{ mm}^2 \\ A_s - \text{tumpuan} &= 1134,115 \text{ mm}^2 \\ A_{pr+} &= 116,747 \text{ mm} \\ A_{pr-} &= 116,747 \text{ mm} \\ M_{pr+} &= 173935103 \text{ N/mm} \\ M_{pr-} &= 173935103 \text{ N/mm} \\ V_{\text{sway}} / V_{pr} &= 70994 \text{ N} \\ V_e &= 84583 \text{ N}\end{aligned}$$

Tahanan geser beton

$$\begin{aligned}V_{pr} &= 70994 \text{ N} \\ \frac{1}{2} V_e &= 42291 \text{ N} \\ P_u &= 6841,5 \text{ N}\end{aligned}$$

$$\frac{A_g f_c'}{20} = 1200 \text{ N}$$

Penulangan geser

$$n = 4$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 4 \times \frac{3,14}{4} \times 10^2 \\ &= 314,159 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 50 \text{ mm}$$

$$\text{Spasi maksimum 1} = \frac{d}{4} = \frac{350,5}{4} = 87,63 \text{ mm}$$

$$\begin{aligned} \text{Spasi maksimum 2} &= 6 \times d_b \\ &= 6 \times 19 \\ &= 114 \text{ mm} \end{aligned}$$

$$\text{Spasi maksimum 3} = 150 \text{ mm}$$

Cek spasi → **OK**

$$\begin{aligned} V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 314,159 \times 280 \times \frac{350,5}{100} \\ &= 616632 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 200 \times 350,5 \\ &= 253409 \text{ N} \end{aligned}$$

$$\phi = 0,75$$

$$\begin{aligned} V_n &= V_c + V_s \\ &= 0 + 253409 \\ &= 253409 \text{ N} \end{aligned}$$

$$V_u = 84583 \text{ N}$$

$$\begin{aligned}\phi V_n/V_u &= 0,75 \times \frac{253409}{84583} \\ &= 2,247\end{aligned}$$

$$\text{Cek kapasitas} = \phi V_n/V_u \geq 1 \rightarrow \mathbf{OK}$$

- Lapangan

Penulangan geser

$$n = 2$$

$$\begin{aligned}A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 2 \times \frac{3,14}{4} \times 10^2 \\ &= 157,080 \text{ mm}^2\end{aligned}$$

$$\text{Spasi} = 100 \text{ mm}$$

$$\text{Spasi maksimum} = \frac{d}{2} = \frac{350,5}{2} = 172,25 \text{ mm}$$

$$\text{Cek spasi} \rightarrow \mathbf{OK}$$

$$\begin{aligned}V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 157,080 \times 280 \times \frac{350,5}{150} \\ &= 154158 \text{ N}\end{aligned}$$

$$\begin{aligned}\text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 200 \times 350,5 \\ &= 253409 \text{ N}\end{aligned}$$

$$\begin{aligned}V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\ &= 0,17 \times 30^{0,5} \times 200 \times 350,5 \\ &= 65272 \text{ N}\end{aligned}$$

$$\phi = 0,75$$

$$V_n = 219430$$

$$V_u = 18693,4 \text{ N}$$

$$\begin{aligned}\phi V_n/V_u &= 0,75 \times \frac{219430}{18693,4} \\ &= 8,804\end{aligned}$$

Cek kapasitas $= \phi V_n / V_u \geq 1 \rightarrow \mathbf{OK}$

- **Desain Torsi**

- Data materail dan penampang

Panjang balok (L) = 5500 mm

Lebar balok (b) = 200 mm

Tinggi balok (h) = 400 mm

Panjang tumpuan = 2 x h

= 2 x 400

= 800 mm

db = 19

dbt = 13

ds = 10

selimut bersih (cc) = 30

tinggi efektif balok = $h - cc - ds - db/2$

= $400 - 30 - 10 - 19/2$

= 350,5 mm

fc' = 30 Mpa

fy = 420 Mpa

fyv = 280 Mpa

$\beta_1 = 0,8357$

Panjang kolom (c1) = 600 mm

Lebar kolom (c2) = 600 mm

Ln = L - c1

= 5500 - 600

= 4900 mm

- Parameter geometri penampang untuk perhitungan torsi

Acp = b x h

= 200 x 400

$$\begin{aligned}
 &= 80000 \text{ mm}^2 \\
 P_{cp} &= 2 \times (b + h) \\
 &= 2 \times (200 + 400) \\
 &= 1200 \text{ mm} \\
 X_0 &= b - 2 C_c - d_s \\
 &= 200 - 2 \times 30 - 10 \\
 &= 130 \text{ mm} \\
 Y_0 &= h - 2 c_c - d_s \\
 &= 400 - 2 \times 30 - 10 \\
 &= 330 \text{ mm} \\
 A_{oh} &= X_0 \times Y_0 \\
 &= 130 \times 330 \\
 &= 42900 \text{ mm}^2 \\
 A_0 &= 0,85 \times A_{oh} \\
 &= 36465 \text{ mm}^2 \\
 Ph &= 2 \times (X_0 + Y_0) \\
 &= 920 \text{ mm}
 \end{aligned}$$

- Gaya dalam

Tabel 2. 37 Gaya Dalam Balok Anak Melintang

Tu	4,7049 kN/m
----	-------------

- Pengecekan kebutuhan tulangan torsi

$$\begin{aligned}
 T_{cr} &= 0,33 \times f_c'^{0,5} \times \frac{A_{cp}^2}{P_{cp}} \\
 &= 0,33 \times 30^{0,5} \times \frac{80000^2}{1200} \\
 &= 9639917 \text{ N/mm} \\
 \phi &= 0,75
 \end{aligned}$$

$$\frac{\phi T_{cr}}{4} = \frac{0,75 \times 9639917}{4} = 1807484 \text{ N/mm}$$

$$\text{Syarat } T_u > \frac{\phi T_{cr}}{4} \rightarrow \text{MEMERLUKAN TULANGAN TORSI}$$

- Pengecekan kecukupan dimensi penampang

$$T_u \text{ pakai} = 4704900 \text{ N/mm}$$

$$V_u = 84583 \text{ N}$$

$$\begin{aligned} V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\ &= 0,17 \times 30^{0,5} \times 200 \times 350,5 \\ &= 65272 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Tegangan ultimate geser + torsi} &= \left\{ \left(\frac{V_u}{b \times d} \right)^2 + \left(\frac{T_u \times P_h}{1,7 \times A_o h^2} \right)^2 \right\}^{0,5} \\ &= \left\{ \left(\frac{84583}{200 \times 350,5} \right)^2 + \left(\frac{4704900 \times 920}{1,7 \times 42900^2} \right)^2 \right\}^{0,5} \\ &= 1,836 \text{ Mpa} \end{aligned}$$

$$\begin{aligned} \text{Kapasitas tegangan beton} &= \phi \times \left\{ \left(\frac{V_u}{b \times d} \right) + 0,66 \times (f_c')^{0,5} \right\} \\ &= 0,75 \times \left\{ \left(\frac{84583}{350 \times 550,5} \right) + 0,66 \times (30)^{0,5} \right\} \\ &= 3,410 \text{ Mpa} \end{aligned}$$

$$\text{Cek dimensi penampang} = \text{luas kiri} \leq \text{luas kanan} \rightarrow \text{OK}$$

- Penulangan transversal torsi

$$n \text{ kaki tumpuan} = 4$$

$$n \text{ kaki lapangan} = 2$$

$$s \text{ tumpuan} = 50 \text{ mm}$$

$$s \text{ lapangan} = 100 \text{ mm}$$

$$s \text{ maksimum 1} = \frac{P_h}{8} = \frac{920}{8} = 115 \text{ mm}$$

$$s \text{ maksimum 2} = 300 \text{ mm}$$

$$\text{Cek spasi tumpuan} = s \text{ tumpuan} \geq s \text{ max} \rightarrow \text{OK}$$

$$\text{Cek spasi lapangan} = s \text{ lapangan} \geq s \text{ max} \rightarrow \text{OK}$$

$$\begin{aligned}\frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 4 \times \frac{3,14}{4} \times \frac{10^2}{100} \\ &= 6,283 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 2 \times \frac{3,14}{4} \times \frac{10^2}{100} \\ &= 1,571 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{At}{s} &= \frac{Tu}{(2 \times \phi \times A_o \times f_{yv})} \\ &= \frac{4704900}{(2 \times 0,75 \times 36465 \times 280)} \\ &= 0,307 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{Av}{s \text{ tumpuan perlu}} &= \frac{\left(\frac{Vu \text{ tumpuan}}{\phi - V_c}\right)}{f_{yv} \times d} \\ &= 1,149 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{Av}{s \text{ lapangan perlu}} &= \frac{\left(\frac{Vu \text{ lapangan}}{\phi - V_c}\right)}{f_{yv} \times d} \\ &= -0,411 \text{ mm}^2/\text{mm}\end{aligned}$$

$$\begin{aligned}\frac{Av+s}{s \text{ tumpuan perlu}} &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times 0,307 + 1,149 \\ &= 1,764\end{aligned}$$

$$\begin{aligned}\frac{Av+s}{s \text{ tumpuan perlu}} &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times 0,307 + (-0,411) \\ &= 0,203\end{aligned}$$

$$\begin{aligned}\frac{Av+t}{s \text{ min } 1} &= 0,062 \times f_c'^{0,5} \times \frac{b}{f_{yv}} \\ &= 0,062 \times 30^{0,5} \times \frac{200}{280} \\ &= 0,243\end{aligned}$$

$$\begin{aligned}
 \frac{Av+t}{s \text{ min } 2} &= \frac{0,35 \times b}{fyv} \\
 &= \frac{0,35 \times 200}{280} \\
 &= 0,250
 \end{aligned}$$

$$\text{Cek geser + torsi tumpuan} = \frac{Av+t}{s \text{ pasang}} \geq \frac{Av+t}{s \text{ perlu}} \rightarrow \mathbf{OK}$$

$$\text{Cek geser + torsi lapangan} = \frac{Av+t}{s \text{ pasang}} \geq \frac{Av+t}{s \text{ perlu}} \rightarrow \mathbf{OK}$$

- Penulangan longitudinal torsi

$$\text{db atau dbt} = 13 \text{ mm}$$

$$\text{db, minimum} = 0,042 \times s = 4,2 \text{ mm}$$

$$\text{Cek db} = \text{db} \geq \text{db min} \rightarrow \mathbf{OK}$$

$$\text{Kebutuhan As tumpuan atas} = 135,900 \text{ mm}^2$$

$$\text{Kebutuhan As tumpuan bawah} = 128,963 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan atas} = 141,260 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan bawah} = 129,452 \text{ mm}^2$$

$$\begin{aligned}
 A_1 &= \frac{At}{s} \times Ph \\
 &= 0,540 \times 1320 \\
 &= 282,626 \text{ mm}^2
 \end{aligned}$$

$$\begin{aligned}
 A_1 \text{ min} &= \frac{0,42 \times f_{cr}^{0,5} \times A_{cp}}{fy - \frac{At}{s} \times ph} \\
 &= \frac{0,42 \times 30^{0,5} \times 80000}{30 - 0,540 \times 1320} \\
 &= 155,552 \text{ mm}^2
 \end{aligned}$$

$$\text{As + A1 perlu tumpuan} = 547,489 \text{ mm}^2$$

$$\text{As + A1 perlu lapangan} = 553,338 \text{ mm}^2$$

$$\text{n tumpuan atas} = 4$$

$$\text{n tumpuan tengah} = 4$$

$$\text{n tumpuan bawah} = 4$$

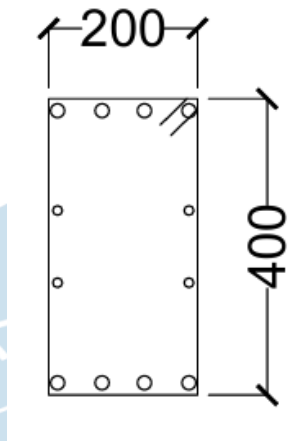
$$\text{n tumpuan vertikal} = 2 + \frac{n \text{ tengah}}{2} = 4$$

$$\begin{aligned}
 n \text{ lapangan atas} &= 5 \\
 n \text{ lapangan tengah} &= 4 \\
 n \text{ lapangan atas} &= 4 \\
 n \text{ tumpuan vertikal} &= 2 + \frac{n \text{ tengah}}{2} = 4 \\
 \text{Spasi horizontal tumpuan} &= 34 \text{ mm} \\
 \text{Spasi vertikal tumpuan} &= 100 \text{ mm} \\
 \text{Spasi horizontal lapangan} &= 34 \text{ mm} \\
 \text{Spasi vertikal lapangan} &= 100 \text{ mm} \\
 \text{Spasi tulangan longitudinal tumpuan} &= \text{spasi} \geq 300 \text{ mm} \rightarrow \mathbf{OK} \\
 \text{Spasi tulangan longitudinal lapangan} &= \text{spasi} \geq 300 \text{ mm} \rightarrow \mathbf{OK} \\
 \text{As} + \text{A1 pasang tumpuan} &= 2799,159 \text{ mm}^2 \\
 \text{As} + \text{A1 pasang lapangan} &= 3082,688 \text{ mm}^2 \\
 \text{Cek lentur} + \text{torsi tumpuan} &= \text{As} + \text{A1 pasang} \geq \text{As} + \text{A1 perlu} \rightarrow \mathbf{OK} \\
 \text{Cek lentur} + \text{torsi lapangan} &= \text{As} + \text{A1 pasang} \geq \text{As} + \text{A1 perlu} \rightarrow \mathbf{OK}
 \end{aligned}$$

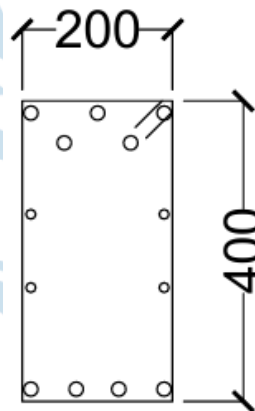
• **Rekap**

Tabel 2. 38 Rekap Balok Anak Melintang

Kesimpulan	
Syarat Gaya dan Geometri	OK
Kapasitas Lentur	OK
Kapasitas Geser	OK
Kapasitas Torsi	OK
Tulangan Longitudinal	
Longitudinal Tumpuan Atas	4 D19
Longitudinal Tumpuan Tengah	4 D13
Longitudinal Tumpuan Bawah	4 D19
Longitudinal Lapangan Atas	5 D19
Longitudinal Lapangan Tengah	4 D13
Longitudinal Lapangan Bawah	4 D19
Tulangan Transversal/Sengkang	
Sengkang Tumpuan	4D10-50
Sengkang Lapangan	2D10-100



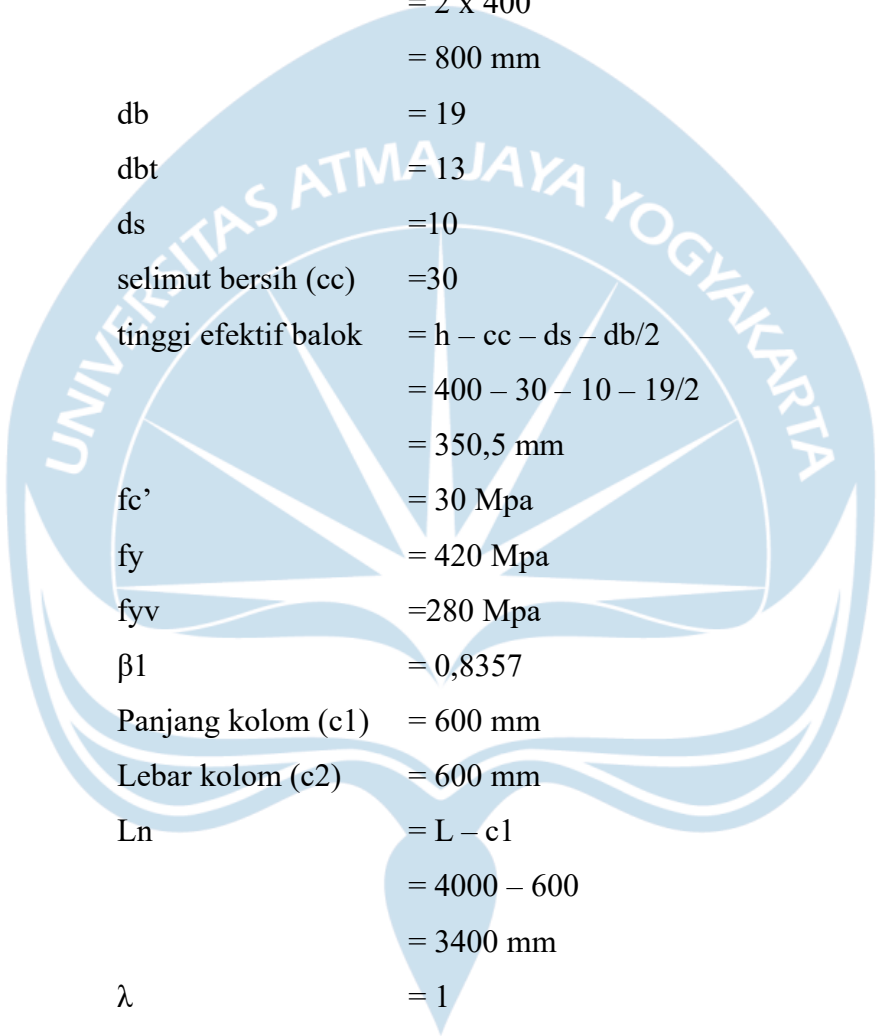
Gambar 2. 55 Penulangan Tumpuan Balok Anak 1 Melintang



Gambar 2. 56 Penulangan Lapangan Balok Anak 1 Melintang

2.12.4 Balok Anak 1 Memanjang

- **Desain Lentur**
- Data material dan penampang
 Panjang balok (L) = 4000 mm



Lebar balok (b)	= 200 mm
Tinggi balok (h)	= 400 mm
Panjang tumpuan	= 2 x h
	= 2 x 400
	= 800 mm
db	= 19
dbt	= 13
ds	= 10
selimut bersih (cc)	= 30
tinggi efektif balok	= $h - cc - ds - db/2$
	= $400 - 30 - 10 - 19/2$
	= 350,5 mm
fc'	= 30 Mpa
fy	= 420 Mpa
fyv	= 280 Mpa
β_1	= 0,8357
Panjang kolom (c1)	= 600 mm
Lebar kolom (c2)	= 600 mm
Ln	= L - c1
	= 4000 - 600
	= 3400 mm
λ	= 1

- Gaya dalam

Tabel 2. 39 Gaya Dalam Balok Anak Memanjang

Mu tumpuan (-)	-17,3404 kN/m
Mu tumpuan (+)	16,5176 kN/m
Mu lapangan (-)	-9,3534 kN/m
Mu lapangan (+)	13,8592 kN/m
Pu	6,8415 kN

- Syarat gaya dan geometri

$$\begin{aligned}\text{Syarat gaya aksial} &= Pu \leq 0,1 \times Ag \times f_c' \\ &= 6,8415 \leq 0,1 \times 200 \times 400 \times 30 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat tinggi efektif} &= L_n \geq 4d \\ &= 3400 \geq 4 \times 350,5 \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 1} &= b \geq \min (0,3 \times h, 250 \text{ mm}) \\ &= 200 \geq \min (0,3 \times 400, 250 \text{ mm}) \rightarrow \mathbf{OK}\end{aligned}$$

$$\begin{aligned}\text{Syarat lebar 2} &= b \leq c_2 + 2 \times \min (c_2, 0,75 c_i) \\ &= 200 \leq 600 + 2 \times \min (600, 0,75 c_i) \rightarrow \mathbf{OK}\end{aligned}$$

- Penulangan lentur

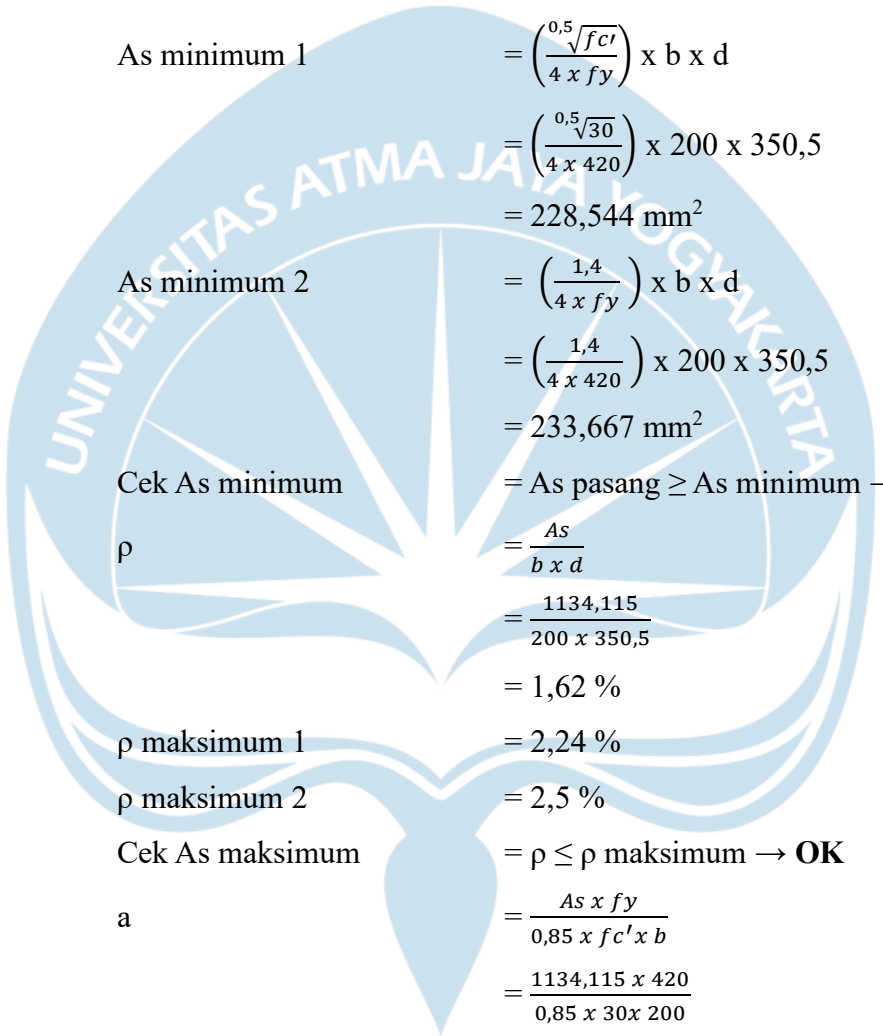
Tumpuan negatif

$$n = 4$$

$$d_b = 19 \text{ mm}$$

$$\begin{aligned}\text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\ &= \frac{(200 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{4-1} \\ &= 14,667 \text{ mm}\end{aligned}$$

$$\text{Jumlah lapis} = 2$$



As pasang $= n \times \frac{\pi}{4} \times db^2$

$$= 4 \times \frac{3,14}{4} \times 19^2$$

$$= 1134,115 \text{ mm}^2$$

As minimum 1 $= \left(\frac{0,5 \sqrt{f'c'}}{4 \times f_y} \right) \times b \times d$

$$= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5$$

$$= 228,544 \text{ mm}^2$$

As minimum 2 $= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d$

$$= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5$$

$$= 233,667 \text{ mm}^2$$

Cek As minimum $= \text{As pasang} \geq \text{As minimum} \rightarrow \text{OK}$

$\rho = \frac{As}{b \times d}$

$$= \frac{1134,115}{200 \times 350,5}$$

$$= 1,62 \%$$

ρ maksimum 1 $= 2,24 \%$

ρ maksimum 2 $= 2,5 \%$

Cek As maksimum $= \rho \leq \rho \text{ maksimum} \rightarrow \text{OK}$

$a = \frac{As \times f_y}{0,85 \times f'c' \times b}$

$$= \frac{1134,115 \times 420}{0,85 \times 30 \times 200}$$

$$= 93,398 \text{ mm}$$

Mn $= As \times f_y \times \left(d - \frac{a}{2} \right)$

$$= 1134,115 \times 30 \times \left(350,5 - \frac{93,398}{2} \right)$$

$$= 144,709 \text{ kN/m}$$

c $= \frac{a}{\beta_1}$

$$\begin{aligned}
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \varepsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5-111,758}{111,758} \times 0,003 \\
 &= 0,006 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 144,709 \\
 &= 130,238 \text{ kN/m} \\
 M_{u,\text{tumpuan (-)}} &= 17,340 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{17,340}{\left[420 \times \left(350,5 - \frac{93,398}{2} \right) \right]} \\
 &= 135,900 \text{ mm}^2
 \end{aligned}$$

Tumpuan positif

$$n = 4$$

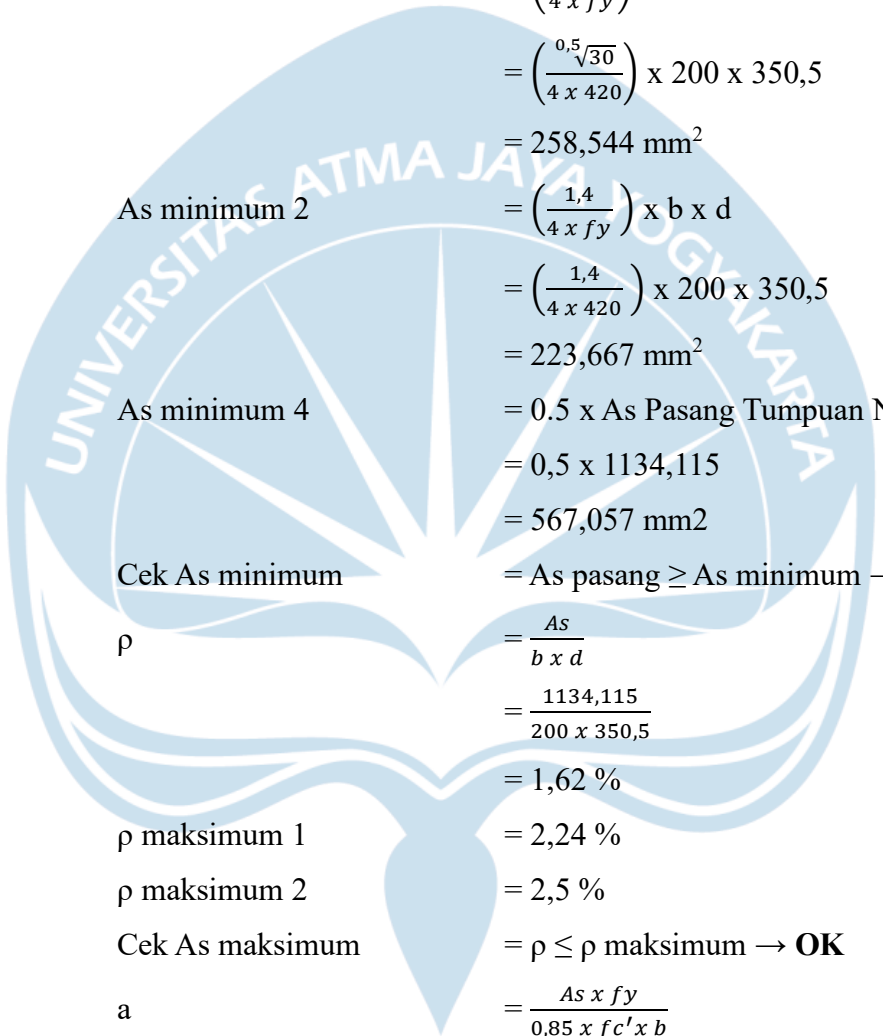
$$d_b = 19 \text{ mm}$$

$$\begin{aligned}
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(200 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{19-1}
 \end{aligned}$$

$$= 14,667 \text{ mm}$$

$$\text{Jumlah lapis} = 2$$

$$\text{As pasang} = n \times \frac{\pi}{4} \times d_b^2$$



$$\begin{aligned}
 &= 4 \times \frac{\pi}{4} \times 19^2 \\
 &= 1134,115 \text{ mm}^2 \\
 \text{As minimum 1} &= \left(\frac{0,5 \sqrt{f'c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 258,544 \text{ mm}^2 \\
 \text{As minimum 2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 223,667 \text{ mm}^2 \\
 \text{As minimum 4} &= 0,5 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,5 \times 1134,115 \\
 &= 567,057 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1134,115}{200 \times 350,5} \\
 &= 1,62 \% \\
 \rho \text{ maksimum 1} &= 2,24 \% \\
 \rho \text{ maksimum 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f'c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 200} \\
 &= 93,398 \text{ mm} \\
 Mn &= As \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1134,115 \times 420 \times \left(350,5 - \frac{93,398}{2} \right) \\
 &= 144,709 \text{ kN/m}
 \end{aligned}$$

$$\begin{aligned}
 c &= \frac{a}{\beta_1} \\
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5-111,758}{111,758} \times 0,003 \\
 &= 0,006 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 144,709 \\
 &= 130,238 \text{ kN/m} \\
 M_u &= 16,518 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{16,518}{\left[420 \times \left(350,5 - \frac{93,398}{2} \right) \right]} \\
 &= 129,452 \text{ mm}^2
 \end{aligned}$$

Lapangan negatif

$$n = 5$$

$$d_b = 19 \text{ mm}$$

$$\begin{aligned}
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(200 - 2 \times 30 - 2 \times 10 - 5 \times 19)}{19-1} \\
 &= 6,250 \text{ mm}
 \end{aligned}$$

$$\text{Jumlah lapis} = 2$$

$$\text{As pasang} = n \times \frac{\pi}{4} \times d_b^2$$

$$\begin{aligned}
 &= 5 \times \frac{3,14}{4} \times 19^2 \\
 &= 1417,644 \text{ mm}^2 \\
 \text{As minimum 1} &= \left(\frac{0,5 \sqrt{f'c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 228,544 \text{ mm}^2 \\
 \text{As minimum 2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 233,667 \text{ mm}^2 \\
 \text{As minimum 4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1134,115 \\
 &= 283,529 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1417,644}{200 \times 350,5} \\
 &= 2,02 \% \\
 \rho \text{ maksimum 1} &= 2,24 \% \\
 \rho \text{ maksimum 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f'c' \times b} \\
 &= \frac{1417,644 \times 420}{0,85 \times 30 \times 200} \\
 &= 116,747 \text{ mm} \\
 M_n &= As \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1417,644 \times 30 \times \left(350,5 - \frac{116,747}{2} \right) \\
 &= 173,935 \text{ kN/m}
 \end{aligned}$$

$$\begin{aligned}
 c &= \frac{a}{\beta_1} \\
 &= \frac{116,747}{0,8357} \\
 &= 139,697 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5-139,697}{139,697} \times 0,003 \\
 &= 0,005 \\
 \phi &= 0,861 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,861 \times 173,935 \\
 &= 149,685 \text{ kN/m} \\
 M_u &= 9,353 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{9,353}{\left[420 \times \left(350,5 - \frac{116,747}{2} \right) \right]} \\
 &= 76,234 \text{ mm}^2
 \end{aligned}$$

Lapangan positif

$$n = 4$$

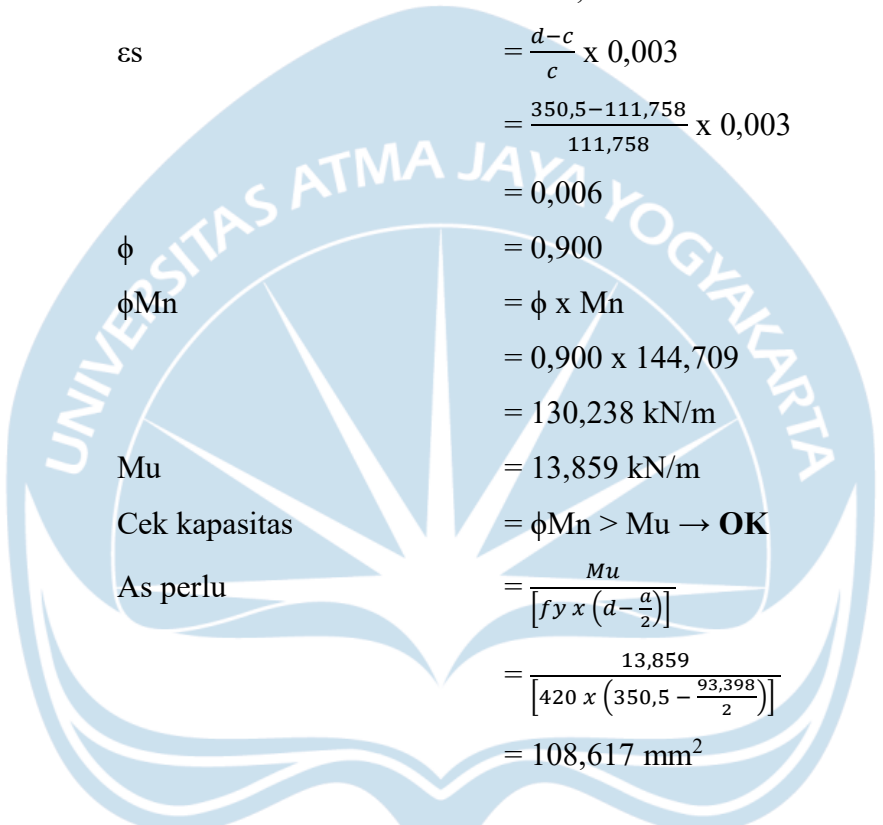
$$d_b = 19 \text{ mm}$$

$$\begin{aligned}
 \text{Jarak bersih antar tulangan} &= \frac{(b - 2 \times c_c - 2 \times d_s - n \times d_b)}{n-1} \\
 &= \frac{(200 - 2 \times 30 - 2 \times 10 - 4 \times 19)}{4-1} \\
 &= 14,667 \text{ mm}
 \end{aligned}$$

$$\text{Jumlah lapis} = 2$$

$$\text{As pasang} = n \times \frac{\pi}{4} \times d_b^2$$

$$\begin{aligned}
 &= 4 \times \frac{3,14}{4} \times 19^2 \\
 &= 1134,115 \text{ mm}^2 \\
 \text{As minimum 1} &= \left(\frac{0,5 \sqrt{f'c'}}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{0,5 \sqrt{30}}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 228,544 \text{ mm}^2 \\
 \text{As minimum 2} &= \left(\frac{1,4}{4 \times f_y} \right) \times b \times d \\
 &= \left(\frac{1,4}{4 \times 420} \right) \times 200 \times 350,5 \\
 &= 233,667 \text{ mm}^2 \\
 \text{As minimum 4} &= 0,25 \times \text{As Pasang Tumpuan Negatif} \\
 &= 0,25 \times 1134,115 \\
 &= 283,529 \text{ mm}^2 \\
 \text{Cek As minimum} &= \text{As pasang} \geq \text{As minimum} \rightarrow \mathbf{OK} \\
 \rho &= \frac{As}{b \times d} \\
 &= \frac{1134,115}{200 \times 350,5} \\
 &= 1,62 \% \\
 \rho \text{ maksimum 1} &= 2,24 \% \\
 \rho \text{ maksimum 2} &= 2,5 \% \\
 \text{Cek As maksimum} &= \rho \leq \rho \text{ maksimum} \rightarrow \mathbf{OK} \\
 a &= \frac{As \times f_y}{0,85 \times f'c' \times b} \\
 &= \frac{1134,115 \times 420}{0,85 \times 30 \times 200} \\
 &= 93,398 \text{ mm} \\
 M_n &= As \times f_y \times \left(d - \frac{a}{2} \right) \\
 &= 1134,115 \times 30 \times \left(450,5 - \frac{93,398}{2} \right) \\
 &= 144,709 \text{ kN/m}
 \end{aligned}$$



$$\begin{aligned}
 c &= \frac{a}{\beta_1} \\
 &= \frac{93,398}{0,8357} \\
 &= 111,758 \text{ mm} \\
 \epsilon_s &= \frac{d-c}{c} \times 0,003 \\
 &= \frac{350,5-111,758}{111,758} \times 0,003 \\
 &= 0,006 \\
 \phi &= 0,900 \\
 \phi M_n &= \phi \times M_n \\
 &= 0,900 \times 144,709 \\
 &= 130,238 \text{ kN/m} \\
 M_u &= 13,859 \text{ kN/m} \\
 \text{Cek kapasitas} &= \phi M_n > M_u \rightarrow \mathbf{OK} \\
 \text{As perlu} &= \frac{M_u}{\left[f_y \times \left(d - \frac{a}{2} \right) \right]} \\
 &= \frac{13,859}{\left[420 \times \left(350,5 - \frac{93,398}{2} \right) \right]} \\
 &= 108,617 \text{ mm}^2
 \end{aligned}$$

- **Desain Geser**
- Data material dan penampang

Panjang balok (L)	= 4000 mm
Lebar balok (b)	= 200 mm
Tinggi balok (h)	= 400 mm
Panjang tumpuan	= 2 x h
	= 2 x 400
	= 800 mm
db	= 19
dbt	= 13

$$\begin{aligned}
 d_s &= 10 \\
 \text{selimut bersih (cc)} &= 30 \\
 \text{tinggi efektif balok} &= h - cc - d_s - db/2 \\
 &= 400 - 30 - 10 - 19/2 \\
 &= 350,5 \text{ mm} \\
 f_c' &= 30 \text{ Mpa} \\
 f_y &= 420 \text{ Mpa} \\
 f_{yv} &= 280 \text{ Mpa} \\
 \beta_1 &= 0,8357 \\
 \text{Panjang kolom (c1)} &= 600 \text{ mm} \\
 \text{Lebar kolom (c2)} &= 600 \text{ mm} \\
 L_n &= L - c1 \\
 &= 4000 - 600 \\
 &= 3400 \text{ mm}
 \end{aligned}$$

- Gaya dalam

Tabel 2. 40 Gaya Dalam Balok Anak Memanjang

Vu,tumpuan	18,2099 kN
Vu,lapangan	18,6934 kN

- Tumpuan

Gaya desain

$$V_{g,\text{tumpuan}} = 13,5889 \text{ kN}$$

$$A_s + \text{tumpuan} = 1134,115 \text{ mm}^2$$

$$A_s - \text{tumpuan} = 1134,115 \text{ mm}^2$$

$$A_{pr} + = 116,747 \text{ mm}$$

$$A_{pr} - = 116,747 \text{ mm}$$

$$M_{pr} + = 173935103 \text{ N/mm}$$

$$M_{pr} - = 173935103 \text{ N/mm}$$

$$V_{\text{sway}} / V_{\text{pr}} = 102315 \text{ N}$$

$$V_e = 115904 \text{ N}$$

Tahanan geser beton

$$V_{\text{pr}} = 102315 \text{ N}$$

$$\frac{1}{2} V_e = 57952 \text{ N}$$

$$P_u = 6841,5 \text{ N}$$

$$\frac{A_g f_c'}{20} = 1200 \text{ N}$$

Penulangan geser

$$n = 4$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 4 \times \frac{3,14}{4} \times 10^2 \\ &= 314,159 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 50 \text{ mm}$$

$$\text{Spasi maksimum 1} = \frac{d}{4} = \frac{350,5}{4} = 87,63 \text{ mm}$$

$$\begin{aligned} \text{Spasi maksimum 2} &= 6 \times d_b \\ &= 6 \times 19 \\ &= 114 \text{ mm} \end{aligned}$$

$$\text{Spasi maksimum 3} = 150 \text{ mm}$$

Cek spasi → **OK**

$$\begin{aligned} V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 314,159 \times 280 \times \frac{350,5}{100} \\ &= 616632 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 200 \times 350,5 \\ &= 253409 \text{ N} \end{aligned}$$

$$\phi = 0,75$$

$$\begin{aligned} V_n &= V_c + V_s \\ &= 0 + 253409 \\ &= 253409 \text{ N} \end{aligned}$$

$$V_u = 115904 \text{ N}$$

$$\begin{aligned} \phi V_n / V_u &= 0,75 \times \frac{253409}{115904} \\ &= 1,640 \end{aligned}$$

$$\text{Cek kapasitas} = \phi V_n / V_u \geq 1 \rightarrow \text{OK}$$

- Lapangan

Penulangan geser

$$n = 2$$

$$\begin{aligned} A_v &= n \times \frac{\pi}{4} \times d_s^2 \\ &= 2 \times \frac{3,14}{4} \times 10^2 \\ &= 157,080 \text{ mm}^2 \end{aligned}$$

$$\text{Spasi} = 100 \text{ mm}$$

$$\text{Spasi maksimum} = \frac{d}{2} = \frac{350,5}{2} = 172,25 \text{ mm}$$

$$\text{Cek spasi} \rightarrow \text{OK}$$

$$\begin{aligned} V_s &= A_v \times f_{yv} \times \frac{d}{s} \\ &= 157,080 \times 280 \times \frac{350,5}{150} \\ &= 154158 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Batas } V_s &= 0,66 \times f_c'^{0,5} \times b \times d \\ &= 0,66 \times 30^{0,5} \times 200 \times 350,5 \\ &= 253409 \text{ N} \end{aligned}$$

$$\begin{aligned} V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\ &= 0,17 \times 30^{0,5} \times 200 \times 350,5 \\ &= 65272 \text{ N} \end{aligned}$$

$$\begin{aligned}\phi &= 0,75 \\ V_n &= 219430 \\ V_u &= 18693,4 \text{ N} \\ \phi V_n/V_u &= 0,75 \times \frac{219430}{18693,4} \\ &= 8,804 \\ \text{Cek kapasitas} &= \phi V_n/V_u \geq 1 \rightarrow \text{OK}\end{aligned}$$

- **Desain Torsi**

- Data materail dan penampang

$$\begin{aligned}\text{Panjang balok (L)} &= 4000 \text{ mm} \\ \text{Lebar balok (b)} &= 200 \text{ mm} \\ \text{Tinggi balok (h)} &= 400 \text{ mm} \\ \text{Panjang tumpuan} &= 2 \times h \\ &= 2 \times 400 \\ &= 800 \text{ mm} \\ d_b &= 19 \\ d_{bt} &= 13 \\ d_s &= 10 \\ \text{selimut bersih (cc)} &= 30 \\ \text{tinggi efektif balok} &= h - cc - d_s - d_b/2 \\ &= 400 - 30 - 10 - 19/2 \\ &= 350,5 \text{ mm} \\ f_c' &= 30 \text{ Mpa} \\ f_y &= 420 \text{ Mpa} \\ f_{yv} &= 280 \text{ Mpa} \\ \beta_1 &= 0,8357 \\ \text{Panjang kolom (c1)} &= 600 \text{ mm} \\ \text{Lebar kolom (c2)} &= 600 \text{ mm}\end{aligned}$$

$$\begin{aligned}
 L_n &= L - c_l \\
 &= 4000 - 600 \\
 &= 3400 \text{ mm}
 \end{aligned}$$

- Parameter geometri penampang untuk perhitungan torsi

$$\begin{aligned}
 A_{cp} &= b \times h \\
 &= 200 \times 400 \\
 &= 80000 \text{ mm}^2
 \end{aligned}$$

$$\begin{aligned}
 P_{cp} &= 2 \times (b + h) \\
 &= 2 \times (200 + 400) \\
 &= 1200 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 X_0 &= b - 2 C_c - d_s \\
 &= 200 - 2 \times 30 - 10 \\
 &= 130 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 Y_0 &= h - 2 c_c - d_s \\
 &= 400 - 2 \times 30 - 10 \\
 &= 330 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 A_{oh} &= X_0 \times Y_0 \\
 &= 130 \times 330 \\
 &= 42900 \text{ mm}^2
 \end{aligned}$$

$$\begin{aligned}
 A_0 &= 0,85 \times A_{oh} \\
 &= 36465 \text{ mm}^2
 \end{aligned}$$

$$\begin{aligned}
 P_h &= 2 \times (X_0 + Y_0) \\
 &= 920 \text{ mm}
 \end{aligned}$$

- Gaya dalam

Tabel 2. 41 Gaya Dalam Balok Anak Memanjang

Tu	4,7049 kN/m
----	-------------

- Pengecekan kebutuhan tulangan torsi

$$\begin{aligned} T_{cr} &= 0,33 \times f_c'^{0,5} \times \frac{A_{cp}^2}{P_{cp}} \\ &= 0,33 \times 30^{0,5} \times \frac{80000^2}{1200} \\ &= 9639917 \text{ N/mm} \end{aligned}$$

$$\phi = 0,75$$

$$\frac{\phi T_{cr}}{4} = \frac{0,75 \times 9639917}{4} = 1807484 \text{ N/mm}$$

$$\text{Syarat } T_u > \frac{\phi T_{cr}}{4} \rightarrow \text{MEMERLUKAN TULANGAN TORSI}$$

- Pengecekan kecukupan dimensi penampang

$$T_u \text{ pakai} = 4704900 \text{ N/mm}$$

$$V_u = 115904 \text{ N}$$

$$\begin{aligned} V_c &= 0,17 \times f_c'^{0,5} \times b \times d \\ &= 0,17 \times 30^{0,5} \times 200 \times 350,5 \\ &= 65272 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Tegangan ultimate geser + torsi} &= \left\{ \left(\frac{V_u}{b \times d} \right)^2 + \left(\frac{T_u \times P_h}{1,7 \times A_o h^2} \right)^2 \right\}^{0,5} \\ &= \left\{ \left(\frac{115904}{200 \times 350,5} \right)^2 + \left(\frac{4704900 \times 920}{1,7 \times 42900^2} \right)^2 \right\}^{0,5} \\ &= 2,156 \text{ Mpa} \end{aligned}$$

$$\begin{aligned} \text{Kapasitas tegangan beton} &= \phi \times \left\{ \left(\frac{V_u}{b \times d} \right) + 0,66 \times (f_c')^{0,5} \right\} \\ &= 0,75 \times \left\{ \left(\frac{84583}{350 \times 550,5} \right) + 0,66 \times (30)^{0,5} \right\} \\ &= 3,410 \text{ Mpa} \end{aligned}$$

$$\text{Cek dimensi penampang} = \text{ruas kiri} \leq \text{ruas kanan} \rightarrow \text{OK}$$

- Penulangan transversal torsi

$$n \text{ kaki tumpuan} = 4$$

$$n \text{ kaki lapangan} = 2$$

$$s \text{ tumpuan} = 50 \text{ mm}$$

$$s \text{ lapangan} = 100 \text{ mm}$$

$$s \text{ maksimum 1} = \frac{Ph}{8} = \frac{920}{8} = 115 \text{ mm}$$

$$s \text{ maksimum 2} = 300 \text{ mm}$$

$$\text{Cek spasi tumpuan} = s \text{ tumpuan} \geq s \text{ max} \rightarrow \mathbf{OK}$$

$$\text{Cek spasi lapangan} = s \text{ lapangan} \geq s \text{ max} \rightarrow \mathbf{OK}$$

$$\begin{aligned} \frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 4 \times \frac{3,14}{4} \times \frac{10^2}{100} \\ &= 6,283 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av+t}{s \text{ tumpuan pasang}} &= n \times \frac{\pi}{4} \times \frac{ds^2}{s} \\ &= 2 \times \frac{3,14}{4} \times \frac{10^2}{100} \\ &= 1,571 \text{ mm}^2/\text{mm} \\ \frac{At}{s} &= \frac{T_u}{(2 \times \phi \times A_o \times f_{yv})} \\ &= \frac{4704900}{(2 \times 0,75 \times 36465 \times 280)} \\ &= 0,307 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av}{s \text{ tumpuan perlu}} &= \frac{\left(\frac{V_u \text{ tumpuan}}{\phi - V_c}\right)}{f_{yv} \times d} \\ &= 1,575 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av}{s \text{ lapangan perlu}} &= \frac{\left(\frac{V_u \text{ lapangan}}{\phi - V_c}\right)}{f_{yv} \times d} \\ &= -0,411 \text{ mm}^2/\text{mm} \end{aligned}$$

$$\begin{aligned} \frac{Av+s}{s \text{ tumpuan perlu}} &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times 0,307 + 1,575 \\ &= 2,189 \end{aligned}$$

$$\begin{aligned} \frac{Av+s}{s \text{ tumpuan perlu}} &= 2 \times \frac{At}{s} + \frac{Av}{s} \\ &= 2 \times 0,307 + (-0,411) \end{aligned}$$

$$\begin{aligned}
 &= 0,203 \\
 \frac{Av+t}{s \text{ min } 1} &= 0,062 \times f_c'^{0,5} \times \frac{b}{f_{yv}} \\
 &= 0,062 \times 30^{0,5} \times \frac{200}{280}
 \end{aligned}$$

$$\begin{aligned}
 &= 0,243 \\
 \frac{Av+t}{s \text{ min } 2} &= \frac{0,35 \times b}{f_{yv}} \\
 &= \frac{0,35 \times 200}{280}
 \end{aligned}$$

$$= 0,250$$

$$\text{Cek geser + torsi tumpuan} = \frac{Av+t}{s \text{ pasang}} \geq \frac{Av+t}{s \text{ perlu}} \rightarrow \text{OK}$$

$$\text{Cek geser + torsi lapangan} = \frac{Av+t}{s \text{ pasang}} \geq \frac{Av+t}{s \text{ perlu}} \rightarrow \text{OK}$$

- Penulangan longitudinal torsi

$$\text{db atau dbt} = 13 \text{ mm}$$

$$\text{db, min} = 0,042 \times s = 4,2 \text{ mm}$$

$$\text{Cek db} = \text{db} \geq \text{db min} \rightarrow \text{OK}$$

$$\text{Kebutuhan As tumpuan atas} = 135,900 \text{ mm}^2$$

$$\text{Kebutuhan As tumpuan bawah} = 129,452 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan atas} = 76,234 \text{ mm}^2$$

$$\text{Kebutuhan As lapangan bawah} = 108,617 \text{ mm}^2$$

$$A_1 = \frac{At}{s} \times Ph$$

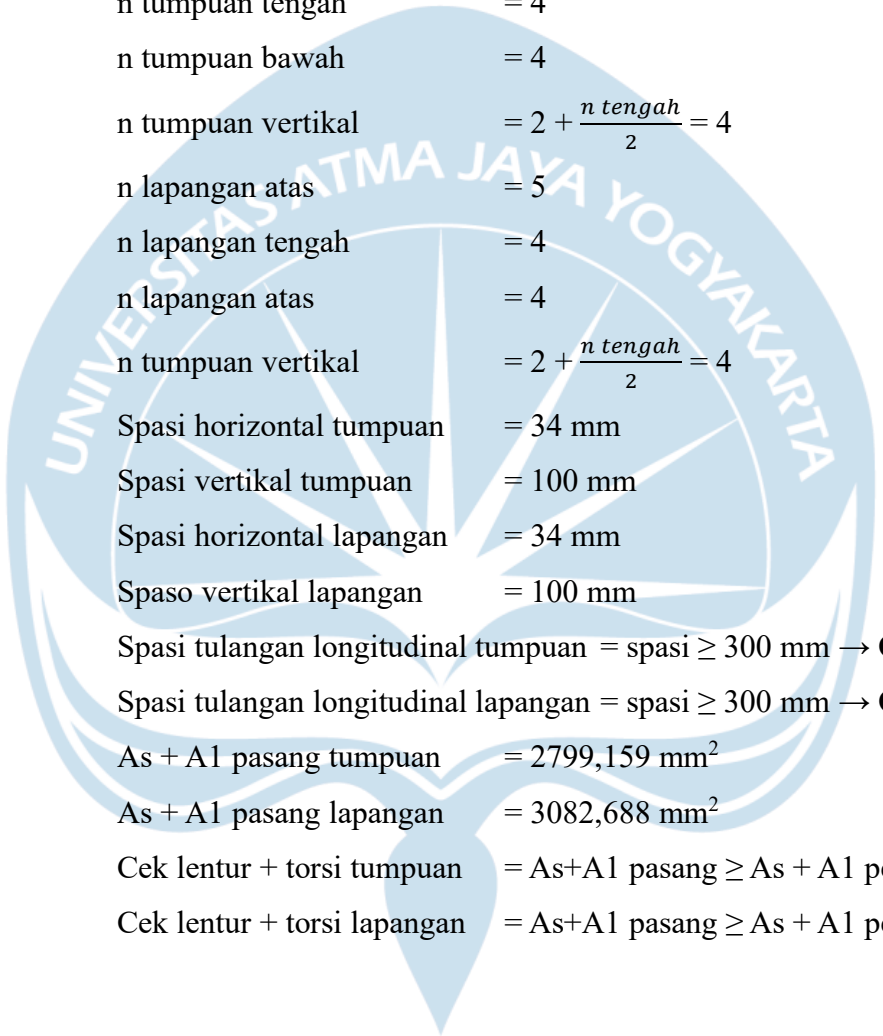
$$= 0,540 \times 1320$$

$$= 282,626 \text{ mm}^2$$

$$A_1 \text{ minimum} = \frac{0,42 \times f_c'^{0,5} \times A_{cp}}{f_y - \frac{At}{s} \times ph}$$

$$= \frac{0,42 \times 30^{0,5} \times 80000}{30 - 0,540 \times 1320}$$

$$= 155,552 \text{ mm}^2$$

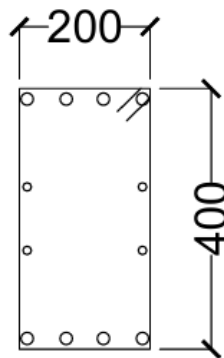


As + A1 perlu tumpuan	= 547,489 mm ²
As + A1 perlu lapangan	= 467,478 mm ²
n tumpuan atas	= 4
n tumpuan tengah	= 4
n tumpuan bawah	= 4
n tumpuan vertikal	= $2 + \frac{n \text{ tengah}}{2} = 4$
n lapangan atas	= 5
n lapangan tengah	= 4
n lapangan atas	= 4
n tumpuan vertikal	= $2 + \frac{n \text{ tengah}}{2} = 4$
Spasi horizontal tumpuan	= 34 mm
Spasi vertikal tumpuan	= 100 mm
Spasi horizontal lapangan	= 34 mm
Spasi vertikal lapangan	= 100 mm
Spasi tulangan longitudinal tumpuan	= spasi ≥ 300 mm → OK
Spasi tulangan longitudinal lapangan	= spasi ≥ 300 mm → OK
As + A1 pasang tumpuan	= 2799,159 mm ²
As + A1 pasang lapangan	= 3082,688 mm ²
Cek lentur + torsi tumpuan	= As+A1 pasang $\geq$ As + A1 perlu → OK
Cek lentur + torsi lapangan	= As+A1 pasang $\geq$ As + A1 perlu → OK

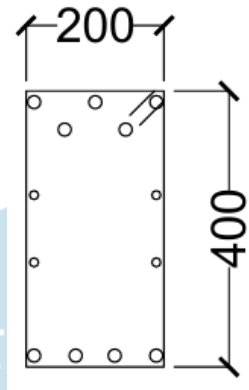
- **Rekap**

Tabel 2. 42 Rekap Balok Anak Memanjang

Kesimpulan	
Syarat Gaya dan Geometri	OK
Kapasitas Lentur	OK
Kapasitas Geser	OK
Kapasitas Torsi	OK
Tulangan Longitudinal	
Longitudinal Tumpuan Atas	4 D19
Longitudinal Tumpuan Tengah	4 D13
Longitudinal Tumpuan Bawah	4 D19
Longitudinal Lapangan Atas	5 D19
Longitudinal Lapangan Tengah	4 D13
Longitudinal Lapangan Bawah	4 D19
Tulangan Transversal/Sengkang	
Sengkang Tumpuan	4D10-50
Sengkang Lapangan	2D10-100



Gambar 2. 57 Penulangan Tumpuan Balok Anak 1 Memanjang



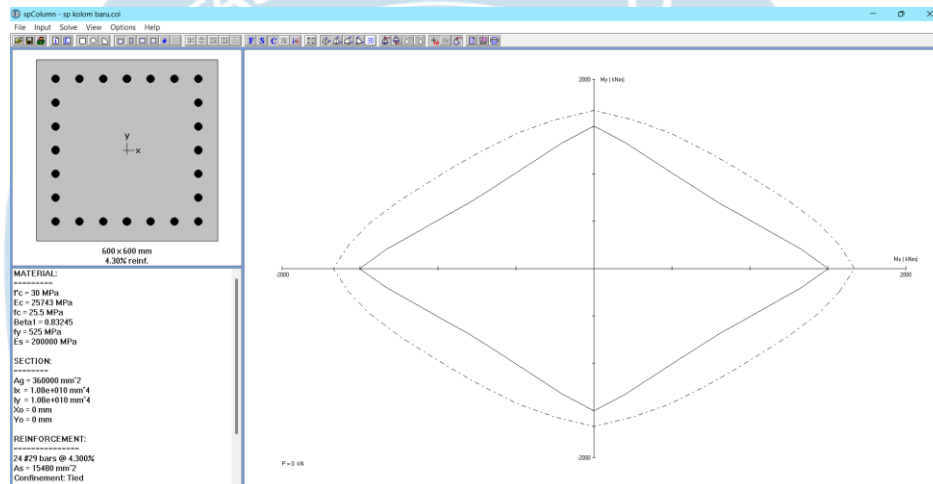
Gambar 2. 58 Penulangan Lapangan Balok Anak 1 Memanjang

2.13 Perencanaan Kolom

- Data
 - $b = 600$
 - $h = 600$
 - Tinggi kolom = 4
 - $F'_c = 30$
 - $F_y = 420$
 - F_y sengkang = 280
 - D utama = 29
 - Tulangan = 24D29

Tabel 2. 43 Gaya Dalam Kolom

	P	M2	M3
P Max	316,3929	85,4912	121,1428
Pu Min	-1636,8703	-235,5191	-218,864
M2 Max	-246,6778	249,72	227,3498
M2 Min	-1130,6502	-249,6847	-191,8143
M3 Max	-244,6827	249,2342	232,5078
M3 Min	-1128,2872	-183,2189	-232,4543



Gambar 2. 59 Penulangan Kolom menggunakan SP Column

Tabel 2. 44 Rekapitulasi Parameter Desain Kolom dari Interaksi Gaya Aksial dan Momen

No	P _u kN	M _{ux} kNm	M _{uy} kNm	φM _{nx} kNm	φM _{ny} kNm	φM _n /M _u	NA Depth mm	d _t Depth mm	ε _t	φ
1	-355,27	53,39	61,06	676,45	773,71	12,671	314	755	0,00421	0,832
2	1939,14	-95,54	-97,25	-652,22	-663,89	6,827	418	755	0,00243	0,678
3	253,44	256,49	232,09	754,81	682,99	2,943	339	755	0,00368	0,786
4	1249,2	-256,45	-195,92	-785,43	-600,05	3,063	380	751	0,00293	0,721
5	251,62	255,99	236,94	746,72	691,14	2,917	339	755	0,00368	0,786
6	1219,39	-186,97	-236,71	-612,34	-775,21	3,275	380	752	0,00294	0,723

Syarat

Tabel 2. 45 Gaya Aksial Kolom

P maksimum	813,0409 kN
P minimum	961,9764 kN
Total	1544,7 kN

Tabel 2. 46 Momen Lentur Rencana Kolom

Mpr (-)	867,7313 kN
Mpr (+)	1544,7 kN
	1044,27 kN

Jika $1544,7 \geq 1044,27$ maka $\rightarrow$ **OK**

$$V_u = 111,1947 \text{ kN}$$

$$M_{pr \text{ ki (-)}} = 867,7313 \text{ kN}$$

$$M_{pr \text{ ki (+)}} = 1544,6995 \text{ kN}$$

$$M_{pr \text{ ka (-)}} = 867,7313 \text{ kN}$$

$$M_{pa \text{ ka (+)}} = 1544,6995 \text{ kN}$$

$$\begin{aligned} M_{pr} &= 0,5 \times (867,7313 + 1544,6995) \\ &= 1206,2154 \text{ kN} \end{aligned}$$

- Menghitung Kuat Geser Perlu

$$V_e = 709,538 \text{ kN}$$

$$\text{Syarat} = V_e > V_u \text{ (OK)}$$

$$\text{Maka digunakan} = 709,538 \text{ kN}$$

$$D \text{ sengkang} = 13 \text{ mm}$$

$$\text{Selimut} = 40 \text{ mm}$$

$$\begin{aligned}
 D &= 600 - 40 - (13/2) \\
 &= 553,5 \text{ mm}
 \end{aligned}$$

Kuat geser beton diabaikan karena $V_c = 0$, karena $V_e > V_u$

$$\begin{aligned}
 V_s &= 709,538 \times 1000 / 0,75 \\
 &= 946,051 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 A_v / s &= 946,051 / (553,5 \times 280) \\
 &= 0,006 \text{ kN}
 \end{aligned}$$

- Tulangan Transversal Pengekangan

$$P_u = 316392,9 < 3240000$$

$$B_c = 520 \text{ mm}$$

$$A_g = 360000 \text{ mm}^2$$

$$A_{ch} = 270400 \text{ mm}^2$$

$$\begin{aligned}
 A_{sh} / S_{bc} &= 0,3 \times ((360000 / 270400) - 1) \times 30 / 280 \\
 &= 0,01065089
 \end{aligned}$$

$$\begin{aligned}
 A_{sh} / S &= 0,01065089 \times 520 \\
 &= 5,53846154 \text{ mm}^2 / \text{mm}
 \end{aligned}$$

$$\begin{aligned}
 A_{sh} / S_{bc} &= 0,09 \times 30 / 280 \\
 &= 0,009642857
 \end{aligned}$$

$$\begin{aligned}
 A_{sh} / S &= 0,009642857 \times 520 \\
 &= 5,014
 \end{aligned}$$

$$A_{sh} / S \text{ pakai} = 6,1043 \text{ mm}^2$$

$$S = 100$$

$$A_{sh} = ,1043 \text{ mm}^2$$

$$A_v = \frac{1}{4} \times \pi \times 13^2$$

$$= 132,73229$$

$$n = \frac{6,1043}{132,73229}$$

$$= 4,599$$

$$\text{Digunakan} = 4D13-100$$

$$S \text{ maksimum } 1 = \frac{1}{4} \times h$$

$$= \frac{1}{4} \times 600$$

$$= 150 \text{ (OK)}$$

$$S \text{ maksimum } 2 = 6 \times D \text{ utama}$$

$$= 6 \times 29$$

$$= 174 \text{ (OK)}$$

$$hx = \left(\frac{600 - 3 \times 40 - 3 \times 13 - 3 \times \frac{29}{3}}{4 - 1} \right)$$

$$= 137,333$$

$$S_0 = \left(\frac{100 + (350 - 137,333)}{3} \right)$$

$$= 170,889 \text{ (OK)}$$

- Tulangan Trasnversal di Daerah L0

$$V_e = 709,538 \text{ kN}$$

$$V_c = 0,17 \times \sqrt{30} \times 600 \times 553,5$$

$$= 309227,724 \text{ N} = 309,2277 \text{ kN} < 709,538$$

$$\text{Digunakan} = 4D13-200$$

- Panjang Sambungan Lewatan

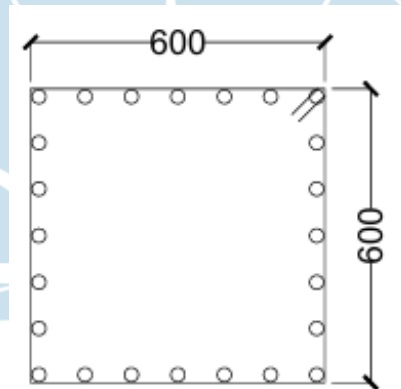
$$s = 100$$

$$\lambda = 1$$

$$A_b = 0,25 \times \pi \times 13^2$$

$$= 132,73229$$

$$\begin{aligned}
 l_d &= 3,3 \times \left(\frac{420}{1} \times \sqrt{30} \right) \times \left(\frac{132,73229}{100} \right) \\
 &= 335,876 \text{ mm} = 350 \text{ mm} \\
 \text{Lst 1} &= 100 + 50 \\
 &= 150 \text{ mm} \\
 \text{Lst 2} &= 1,5 \times 350 \\
 &= 525 \text{ mm} \\
 \text{Lst 3} &= 150 \text{ mm} \\
 \text{Digunakan} &= 525 \text{ mm}
 \end{aligned}$$



Gambar 2. 60 Penulangan Kolom

2.14 Hubungan Balok Kolom

- Data material dan penampang

$$\text{Lebar Y kolom (b)} = 600 \text{ mm}$$

$$\text{Lebar X kolom (h)} = 600 \text{ mm}$$

$$\text{Panjang kolom (L)} = 3500 \text{ mm}$$

$$f_c' = 30 \text{ Mpa}$$

$$f_y = 420 \text{ Mpa}$$

$$\lambda = 1$$

$$h_b = 600 \text{ mm}$$

$$L_n = 3500 - 600$$

$$= 2900 \text{ mm}$$

- Data lebar dan eksentrisitas balok

$$\text{Lebar balok 1} = 300 \text{ mm}$$

$$\text{Lebar balok 2} = 300 \text{ mm}$$

$$\text{Lebar balok 3} = 350 \text{ mm}$$

$$\text{Lebar balok 4} = 350 \text{ mm}$$

$$X_{1a} = 150 \text{ mm}$$

$$X_{1b} = 150 \text{ mm}$$

$$\text{Cek lebar sisi kolom 1} = 600 \text{ mm}$$

$$X_{2a} = 150 \text{ mm}$$

$$X_{2b} = 150 \text{ mm}$$

$$\text{Cek lebar sisi kolom 2} = 600 \text{ mm}$$

$$X_{3a} = 125 \text{ mm}$$

$$X_{3b} = 125 \text{ mm}$$

$$\text{Cek lebar sisi kolom 3} = 600 \text{ mm}$$

$$X_{4a} = 125 \text{ mm}$$

$$X_{4b} = 125 \text{ mm}$$

$$\text{Cek lebar sisi kolom 4} = 600 \text{ mm}$$

- Dimensi joint

$$X \text{ terkecil sisi 1 (x1)} = 150 \text{ mm}$$

$$X \text{ terkecil sisi 1 (x2)} = 150 \text{ mm}$$

$$X \text{ terkecil sisi 1 (x3)} = 125 \text{ mm}$$

$$X \text{ terkecil sisi 1 (x4)} = 125 \text{ mm}$$

$$\text{Lebar joint sisi 1 (bj1)} = 600 \text{ mm}$$

$$\text{Lebar joint sisi 1 (bj2)} = 600 \text{ mm}$$

$$\text{Lebar joint sisi 1 (bj3)} = 600 \text{ mm}$$

Lebar joint sisi 1 (b_{j4}) = 600 mm

b_j = 600 mm

h_j = 600 mm

A_{jX} = 360000 mm²

A_{jY} = 360000 mm²

Cek tinggi joint = $h_j \geq \frac{1}{2} h_b$

= 600 $\geq$ 300 → **OK**

- Data dan gaya tulangan balok

d_b = 13

Cek dimensi kolom = $b \geq 20 d_b$

= 600 $\geq$ 260 → **OK**

A_s^{-1} = 929,126 mm

A_s^{+1} = 530,629 mm

A_s^{-2} = 929,126 mm

A_s^{+2} = 530,929 mm

A_s^{-3} = 929,126 mm

A_s^{+3} = 530,929 mm

A_s^{-4} = 929,126 mm

A_s^{+4} = 530,929 mm

F_{pr} = 1,25 x f_y

= 1,25 x 420

= 525 Mpa

F_s^{-1} = $A_s^{-1} \times F_{pr}$

= 929,126 x 525

= 487791 N

F_s^{+1} = $A_s^{+1} \times F_{pr}$

= 530,629 x 525

$$\begin{aligned}
 &= 278738 \text{ N} \\
 F_s^{-2} &= A_s^{-2} \times F_{pr} \\
 &= 929,126 \times 525 \\
 &= 487791 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 F_s^{+2} &= A_s^{+2} \times F_{pr} \\
 &= 530,929 \times 525 \\
 &= 278738 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 F_s^{-3} &= A_s^{-3} \times F_{pr} \\
 &= 530,929 \times 525 \\
 &= 487791 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 F_s^{+3} &= A_s^{+3} \times F_{pr} \\
 &= 530,929 \times 525 \\
 &= 278738 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 F_s^{-4} &= A_s^{-4} \times F_{pr} \\
 &= 929,126 \times 525 \\
 &= 487791 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 F_s^{+4} &= A_s^{+4} \times F_{pr} \\
 &= 530,929 \times 525 \\
 &= 278738 \text{ N}
 \end{aligned}$$

- Gaya geser akibat balok

$$\begin{aligned}
 X^{-} &= F_s^{-3} + C_4 = F_s^{-3} + F_s^{+4} \\
 &= 487791 + 278738 \\
 &= 766529 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 X^{+} &= F_s^{-4} + C_3 = F_s^{+4} + F_s^{+3} \\
 &= 278738 + 487791 \\
 &= 766529 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 Y^{-} &= F_s^{-1} + C_2 = F_s^{-1} + F_s^{+2} \\
 &= 487791 + 278738
 \end{aligned}$$

$$= 766529 \text{ N}$$

$$\begin{aligned} Y^+ &= F_s^-2 + C1 = F_s^-2 + F_s^+1 \\ &= 487791 + 278738 \\ &= 766529 \text{ N} \end{aligned}$$

- Gaya geser kolom

$$M_{pr}^- \text{ balok 1} = 398446009 \text{ N/mm}$$

$$M_{pr}^+ \text{ balok 1} = 245061546 \text{ N/mm}$$

$$M_{pr}^- \text{ balok 2} = 398446009 \text{ N/mm}$$

$$M_{pr}^+ \text{ balok 2} = 245061546 \text{ N/mm}$$

$$M_{pr}^- \text{ balok 3} = 512780052 \text{ N/mm}$$

$$M_{pr}^+ \text{ balok 3} = 307912697 \text{ N/mm}$$

$$M_{pr}^- \text{ balok 4} = 512780052 \text{ N/mm}$$

$$M_{pr}^+ \text{ balok 4} = 307912697 \text{ N/mm}$$

$$V_e \text{ balok 1} = 241801 \text{ N}$$

$$V_e \text{ balok 2} = 241801 \text{ N}$$

$$V_e \text{ balok 3} = 259711 \text{ N}$$

$$V_e \text{ balok 4} = 259711 \text{ N}$$

Geser kolom arah gempa X^-

$$= \left(\frac{[(M_{pr+4} + M_{pr-3}) + (V_e3 + V_e4) + \frac{h_1}{2}]}{Ln} \right)$$

$$= \left(\frac{[(307912697 + 512780052) + (259711 + 259711) + \frac{600}{2}]}{2900} \right)$$

$$= 336731 \text{ N}$$

Geser kolom arah gempa X^+

$$= \left(\frac{[(M_{pr+3} + M_{pr-4}) + (V_{e3} + V_{e4}) + \frac{h_1}{2}]}{L_n} \right)$$

$$= \left(\frac{[(307912697 + 512780052) + (259711 + 259711) + \frac{600}{2}]}{2900} \right)$$

$$= 336731 \text{ N}$$

Geser kolom arah gempa Y^-

$$= \left(\frac{[(M_{pr+2} + M_{pr-1}) + (V_{e1} + V_{e2}) + \frac{h_1}{2}]}{L_n} \right)$$

$$= \left(\frac{[(245061546 + 398446009) + (259711 + 259711) + \frac{600}{2}]}{2900} \right)$$

$$= 336731 \text{ N}$$

Geser kolom arah gempa Y^+

$$= \left(\frac{[(M_{pr+1} + M_{pr-2}) + (V_{e1} + V_{e2}) + \frac{h_1}{2}]}{L_n} \right)$$

$$= \left(\frac{[(245061546 + 398446009) + (259711 + 259711) + \frac{600}{2}]}{2900} \right)$$

$$= 336731 \text{ N}$$

- Gaya geser total joint

Geser joint arah gempa X^- = 429798 N

Geser joint arah gempa X^+ = 429798 N

Geser joint arah gempa Y^- = 494602 N

Geser joint arah gempa Y^+ = 494602 N

- Kuat geser joint

Konfigurasi joint = 3

C = 1

$V_{nx} = C \times \lambda \times \sqrt{f c' x A j x}$
 $= 1 \times 1 \times \sqrt{30 \times 360000}$
 $= 1971801 \text{ N}$

$V_{ny} = C \times \lambda \times \sqrt{f c' x A j y}$
 $= 1 \times 1 \times \sqrt{30 \times 360000}$
 $= 1971801 \text{ N}$

Faktor reduksi (Φ) = 0,85

$\Phi V_{nx} = \Phi \times V_{nx}$
 $= 0,85 \times 1971801$
 $= 1676031 \text{ N}$

$\Phi V_{ny} = \Phi \times V_{ny}$
 $= 0,85 \times 1971801$
 $= 1676031 \text{ N}$

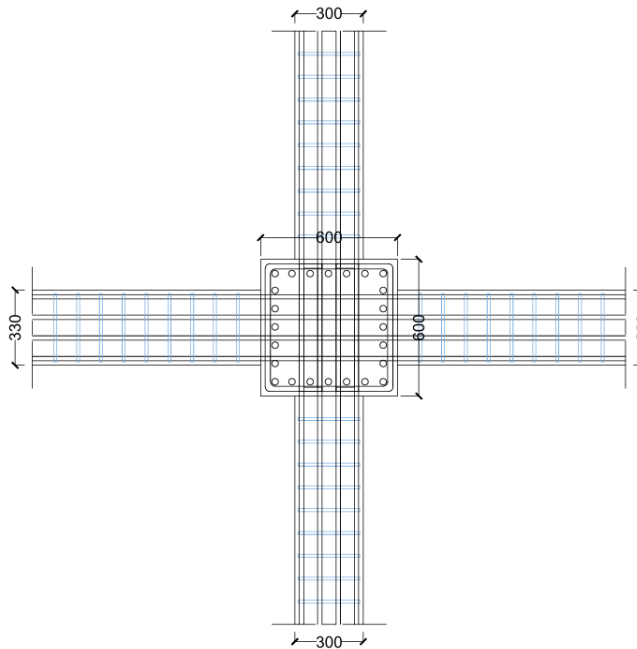
$V_{ux} = 429798 \text{ N}$
 $V_{uy} = 494602 \text{ N}$

$SF_x = \frac{\Phi V_{nx}}{V_{ux}}$
 $= \frac{1676031}{429798}$
 $= 3,900$

$SF_y = \frac{\Phi V_{ny}}{V_{uy}}$
 $= \frac{1676031}{429798}$
 $= 3,900$

Cek kuat geser joint = $SF \geq 1 \rightarrow \mathbf{OK}$

- Tulangan transversal
Tulangan transversal joint = menggunakan tumpuan kolom
- Panjang penyaluran tarik
 I_{dh} hitung = 184,603 mm
 I_{dh} pakai = 184,603 mm



Gambar 2. 61 Penulangan Hubungan Balok Kolom