BAB V
PERENCANAAN FLYOVER

V.1. Perencanaan Flyover

V.1.1. Spesifikasi Umum

Secara umum perencanaan Flyover pada jalur Jl. Pemuda pada bundaran dimuka Kantor PLN Semarang, adalah sebagai berikut :

1. Jenis jembatan : Jembatan beton prestress kelas A
2. Bentang jembatan : 35 m + 30m + 35m
3. Lebar total jembatan : 12,80m
   - Lebar lantai jembatan : 2 x 5,25m = 10,50m
   - Lebar trotoar : 2 x 1,00m = 2m
   - Lebar tiang sandaran 2 x 15 cm = 30cm
4. Konstruksi atas :
   * Plat lantai : - Beton bertulang mutu K-250
     - Baja U-24 (fy = 2400 kg/cm^2 = 240 Mpa)
     - Tebal plat lantai = 20cm
   * Sandaran : - Beton bertulang mutu K-150
     - Baja U-24 (fy = 2400 kg/cm^2 = 240 Mpa)
     - Tinggi sandaran = 1,25m = 125cm
   * Gelagar utama : - Beton prestress mutu K-500
     - Baja BJTD 40 (fy = 4000 kg/cm^2 = 400 Mpa)
     - Bentuk gelagar I
     - Jumlah gelagar tiap bentang = 7 buah
     - Jarak antara gelagar = 1,75m = 175cm
5. Konstruksi bawah :
   * Abutment : - Beton bertulang mutu K-300
     - Baja BJTD 40 (fy = 4000 kg/cm^2 = 400 Mpa)

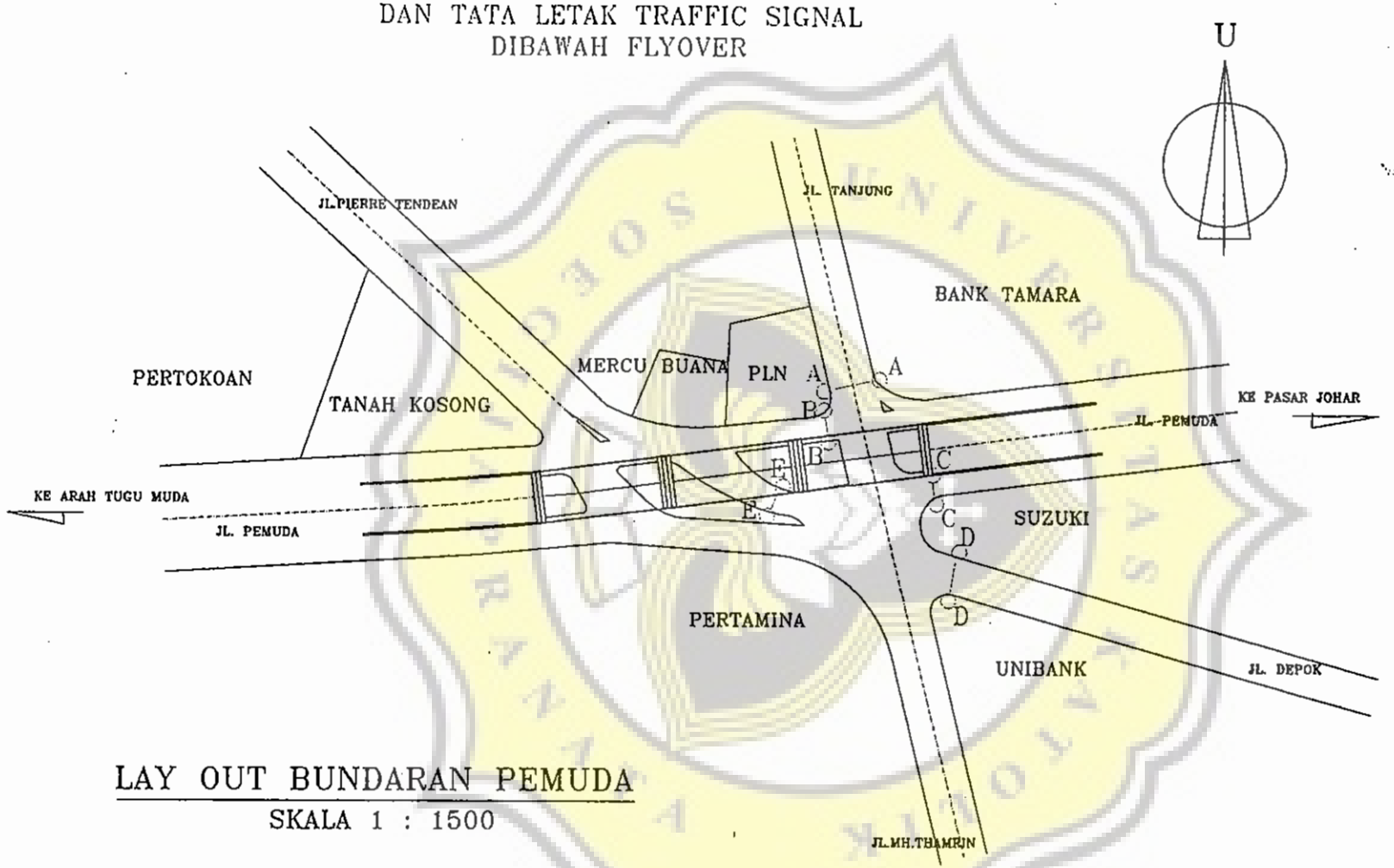
* Pilar : - Beton bertulang mutu K-300
- Baja BJTD 40 (fy = 4000 kg/cm² = 400 Mpa)

* Pondasi tiang pancang : - Beton bertulang mutu K-300
- Baja tulangan BJTD 40 (fy = 4000 kg/cm² = 400 Mpa)

Secara umum perencanaan Flyover pada bundaran Jl. Pemuda di muka Kantor PLN Semarang dapat dilihat pada gambar berikut ini :

Gambar 5.1 Denah Lokasi Flyover pada Bundaran Jalan Pemuda Semarang

RENCANA LAY OUT FLY OVER
DAN TATA LETAK TRAFFIC SIGNAL
DIBAWAH FLYOVER



LAY OUT BUNDARAN PEMUDA

SKALA 1 : 1500

BAB V
PERENCANAAN FLYOVER

V.1. Perencanaan Flyover

V.1.1. Spesifikasi Umum

Secara umum perencanaan Flyover pada jalur Jl. Pemuda pada bundaran dimuka Kantor PLN Semarang, adalah sebagai berikut :

1. Jenis jembatan : Jembatan beton prestress kelas A
2. Bentang jembatan : 35 m + 30m + 35m
3. Lebar total jembatan : 12,80m
   - Lebar lantai jembatan : 2 x 5,25m = 10,50m
   - Lebar trotoar : 2 x 1,00m = 2m
   - Lebar tiang sandaran 2 x 15 cm = 30cm
4. Konstruksi atas :
   * Plat lantai :
     - Beton bertulang mutu K-250
     - Baja U-24 (fy = 2400 kg/cm² = 240 Mpa)
     - Tebal plat lantai = 20cm
   * Sandaran :
     - Beton bertulang mutu K-150
     - Baja U-24 (fy = 2400 kg/cm² = 240 Mpa)
     - Tinggi sandaran = 1,25m = 125cm
   * Gelagar utama :
     - Beton prestress mutu K-500
     - Baja BJTD 40 (fy = 4000 kg/cm² = 400 Mpa)
     - Bentuk gelagar I
     - Jumlah gelagar tiap bentang = 7 buah
     - Jarak antara gelagar = 1,75m = 175cm
5. Konstruksi bawah :
   * Abutment :
     - Beton bertulang mutu K-300
     - Baja BJTD 40 (fy = 4000 kg/cm² = 400 Mpa)

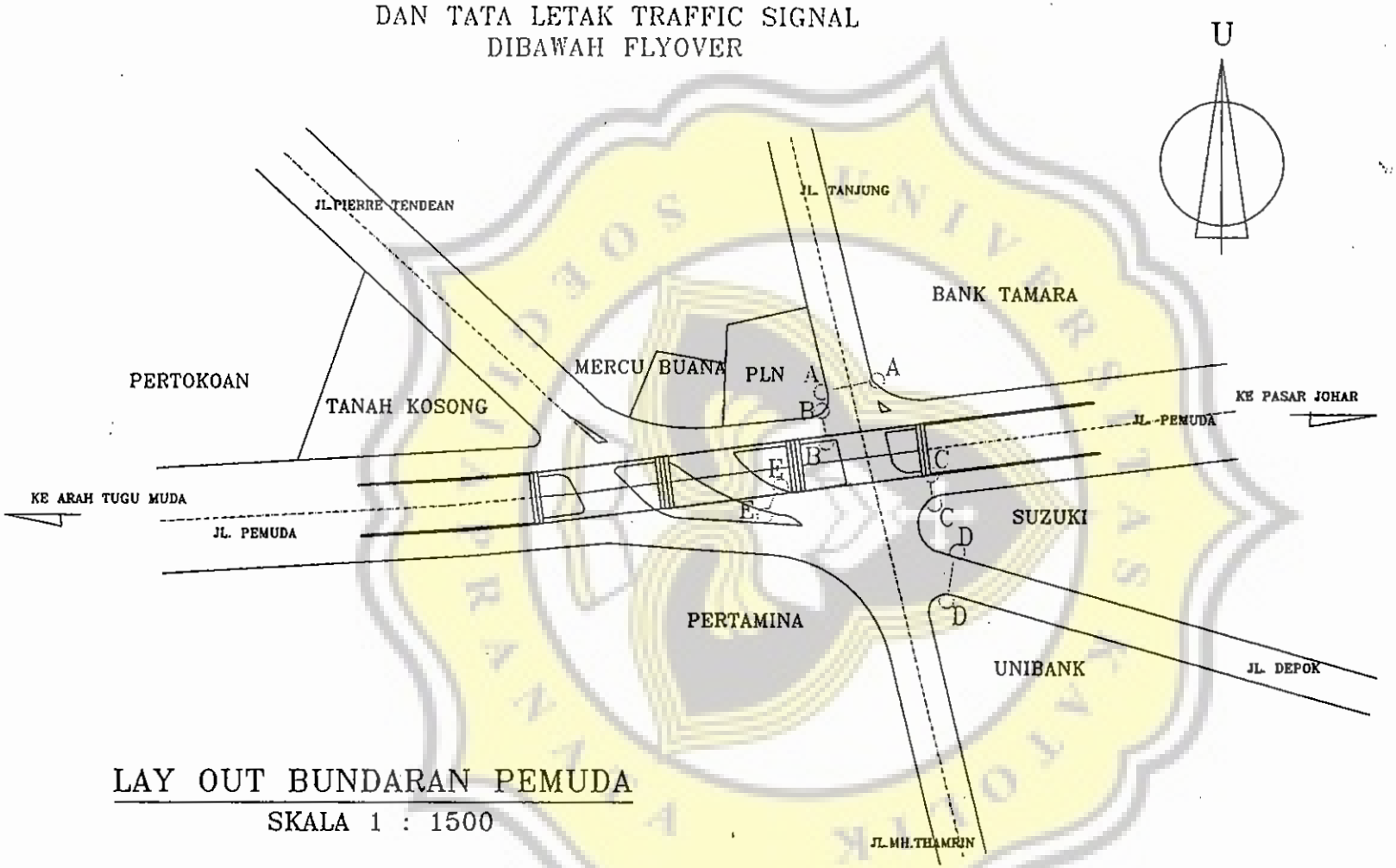
* Pilar : - Beton bertulang mutu K-300
- Baja BJTD 40 (fy = 4000 kg/cm² = 400 Mpa)

* Pondasi tiang pancang : - Beton bertulang mutu K-300
- Baja tulangan BJTD 40 (fy = 4000 kg/cm² = 400 Mpa)

Secara umum perencanaan Flyover pada bundaran Jl. Pemuda di muka Kantor PLN Semarang dapat dilihat pada gambar berikut ini :

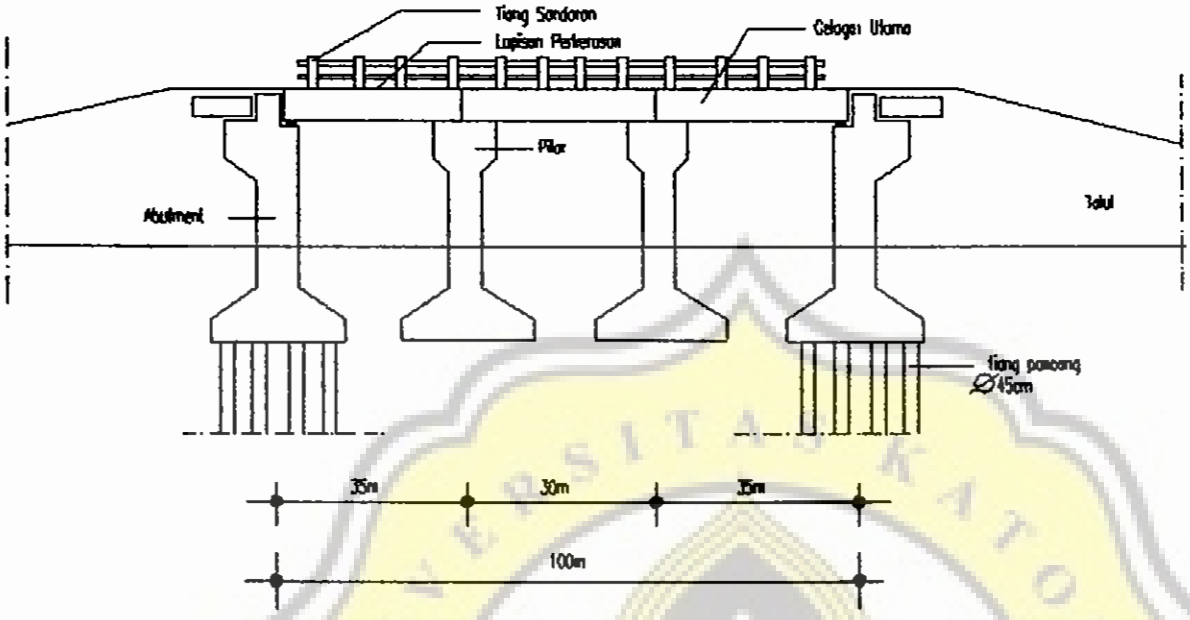
Gambar 5.1 Denah Lokasi Flyover pada Bundaran Jalan Pemuda Semarang

RENCANA LAY OUT FLY OVER
DAN TATA LETAK TRAFFIC SIGNAL
DIBAWAH FLYOVER

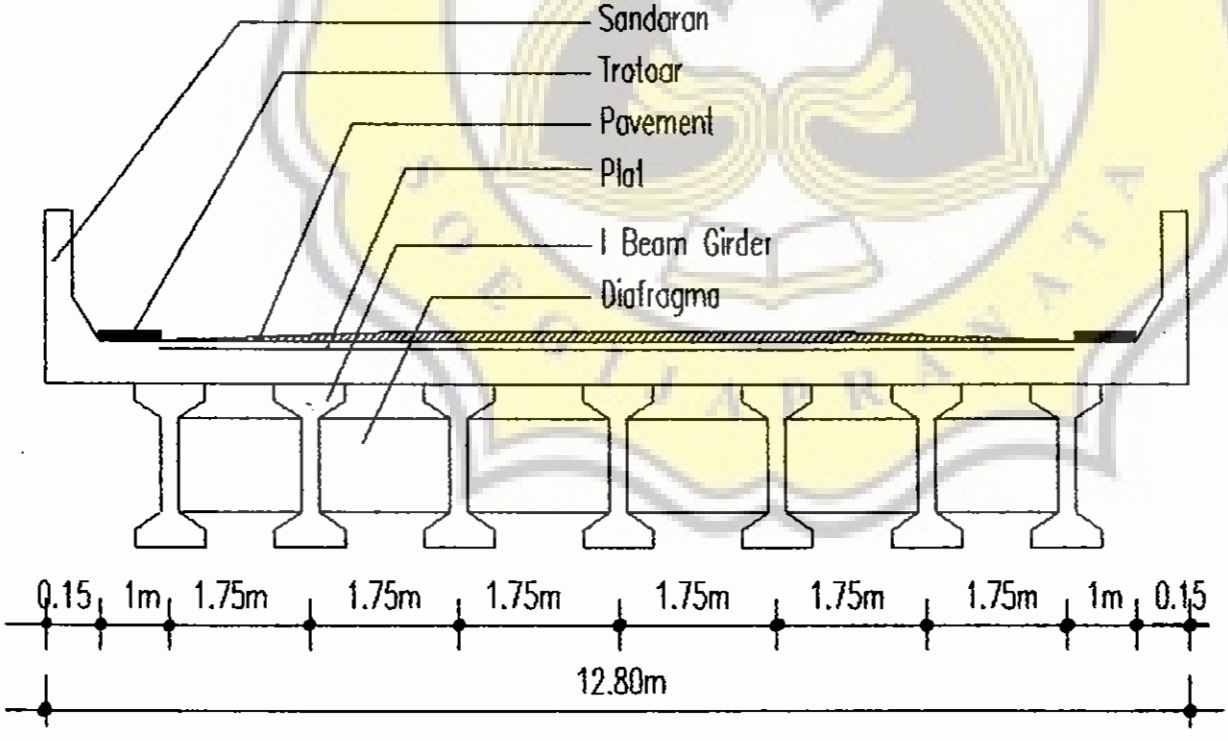


LAY OUT BUNDARAN PEMUDA

SKALA 1 : 1500



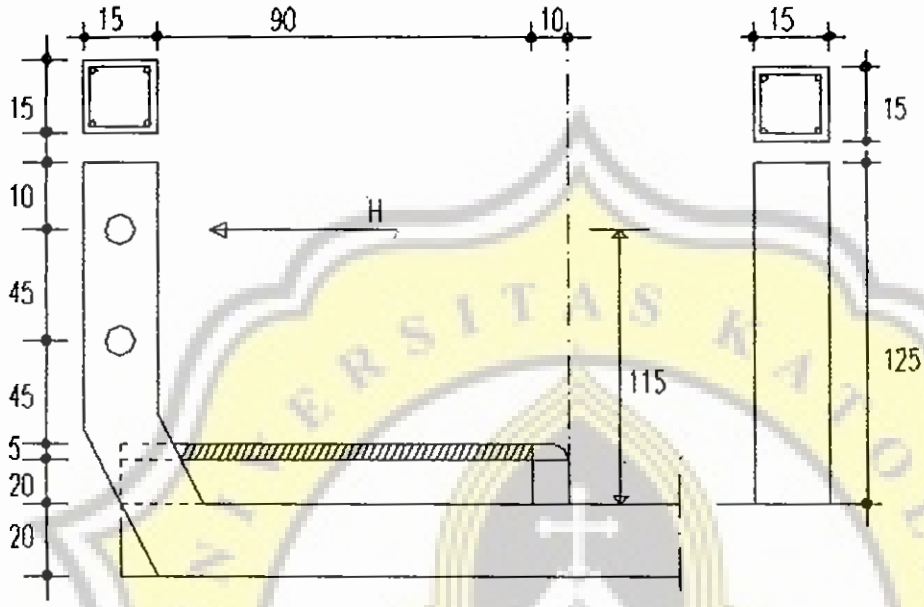
Gambar 5.2. Potongan Memanjang Flyover



Gambar 5.3 Potongan melintang Flyover

V.1.2. Perhitungan Struktur Atas

V. 1.2.1. Tiang Sandaran



Gambar 5.4. Penampang melintang tiang sandaran

* Mutu Beton : K-150 (fc = 15 Mpa = 150 kg/cm²)

* Mutu Baja : U-24 (fy = 240 Mpa = 2400 kg/cm ²)

* Jarak Sandaran : 2 m

* Dimensi Sandaran : 150 mm x 150 mm

- Lebar Tampang(b) : 150 mm
- Tinggi Tampang (h) : 150 mm
- Tebal selimut beton (p) : 30 mm
- Diameter tulangan (Øtu): 10 mm
- Diameter sengkang (Øts) : 6 mm
- Tinggi efektif (d): d = h - p - 0,5 x Øtu - Øts
  = 150 - 30 - 0,5 x 10 - 60
  = 109 mm = 0,0109 m
- Pipa Sandaran : Ø luar = 76 mm
  Ø dalam = 73 mm

Menurut PPJJR SKBI - 1987 (hal 10), tiang-tiang sandaran pada setiap tepi trotoar harus dipertimbangkan untuk dapat menahan beban horisontal sebesar 100 Kg/m, setinggi 90cm.

Beban Horisontal (H) = 100 kg/m = 1 kg/cm.

$W_L = H \times 200 = 1 \times 200\ Kg = 200\ Kg$

$M_L = 200 \times 115 = 23000\ Kgcm$

$M_U = 1{,}6 \times M_L = 1{,}6 \times 23000 = 36800\ Kgcm$

$$\frac{Mu}{b \times d^2} = \frac{36800}{15 \times 10.9^2} = 20.64\ Kg/cm^2 = 2.064\ Mpa$$

Menurut SKSNI T-15-1991-03 (Gideon Kusuma dan W.C. Vis hal. 54)

$$\frac{Mu}{b \times d^2} = \rho \times 0.8 \times f_y \times \left(1 - 0{,}588 \times \rho \times \frac{f_y}{f'_c} \right)$$

$$2.064 = \rho \times 0{,}8 \times 240 \times \left(1 - 0{,}588 \times \rho \times \frac{240}{15} \right)$$

$$2.064 = 192\,\rho - 1806.336\,\rho^2$$

$$\rho^2 - 0.1063\rho + 0.00143 = 0$$

$$\rho = 0.00125 < \rho_{min}$$

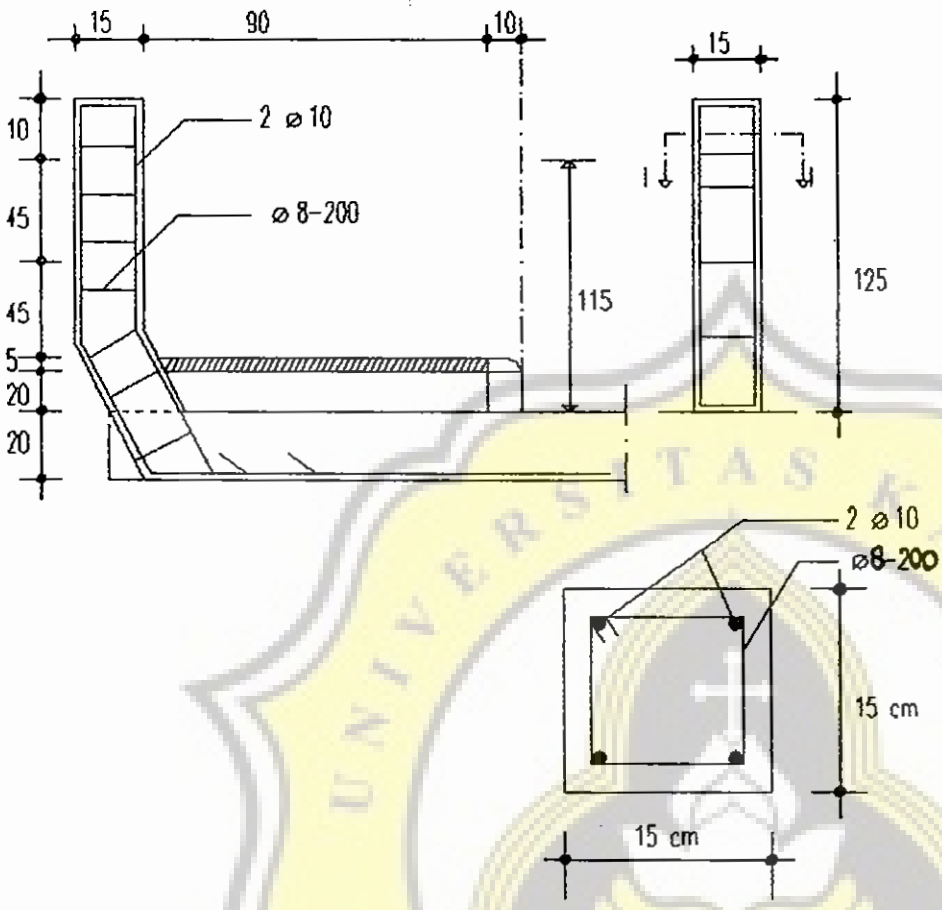
$\rho_{min} = 0.0058$ (tabel 7) Gideon Kusuma dan Wc Vis, hal 51

$\rho_{max} = 0.0242$ (tabel 8) Gideon Kusuma dan Wc Vis, hal 52

$A_s = \rho_{min}.\ b.\ d. = 94.83\ mm^2$

Dipakai tulangan : 2 Ø 10 (As=158 mm²)

Tulangan beugel praktis : Ø 8-200 (As = 251 mm²)

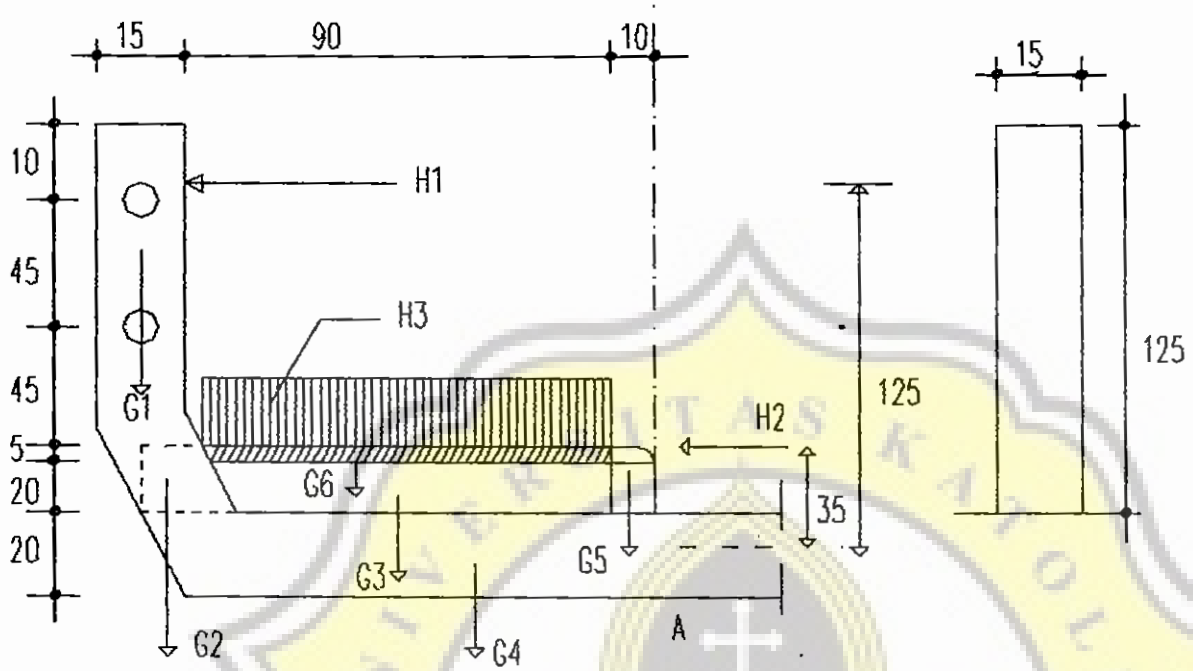


Gambar 5.5. Penulangan Sandaran

V.1.2.2. Lantai Trotoar

* Mutu beton : K-250(fc = 25 Mpa = 250 Kg/cm²)
* Mutu Baja : BJTD-24 (fy = 240 Mpa = 2400 kg/cm²
* Dimensi tampang plat lantai trotoar
  * Lebar tampang (b) = 1000 mm
  * Tinggi tampang (h) = 200 mm
  * Tebal kulit beton (p) = 30 mm
  * Diameter tulangan utama (Øtu) = 12 mm
  * Tinggi efektif (d) = h - p - 1/2 xØtu
    = 164mm = 0,164m

A. Pembebanan



Gambar 5.6. Pembebanan lantai trotoar dan jarak dalam cm

Plat lantai trotoar diasumsikan sebagai lantai kantilever. Pembebanan menurut PPJJR SKB - 1987 (ditinjau 1 m'arah memanjang), adalah sebagai berikut :

* H1= 100 kg/m, adalah gaya horisontal yang harus ditahan tiang-tiang sandaran pada setiap tepi trotoar yang bekerja pada ketinggian 90 cm diatas lantai trotoar.
* H2 = 500 kg/m, adalah muatan horisontal kearah melintang yang harus ditahan kerb, yang terdapat pada tiap-tiap lantai kendaraan yang bekerja pada puncak kerb yang bersangkutan atau pada ketinggian 25 cm diatas permukaan lantai kendaraan bila kerb yang bersangkutan lebih tinggi 25 cm.
* H3 = 500 kg/m^2, adalah muatan yang harus ditahan konstruksi dari trotoar.
* Beban Mati

  A pipa = (1/4 x3,14x7,6^2)-(1/4x3,14x7,3^2) = 3,51cm^2=3,51.E0-4 m^2

G_1 (berat pipa) = 2x 2x 3, 51.E0-4 x 7250 = 10,179 kg/m'

G_2 (berat sandaran) = 1.25x0.15²x2400 = 67.50 kg/m'

G_3 (berat trotoar) = 0.20 x 0.90 x2200 = 396.00 kg/m'

G_4 (lantai trotoar) = 0.20 x 1.00 x 2400 = 480.00 kg/m'

G_5 (berat kerb) = 1.00x0.10x0.25x2200 = 55.00 kg/m'

G_6 (berat tegel) = 1.00x1.00x24 = 24.00 kg/m'

* Momen Terhadap Potongan Titik A

  * Akibat beban hidup

M_{H1} = 100x1x1.25 = 125.00 kgm

M_{H2} = 500x1x0.35 = 175.00 kgm

M_{H3} = 500x1x1x(0.10+0.45) = 275.00 kgm +

ΣM_L = 575.00 kgm

  * **Akibat beban mati**

M_{G1} = 10,179x1,075 = 10,942 kgm

M_{G2} = 67.5x1, 075 = 72,5625

M_{G3} = 396x0.56 = 217.80 kgm

M_{G4} = 480x0.5 = 240.00 kgm

M_{G5} = 55x 0.05 =2.75 kgm

M_{G6} = 24x 0.55 =13.20 kgm +

ΣM_D = 557,2545 kgm

ΣM_{total} = 1.2 M_D + 1.6 M_L

= 1.2 x 557,2545 + 1.6 x 575.00

= 1588,7054 kgm

= 1588,7054.10.1000 Nmm

= 1,5887E + 07 Nmm

B. Penulangan

$$\frac{Mu}{bxd^2} = \frac{1.5887\ E + 07}{1000x\ 164^2} = 0.59068\ \frac{Nmm}{mm^3} = 0,59\ \frac{N}{m^2} = 0,59Mpa$$

$$\frac{Mu}{bxd^2} = \rho x 0.8x\, f_y x \left(1-0.588x\rho x \frac{f_y}{f'_c}\right)$$

$$0.59 = \rho\, x0.8x240x \left(1-0.588x\rho x \frac{240}{25}\right)$$

$0.59 = 192\,\rho - 1083.8\,\rho^2$

$\rho = 0.0031$

$\rho\ min = 0.0032$

$\rho\ max = 0.0404$

Karena $\rho < \rho$ min sehingga perhitungan tulangan dipakai ρ min

$As = \rho x b x d$

$= 0.0032x1000x164$

$= 524.8\ mm^2$

Jadi tulangan yang digunakan : ∅12 - 20 ($As = 565\ mm^2$)

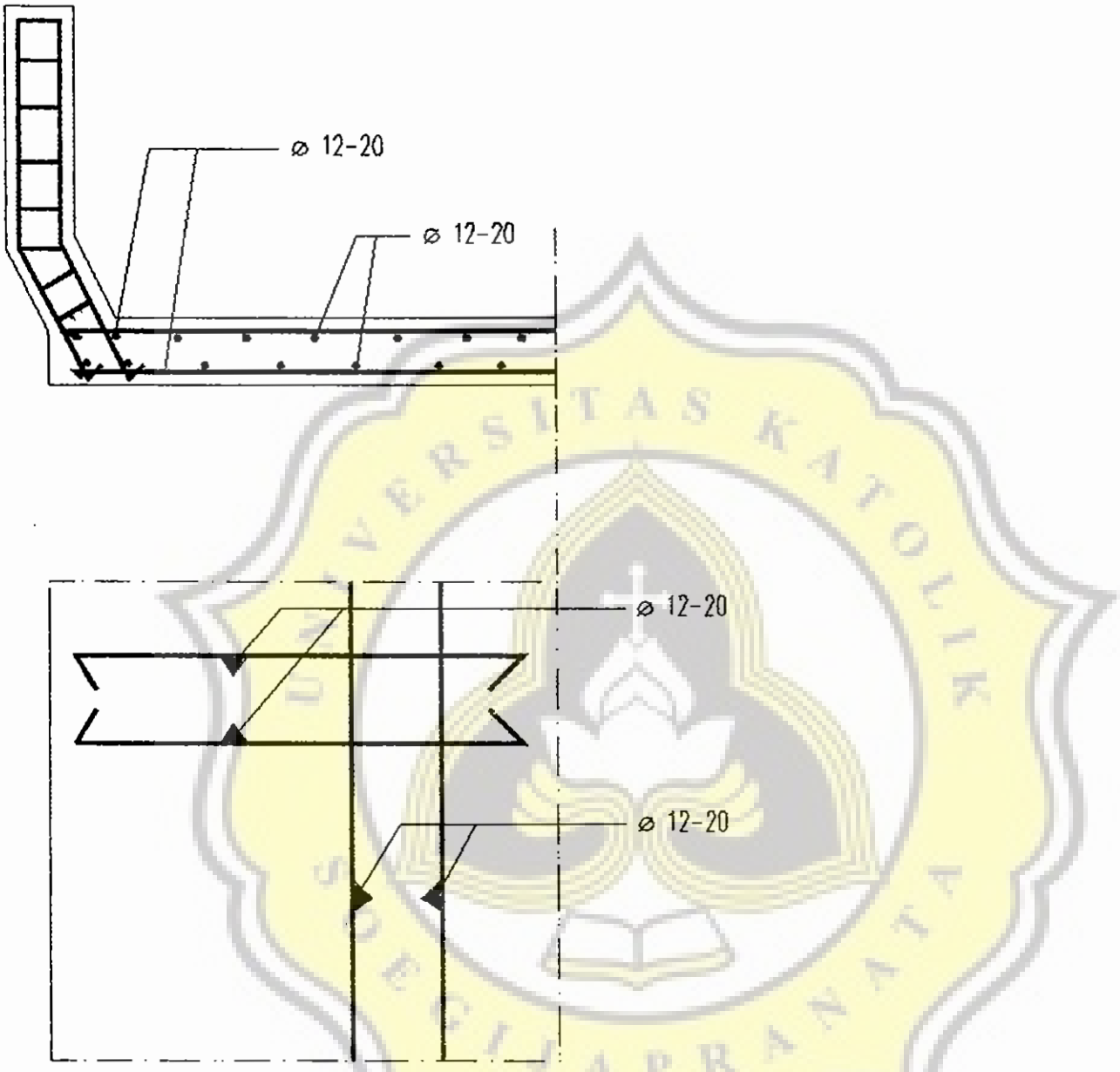
Perhitungan tulangan susut (Sesuai dengan SKSNI. T-15-1991-03, WC Vis, Gideon Kusuma, hal. 78)

$As = 0{,}0025 \times b \times h$

$= 0{,}0025 \times 1000 \times 200$

$= 500\ mm^2$

Jadi tulangan susut yang digunakan : ∅ 12-20 ($As = 565\ mm^2$)



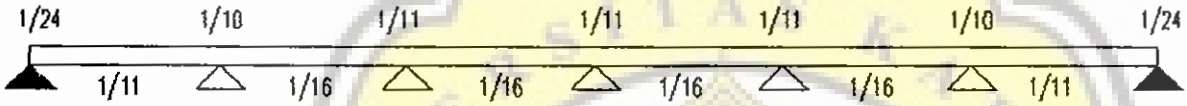
Gambar 5.7. Penulangan Plat Lantai

V.1.2.3. Perhitungan Plat Lantai

* Mutu beton = K-250
* Mutu baja BJTP 24 (fy = 240 Mpa = 2400 kg/cm²)
* Dimensi plat lantai kendaraan:
  - Lebar tampang (b) = 1000 mm
  - Tinggi tampang (h) = 200 mm

- Tebal selimut beton (p) = 30 mm
- Diameter tulangan utama (∅) =20 mm
- Tinggi efektif (d)= 200-30-1/2 x2=160 mm

Plat lantai merupakan plat menerus satu arah dengan koefisien momen plat menerus (menurut Dasar-dasar Perencanaan Beton bertulang, WC Vis, Gideon Kusuma tabel 12, hal. 75) sebagai berikut :



tumpuan sederhana

menerus diatas tumpuan

Menurut SKSNI T-15-1991-03:

$M_{lapangan} = {}^{1}/_{11} x\ WxL^2$

$M_{tumpuan} = {}^{1}/_{10} x\ WxL^2$

A. Pembebanan

1. Beban Tetap (Mati)

Beban Aspal = 0,05x1x2500 = 125 kg/m

Berat sendiri plat = 0.2x1x2400 = 480 kg/m +

W_D = 605 kg/m

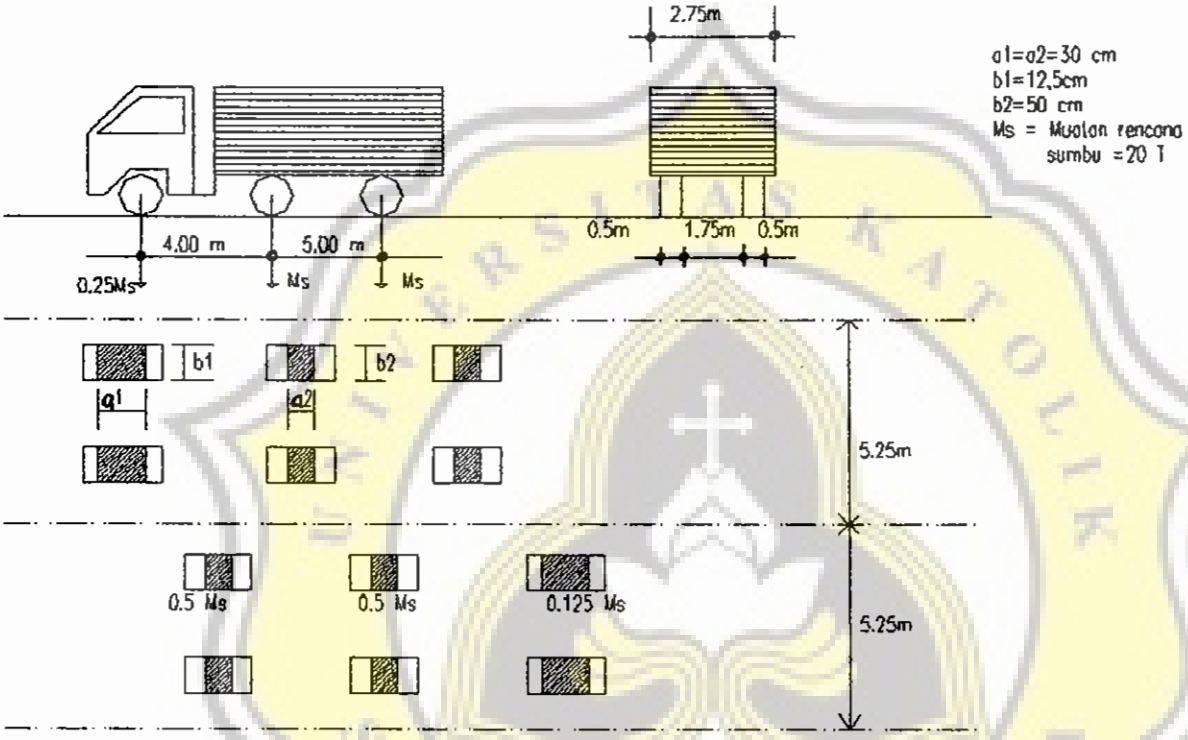
=6050 N/m

$M_{lapangan}$ = 1/11x6050x1.75² = 1684,375 Nm

$M_{tumpuan}$ = 1/10 x6050x1.75² = 1852,8125 Nm

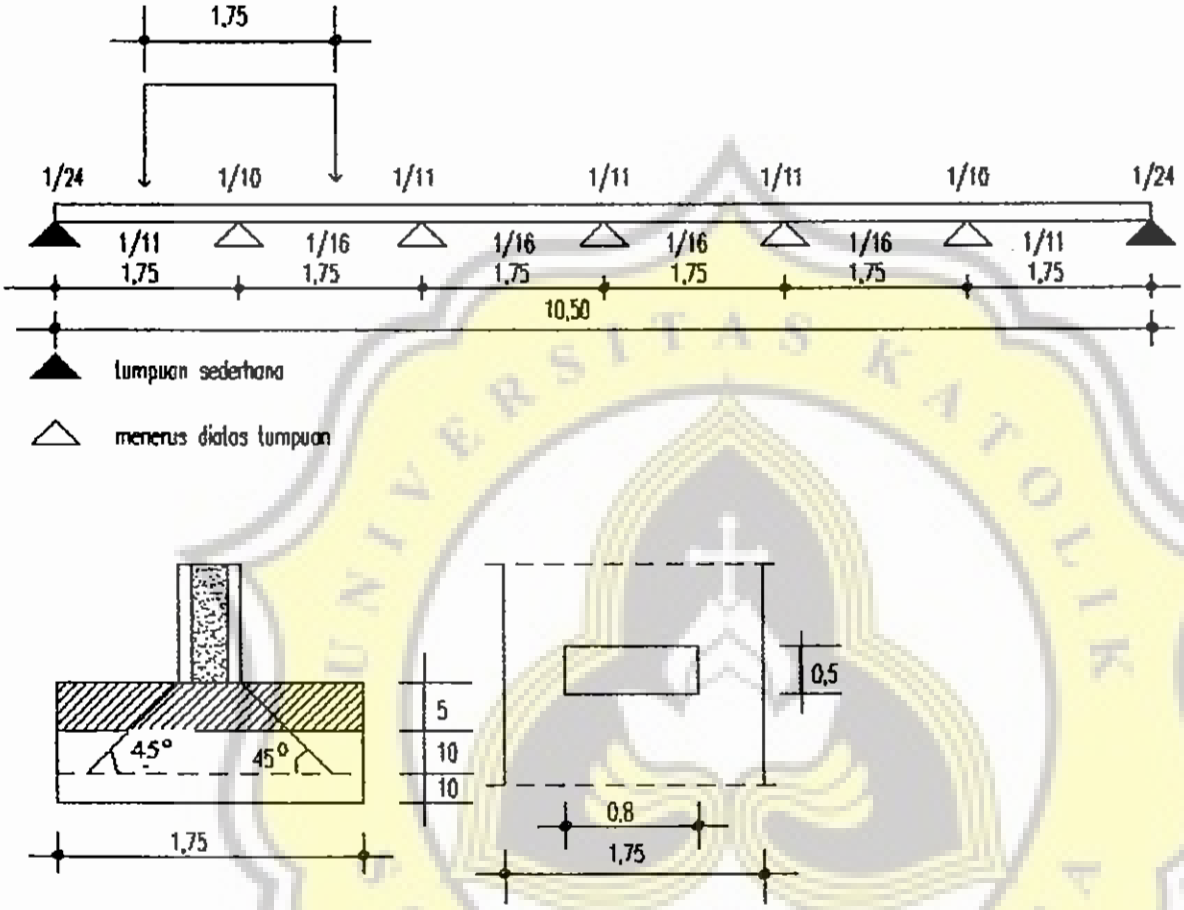
2. Beban Sementara Hidup

a. Beban Muatan T



Gambar 5.5. Beban "T"

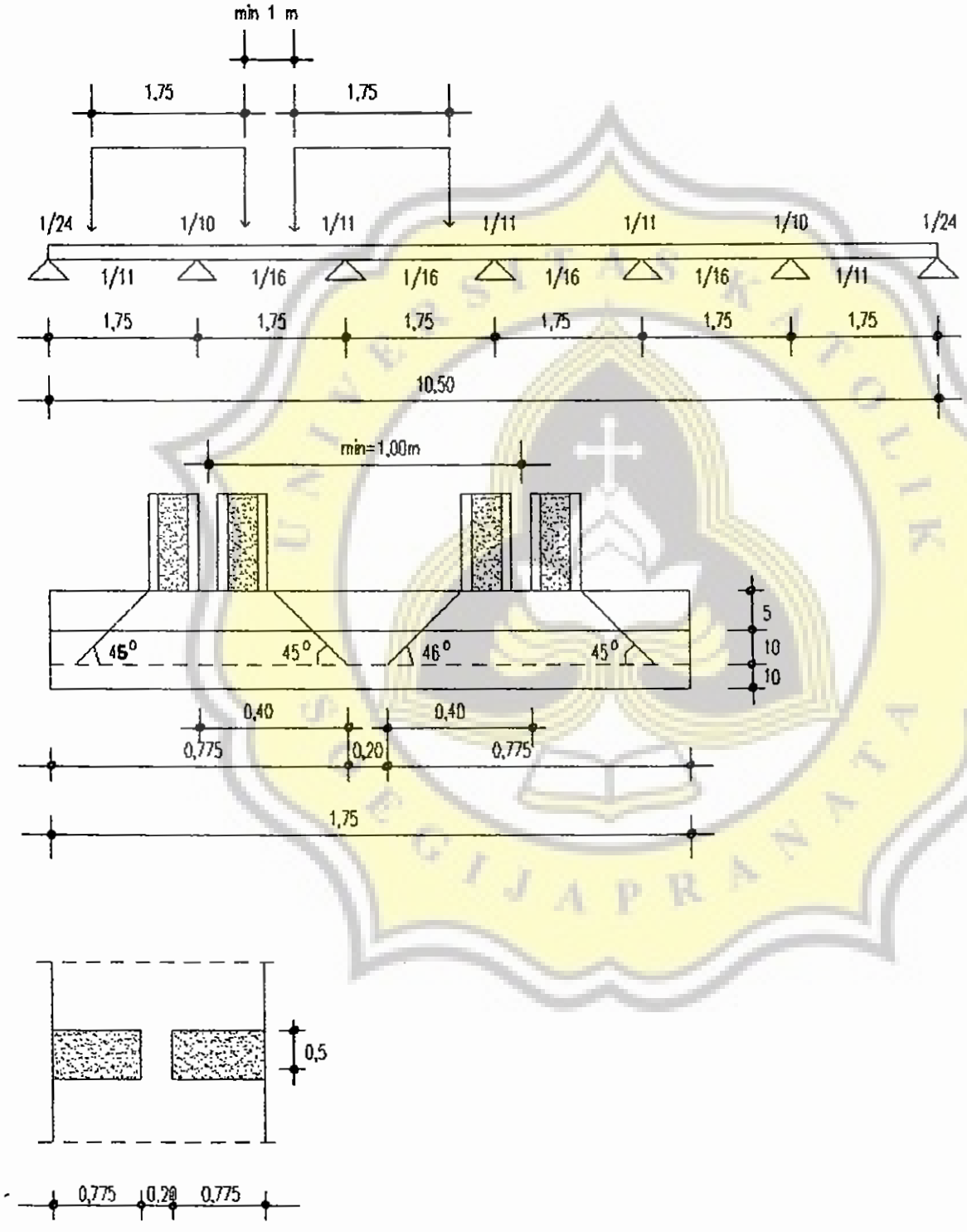
*** Saat satu roda berada pada plat :**



Gambar 5.6. Pembebanan satu roda pada plat lantai

$$W_L = \frac{100.000}{0.8x05} = 250.000 \text{ N/m}^2$$

*** Saat dua roda berada pada plat (jarak antar as roda min. 1.00m)**



Gambar 5.7. Pembebanan dua roda pada plat lantai

$$W_L = \frac{200.000}{2x(0.5\ x0.775)} = 258.064,5161\ N/m$$

Dari kedua kondisi di atas, maka diambil W_L terbesar (akibat 2 roda diatas plat), sehingga $W_{11} = 258.064,5161\ N/m^2$ (ditinjau per meter arah memanjang)

b. Beban Air Hujan

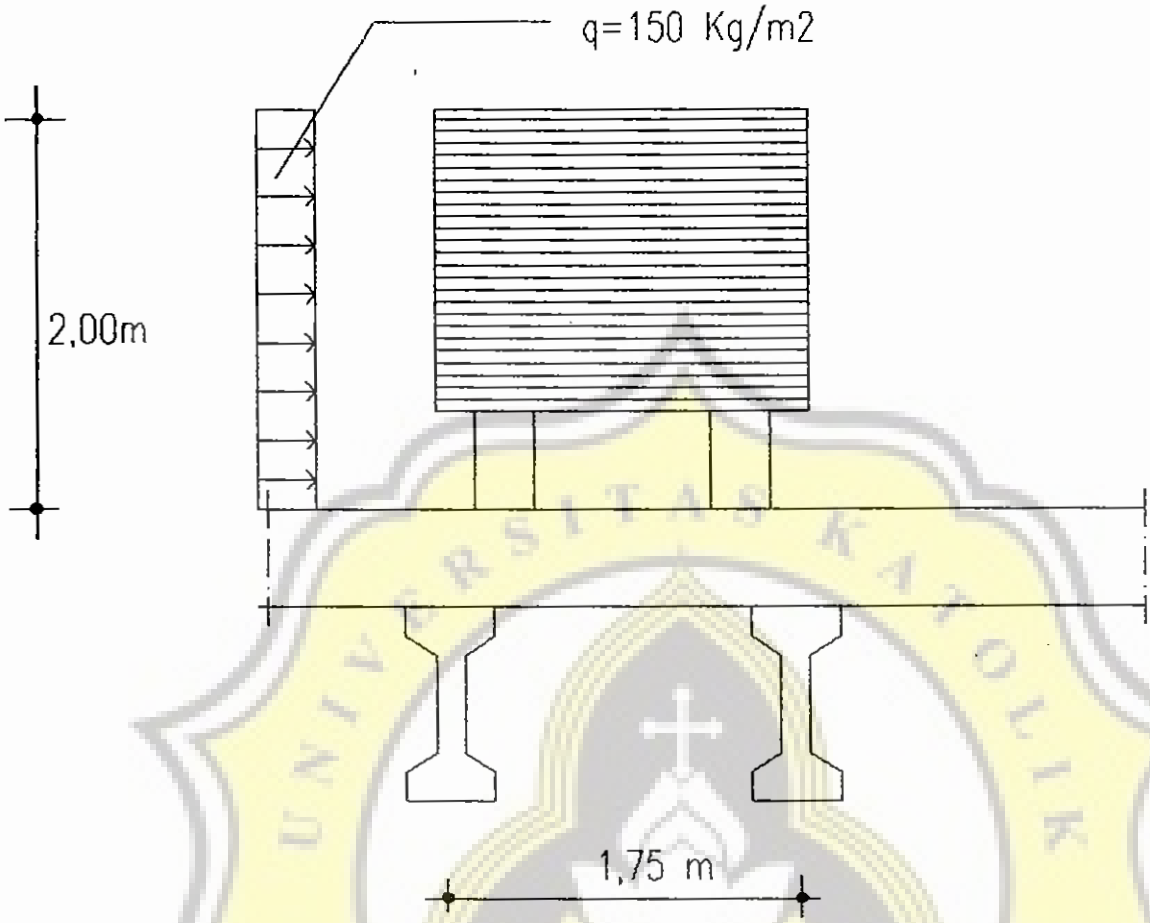
$W_{L2} = 40x1.00$

$= 40\ kg/m$

$= 400\ N/m$

c. Beban Angin

Beban angin yang bekerja adalah sebesar q sebesar $q = 150\ kg/m^2$ (PPJR 1987 hal,13)



Reaksi pada roda :

$$R = \frac{2x5x1x150}{1,75} = 857,143 \text{ Kg}$$

(beban angin menjadi muatan "T")

$$W_{L3} = \frac{857,143}{0,8x0,5} = 2142,86 \text{ N/m}$$

Sehingga diperoleh $W_L = W_{L1}+W_{L2}+W_{L3} = 258064,516+400+2142,86$

$= 260.607,376$ N/m

B. Momen Rencana

1. Momen Akibat Beban Hidup/M_L (Beban T + Angin + Air Hujan) :

$M_{L\ lapangan} = 1/11 * W_L * L^2 = 1/11*260.607,376*1.75^2$

= 72555,4626 Nm

$M_{L\ tumpuan}$ = 1/10*W_L*L^2 = 1/10*260.607,376*1.75^2

= 79811,0089 Nm

2. Momen Total Rencana (MD +ML):

$M_{U\ lapangan}$ = 1,2*1684,375+1,6*72555,4626

= 118109,9902 Nm = 1,18E + 08 Nmm

$M_{U\ tumpuan}$ = 1,2 x 1852,8125 + 1,6 x 79811,0089

= 1,299E + 05 Nm

= 1,299E + 08 Nmm

C. Penulangan Plat Lantai Kendaraan

1. Tulangan Lapangan

$$\frac{Mu}{bxd^2} = \frac{1,18E+08}{1000x160^2} = 4,61\ Mpa$$

$$4,61 = \rho x0.8x240x(1-0.588x\rho x\frac{240}{25})$$

$4,61 = 192\rho - 1083,8\ \rho^2$

$\rho = 0,0286$

$\rho min = 0,0032$

$\rho max = 0,0404$

Karena $\rho min < \rho < \rho max$ sehingga perhitungan tulangan dipakai ρ

As = ρxbxdx

= 0,0286x 1000x160 = 4576 mm^2

Jadi digunakan tulangan Ø 19-50 (As = 5671 mm^2)

2. Tulangan Tumpuan

$$\frac{Mu}{bx\ d^2} = \frac{1{,}299E+08}{1000x160^2} = 5{,}074\ Mpa$$

$$5{,}074 = \rho x0{,}8x240x\left(1 - 0.588 \times \rho x \frac{240}{25}\right)$$

$$5{,}074 = 192\ \rho - 1083{,}8\rho^2$$

$$\rho = 0{,}0323$$

$\rho min = 0{,}0032$

$\rho\ max = 0{,}0404$

Karena $\rho min < \rho < \rho max$ sehingga perhitungan tulangan dipakai ρ

$As = \rho x b\ xd$

$= 0{,}0323x1000x160 = 5168\ mm^2$

Jadi digunakan tulangan ∅ 19-50 ($As = 5671\ mm^2$)

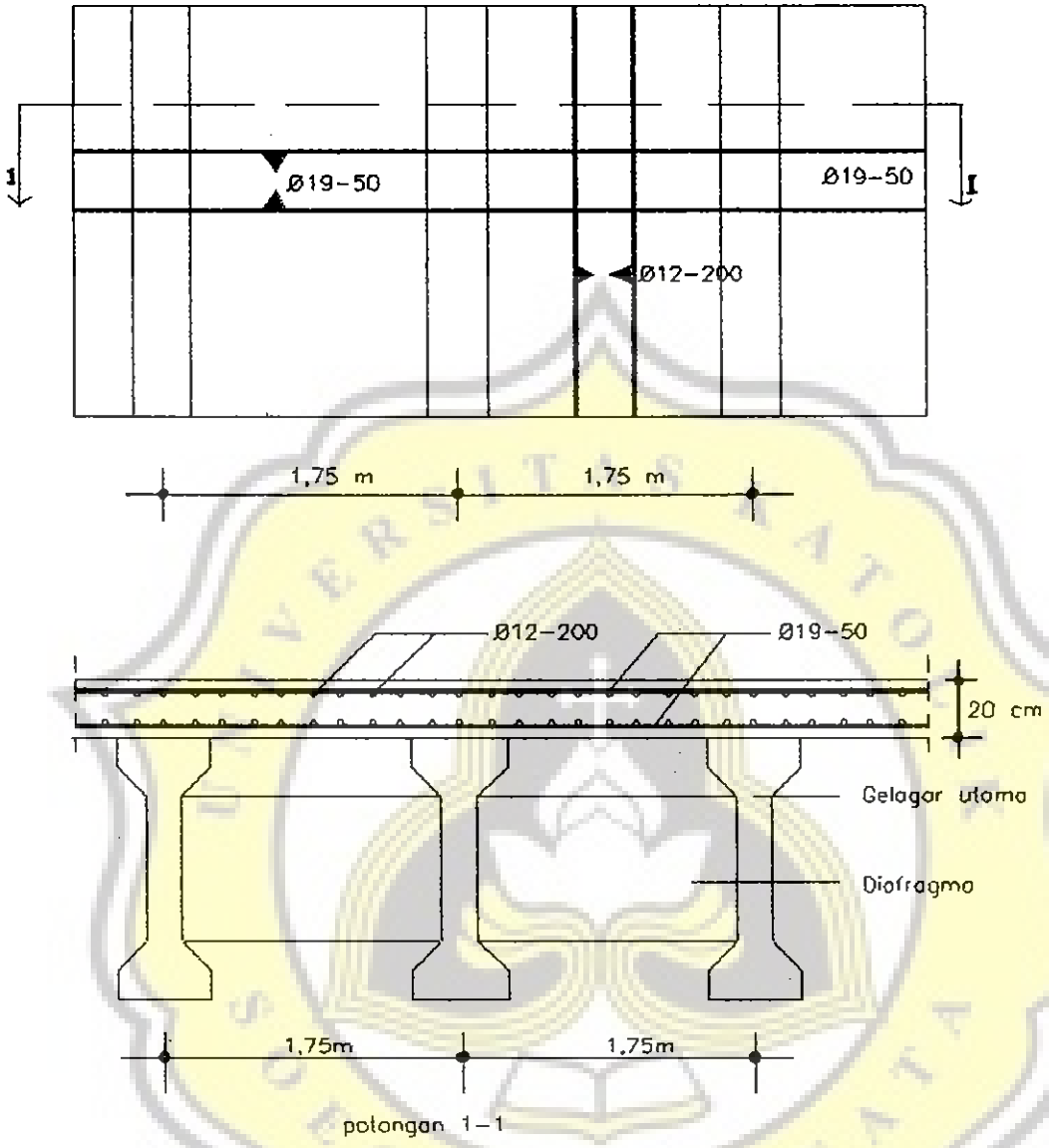
3. Tulangan susut

$As = 0{,}0025xbxh$

$= 0{,}0025x1000x200$

$= 500\ mm^2$

Jadi tulangan susut yang digunakan : ∅ 12-200 ($As = 565\ mm^2$) (Sesuai dengan SKSNI T.15-1991-03 Pasal 3.16.12, dalam arah tegak lurus terhadap tulangan utama harus disediakan tulangan pembagi (demi tegangan susut dan suhu) W.C. Vis, Gideon Kusuma hal, 78 untuk fy = 240 Mpa : As susut $= \frac{0.25}{100}$ .b.h)



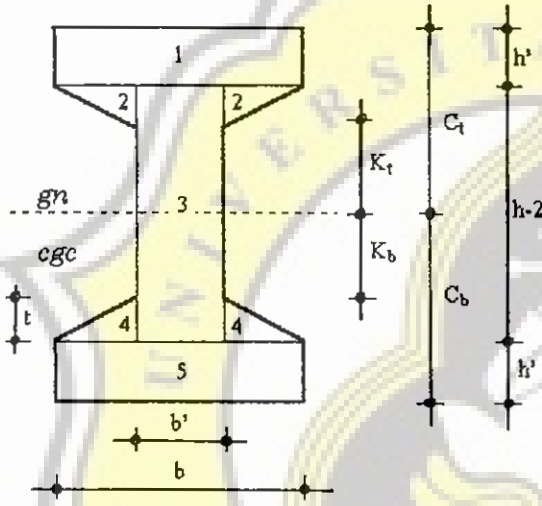
Gambar 5.8. Penulangan plat lantai jembatan.

V.1.2.4. Perhitungan Gelagar (Bentang 30 m)

Spesifikasi :

- Beton pratekan sistem posttension
- Mutu beton : K-500(f'c = 500 Kg/cm²=50 Mpa)
- Baja mutu BJTD 40(fy = 4000 Kg/cm²=400 Mpa)

A. Dimensi Gelagar



Di mana : $h = 1600$ *mm*
$b = 950$ *mm*
$t = 150$ *mm*
$h' = 200$ *mm*
$b' = 350$ *mm*
gn = garis normal

Gambar 5.9. Penampang gelagar pratekan

A_x = *Luas penampang*

A_c = *Luas Penampang total*

$S_x = A_x * Y$

I_x = *Momen Inersia tiap luasan*

$I_c = I_x + A_x * (Y_1 - Y_0)^2$

I = *Momen inersia penampang balok pratekan*=I_c

Tabel 5.1. Section properties gelagar utama

	Ax (mm^2)	Y(mm)	Sx (mm^3)	Ix(mm^4)	Ax*(Y_1-Y_0)^2	Ic (mm^4)
1	1,9E+05	1500	2,85E+08	6,33E+08	9,31E+10	9,373E+10
2	4,5E+04	1350	6,075E+07	4,22E+07	1,363+10	1,367E+10
3	4,2E+05	800	3,36E+08	5,04E+10	0	5,04E+10
4	4,5E+04	250	1,125E+07	4,22E+07	1,363+10	1,367E+10
5	1,9E+05	100	1,9E+07	6,33E+08	9,31E+10	9,373E+10
Ac=	8,9E+05	Sc=	7,12E+08		Ic =	2,652E+11

A_C =8,9E+05 mm^2 S_C = 7,12E+08 mm^3

I_C = 2,652E+11 mm^4

$C_b = C_t = S_c / A_c$

$= \frac{7{,}12\,E+08}{8{,}9\,E+05}$

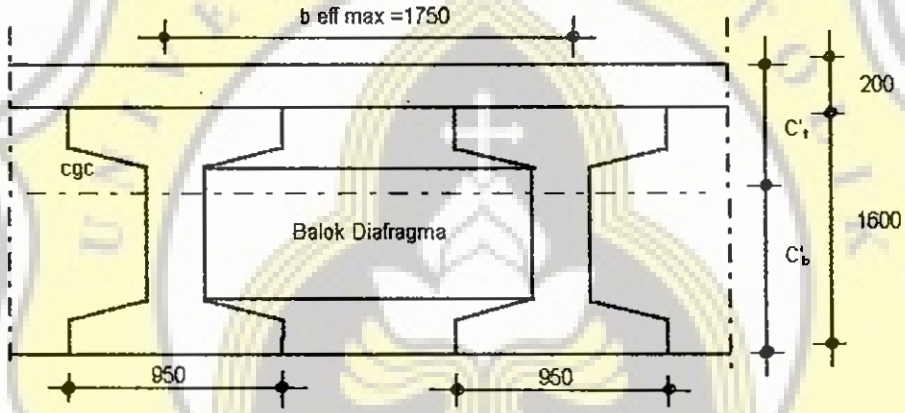
$= 800$ mm

$K_b = K_t = \frac{I}{(A_c * C_t)}$

$= \frac{2{,}652E+11}{8{,}9E+05*800}$

$= 372{,}5$ mm

❑ Balok Komposit



Gambar 5.10. Penampang komposit

Penampang Komposit

$b_{eff\ max.}$ = 1750 mm (jarak bersih antara gelagar)

$n = \frac{\varepsilon_b 250}{\varepsilon_b 450} = \frac{\text{Ec plat}}{\text{Ec balok}} = \frac{6400*\sqrt{250}}{6400*\sqrt{500}}$

$= 0{,}707$

$b_{eff} = 0{,}707*1750 = 1237$ mm

sehingga digunakan b_{eff} = 1237 mm (Ty Lin Ned, hal 201 PBI 1971, hal 131)

$A_{slab} = h_{slab} * b_{eff}$

$= 200 * 1237$

$= 2{,}475\ E+05\ mm^2$

$A_c' = A_{slab} + A_c$

$= (2{,}475E{+}05) + (8{,}9E{+}05)$

$= 1{,}1375E{+}06\ mm^2$

$S_c' = (A_c * C_b) + [A_{slab}(h + 0{,}5 * h_{slab})]$

$= (8{,}9E{+}05 * 800) + [2{,}475E{+}05\ (1600{+}0{,}5{*}200)]$

$= 1{,}1327\ E{+}09\ mm^3$

$$C_b' = \frac{S_c'}{A_c'}$$

$$= \frac{1{,}1327E{+}09}{1{,}1375E{+}06} = 995{,}7\ mm$$

$C_t' = h + h_{slab} - C_b'$

$= 1600 + 200 - 995{,}7$

$= 804{,}3\ mm$

$$I_c' = I_c + A_c (C_b' - C_b)^2 + \frac{1}{12} * b_{eff} * h_{slab}^3 + A_{slab} (C_t' - 0{,}5\ h_{slab})^2$$

$$= 2{,}652E{+}11 + 8{,}9E{+}05\ (995{,}7 - 800)^2 + \frac{1}{12} * 1237 *$$

$200^3 + 2{,}475E{+}05\ (804{,}3 - 0{,}5 * 200)^2$

$= 4{,}202\ E{+}11\ mm^4$

$$K_b' = \frac{I_c'}{A_c' * C_t'}$$

$$= \frac{4{,}202E{+}11}{1{,}1375E{+}06 * 804{,}3} = 459{,}29\ mm$$

$$K_t' = \frac{I_c'}{A_c' * C_b'}$$

$$= \frac{4{,}202E{+}11}{1{,}1375E{+}06 * 995{,}7} = 371{,}01\ mm$$

❑ Perbandingan Modulus Penampang Balok Dengan Balok Setelah Komposit

$$m_b = \frac{I_c / C_b}{I_c' / C_b'}$$

$$= \frac{2{,}652E{+}11 / 800}{4{,}202E{+}11 / 995{,}7}$$

$= 0{,}7855$

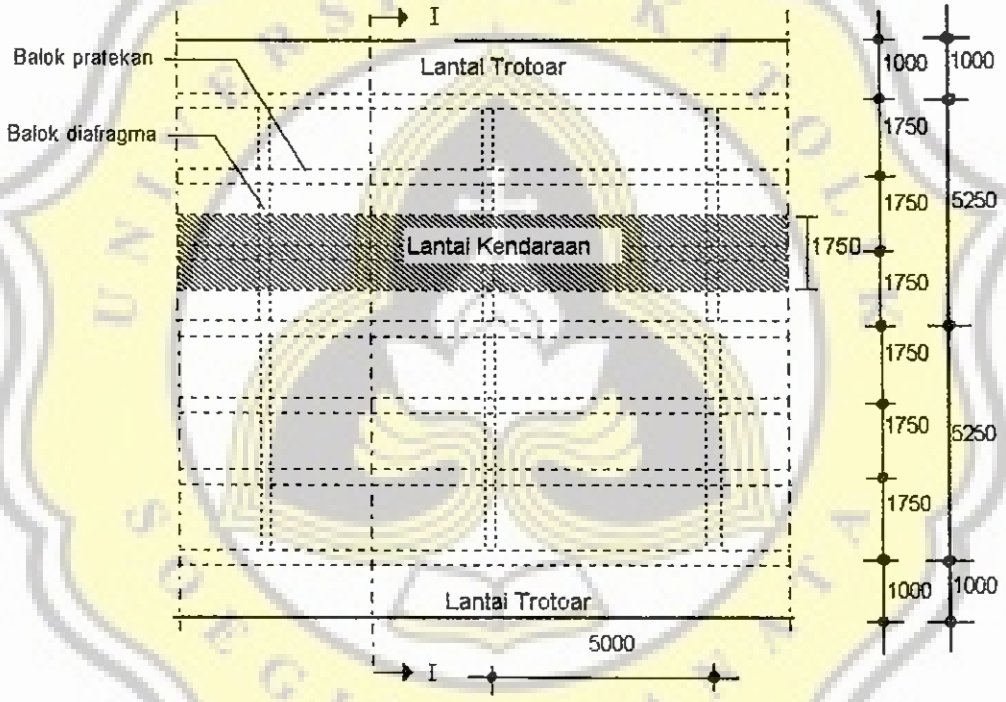
$$m_t = \frac{I_o / C_t}{I_o' / C_t'}$$

$$= \frac{2{,}652E+11/800}{4{,}202E+11/804{,}3}$$

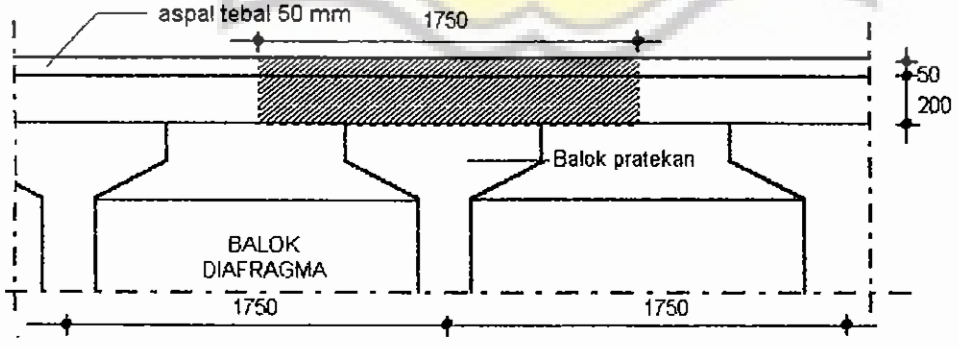
$$= 0{,}6345$$

B. Pembebanan Pada Gelagar

Perhitungan gelagar utama didasakan pada beban yang bekerja pada gelagar tengah (tipikal)



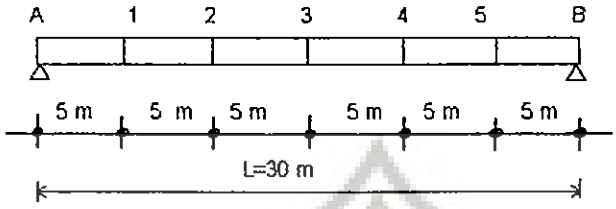
Gambar 5.11 . Denah pembebanan



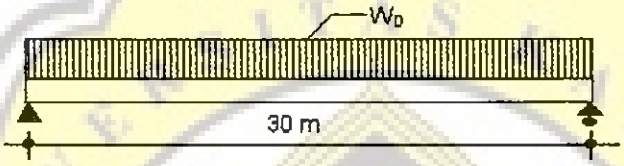
Gambar 5.12. Potongan I - I

❑ Perhitungan Mekanika Gelagar

1. Akibat Beban Mati / DL (PPPJJR SKBI 1987, hal 4)



a. Beban Merata (Gelagar + Plat + Aspal)



Berat balok prestress	= 0,89 * 2500	=	2225 Kg/m
Berat plat	= 0,2 * 1,75 * 2400	=	840 Kg/m
Berat Aspal	= 14 *5 *1,75	=	122,5 Kg/m
	W_D	=	3187,5 Kg/m
		=	31875 N/m

W_D = 31875 N/m = 3,1875E+04 N/m

$R_A = 0{,}5 * W_D * L = \frac{1}{2} * 31875 * 30 = 4{,}78E+05$ N

$M_x = R_A * x - \frac{1}{2} * WD * x^2$

$M_1 = 4{,}78E+05 * 5 - \frac{1}{2} * 3{,}1875E+04 * 5^2 = 1{,}9900E+06$ Nm

$M_2 = 4{,}78E+05 * 10 - \frac{1}{2} * 3{,}1875E+04 * 10^2 = 3{,}19000E+06$ Nm

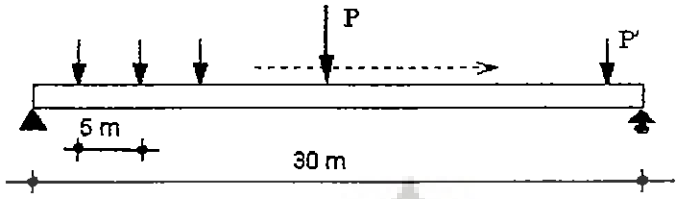
$M_3 = 4{,}78E+05 * 15 - \frac{1}{2} * 3{,}1875E+04 * 15^2 = 3{,}584E+06$ Nm

$M_4 = 4{,}78E+05 * 20 - \frac{1}{2} * 3{,}1875E+04 * 20^2 = 3{,}19000E+06$ Nm

$M_5 = 4{,}78E+05 * 25 - \frac{1}{2} * 3{,}1875E+04 * 25^2 = 1{,}9900E+06$ Nm

$M_{max} = \frac{1}{8} * 3{,}1875E+04 * 30^2 = 3{,}586E+06$ Nm

b. Akibat Beban Terpusat (Balok Diafragma)



Balok Diafragma (P') = (0,2*0,745*1,4)*2400

= 500,64 Kg*10 m/dt²

= 5,0064E+03 N

Jumlah balok diafragma (Jarak = 5m)=30/5 + 1 = 7 buah

P_{total} = 5,0064E+03 N * 7

= 3,5045E+04 N

$$RA = \frac{5{,}0064E+03*(5+10+15+20+25+30)}{30}$$

= 1,75224E+04 N

Momen

M1 = M5 = (RA-P1)*x1

= (1,75224E+04 - 5,0064E+03)*5

= 6,258E+04 Nm

M2 = M4 = (RA-P2)*x2- P1*x1

= (1,75224E+04 - 5,0064E+03)*10 - 5,0064*5

= 1,00124E+05 Nm

M3 = (RA-P3)*x3- P1*x1-P2*x2

= (1,75224E+04 - 5,0064E+03)*10 - 5,0064*10 - 5,0064*5

= 1,1264E+05 Nm

Gaya Lintang

DA = RA = 1,75224E+04 N

D1 = - D5 = RA - P = 1,75224E+04 -5,0064E+03 = 1,252E+04 N

D2 = - D4 = RA - 2P = 1,75224E+04 - 2*5,0064E+03

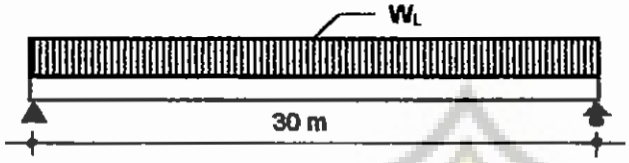
= 7,5096E+03 N

D3 = RA - 3P = 2,5032E+03 N

2. Akibat Beban Hidup / LL

a. Beban Merata (Air Hujan)

(PPP JJR SKBI 1987 Pasal 1 Ayat 1 hal 4)



Air hujan = 0,04 * 1000 * 1,75

= 70 Kg/m

= 700 N/m

W_L = 700 N/m = 7E+02 N/m

R_A = 0,5 * WD*L = $\frac{1}{2}$ * 700*30

=10500 N

$M_x = R_A * x - \frac{1}{2} * W_L * x^2$

$M_1 = 10500 * 5 - \frac{1}{2} * 700 * 5^2$ = 4,375E+04 Nm

M_2 =10500 * 10 - $\frac{1}{2}$ *700 *10^2 = 7E+04 Nm

M_3 = 10500* 15 - $\frac{1}{2}$ *700 *15^2 = 7,875E+04 Nm

M_4 = 10500 * 20 - $\frac{1}{2}$ *700 *20^2 = 7E+04 Nm

M_5 = 10500* 25 - $\frac{1}{2}$ *700 *25^2 = 4,375E+04 Nm

$M_{max} = \frac{1}{8} * 700 * 30^2$ =7,875E+04 Nm

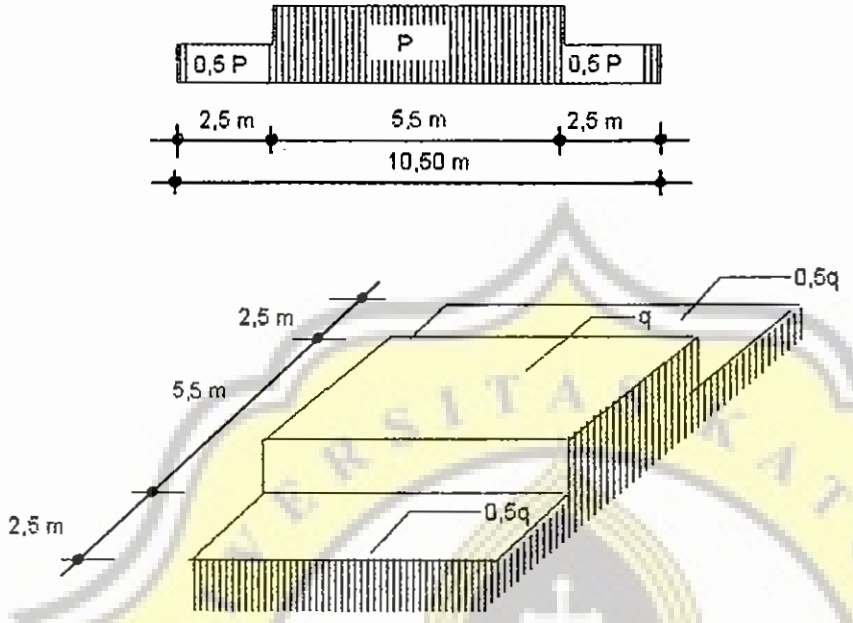
b. Beban Merata (Beban "D")

Beban q' (dari beban D) untuk bentang $30 \le L \le 60$ m

q' = 2,2 - 1,1/60 (L - 30)

= 2,2 - 1,1/60 (50 - 30)

= 1,833 T/m^2 = 1833 Kg/m^2



Gambar 5.13. Ketentuan penggunaan beban "D" (PPPJJR SKBI 1987 hal,8)

$$q = \frac{q'}{2,75} * 1,75$$

$$= \frac{1833}{2,75} * 1,75$$

$$= 1166,45 \text{ Kg/m}$$

$$= 11664,5 \text{ N/m}$$

c. Akibat Beban Garis (Beban "D")

P = 12 Ton/jalur (PPPJJR - hal. 7)

Koefisien kejut (K) $= 1 + \frac{20}{50+L}$ (PPPJJR - hal. 10)

$$= 1 + \frac{20}{50+30}$$

$$= 1,2$$

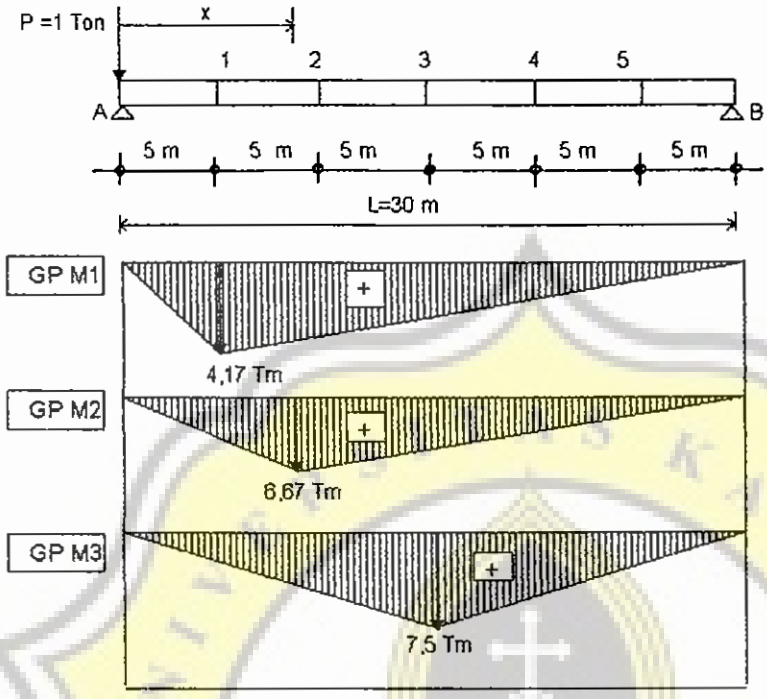
$$P_L = \frac{P}{\text{Lebar lajur PPPJJR}} * \text{Jarak gelagar} * K$$

$$= \frac{P}{2,75} * 1,75 * 1,2$$

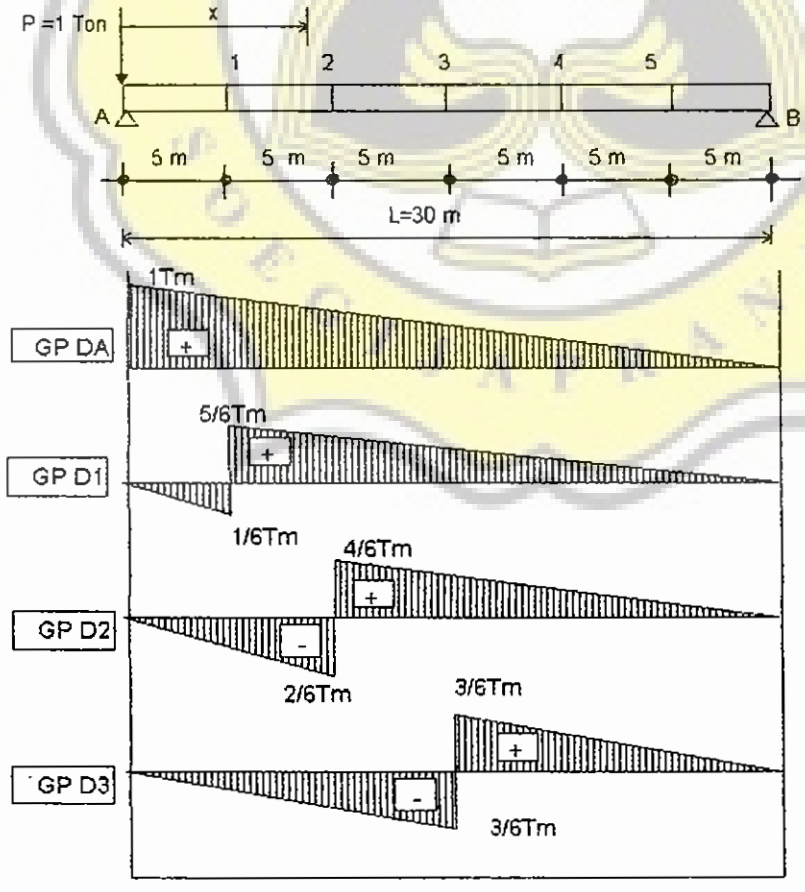
$$= 9,16 \text{ ton}$$

$$= 91.600 \text{ N}$$

Garis pengaruh momen (RA*x)



Garis pengaruh gaya lintang (-RA + Dx)



Momen yang terjadi

$M_1 = M_5 = (9{,}16*4{,}17)+(\frac{1}{2}*1{,}16645*30*4{,}17) = 111{,}159$ Tm

$M_2 = M_4 = (9{,}16*6{,}67)+(\frac{1}{2}*1{,}16645*30*6{,}67) = 177{,}8$ Tm

$M_3 = (9{,}16*7{,}5)+(\frac{1}{2}*1{,}16645*30*7{,}5) = 199{,}9256$ Tm

Gaya lintang yang terjadi

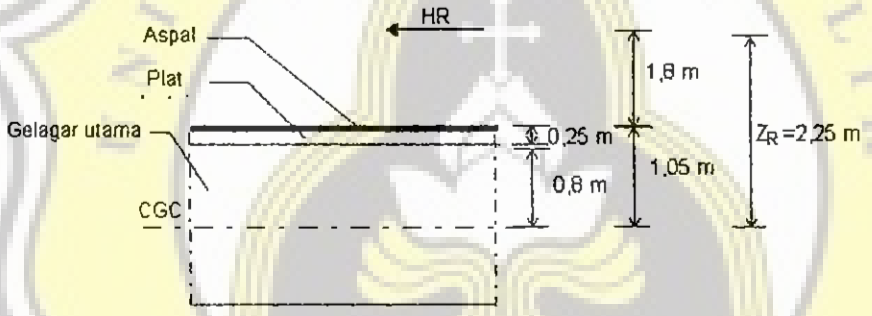
$D_A = (1*9{,}16)+(\frac{1}{2}*1*30*1{,}16645) = 26{,}65675$ T

$D_1 = (\frac{5}{6}-\frac{1}{6})*9{,}16+\{(\frac{1}{2}*\frac{5}{6}*25)-(\frac{1}{2}*\frac{1}{6}*5)\}*1{,}16645 = 17{,}7712$ T

$D_2 = (\frac{4}{6}-\frac{2}{6})*9{,}16+\{(\frac{1}{2}*\frac{4}{6}*20)-(\frac{1}{2}*\frac{2}{6}*10)\}*1{,}16645 = 8{,}8856$ T

$D_3 = 0$

d. **Akibat Rem Dan Traksi**



Dari perhitungan muatan D diketahui :

P = 12 T/jalur (PPPJJR - hal. 7)

q' = 1,833 T/m/jalur

Akibat muatan D untuk plas 1,75 m

$$P_1 = \frac{\text{Jarak gelagar}}{\text{Lebar lajur PPPJJR}} * P = \frac{1{,}75}{2{,}75} * 12 = 7{,}6364 \text{ T}$$

$$P_2 = \frac{\text{Jarak gelagar}}{\text{Lebar lajur PPPJJR}} * q' * L = \frac{1{,}75}{2{,}75} * 1{,}833 * 30 = 40{,}091 \text{ T}$$

$P_L = P_1 + P_2 = 7{,}6364 + 40{,}091 = 47{,}7273$ T

$H_R = 5\% * P_L = 5\% * 47{,}7273$

$= 2{,}386$ T

$M_R = H_R * Z_R$

$= 2{,}386 * 2{,}25 = 5{,}3693$ TM $= 5{,}3693E+04$ Nm

e. Akibat Angin

Pengaruh angin q =150 Kg/m^2

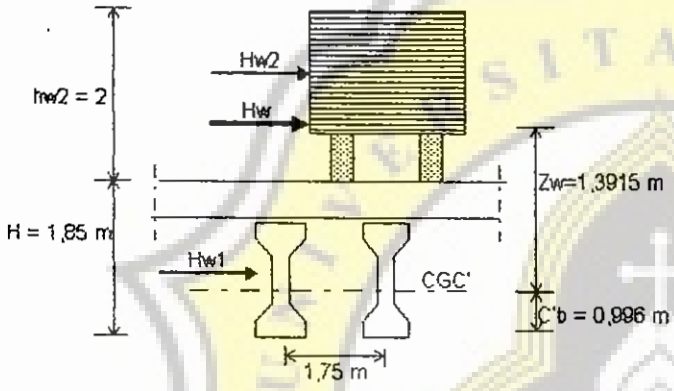
Keadaan dengan beban hidup, gelagar penuh (PPPJJRhal. 13):

⇒ Beban angin pada Jembatan (H_{w1}):

Luas sisi jembatan = 0,5 *(100% sisi I + 50% sisi II)

⇒ Beban angin pada kendaraan (H_{w2}):

Luas sisi kendaraan = 100% *luas bidang sisi kendaraan



H_{w1} =0,5*(100%*H +50%H)*q

=0,5*(150%*1,85)*150

= 208,125 Kg/m'

H_{w2} = 100%*h_{w2}* 150

=100%*2*150

= 300 Kg/m'

H_w = H_{w1}+H_{w2}

= 208,125 + 300

= 508,125 Kg/m'

Zw = 0,5 * (h_{w2}+150% *H) - C'$_b$

=0,5*(2+2,775) - 0,996

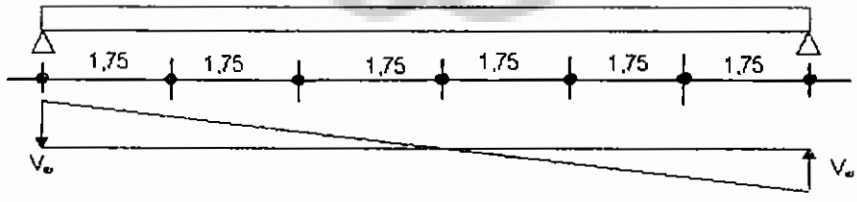
= 1,3915 m

Momen akibat angin :

M_{Luar} = Z_w*H_w

= 1,3915 *508,125 Kg/m'

= 707,056 Kgm/m' = 7,071E+03 Nm/m'



Momen dalam (M_{dalam})

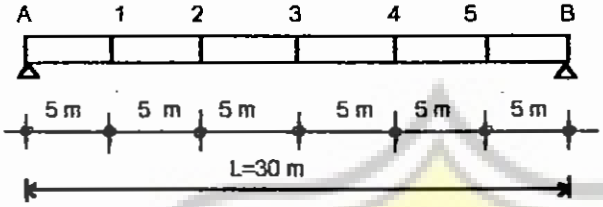
$$= 2*V_w*5,25 + 2*V_w*\frac{1,75^2}{5,25}$$

$$= 11,667V_w$$

$M_{dalam} = M_{Luar}$

$11,667 * V_w = 7,071E+03$ Nm

$V_w = 6,061E+02$ N/m'



$R_A = \frac{1}{2} * 6,061E+02*30 = 9,090E+03$ N

Momen yang terjadi :

$M_x = RA*x - \frac{1}{2} * q * x^2$

$M_1 = M_5 = 9,090E+03*5 - \frac{1}{2}*6,061E+02*5^2 = 3,790E+04$ Nm

$M_2 = M_4 = 9,090E+03*10 - \frac{1}{2}*6,061E+02*10^2 = 6,06E+04$ Nm

$M_3 = 9,090E+03*15 - \frac{1}{2}*6,061E+02*15^2 = 6,820E+04$ Nm

Gaya lintang yang terjadi

$Dx = R_A - q*x$

$D_A = D_B = R_A = 9,090E+03$ N

$D_1 = D_5 = 9,090E+03 - 6,061E+02*5 = 6,059E+03$ N

$D_2 = D_4 = 9,090E+03 - 6,061E+02*10 = 3,029E+03$ N

$D_3 = 0$

Selanjutnya perhitungan momen dapat dilihat pada tabel 5.2. Perhitungan momen dan Tabel 5.3. Perhitungan gaya lintang pada gelagar (L= 30 m).

Tabel 5.2. Perhitungan momen pada gelagar

Titik	Jarak (m)	Beban Mati/M_D (Nm)		Beban Hidup / M_L (Nm)				Total (Nm)
		Merata	Terpusat	Air	D	Rem	Angin	$1,2M_D+1,6M_L$
A	0	0	0	0	0	5,3693E+04	0	8,5910E+04
1	5	1,9900E+06	6,258E+04	4,375E+04	1,112E+06	5,3693E+04	3,790E+04	4,4590E+06
2	10	3,1900E+06	1,0012E+05	7E+04	1,778E+06	5,3693E+04	6,06E+04	7,0880E+06
3*	15	3,584E+06	1,1264E+05	7,875E+04	1,999E+06	5,3693E+04	6,820E+04	**7,970E+06**
4	20	3,1900E+06	1,0012E+05	7E+04	1,778E+06	5,3693E+04	6,06E+04	7,0880E+06
5	25	1,9900E+06	6,258E+04	4,375E+04	1,112E+06	5,3693E+04	3,790E+04	4,4590E+06
B	30	0	0	0	0	5,3693E+04	0	8,5910E+04

Tabel 5.3. Perhitungan gaya lintang pada gelagar

Titik	Jarak (m)	Beban Mati/D_D (N)		Beban Hidup / D_L (N)			Total (N)
		Merata	Terpusat	Air	D	Angin	$1,2D_D+1,6D_L$
A	0	4,78E+05	1,752E+04	1,05E+04	2,6567E+05	9,090E+03	1,032E+06
1	5	3,1863E+05	1,252E+04	7E+03	1,777E+05	6,059E+03	6,981E+05
2	10	1,593E+05	7,5096E+03	3,5E+03	8,8856E+04	3,029E+03	3,497E+05
3*	15	0	0	0	0	0	0
4	20	1,593E+05	7,5096E+03	3,5E+03	8,8856E+04	3,029E+03	3,497E+05
5	25	3,1863E+05	1,252E+04	7E+03	1,777E+05	6,059E+03	6,981E+05
B	30	4,78E+05	1,752E+04	1,05E+04	2,6567E+05	9,090E+03	1,032E+06

❑ **Moment Yang Diperhitungkan**

Momen yang digunakan dalam perhitungan desain gelagar pratekan adalah momen-momen maksimum yang terjadi akibat pembebanan sebagai berikut :

M_G = Momen akibat berat sendiri gelagar

= $1,2\ (\ ^1/_8 * W_{BS} * L^2)$

= $1,2\ (\ ^1/_8 * 2225 * 30^2)$

= **3,004E+05 Kgm**

= **3,004E+09 Nmm**

M_T = Momen total $(1,2\ M_D + 1,6\ M_L)$

= **7,97E+06 Nm**

= **7,97E+09 Nmm**

M_P = Momen pada pratekan akibat berat sendiri balok, plat dan balok diafragma sebelum plat/komposit berfungsi

= **1,2 [$^1/_8$ (2225+840) 30^2+1,1264E+04** (Mmax beban terpusat) **]**

= **4,2729E+05 Kgm**

= **4,2729E+09 Nmm**

M_C = Momen pada penampang komposit

= $M_T - M_P$

= **7,97E+09 - 4,2729E+09**

= **3,6971E+09 Nmm**

C. Disain Penampang Balok

❑ **Tegangan Batas Beton K-500(TY. Lin, hal 24)**

f'_o = *tegangan beton umur 28 hari* = 50 MPa

f'_{ci} = *tegangan beton saat transfer pada umur 14 hari*

= $0{,}9\ f_o'$ (PBI 1971 - tabel 4.1.4)

= 0,9 * 50

= 45 MPa

- **Segera setelah peralihan gaya prategang (sebelum kehilangan gaya prategang),tegangan serat-serat terluar:**

tekan : f = $-0{,}6\ f'_{ci}$

= -0,6 * 45

= -27 MPa

tarik : f' = $0{,}5\sqrt{f'_{ci}}$

= $0{,}5\sqrt{45}$

= 3,35 MPa

- **Pada beban kerja setelah terjadi seluruh kehilangan gaya prategang tegangan (setelah kehilangan gaya prategang)**

tekan : f = $-0{,}45\ f'_o$

= -0,45 * 50

= -22,5 MPa

tarik : f' = $0{,}5\sqrt{f'_c}$

= $0{,}5\sqrt{50}$

= 3,536 MPa

❑ **Perkiraan Gaya Prategang Awal**

Gaya prategang yang bekerja pada gelagar :

$$F = \frac{M_t}{0{,}65 * h}$$

$$= \frac{7,97E+09}{0,65 * 1600}$$

$$= 7,664E+06 \text{ N}$$

Kehilangan tegangan rata-rata untuk sistem Post Tensioning adalah 20 % (TY. Lin, hal 103), sehingga gaya awal prategang adalah :

$$F_o = \frac{F}{0,8}$$

$$= \frac{7,664E+06}{0,8}$$

$$= 9,580E+06 \text{ N}$$

❑ **Menentukan Letak Garis Eksentrisitas (cgs)**

$$e_1 = \frac{f_t' * I_C}{C_t * F_o}$$

$$= \frac{3,35*2,652E+11}{800*9,580E+06} = 115,92 \text{ mm}$$

$$e_2 = \frac{M_G}{F_o}$$

$$= \frac{3,004E+09}{9,580E+06} = 313,570 \text{ mm}$$

$$e = e_1 + e_2 + K_b$$

$$= 115,92 + 313,570 + 372,5$$

$$= 801,990 \text{ mm} \approx 802 \text{ mm}$$

Selanjutnya direncanakan tendon terletak **500 mm** dari serat terbawah (e = 300 mm)

❑ **Perhitungan Gaya Pratekan Yang Dibutuhkan**

$$F = \frac{M_b + (m_b * M_c)}{e + K_t}$$

$$= \frac{(4,2729E+09) + (0,7855*3,6971E+09)}{300 + 372,5}$$

$$= 9,8625E+06 \text{ N}$$

$$F_o = \frac{F}{0,8}$$

$$= \frac{9,8625E+06}{0,8} = 1,233E+07\ N$$

❑ **Kontrol Tegangan**

1. Akibat gaya pratekan awal

$$f_{bottom} = -\frac{F_0}{A}\left(1+\frac{e_t}{K_t}\right)$$

$$= -\frac{1,233E+07}{8,9E+05}\left(1+\frac{300}{372,5}\right)$$

$$= -25,011\ Mpa$$

$$f_{top} = -\frac{F_0}{A}\left(1-\frac{e_t}{K_b}\right)$$

$$= -\frac{1,233E+07}{8,9E+05}\left(1-\frac{300}{372,5}\right)$$

$$= -2,696\ Mpa$$

2. Akibat gaya pratekan efektif (F)

$$f_{bottom} = -\frac{F_0}{A}\left(1+\frac{e_t}{K_t}\right)$$

$$= -\frac{9,8625E+06}{8,9E+05}\left(1+\frac{300}{372,5}\right)$$

$$= -19,42\ Mpa$$

$$f_{top} = -\frac{F_0}{A}\left(1-\frac{e_t}{K_b}\right)$$

$$= -\frac{9,8625E+06}{8,9E+05}\left(1-\frac{300}{372,5}\right)$$

$$= -2,157\ Mpa$$

3. Akibat berat sendiri balok prategang

$$f_{bottom} = -\frac{M_G}{A * K_t}$$

$$= -\frac{3{,}004E+09}{8{,}9E+05*372{,}5}$$

$$= -9{,}061 \text{ Mpa}$$

$$f_{top} = +\frac{M_G}{A * K_b}$$

$$= +\frac{3{,}004E+09}{8{,}9E+05*372{,}5}$$

$$= +9{,}061 \text{ Mpa}$$

4. Akibat muatan mati (M_D)

$$f_{bottom} = +\frac{M_D}{A * K_t}$$

$$= +\frac{4{,}564E+09}{8{,}9E+05 * 372{,}5}$$

$$= +13{,}7 \text{ Mpa}$$

$$f_{top} = -\frac{M_D}{A * K_b}$$

$$= -\frac{4{,}564E+09}{8{,}9E+05 * 372{,}5}$$

$$= -13{,}7 \text{ Mpa}$$

5. Akibat muatan hidup

$$f_{bottom} = +\frac{M_L}{A' * K_t'}$$

$$= +\frac{3{,}406E+09}{1{,}1375E+06 * 371{,}01}$$

$$= +7{,}88 \text{ Mpa}$$

$$f_{top} = -\frac{M_L}{A * K_b} * \frac{(C_b' - Z_t)}{C_t'}$$

$$= -\frac{3{,}406E{+}09}{1{,}1375E{+}06 * 459{,}29} * \frac{(995{,}7 - 200)}{804{,}3}$$

$$= -3{,}86 \text{ Mpa}$$

$$f_{plat} = -\frac{M_L}{A' * K_b'} = -6{,}364 \text{ Mpa}$$

- **Kombinasi Tegangan**

1. Keadaan Awal (1 + 3)

Serat atas (f_t) = -2,696 - 9,061 = - 11,757 Mpa < 3,35 Mpa

Serat bawah (f_b) = - 25,011 +9,061 = -15,950 Mpa < - 27 Mpa

2. Keadaan Akhir (2 + 4 + 5)

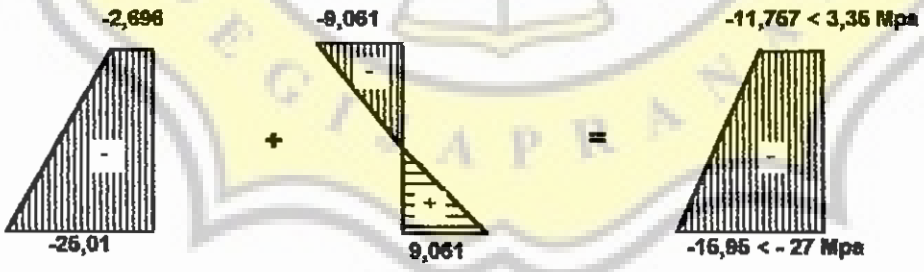
Serat Atas (f_t) = -2,157 - 13,7 - 3,86 = -19,72 Mpa< -22,5Mpa

Serat bawah (f_b) = -19,42 +13,7+7,88 = 2,16 Mpa < 3,53 Mpa

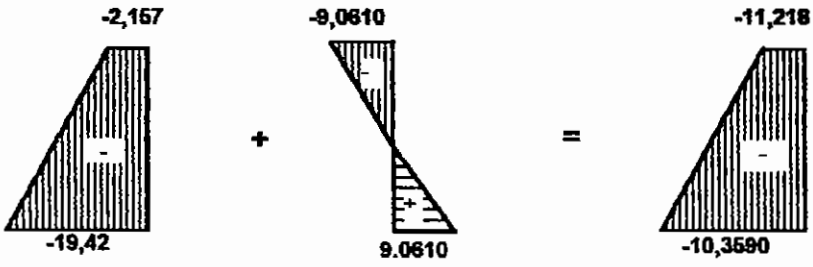
Pada plat lantai (f_{plat}) = -6,364 Mpa

- **Diagram Tegangan**

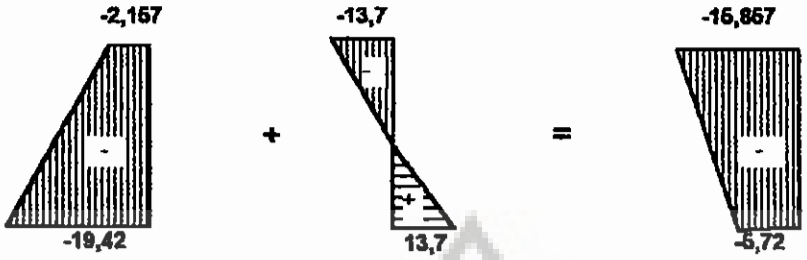
1. Keadaan Awal



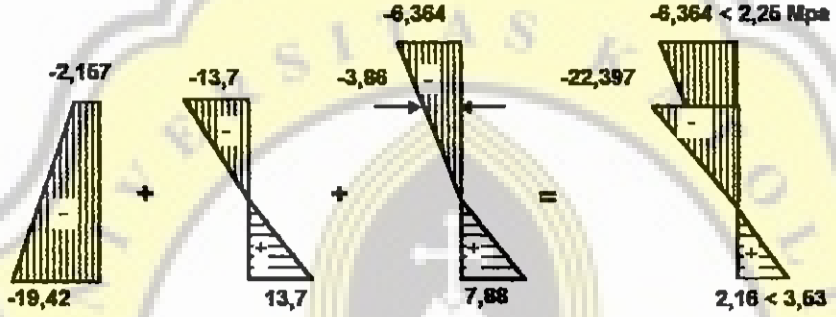
2.Kondisi Setelah Kehilangan Teganagan(2+3)



3. Kondisi Setelah Kehilangan TegangaN (2+4)



4. Kondisi Setelah Kehilangan Tegangan (2+4+5)



5.1.2.5. Perhitungan Tendon Pratekan

Digunakan tendon tipe " *Uncoated Seven Wire Stress Relieved for Prestressed Concrete* ", dengan spesifikasi menurut ASTM A-416 (*lampiran B - hal 305, tabel 2-2 hal 49, TY Lin "Desain Struktur Beton Prategang"*) adalah :

- Diameter Nominal : 12,70 mm
- Luas Nominal Strand : 98,71 mm^2
- Kekuatan Putus : 183,7 KN
- Teg. Putus Min. (f_{pu}) : 1860 Mpa
- Beban Min. Muai 1% (f_{py}) : 156,1 KN
- Modulus Elastisitas (E_s) : 190.000 Mpa

Untuk angkur digunakan *angkur VSL tipe E5-12*, dengan jumlah strand 12 buah pada setiap tendon (*Lampiran B, TY. Lin, "Desain Struktur Beton Prategang"*)

Luas tampang tendon (As tendon) = 12*98,71 = 1184,52 mm^2

Beban Putus 1 (satu) tendon = 1184,52*1860 = 2203207 N

= 2,203E+06 N

A. Perhitungan Jumlah Tendon

$$n_1 = \frac{Fo}{90\% * f_{pu}}$$

$$= \frac{1,233E+07}{0,9*2,203E+06}$$

$$= 6,22 \approx 6 \text{ buah.}$$

$$n_1 = \frac{Fo}{80\% * f_{pu}}$$

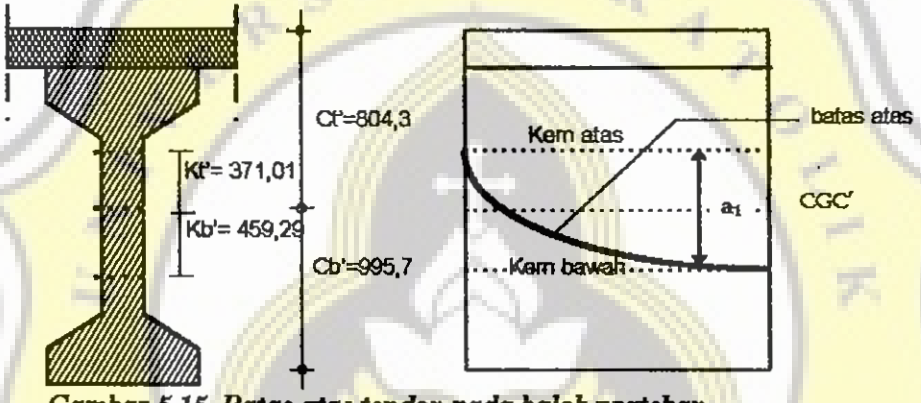
$$= \frac{9,8625E+06}{0,8*2,203E+06}$$

$$= 5,60 \approx 6 \text{ buah.}$$

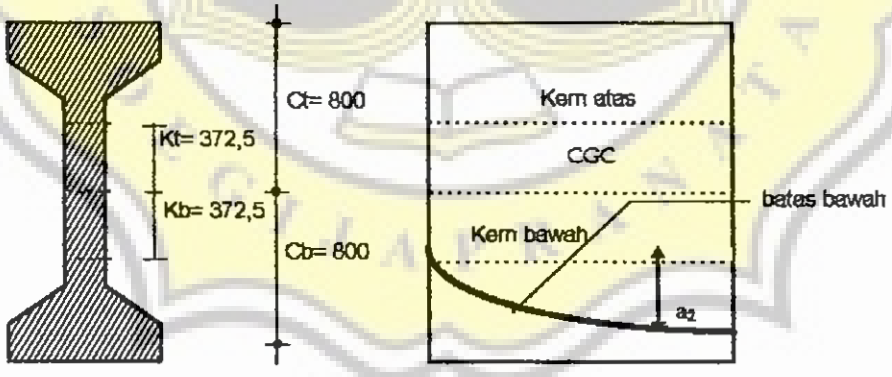
(Jadi digunakan tendon sebanyak 6 buah)

B. Lay Out Tendon

Letak kabel pratekan di dalam beton harus berada pada daerah aman untuk kabel, di mana daerah aman tersebut berada di antara batas atas dan batas bawah kabel. Selain itu harus diperhatikan pula kombinasi penempatan tendon sehingga badan beton dapat menampung penempatan tendon.

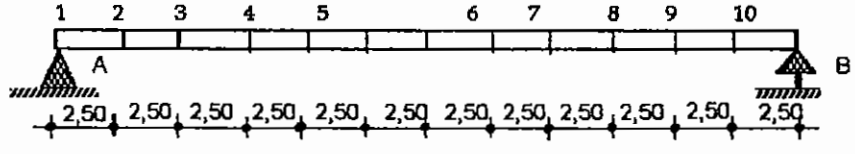


Gambar 5.15. Batas atas tendon pada balok pratekan



Gambar 5.16. Batas bawah tendon pada balok pratekan

❑ Daerah Aman Tendon



Gambar 5.17. Gelagar memanjang (balok induk)

RUMUS :

$$a_1 = \frac{M_T}{F}$$

$$a_2 = \frac{M_G}{F_0}$$

Batas Atas = $C_b' + K_t' - a_1$

Batas Bawah = $C_b - K_b - a_2$

Dari hasil perhitungan sebelumnya diperoleh :

$F = 9{,}8625E{+}06$ N $\quad C_b' = 995{,}7$ mm

$F_O = 1{,}233E{+}07$ N $\quad K_t = 372{,}5$ mm

$C_t = 800$ mm $\quad K_b = 372{,}5$ mm

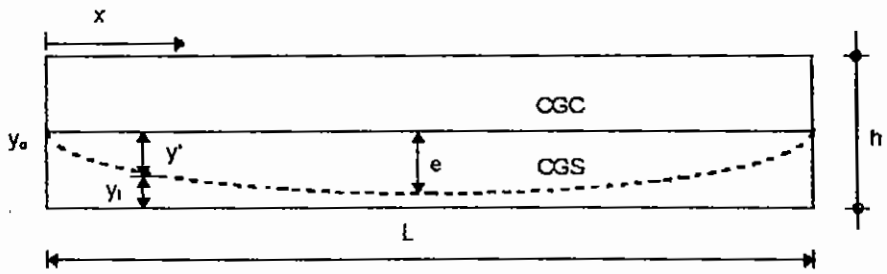
$C_b = 800$ mm $\quad K_t' = 371{,}01$ mm

$C_t' = 804{,}3$ mm $\quad K_b' = 459{,}29$ mm

Tabel 5.4. Perhitungan daerah aman tendon

NO	X (mm)	M_G (N/mm)	M_T (N/mm)	a_1 (mm)	a_2 (mm)	BATAS ATAS	BATAS BAWAH
1	0	0	0	0	0	1366,71	427,5
2	2.500	8,55E+08	2,41E+09	244,36	69,34	1122,35	358,16
3	5.000	1,55E+09	4,459E+09	452,17	125,71	914,54	301,79
4	7.500	2,11E+09	5,92E+09	600,25	171,13	766,46	256,37
5	10.000	2,48E+09	7,09E+09	718,88	201,14	647,83	226,36
6	12.500	2,72E+09	7,67E+09	777,69	220,60	589,02	206,90
7	15.000	3,004E+09	7,970E+09	808,11	243,63	558,60	183,87

❑ Lintasan Tendon



Gambar 5.19. Lintasan tendon pratekan

Untuk penempatan group tendon diusahakan agar titik berat group tendon tersebut berimpit dengan lintasan CGS, sehingga tidak menimbulkan momen sekunder. Lintasan kabel merupakan lintasan parabola dengan mengikuti rumus parabola :

$$y' = \frac{4.f.x(L-x)}{L^2}$$

$$y_i = y_o - y'$$

di mana :

f = *kelengkungan parabola* ($y_{ujung} - y_{tengah}$)

L = *30.000 mm*

h = *1600 mm*

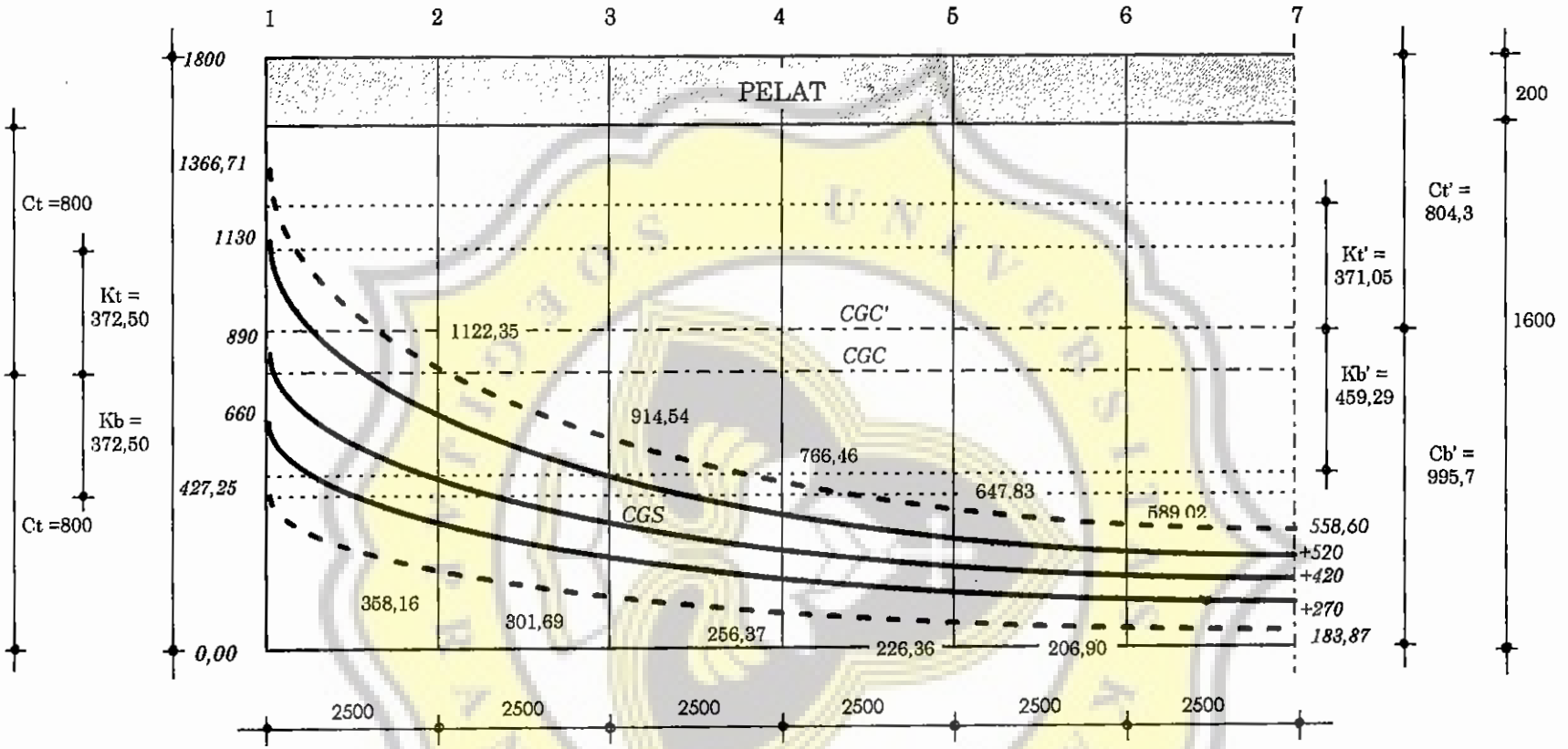
i = *1, 2, ..., n*

n = *jumlah lintasan tendon*

$\varnothing_{selongsong}$ = *3,94 inc. = 100 mm*

Tabel 5.5. Perhitungan lintasan tendon

NO		TRACE TENDON 1&2 (y_1)	TRACE TENDON 3&4 (y_2)	TRACE TENDON 5&6 (y_3)
	yo =	660	890	1130
	x f =	390	470	610
1	0	660	890	1130
2	2.500	540,83	746,39	925,83
3	5.000	443,33	628,89	783,33
4	7.500	367,50	357,50	672,50
5	10.000	312,33	472,22	593,33
6	12.500	280,83	433,06	543,83
7	15.000	270	420	520



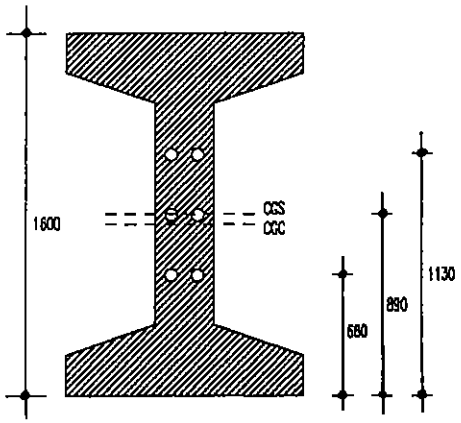
Gambar 5.20 : Lay out tendon balok pratekan (bentang 30 m)

KETERANGAN :

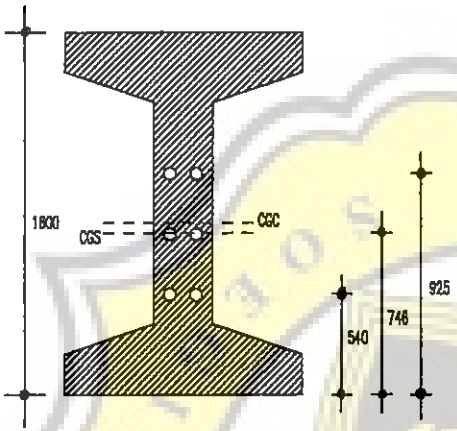
- - - - - = Batas daerah aman tendon

——— = Lintasan tendon

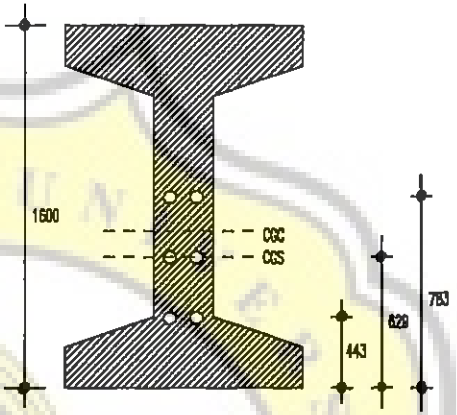
Potongan pada titik lintasan tendon bentang 30 m



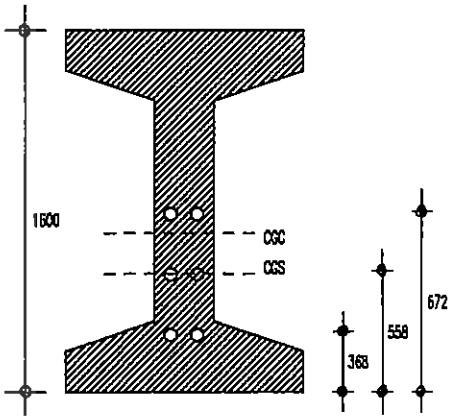
POTONGAN TITIK 1



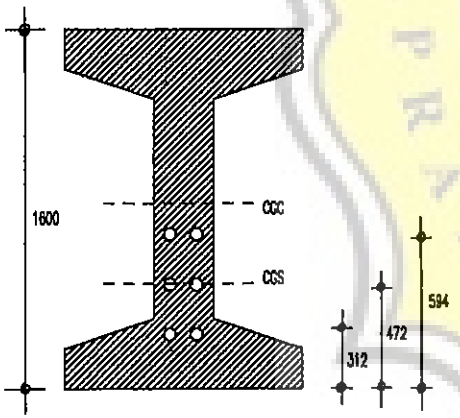
POTONGAN TITIK 2



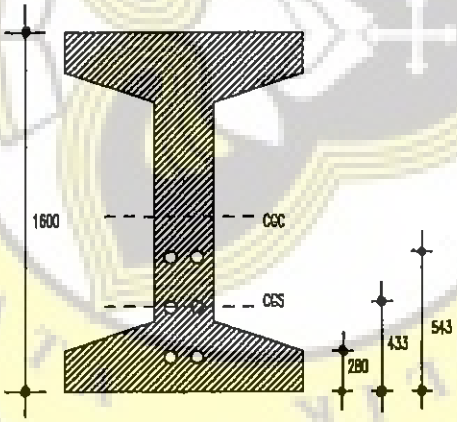
POTONGAN TITIK 3



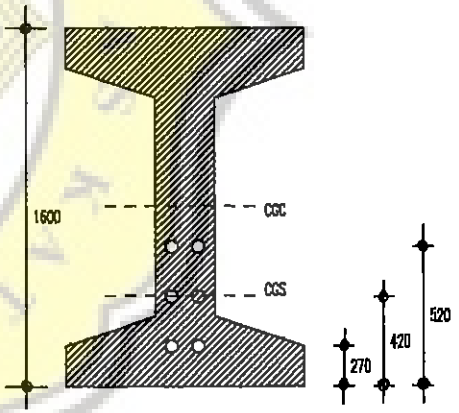
POTONGAN TITIK 4



POTONGAN TITIK 5



POTONGAN TITIK 6



POTONGAN TITIK 7

❑ **Kontrol Lendutan**

E_c = 4730 * $\sqrt{f'_c}$

= 4730 * $\sqrt{50}$ = 31,73 E+03 Mpa (Peraturan ACI, TY lin hal 38)

I_c = 2,65E+11 mm^4

I_c' = 4,202E+11 mm^4

e = 300 mm

F_o = 1,233E+07 N

W_{D1} = 31875 N/m (Beban mati merata balok +plat +pavement)

W_L = 1,2365E+04 N/m (Beban hidup merata)

P_L = 9,16E+4 N/m' (Beban hidup terpusat)

M_{D2} = 1,1264E+08 Nmm (Momen akibat beban diafragma)

M_G = 3,004E+09 Nmm (Momen akibat berat sendiri balok)

❑ **Syarat Lendutan :**

Lendutan yang terjadi $\leq \frac{1}{360}$ * Panjang bentang

$\leq \frac{1}{360}$ * 30.000 mm

$\leq$ 83,33 mm

1. Kondisi Awal (Transfer Tegangan)

$\Delta F_o = \frac{40 * F_o * e * L^2}{384 * E_c * I_c}$ (Akibat gaya prategang awal)

$= \frac{40*1,233E+07*300*30000^2}{384*31,73E+03*2,65E+11}$ = 41,242 mm (↑)

$\Delta M_G = \frac{5 * M_G * L^2}{384 * E_c * I_c}$ (Akibat berat sendiri balok)

$= \frac{40*3,004E+09*300*30000^2}{384*31,73E+03*2,65E+11}$ = 4,187 mm (↓)

Δ_{tot} = ΔF_o - ΔM_G (*TY. Lin - halaman 269*)

= 41,242 - 4,187

= 37,055 mm (↑) ≤ 83,33 mm O.K !!!

2. Kondisi Akhir (Beban Kerja)

$\Delta F = 0{,}8 * \Delta F_o$ (Akibat gaya prategang efektif)

$= 0{,}8 * 41{,}242 = 32{,}9936$ mm (↑)

$$\Delta M_{D1} = \frac{5 * M_{D1} * L^4}{384 * E_C * I_C'}$$ (Akibat beban mati merata)

$$= \frac{5*31{,}875*30000^4}{384*31{,}73E{+}03*4{,}202E{+}11} = 25{,}21 \text{ mm } (\downarrow)$$

$$\Delta M_{D2} = \frac{5 * M_{D2} * L^2}{384 * E_C * I_c'}$$ (Akibat berat diafragma)

$$= \frac{5*1{,}1264E{+}08*30000^2}{384*31{,}73E{+}03*4{,}202E{+}11} = 0{,}099 \text{ mm } (\downarrow)$$

$$\Delta M_{WL} = \frac{5 * W_L * L^4}{384 * E_C * I_c'}$$ (Beban hidup merata)

$$= \frac{5*12{,}365*30000^4}{384*31{,}73E{+}03*4{,}202E{+}11} = 9{,}781 \text{ mm } (\downarrow)$$

$$\Delta M_{PL} = \frac{P_L * L^3}{48 * E_C * I_c'}$$ (Beban hidup terpusat)

$$= \frac{9{,}16E+04 * 30000^3}{48 * 31{,}73E+03 * 4{,}202E+11} = 3{,}8 \text{ mm } (\downarrow)$$

$\Delta tot = \Delta F - \Delta M_{D1} - \Delta M_{D2} - \Delta M_{WL} - \Delta M_{PL}$ (*TY. Lin- halaman 269*)

$= 32{,}9936 - 25{,}21 - 0{,}099 - 9{,}781 - 3{,}8$

$= 5{,}8964$ mm (↓) ≤ 83,33 mm O.K !!!

V.1.2.6. Kehilangan Tegangan

❑ **Perpendekan Elastis Beton**

Dari hasil perhitungan sebelumnya diperoleh :

F_O = 1,233E+07 N

E_C = 31,73 E+03 MPa

E_S = 1,9 E+05 Mpa

A_C = 8,9 E+05 mm^2

$$n = \frac{E_s}{E_c} = \frac{1,9E+05}{3,173E+04}$$

= 5,988

A_S = 1184,52 mm^2 (As tendon)

$$f_O = \frac{1,233E+07}{6*1184,52}$$

= 1,735E+03 Mpa

Kehilangan tegangan pada tendon disebabkan oleh gaya prategang pada 5 (lima) tendon lainnya yang telah dipasang lebih dahulu, yaitu sebesar:

F_{po} = 5*1184,52*1,735E+03

= 10,276E+06 Mpa

$$\Delta f_s = E_s = 0,5 * \frac{n * F_{po}}{A_c}$$ (*TY. Lin - halaman 83*)

$$= 0,5 * \frac{5,988*10,276E+06}{8,9E+05}$$

= 34,569 MPa

$$\% \Delta f_s = \frac{\Delta f_s}{f_o} * 100\%$$

$$= \frac{34,569}{1,735E+03} * 100\%$$

= 1,9925 %

❑ **Rangkak Beton**

Dari hasil perhitungan sebelumnya diperoleh :

K_{cr} = 1,6 ⇒ untuk pasca tarik *(TY. Lin - halaman 87)*

n = 5,988

F = 9,8625E+06 N

M_p = 4,2729+09 Nmm

e = 300 mm

I_C = 2,652E+11 mm^4

A_C = 8,9E+05 mm

f_{cir} = *tegangan beton akibat gaya prategang*

$$= \frac{F}{A_c} + \frac{F*e^2}{I}$$

$$= \frac{9,8625E+06}{8,9E+05} + \frac{9,8625E+06*300^2}{2,652E+11}$$

= 14,4285 MPa

f_{cds} = *teg. beton akibat beban mati setelah diberi pratekan*

$$= \frac{M_p * e}{I}$$

$$= \frac{4,2729E+09}{2,652E+11}$$

= 4,834 MPa

$CR = K_{cr} * n (f_{cir} - f_{cds})$

=1,6 * 5,988(14,4285- 4,834)

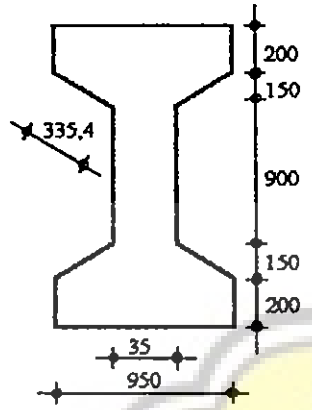
= 91,923 MPa

$$\%CR = \frac{CR}{f_o} * 100\%$$

$$= \frac{91,923}{1,735E+03} * 100\%$$

= 5,298 %

❑ **Susut Beton**



Gambar 5.21. Luas permukaan balok

K_{sh} = 0,64 (*TY.Lin tabel4-4 hal. 88*)

V = *Volume balok*

= Ac * L

= 8,9 E+05 * 30.000

= 2,67 E+10 mm^3

S = *Luas permukaan balok*

= 2*Ac +L{2(950 + 900)

+ 4 (200+ 335,4) }

= 1,770 E+08 mm^2

R_h = *Kelembaban relatif*

= 60 %

$$SH = 8{,}2\ E\text{-}06 * Ksh * Es \left(1 - 0{,}06 * \frac{V}{S}\right)(100 - R_h)$$

$$= 8{,}2E\text{-}06 * 0{,}64 * 1{,}9E+05 \left(1 - 0{,}06 * \frac{2{,}67E+10}{1{,}770E+08}\right)(100 - 60)$$

= - 3,21 MPa

Karena hasil perhitungan bernilai minus, maka SH = 0%

❑ **Relaksasi Baja**

K_{rc} = 138 MPa

J = 0,15

Tabel 4-5, TY. Lin - halaman 90

$$f_{pi} = \frac{F_o}{A_s}$$

$$= \frac{1{,}233E+07}{1{,}1845E+03}$$

= 2081,715 MPa

f_{pu} = 1860 Mpa

$$\frac{f_{pi}}{f_{pu}} = \frac{2081{,}715}{1860}$$

= 1,12

$$RE = \{K_{rc} - (J^*(SH + CR + \Delta f_S))\}^*C$$
$$= \{138 - (0{,}15^*(0 + 87{,}169 + 33{,}552))\}^*1{,}28$$
$$= 113{,}714 \text{ Mpa}$$

$$\%\ RE = \frac{RE}{f_{pu}} * 100\% = \frac{113{,}714}{1860} * 100\%$$
$$= 6{,}114\ \%$$

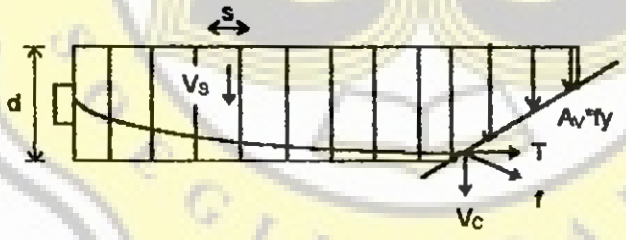
❑ **Kehilangan Gaya Prategang Total**

Dari hasil perhitungan 4 macam kehilangan gaya pratekan yang terjadi pada beton dan baja, maka diperoleh kehilangan gaya pratekan total sebesar :

Kehilangan tegangan total = % ES + % CR + % SH + % RE
= 1,9925 % + 5,298 % + 0 % + 6,114 %
= 13,4045 % < 20 %

(memenuhi asumsi awal dalam perhitungan, TY lin hal 103)

V.1.2.7. Tulangan Sengkang Balok Pratekan



Gambar 5.22. Reaksi gaya geser akibat tendon pratekan

Persamaaan trase tendon :

$$y = \frac{4 * f * x}{L^2}(L - x)$$

$$y' = \tan\theta = \frac{4 * f}{L^2}(L - 2x)$$

$$f = e - e_o = 300 - 0 = 300 \text{ (gradien CGS)}$$

$$y' = \frac{4 * 300}{30000^2}(30000 - 2x) = 0.0399 - 0{,}0000267\ x$$

Jarak sengkang (s) = $\frac{A_v * f_y * d}{V_s}$

Dimana :

s : *jarak sengkang*

Av : *luas sengkang* = *2A*(Ø **10, 2A = 157 mm^2**)

d : *tinggi balok*

fy : *400 Mpa*

$V_S = V_U - V_C$

V_U : *reaksi pada titik yang ditinjau* = **D x** *(Tabel 5.3 Perhitungan gaya lintang pada gelagar)*

V_C = **F sin θ**

F : *gaya prategang* = **9,8625E+06 N**

Selanjutnya hasil perhitungan dapat dilihat pada tabel berikut :

Tabel 5.6. Perhitungan penulangan sengkang balok pratekan

Titik	tan θ	sin θ	V_U	V_C	V_S	Ø sengkang	jarak sengkang (s)
0	0,0399	0,0390	1,032E+06	3,82E+05	6,5E+05	10 mm	150 mm
5	0,0307	0,0385	6,981E+05	3,80E+05	3,181E+05	10 mm	315 mm
10	0,03633	0,0384	3,497E+05	3,79E+05	2,93E+04	10 mm	3429 mm

❑ **Penulangan Sengkang Minimum**

Pembesian sengkang minimum didasarkan pada rumus :

As_{min} = 0,25 % *b_o mm^2/cm

= 0,25%*950 mm^2/cm

= 2,37 mm^2/cm = 237 mm^2/m

Bila tiap meter dipasang 4 buah sengkang (jarak 200 mm) maka :

As_{min} = 4* $\frac{1}{4}$*π*d^2

237 = 4* $\frac{1}{4}$*3,14*d^2

d^2 = 75,478

d = 8,688 ≈ 10 mm

Jadi sengkang minimum adalah Ø **10 - 250 (As = 314 mm^2)**

(WC. Vis, tabel 13a hal 82)

❑ **Penulangan Memanjang Minimum**

Jumlah penulangan memanjang minimum untuk sengkang adalah **0,15 % - 0,25%*Ac**

Sehingga :

$A_{S\,min}$ = 0,25 %*bo*h

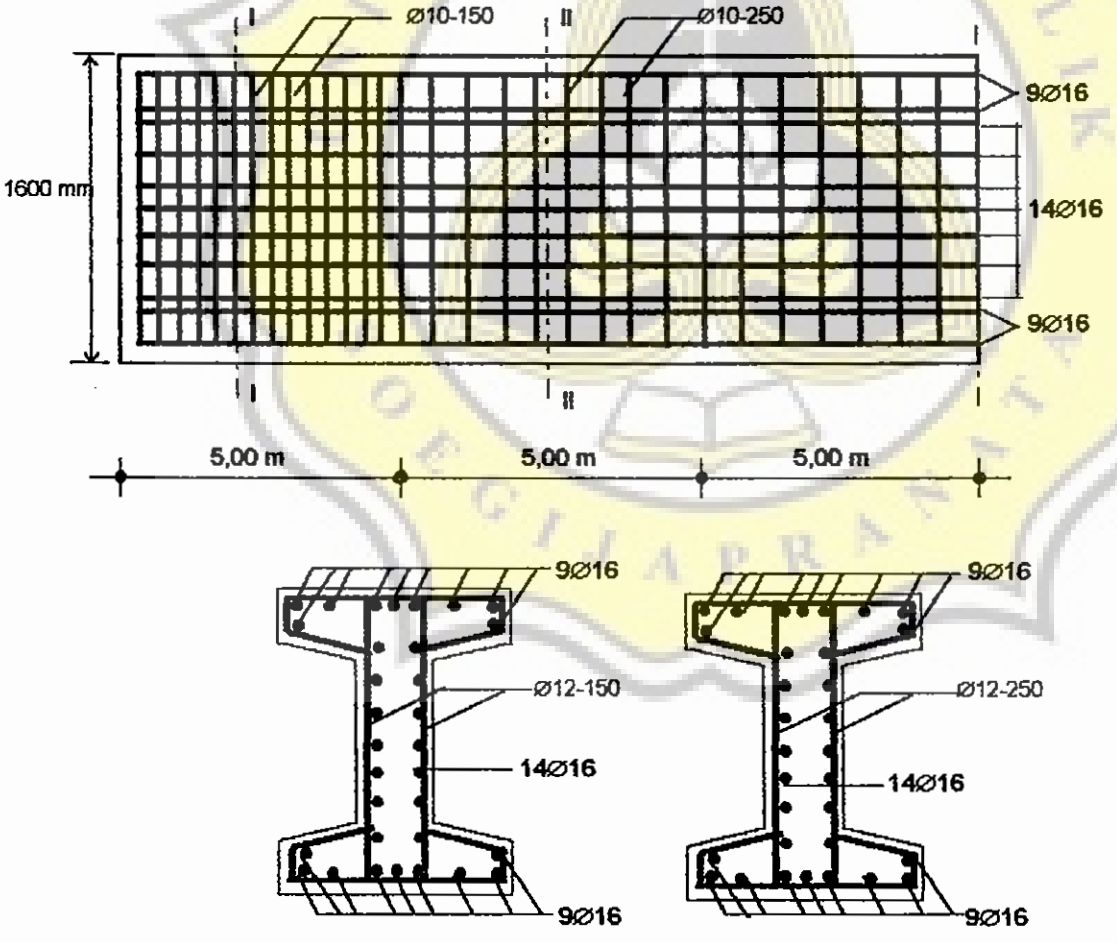
= 0,25 %*950*1600

= 3800 mm^2

Dipakai tulangan 18 Ø16 (As = 3620 mm^2)

14Ø16 (As = 2816 mm^2)

(As = 6436 mm^2)



POT I-I POT II-II

Gambar 5.23. Penulangan sengkang balok pratekan

V.1.2.8. Perencanaan Shear Connector

Pada penampang komposit dengan konsep full interaksi maupun parsial interaksi, pada bidang kontak antara plat dan balok akan terjadi gaya geser yang diperlukan untuk menahan slip . Gaya geser horisontal pada bidang kontak tersebut ditimbulkan oleh beban-beban yang bekerja pada penampang komposit saja.

$$V_{ni} = \frac{D_i * W}{I_c' * b_o}$$

$$W = h_{plat} * H * (K_t' - 0{,}5\, h_{plat})$$

$$V_u = V_{ni} * A_C'$$

$$V_{SC} = 55 * d^2 * \sqrt{f'_{plat}} \rightarrow H/d > 5{,}5$$

$$= 10 * d * H * \sqrt{f'_{plat}} \rightarrow H/d < 5{,}5$$

$$n = \frac{V_U}{V_{SC}}$$

Dimana

V_{ni} = *tegangan geser yang ditahan oleh bidang kontak*

Di = *gaya lintang maksimum pada potongan yang ditinjau*

W = *statis momen plat terhadap CGC'*

Ic' = *momen inersia komposit* = **4,202E+11 mm^4**

b_0 = *lebar bidang kontak* = **950 mm**

V_u = *tegangan geser akibat gaya lintang pada titik*

Ac' = *luas komposit* = **1,1375E+07 mm^2**

d = *diameter shear connector*

H = *tinggi shear conector*

V_{sc} = *tegangan geser yang ditahan oleh SC*

f'_{plat} = *tegangan tekan pada plat*

n = *jumlah shear connector*

Digunakan Shear Connector (SC) type U, dengan tulangan ∅ 20 (**A = 314,16 mm^2**)

d = 20 mm

H = 200 mm

$$\frac{H}{d} = \frac{200}{20} = 10 > 5{,}5$$

$V_{SC} = 55*d^2*\sqrt{f_{plat}'}$

$= 55* 20^2*\sqrt{6{,}364} = 5{,}55E{+}04$ N

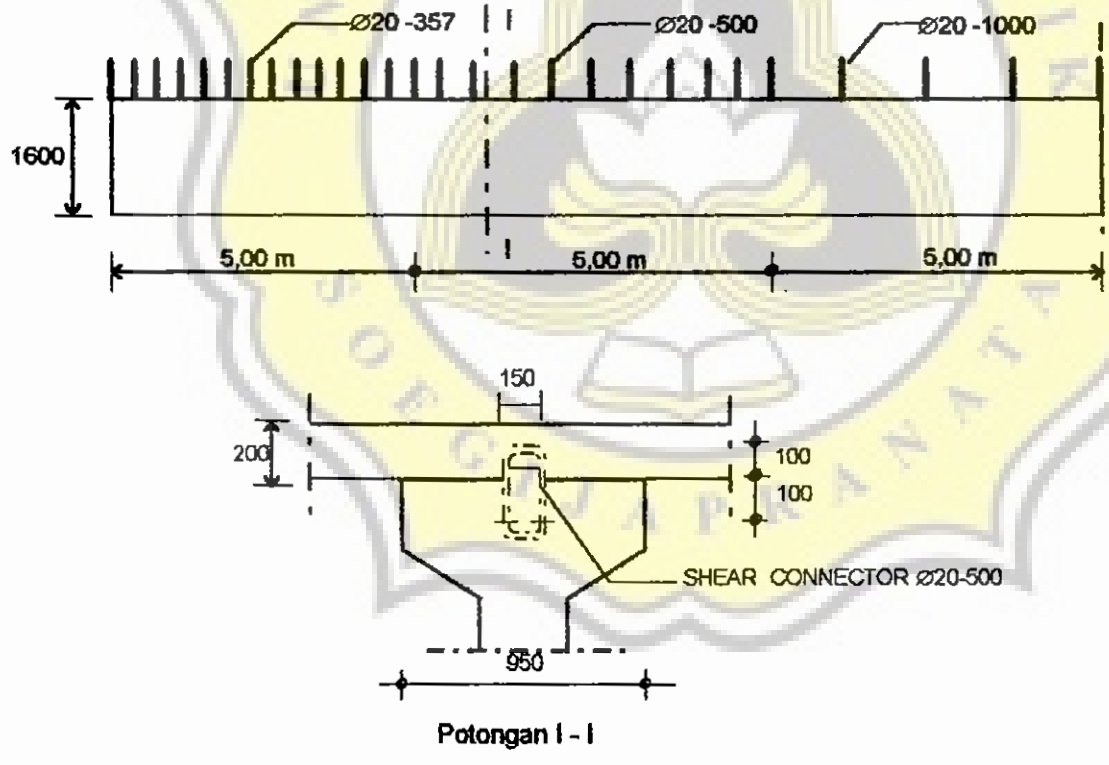
$W = 200*1600*(804{,}3 - \frac{1}{2}*200)$

$= 2{,}254E{+}08$ mm^4

Selanjutnya hasil perhitungan dapat dilihat pada tabel berikut :

Tabel 5.7. Perhitungan shear connector balok pratekan

Jarak (m)	DI (N)	Vnl (N/mm^2)	Vsc (N)	Vu (N)	n (buah)
0-5	1,032E+06	0,6	5,55E+04	6,825E+05	14
5-10	6,981E+05	0,4	5,55E+04	4,55E+05	10
10-15	3,497E+05	0,2	5,55E+04	2,275E+05	5

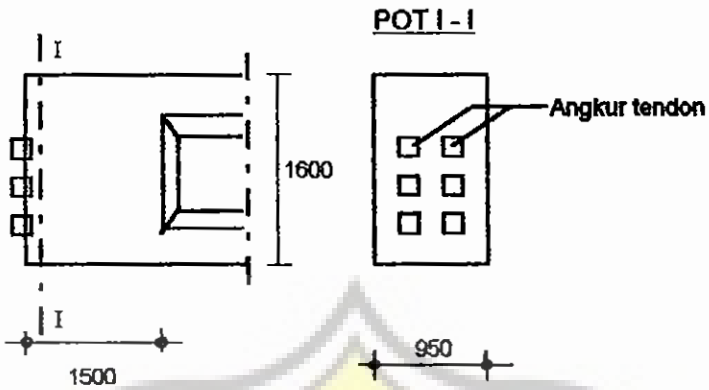


Gambar 5.24. Penempatan Shear Connector

V.1.2.9. Penulangan End Block

Panjang *end block* ≤ h (*TY. Lin -halaman 246*)

Diambil panjang **1500 mm** = **1,5 m**



Gambar 5.25. End Block

A_C = 950*1600 = 8,9E+05 mm^2

C_t = C_b = 800 mm

I_C = 2,652E+11 mm^4

K_t = 372,5 mm

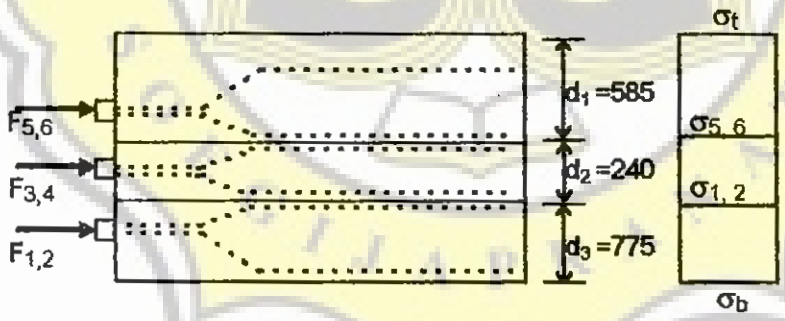
e = C_b - CGS_0

= 800 - 800 = 0

h = 1600 mm

F_O = 1,233E+07 N

❑ **Beban - Beban Yang Bekerja**



$$\sigma_b = -\frac{F_o}{A_c}\left(1+\frac{e}{K_b}\right)$$

$$= -\frac{1{,}233E+07}{8{,}9E+05}\left(1+\frac{0}{372{,}5}\right)$$

$$= -13{,}85\ N/mm^2$$

$$\sigma_t = -\frac{F_o}{A_c}\left(1-\frac{e}{K_b}\right)$$

$$= -\frac{1{,}233E+07}{8{,}9E+05}\left(1-\frac{0}{372{,}5}\right)$$

$$= -13{,}85\ N/mm^2$$

$$\sigma_1 = \sigma_t + \frac{d_1}{h}(\sigma_b - \sigma_t)$$

$$= -13{,}85 + \{\frac{585}{1600}(-13{,}85+13{,}85)\}$$

$$= -13{,}85 \text{ N/mm}^2$$

❑ **Pembesian End Block**

Rumus umum : $F = \sigma^* d^* b_o$

$$T = 0{,}3^*F^*(1-\frac{a}{d})$$

$$A = \frac{T}{\sigma_a}$$

Dimana :

σ = 13,85 N/mm^2

d = *d pada masing - masing keadaan*

b_o = *lebar balok*

a = *tinggi angkurVSL tipe E5-12* = 266,7 mm

σ_a = *tegangan tendon baja* = 160 Mpa

A = *luas pada masing - masing balok*

Pada kondisi plat angkur 5 dan 6

$F_1 = \sigma^* d^* b_o$

$= 13{,}85^*585^*950 = 7{,}475E+06$ N

$T_1 = 0{,}3^*7{,}475E+06\ ^*(1-\frac{266{,}7}{585}) = 1{,}22E+06$ mm^2

$A_1 = \frac{1{,}22E+06}{160} = 7625{,}77$ mm^2

Pada kondisi plat angkur 3 dan 4

$F_2 = \sigma^* d^* b_o$

$= 13{,}85^*240^*950 = 3{,}067E+06$ N

$T_2 = 0{,}3^*3{,}067E+06\ ^*(1-\frac{266{,}7}{240}) = 1{,}0235E+06$ mm^2

$A_2 = \frac{1{,}0235E+06}{160} = 6396{,}74$ mm^2

Karena $T_2 < T_1$ maka pembesian didasarkan pada T_1 dimana

A = 762,577 mm^2

Luas tulangan total yang diperlukan

As = 3* A

= 3* 7625,77 mm^2

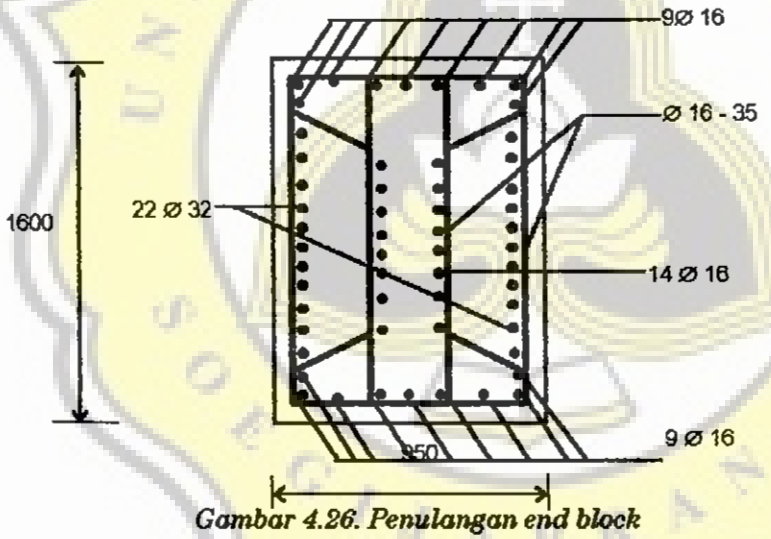
= 22877,31 mm^2

Digunakan tulangan **18 Ø 16 (A_s = 3620 mm^2)**

14 Ø 16 (A_s = 2816 mm^2)

22 Ø 32 (A_s = 17688mm^2)

(A_s = 24124 mm^2)

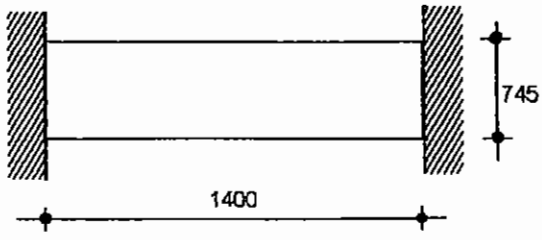


Gambar 4.26. Penulangan end block

V.1.2.10. Balok Diafragma

Dimensi = **745 * 1400 * 200 (tiap 5 meter)**

t = 200 mm



Gambar 5.27. Balok Diafragma

❑ **Pembebanan**

Berat sendiri (q) = { 0,2 * 0,745 * 1,4 }* 2400

= 500,64 kg/m

= 5006,4 N/m

Momen yang terjadi = $\frac{1}{12} * q * L^2 * 1,2$

= $\frac{1}{12} * 500,4 * 1,4^2 * 1,2$

= 980,784 Nm

= 9,80784E+05 Nmm (1,2 untuk moment ultimit akibat berat sendiri)

$\frac{M_u}{b*d^2} = \frac{9,807E+05}{200*715^2}$

= 0,009592 Mpa

= 9,592 KN/m^2

ρ = 0,00037

ρ_{min} = 0,0032

Karena $\rho < \rho_{min}$ maka digunakan ρ_{min}

As = ρ * b * d

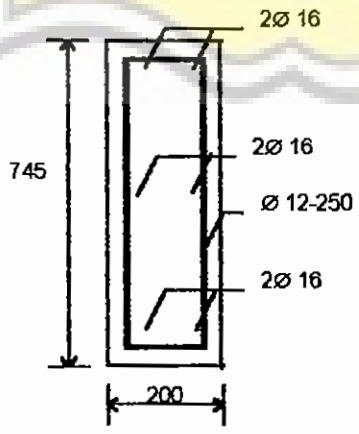
= 0,0032* 200 * 870

= 556,8 mm^2

Digunakan tulangan 4 Ø 16 (As = 804 mm^2) dan

Tulangan praktis 2 Ø 16

Sengkang praktis Ø 12 - 250



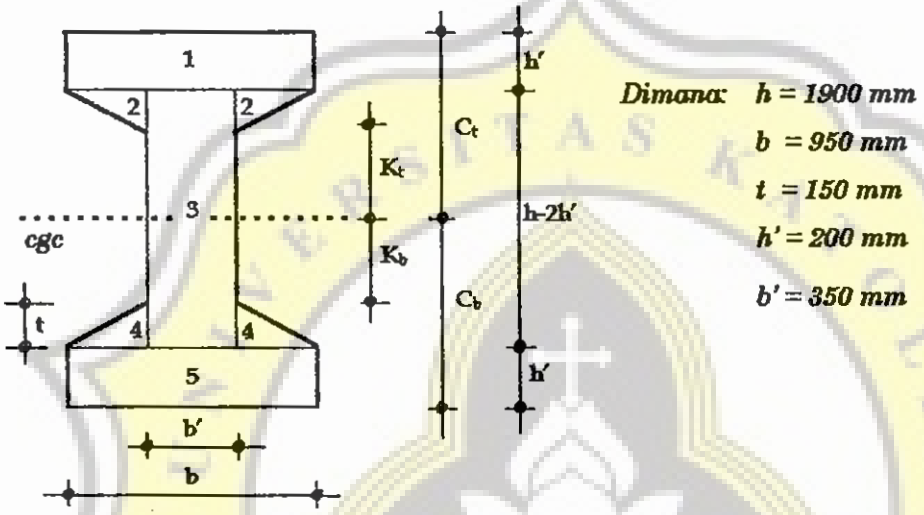
Gambar 5.28. Penulangan balok diafragma

V.1.2.11. Perhitungan Gelagar (Bentang 35 m)

Spesifikasi:

- Mutu beton : K- 500 (f'c = 500 Kg/cm² = 50 Mpa)
- Baja mutu BJTD 40 (fy = 4000 Kg/cm² = 400 Mpa)

A. Dimensi Gelagar



Gambar 5.29 : Penampang gelagar pratekan (bentang 35 m)

A_x = *Luas penampang*

A_c = *Luas Penampang total*

S_x = $A_x * Y$

I_x = *Momen Inersia tiap luasan*

I_c = $I_x + A_x * (Y_1 - Y_0)^2$

I = *Momen inersia penampang balok pratekan* = I_c

Tabel 5.8. Section properties gelagar pratekan (bentang 35 m)

	Ax (mm²)	Y(mm)	Sx (mm³)	Ix(mm⁴)	Ax*(Y1-Y0)²	Ic (mm⁴)
1	1,9E+05	1700	3,23E+08	6,33E+08	1,373E+11	1,379E+11
2	4,5E+04	1625	7,31E+07	4,22E+07	2,05+10	2,054E+10
3	5,95E+05	950	5,65E+08	9,84E+10	0	9,844E+10
4	4,5E+04	275	1,24E+07	4,22E+07	2,05E+10	2,054E+10
5	1,9E+05	100	1,9E+07	6,33E+08	1,373E+11	1,379E+11
Ac=	1,065E+06	Sc=	9,925E+08		Ic =	4,1532E+11

A_c = 1,065E+06 mm² **I_c = 4,1532E+11 mm⁴**

S_c = 9,925E+08 mm³

$C_b = C_t = S_c / A_c$

$= \frac{9{,}925E+08}{1{,}065\,E+06}$

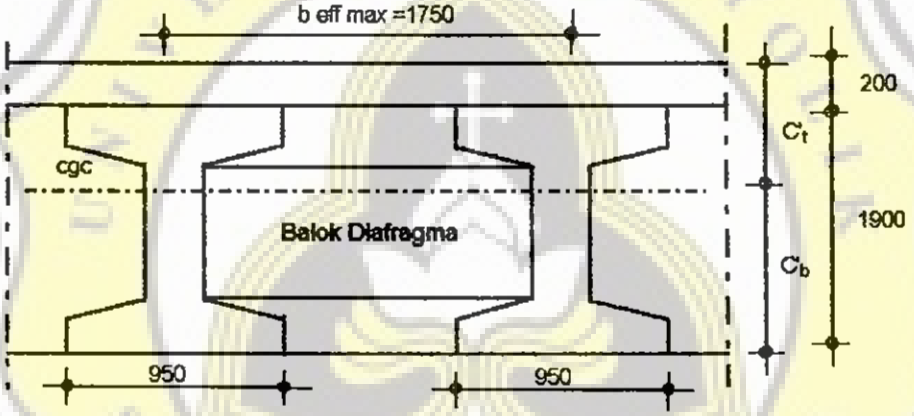
$= 950$ mm

$K_b = K_t = \frac{I}{(Ac * Ct)}$

$= \frac{4{,}1532E+11}{1{,}065E+05 * 950}$

$= 410{,}496$ mm

❑ **Balok Komposit**



Gambar 5.30. Penampang komposit

Penampang Komposit

$b_{eff\ max.}$ = **1750 mm** (jarak bersih antara gelagar)

$n = \frac{\varepsilon_b\,250}{\varepsilon_b\,450} = \frac{\text{Ec plat}}{\text{Ec balok}} = \frac{6400 * \sqrt{250}}{6400 * \sqrt{500}}$

$= 0{,}707$

b_{eff} = 0,707*1750 = 1237 mm

sehingga digunakan b_{eff} = **1237 mm** (TY Iin Ned Hal 201 PBI 1971 hal 131)

A_{slab} = $h_{slab} * b_{eff}$

= 200 * 1237

= 2,475 E+05 mm^2

$A_o' = A_{slab} + A_o$

$= (2{,}475E{+}05) + (1{,}065E{+}06)$

$= 1{,}3125E{+}06\ mm^2$

$S_o' = (A_c * C_b) + [A_{slab}(h + 0{,}5 * h_{slab})]$

$= (1{,}065E{+}06 * 950) + [2{,}475E{+}05\ (1900{+}0{,}5{*}200)]$

$= 1{,}507E{+}09\ mm^3$

$$C_b' = \frac{S_c'}{A_c'}$$

$$= \frac{1{,}507E{+}09}{1{,}3125E{+}06} = 1148{,}63\ mm$$

$C_t' = h + h_{slab} - C_b'$

$= 1900 + 200 - 1148{,}63$

$= 951{,}37\ mm$

$$I_c' = I_c + A_c(C_b' - C_b)^2 + \frac{1}{12} * b_{eff} * h_{slab}^3 + A_{slab}(C_t' - 0{,}5\ h_{slab})^2$$

$$= 2{,}652E{+}11 + 8{,}9E{+}05(1148{,}63 - 800)^2 + \frac{1}{12} * 1237 * 200^3 +$$

$$2{,}475E{+}05\ (951{,}37 - 0{,}5 * 200)^2$$

$= 4{,}875E{+}11\ mm^4$

$$K_b' = \frac{I_c'}{A_c' * C_t'}$$

$$= \frac{4{,}875E{+}11}{1{,}312E{+}06 * 951{,}37} = 390{,}56\ mm$$

$$K_t' = \frac{I_o'}{A_o' * C_b'}$$

$$= \frac{4{,}875E{+}11}{1{,}312E{+}06 * 1148{,}63} = 323{,}49\ mm$$

❑ **Perbandingan Modulus Penampang Balok Dengan Balok Setelah Komposit**

$$m_b = \frac{I_c / C_b}{I_c' / C_b'}$$

$$= \frac{4{,}1532E{+}11 / 950}{4{,}875E{+}11 / 1148{,}63}$$

$= 1{,}03$

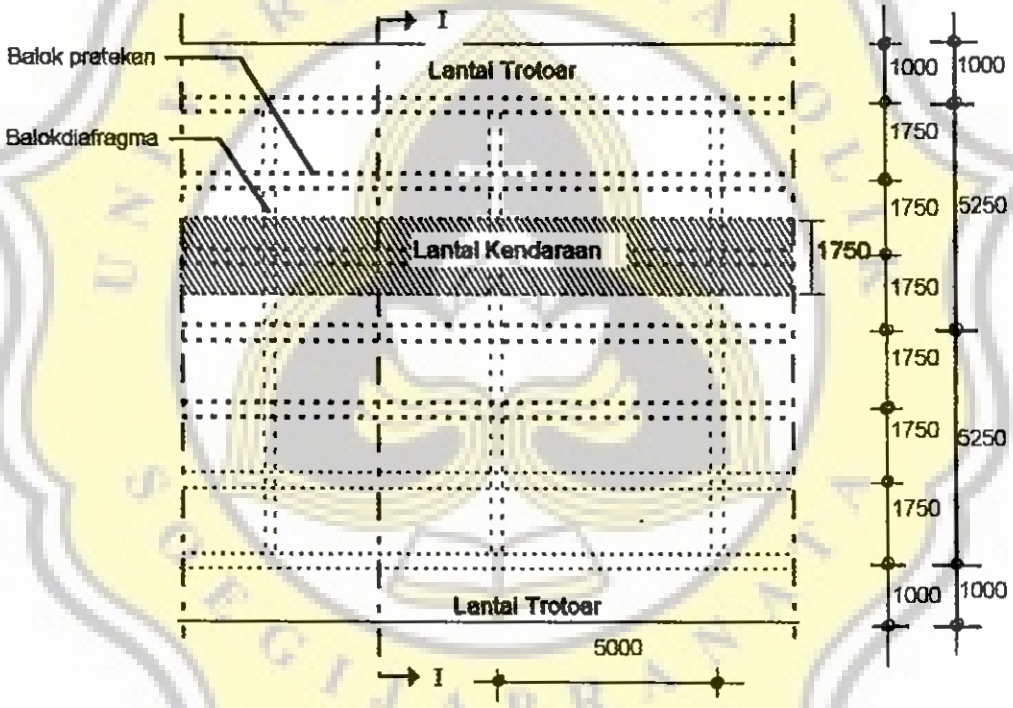
$$m_t = \frac{I_c / C_t}{I_c' / C_t'}$$

$$= \frac{4{,}1532E+11/950}{4{,}875E+11/951{,}37}$$

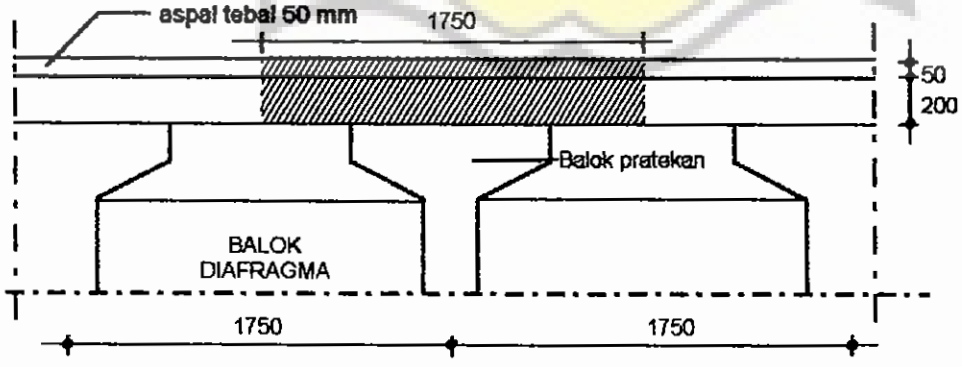
$$= 0{,}853$$

B. Pembebanan Pada Gelagar

Perhitungan gelagar utama didasarkan pada beban yang bekerja pada gelagar tengah (tipikal)



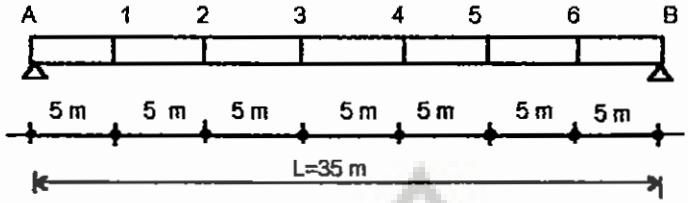
Gambar 5.31 . Denah pembebanan



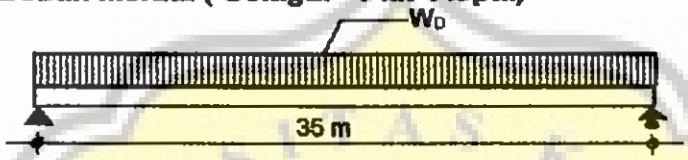
Gambar 5.32. Potongan I - I

❑ Perhitungan Mekanika Gelagar

1. Akibat Beban Mati / DL



a. Beban Merata (Gelagar+ Plat+Aspal)



Berat balok prestress	= 1,065* 2500	=	2662,5 Kg/m
Berat plat	= 0,2 * 1,75 * 2400	=	840 Kg/m
Berat Aspal	= 14 *5 *1,75	=	122,5 Kg/m
	W_D	=	3625 Kg/m
		=	36250 N/m

W_D = 36250 N/m = 3,6250E+04 N/m

$R_A = \frac{1}{2} * W_D * L = \frac{1}{2} * 36250 * 35 = 6,3438E+05$ N

$M_x = R_A * x - \frac{1}{2} * W_D * x^2$

$M_1 = 6,3438E+05 * 5 - \frac{1}{2} * 3,6250E+04 * 5^2 = 2,639E+06$ Nm

$M_2 = 6,3438E+05 * 10 - \frac{1}{2} * 3,6250E+04 * 10^2 = 4,398E+06$ Nm

$M_3 = 6,3438E+05 * 15 - \frac{1}{2} * 3,6250E+04 * 15^2 = 5,278E+06$ Nm

$M_4 = 6,3438E+05 * 20 - \frac{1}{2} * 3,6250E+04 * 20^2 = 5,278E+06$ Nm

$M_5 = 6,3438E+05 * 25 - \frac{1}{2} * 3,6250E+04 * 25^2 = 4,398E+06$ Nm

$M_6 = 6,3438E+05 * 30 - \frac{1}{2} * 3,6250E+04 * 30^2 = 2,639E+06$ Nm

$M_{max} = \frac{1}{8} * 3,6250E+04 * 35^2 = 5,3877E+06$ Nm

Gaya Lintang :

$D_X = R_A - q * L$

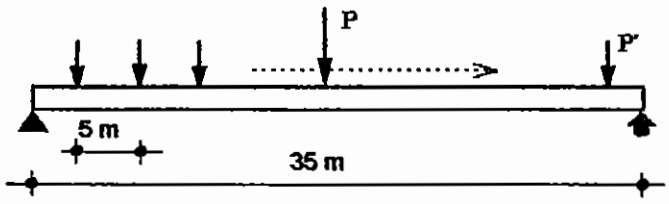
$D_A = D_B = R_A = 6,3438E+05$ N

$D_1 = D_6 = 6,3438E+05 - 3,6250E+04 * 5 = 4,3982E+05$ N

$D_2 = D_5 = 6,3438E+05 - 3,6250E+04 * 10 = 2,6389E+05$ N

$D_3 = D_4 = 6,3438E+05 - 3,6250E+04 * 15 = 8,7965E+04$

b. Akibat Beban Terpusat (Balok Diafragma)



Balok Diafragma (P') = (0,2*0,82*1,4)*2400

= 551,04 Kg

= 5,5104E+03 N

Jumlah balok diafragma (Jarak = 5m)=35/5 + 1 = 8 buah

P = 5,5104E+03 N * 8

= 4,408E+04 N

$$R_A = \frac{5{,}5104E+03 * (5+10+15+20+25+30+35)}{35}$$

= 2,2042E+04 N

Momen

$M_1 = M_6 = (R_A - P_1)*x_1$

= (2,2042E+04 - 5,5104E+03)*5

= 7,3469E+04 Nm

$M_2 = M_5 = (RA - P_2)*x_2 - P1*x_1$

= (2,2042E+04 - 5,5104E+03)*10 - 5,5104E+03 *5

= 1,2142E+05 Nm

$M_3 = M_4 = (R_A - P_3)*x_3 - P1*x_1 - P2*x_2$

=(2,2042E+04 - 5,5104E+03) * 15 - 5,5104E+03*10 -

5,5104E+03 *5

= 1,4385E+05 Nm

Gaya Lintang

$D_A = R_A$ = 2,2042E+04 N

$D_1 = -D_5 = RA - P$ = 2,2042E+04 -5,5104E+03 = 1,6532E+04 N

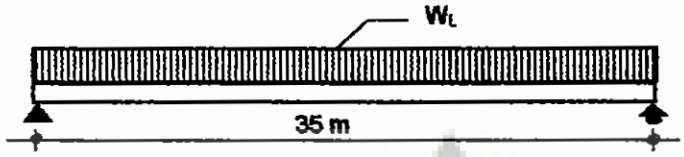
$D_2 = -D_4 = R_A - 2P$ = 12,2042E+04 - 2*5,5104E+03

= 1,1021E+03 N

$D_3 = R_A - 3P$ = 5,5104E+03 N

2. Akibat Beban Hidup / LL

a. Beban Merata (Air Hujan)



Air hujan= 0,04 * 1000*1,75

= 70 Kg/m

= 700 N/m (PPP JJR SKBI 1987 Pasal 1 ayat 1 hal 4)

W_L = 700 N/m = 7E+02 N/m

R_A = 0,5 * W_D*L = ½ * 700*35

=12250 N

M_x = R_A* x - ½ *W_L*x^2

M_1 = M_6 =12250 * 5 - ½*700 *5^2 = 5,25E+04 Nm

M_2 = M_5 = 12250 * 10 - ½*700 *10^2 = 8,75E+04 Nm

M_3 = M_4 = 12250* 15 - ½*700 *15^2 =1,05E+05 Nm

M_{max} = ⅛*700 *35^2 =1,072E+05 Nm

Gaya Lintang :

D_X = R_A-q*L

D_A=D_B= R_A = 1,225E+04 N

D_1=D_6= 1,225E+04 - 700*5 = 9,05E+03 N

D_2=D_5=1,225E+04 - 700*10 = 5,55E+03 N

D_3=D_4=1,225E+04 -700*15 = 2,05E+04

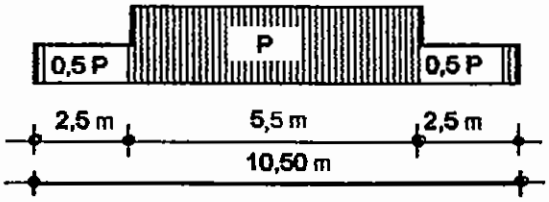
b. Beban Metara (Beban D)

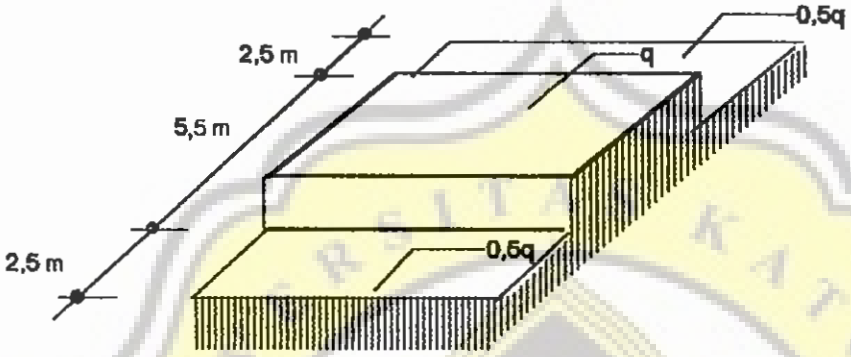
Beban q' (dari beban D) untuk bentang $30 \le L \le 60$ m

q' = 2,2 - 1,1/60 (L - 30)

= 2,2 - 1,1/60 (50 - 35)

= 1,925 T/m^2 = 1925 Kg/m^2





Gambar 5.33. Ketentuan penggunaan beban D (PPP JJR SKBI 1987 hal 8)

$$q = \frac{q'}{2{,}75} * 1{,}75$$

$$= \frac{1925}{2{,}75} * 1{,}75$$

= 1225 Kg/m = 12250 N/m

c. Akibat Beban Garis (Beban "D")

P = 12 Ton/jalur

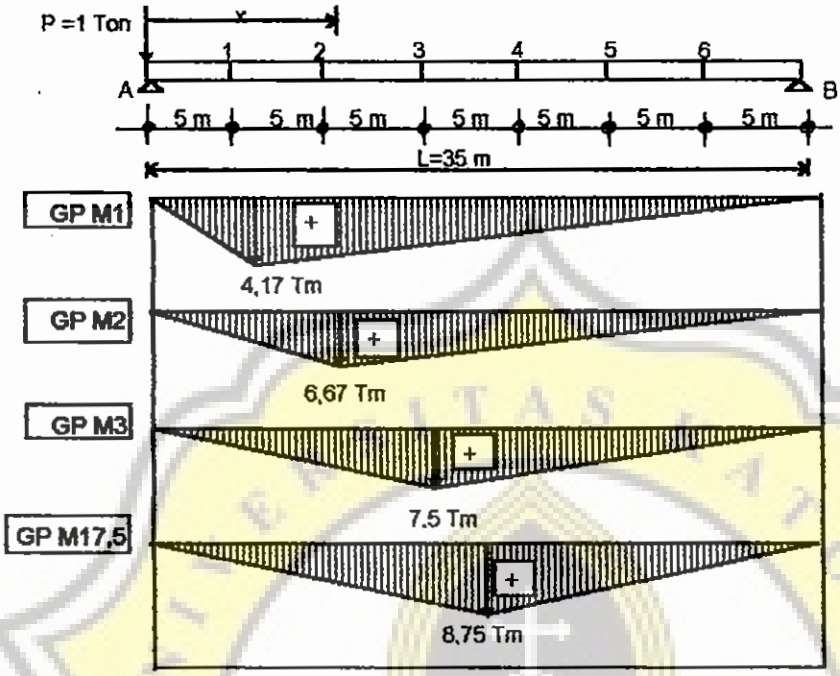
Koefisien kejut (K) $= 1 + \frac{20}{50+L}$ *(PPPJR - hal. 10)*

$$= 1 + \frac{20}{50+35} = 1{,}2354$$

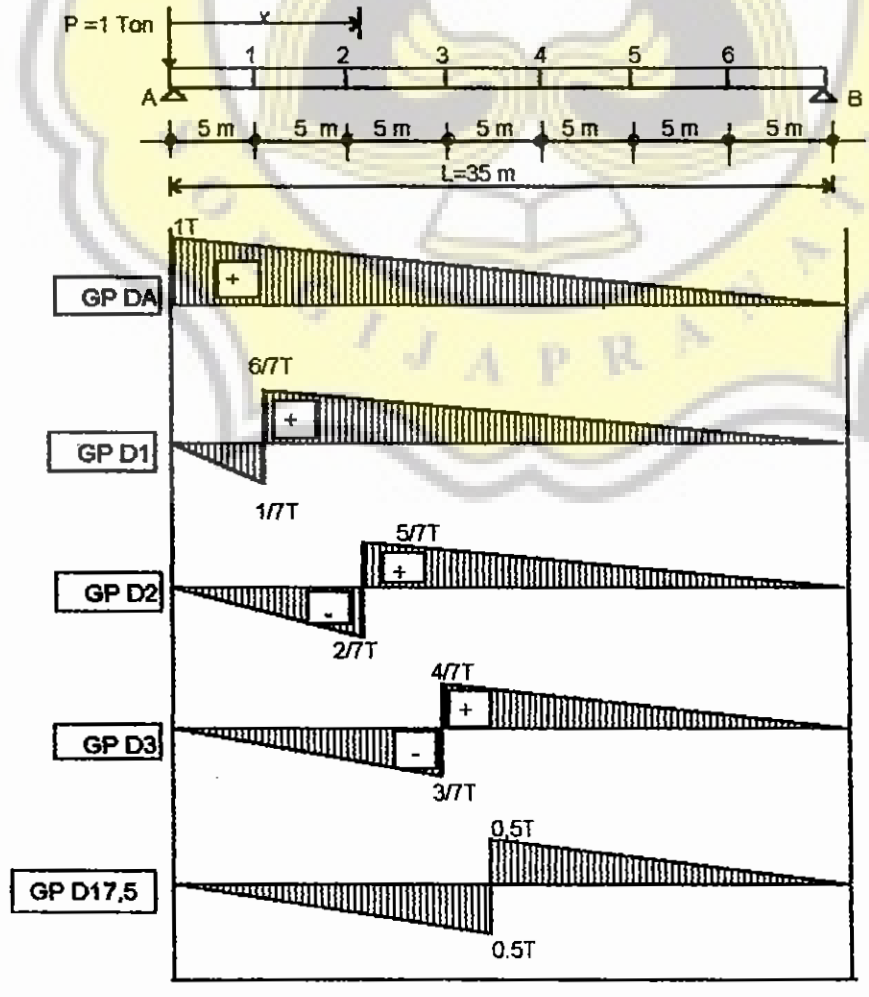
$$P_L = \frac{P}{2{,}75} * 1{,}75 * 1{,}2354$$

= 9,434 ton = 94.340 N

Garis pengaruh momen (RA * X)



Garis pengaruh gaya lintang (- RA + Dx)



Momen yang terjadi

M_1 = (9,434*4,17)+(½*1,225*35*4,17) = 128,734 Tm

M_2 = (9,434*6,67)+(½*1,225*35*6,67) = 205,913 Tm

M_3 = (9,434*7,5)+(½*1,225*35*7,5) = 231,536 Tm

M_{max} = (9,434*8,75)+(½*1,225*35*8,75) = 270,126 Tm

Gaya lintang yang terjadi

D_A = (1*9,434)+(½*1*35*1,225) = 30,8715 T

D_1 = (6/7 - 1/7)*9,434+{(½*6/7*30)-(½*1/7*5)}* 1,225=22,926T

D_2 = (5/7 - 2/7)*9,434+{(½*1/7*25)-(½*2/7*10)}*1,225=16,731T

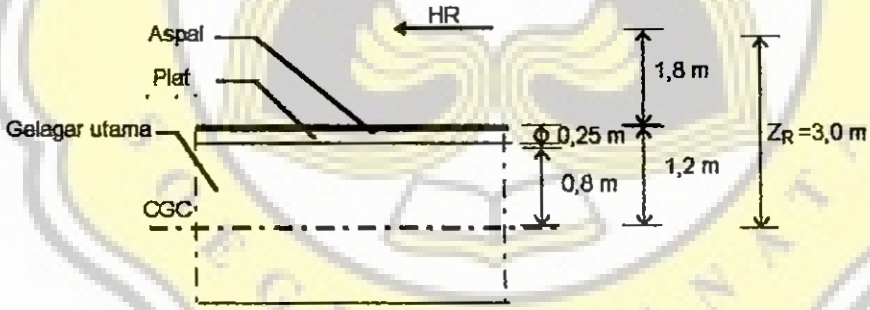
D_3 = (4/7 - 3/7)*9,434+{(½*4/7*20)-(½ *3/7*15)}*1,225=12,285 T

d. AKIBAT REM DAN TRAKSI

Dari perhitungan muatan D diketahui :

P = 12 T/jalur *(PPPJJR - hal. 7)*

q' = 1,925 T/m/jalur



Akibat muatan D untuk plas 1,75 m

$$P_1 = \frac{\text{Jarak gelagar}}{\text{Lebar lajur PPPJJR}} * P = \frac{1,75}{2,75} * 12 = 7,6364 \text{ T}$$

$$P_2 = \frac{\text{Jarak gelagar}}{\text{Lebar lajur PPPJJR}} * q' * L = \frac{1,75}{2,75} * 1,925 * 35 = 42,875 \text{ T}$$

P_L = 7,6364 + 42,875 = 50,511 T

H_R = 5%*50,511

= 2,526 T

M_R = H_R*Z_R

= 2,72045 *3 = 7,578 Tm

e. Akibat Angin

Pengaruh angin **q =150 Kg/m^2**

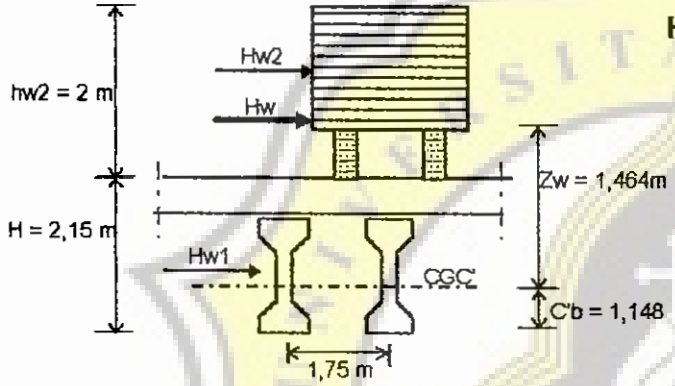
Keadaan dengan beban hidup, gelagar penuh (PPPJJRhal. 13):

⇒ Beban angin pada Jembatan (H_{w1}):

Luas sisi jembatan **= 0,5 *(100% sisi I + 50% sisi II)**

⇒ Beban angin pada kendaraan (H_{w2}):

Luas sisi kendaraan **= 100% *luas bidang sisi kendaraan**



H_{w1} =0,5*(100%*H +50%H)*q

=0,5*(150%*2,15)*150

= 208,125 Kg/m'

H_{w2} = 100%*h_{w2}* 150

=100%*2*150

= 300 Kg/m'

H_w = H_{w1}+H_{w2}

= 208,125 + 300

= 508,125 Kg/m'

Zw = 0,5 * (h_{w2}+150% *H) - C'$_b$

=0,5*(2+3,225) - 1,148

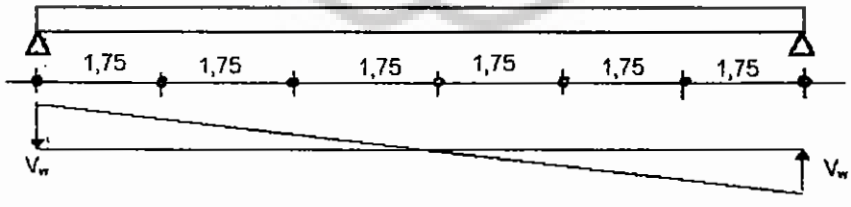
= 1,464m

Momen akibat angin :

M_{Luar} = Z_w*H_w

= 1,464 *508,125

= 743,895 Kgm/m' = 7,439E+03 Nm/m'



Momen dalam (M_{dalam})

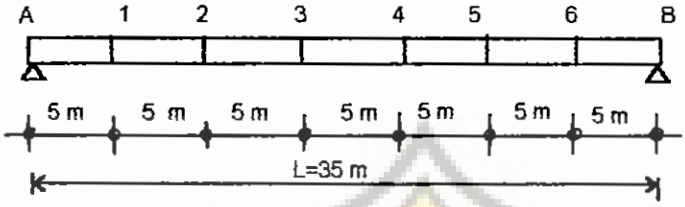
$$= 2*V_w*5,25 + 2*V_w*\frac{1,75^2}{5,25}$$

= 11,667V_w

Momen dalam = M_L

$11,667*V_w$ =7,439E+03 Nm

V_w = 0,6376E+03 N/m'



R_A = ½* 0,6376E+03*35 = 2,2946E+04 N

Momen yang terjadi :

M_1 = 2,2946E+04 *5 - ½*1,3112E+03*5^2 = 9,809E+04 Nm

M_2 = 2,2946E+04 *10 - ½*1,3112E+03*10^2 = 1,629E+05 Nm

M_3= 2,2946E+04 *15 - ½*1,3112E+03*15^2 = 1,9443E+05 Nm

M_{max}=2,2946E+04*17,5- ½*1,3112E+03*$17,5^2$=1,9772E+05 Nm

Gaya lintang yang terjadi

$D_A = R_A$ = 2,2946E+04 N

D_1 = 2,2946E+04 - (1,3112E+03*5) = 1,6408E+04 N

D_2 = 2,2946E+04 - (1,3112E+03*10) = 9,852E+03 N

D_3 = 2,2946E+04 - (1,3112E+03*15) = 3,296E+03 N

Selanjutnya perhitungan momen dapat dilihat pada tabel 5.9. Perhitungan momen pada gelagar dan tabel 5.10. Perhitungan gaya lintang pada gelagar (bentang = 35 m)

Tabel 5.9. Perhitungan momen pada gelagar(bentang= 35 m)

Titik	Jarak (m)	Beban Mati/M_D (Nm)		Beban Hidup/M_L (Nm)				Total (Nm)
		Merata	Terpusat	Air	D	Rem	Angin	1,2M_D+1,6M
A	0	0	0	0	0	6,5291E+04	0	1,0447E+05
1	5	2,639E+06	7,347E+04	5,25E+04	1,287E+06	6,5291E+04	9,809E+04	5,6596E+06
2	10	4,398E+06	1,2142E+05	8,75E+04	2,059E+06	6,5291E+04	1,629E+05	9,223E+06
3	15	5,278E+06	1,4385E+05	1,05E+05	2,3154E+06	6,5291E+04	1,9443E+05	1,0794E+07
0,5L	17,5	5,3877E+06	3,857E+05	1,072E+05	2,701E+06	6,5291E+04	1,9772E+05	**1,1842E+07**
4	20	5,278E+06	1,4385E+05	1,05E+05	2,3154E+06	6,5291E+04	1,9443E+05	1,0794E+07
5	25	4,398E+06	1,2142E+05	8,75E+04	2,059E+06	6,5291E+04	1,629E+05	9,223E+06
6	30	2,639E+06	7,347E+04	5,25E+04	1,287E+06	6,5291E+04	9,809E+04	5,6596E+06
B	35	0	0	0	0	6,5291E+04	0	1,0447E+05

Tabel 5.10. Perhitungan gaya lintang pada gelagar(bentang= 35 m)

Titik	Jarak (m)	Beban Mati/D_D (N)		Beban Hidup/D_L (N)			Total (N)
		Merata	Terpusat	Air	D	Angin	$1,2D_D+1,6D_L$
A	0	6,3438E+05	2,2042E+04	1,225E+04	3,0872E+05	2,2946E+04	**1,316E+06**
1	5	4,3982E+05	1,6532E+04	9,05E+03	2,2926E+05	1,6408E+04	9,5517E+05
2	10	2,6389E+05	1,1021E+04	5,55E+03	1,6731E+05	9,852E+03	6,2222E+05
3	15	8,7965E+04	5,5104E+03	2,05E+03	1,2285E+05	3,296E+03	3,1728E+05
0,5L	17,5	0	0	0	0	0	0
4	20	8,7965E+04	5,5104E+03	2,05E+03	1,2285E+05	3,296E+03	3,1728E+05
5	25	2,6389E+05	1,1021E+04	5,55E+03	1,6731E+05	9,852E+03	6,2222E+05
6	30	4,3982E+05	1,6532E+04	9,05E+03	2,2926E+05	1,6408E+04	9,5517E+05
B	35	6,3438E+05	2,2042E+04	1,225E+04	3,0872E+05	2,2946E+04	**1,316E+06**

❑ **Momen Yang Diperhitungkan**

M_G = Momen akibat gelagar

= $1,2\ (\ ^1/_8 * W_D * L^2\ )$

= $1,2\ (\ ^1/_8 * 2662,5 * 35^2\ )$

= **4,697E +05 Kgm =4,697E+09 Nmm**

M_T = Momen total $(1,2M_D + 1,6M_L)$

= **1,1842E+07 Nm = 1,1842E+10 Nmm**

M_P = Momen pada pratekan akibat berat sendiri balok, plat dan balok diafragma sebelum plat/komposit berfungsi

= $1,2[\ ^1/_8\ (2662,5+840)35^2 + 3,857E+05$ (Mmax beban terpusat)]

= **1,106E+06Kgm =1,106 E+10 Nmm**

M_C = Momen pada penampang komposit

= $M_T - M_P$

= **1,1842E+10 - 1,106 E+10 = 7,820E+08 Nmm**

C. Disain Penampang Balok

❑ **Tegangan Batas Beton K-500 (** *TY. Lin, halaman 24* **)**

f'_c = *tegangan bet on umur 28 hari* = **500 Kg/cm² = 50 MPa**

f'_{ci} = *tegangan beton saat transfer pada umur 14 hari*

= **0,9 f_c'** (*PBI 1971 - tabel 4.1.4*)

= **0,9 * 50 = 45 MPa**

- **Segera setelah peralihan gaya prategang (sebelum kehilangan gaya prategang), tegangan serat-serat terluar:**

tekan : $f = -0{,}6\, f'_{ci}$

$= -0{,}6 * 45 = -27$ MPa

tarik : $f' = 0{,}5\sqrt{f'_{ci}}$

$= 0{,}5\sqrt{45} = 3{,}35$ MPa

- **Pada beban kerja setelah terjadi seluruh kehilangan gaya prategang (setelah kehilangan gaya prategang)**

tekan : $f = -0{,}45\, f'_{c}$

$= -0{,}45 * 50 = -22{,}5$ MPa

tarik : $f' = 0{,}5\sqrt{f'_{c}}$

$= 0{,}5\sqrt{50} = 3{,}53$MPa

❑ **Perkiraan Gaya Prategang Awal**

$$F = \frac{M_T}{0{,}65 * h}$$

$$= \frac{1{,}1842E+10}{0{,}65 * 1900} = 9{,}589E{+}06 \text{ N}$$

Kehilangan tegangan rata-rata untuk sistem Post Tensioning adalah 20 % (*TY. Lin, halaman 103*)

$$F_o = \frac{F}{0{,}8}$$

$$= \frac{9{,}589E{+}06}{0{,}8} = 1{,}1986\ E{+}07 \text{ N}$$

❑ **Menentukan Letak Eksentrisitas (CGS)**

$$e_1 = \frac{f_t' * I_c}{C_t * F_o}$$

$$= \frac{3{,}35 * 4{,}1532E+11}{800 * 1{,}1986E+07} = 145{,}0986 \text{ mm}$$

$$e_2 = \frac{M_e}{F_o}$$

$$= \frac{4{,}697E+09}{1{,}16E+07} = 404{,}31 \text{ mm}$$

$$e = e_1 + e_2 + K_b$$

$$= 145{,}0986 + 404{,}31 + 410{,}496$$

$$= 926{,}74 \text{ mm}$$

Selanjutnya direncanakan tendon terletak **500 mm** dari serat terbawah (**e = 300 mm**)

- **Perhitungan Gaya Pratekan Yang Dibutuhkan**

1. Gaya Pratekan Efektif

$$F = \frac{M_p + (m_b * M_c)}{e + K_t}$$

$$= \frac{1{,}106E+10 + (1{,}03 * 7{,}82E+08)}{300 + 410{,}496}$$

$$= 1{,}670E+07 \text{ N}$$

2. Gaya Pratekan Awal

$$F_o = \frac{F}{0{,}8} = \frac{1{,}670E+07}{0{,}8}$$

$$= 2{,}0875E+07 \text{ N}$$

- **Kontrol Tegangan**

1. Akibat gaya pratekan awal (F_o)

$$f_{bottom} = -\frac{F_o}{A}\left(1 + \frac{e_t}{K_t}\right)$$

$$= -\frac{2{,}0875E+07}{1{,}065E+06}\left(1 + \frac{300}{410{,}496}\right) = -32{,}82 \text{ Mpa}$$

$$f_{top} = -\frac{F_o}{A}\left(1 - \frac{e_t}{K_b}\right)$$

$$= -\frac{2{,}0875E+07}{1{,}065E+06}\left(1 - \frac{300}{410{,}496}\right) = -5.106 \text{ Mpa}$$

2. Akibat gaya pratekan efektif (F)

$$f_{bottom} = -\frac{F}{A}\left(1+\frac{e_t}{K_t}\right)$$

$$= -\frac{1{,}670E{+}07}{1{,}065E{+}06}\left(1+\frac{300}{410{,}496}\right) = -28{,}585 \text{ Mpa}$$

$$f_{top} = -\frac{F}{A}\left(1-\frac{e_t}{K_b}\right)$$

$$= -\frac{1{,}670E{+}07}{1{,}065E{+}06}\left(1-\frac{300}{410{,}496}\right) = -4{,}085 \text{ Mpa}$$

3. Akibat berat sendiri balok prategang (M_G)

$$f_{bottom} = +\frac{M_G}{A * K_t}$$

$$= +\frac{4{,}697E{+}09}{1{,}065E{+}06 * 410{,}496} = +10{,}744 \text{ Mpa}$$

$$f_{top} = -\frac{M_G}{A * K_b}$$

$$= -\frac{4{,}697E{+}09}{1{,}065E{+}06 * 410{,}496} = -10{,}744 \text{ Mpa}$$

4. Akibat muatan mati (M_D)

$$f_{bottom} = +\frac{M_D}{A * K_t}$$

$$= +\frac{6{,}928E{+}09}{1{,}065E{+}06 * 410{,}496} = +15{,}85 \text{ Mpa}$$

$$f_{top} = -\frac{M_D}{A * K_b}$$

$$= -\frac{6{,}928E{+}09}{1{,}065E{+}06 * 410{,}496} = -15{,}85 \text{ Mpa}$$

5. Akibat muatan hidup (M_L)

$$f_{bottom} = + \frac{M_L}{A' * K_t'}$$

$$= + \frac{4{,}914E+09}{1{,}3125E+06 * 323{,}49} = +11{,}574 \text{ Mpa}$$

$$f_{top} = - \frac{M_L}{A * K_b} * \frac{(C_b' - Z_t)}{C_t'}$$

$$= - \frac{4{,}914E+09}{1{,}3125E+06 * 410{,}496} * \frac{(1148{,}63 - 200)}{951{,}37}$$

$$= -2{,}086 \text{ Mpa}$$

$$f_{plat} = - \frac{M_L}{A' * K_b'}$$

$$= - \frac{4{,}914E+09}{1{,}3125E+06 * 390{,}56} = -9{,}586 \text{ Mpa}$$

❑ **Kombinasi Tegangan**

1. Keadaan Awal (1 + 3)

Serat atas (f_t) = -5,106 - 10,744 = - 15,85 Mpa < 3,35 Mpa

Serat bawah (f_b) = - 32,82 +10,744 = -22,076 Mpa < - 27 Mpa

2. Keadaan Akhir (2 + 4 + 5)

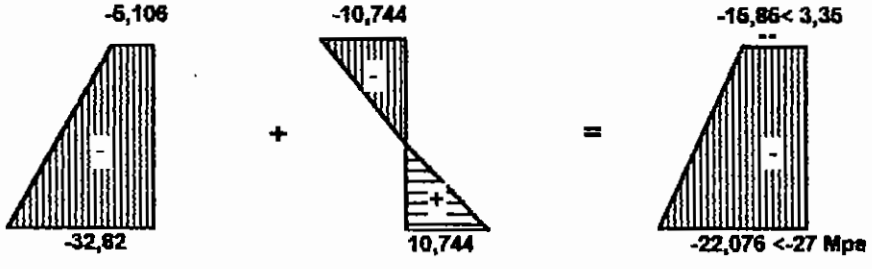
Serat Atas(f_t)=-4,085-15,85 - 2,086 = -22,021 Mpa< -22,5Mpa

Serat bawah(f_b)=-28,585+15,85+11,574=-1,16Mpa<3,53Mpa

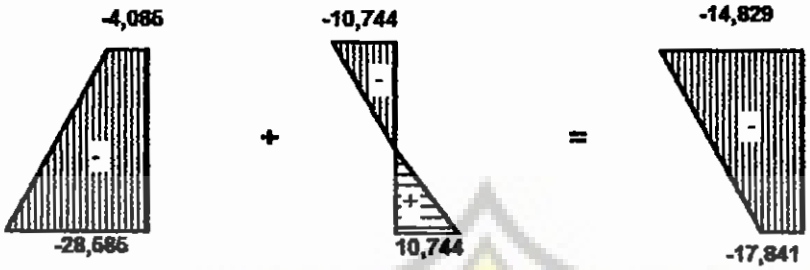
Pada Plat lantai (f_{plat}) = - 9,586 Mpa

❑ **Diagram Tegangan**

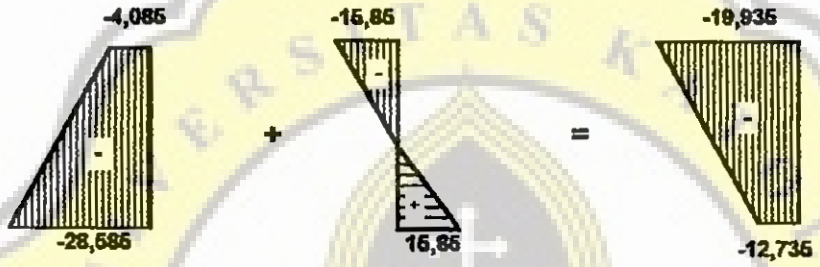
1. Keadaan Awal (1+3)



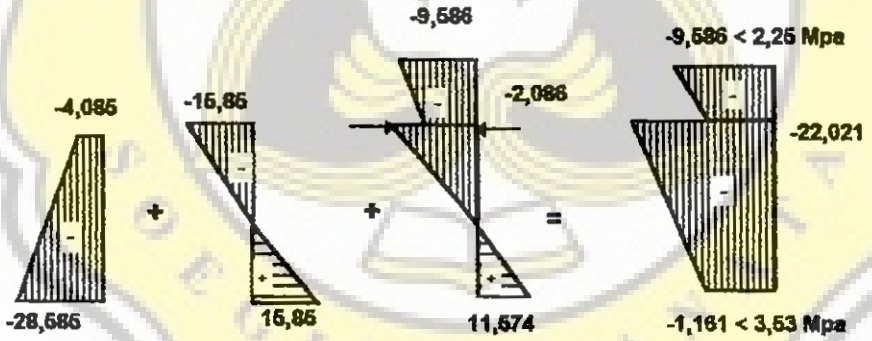
2. Kondisi Setelah Kehilangan Tegangan (2+3)



3. Kondisi Setelah Kehilangan Tegangan (2+4)



4. Kondisi Setelah Kehilangan Tegangan (2+4+5)



V.1.2.12. Perhitungan Tendon Pratekan

Digunakan tendon tipe " *Uncoated Seven Wire Stress Relieved for Prestressed Concrete* ", dengan spesifikasi menurut ASTM A-416 (*lampiran B - hal 305, tabel 2-2 hal 49, TY Lin "Desain Struktur Beton Prategang"*) adalah :

- Diameter Nominal : **12,70 mm**
- Luas Nominal Strand : **98,71 mm^2**
- Kekuatan Putus : **183,7 KN**
- Teg. Putus Min. (f_{pu}) : **1860 Mpa**
- Beban Min. Muai 1% (f_{py}) : **156,1 KN**
- Modulus Elastisitas (E_s) : **190.000 Mpa**

Untuk angkur digunakan *angkur VSL tipe E 5-22*, dengan jumlah strand 22 buah pada setiap tendon (*Lampiran B, TY. Lin, "Desain Struktur Beton Prategang"*)

Luas tampang tendon = **22 * 98,71 = 2171,6 mm^2**

Beban Putus 1 (satu) tendon = **2171,6 *1860 = 4039191,922 N**

(fpu) = **4,0392E+06 N**

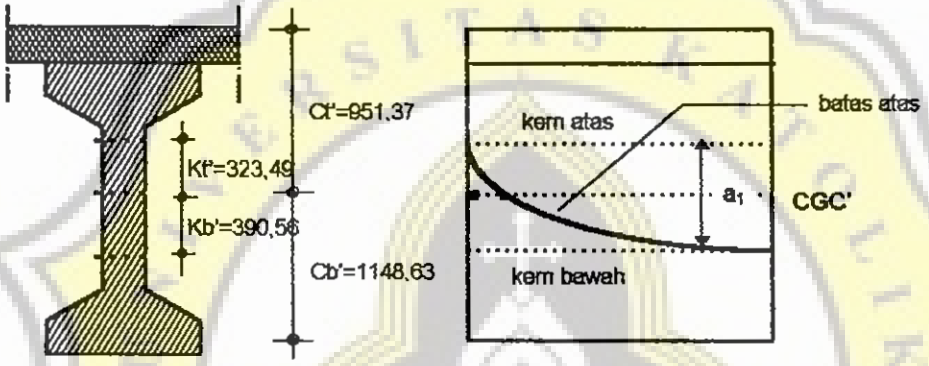
A. Perhitungan Jumlah Tendon

$$n_1 = \frac{Fo}{90\%*fpu} = \frac{2{,}0875E+07}{0{,}9*4{,}039E+06} = 5{,}74 \approx 6 \text{ buah.}$$

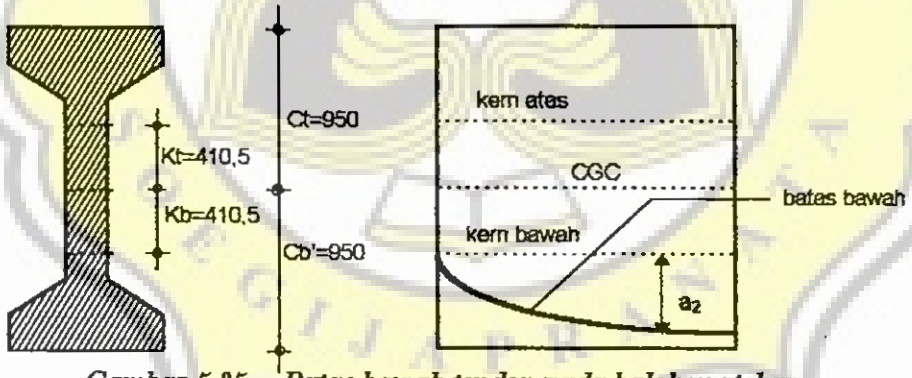
$$n_1 = \frac{F}{80\%*fpu} = \frac{1{,}670E+07}{0{,}8*4{,}039E+06} = 5{,}17 \approx 6 \text{ buah}$$

(Jadi digunakan tendon sebanyak 6 buah)

B. Lay Out Tendon

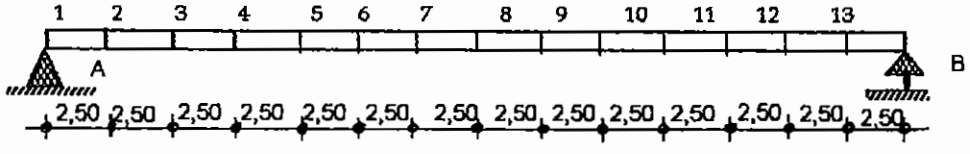


Gambar 5.34. Batas atas tendon pada balok pratekan



Gambar 5.35. Batas bawah tendon pada balok pratekan

❑ Daerah Aman Tendon



Gambar 5.36. Gelagar memanjang (bentang 35 m)

Rumus : $a_1 = \frac{M_T}{F}$; $a_2 = \frac{M_G}{F_0}$

Batas Atas = $C_b' + K_t' - a_1$

Batas Bawah = $C_b - K_b - a_2$

Dari hasil perhitungan sebelumnya diperoleh :

M_G = 4,697E+09 Nmm

M_T = 1,1842E+10 Nmm

F = 1,670E+07 N

F_o = 2,0875E+07 N

C_t = 950 mm

C_b = 950 mm

C_t' = 951,37 mm

C_b' = 1148,63 mm

K_t = 410,496 mm

K_b = 410,496 mm

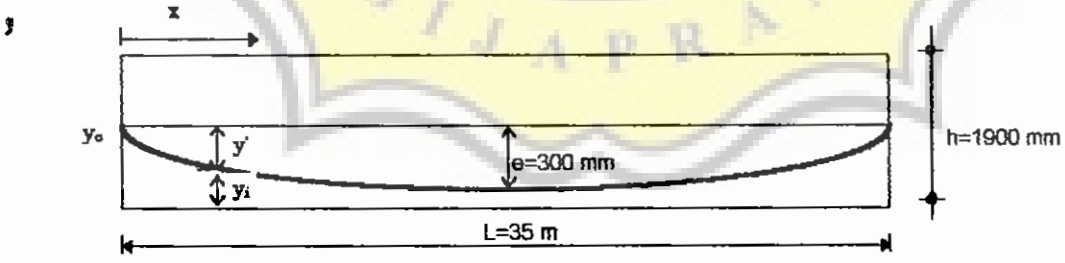
K_t' = 323,49 mm

K_b' = 390,56 mm

Tabel 5.11. Perhitungan daerah aman tendon (bentang 35 m)

NO	X (mm)	M_G (Nmm)	M_T (Nmm)	a_1 (mm)	a_2 (mm)	BATAS ATAS	BATAS BAWAH
1	0	0	0	0	0	1472,12	539,504
2	2.500	1,246E+08	3,04E+09	185,48	60,81	1286,64	478,694
3	5.000	2,30E+09	5,62E+09	342,89	112,25	1129,23	427,254
4	7.500	3,163E+09	7,72E+09	471,02	154,37	1001,1	385,134
5	10.000	3,384E+09	9,36E+09	571,08	165,15	901,04	374,354
6	12.500	4,316E+09	1,053E+10	642,46	210,64	829,66	328,864
7	15.000	4,601E+09	1,124E+09	685,78	224,55	786,34	314,954
8	17.500	4,697E+09	1,147E+10	699,82	229,23	772,3	310,274

❑ **Lintasan Tendon**



Gambar 5.37. Lintasan tendon pratekan(bentang 35 m)

Lintasan kabel merupakan lintasan parabola dengan mengikuti rumus parabola : $y' = \frac{4.f.x(L-x)}{L^2}$

$y_i = y_o - y'$

di mana :

f = kelengkungan parabola

L = 35.000 mm

h = 1900 mm

i = 1, 2, ..., n

n = jumlah lintasan tendon

$\varnothing_{selongsong} = 5,5$ *in.* $= 139,7$ *mm*

Tabel 5.12. Perhitungan lintasan tendon

NO		TRACE TENDON 1&2 (y_1)	TRACE TENDON 3&4 (y_2)	TRACE TENDON 5&6 (y_3)
	y_o =	773	1006	1239
	x / f =	347	465	583
1	0	773	1006	1239
2	2.500	680,94	882,63	1084,33
3	5.000	603,04	778,25	953,45
4	7.500	539,31	692,84	846,37
5	10.000	489,74	626,41	763,08
6	12.500	454,33	578,96	703,59
7	15.000	433,08	550,49	667,9
8	17.500	426	541	656

❑ **Kontrol Lendutan**

E_C = 4730 * $\sqrt{f'_c}$

= 4730 * $\sqrt{50}$

= 31,73 E+03 Mpa (Peraturan ACI, TY lin Ned hal 38)

I_C = 4,153E+11 mm^4

I_C' = 4,875E+11 mm^4

e = 300 mm

F_o = 2,0875E+07 N

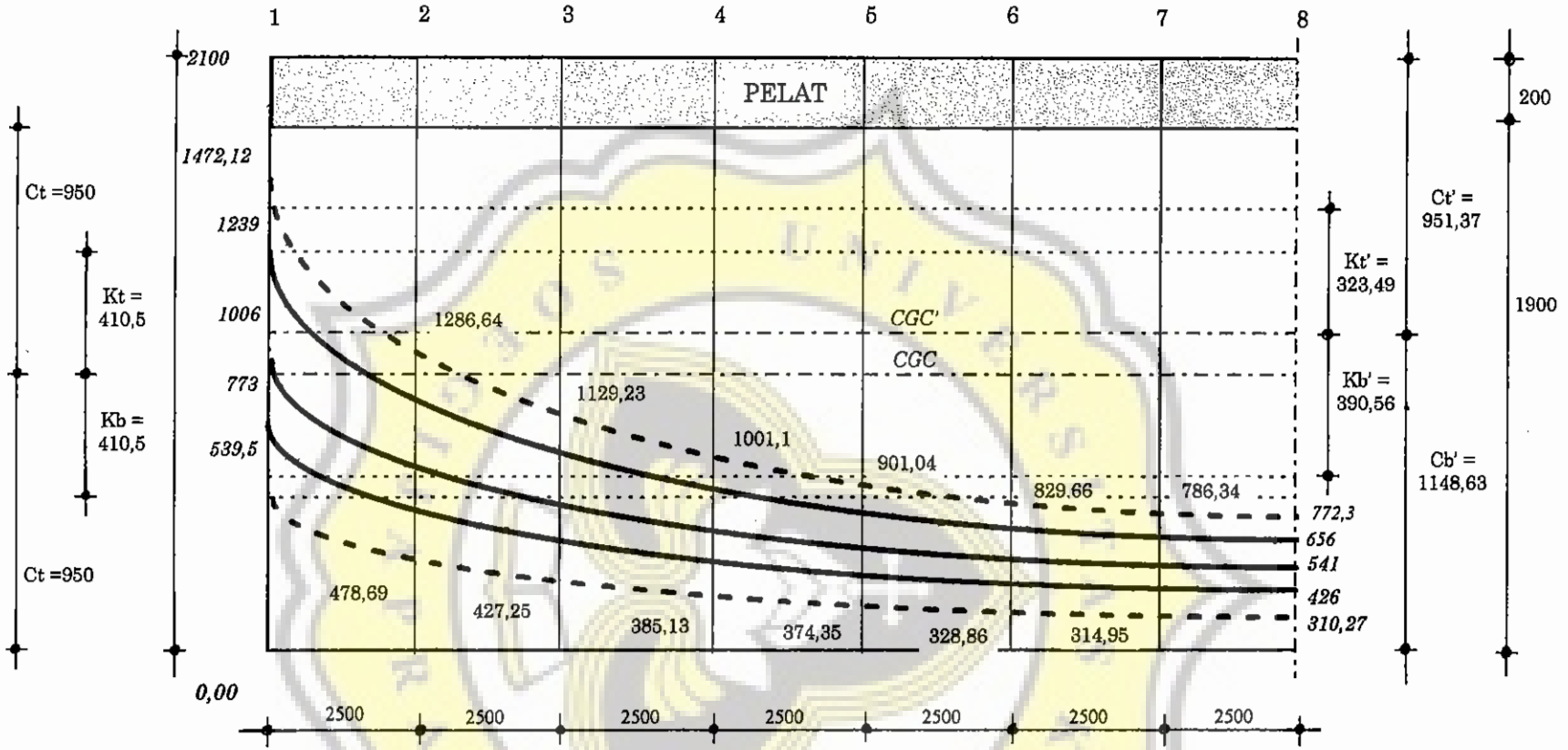
W_{D1} = 35185 N/m (Beban mati merata balok +plat +pavement)

W_L = 1,295E+04 N/m (Beban hidup merata)

P_L = 9,434E+04 N/m' (Beban hidup terpusat)

M_{D2} = 3,857E+08 Nmm (Momen akibat beban diafragma)

M_G = 4,697E+09 Nmm



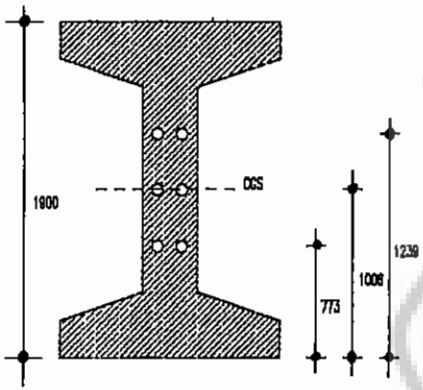
Gambar 5.35 : Lay out tendon balok pratekan (bentang 35 m)

KETERANGAN

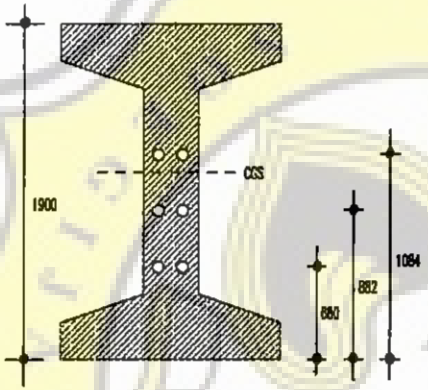
- - - - - = Batas daerah aman tendon

——— = Lintasan tendon

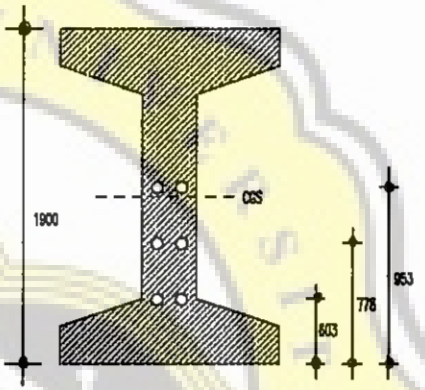
POTONGAN PADA TITIK LINTASAN TENDON BALOK 35 M



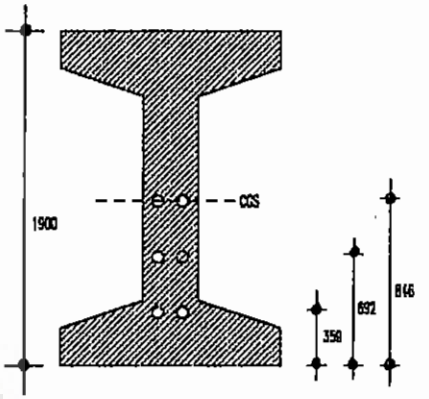
POTONGAN TITIK 1



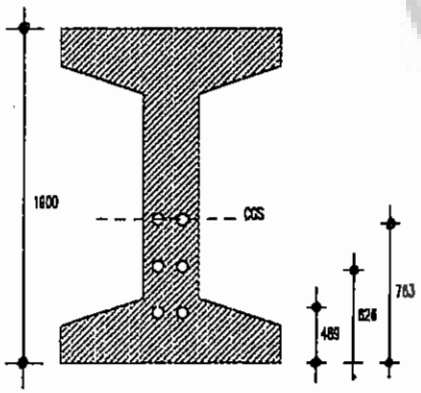
POTONGAN TITIK 2



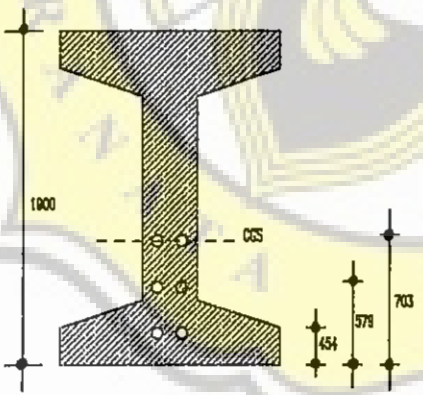
POTONGAN TITIK 3



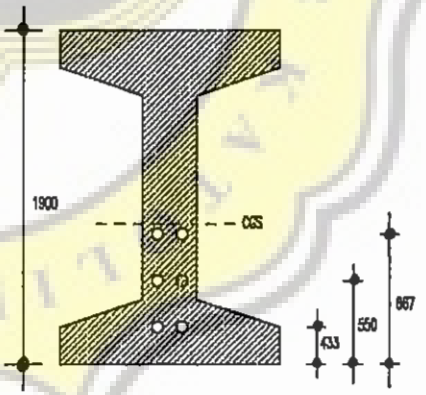
POTONGAN TITIK 4



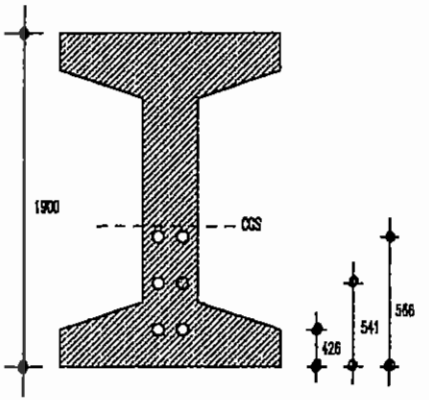
POTONGAN TITIK 5



POTONGAN TITIK 6



POTONGAN TITIK 7



POTONGAN TITIK 8

❑ **Syarat Lendutan :**

Lendutan yang terjadi $\leq \frac{1}{360} * L$

$\leq \frac{1}{360} * 35.000$ mm

$\leq$ 97,22 mm (↓)

1. Kondisi Awal (Transfer Tegangan)

$$\Delta F_o = \frac{40 * F_o * e * L^2}{384 * E_c * I_c}$$

$$= \frac{40*2,0875E+07 * 300 *35000^2}{384 * 31,73E+03 * 4,153E+11} = 60,64 \text{ mm } (\uparrow)$$

$$\Delta M_G = \frac{5 * M_G * L^2}{384 * E_c * I_c}$$

$$= \frac{5 * 4,697E+09 * 35000^2}{384 * 31,73E+03 * 4,153E+11} = 5,69 \text{ mm } (\downarrow)$$

Δ_{tot} = ΔF_o - ΔM_G (*TY. Lin -halaman 269*)

= 60,64 - 5,69

= 54,95 mm (↑) ≤ 97,22 mm O.K !!!

2. Kondisi Akhir (Beban Kerja)

ΔF = 0,8* ΔF_o (Akibat gaya prategang efektif)

= 0,8* 60,64 = 48,512 mm (↑)

$$\Delta M_{D1} = \frac{5 * W_{D1} * L^4}{384 * E_c * I_c}$$ (Akibat beban mati merata)

$$= \frac{5 * 35,185 * 35000^4}{384 * 31,73E+03 * 4,875E+11} = 44,446 \text{ mm } (\downarrow)$$

$$\Delta M_{D2} = \frac{5 * M_{D2} * L^2}{384 * E_c * I_c}$$ (Akibat berat diafragma)

$$= \frac{5*3,857E+08 *35000^2}{384 * 31,73E+03 * 4,875E+11} = 0,398 \text{ mm } (\downarrow)$$

$$\Delta M_{WL} = \frac{5 * W_L * L^4}{384 * E_c * I_c} \text{ (Beban hidup merata)}$$

$$= \frac{5 * 12,95 * 35000^4}{384 * 31,73E+03 * 4,875E+11}$$

$$= 16,37 \text{ mm } (\downarrow)$$

$$\Delta M_{PL} = \frac{P_L * L^3}{48 * E_c * I_c} \text{ (Beban hidup terpusat)}$$

$$= \frac{9,434E+04 * 35000^3}{48 * 31,73E+03 * 4,875E+11} = 5,448 \text{ mm } (\downarrow)$$

$\Delta tot = \Delta F - \Delta M_{D1} - \Delta M_{D2} - \Delta M_{WL} - \Delta M_{PL}$ (*TY. Lin- halaman 269*)

$= 48,512 - 44,446 - 0,398 - 16,37 - 5,448$

$= 18,45 \text{ mm } (\downarrow) \leq 97,22 \text{ mm}$ O.K III

V.1.2.13. Kehilangan Tegangan

❑ **Perpendekan Elastis Beton**

Dari hasil perhitungan sebelumnya diperoleh :

$F_o = 2,0875E+07$ N

$A_s = 2171,6 \text{ mm}^2$

$f_o = \frac{2,0875E+07}{6*2171,6} = 1602,12$ Mpa

$A_o = 1,065E+06 \text{ mm}^2$

$E_o = 31,73 E+03$ MPa

$E_S = 1,9E+05$ Mpa

$n = \frac{E_s}{E_c}$

$= \frac{1,9E+05}{31,73E+03} = 5,988$

Kehilangan tegangan pada tendon disebabkan oleh gaya prategang pada 5 (lima) tendon lainnya yang telah dipasang lebih dahulu, yaitu sebesar:

$F_{po} = 5*2171,6 *1602,12 = 1,7396E+07$ Mpa

$\Delta f_S = E_s$

$= 0,5 * \frac{n * F_{po}}{A_c}$ *(TY. Lin - halaman 83)*

$= 0,5 * \frac{5,988 * 1,7396E+07}{1,065E+06} = 48,91$ Mpa

$\Delta f_s = \frac{\Delta f_s}{f_o} * 100\%$

$= \frac{48,91}{1602,12} * 100\% = 3,053\ \%$

❑ **Rangkak Beton**

Dari hasil perhitungan sebelumnya diperoleh :

$K_{cr} = 1,6 \Rightarrow$ untuk pasca tarik *(TY. Lin -halaman 83)*

$n = 5,988$

$F = 1,670$ E+07N

$M_p = 1,106E+10$ Nmm

$e = 300$ mm

$I_C = 4,153E+11 mm^4$

f_{cir} = *tegangan beton akibat gaya prategang*

$= \frac{F}{A_c} + \frac{F * e^2}{I}$

$= \frac{1,670E+07}{1,065E+06} + \frac{1,670E+07 * 300^2}{4,153E+11}$

$= 19,300$ Mpa

f_{cds} = *teg. beton akibat beban mati setelah diberi pratekan*

$= \frac{M_p * e}{I}$

$= \frac{1,106E+10 * 300}{4,153E+11}$

$= 7,989$ Mpa

$CR = K_{cr} * n\ (f_{cir} - f_{cds})$

$= 1,6 * 5,988\ (19,300 - 7,989) = 108,368$ MPa

$\%CR = \frac{CR}{f_o} * 100\%$

$= \frac{108,368}{1602,12}\ 100\% = 6,764\ \%$

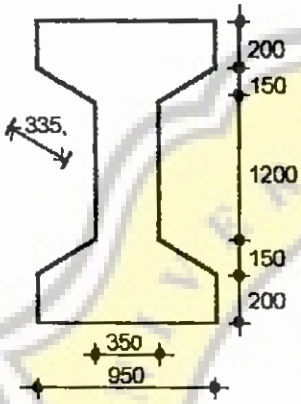
❑ **Susut Beton**

K_{sh} = 0,64 *(TY. Lin tabel 4-4, hal. 88)*

V = *Volume balok*

= A_c * L

= 1,065 E+06* 35.000 = 3,728 E+10 mm^3



S = *Luas permukaan balok*

= 2 *A_c + L { 2 (950 +1200)

+ 4 (200+ 335,4) }

= 2,4676E+07 mm^2

Rh = *Kelembaban relatif*

= 60 %

Gambar 5.38. Luas permukaan balok

$$SH = 8,2\ E\text{-}06 * K_{sh} * Es\left(1 - 0,06 * \frac{V}{S}\right)(100 - Rh)$$

$$= 8,2E\text{-}06 * 0,64 * 1,9E+05\left(1 - 0,06 * \frac{3,728E+10}{2,4676E+07}\right)(100 - 60)$$

= - 36,16 MPa

Karena hasil perhitungan bernilai minus, maka SH = 0%

❑ **Rekaksasi Baja**

K_{rc} = 138 MPa

J = 0,15

Tabel 4-5 TY. Lin- halaman 90

$$f_{pi} = \frac{F_o}{A_s} = \frac{2,0875E+07}{2171,6} = 9612,73\ Mpa$$

f_{pu} = 1860 MPa

RE = { K_{rc} - (J* (SH + CR + Δf_S))}* C

= { 138 - (0,15* (0 + 108,368 + 48,91))}*1,28

= 146,4426 MPa

$$\% RE = \frac{RE}{f_{pu}} * 100\%$$

$$= \frac{146,4426}{1860} * 100\ \%$$

$$= 7,8733\ \%$$

❑ **Kehilangan Gaya Prategang Total**

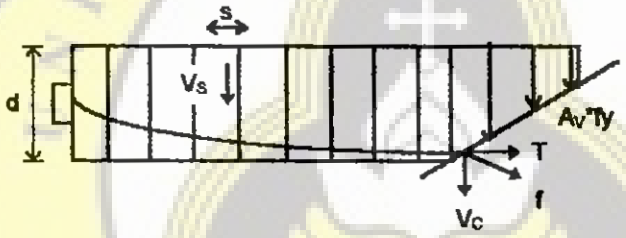
Kehilangan tegangan = % ES + % CR + % SH + % RE

total = 3,020 % + 6,764 %+ 0 % + 7,8733 %

= 17,657 % < 20 % (OK !!!)

(memenuhi asumsi awal dalam perhitungan, TY lin hal 103)

V.1.2.14. Tulangan Sengkang Balok Pratekan



Gambar 5.39. Reaksi gaya geser akibat tendon pratekan

Persamaan trase tendon :

$$y = \frac{4 * f * x}{L^2}(L - x)$$

$$y' = \tan\theta = \frac{4 * f}{L^2}(L - 2x)$$

$$f = e - e_o = 300 - 0 = 300 \text{ (gradien CGS)}$$

$$y' = \frac{4 * 300}{35000^2}(35000 - 2x) = 0.0343 - 0,00001956\ x$$

Jarak sengkang **(s)** $= \frac{A_v * f_y * d}{V_s}$

Dimana :

s : jarak sengkang

Av : luas sengkang = 2A (Ø 10,2 A = 157 mm²)

d : tinggi balok

fy : 400 Mpa

$V_S = V_U - V_C$

V_U : *reaksi pada titik yang ditinjau* = **Dx** *(Tabel 5.10. Perhitungan gaya lintang pada gelagar)*

$V_C = F \sin \theta$

F : *gaya prategang* **=1,670E+07 N**

Selanjutnya hasil perhitungan dapat dilihat pada tabel berikut :

Tabel 5.13. Perhitungan penulangan sengkang balok pratekan

Titik	tan θ	sin θ	V_U	V_C	V_S	Ø sengkang	jarak sengkang (s)
0	0,0399	0,0399	1,32E+06	5,79E+05	7,42E+05	10 mm	160 mm
5	0,0307	0,0397	9,55E+05	5,77E+05	3,811E+05	10 mm	310 mm
10	0,03633	0,03961	6,22E+05	5,75E+05	4,72E+04	10 mm	2527 mm
15	0,03633	0,03961	3,173E+05	5,74E+05	2,56E+05	10 mm	2550 mm

❑ **Sengkang Minimum**

Pembesian sengkang minimum didasarkan pada rumus :

$A_{s\,min} = 0{,}25\,\% * b_o\ mm^2/cm$

$= 0{,}25\%*950\ mm^2/cm$

$= 2{,}37\ mm^2/cm = 237\ mm^2/m$

Bila tiap meter dipasang 4 buah sengkang (jarak 200 mm) maka :

$A_{s\,min} = 4 * \frac{1}{4} * \pi * d^2$

$237 = 4 * \frac{1}{4} * 3{,}14 * d^2$

$d^2 = 75{,}478$

$d = 8{,}688 \approx 10\ mm$

Jadi sengkang minimum adalah Ø **10 - 250 (As = 314 mm^2)**

(WC Vis tabel 13a hal 82)

❑ **Penulangan Memanjang Minimum**

Jumlah penulangan memanjang minimum untuk sengkang adalah **0,15 % - 0,25%*Ac**

Sehingga :

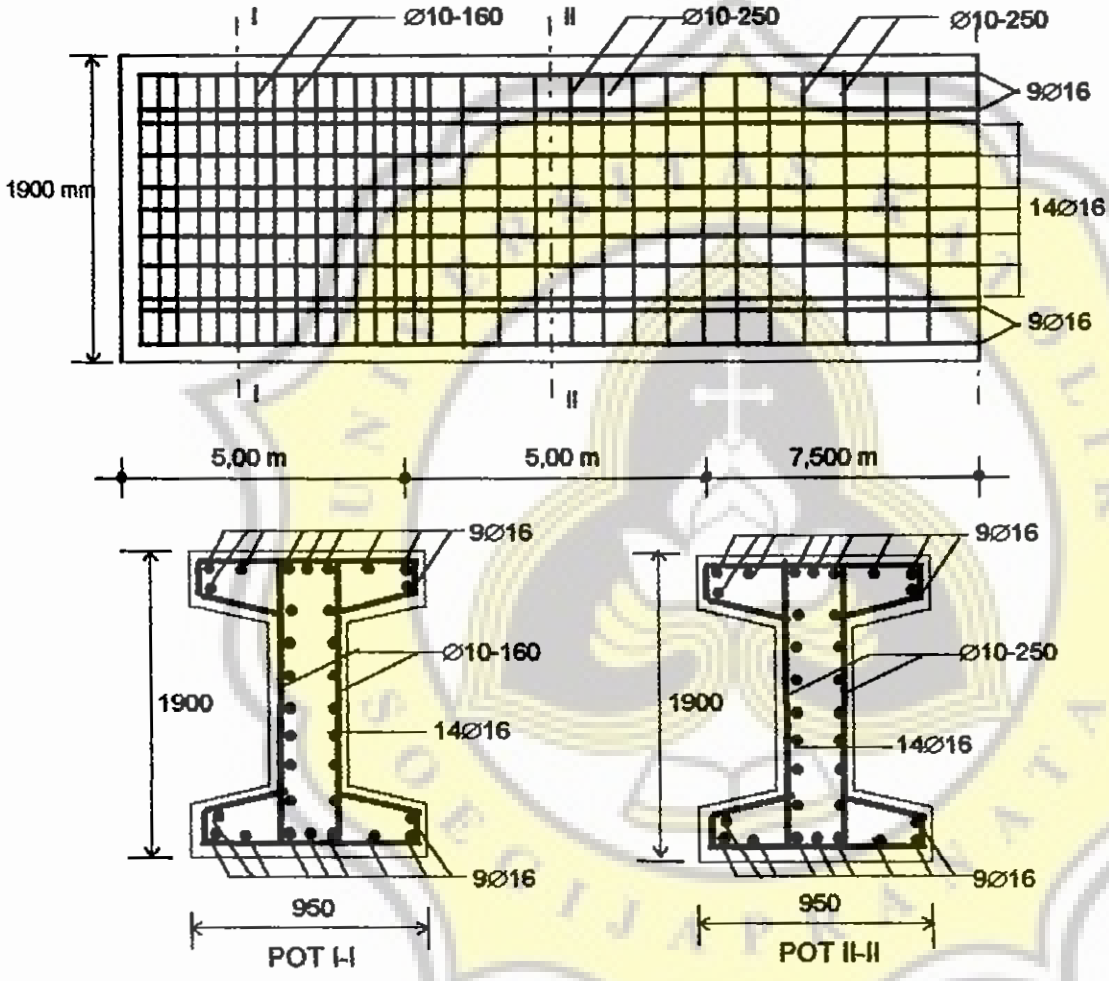
$A_{S\,min} = 0{,}25\,\% * bo * h = 0{,}25\,\% * 950 * 1900$

$= 4512{,}52\ mm^2$

Dipakai tulangan **18 Ø16 (As = 3620 mm^2)**

14Ø16 (As = 2816 mm^2)

(As = 6436 mm^2)



Gambar 5.39. Penulangan sengkang balok pratekan

V.1.2.15. Perencanaan Shear Connector

$$V_{ni} = \frac{D_i * W}{I_c' * b_o}$$

$W = h_{plat} * H * (K_t' - 0{,}5\ h_{plat})$

$V_u = V_{ni} * A_C'$

$V_{SC} = 55 * d^2 * \sqrt{f'_{plat}} \rightarrow H/d > 5{,}5$

$= 10 * d * H * \sqrt{f'_{plat}} \rightarrow H/d < 5{,}5$

$$n = \frac{V_u}{V_{sc}}$$

Dimana

V_{ni} = *tegangan geser yang ditahan oleh bidang kontak*

Di = *gaya lintang maksimum pada potongan yang ditinjau*

W = *statis momen plat terhadap CGC'*

Ic' = *momen inersia komposit* = **4,875E+11 mm^4**

b_0 = *lebar bidang kontak* = **950 mm**

V_u = *tegangan geser akibat gaya lintang pada titik*

Ac' = *luas komposit* = **1,312E+06 mm^2**

d = *diameter shear connector*

H = *tinggi shear connector*

V_{sc} = *tegangan geser yang ditahan oleh SC*

n = *jumlah shear connector*

Digunakan Shear Connector (SC) type U, dengan tulangan ∅ 20 (**A = 314,16 mm^2**)

d = 20 mm

H = 200 mm

$$\frac{H}{d} = \frac{200}{20} = 10 > 5{,}5$$

$$V_{SC} = 55 * d^2 * \sqrt{f_C'} = 55 * 20^2 * \sqrt{9{,}586} = 6{,}81E{+}04\ N$$

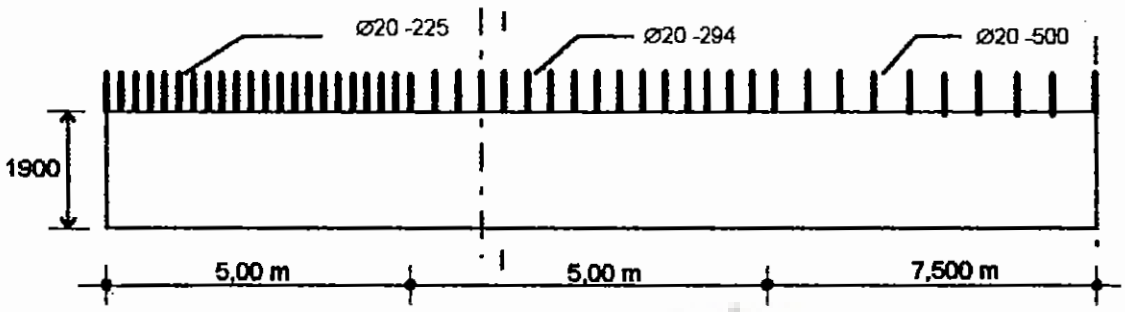
$$W = 200 * 1900 * (951{,}37 - \tfrac{1}{2} * 200)$$

$$= 3{,}235E{+}08\ mm^4$$

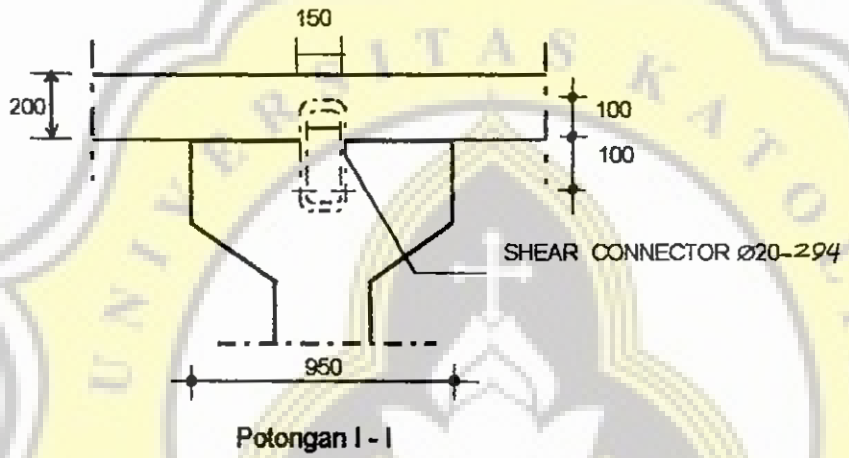
Selanjutnya hasil perhitungan dapat dilihat pada tabel berikut :

Tabel 5.14. Perhitungan shear connector balok pratekan

Jarak (m)	DI (N)	Vni (N)	Vsc (N)	Vu (N)	n (buah)
0-5	1,316E+06	0,9	6,81E+04	1,1808E+06	22
5-10	9,551E+05	0,7	6,81E+04	9,184E+05	17
10-15	6,221E+05	0,4	6,81E+04	5,248E+05	10
15-17,5	3,172E+05	0,2	6,81E+04	2,6244E+05	5



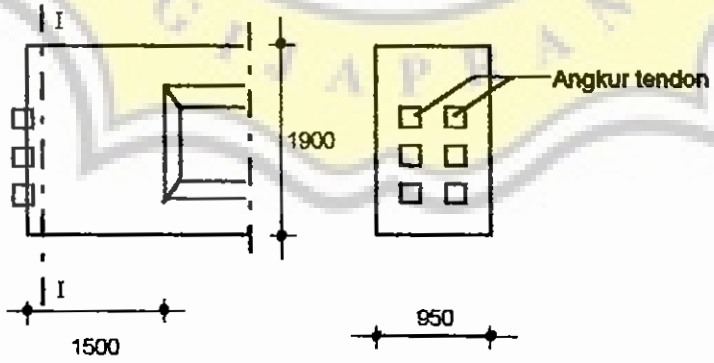
Gambar 5.40. Penempatan Shear Connector



V.1.2.16. Penulangan End Block

Panjang *end block* ≤ h (*TY. Lin -halaman 246*)

Diambil panjang **1500 mm = 1,5 m**



Gambar 5.41. End Block

A_C = 950*1900 = 1,808E+06 mm^2

C_t = C_b = 950 mm

I_C = 2,652E+11 mm^4

K_t = 410,5 mm

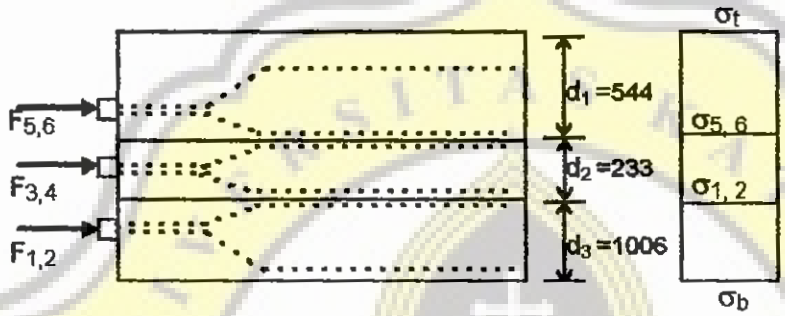
e = C_b - CGS_0

= 950 - 950 = 0

h = 1900 mm

F_O = 2,0875E+07 N

❑ **Beban - Beban Yang Bekerja**



$$\sigma_b = -\frac{F_o}{A_c}\left(1+\frac{e}{K_b}\right)$$

$$= -\frac{2,0875E+07}{1,808E+06}\left(1+\frac{0}{410,5}\right) = -11,55\ N/mm^2$$

$$\sigma_t = -\frac{F_o}{A_c}\left(1-\frac{e}{K_b}\right)$$

$$= -\frac{2,0875E+07}{1,808E+06}\left(1-\frac{0}{410,5}\right) = -11,55\ N/mm^2$$

$$\sigma_1 = \sigma_t + \left\{\frac{d_1}{h} * (\sigma_b - \sigma_t)\right\}$$

$$= -11,55 - \left\{\frac{585}{1600} * (-11,55 + 11,55)\right\}$$

$$= -11,55\ N/mm^2$$

❑ **Pembesian End Block**

Rumus umum : $F = \sigma * d * b_o$

$$T = 0,3 * F * \left(1-\frac{a}{d}\right)$$

$$A = \frac{T}{\sigma_a}$$

Dimana :

σ = **11,55 N/mm^2**

d = *d pada masing - masing keadaan*

b_o = *lebar balok*

a = *tinggi angkurVSL tipe E5-12* = **266,7 mm**

σ_a = *tegangan tendon baja* = **160 Mpa**

A = *luas pada masing - masing balok*

Pada kondisi plat angkur 5 dan 6

$F_1 = \sigma^* d^* b_o$ = **11,55 *544*950 =5,969E+06 N**

T_1 = **0,3*5,969E+06 *(1-$\frac{266,7}{544}$) = 9,128E+05 mm2**

$A_1 = \frac{T_1}{\sigma_a} = \frac{9,128E+05}{160}$ = **5705 mm^2**

Pada kondisi plat angkur 3 dan 4

$F_2 = \sigma^* d^* b_o$ = **11,55*233*950 =2,557E+06 N**

T_2 = **0,3*2,557E+06 *(1-$\frac{266,7}{233}$) = 1,121E+05 mm^2**

$A_2 = \frac{1,121E+05}{160}$ = **700 mm^2**

Karena $T_2 < T_1$ maka pembesian didasarkan pada T_1 dimana

A = 5705 mm^2

Luas tulangan total yang diperlukan

As = 3* A

= 3* 5760 mm^2

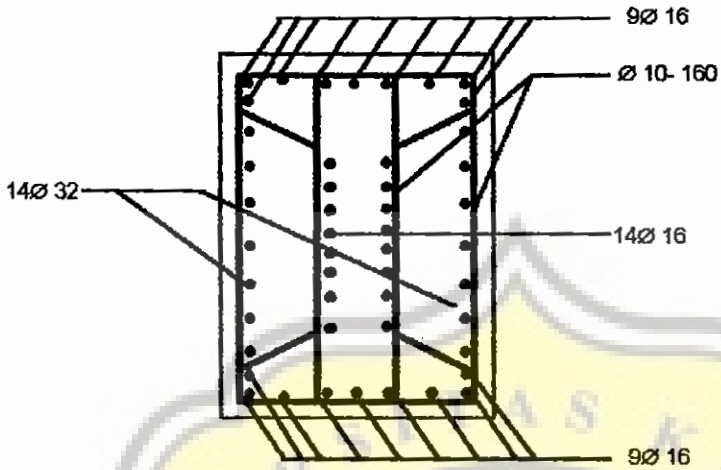
= 17115 mm^2

Digunakan tulangan **18 Ø 16 (A_s = 3620 mm^2)**

14 Ø 16 (A_s = 2816 mm^2)

14 Ø 32 (A_s = 11260 mm^2)

(A_s = 17696 mm^2)



Gambar 4.42. Penulangan end block

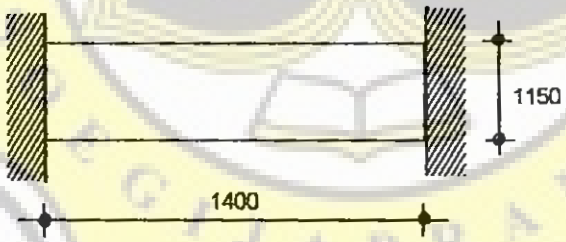
V.1.2.17. Balok Diafragma

Dimensi : **1150* 1400 * 200 (tiap 5 meter)**

b = 200 mm

$\frac{h}{L} \geq \frac{4}{5}$ *(Syarat struktur lentur tinggi)*

$\frac{h}{L} = \frac{1150}{1400} \geq \frac{4}{5}$ **O.K !!!**



Gambar 5.43. Balok Diafragma

❑ **Pembebanan**

Berat sendiri (q) = **{ 0,2 * 1,15 * 1,4} * 2400**

= **772,8 kg/m = 7728 N/m**

Momen yang terjadi = $\frac{1}{12} * q * L^2 * 1,2$

$= \frac{1}{12} * 7728 * 1,4^2 * 1,2$

= **1514,688 Nm = 1,5147 E+06 Nmm**

(1,2 untuk momen ultimit akibat berat sendiri)

$$\frac{M_u}{b*d^2} = \frac{1,5147E+06}{200*1120^2} = 0,00604\ N/mm^2$$

ρ = 0,00003

ρ_{min} = 0,0032

ρ_{max} = 0,0404

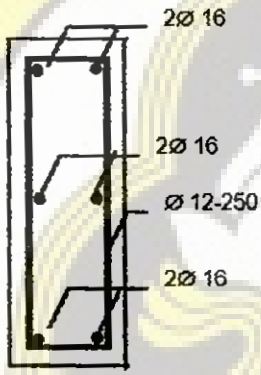
Karena $\rho < \rho_{min}$ maka digunakan ρ_{min}

$A_s = \rho * b * d$

$= 0,0032 * 200 * 1120 = 716,8\ mm^2$

Digunakan tulangan 4 Ø 16 (As = 804 mm^2) dan

Tulangan praktis 2 Ø 16 , sengkang praktis Ø12 - 250



Gambar 5.44. Penulangan Balok Diafragma

V.1.2.18. Perencanaan Perletakan (Elastorer)

- **Bentang gelagar (L) = 30 m**

  V_U = *Reaksi tumpuan gelagar30 m*

  = 1,0316E+06 N

- **Bentang Gelagar (L) = 35 m**

  V_U = *Reaksi tumpuan gelagar bentang 35 m*

  = 1,316E+06 N

- **Dimensi Elastomic bearing :**

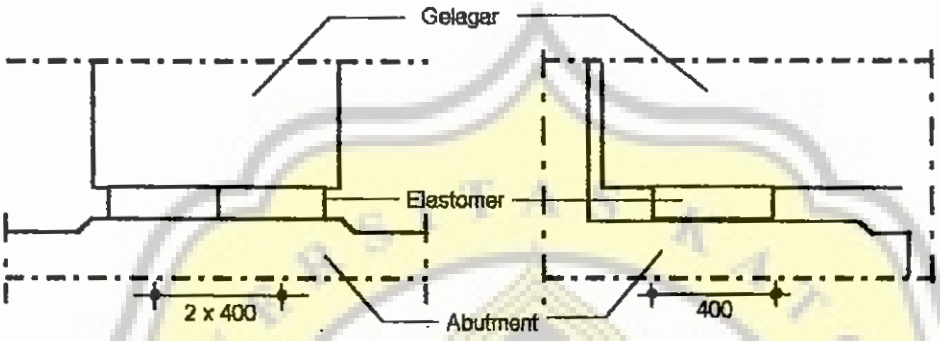
  Digunakan mutu beton K-300 $f_c = 0,85.\ f'_c$

  $= 0,85 * 30 = 25,5$ Mpa

$$A_{perletakan} = \frac{V}{f_c} = \frac{1,316E+06}{25,5} = 51607,84\ mm^2$$

Spesifikasi elastomic bearing (jenis B) :

- Ukuran : **2x(400 * 400) mm^2**
- Tebal total : **60 mm**
- Beban yang mampu ditahan : **2,24 E+06 N**



Gambar 5.45. Perletakan dengan Elastomer

V.1.3. Perhitungan Struktur Bawah

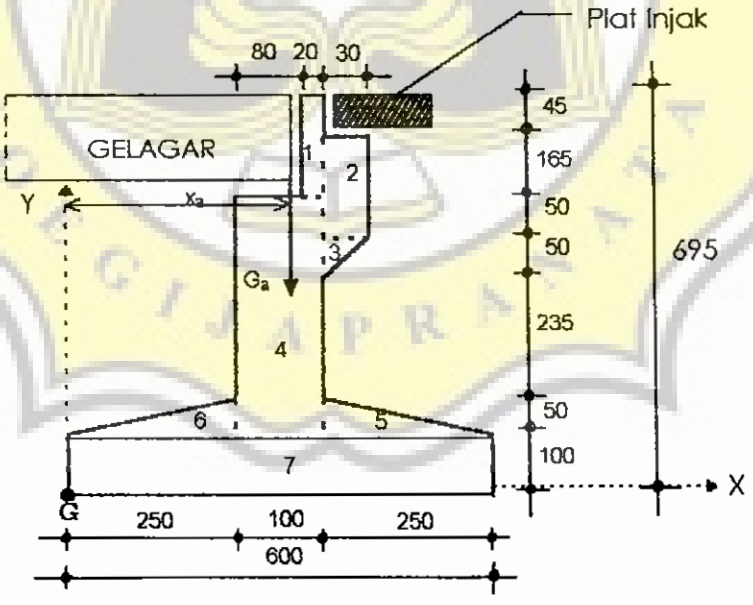
V.1.3.1. Abutment

A. Pembebabanan

Gaya-gaya yang bekerja pada abutment :

a. Gaya akibat berat sendiri abutment
b. Beban mati akibat bangunan (konstruksi) atas
c. Beban hidup akibat bangunan (konstruksi) atas
d. Gaya akibat berat tanah vertikal
e. Gaya horisontal akibat rem dan traksi
f. Gaya akibat tekanan tanah aktif
g. Gaya geser tumpuan dengan balok pratekan
h. Gaya akibat gempa
i. Tekanan tanah aktif akibat gempa

a. Gaya Akibat Berat Sendiri Abutment



Gambar 5.46. Pembebanan berat sendiri abutment (skala jarak dalam cm)

Lebar Abutment = **1400 cm = 14 m**

Selanjutnya perhitungan berat sendiri abutment dapat kita lihat pada tabel 5.15. sebagai berikut :

Tabel 5.15. Perhitungan beban sendiri abutment

No	Luas (m^2)	Berat (Ton/m')	x(m)	Mx (Tm/m')	y(m)	Luas * y (m^3)
	a	b= a*2,4 t/m^3	x	b * x	y	a * y
1	0,42	1,008	3,40	3,4272	5,9	2,478
2	0,645	1,548	3,65	5,6502	5,425	3,499
3	0,075	1,8	3,60	6,48	4,183	0,314
4	3,85	9,24	3	27,72	2,925	11,26
5	0,625	1,5	4,333	6,4995	1,167	0,729
6	0,625	1,5	1,667	2,5005	1,167	0,729
7	6	14,4	3	43,2	0,5	3
Σ =	12,24	30,996		95,4774		22,009

Jarak Titik Berat $(x_a) = \frac{95,4774}{30,996} = 3,08$ m

$$y_a = \frac{22,009}{12,24} = 1,798 \text{ m}$$

Berat Sendiri Abutment :

$G_a = L_{abutment} * \text{Berat}$

$= 14*30,996 = 433,944$ Ton/m $= 4,3394E+06$ N

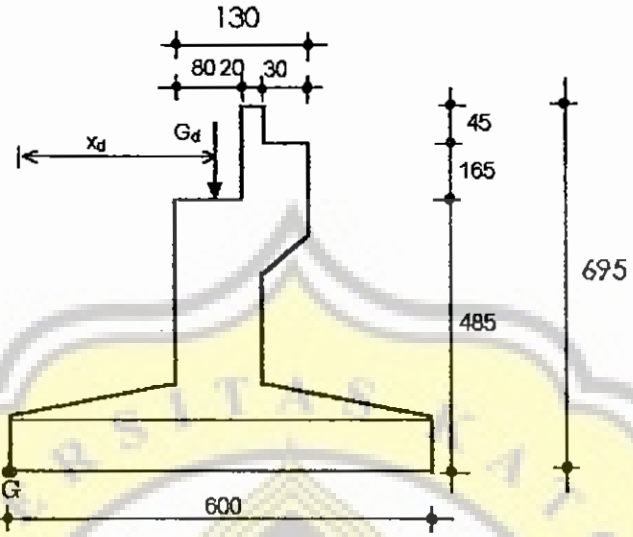
Momen abutment terhadap titik G :

$M_{Ga} = G_a * x_a$

$= 433,944 * 3,08 = 1336,548$ Ton/m

b. Beban Mati Akibat Konstruksi Atas

Beban mati konstruksi atas = beban mati pada seluruh gelagar (7 buah gelagar)



Gambar 5.47 : Beban mati konstruksi atas

Dari hasil perhitungan mekanika gelagar bentang 35 m hal 133 diperoleh beban mati untuk tiap gelagar (bentang 35 m) :

W_D = 36250 N/m

P_D = 5510,4 N

Beban pada setiap abutment :

$G_d = 0{,}5 * (W_D * L + P_D) * 7$

$= 0{,}5 * (36250 * 35 + 5510{,}4) * 7$

$= 4{,}46E+06$ N

Lengan gaya terhadap titik G :

x_d = 2,90 m

Momen terhadap titik G :

$M_{Gd} = G_d * x_d$

$= 4{,}46E+06 * 2{,}9$

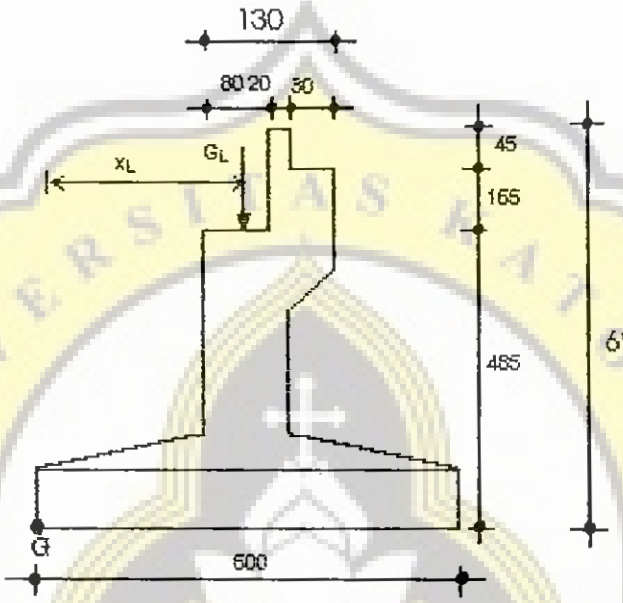
$= 1{,}2934\ E+07$ Nm

c. Beban Hidup Akibat Konstruksi Atas

Beban hidup pada konstruksi atas = beban hidup pada seluruh gelagar (7 buah gelagar)

c. Beban Hidup Akibat Konstruksi Atas

Beban hidup pada konstruksi atas = beban hidup pada seluruh gelagar (7 buah gelagar)



Gambar 5.46. Beban hidup konstruksi atas

Dari hasil perhitungan sebelumnya (*hal. 135 s/d 136*) diperoleh beban mati untuk tiap gelagar (bentang 35 m) :

W_L = **12950 N/m**

P_L = **94340 N**

Beban Pada Abutment :

G_L = **0,5 * (W_L * L + P_L) * 7**

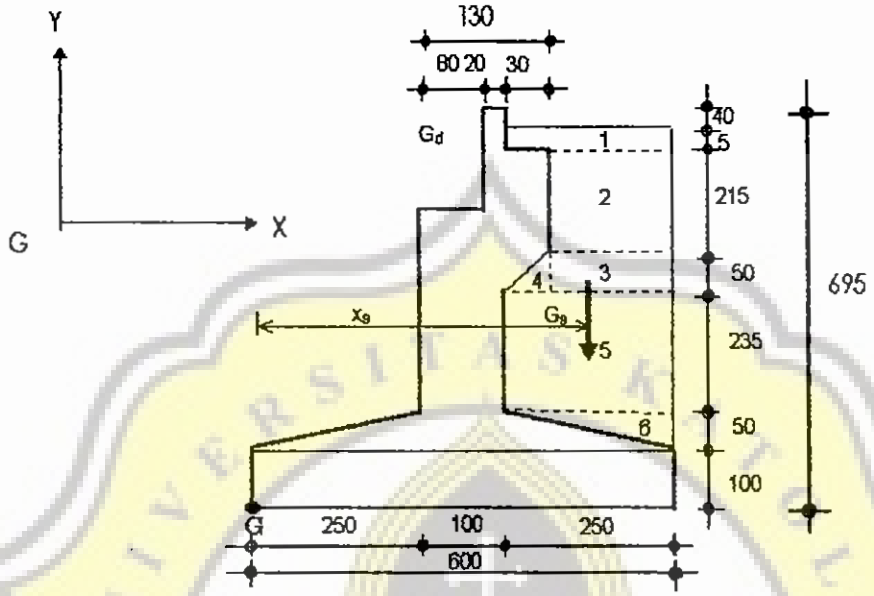
= **0,5 * (12950*35 + 94340) * 7**

= **1,9166E+06 N**

Lengan gaya terhadap titik G :

x_L = **2,90 m**

d. Beban Akibat Backfill Abutment



Gambar.5.17. Beban akibat backfill abutment

Selanjutnya perhitungan beban yang bekerja akibat berat tanah diatas abutment adalah sebagai berikut :

Tabel 5.16. Perhitungan beban akibat backfill abutment

NO	Luas (m^2)	γ (T/m^3)	Berat (T/m')	x (m)	Mx (Tm)	y (m)	Luas* y (m^3)
	a	b	c= a * b	x	c * x	y	a * y
1	0,125	1,8	0,225	4,75	1,069	6,525	0,816
2	4,73	1,8	8,514	4,90	41,719	5,425	25,660
3	1,1	1,8	1,98	4,90	9,702	4,1	4,51
4	0,075	1,8	0,135	3,70	0,4995	4,0167	0,3013
5	5,875	1,8	10,575	4,75	50,231	2,675	15,716
6	0,625	1,8	1,125	5,1667	5,8125	1,33	0,831
Jumlah	12,53		22,554		109,033		47,834

Lengan gaya terhadap titik G :

$$x_S = \frac{109,033}{22,554} = 4,8343 \text{ m}$$

$$y_S = \frac{47,834}{12,53} = 3,8176 \text{ m}$$

Berat tanah di atas abutment :

$G_S = L_{abutment} * Berat$

$= 14 * 22{,}554 = 315{,}756 \text{ Ton} = 3{,}1576E+06 \text{ N}$

Momen terhadap titik G

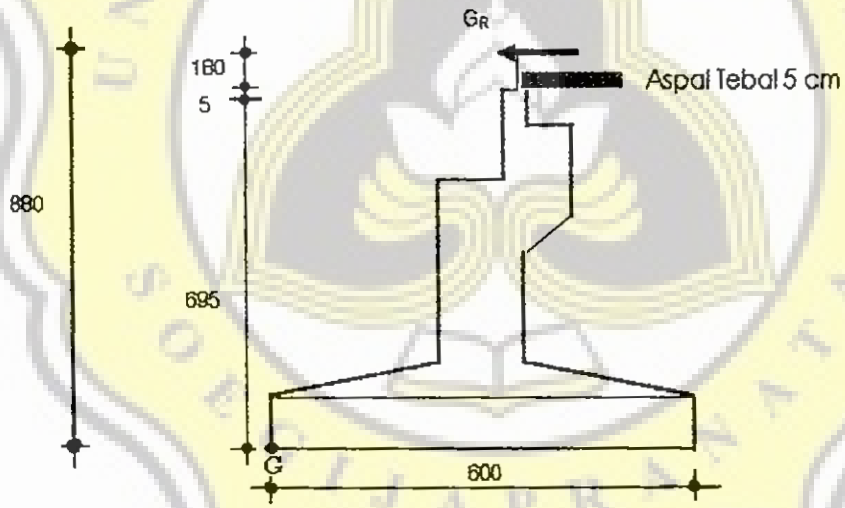
$M_{GS} = G_S * x_S$

$= 315{,}756 * 4{,}8343$

$= 1526{,}459 \text{ Tm} = 1{,}5265E+07 \text{ Nm}$

e. Gaya Rem dan Traksi

Gaya rem dan traksi (G_R) pada 1,8 m di atas permukaan lantai kendaraan dan diambil sebesar 5 % dari beban hidup (PPPJR SKBI - 1987 hal 15) yang bekerja pada konstruksi atas.



Gambar 5.48. Gaya rem dan traksi

Beban horizontal terhadap abutment

$G_L = 1{,}9166E+06 \quad N$

$G_R = 5\% * G_L$ (*PPPJR - SKBI - 1987* Hal 15)

$= 5\% * 1{,}9166 E+06 \quad N$

$= 9{,}583 E+04 \quad N$

Lengan gaya terhadap titik G :

y_R = 8,80 m

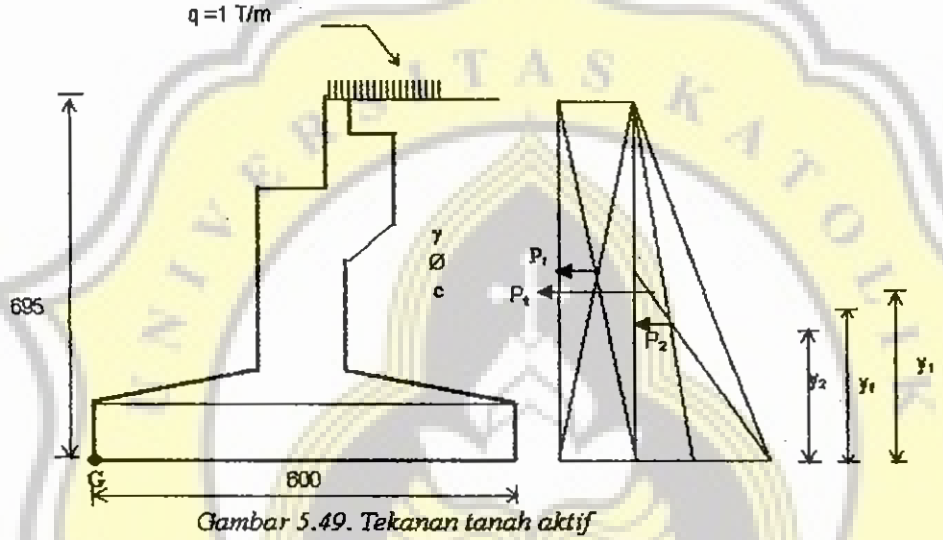
Momen terhadap titik G:

$M_{GR} = G_R * y_R$

= 9,583 E+04 * 8,80

= 8,433E+05 Nm

f. Gaya Akibat Tekanan Tanah Aktif



Gambar 5.49. Tekanan tanah aktif

Diketahui :

γ = 1,8 T/m^3 = 18000 = 1,8 E+04 N/m^3

Ø = 21 ^{O}

c = 0,06 Kg/cm^2

q = 1E+04 N/m

H = 6,95 m

$L_{abutment}$ = 14,00 m

$K_a = tg^2(45^O - \phi/2)$

$= tg^2(45^O - 21/2)$

= 0,472

Gaya tekanan tanah aktif :

$P_1 = q * K_a * H * L_{abutment}$

= 1 E+04 * 0,472 * 6,95 * 14

$= 4{,}5926\ E{+}05 \quad N$

$P_2 = {}^1/_2 * \gamma * K_a * H^2 * L_{abutmen}$

$= {}^1/_2 * 1{,}8\ E{+}04 * 0{,}472 * 6{,}95^{\,2} * 14$

$= 2{,}8727E{+}06 \quad N$

$P_{tot} = P_1 + P_2$

$= 3{,}332E{+}06 \quad N$

$$y_t = \frac{\sum_{i=1}^{2}(P_i * y_i)}{P_{tot}} = 2{,}4763 \quad m$$

Momen terhadap titik G :

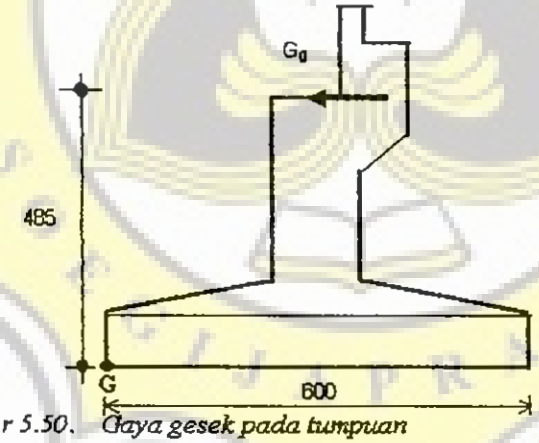
$M_{Pa} = P_{tot} * y_t$

$= 3{,}332E{+}06 * 2{,}4763$

$= 8{,}251\ E{+}06 \quad Nm$

g. Gaya Gesek Pada Tumpuan

Ditinjau akibat beban mati pada konstruksi atas.



Gambar 5.50. Gaya gesek pada tumpuan

Gaya gesek pada tumpuan :

$G_g = f_s * G_d$

dimana :

G_g = *gaya gesek antara tumpuan dengan balok*

f_s = *koefisien gesek = 0,15 (PPPJJR SKBI - 1987 hal. 15)*

G_d = *beban mati konstruksi atas* = 4,46E+06 N

$G_g = 0{,}15 * 4\ ,46E{+}06\ N = 6{,}69E{+}05\ N$

Lengan gaya terhadap titik G :

y_g = 4,85 m

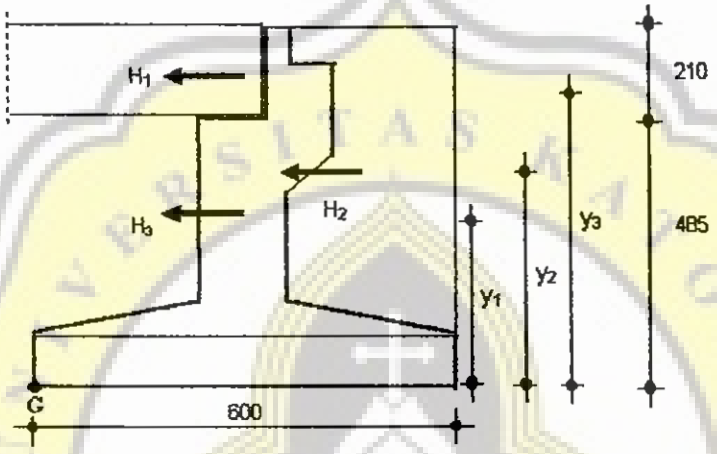
Momen terhadap titik G :

$M_{Gg} = G_g * y_g$

= 6,69E+05 * 4,85

= 3,2447E+06 Nm

h. Gaya Akibat Gempa



Gambar 4.51. Gaya akibat gempa

h = E * M

dimana :

h = *gaya horisontal akibat gempa*

E = *koefisien gempa untuk daerah Jawa Tengah,* = *0,14*

M = *muatan mati dari konstruksi yang ditinjau*

Titik berat : $y = \frac{\sum_{i=1}^{n} (h_i * y_i)}{\sum_{i=1}^{n} h_i}$

Tabel 5.17. Perhitungan gaya gempa

No	BERAT (N)	h (N)	yi (m)	hi*yi
1.	Kons.atas (b) = 4,46E+06	6,244E+05	5,9	3,684E+06
2.	Tanah (d) = 3,1576E+06	4,4206E+05	3,8176	1,6876 E+06
3.	Abutment (a) = 4,3394E+06	6,0752E+05	1,798	1,0923 E+06
	Σ =	1,674 E+06		6,4639E+06

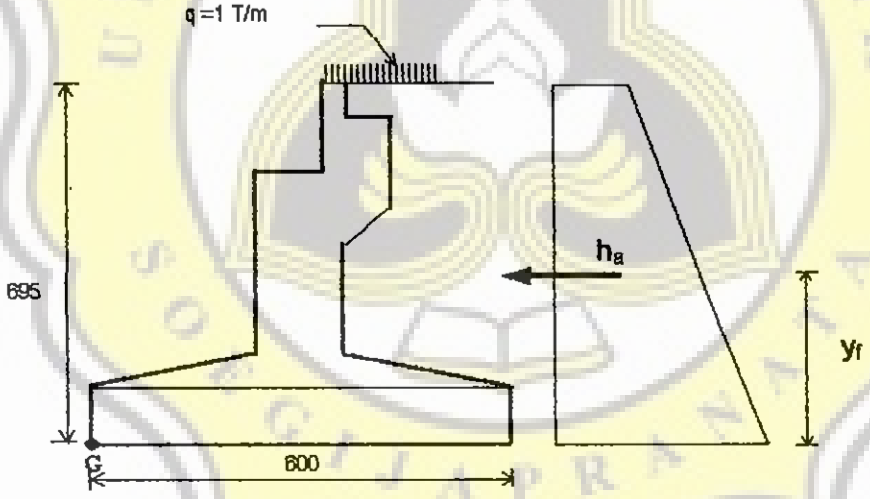
Gaya gempa :

h = 1,674E+06 N

Momen terhadap titik G :

M_{Gh} = 6,4639E+06 Nm

I. Gaya Tekanan Tanah Akibat Gempa Bumi



Gambar 5.52 Gaya tekanan tanah akibat gempa

P_t = *Gaya akibat tekanan tanah aktif*

= 3,332E+06 N

E = *Koefisien gempa* =0,14

Tekanan tanah akibat gempa :

$h_a = P_t * E$

= 3,332E+06 * 0,14

= 4,6648 E+05 N

Lengan gaya terhadap titik G :

y_h = 2,4763 m

Momen terhadap titik G :

$M_{Gh} = f * y_1$

= 4,6648 E+05 *2,4763

= 1,1551 E+06 Nm

Kontrol Terhadap Kestabilan Konstruksi

Kestabilan konstruksi harus ditinjau berdasarkan kombinasi pembebanan dan gaya yang mungkin akan terjadi. Tegangan/gaya yang digunakan dalam pemeriksaan kekuatan konstruksi yang bersangkutan dinaikkan terhadap tegangan ijin/batas yang ditentukan yang dinyatakan dalam prosen *(PPPJR - SKBI - 1987 hal 21).*

Tabel 5.18. Kombinasi pembebanan

JENIS	KOMBINASI BEBAN	TEGANGAN YANG DIGUNAKAN THD. TEG. YG DIIJINKAN
I	$M + H + K + T_a$	100 %
II	$M + T_a + A_h + G_g + A + S_R + T$	125 %
III	$(I) + R + G_g + A + S_R + T$	140 %
IV	$M + G_h + T_{ag} + G_g$	150 %

Di mana :

M : *muatan mati*

H : *muatan hidup*

K : *beban kejut*

G_g : *gaya geser pada tumpuan*

A : *muatan angin*

S_R : *gaya geser akibat susut dan rangkak*

T_a : *tekanan tanah aktif*

T_{ag} : *tekanan tanah aktif akibat gempa*

A_h : *aliran arus dan hanyutan*

G_h : *gaya akibat gempa*

T : *gaya akibat perubahan suhu*

R : *gaya rem + traksi*

Tabel 5.19. Kombinasi I → M +(H + K) + Ta (100 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
M	a	4,3394E+06	-	13,3655E+06	-
	b	4,46E+06	-	12,9340E+06	-
	d	3,1576E+06	-	15,2650E+06	-
H+K	c	1,9166E+06	-	5,5580E+06	-
Ta	f		3,332E+06		8,251E+06
	Jumlah =	1,3974E+07	3,332E+06	4,7123E+07	8,251E+06

ΣV = 1,3874E+07 N

ΣH = 3,332E+06 N

ΣM_{V+H} = 5,5374E+07 Nm

Tabel 5.20. Kombinasi II → $M + T_a + A_h + G_g + A + S_R + T$ (125 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
M	a	4,339E+06	-	13,368E+06	-
	b	4,460E+06	-	12,934E+06	-
	d	3,158E+06	-	15,265E+06	-
Ta	f	-	3,332E+06	-	8,251E+06
Ah	-	-	-	-	-
Gg	-		6,690E+05		3,245E+06
A	-	-	-	-	-
SR	-	-	-	-	-
T	-	-	-	-	-
	Jumlah =	1,196E+07	4,001E+06	4,156E+07	1,149E+06

ΣV = 1,196 E+07 N

ΣH = 4,001E+06 N

ΣM_{V+H} = 5,306E+07 Nm

Tabel 5.21. Kombinasi III → Komb.I + R + G_g + A + S_R + T (140 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
Komb. I		1,387E+07	3,332E+06	4,712E+07	8,251E+06
R	e		9,583E+04		8,433E+05
Gg	g		4,690E+05	-	3,245E+06
A		-	-	-	-
SR		-	-	-	-
T		-	-	-	-
	Jumlah =	1,387+07	4,097E+06	4,712E+07	1,234E+07

ΣV = 1,387E+07 N

ΣH = 4,097E+06 N

ΣM_{V+H} = 5,946E+07 Nm

Tabel 5.24. Kombinasi IV → M + G_h + T_{ag} + G_g (150 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
M	a	4,339E+06	-	13,366E+06	-
	b	4,460E+06	-	12,934E+06	-
	d	3,158E+06	-	15,265E+06	-
G_h	h	-	1,874E+06	-	8,464E+06
T_{ag}	i	-	4,685E+05	-	1,155E+06
G_g	g	-	6,690E+05	-	3,245E+06
	Jumlah =	1,196E+07	2,810E+06	4,156E+07	1,086E+07

ΣV = 1,196E+07 N

ΣH = 2,810E+06 N

ΣM_{V+H} = 5,243E+07 Nm

Tabel 5.26. Hasil perhitungan kombinasi gaya

Kombinasi	V (N)	H (N)	M_{V+H} (Nm)
I	1,387E+07	3,332E+06	5,537E+07
II	1,196E+07	4,001E+06	5,306E+07
III	1,387E+07	4,097E+06	5,946E+07
IV	1,196E+07	2,81E+06	5,243E+07

Dari perhitungan diatas maka gaya yang paling menentukan adalah kombinasi III sebagai berikut :

ΣV = 1,387E+07 N

ΣH = 4,097E+06 N

ΣM_V = 4,712E+07 Nm

ΣM_H = 1,234E+07 Nm

ΣM_{V+H} = 5,946E+07 Nm

⇒ Kontrol Guling : $\frac{\sum M_v}{\sum M_H} > 140\%\ SF$

$$\frac{4,712E+07}{1,234E+07} > 2,1$$

3,82 > 2,1 → O.K !!!

⇒ Kontrol Geser : $\frac{\Sigma V * \tan\theta}{\Sigma H} > 140\%\ S_F$

$$\frac{1,387E+07*0,3839}{4,097E+06} > 2,1$$

1,3 < 2,25 → Tidak O.K !!!

☐ Karena konstruksi tidak aman terhadap geser, kondisi tanah dasar yang jelek, maka digunakan pondasi dalam berupa pondasi tiang pancang.

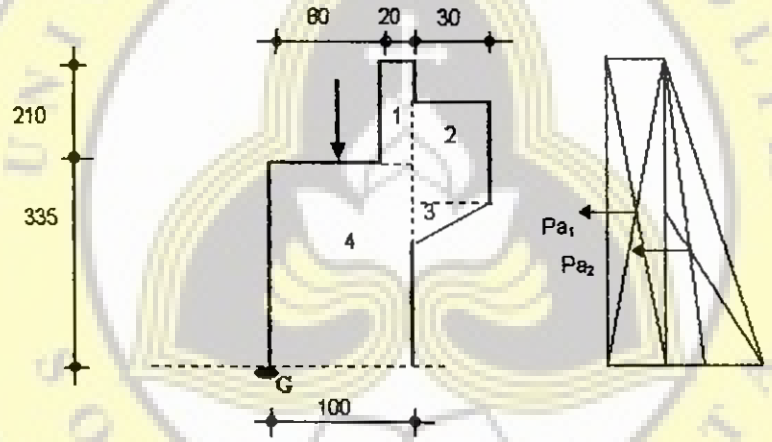
B. Penulangan Abutment

Beban yang digunakan pada perhitungan tulangan abutment adalah berdasarkan beban yang paling kritis yaitu pembebanan kombinasi III.

☐ Penulangan Badan Abutment

Gaya yang bekerja adalah gaya gempa akibat konstruksi atas, gaya gempa akibat abutment, gaya gempa akibat tanah di atas abutment dan gaya akibat gesekan balok dengan abutment.

Pembebanan :



Gambar 5.53. Beban yang bekerja pada badan abutment

a. Gaya Vertikal

⇒ Berat mati akibat konstruksi atas :

$G_d = 0{,}5 * (W_D * L + P_D) * 7$

$= 0{,}5 * (36250 * 35 + 5510{,}4) * 7$

$= 4{,}46E{+}06\ N$

Lengan gaya terhadap titik G :

$x_d = 0{,}4\ m$

Momen terhadap titik G :

$M_{Gd} = G_d * x_d$

$= 4{,}46E{+}06 * 0{,}4$

$= 1{,}784\ E{+}06\ Nm$

⇒ Beban hidup konstruksi atas (G_L)

$G_L = 0{,}5 * (W_L * L + P_L) * 7$

$= 0{,}5 * (12950 * 35 + 94340) * 7$

$= 1{,}9166\ E+06\ N$

Lengan gaya terhadap titik G :

$x_L = 0{,}4\ m$

Momen terhadap titik G :

$M_{GL} = G_L * x_L$

$= 1{,}9166\ E+06 * 0{,}4$

$= 7{,}6664E+05\ Nm$

⇒ Beban sendiri abutment (G_a)

Tabel 5.27. Perhitungan beban sendiri abutment

No	Luas (m^2)	Berat (Ton/m^3)	x(m)	Mx (Tm/m')	y(m)	Luas * y (m^2)
	a	b= a*2,4 t/m^3	x	b * x	y	a * y
1	0,42	1,008	0,9	0,9072	4,4	1,848
2	0,645	1,548	1,15	1,7802	3,95	2,548
3	0,075	1,8	1,1	1,98	2,63	0,1973
4	3,35	8,04	0,5	4,02	1,675	5,611
Jumlah =	4,49	12,396		8,687		10,2043

$G_a = 12{,}396\ T/m' * 14 = 1{,}7354E+06\ N$

$M_{Ga} = 8{,}6874\ Tm' * 14 = 1{,}2162E+06\ Nm$

b. Gaya Horisontal

⇒ Gaya rem dan traksi

$G_L = 1{,}9166\ E+06\ N$

$G_R = 5\% * G_L$ (*PPPJR - SKBI - 1987 hal. 15*)

$= 5\% * 1{,}9166\ E+06\ N$

$= 9{,}583E+04\ N$

Lengan gaya terhadap titik G :

$y_R = 5{,}45\ m$

Momen terhadap titik G:

$M_{GR} = G_R * y_R$

$= 9{,}583\ E+04 * 5{,}45$

$= 5{,}223E+05\ Nm$

⇒ Gaya gesek pada tumpuan

$G_g = f_s * G_d$

dimana :

G_g = *gaya gesek antara tumpuan dengan balok*

f_s = *koefisien gesek = 0,15(PPPJJR SKBI-1987)*

G_d = *beban mati konstruksi atas* = 4,46E+06 N

G_g = 0,15*4 ,46E+06 N

= 6,69E+05 N

Lengan gaya terhadap titik G :

y_g = 3,35 m

Momen terhadap titik G :

$M_{Gg} = G_g * y_g$

= 6,69E+05 * 3,35

= 2,2412E+06 Nm

⇒ Tek. tanah aktif

$P_a = P_{a1} + P_{a2} = {}^1/_2 * Ka * \gamma * b * h^2 + q * Ka * \gamma * b * h$

$= {}^1/_2$ *0,472*1,8 *14*5,45 ^{2} +1*0,472*14*1,8*5,45

= 2,4148E+06 N

Momen terhadap titik G :

$M_{TA} = (P_{a1} * y_1) + (P_{a2} * y_2)$

= (1,767E+06*2,725) + (0,648E+06*1,817)

= 5,992E+06 Nm

⇒ Gaya gempa

h = E * M

dimana :

h = *gaya horisontal akibat gempa*

E = *koefisien gempa untuk daerah Jawa Tengah*

= *0,14*

M = *muatan mati dari konstruksi yang ditinjau*

Titik berat : $y = \dfrac{\sum_{i=1}^{n} (h_i * y_i)}{\sum_{i=1}^{n} h_i}$

Tabel 5.28. Perhitungan gaya gempa

No	BERAT (N)	h (N)	y_i (m)	$h * y_i$
1.	Kons.atas = 4,46E+06	6,244 E+05	4,4	2,747E+06
2.	B.S. Abutment = 4,339E+06	6,075E+05	2,27	1,379E+06
	Σ =	1,232 E+06		4,127E+06

Gaya gempa :

h = 1,232E+06 N

Momen terhadap titik G :

M_{Gh} = 4,127E+06 Nm

Tabel 5.29. Kombinasi I → M +(H + K) + Ta (100 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
M	Ga	4,339E+06	-	13,366E+06	-
	Gd	4,46E+06	-	1,784E+06	-
H+K	Gl	1,917E+06	-	7,666E+05	-
Ta	f		2,415E+06		5,992E+06
	Jumlah =	1,072E+07	2,415E+06	1,592E+07	5,992E+06

ΣV = 1,072E+07 N

ΣH = 2,415E+06 N

ΣM_{V+H} = 2,191E+07 Nm

Tabel 5.30. Kombinasi II → $M + T_a + A_h + G_g + A + S_R + T$ (125 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
M	Ga	4,339E+06	-	13,366E+06	-
	Gd	4,46E+06	-	1,784E+06	-
Ta	Pa	-	2,415E+06	-	5,992E+06
Ah	-	-	-	-	-
Gg	-		6,69E+05		2,241+06
A	-	-	-	-	-
SR	-	-	-	-	-
T	-	-	-	-	-
	Jumlah =	8,799E+06	3,082E+06	1,515E+07	1,515E+07

ΣV = 8,799 E+06 N

ΣH = 3,082E+06 N

ΣM_{V+H} = 2,338E+07 Nm

Tabel 5.31. Kombinasi III → Komb.I + R + G_g +A + S_R + T (140 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
Komb. I		1,072E+07	2,415E+06	1,592E+07	5,992E+06
R			9,583E+04		5,223E+05
Gg			6,69E+05	-	2,241E+06
A		-	-	-	-
SR		-	-	-	-
T		-	-	-	-
	Jumlah =	1,072E+07	3,180E+06	3,592E+07	8,755E+06

ΣV = 1,072E+07 N

ΣH = 3,180E+06 N

ΣM_{V+H} = 2,4 67E+07 Nm

Tabel 5.32. Kombinasi IV → M + G_h + T_{og} + G_g (150 %)

Beban	Bagian	V (N)	H (N)	M_V (Nm)	M_H (Nm)
M	Ga	4,339E+06	-	13,388E+06	-
	Gd	4,46E+06	-	1,784E+06	-
G_h	h	-	1,232E+06	-	4,127E+06
G_g	g	-	6,69E+05	-	2,241E+06
	Jumlah =	8,799E+06	1,901E+06	1,515E+07	6,368E+06

ΣV = 8,799E+06 N

ΣH = 1,901E+06 N

ΣM_{V+H} = 2,152E+07 Nm

Tabel 5.33. Hasil perhitungan kombinasi gaya

Kombinasi	V (N)	H (N)	M_{V+H} (Nm)
I	1,072E+07	2,415E+06	2,191E+07
II	8,799E+06	3,084E+06	2,338E+07
III	1,072E+07	3,180E+06	2,467E+07
IV	8,799E+06	1,901E+06	2,152E+07

Dari perhitungan diatas maka gaya yang paling menentukan adalah kombinasi III sebagai berikut :

ΣV = 1.072E+07 N

ΣH = 3,180E+06 N

ΣM_V = 1,592E+07 Nm

ΣM_H = 8,755E+06 Nm

ΣM_{V+H} = 2,467E+07 Nm

M_u = 1,5*2,467E+07 = 3,701E+07 Nm

V_u = 1.072E+07 N

h = 1m = 1000 mm

b = 14 m = 14000 mm

b_{eff} = 14000 - 30 - 32

= 13938 mm

d' = 30 + 32 mm = 62 mm

f'_c = 30 Mpa

f_y = 400 M Pa

Penulangan

Direncanakan menggunakan tulanagan ganda (As= As').

Diketahui untuk mutu beton K-300 :

Ø = 0,8 (Grafik dan *Tabel Perhitungan Beton Bertulang berdasarkan SKSNI T-15-1991-03 seri 4, WC.Vis,Gideon Kusuma Hal. 82*)

$$e_a = \frac{M_u}{V_u}$$

$$= \frac{3,701E+07}{1,072E+07}$$

= 3,454 m = 3454 mm

$e = e_a + {}^{b}/_{2} - d'$

$$= 3454 + \frac{1000}{2} - 62$$

= 3891,7 mm = 3,8917 m

et min = (15 + 0,03 h) = (15 + 0,03 *1000)

= 45 mm < 3891,7 mm

(WC.Vis seri 1 hal 190) maka yang digunakan adalah et)

$$m = \frac{V_u}{\varnothing * 0,85 * f''_c * b * h}$$

$$= \frac{1,072E+07}{0,8*0,85*30*14000*1000}$$

= 0,0375

$$n = \frac{V_u}{\varnothing * 0{,}85 * f'_c * b * h} * \left(\frac{e_t}{b}\right)$$

$$= \frac{1{,}072E+07}{0{,}8 * 0{,}85 * 30 * 1000 * 14000} * \left(\frac{3891{,}7}{1000}\right)$$

$$= 0{,}146$$

$$\frac{d'}{b} = \frac{62}{14000} = 0{,}044 \approx 0{,}1$$

Dari hasil perhitungan m dan n tersebut selanjutnya dilihat pada Grafik dan Tabel Perhitungan Beton Bertulang Gambar 6.1.a WC.Vis Gideon Kusuma Seri 4 berdasarkan SKSNI T-15-1991 -03 hal 83(As = As'), diperoleh :

r = 0,0025

β = 1,2

ρ = r* β = 0,0025*1,2 = 0,003

A_S = ρ * b*h = 0,003*1000*14000= 4,2 E+04 mm^2

$A_{ski} = A_{ska} = 0{,}5\ As = 0{,}5 * 4{,}2E+04 = 2{,}1\ E+04\ mm^2$

Digunakan tulangan 75 ∅ 32 (As = 60300 mm^2), Jarak antar Tulangan = b_{eff} / 75 =13938 / 75 = 185,84 mm

Tulangan bagi = 20 %* A_S = 8400 mm^2 , digunakan tulangan ∅ 25 -50 (A_s = 9818 mm^2), WC.Vis hal. 82

Penulangan Plat Tegak Abutment

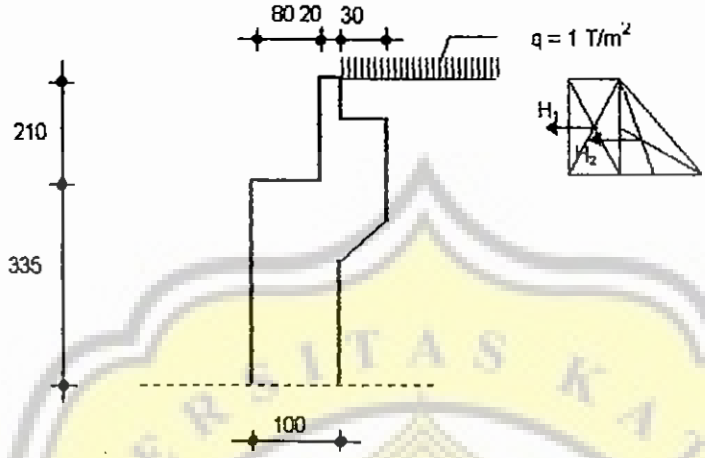
Gaya yang bekerja :

H_1 = q*Ka * γ *b*h

= 1*0,472*1,8*1*2,1= 1,7842E+04 N

$H_2 = {}^1/_2 * Ka * \gamma * b * h^2$

$= {}^1/_2 * 0,472 * 1,8 * 1 * 2,1^2 = 1,8734E+04$ N



Gambar 5.54. Pembebanan pada pelat tegak abutment

$MH_1 = 0,5 * H_1 * h$

$= 1,8734E+04$ Nm

$MH_2 = {}^1/_3 * H_2 * h$

$= 1,3114E+04$ Nm

$\Sigma M = 3,1848E+04$ Nm

$M_u = 1,6 * M$

$= 5,0957E+04$ Nm

Sehingga :

$$\frac{M_u}{b * d^2} = \frac{5,0957E+04}{1 * 0,15^2} = \rho * 0,8 * fy\,(1 - 0,588 * \rho * fy / f'c)$$

$2,26447 = \rho * 0,8 * 400\,(1 - 0,588 * \rho * 400 / 30)$

$\rho = 0,0050$

$\rho_{min} = 0,0035$

$\rho_{max} = 0,0244$

Karena $\rho_{min} < \rho < \rho_{max}$ maka digunakan nilai $\rho = 0,0050$

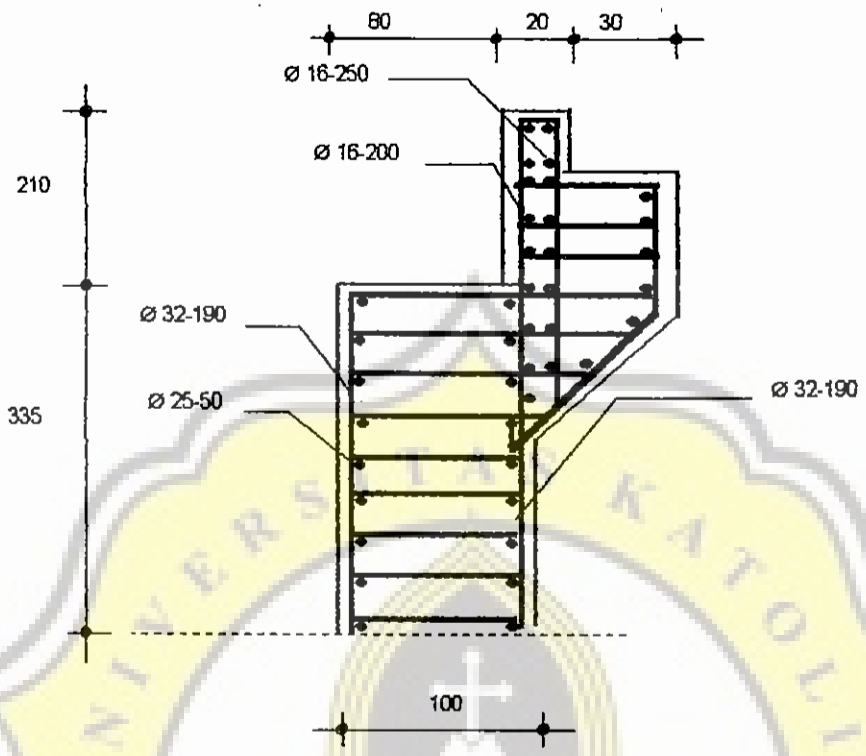
$As = \rho * b * d$

$= 0,0050 * 1000 * 150$

$= 750$ mm^2

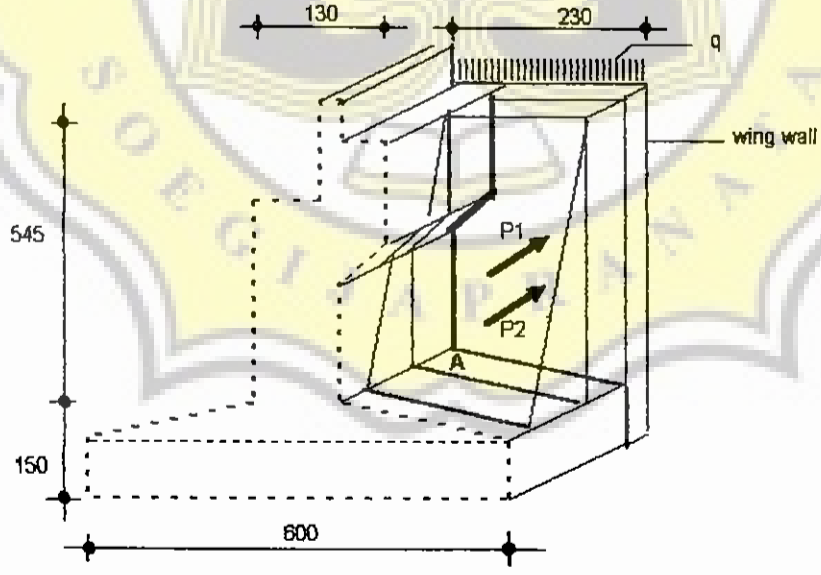
Maka digunakan tulangan $\varnothing$ 16-200($A_s = 1005$ mm^2)

Tulangan bagi = 20 %* A_s = 150,8 mm^2 , digunakan tulangan $\varnothing$ 16 - 250 ($A_s = 804$ mm^2)



Gambar 5.55. Penulangan plat tegak dan badan abutment

Dinding Sayap (Wing Wall)



Gambar 5.56. Pembebanan wing wall abutment

Pembebanan :

P_1 = q*Ka * γ*b*h

= 1*0,472*1,8*1*5,45

= 4,6303E+04 N

$P_2 = {}^1/_2 * Ka * \gamma * b * h^2$

$= {}^1/_2 * 0,472 * 1,8 * 1 * 5,45^2$

$= 1\ ,2618E+05\ N$

$P_{tot} = P_1 + P_2$

$= 1,7248E+05\ N$

$MP_{tot} = P_{tot} * 2,3$

$= 3,967E+05\ Nm$

$M_u = 1,6 * MP_{tot}$

$= 6,347\ 3E+05\ Nm$

Sehingga :

$$\frac{M_u}{b * d^2} = \frac{6.3473E+05}{5,45 * 0,30^2}$$

$= 1,294E+06\ N/m^2$

$= 1,294E+03\ KN/m^2$

$\rho = 0,008525$

$\rho_{min} = 0,0035$

$\rho_{max} = 0.0244$

Karena $\rho_{min} < \rho < \rho_{max}$ maka digunakan nilai $\rho = 0,008525$

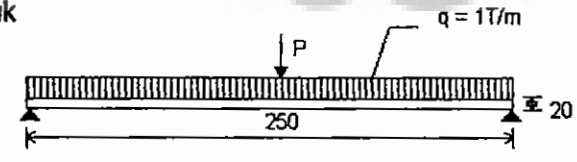
$As = \rho * b * d$

$= 0,008525 * 1000 * 300 = 2557,5\ mm^2$

Maka digunakan tulangan $\varnothing$ 20-100 ($A_s = 3142\ mm^2$)

Tulangan bagi = 20 %* A_S = 511,5 mm^2 , digunakan tulangan $\varnothing$ 12 - 175 ($A_s = 646\ mm^2$)

Plat Injak



Gambar 5.57. Pembebanan plat injak abutment

Ukuran Plat injak : 20 x 1050x 250

Pembebanan :

- Berat sendiri = 0,2 * 1*2,4 = 0,48 T/m
- Beban merata = 1 T/m

- Berat pavement = 0,15 * 1* 2,2 = 0,33 T/m
- Muatan garis (P) $= \frac{12}{2,75} * 1 = 4,364$ T

$$M = \frac{1}{8} * q * L^2 + \frac{1}{4} * P * L$$

$$= \frac{1}{8} * (0,48+1+0.33) * 2,5^2 + \frac{1}{4} * 4,364 * 2,5$$

$$= 4,1415 \text{ Tm} = 4,1415E+04 \text{ Nm}$$

$$M_u = 1,6 * M = 6,6265E+04 \text{ Nm}$$

Sehingga :

$$\frac{M_u}{b * d^2} = \frac{6,6265E+04}{1 * 0,15^2} = 2,945E+06 \text{ N/m}^2$$

$$= 2,945E+03 \text{ KN/m}^2$$

$\rho = 0,00985$

$\rho_{min} = 0,0035$

$\rho_{max} = 0,0244$

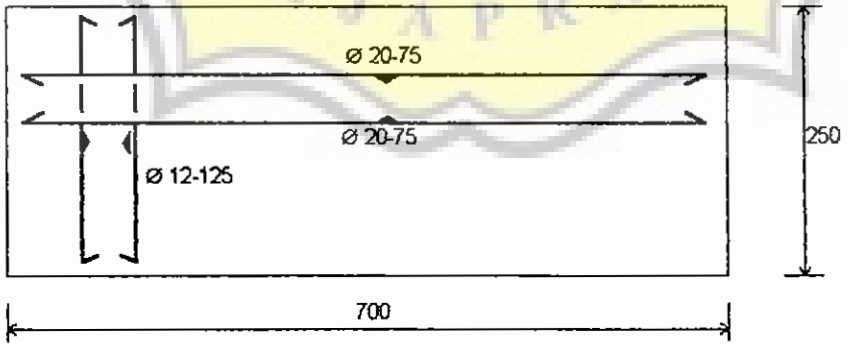
Karena $\rho_{min} < \rho < \rho_{max}$ maka digunakan nilai $\rho = 0,00985$

$As = \rho * b * d$

$= 0,00985 * 2500 * 150 = 3693,75 \text{ mm}^2$

Maka digunakan tulangan ∅ 20-75 ($A_s = 4189 \text{ mm}^2$)

Tulangan bagi = 20 %* A_s = 837,8 mm^2 , digunakan tulangan bagi ∅ 12 - 125 ($A_s = 905 \text{ mm}^2$)



Gambar 5.58. Penulangan plat injak abutment

V.1.3.2. Pondasi Abutment

Direncanakan digunakan pondasi tiang pancang sebanyak 4 baris pada arah Lx (m = 4) dan 10 kolom pada arah Ly (n = 10).

Dengan diameter tiang 50 cm, maka jarak antar tiang disesuaikan dengan syarat sbb :

$2{,}5 * D \leq S \leq 3 * D$

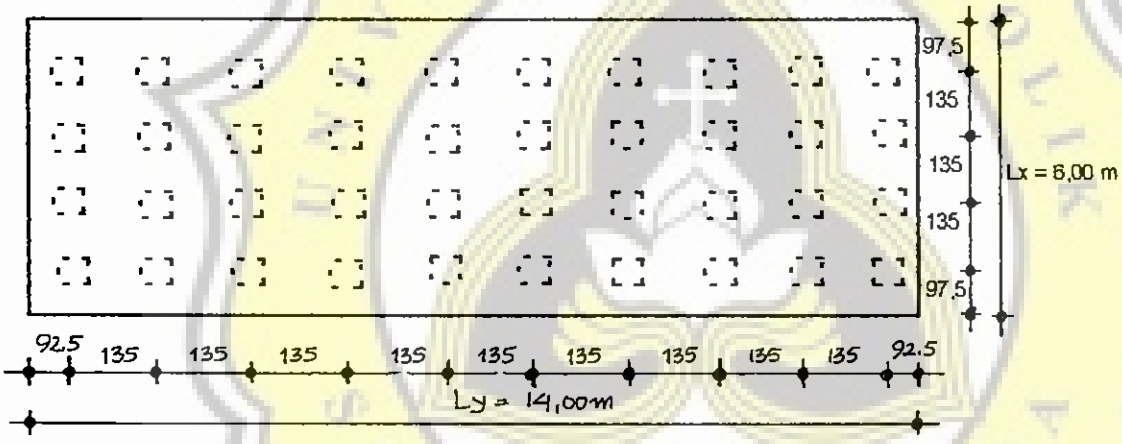
$125 \leq S \leq 150$ cm

Diambil $S = 135$ cm

Ukuran pile cap $= 6 * 10 = 60\ m^2$

Spesifikasi tiang pancang :

- Beton bertulang K- 300 , tulangan BJTD 40
- Kedalaman pemancangan/panjang tiang pancang : 26 m
- Ukuran : 50 x 50 cm ^{2}



Gambar 5.59. Denah pondasi abutment

Daya Dukung Tiang Pancang

Rumus : $Q = \frac{q * A_b}{3} + \frac{f * A_s}{5}$

Dimana :

q : *tahanan conus = 150 Kg/cm²*

f : *total friction = 2100 Kg/cm²*

A_b : *Luas penampang tiang = 50 x 50 = 2500 cm²*

A_s : *Keliling tiang = 200 cm*

W_p : *Berat tiang pancang = 0,5*0,5*26*2400 = 15600 Kg*

Jadi :

$$Q = \frac{q * A_b}{3} + \frac{f * A_s}{5}$$

$$Q = \frac{150 * 2500}{3} + \frac{2100 * 200}{5}$$

= 209000 Kg = 2,09E+06 N

$Q_{netto} = Q - W_p = 209000 - 15600$

= 193400 Kg

= 1,934E+06 N

Efisiensi Tiang Pancang

Rumus :

$$E = 1 - \theta * \frac{(n-1)m + (m-1)n}{90mn}$$

Dimana :

m : *jumlah baris (arah Lx) = 4*

n : *jumlah kolom dalam satu baris (arah Ly) = 7*

θ : *arc tan*(d/s)

d : *diameter tiang pancang = 50 cm*

s : *jarak antar tiang pancang = 135 cm*

Jadi :

$$\theta = \arctan \frac{50}{135} = 20{,}323^{\circ}$$

$$E = 1 - \theta * \frac{(n-1)m + (m-1)n}{90mn}$$

$$= 1 - 20{,}323 * \frac{(10-1)4 + (4-1)10}{90 * 4 * 10}$$

$$= 1 - 20{,}323 * \frac{66}{3600}$$

= 0,627 = 62,7 %

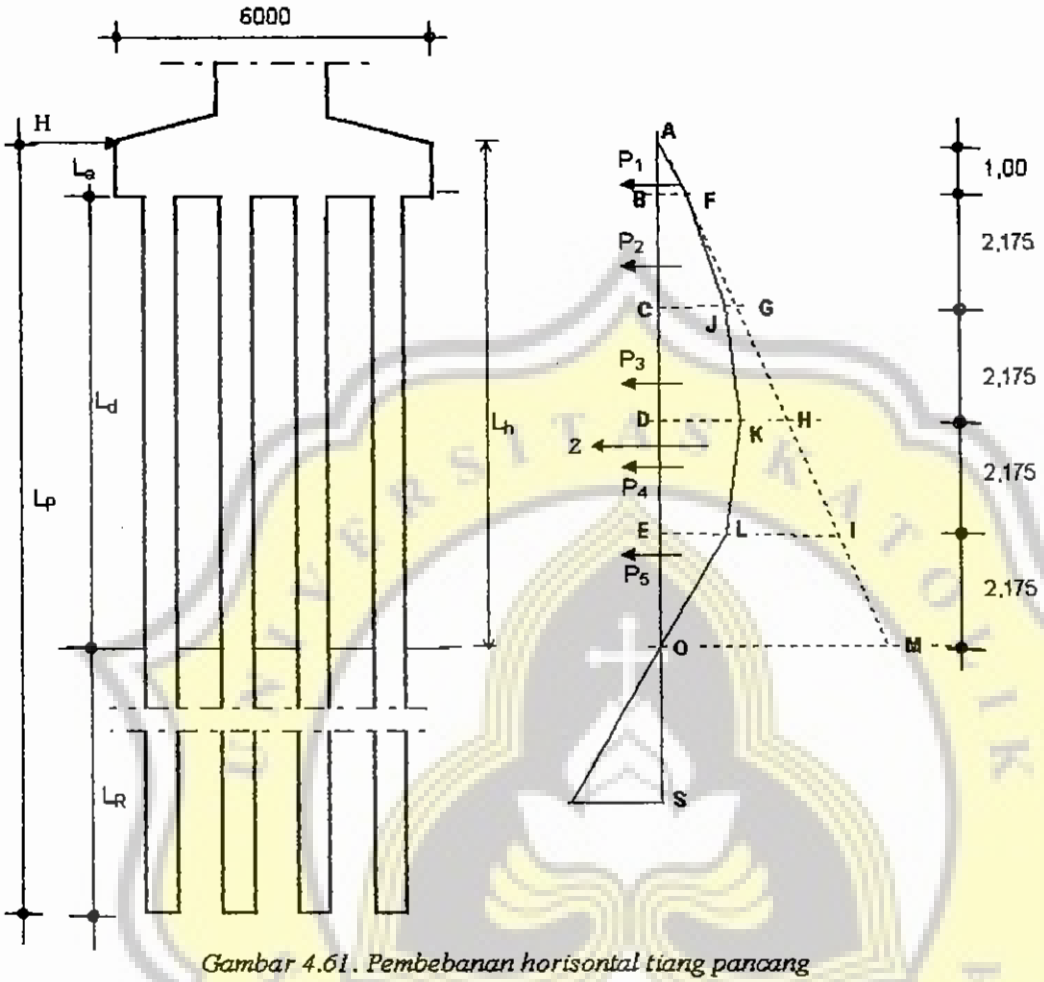
Kapasitas Daya Dukung Tiang

Rumus :

$$P = \frac{\sum V}{n} \pm \frac{\sum M * x}{n_y * \sum x^2} + \frac{\sum M * y}{n_x * \sum y^2}$$

dimana :

n : *jumlah tiang pancang (4*10= 40 tiang)*



Gambar 4.61. Pembebanan horisontal tiang pancang

Perhitungan Diagram Tekanan Tanah Pasif

BF = 2,46*1,6*1*1*14

= 55,104 T/m

CG = 2,46*1,6*3,175*14

= 174,956 T/m

DH = 2,46*1,6*5,35*14

= 294,806 T/m

EI = 2,46*1,6*7,525*14

= 414,658 T/m

OM = 2,46*1,82*9,67*14

= 606,123 T/m

☐ Tekanan Tanah Pasif Efektif

BF = 55 ,104 T/m

CJ = $^3I_4$ * CG

= $^3I_4$ *174,956 T/m

= 131,217 T/m

DK = $^1I_2$ * DH

= $^1I_2$ * 294,806 T/m

= 147,403 T/m

EL = $^1I_4$ * EI

= $^1I_4$ * 414,658 T/m

= 103,665 T/m

O = 0

Besarnya Tekanan Tanah Pasif

P_1 = $^1I_2$ * 1 * BF

= $^1I_2$ * 1 * 55,104 T/m

= 27,552 T

P_2 = $^1I_2$ * 2,175 *(BF+CJ)

= $^1I_2$ *2,175 * (55,104 +131,217)

= 202,624 T

P_3 = $^1I_2$ * 2,175 * (CJ+DK)

= $^1I_2$ * 2,175 * (131,217+ 147,403)

= 302,999 T

P_4 = $^1I_2$ * 2,175 * (DK+EL)

= $^1I_2$ * 2,175 * (147,403 +103,665)

=273,037 T

P_5 = $^1I_2$ * 2,175 *EL

= $^1I_2$ * 2,175 * 103,665

=112,736 T

P_{tot} = $P_1 + P_2 + P_3 + P_4 + P_5$

= 27,552 +202,624 + 302,999 + 273,031 +112,736

= 91 8,948 T

$\Sigma M_O = 0$

$$L_R = \frac{P_1 * L_1 + P_2 * L_2 + P_3 * L_3 + P_4 * L_4 + P_5 * L_5}{P_{tot}}$$

$$= \frac{27,55*9,03+202,624*7,447+302,999*5,35+273,037*3,304+112,736*0,725}{918,948}$$

= 4,748 m

☐ Gaya Horisontal Yang Diijinkan

Gaya akibat tekanan tanah pasif

$$\bar{H} = \frac{P_{tot} * 2 * L_R}{La + Ld + L_R}$$

$$= \frac{918,948*2*4,748}{1 + 8,67 + 4,748}$$

= 605,2386 T = 6,0524E+06 N

Dari pembebanan pada kombinasi III diperoleh :

H = 4,0968E+06 N < $\bar{H}$ = 6,0524E+06 N → O.K III

Momen Akibat Tekanan Tanah Pasif

M_1= H* $^2/_3$ AB = 605,24*0,67 = 405,511 T m

M_2= H* $^2/_3$ AC - P1* $^2/_3$ (AC-AB) = 605,24*1,45- 27,55*0,78

= 856,109 T m

M_3= H* $^2/_3$ AD - P1* $^2/_3$ (AD- AB)- P2* $^2/_3$ (AD- AC)

= 605,24*3,567- 27, 55*2,9- 202,624*1,45 = 1785,191 T m

M_4= H* $^2/_3$ AE- P1* $^2/_3$ (AE- AB)- P2* $^2/_3$ (AE- AC)-P3* $^2/_3$(AE-AD)

= 605,24*5,0167- 27 ,55*4,35-202,624*2,9-302,999*1,45

= 1889,507 T m

M_5= H* $^2/_3$ AO- P1* $^2/_3$ (AO- AB)- P2* $^2/_3$ (AO- AC) - P3* $^2/_3$ (AO- AD)-

P4*(AO- AE)

= 605,24*6,467- 27, 55*5,79-202,624*4,35-302,999*2,9 -

273,037*1,45

= 1598,557 T m

M_{max} = 1889,507 Tm = 1,8895E+07 Nm (dipertimbangkan dalam penulangan tiang pancang)

Penulangan Poer Abutment

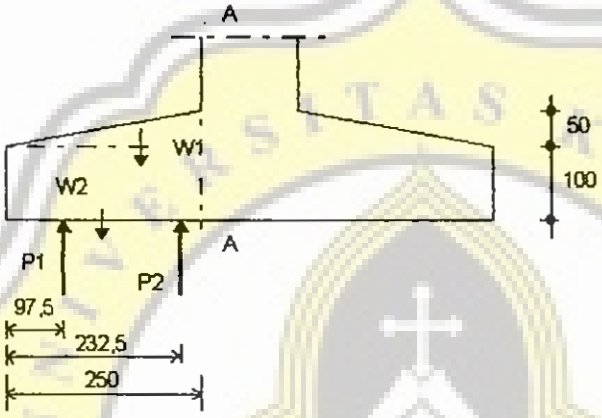
Beban Yang Bekerja

W_1 = 0,5*0,5*2,50 *2,4 = 1,5 T/m'= 1,5E+04N

W_2 = 1*2,5*2,4 =6 T/m'= 6E+04 N

P_1 = 1,4288E+06 N

P_2 = 1,034E+06 N



Gambar 5.62.Sistem pembebanan pada kaki poer

Momen Terhadap Potongan A-A

$M_A = P_1*1,525+P_2*0,175- W_1*0,8333-W_2*1,25$

=1,4288E+06*1,525+1,034E+06*0,175-1,5E+04*0,833

-6E+04*1,25

= 2,27 24E+06 Nm

Gaya Lintang Potongan A-A

$D_A = P_1+P_2*- W_1-W_2$

=1,4288E+06 + 1,034E+06 - 1,5E+04 - 6E+04

= 2,3878+06 N

Penulangan Poer

$M_U = 1,6*M_A$

= 1,6*2,2724E+06 Nm

= 3,6358E+06 Nm

$V_U = 1,2*D_A$

= 1,2*2,3878+06 N

= 2,8654E+06 N

$$\frac{Mu}{b * d^2} = \frac{3,6358E+06}{2,5 * 1,20^2} = 1,0099E+06\ N/m^2 = 1009,9\ kN/m^2$$

ρ = 0,0037

ρ_{min} = 0,0035

ρ_{max} = 0,0244

$A_S = A_S' = 0,5 * \rho_{min} * b*d = 0,5 * 0,0037*2500*1200$

$= 5550\ mm^2$

Digunakan tulangan Ø 20 - 50 ($A_S = 6284\ mm^2$)

Tulangan bagi = $20\%*A_S = 1110\ mm^2$

Digunakan tulangan bagi Ø 16 - 125 ($A_S = 1608\ mm^2$)

Kontrol Gesek Dinding Poer Dengan Abutment

$h_{pons} = 100+(\frac{100}{250})*50 = 120$ cm

$A_{pons} = 120*1000 = 1,2E+05\ cm^2$

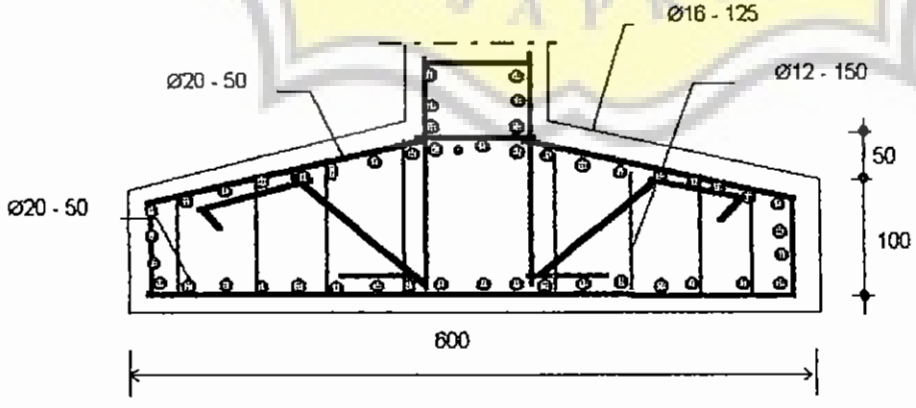
$V_U = 2,8654E+06\ N = 2,8654E+05$ Kg

$\tau_{pons} = \frac{V_U}{A_{PONS}} = \frac{2.8654E+05}{1,2E+05} = 2,3878\ Kg/cm^2$

$\tau_{ijin} = 0,97 * \sqrt{300} = 16,801\ Kg/cm^2$

$\tau_{pons} < \tau_{ijin}$ OK !!!

Aman terhadap geser, hanya digunakan tulangan geser praktis Ø 12 - 150 (As = 754 mm²)



Gambar 5.63.Penulangan poer abutment

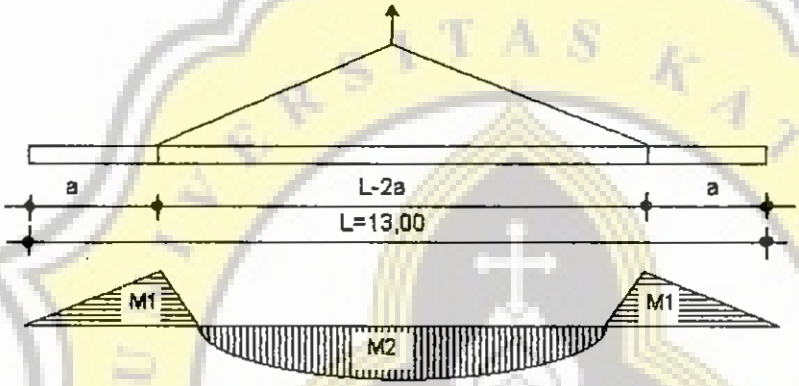
V.1.3.2. Penulangan Tiang Pancang

Spesifikasi :

- Mutu beton : K-300
- Mutu tulangan : BJTD 40 (fy = 400 Mpa)
- Panjang tiang pancang : 2x 13,00m =26,00 m
- Berat tiang pancang = 0,5*0,5*2,4

  = 0,6T/m = 6 E+03 N/m

Kondisi I



Gambar 5.64.Kondisi I pengangkatan tiang pancang

Tiang pancang ukuran 2x13,00 m = 26,00 m

$$M_1 = \frac{1}{2} * q * a^2$$

$$M_2 = \frac{1}{8} * q * (L-2a)^2 - \frac{1}{2} * q * a^2$$

$$M_1 = M_2$$

$$\frac{1}{2} * q * a^2 = \frac{1}{8} * q * (L-2a)^2 - \frac{1}{2} * q * a^2$$

$$\frac{1}{2} * q * a^2 = \frac{1}{8} * q * L^2 - \frac{1}{2} * q * a * L + \frac{1}{2} * q * a^2 - \frac{1}{2} * q * a^2$$

$$\frac{1}{2} * q * a^2 = \frac{1}{8} * q * L^2 - \frac{1}{2} * q * a * L$$

$$a^2 = \frac{1}{4} * L^2 - a * L$$

$$4a^2 = L^2 - 4aL$$

$$4a^2 - 4aL - L^2 = 0$$

$4a^2 - 4a*13 - 13^2 = 0$

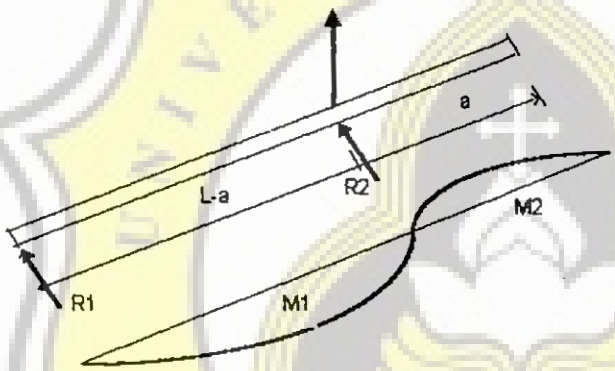
$a^2 - 13a - 42,25 = 0$

$$a = \frac{-13 + \sqrt{13^2 + 4*1*42,25}}{2*1} = \frac{-13 + \sqrt{338}}{2*1}$$

$= 2,69$ m

$$M = \frac{1}{2}*q*a^2 = \frac{1}{2}*0,6*2,69^2 = 2,1708 \text{ Tm}$$

Kondisi II



Gambar 5.65.Kondisi II pengangkatan tiang pancang

Tiang pancang ukuran 10,00 +13,00 m = 23,00 m

$$M2 = \frac{1}{2}*q*a^2$$

$$Mx = R1*x - \frac{1}{2}*q*a^2$$

$$Dx = \frac{dMx}{dx} = 0$$

$$R_1 - q*x = 0 \quad \Rightarrow x = \frac{R1}{q}$$

$$M_1 = R_1*\frac{R_1}{q} - \frac{1}{2}*q*\left(\frac{R_1}{q}\right)^2$$

$$= \frac{R_1^2}{q} - \frac{1}{2}*\left\{\frac{R_1^2}{q}\right\} = \frac{1}{2}*\left\{\frac{R_1^2}{q}\right\}$$

$M_1 = M_2$

$$\frac{1}{2}*\left(\frac{R_1^2}{q}\right) = \frac{1}{2}*q*a^2$$

$$\Sigma M_L = R_1*(L-a) - \frac{1}{2}*q*(L-a)^2 + \frac{1}{2}*q*a^2$$

$$R_1 = \frac{1}{2}*q*(L-a) - \frac{q*a^2}{2*(L-a)}$$

$$q*a = \frac{1}{2}*q*(L-a) - \frac{q*a^2}{2*(L-a)}$$

$$a = \frac{(L-a)}{2} - \frac{a^2}{2*(L-a)}$$

$$a = \frac{2*(L-a)^2 - 2a^2}{4*(L-a)}$$

$$4a*(L-a) = 2*(L-a)^2 - 2a^2$$

$$2aL - 2a^2 = L^2 - 2aL + a^2 - a^2$$

$$4aL - 2a^2 - L^2 = 0$$

$$4*13*a - 2a^2 - 13^2 = 0$$

$$52a - 2a^2 - 169 = 0$$

$$a2 - 26a + 84,5 = 0$$

$$a = \frac{26 \pm \sqrt{26^2 - 4*1*84,5}}{2*1} = \frac{26 \pm \sqrt{338}}{2*1}$$

a_1 = 3,807 m

a_2 = 24,192 m (Tidak memenuhi)

$$M = \frac{1}{2}*q*a^2 = \frac{1}{2}*0,6*3,807^2 = 4,348\ Tm = 4,348E+04 Nm$$

Momen Akibat Tekanan Tanah Pasif

M_{max} = 1889,507 T m = 1,8895E+07 Nm

Momen yang ditahan 1 buah tiang $= \frac{M_{max}}{m*n}$

$$= \frac{1,8895E+07}{40}$$

$$= 4,7238E+05\ Nm$$

Jadi dalam penulangan tiang pancang digunakan Kondisi akibat tekanan tanah pasif .

Penulangan

b =h = 50 cm h_{eff} = 47 cm

M_u = 4,7238E+05 Nm

$$\frac{Mu}{b * d^2} = \frac{\boxed{4,7238E+05}}{0,5 * 0,47^2} = 4,2769E+06\ N/m = 4276,88\ KN/m$$

ρ = 0,0174

ρ_{min} = 0,0035

ρ_{max} = 0,0244

$\rho > \rho_{max}$ (digunakan tulangan ganda)

$A_S = As' = 0,5 * \rho * b*d$

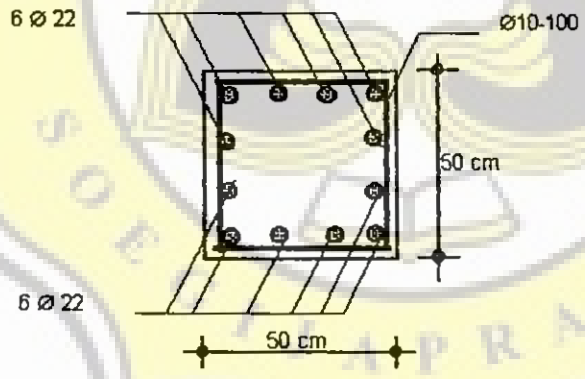
$= 0,5*0,0174* 500*470$

$= 2044,5\ mm^2$

Digunakan tulangan 6 Ø 22 (A_S = 2281 mm^2)

Tulangan bagi = 20%*A_S = 456 mm^2

Digunakan tulangan bagi Ø 10 - 100 (A_S = 785 mm^2)



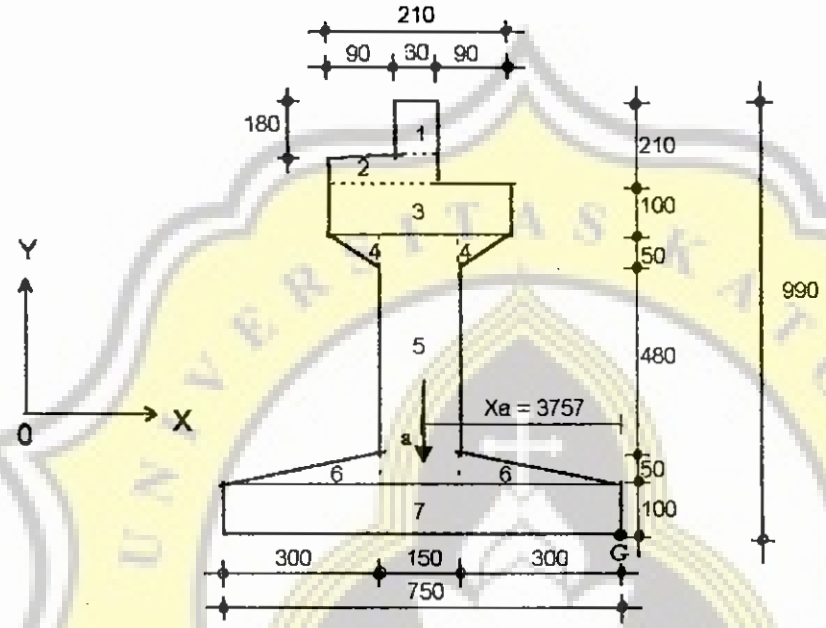
Gambar 5.66.Penulangan tiang pancang

V.1.3.3. Pilar

A. Pembebanan

Gaya-gaya yang bekerja pada pilar :

a. Gaya Akibat Berat Sendiri Pilar



Gambar 5.67. Pembebanan pada pilar (skala jarak dalam cm)

Tabel 5.34. Perhitungan beban sendiri pilar

No	Luas (m^2) a	Berat (Ton/m') b= a*2,4 t/m^3	x(m) x	Mx (Tm/m') b * x	y(m) y	Luas * y (m^3) a * y
1	0,54	1,296	3,75	4,86	9	4,48
2	0,36	0,864	4,2	3,63	7,95	2,862
3	2,1	5,04	3,75	18,9	7,30	15,33
4	0,15	0,36	3,75	1,35	6,633	0,995
5	8,7	20,88	3,75	78,3	3,9	33,93
6	1,5	3,6	3,75	13,5	1,167	1,751
7	7,5	18	3,75	67,5	0,5	3,75
Jumlah	20,85	50,04		188,04		63,478

$$\text{Jarak Titik Berat pilar } (x_a) = \frac{188,04}{50,04} = 3,7578 \text{ m}$$

$$y_a = \frac{63,478}{20,85} = 3,045 \text{ m}$$

Berat Sendiri Pilar :

$G_a = L_{pilar} * Berat$

$= 14 * 50,04$

$= 700,56$ Ton

Momen Pilar terhadap titik G :

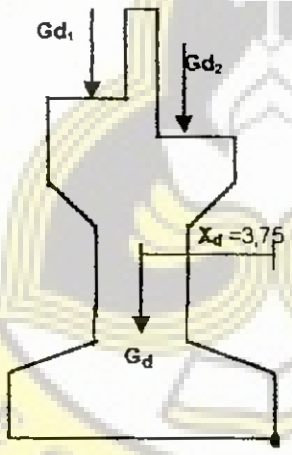
$M_{Ga} = G_a * x_a$

$= 700,56 * 3,7578$

$= 2632,564$ Tm $= 2,626E+07$ Nm

b. Beban Mati Akibat Konstruksi Atas

Beban mati konstruksi atas = beban mati pada seluruh gelagar. (7 buah gelagar)



Gambar 5.68.Beban mati konstruksi atas

Dari hasil perhitungan sebelumnya (hal. 95 s.d 96 dan 133 s.d 134) diperoleh beban mati untuk tiap gelagar (bentang 30 m dan bentang 35 m) :

$W_{D1} = 31875$ N/m

$P_{D1} = 5006,4$ N

$W_{D2} = 36250$ N/m

$P_{D2} = 5510,4$ N

Beban pada pilar :

$G_{d1} = 0,5 * (W_D * L + P_D) * 7$

$= 0,5 * (31875 * 30 + 5006,4) * 7$

$= 3,3644E+06$ N

G_{d2} = 0,5 * (W_D * L + P_D) * 7

= 0,5 * (36250* 35 + 5510,4) * 7

= 4,46E+06 N

G_d = 3,3644E+06 + 4,46E+06N

= 7,8244 E+06 N

Lengan gaya terhadap titik G :

x_d = 3,75 m

Momen terhadap titik G :

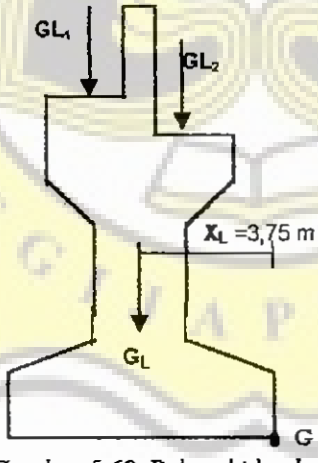
M_{Gd} = G_d * x_d

= 7,8244 E+06 * 3,75

= 2,9342E+07 Nm

c. Beban Hidup Akibat Konstruksi Atas

Beban hidup pada konstruksi atas = beban hidup pada seluruh gelagar (7 buah gelagar)



Gambar 5.69. Beban hidup konstruksi atas

Dari hasil perhitungan sebelumnya (hal. 97 s.d 98 dan 135 s.d 136) diperoleh :

W_{L1} = 12364,54 N/m

P_{L1} = 91600 N

W_{L2} = 12950 N/m

P_{L2} = 94340 N

Beban pada pilar :

G_{L1} = 0,5 * (W_{L1} * L + P_{L1}) * 7

= 0,5 * (12364,54* 35 + 91600) * 7

= 1,835E+06 N

G_{L2} = 0,5 * (W_{L2} * L + P_{L2}) * 7

= 0,5 * (12950* 35 + 94340) * 7

= 1,9166E+06 N

G_L = 1,835E+06 + 1,9166E+06 N

= 3,752 E+06 N

Lengan gaya terhadap titik G :

x_L = 3,75 m

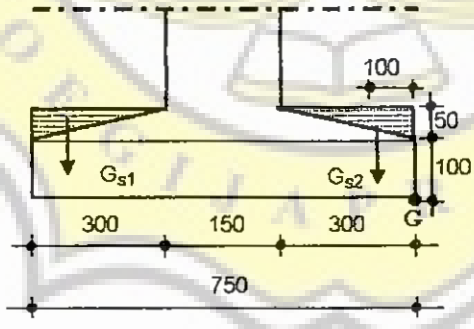
Momen terhadap titik G :

M_{GL} = G_L * x_L

= 3,752E+06 * 3,75

= 1,41E+07 Nm

d. Beban Akibat Tanah Di Atas Pilar



Gambar 5.70. Beban akibat tanah diatas pilar

A_{S1} = A_{S2} =0,75 m^2

L_{pilar} = 14 m

γ = 1,8 T/m^2

Berat tanah di atas pilar :

G_S = A_{tanah} * L_{pilar} * γ

= 1,5 * 14 * 1,8 = 37,8 T

= 3,78E+05 N

Lengan Gaya terhadap titik G :

x_S = 3,75 m

Momen terhadap titik G

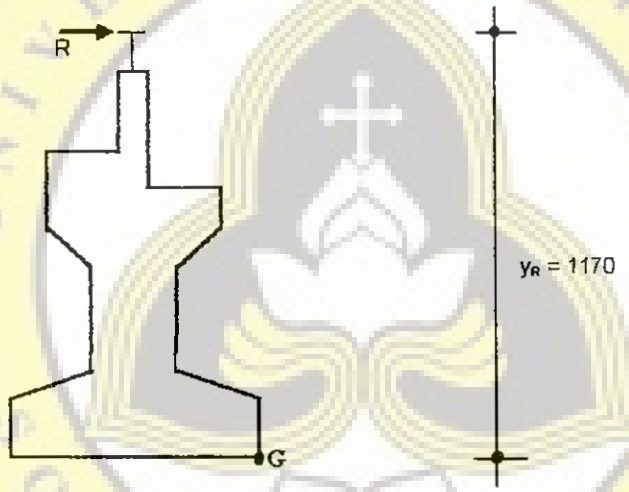
$M_{GS} = G_S * x_S$

= 3,78E+05* 3,75

= 1,4175E+06 Nm

e. Gaya Rem dan Traksi

Diambil 5 % dari beban hidup (PPPJR SKBI - 1987 hal. 15) yang bekerja pada konstruksi atas.



Gambar 5.71.Gaya rem dan traksi

Beban horizontal terhadap pilar

G_L = 3,752 E+06 N

R = 5% * G_L *(PPPJJR - SKBI - 1987 hal. 15)*

= 5% * 3,752 E+06

= 1,876 E+05 N

Lengan gaya terhadap titik G :

R bekerja pada 1,8 m di atas permukaan lantai kendaraan, (*PPPJJR - SKBI - 1987*)

y_R = 11,7 m

Momen terhadap titik A :

M_R = R * 11,7

= 1,876 E+05* 11,7 = 2,195 E+06 Nm

f. Gaya Gesek Pada Tumpuan

Ditinjau akibat beban mati pada konstruksi atas.

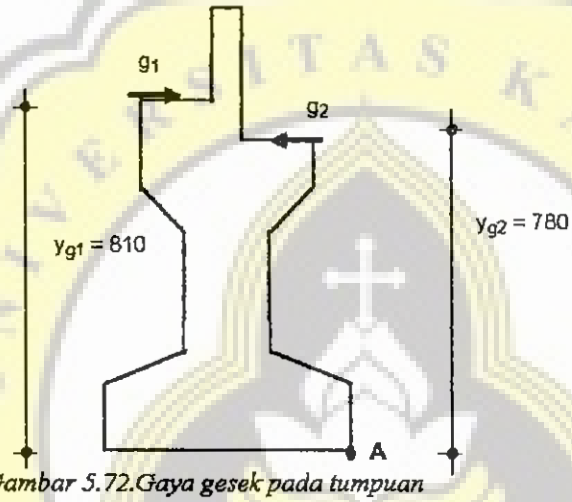
$G_g = f_s * b$

dimana :

g : gaya gesek antara tumpuan dengan balok

f_s : koefisien gesek = 0,15 (PPPJJR SKBI - 1987 hal. 15)

b : beban mati konstruksi atas = 7,8244 E+06 N



Gambar 5.72.Gaya gesek pada tumpuan

G_d = 3,3644E+06 + 4,46E+06 N

= 7,8244 E+06 N

G_{g1} = 0,15 * 3,3644E+06

= 5,0466E+05 N

G_{g2} = 0,15 *4,46E+06

= 6,69E+05 N

Lengan gaya terhadap titik A :

y_{g1} = 8,1 m

y_{g2} = 7,8 m

Momen terhadap titik A :

M_{Gg} = $G_g * y_g$

4,087746 E+06 5,2182E+06

= (5,0466E+05* 8,1) +(6,69E+05 * 7,8)

= 9,306 E+06 Nm