1. Data Dimensi Box Culvert :

   a. Tinggi Box Culvert (H) = 2,3 m

   b. Lebar Box Culvert (L) = 2,3 m

   c. Tebal Plat Atas (t1) = 0,3 m

   d. Tebal Plat Dinding (t2) = 0,3 m

   e. Tebal Plat Bawah (t3) = 0,3 m

   f. Tinggi muka air rencana (t4) = 0,5 m

2. Data Bahan Struktur Beton Box Culvert :

Tabel 3.1 *Data mutu beton box culvert*

Mutu Beton	=	K-250
Kuat Tekan Beton (fc')	=	0,83 * K / 10
	=	0,83 * 250 / 10
	=	20,75 Mpa
Modulus Elastis (Ec)	=	$0{,}043 * Wc^{1,5} * \sqrt{fc'}$
	=	$0{,}043 * 25^{1,5} * \sqrt{20{,}75}$
	=	24484 Mpa
Angka Poisson (ϑ)	=	0,20
Modulus Geser (G)	=	$E_c / [2* (1 + \upsilon)]$
	=	24484 / [2* (1 + 0,2)]
	=	10201 Mpa
Koef. muai panjang beton (α)	=	1.0E - 05 /^{o}C

***Tabel 3.2** Data mutu baja box culvert*

Mutu Baja Tulangan	
Untuk baja tulangan dengan ϕ > 12 mm	= U - 39
Tegangan leleh baja (fy)	= U * 10 = 39 * 10 = 390 Mpa
Untuk baja tulangan dengan ϕ ≤ 12 mm	= U - 24
Tegangan leleh baja (fy)	= U * 10 = 24 * 10 = 240 Mpa

***Tabel 3.3** Data berat jenis pada box culvert*

Data berat jenis	
Berat jenis beton bertulang (Wc)	= 25 kN/m^3
Berat jenis beton tidak bertulang (W'c)	= 24 kN/m^3
Berat jenis tanah dipadatkan (Ws)	= 17,2 kN/m^3
Berat jenis air (Ww)	= 9,8 kN/m^3

3.1.2 Data Tanah

Data tanah dalam proyek ini berasal dari hasil penyelidikan tanah pada *box culvert* tol Semarang – Solo paket 3.3D, didapatkan data sebagai berikut :

- Berat isi tanah basah (γm) = 1,554 gr/cm^3
- Berat isi tanah kering (γd) = 1,342 gr/cm^3

- Berat jenis tanah (Gs) = 2,63
- Angka Pori (e) = 0,342
- Kadar Air (w) = 15,8 %
- Kohesi (c) = 0,33 kg/cm²
- Sudut geser dalam (φ) = 11,7 º
- Porositas (n) = 25,48 %

3.2 ANALISA PEMBEBANAN STRUKTUR BETON BOX CULVERT

3.2.1 Beban Primer

1. Beban Mati (Q_{MA})

Beban mati (dead load), adalah berat seluruh bahan yang menimbulkan suatu beban yang bersifat pasif pada box girder. Box culvert dianalisis harus mampu memikul beban mati seperti :

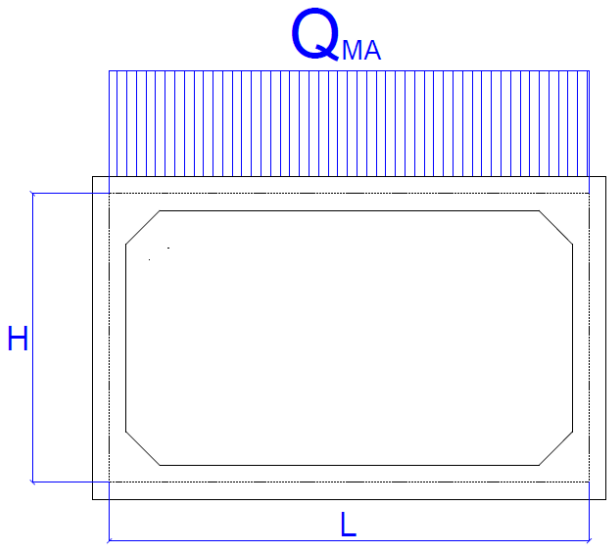
1) Lapisan perkerasan beton rigid pavement,

2) Genangan air hujan di permukaan lapisan perkerasan,

NO	JENIS	TEBAL (m)	BERAT (kN/m^3)	BEBAN (kN/m)
1	Perkerasan Beton	0,3	25	7,5
2	Air hujan	0,05	9,8	0,49
Jumlah Total Beban Mati (Q_{MA})				7,99

Jadi, total beban mati (Q_{MA}) adalah = beban perkerasan beton + beban genangan air hujan

= 7,5 + 0,49
= 7,99 kN/m



Gambar 3.3 *Gaya akibat beban mati*

2. Berat Sendiri Box Culvert (Q_{MS})

Berat sendiri (self weight) adalah berat bahan dan bagian box culvert yang merupakan elemen struktural, ditambah dengan elemen non-struktural yang dipikulnya dan bersifat tetap. Berat sendiri box culvert dihitung dengan meninjau selebar 1 m (tegak lurus bid. gambar) sebagai berikut :

a. Berat sendiri plat atas

Ditinjau struktur underpass selebar (b)	=	1,00 m
Tebal plat (t1)	=	0,30 m
Berat beton bertulang (Wc)	=	25 kN/m^3
Berat sendiri plat atas (Q_{MS1})	=	b * h1 * Wc
	=	1 * 0,30 * 25
	=	7,5 kN/m

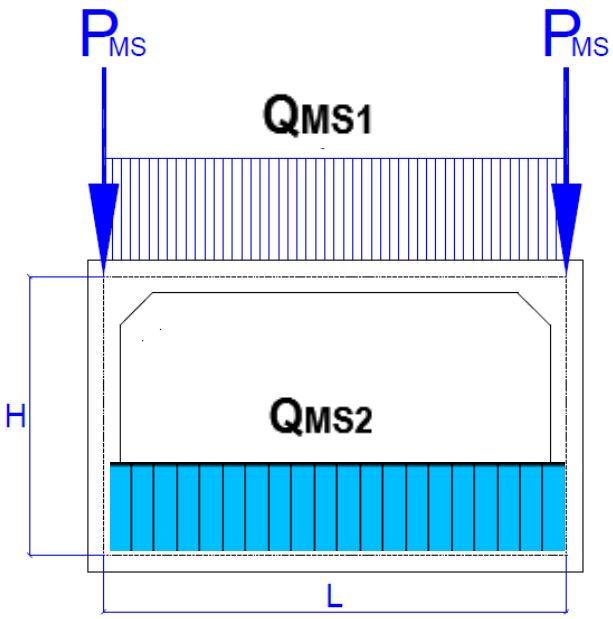
b. Berat sendiri plat dinding

Ditinjau struktur underpass selebar (b)	=	1,00 m
Tebal plat (t2)	=	0,30 m

Berat beton bertulang (Wc)	=	25 kN/m^3
Tinggi plat dinding (H)	=	2,3 m
Berat sendiri plat atas (P_{MS})	=	b * t2 * H * Wc
	=	1 * 0,30 * 2,3 * 25
	=	17,25 kN/m

c. Berat sendiri plat lantai

Ditinjau struktur underpass selebar (b)	=	1,00 m
Tebal plat (t1)	=	0,30 m
Berat beton bertulang (Wc)	=	25 kN/m^3
Berat sendiri plat atas (Q_{MS2})	=	b * h1 * Wc
	=	1 * 0,30 * 25
	=	7,5 kN/m



Gambar 3.4 *Gaya akibat berat sendiri box culvert*

3. Beban Lalu Lintas

a. Beban Lajur “D” (T_D)

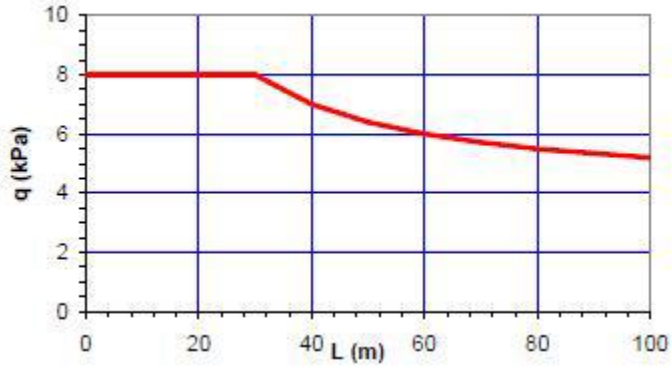
Beban kendaraan yg berupa beban lajur "D" terdiri dari beban terbagi rata (Uniformly Distributed Load) UDL dan beban garis (Knife Edge Load) KEL seperti pada Gambar 1. UDL mempunyai intensitas q (kPa) yang besarnya tergantung pada panjang total L yg dibebani lalu-lintas seperti Gambar 2 atau dinyatakan dengan rumus sebagai berikut :

Lebar jalur lalu lintas (B1) = 24,88 m

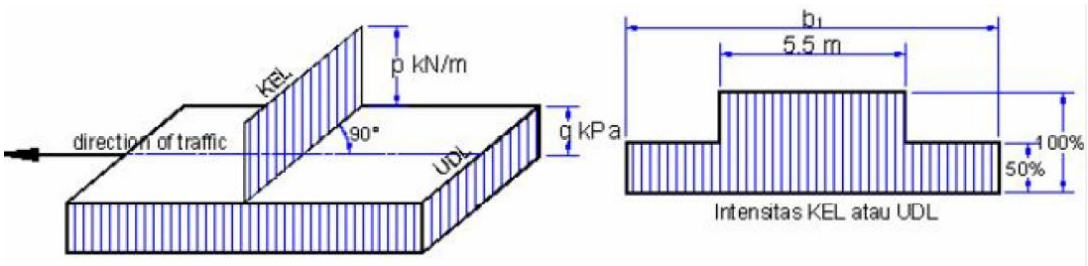
Lebar box culvert (L) = 2,3 m

Berdasarkan PPPJJR 1987, nilai q = 8.0 kPa untuk L ≤ 30 m

q = 8.0 *(0.5 + 15 / L) kPa untuk L > 30 m



Gambar 3.5 *Intensitas Uniformly Distribted Load (UDL)*



Gambar 3.6 *Beban “D”*

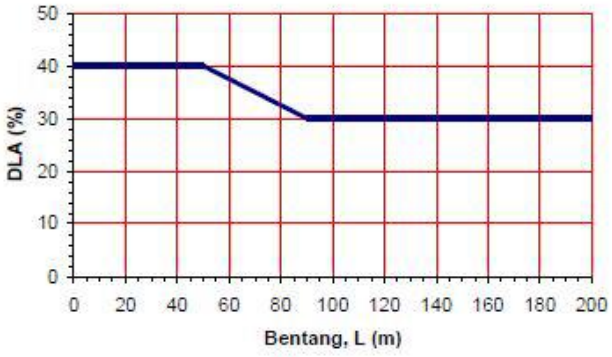
Untuk lebar bentang, L = 24,88 m q = 8.0 kPa

KEL mempunyai intensitas, p = 44,00 kN/m

Faktor beban dinamis (Dinamic Load Allowance) untuk KEL diambil sebagai berikut : DLA = 0.4 untuk L ≤ 50 m

DLA = 0.4 - 0.0025*(L - 50) untuk 50 < L < 90 m

DLA = 0.3 untuk L ≥ 90 m

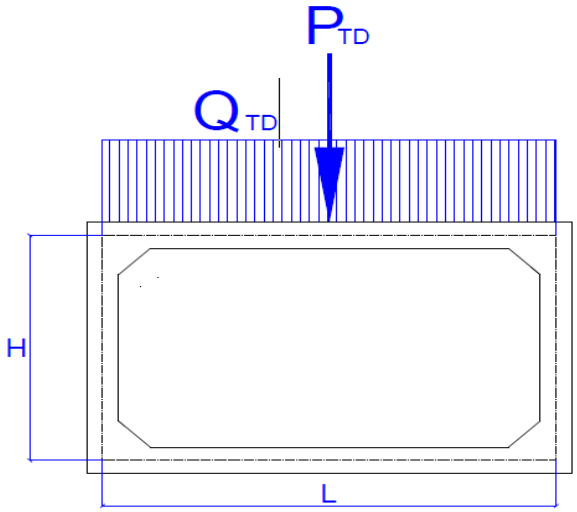


Gambar 3.7 *Faktor beban dinamis (DLA)*

Untuk lebar saluran (L) = 2,3 m, DLA = 0.4

Beban hidup pada lantai : Q_{TD} = q x L = 8 x 2,3 = 18,40 kN/m

P_{TD} = (1 + DLA) x p x L = 141,68 kN

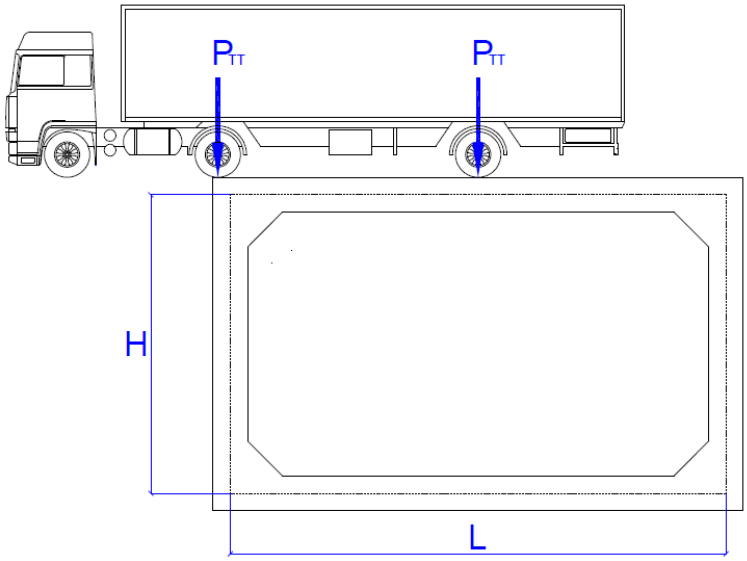


Gambar 3.8 *Gaya akibat beban lajur "D"*

b. Beban Truk “T” (T_T)

Beban hidup pada lantai jembatan berupa beban roda ganda oleh Truk (beban T) yang besarnya, T = 100 kN. Faktor beban dinamis untuk pembebanan truk diambil (DLA) = 0,40.

Beban truk "T" (P_{TT}) = (1 + DLA) x T = 140,00 kN



Gambar 3.9 *Gaya akibat beban truk “T”*

3.2.2 Beban Akibat Tekanan Tanah

Pada bagian tanah di belakang dinding abutment yang dibebani lalu-lintas, harus diperhitungkan adanya beban tambahan yg setara dengan tanah setebal 0.60 m yang berupa beban merata ekivalen beban kendaraan pada bagian tersebut. Tekanan tanah lateral dihitung berdasarkan harga nominal dari berat tanah ws, sudut gesek dalam Ø, dan kohesi c dengan :

ws' = ws

$\emptyset^1 = tan^{-1}\ (K_\emptyset^R\ x\ tan_\emptyset)$ dengan factor reduksi untuk $\emptyset^1$ $K_\emptyset^R$ = 0,70

$C^1 = K_\emptyset^R\ x\ C$ dengan factor reduksi untuk c' $K_\emptyset^R$ = 1,00

Koefisien tanah aktif (K_a) = $tan^2(\ 45^\circ - \frac{\emptyset^1}{2})$

Berat tanah dipadatkan (Ws) = 17,20 kN/m^3

Sudut gesek dalam (ϕ) = 35 ^{o}

Kohesi (C) = 0 kPa

Faktor reduksi sudut gesek dalam ($K_\emptyset^R$) = 0,7

ϕ' = tan^{-1} ($K_\emptyset^R$ * tan ϕ)

= tan^{-1} (0,7 * tan 35)

= 0,455733 rad

= 26,112^o

Koefisien tekanan tanah aktif (Ka)

Ka = $tan^2(\ 45^\circ - \frac{\emptyset^1}{2}$

= $tan^2(\ 45^\circ - \frac{35^1}{2}$

= 0,388773

Beban tekanan tanah pada plat dinding (Q_{TA})

Q_{TA1} = 0,60 * Ws * Ka

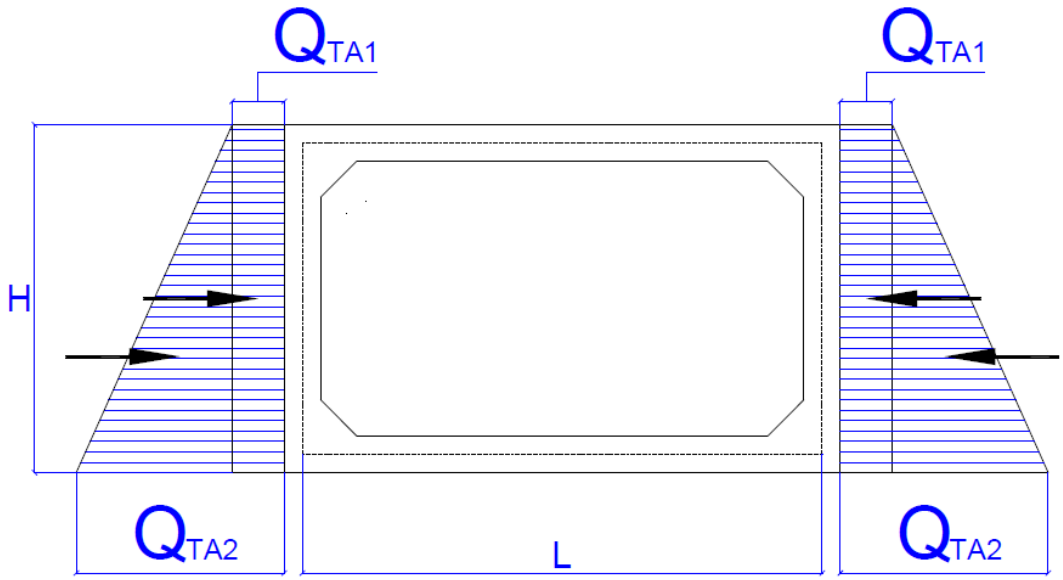
= 0,6 * 17,2 * 0,388773

= 4,012 kN/m

Q_{TA2} = Q_{TA1} + (H * Ws * Ka)

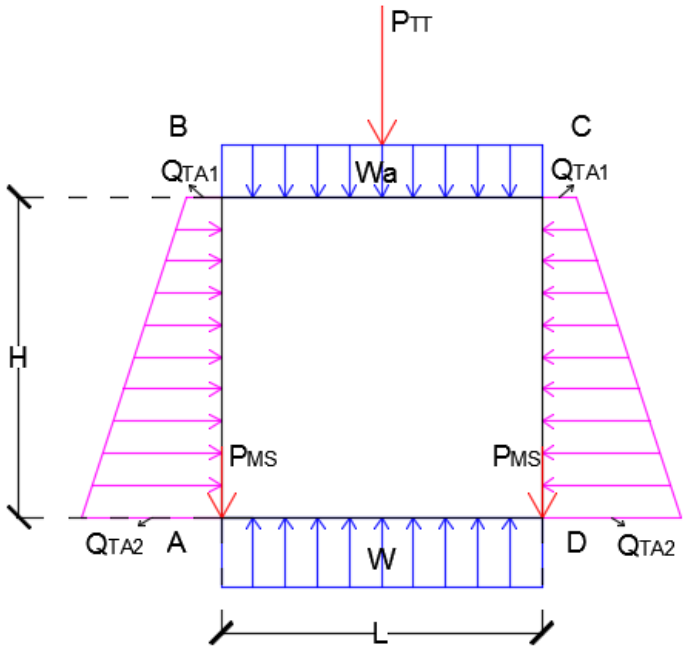
= 4,012 + (2,3 * 17,2 * 0,388773)

= 19,392 kN/m



Gambar 3.10 *Gaya akibat tekanan tanah aktif*

3.3 ANALISA MEKANIKA STRUKTUR BOX CULVERT



Gambar 3.11 *Gaya – gaya yang bekerja pada box culvert*

A. Beban Total Pada Plat Atas (Wa)

Meliputi beban mati, beban sendiri plat atas dan beban lajur "D" :

Wa = $Q_{MA} + Q_{MS1} + Q_{TD}$

= 7,99 kN/m + 7,5 kN/m +18,40 kN/m

= 33,89 kN/m

B. Beban Total Pada Plat Bawah (W)

Meliputi beban sendiri plat bawah + beban muka air (Wb) dan beban raksi akibat tekanan tanah (Wt) :

Wb = Q_{MS2} + Berat air

= 7,5 kN/m + (2,0 x 9,8) kN/m

= 27,1 kN/m

$$Wt = \frac{(Wa\ .\ L)+(Wb\ .\ L)+(2\ .\ P_{TT})+(2\ .P_{MS})}{L}$$

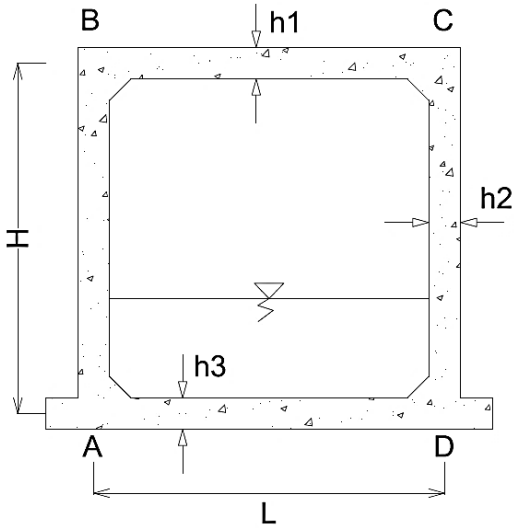
$$= \frac{(33{,}89 \text{ x } 2{,}3) +(12{,}4 \text{ x } 2{,}3) + (2 \text{ x } 140) + (2 \text{ x } 17{,}25)}{2{,}3}$$

$$= \frac{77{,}95 \text{ kN} + 28{,}52 \text{ kN} + 280 \text{ kN} + 34{,}5 \text{ kN}}{2{,}3\ m}$$

$$= 183{,}03 \text{ kN/m}$$

W = Wb - Wt = - 155,93 kN/m

3.3.1 Menghitung Faktor Distribusi



1. Titik A → Batang AD : AB

$$\mathcal{E}_{AD} : \mathcal{E}_{AB} = \frac{4EI}{L\ AD} : \frac{4EI}{L\ AB}$$

$$= \frac{4EI}{2{,}3} : \frac{4EI}{2{,}3}$$

$$= 1{,}74 : 1{,}74$$

➢ $\mathcal{E}_{AD} = \frac{1{,}74}{1{,}74+1{,}74}$

$$= 0{,}5$$

- ε_{AB} $= \frac{1{,}74}{1{,}74+1{,}74}$

  $= 0{,}5$

2. Titik B → Batang BA : BC

$\varepsilon_{BA} : \varepsilon_{BC}$ $= \frac{4EI}{L\ BA} : \frac{4EI}{L\ BC}$

$= \frac{4EI}{2{,}3} : \frac{4EI}{2{,}3}$

$= 1{,}74 : 1{,}74$

- ε_{BA} $= \frac{1{,}74}{1{,}74+1{,}74}$

  $= 0{,}5$

- ε_{BC} $= \frac{1{,}74}{1{,}74+1{,}74}$

  $= 0{,}5$

3. Titik C → Batang CB : CD

$\varepsilon_{CB} : \varepsilon_{CD}$ $= \frac{4EI}{L\ CB} : \frac{4EI}{L\ CD}$

$= \frac{4EI}{2{,}3} : \frac{4EI}{2{,}3}$

$= 1{,}74 : 1{,}74$

- ε_{CB} $= \frac{1{,}74}{1{,}74+1{,}74}$

  $= 0{,}5$

- ε_{CD} $= \frac{1{,}74}{1{,}74+1{,}74}$

  $= 0{,}5$

4. Titik D → Batang DC : DA

$$\varepsilon_{DC} : \varepsilon_{DA} = \frac{4EI}{L\,DC} : \frac{4EI}{L\,DA}$$

$$= \frac{4EI}{2{,}3} : \frac{4EI}{2{,}3}$$

$$= 1{,}74 : 1{,}74$$

- $\varepsilon_{DC} = \frac{1{,}74}{1{,}74+1{,}74}$

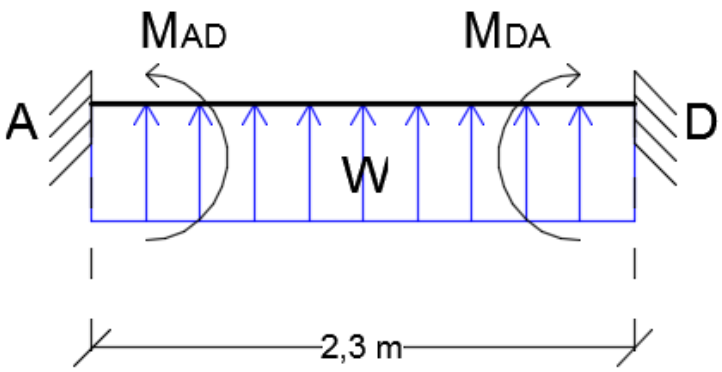
$$= 0{,}5$$

- $\varepsilon_{DA} = \frac{1{,}74}{1{,}74+1{,}74}$

$$= 0{,}5$$

3.3.2 Menghitung Momen Primer

1. Momen Primer pada Batang A → D



- $M_{AD} = -\left[\frac{1}{12}\, x\, W\, x\right]$

$$= -\left[\frac{1}{12}\, x\, 155{,}93\, x\, 2{,}3^2\right]$$

$$= -[68{,}74]$$

$$= -\,68{,}74 \text{ kNm}$$

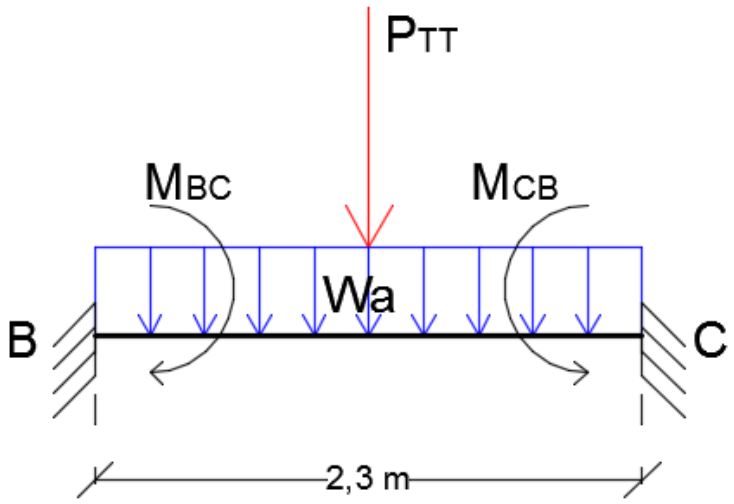
➢ M_{DA} $= \left[\frac{1}{12}\ x\ W\ x\ l^2\right]$

$= \left[\frac{1}{12}\ x\ 155{,}93\ x\ 2{,}3^2\right]$

$= [68{,}74]$

$= 68{,}74$ kNm

2. Momen Primer pada Batang B → C



➢ M_{BC} $= \left[\frac{1}{12}\ x\ Wa\ x\ l^2 + \frac{P_{TT}\ x\ a\ x\ b^2}{l^2}\right]$

$= \left[\frac{1}{12}\ x\ 33{,}89\ x\ 2{,}3^2 + \frac{140\ x\ 1{,}15\ x\ 1{,}15^2}{2{,}3^2}\right]$

$= [14{,}94 + 40{,}25]$

$= 55{,}19$ kNm

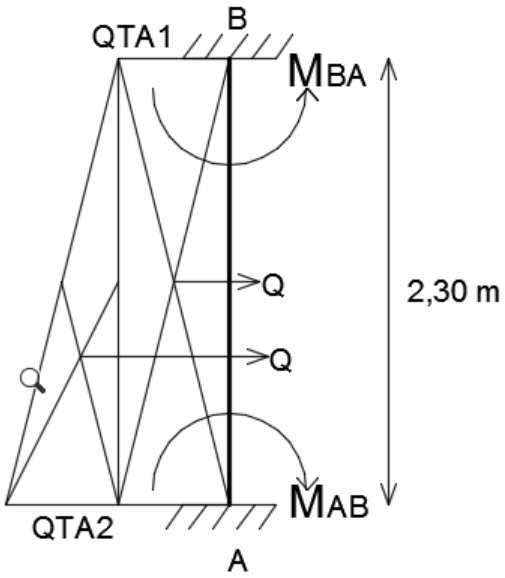
➢ M_{CB} $= -\left[\frac{1}{12}\ x\ Wa\ x\ l^2 + \frac{P_{TT}\ x\ a\ x\ b^2}{l^2}\right]$

$= -\left[\frac{1}{12}\ x\ 33{,}89\ x\ 2{,}3^2 + \frac{140\ x\ 1{,}15\ x\ 1{,}15^2}{2{,}3^2}\right]$

$= -[14{,}94 + 40{,}25]$

$= -55{,}19$ kNm

3. Momen Primer pada Batang A → B



- $M_{AB} = \left[\frac{L^2}{60}(3 . Q_{TA2} + 2 . Q_{TA1})\right]$

$= \left[\frac{2{,}3^2}{60}(3 . 19{,}392 + 2 . 4{,}012)\right]$

$= \left[\frac{5{,}29}{60}(58{,}176 + 8{,}024)\right]$

$= \left[\frac{5{,}29}{60}(66{,}2)\right]$

$= 5{,}836$ kNm

- $M_{BA} = -\left[\frac{L^2}{60}(2 . Q_{TA2} + 3 . Q_{TA1})\right]$

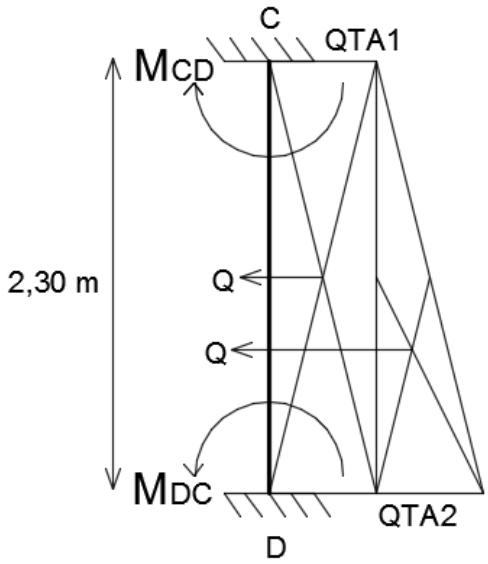
$= -\left[\frac{2{,}3^2}{60}(2 . 19{,}392 + 3 . 4{,}012)\right]$

$= -\left[\frac{5{,}29}{60}(38{,}784 + 12{,}036)\right]$

$$= -\left[\frac{5,29}{60}(50,82)\right]$$

$$= -\ 4,481 \text{ kNm}$$

4. Momen Primer pada Batang C → D



- $M_{CD} = \left[\frac{L^2}{60}(\ 2\ .\ Q_{TA2} + \ 3\ .\ Q_{TA1})\right]$

$$= \left[\frac{2,3^2}{60}(\ 2\ .19,392 + \ 3\ .\ 4,012)\right]$$

$$= \left[\frac{5,29}{60}(\ 38,784 + \ 12,036\ )\right]$$

$$= \left[\frac{5,29}{60}(50,82)\right]$$

$$= \ 4,481 \text{ kNm}$$

- $M_{DC} = -\left[\frac{L^2}{60}(\ 3\ .\ Q_{TA2} + \ 2\ .\ Q_{TA1})\right]$

$$= -\left[\frac{2,3^2}{60}(\ 3\ .19,392 + \ 2\ .\ 4,012)\right]$$

$$= -\left[\frac{5,29}{60}(58,176 + 8,024)\right]$$

$$= -\left[\frac{5,29}{60}(66,2)\right]$$

$$= -5,836 \text{ kNm}$$

3.3.3 Menghitung Momen dengan Metode Cross

Tabel 3.4 *Perhitungan Momen dengan Metode Cross*

JOINT	A		B		C		D	
BATANG	AD	AB	BA	BC	CB	CD	DC	DA
DF	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
FEM	-68.740	5.836	-4.481	55.190	-55.190	4.481	-5.836	68.740
BAL	31.452	31.452	-25.355	-25.355	25.355	25.355	-31.452	-31.452
CO	-15.726	-12.677	15.726	12.677	-12.677	-15.726	12.677	15.726
BAL	14.202	14.202	-14.202	-14.202	14.202	14.202	-14.202	-14.202
CO	-7.101	-7.101	7.101	7.101	-7.101	-7.101	7.101	7.101
BAL	7.101	7.101	-7.101	-7.101	7.101	7.101	-7.101	-7.101
CO	-3.550	-3.550	3.550	3.550	-3.550	-3.550	3.550	3.550
BAL	3.550	3.550	-3.550	-3.550	3.550	3.550	-3.550	-3.550
CO	-1.775	-1.775	1.775	1.775	-1.775	-1.775	1.775	1.775
BAL	1.775	1.775	-1.775	-1.775	1.775	1.775	-1.775	-1.775
CO	-0.888	-0.888	0.888	0.888	-0.888	-0.888	0.888	0.888
BAL	0.888	0.888	-0.888	-0.888	0.888	0.888	-0.888	-0.888
CO	-0.444	-0.444	0.444	0.444	-0.444	-0.444	0.444	0.444
BAL	0.444	0.444	-0.444	-0.444	0.444	0.444	-0.444	-0.444
CO	-0.222	-0.222	0.222	0.222	-0.222	-0.222	0.222	0.222
BAL	0.222	0.222	-0.222	-0.222	0.222	0.222	-0.222	-0.222
CO	-0.111	-0.111	0.111	0.111	-0.111	-0.111	0.111	0.111
BAL	0.111	0.111	-0.111	-0.111	0.111	0.111	-0.111	-0.111
CO	-0.055	-0.055	0.055	0.055	-0.055	-0.055	0.055	0.055
BAL	0.055	0.055	-0.055	-0.055	0.055	0.055	-0.055	-0.055
CO	-0.028	-0.028	0.028	0.028	-0.028	-0.028	0.028	0.028
BAL	0.028	0.028	-0.028	-0.028	0.028	0.028	-0.028	-0.028
CO	-0.014	-0.014	0.014	0.014	-0.014	-0.014	0.014	0.014
BAL	0.014	0.014	-0.014	-0.014	0.014	0.014	-0.014	-0.014

CO	-0.007	-0.007	0.007	0.007	-0.007	-0.007	0.007	0.007
BAL	0.007	0.007	-0.007	-0.007	0.007	0.007	-0.007	-0.007
CO	-0.003	-0.003	0.003	0.003	-0.003	-0.003	0.003	0.003
BAL	0.003	0.003	-0.003	-0.003	0.003	0.003	-0.003	-0.003
CO	-0.002	-0.002	0.002	0.002	-0.002	-0.002	0.002	0.002
BAL	0.002	0.002	-0.002	-0.002	0.002	0.002	-0.002	-0.002
CO	-0.001	-0.001	0.001	0.001	-0.001	-0.001	0.001	0.001
BAL	0.001	0.001	-0.001	-0.001	0.001	0.001	-0.001	-0.001
CO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BAL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M. UJUNG	**-38.812**	**38.812**	**-28.311**	**28.311**	**-28.311**	**28.311**	**-38.812**	**38.812**
M. AKHIR	**38.812**	**-38.812**	**28.311**	**-28.311**	**28.311**	**-28.311**	**38.812**	**-38.812**
JUMLAH	**0.000**		**0.000**		**0.000**		**0.000**	

Keterangan :

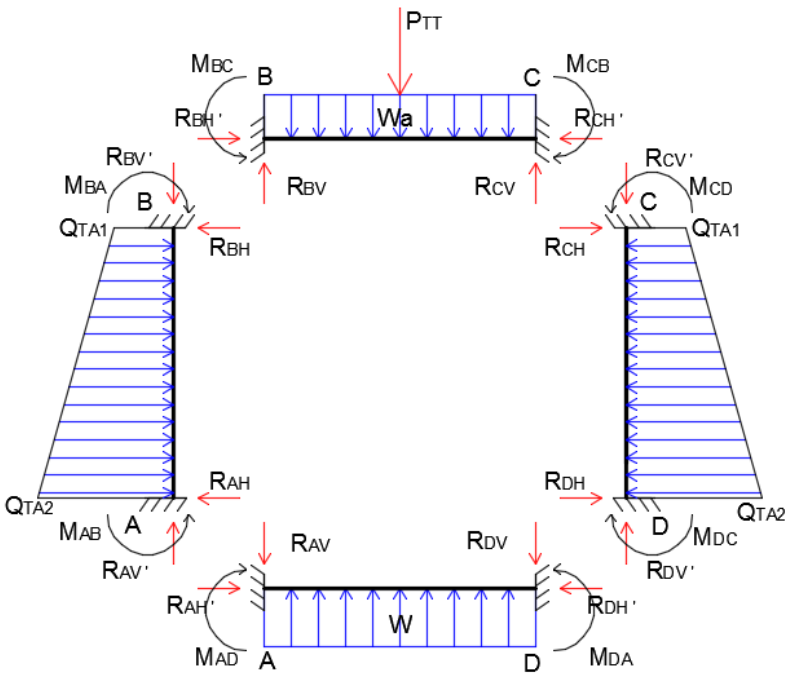
DF : Koefisien Distribusi

FEM : Fixed End Momen (Momen Primer)

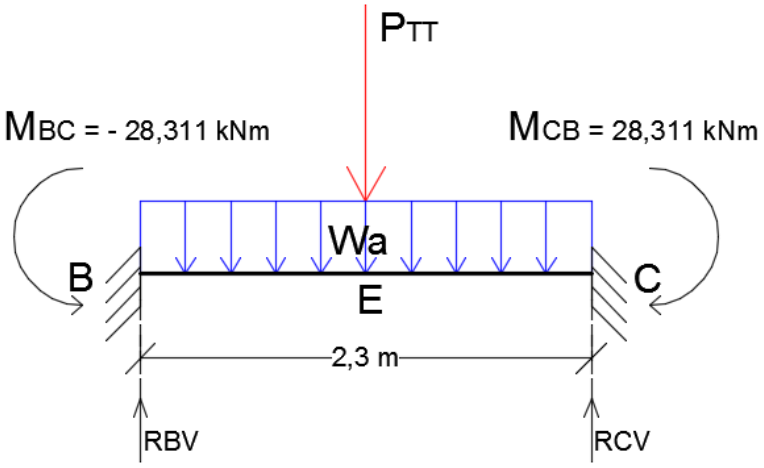
BAL : Balancing (Momen Distribusi)

CO : Carry Over (Momen Induksi)

3.3.4 Menentukan Reaksi Perletakan



1. **Reaksi Perletakan pada Batang B → C**



- $R_{BV} \rightarrow \sum M_C = 0$

R_{BV} . 2,3 - M_{BC} – P_{TT} . 1,15 - Q . 1,15 + M_{CB} = 0

R_{BV} . 2,3 – 28,311 - (140 . 1,15) - (33,89 x 2,3) . 1,15 . 1,15 + 28,311 = 0

R_{BV} . 2,3 – 28,311 – 161 - 89,64 + 28,311 = 0

R_{BV} . 2,3 - 250,64 = 0

$$R_{BV} = \frac{250,64}{2,3}$$

R_{BV} = 108,97 kN

- $R_{BV} \rightarrow \sum M_B = 0$

- R_{CV} . 2,3 + M_{CB} + P_{TT} . 1,15 + Q . 1,15 - M_{BC} = 0

- R_{CV} . 2,3 + 28,311 + 140 . 1,15 + (33,89 x 2,3) . 1,15 – 28,311 = 0

- R_{CV} . 2,3 + 28,311 + 161 + 89,64 – 28,311 = 0

- R_{CV} . 2,3 + 250,64 = 0

$$R_{CV} = \frac{-250,64}{-2,3}$$

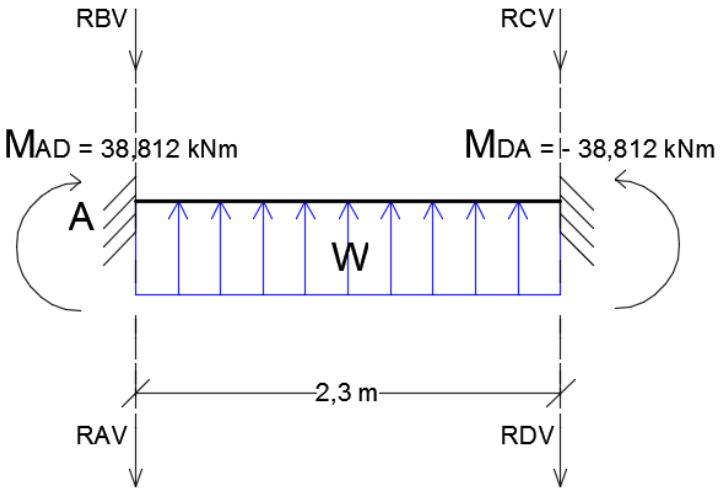
R_{CV} = 108,87 kN

- Cek $\rightarrow \sum Kv = 0$

$R_{BV} + R_{CV} - P_{TT} - Q = 0$

$108,97 + 108,97 - 140 - 77,94 = 0$

2. Reaksi Perletakan pada Batang A → D



- $R_{AV} \rightarrow \sum M_D = 0$

$-R_{AV} . 2,3 - R_{BV} . 2,3 + M_{AD} + Q . 1,15 - M_{DA} = 0$

$-R_{AV} . 2,3 - 108,97 . 2,3 + 38,812 + (155,93 . 2,3) . 1,15 - 38,812 = 0$

$-R_{AV} . 2,3 - 250,63 + 38,812 + 412,43 - 38,812 = 0$

$-R_{AV} . 2,3 - 161,8 = 0$

$-R_{AV} = \frac{161,8}{2,3}$

$R_{AV} = - 70,35$ kN

- $R_{DV} \rightarrow \sum M_A = 0$

R_{DV} . 2,3 + R_{CV} . 2,3 - M_{DA} – Q . 1,15 + M_{AD} = 0

R_{DV} . 2,3 + 108,97 . 2,3 – 38,812 – (155,93 x 2,3) . 1,15 + 38,812 = 0

R_{DV} . 2,3 + 250,63 – 38,812 – 412,43 + 38,812 = 0

R_{DV} . 2,3 + 412,43 = 0

$R_{DV} = \frac{-412,43}{2,3}$

R_{DV} = – 70,35 kN

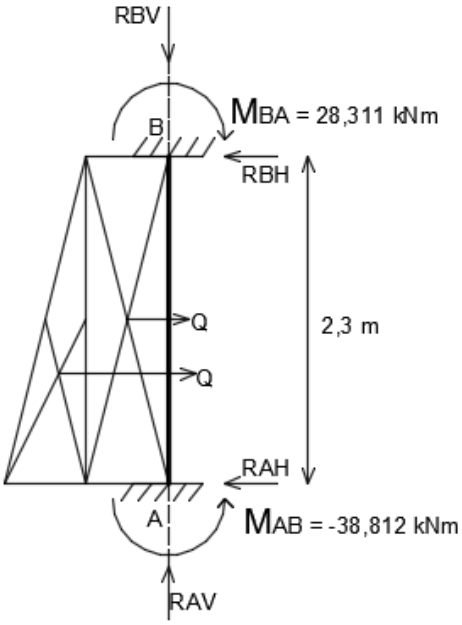
- Cek $\rightarrow \sum Kv = 0$

– R_{AV} – R_{DV} – R_{BV} – R_{CV} + Q = 0

– 70,35 – 70,35 – 108,97 – 108,97 + (155,93) . 2,3 = 0

–70,35 – 70,35 – 108,97 – 108,97 + 358,64 = 0

3. Reaksi Perletakan pada Batang A → B



- $R_{BH} \rightarrow \sum M_A = 0$

$- R_{BH} . 2,23 + M_{BA} + (Q_{TA1} . 2,3) . 1,15 + [0,5 . 2,3 (Q_{TA2} - Q_{TA1})] . 0,767 - M_{AB} = 0$

$- R_{BH} . 2,3 + 28,311 + (4,012 . 2,3) . 1,15 + [0,5 . 2,3 (19,392 - 4,012)] . 0,767 – 38,812 = 0$

$- R_{BH} . 2,3 + 28,311 + 10,612 + 13,566 – 38,812 = 0$

$- R_{BH} . 2,3 + 13,677 = 0$

$$R_{BH} = \frac{-13,677}{-2,3}$$

$R_{BH} = 5,947$ kN

- $R_{AH} \rightarrow \sum M_B = 0$

$R_{AH} . 2,3 - M_{AB} - [0,5 . 2,3 (Q_{TA2} - Q_{TA1})] . 1,533 - (Q_{TA1} . 2,3) . 1,15 + M_{BA} = 0$

$R_{AH} . 2,3 - 38,812 - [0,5 . 2,3 (19,392 - 4,012)] . 1,533 - (4,012 . 2,3) . 1,15 + 28,311 = 0$

$R_{AH} . 2,3 - 38,812 – 27,114 – 10,612 + 28,311 = 0$

$R_{AH} . 2,3 – 48,227 = 0$

$$R_{AH} = \frac{48,227}{2,3}$$

$R_{AH} = 20,968$ kN

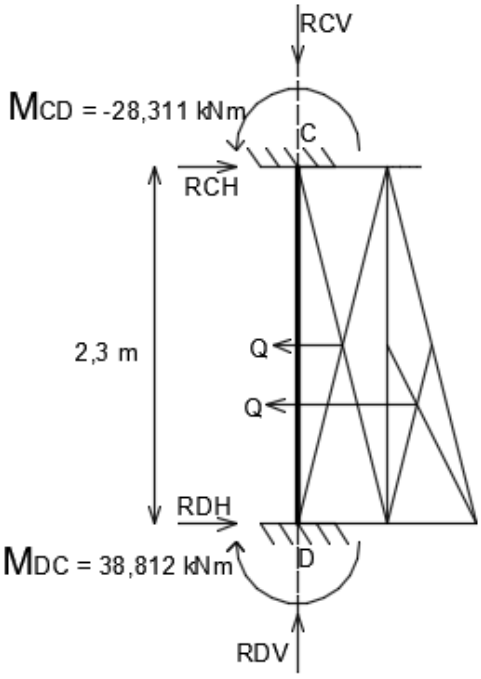
- Cek $\rightarrow \sum KH = 0$

$R_{AH} + R_{BH} – Q_{TA1} – Q_{TA2} = 0$

$20,968 + 5,947 - (4,01 \times 2,3) - [0,5 . 2,3 (19,392 - 4,012)] = 0$

$20,968 + 5,947 – 9,228 - 17,687 = 0$

4. Reaksi Perletakan pada Batang C → D



- $R_{CH} \rightarrow \sum M_D = 0$

R_{CH} . 2,3 - M_{CD} - (Q_{TA1} . 2,3) . 1,15 - [0,5 . 2,3 (Q_{TA2} - Q_{TA1})] . 0,767 + M_{DC} = 0

R_{CH}. 2,3 -28,311-(4,012. 2,3) . 1,15 -[0,5 . 2,3 (19,392–4,012)] . 0,767+38,812 = 0

R_{CH} . 2,3 - 28,311– 10,612 - 13,566 + 38,812 = 0

R_{CH} . 2,3 – 13,677 = 0

$$R_{CH} = \frac{13,677}{2,3}$$

R_{CH} = 5,947 kN

- $R_{DH} \rightarrow \sum M_C = 0$

- R_{DH} . 2,3 +M_{DC} + [0,5 . 2,3 (Q_{TA2} - Q_{TA1})] . 1,533 + (Q_{TA1} . 2,3) . 1,15 - M_{CD} = 0

- R_{DH} . 2,3+38,812+[0,5. 2,3(19,392-4,012)] .1,533+(4,012. 2,3) . 1,15-28,311 = 0

$- R_{DH} . 2,3 + 38,812 + 27,061 + 10,612 - 28,311 = 0$

$- R_{DH} . 2,3 + 48,227 = 0$

$$R_{DH} = \frac{-48,227}{-2,3}$$

$R_{DH} = 20,968$ kN

- Cek $\rightarrow \sum KH = 0$

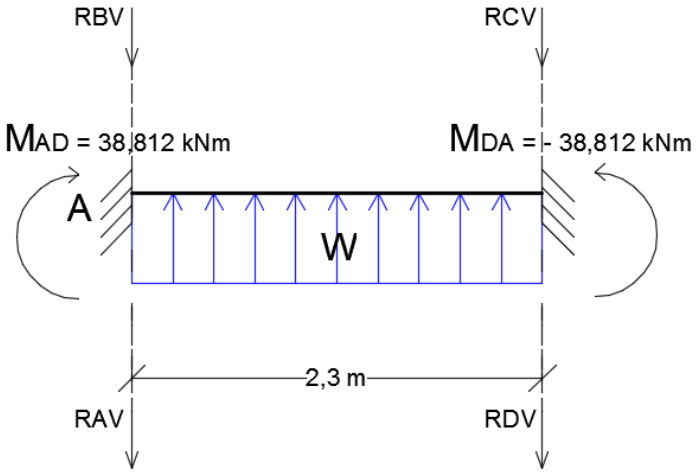
$R_{DH} + R_{CH} – Q_{TA1} – Q_{TA2} = 0$

$20,968 + 5,947 - (4,012 \times 2,3) - (0,5 . 2,3 [19,392 - 4,012]) = 0$

$20,968 + 5,947 – 9,228 - 17,687 = 0$

3.3.5 Menghitung Gaya Lintang (Bidang D)

1. Gaya Lintang pada Batang A → D



- $D_A = – R_{AV} – R_{BV}$

  $= – 70,35 – 108,97$

  $= – 179,32$ kN

- D_D kiri $= D_A + Q$

  $= – 179,32 + (155,93 \times 2,3)$

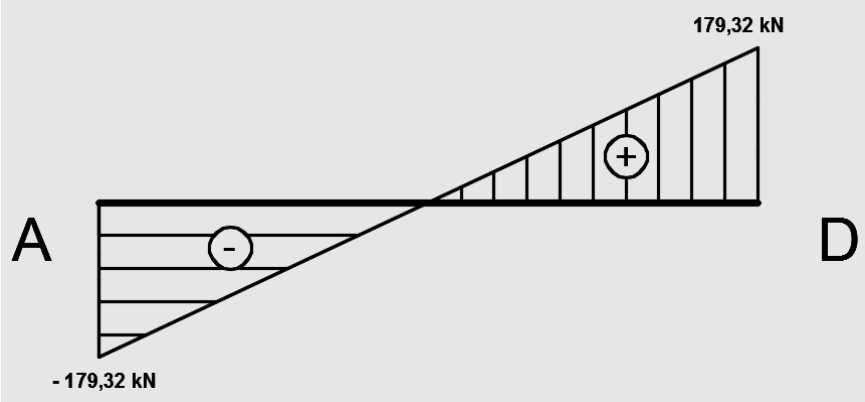
  $= – 179,32 + 358,639$

  $= 179,32$ kN

- D_D kanan $= D_D$ kiri $– R_{CV} – R_{DV}$

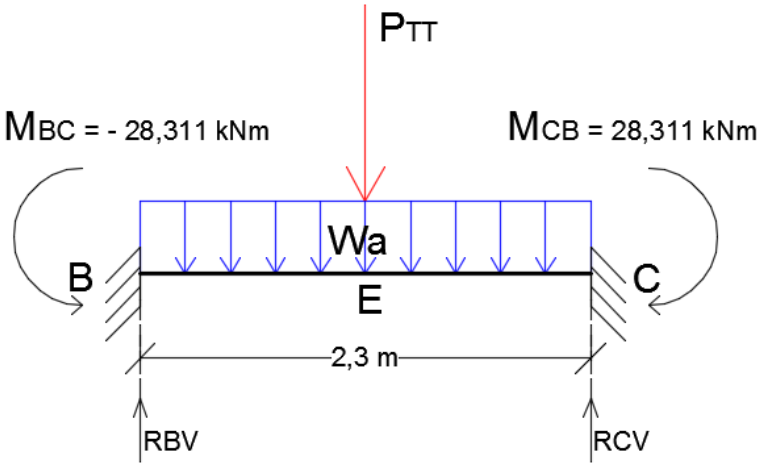
  $= 179,32 – 108,97 – 70,35$

  $= 0$ kN



Gambar 3.12 *Gambar Bidang D (Gaya Lintang) Batang A - D*

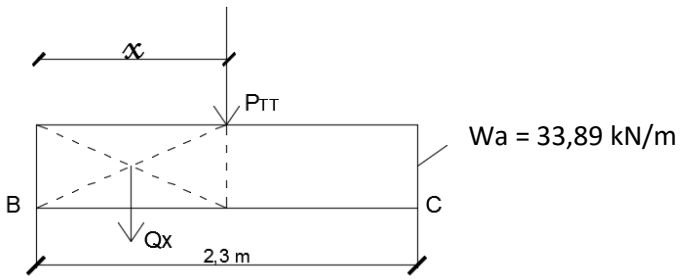
2. Gaya Lintang pada Batang B → C



- D_B $= R_{BV}$

  $= 108,97$ kN

➢ Ditinjau dari titik sejarak x di kanan B ($0 \leq x \leq 1{,}15$)



Qx = Wa . x

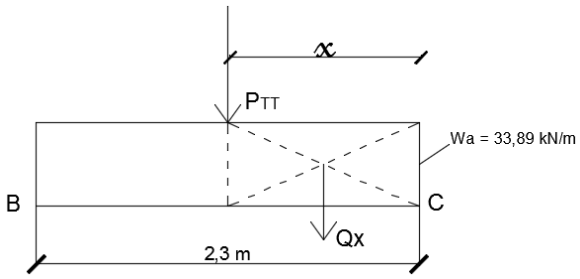
= 33,89 x

Dx = D_B - Qx

Dx = 108,97 – 33,89x ⟶ Persamaan linear (garis lurus)

Untuk x = 0,00 ⟶ Dx = D_B = 108,97 kN
x = 0,23 ⟶ Dx = 108,97 – 33,89 . 0,23 = 101,18 kN
x = 0,46 ⟶ Dx = 108,97 – 33,89 . 0,46 = 93,38 kN
x = 0,69 ⟶ Dx = 108,97 – 33,89 . 0,69 = 85,59 kN
x = 0,92 ⟶ Dx = 108,97 – 33,89 . 0,92 = 77,79 kN
x = 1,15 ⟶ Dx = 108,97 – 33,89 . 1,15 = 69,10 kN

➢ Ditinjau dari titik sejarak x di kiri C ($1{,}15 \leq x \leq 2{,}3$)



Dx = D_B - Qx - P_{TT}

= 108,97 – 33,89 . x – 140

Dx = – 31,03 – 33,89x ⟶ Persamaan linear (garis lurus)

Untuk x = 1,15 ⟶ Dx = – 31,03 – 33,89 . 1,15 = - 70,00 kN
x = 1,38 ⟶ Dx = – 31,03 – 33,89 . 1,38 = - 77,89 kN
x = 0,46 ⟶ Dx = – 31,03 – 33,89 . 1,61 = - 85,59 kN

x = 0,69 ⟶ Dx = – 31,03 – 33,89 . 1,84 = - 93,38 kN
x = 0,92 ⟶ Dx = – 31,03 – 33,89 . 2,07 = - 101,18 kN
x = 1,15 ⟶ Dx = – 31,03 – 33,89 . 2,3 = - 108,97 kN

- D_C kiri = $R_{BV} – P_{TT}$ - Q

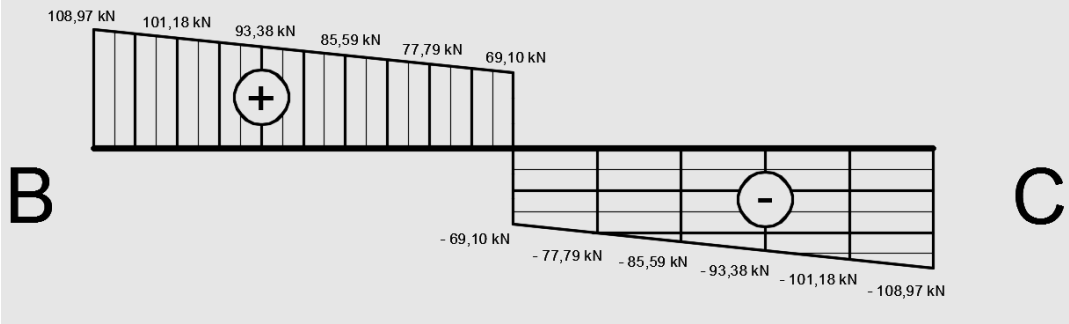
  = 108,97 - 140 - (33,89 x 2,3)

  = - 108,97 kN

- D_C kanan = D_C kiri + R_{CV}

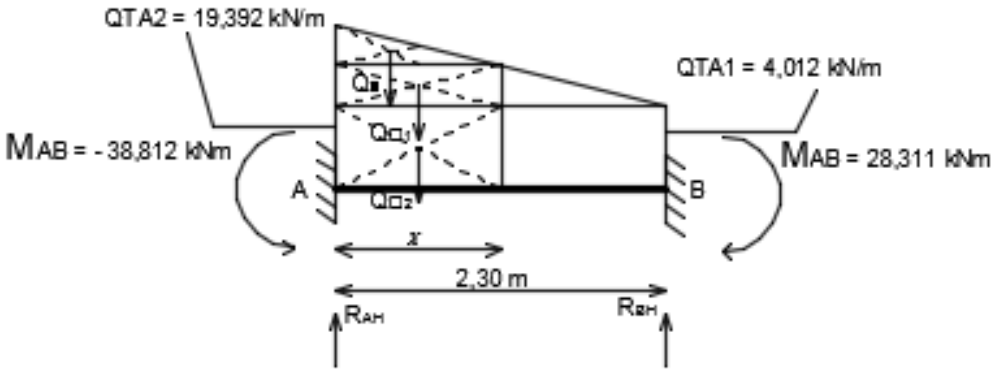
  = - 108,97 + 108,97

  = 0 kN



Gambar 3.12 *Gambar Bidang D (Gaya Lintang) Batang B – C*

3. Gaya Lintang pada Batang A ⟶ B



- D_A = R_{AH}

  = 20,968 kN

- Ditinjau dari titik sejarak *x* di kanan A ($0 \leq x \leq 2{,}3$)

$$q_x = \frac{(19{,}392-4{,}012)\ (2{,}3-x)}{2{,}3}$$

$$= \frac{15{,}38\ (2{,}3-x)}{2{,}3}$$

$$= 15{,}38 - 6{,}687\ x$$

$$\text{Qx } \Delta = \frac{1}{2}\ x\ q_x\ x\ l$$

$$= \frac{1}{2}\ .\ (15{,}38 - (15{,}38 - 6{,}687\ x)).\ x$$

$$= 3{,}344\ x^2$$

$$\text{Qx } \square 1 = (15{,}38 - 6{,}687\ x)\ x$$

$$= 15{,}38\ x - 6{,}687\ x^2$$

$$\text{Qx } \square 2 = Q_{TA1}\ .\ l$$

$$= 4{,}012\ .\ x$$

$$\text{Dx} = D_A - \text{Qx } \Delta - \text{Qx } \square 1 - \text{Qx } \square 2$$

$$= 20{,}968 - 3{,}344\ x^2 - 15{,}38\ x - 6{,}687\ x^2 - 4{,}012\ x$$

$$\mathbf{Dx = 20{,}968 - 19{,}392\ x + 3{,}343\ x^2}$$

Untuk x = 0,00 ⟶ Dx = 20,968 – 19,392 . 0 + 3,343 . 0^2

= 20,968 – 0 – 0

= 20,968 kN

x = 0,46 ⟶ Dx = 20,968 – 19,392 . 0,46 + 3,343 . $0{,}46^2$

= 20,968 – 8,92 + 0,707

= 12,755 kN

x = 0,92 ⟶ Dx = 20,968 – 19,392 . 0,92 + 3,343 . $0{,}92^2$

= 20,968 – 17,841 – 2,83

= 5,957 kN

$x = 1{,}38 \rightarrow Dx = 20{,}968 - 19{,}392 \cdot 1{,}38 + 3{,}343 \cdot 1{,}38^2$

$= 20{,}968 - 26{,}761 - 6{,}366$

$= 0{,}573$ kN

$x = 1{,}84 \rightarrow Dx = 20{,}968 - 19{,}392 \cdot 1{,}84 + 3{,}343 \cdot 1{,}84^2$

$= 20{,}968 - 35{,}681 - 11{,}318$

$= -3{,}395$ kN

$x = 2{,}3 \rightarrow Dx = 20{,}968 - 19{,}392 \cdot 2{,}3 + 3{,}343 \cdot 2{,}3^2$

$= 20{,}968 - 44{,}6 + 17{,}685$

$= -5{,}947$ kN

- D_B atas $= D_A - Q1 - Q2$

$= 20{,}968 - (Q_{TA1} \times 2{,}3) - (0{,}5 \times 2{,}3\ [Q_{TA2} - Q_{TA1}])$

$= 20{,}968 - (4{,}012 \times 2{,}3) - (0{,}5 \times 2{,}3\ [19{,}392 - 4{,}012])$

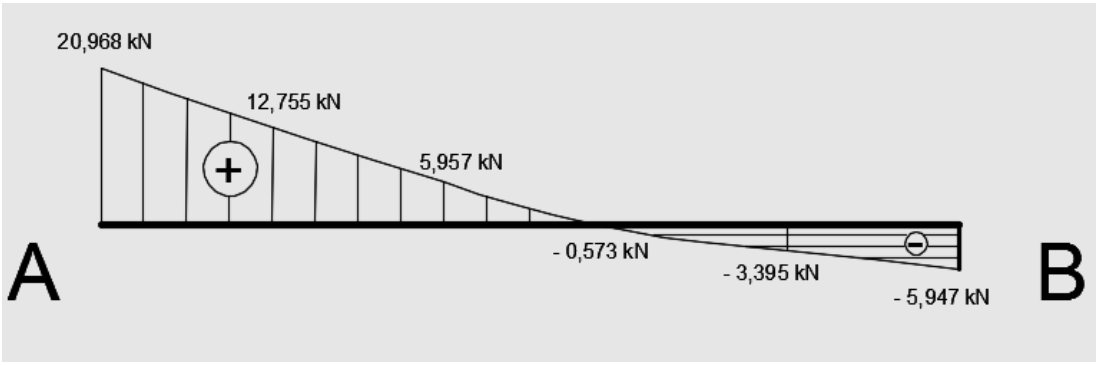
$= 20{,}968 - 9{,}228 - 17{,}687$

$= -20{,}968$ kN

- D_B bawah $= D_A$ atas $+ R_{AH}$

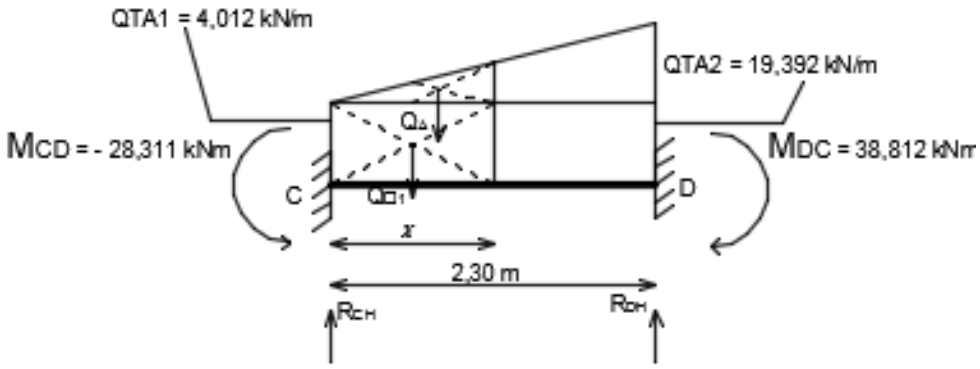
$= -20{,}968 + 20{,}968$

$= 0$ kN



Gambar 3.13 *Gambar Bidang D (Gaya Lintang) Batang A – B*

4. Gaya Lintang pada Batang C → D



- D_C = R_{CH}

  = 5,947 kN

➢ Ditinjau dari titik sejarak *x* di kanan C ($0 \leq x \leq 2{,}3$)

$q_x\Delta = \frac{(19{,}392-4{,}012)\,.\,x}{2{,}3}$

$= 6{,}687\,x$

$Qx\,\Delta = \frac{1}{2}\,x\,q_{x\Delta}\,x\,l$

$= \frac{1}{2}\,.\,6{,}687\,x\,.\,x$

$= 3{,}344\,x^2$

Qx □ = 4,012 *x*

Dx = D_C - Qx Δ - Qx □

Dx = 5,947 - 3,344 x^2 - 4,012 *x*

Untuk x = 0,00 ⟶ Dx = 5,947 – 3,344 . 0^2 – 4,012 . 0

= 5,947 – 0 – 0

= 5,947 kN

$$x = 0{,}46 \rightarrow Dx = 5{,}947 - 3{,}344 \cdot 0{,}46^2 - 4{,}012 \cdot 0{,}46$$

$$= 5{,}947 - 0{,}707 - 1{,}845$$

$$= 3{,}395 \text{ kN}$$

$$x = 0{,}92 \rightarrow Dx = 5{,}947 - 3{,}344 \cdot 0{,}92^2 - 4{,}012 \cdot 0{,}92$$

$$= 5{,}947 - 2{,}83 - 3{,}69$$

$$= - 0{,}573 \text{ kN}$$

$$x = 1{,}38 \rightarrow Dx = 5{,}947 - 3{,}344 \cdot 1{,}38^2 - 4{,}012 \cdot 1{,}38$$

$$= 5{,}947 - 6{,}368 - 5{,}536$$

$$= - 5{,}957 \text{ kN}$$

$$x = 1{,}84 \rightarrow Dx = 5{,}947 - 3{,}344 \cdot 1{,}84^2 - 4{,}012 \cdot 1{,}84$$

$$= 5{,}947 - 11{,}321 - 7{,}381$$

$$= - 12{,}755 \text{ kN}$$

$$x = 2{,}3 \rightarrow Dx = 5{,}947 - 3{,}344 \cdot 2{,}3^2 - 4{,}012 \cdot 2{,}3$$

$$= 5{,}947 - 17{,}687 - 9{,}228$$

$$= - 20{,}968 \text{ kN}$$

- D_D atas $= D_C - Q1 - Q2$

  $= 5{,}947 - (Q_{TA1} \times 2{,}3) - (0{,}5 \times 2{,}3\ [Q_{TA2} - Q_{TA1}])$

  $= 5{,}947 - (4{,}012 \times 2{,}3) - (0{,}5 \times 2{,}3\ [19{,}392 - 4{,}012])$

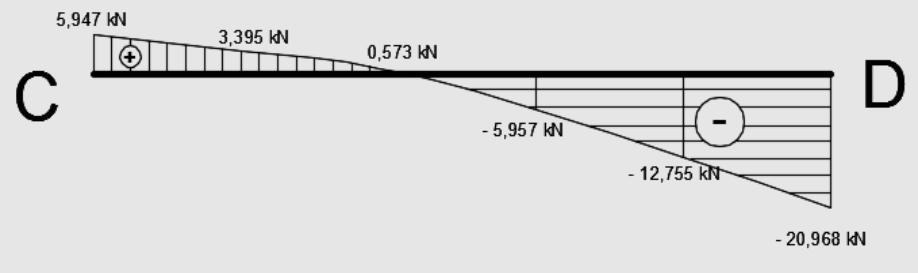
  $= 5{,}947 - 9{,}228 - 17{,}687$

  $= - 20{,}968$ kN

- D_D bawah $= D_D$ atas $+ R_{DH}$

  $= -20{,}968 + 20{,}968$

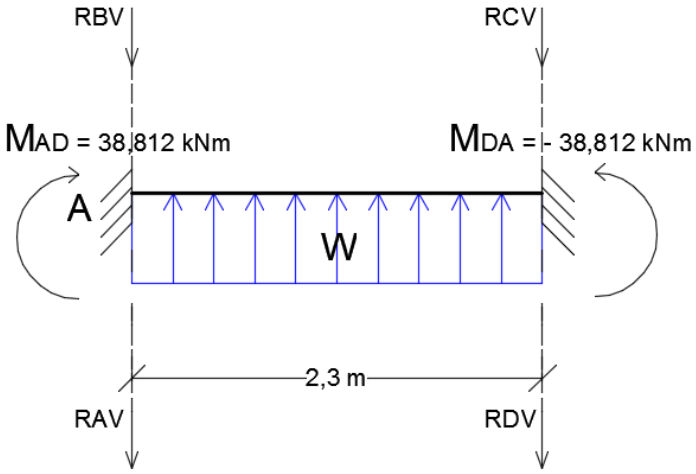
  $= 0$ kN



Gambar 3.14 *Gambar Bidang D (Gaya Lintang) Batang C – D*

3.3.6 Menghitung Momen (Bidang M)

1. Momen pada Batang A ⟶ D



- $M_A = M_{AD}$

  $= 38{,}812$ kNm

➢ Ditinjau dari titik sejarak *x* di kanan A ($0 \leq x \leq 2{,}3$)

$Mx = M_{AD} - R_{AV} \cdot x - R_{BV} \cdot x - \frac{1}{2} \cdot W \cdot x \cdot x$

$= 38{,}812 - 70{,}35x - 108{,}97x + \frac{1}{2} \cdot 155{,}93\, x^2$

$= \mathbf{38{,}812 - 179{,}32x + 77{,}965\, x^2}$

Untuk $x = 0{,}00 \longrightarrow Mx = 38{,}812 - 179{,}32 \cdot 0 + 77{,}965 \cdot 0{,}00^2$

$= 38{,}812 - 0 - 0$

$= 38{,}812$ kNm

x = 0,46 ⟶ Mx = 38,812 – 179,32 . 0,46 + 77,965 . $0,46^2$

= 38,812 – 82,487 + 16,497

= - 27,178 kNm

x = 0,92 ⟶ Mx = 38,812 – 179,32 . 0,92 + 77,965 . $0,92^2$

= 38,812 – 164,974 – 65,99

= - 60,172 kNm

x = 1,15 ⟶ Mx = 38,812 – 179,32 . 1,15 + 77,965 . $1,15^2$

= 38,812 – 206,218 – 103,109

= - 64,297 kNm

x = 1,38 ⟶ Mx = 38,812 – 179,32 . 1,38 + 77,965 . $1,38^2$

= 38,812 – 247,462 + 148,478

= - 60,172 kNm

x = 1,84 ⟶ Mx = 38,812 – 179,32 . 1,84 + 77,965 . $1,84^2$

= 38,812 – 329,949 + 263,958

= - 27,178 kNm

x = 2,3 ⟶ Mx = 38,812 – 179,32 . 2,3 + 77,965 . $2,3^2$

= 38,812 – 412,436 + 412,436

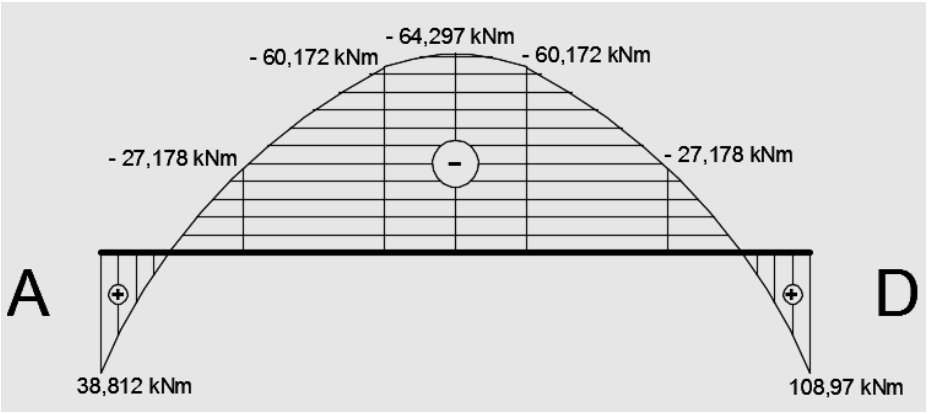
= - 38,812 kNm

- M_D = M_{AD} – R_{AV} . 2,3 – R_{BV} . 2,3 + Q . 1,15

= 38,812 – 70,35 . 2,3 – 108,97 . 2,3 + (155,93 x 2,3) . 1,15

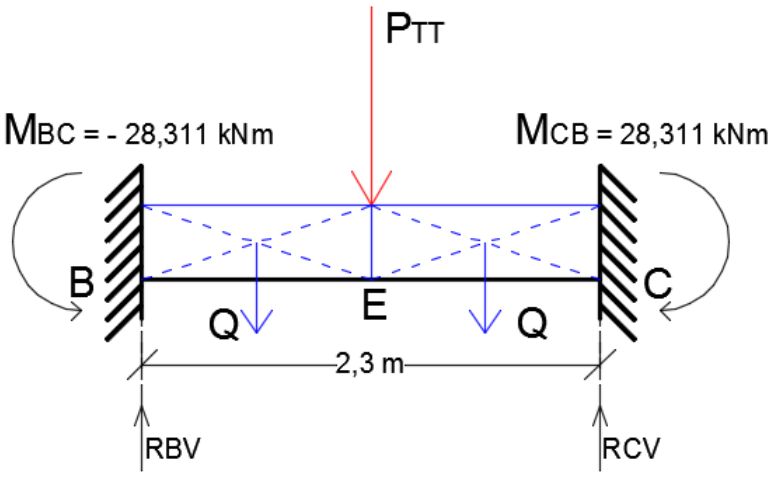
= 38,812 – 161,805 - 250,631 + 412,435

= – 38,812 kNm



Gambar 3.15 *Gambar Bidang M (Momen) Batang A – D*

2. Momen pada Batang B → C



- $M_B = M_{BC}$

  $= -28{,}311$ kNm

➢ $M_E = M_{BC} + R_{BV} \cdot 1{,}15 - Q \cdot 0{,}575$

$= -28{,}311 + 108{,}97 \cdot 1{,}15 - (33{,}89 \cdot 2{,}3) \cdot 0{,}575$

$= -28{,}311 + 125{,}316 - 44{,}82$

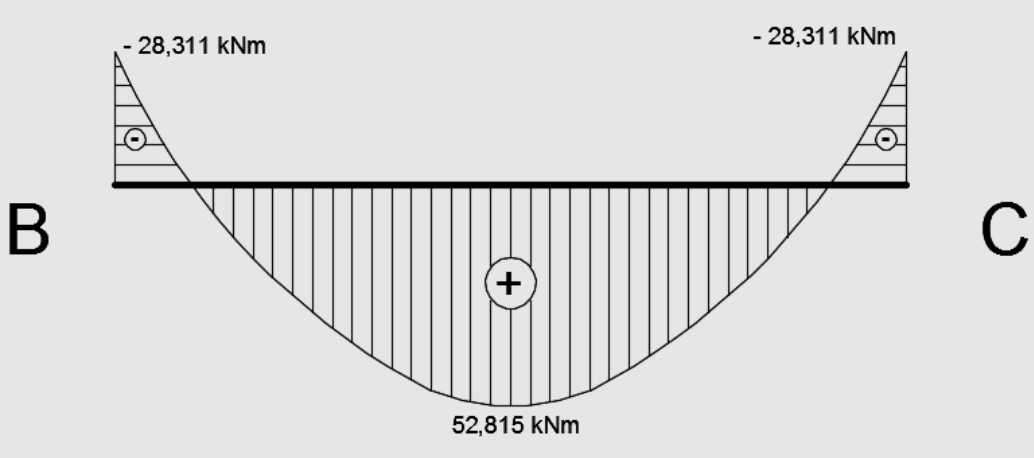
$= 52{,}815$ kNm

- M_C = $M_{BC} + R_{BV} . 2,3 – P_{TT} . 1,15 - Q . 1,15$

  = - 28,311 + 108,97 . 2,3 - 140 . 1,15 - (33,89 x 2,3) . 1,15

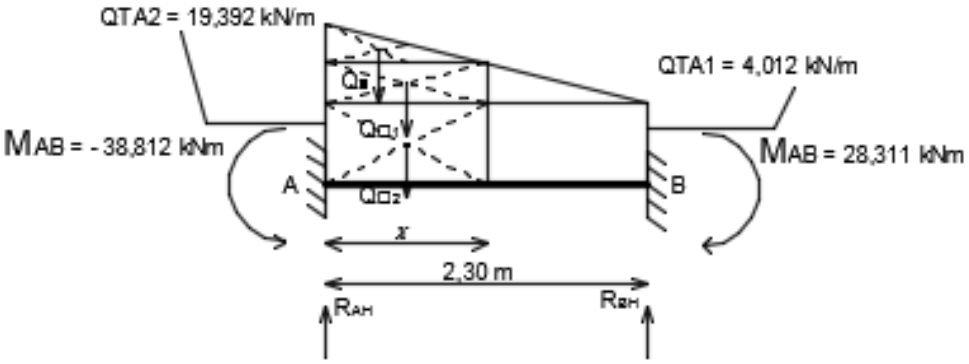
  = - 28,311 + 250,631 - 161 – 89,639

  = - 28,311 kNm



Gambar 3.16 *Gambar Bidang M (Momen) Batang A – D*

3. Momen pada Batang A → B



- M_A = M_{AB}

  = - 38,812 kNm

➢ Ditinjau dari titik sejarak *x* di kanan A ($0 \leq x \leq 2,3$)

$$q_x = \frac{(19{,}392-4{,}012)\,(2{,}3-x)}{2{,}3}$$

$$= \frac{15{,}38\,(2{,}3-x)}{2{,}3}$$

$$= 15{,}38 - 6{,}687\,x$$

$$\text{Qx }\Delta = \frac{1}{2} \,.\, q_x \,.\, l \,.\, \frac{2}{3} \,.\, x$$

$$= \frac{1}{2} \,.\, [(15{,}38 - (15{,}38 - 6{,}687\,x)] \,.\, x \,.\, \frac{2}{3} \,.\, x$$

$$= 2{,}229\,x^3$$

$$\text{Qx }\square 1 = q_x \,.\, x \,.\, 0{,}5 \,.\, x$$

$$= 15{,}38 - 6{,}687\,x \,.\, x \,.\, 0{,}5 \,.\, x$$

$$= 7{,}69\,x^2 - 3{,}344\,x^3$$

$$\text{Qx }\square 2 = Q_{TA1} \,.\, x \,.\, 0{,}5 \,.\, x$$

$$= 4{,}012\,x \,.\, 0{,}5 \,.\, x$$

$$= 2{,}006\,x^2$$

$$\text{Mx} = M_{AB} + R_{AH} \,.\, x - \text{Qx }\Delta - \text{Qx }\square 1 - \text{Qx }\square 2$$

$$= -38{,}812 + 20{,}968x - 2{,}229\,x^3 - 7{,}69\,x^2 + 3{,}344\,x^3 - 2{,}006\,x^2$$

$$= \mathbf{1{,}115x^3 - 9{,}696\,x^2 + 20{,}968x - 38{,}812}$$

Untuk $x = 0{,}00 \rightarrow Mx = 1{,}115 . 0^3 - 9{,}696 . 0^2 + 20{,}968 . 0 - 38{,}812$

$= 0 - 0 + 0 - 38{,}812$

$= -38{,}812$ kNm

$x = 0{,}46 \rightarrow Mx = 1{,}115 . 0{,}46^3 - 9{,}696 . 0{,}46^2 + 20{,}968 . 0{,}46 - 38{,}812$

$= 0{,}109 - 2{,}052 + 9{,}645 - 38{,}812$

$= -31{,}11$ kNm

$x = 0{,}92 \rightarrow Mx = 1{,}115 . 92^3 - 9{,}696 . 0{,}92^2 + 20{,}968 . 0{,}92 - 38{,}812$

$= 0{,}868 - 8{,}207 + 19{,}291 - 38{,}812$

$= -26{,}86$ kNm

$x = 1{,}15 \rightarrow Mx = 1{,}115.1{,}15^3 - 9{,}696 . 1{,}15^2 + 20{,}968 . 1{,}15 - 38{,}812$

$= 1{,}696 - 12{,}823 + 24{,}113 - 38{,}812$

$= -25{,}826$ kNm

$x = 1{,}38 \rightarrow Mx = 1{,}115.1{,}38^3 - 9{,}696 . 1{,}38^2 + 20{,}968 . 1{,}38 - 38{,}812$

$= 2{,}93 - 18{,}465 + 28{,}936 - 38{,}812$

$= -25{,}411$ kNm

$x = 1{,}84 \rightarrow Mx = 1{,}115.1{,}84^3 - 9{,}696 . 1{,}84^2 + 20{,}968 . 1{,}84 - 38{,}812$

$= 6{,}946 - 32{,}827 + 38{,}581 - 38{,}812$

$= -26{,}112$ kNm

$x = 2{,}3 \rightarrow Mx = 1{,}115.2{,}3^3 - 9{,}696 . 2{,}3^2 + 20{,}968 . 2{,}3 - 38{,}812$

$= 13{,}566 - 51{,}292 + 48{,}226 - 38{,}811$

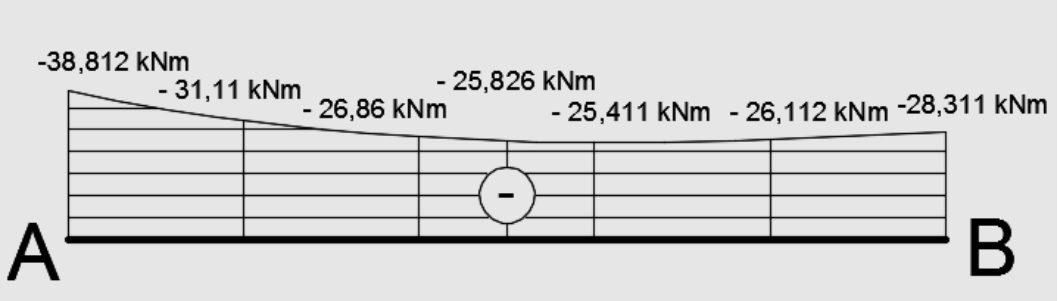
$= -28{,}311$ kNm

- $M_B = M_{AB} + R_{AH} . 2{,}3 - Q1 . 1{,}15 - Q2 . 1{,}533$

  $= -38{,}812 + (20{,}968 . 2{,}3) - (9{,}228 . 1{,}15) - (17{,}687 . 1{,}533)$

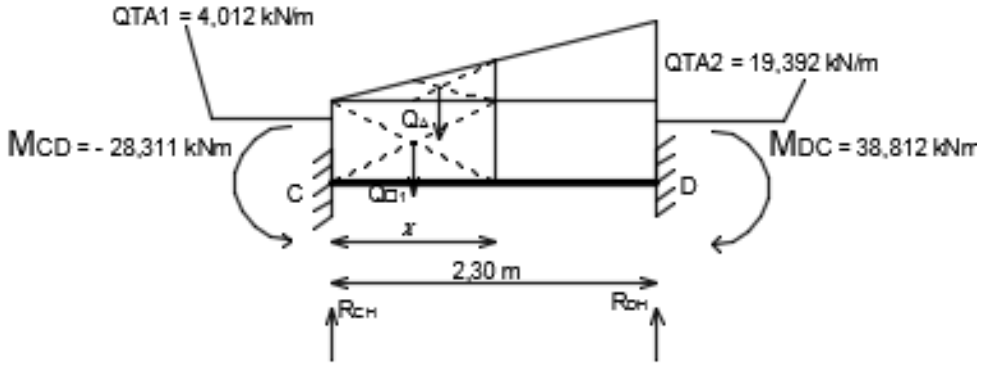
  $= -38{,}812 + 48{,}226 - 10{,}612 - 27{,}113$

  $= -28{,}311$ kNm



Gambar 3.17 *Gambar Bidang M (Momen) Batang A – B*

4. Momen pada Batang C → D



- $M_C = M_{CD}$

  $= -28{,}311$ kNm

➢ Ditinjau dari titik sejarak *x* di kanan C ($0 \leq x \leq 2{,}3$)

$$q_x = \frac{(19{,}392-4{,}012)\,.\,x}{l}$$

$$= \frac{15{,}38\,.\,x}{2{,}3}$$

$$= 6{,}687\,x$$

$$Qx\,\Delta = \frac{1}{2}\,.\,q_x\,.\,l\,.\frac{1}{3}\,.x$$

$$= \frac{1}{2}\,.\,6{,}687x\,.\,x\,.\frac{1}{3}\,.x$$

$$= 1{,}115\,x^3$$

$$Qx\,\square = Q_{TA1}\,.\,x\,.\,0{,}5\,.\,x$$

$$= 4{,}012\,x\,.\,0{,}5\,.\,x$$

$$= 2{,}006\,x^2$$

$$Mx = M_{CD} + R_{CH}\,.\,x - Qx\,\Delta - Qx\,\square$$

$$= \mathbf{-28{,}311 + 5{,}947\,x - 1{,}115\,x^3 - 2{,}006\,x^2}$$

Untuk x = 0,00 → $Mx = -28{,}311 + 5{,}947\,.\,0 - 1{,}115\,0^3 - 2{,}006\,0^2$

$$= -28{,}311 + 0 - 0 - 0$$

$= -28{,}311$ kNm

$x = 0{,}46 \rightarrow Mx = -28{,}311 + 5{,}947 \cdot 0{,}46 - 1{,}115\ 0{,}46^3 - 2{,}006\ 0{,}46^2$

$= -28{,}311 + 2{,}736 - 0{,}11 - 0{,}425$

$= -26{,}112$ kNm

$x = 0{,}92 \rightarrow Mx = -28{,}311 + 5{,}947 \cdot 0{,}92 - 1{,}115 \cdot 0{,}92^3 - 2{,}006 \cdot 0{,}92^2$

$= -28{,}311 + 5{,}47 - 0{,}87 - 1{,}7$

$= -25{,}411$ kNm

$x = 1{,}15 \rightarrow Mx = -28{,}311 + 5{,}947 \cdot 1{,}15 - 1{,}115\ 1{,}15^3 - 2{,}006\ 1{,}15^2$

$= -28{,}311 + 6{,}83 - 1{,}696 - 2{,}65$

$= -25{,}826$ kNm

$x = 1{,}38 \rightarrow Mx = -28{,}311 + 5{,}947 \cdot 1{,}38 - 1{,}115\ 1{,}38^3 - 2{,}006\ 1{,}38^2$

$= -28{,}311 + 8{,}2 - 2{,}93 - 3{,}82$

$= -26{,}86$ kNm

$x = 1{,}84 \rightarrow Mx = -28{,}311 + 5{,}947 \cdot 1{,}84 - 1{,}115\ 1{,}84^3 - 2{,}006\ 1{,}84^2$

$= -28{,}311 + 10{,}94 - 6{,}946 - 6{,}792$

$= -31{,}11$ kNm

$x = 2{,}3 \rightarrow Mx = -28{,}311 + 5{,}947 \cdot 2{,}3 - 1{,}115\ 2{,}3^3 - 2{,}006\ 2{,}3^2$

$= -28{,}311 + 13{,}678 - 13{,}566 - 10{,}612$

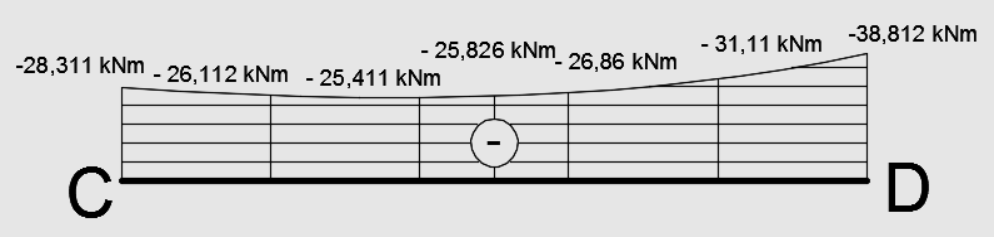
$= -38{,}812$ kNm

- $M_D = M_{CD} + R_{CH} \cdot 2{,}3 - Q1 \cdot 1{,}15 - Q2 \cdot 0{,}767$

  $= -28{,}311 + (5{,}947 \cdot 2{,}3) - (9{,}228 \cdot 1{,}15) - (17{,}687 \cdot 0{,}767)$

  $= -28{,}311 + 13{,}678 - 10{,}612 - 13{,}566$

  $= -38{,}811$ kNm



Gambar 3.18 *Gambar Bidang M (Momen) Batang C – D*

3.3.7 Menghitung Gaya Normal (Bidang N)

1. Gaya Normal pada Batang A → D

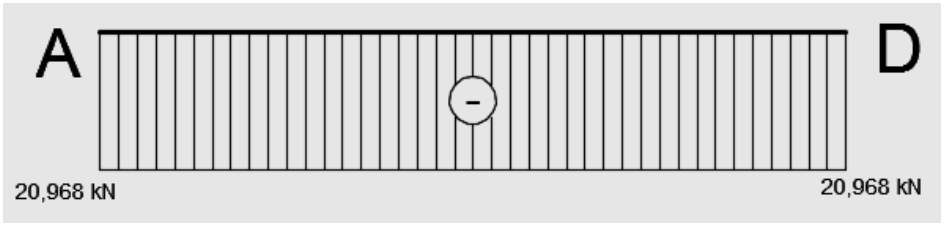
- $N_A = R_{AH'}$

  $= - 20{,}968$ kN

- $N_D = N_A - R_{DH'}$

  $= - 20{,}968 + 20{,}968$

  $= 0$ kN



Gambar 3.19 *Gambar Bidang N (Gaya Normal) Batang A – D*

2. Gaya Normal pada Batang B → C

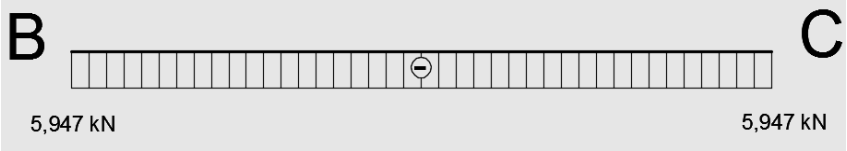
- $N_B = R_{BH'}$

  $= - 5{,}947$ kN

- $N_C = N_B - R_{CH'}$

  $= - 5{,}947 + 5{,}947$

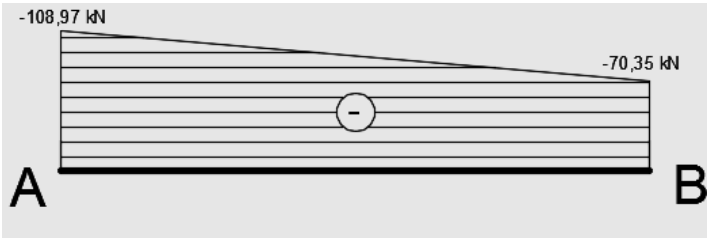
  $= 0$ kN



Gambar 3.20 *Gambar Bidang N (Gaya Normal) Batang B – C*

3. Gaya Normal pada Batang A → B

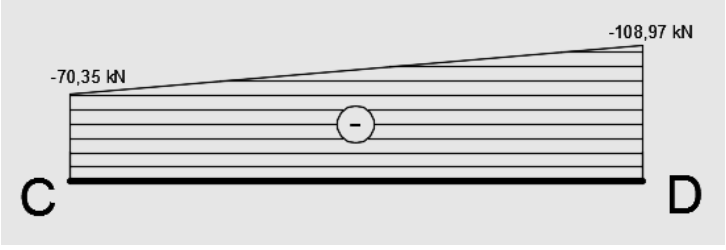
- N_A = - R_{AV}
  = - 70,35 kN
- N_B = R_{BV}
  = - 108,97 kN



Gambar 3.21 *Gambar Bidang N (Gaya Normal) Batang A – B*

4. Gaya Normal pada Batang C → D

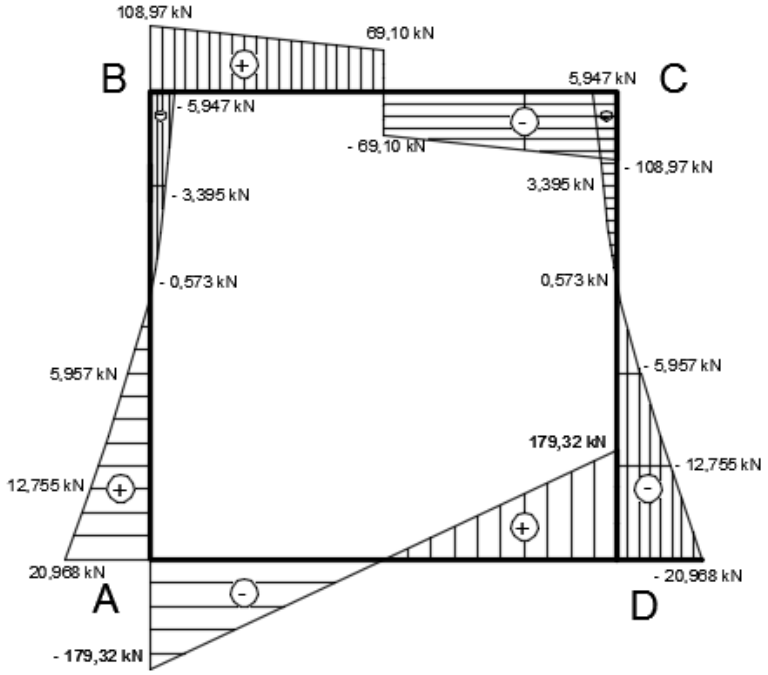
- N_C = - R_{CV}
  = - 108,97 kN
- N_D = - R_{DV}
  = - 70,35 kN



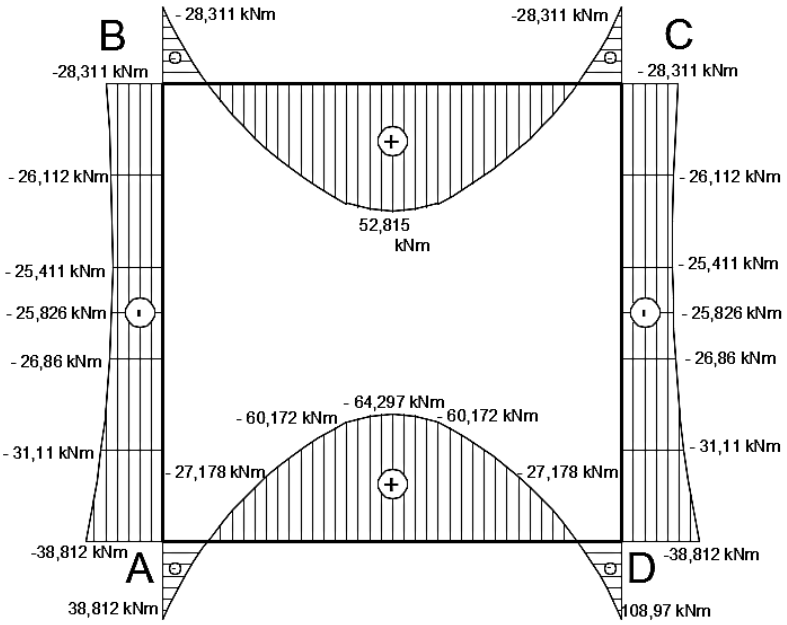
Gambar 3.22 *Gambar Bidang N (Gaya Normal) Batang C – D*

3.3.8 Gambar Bidang D, Bidang M, dan Bidang N

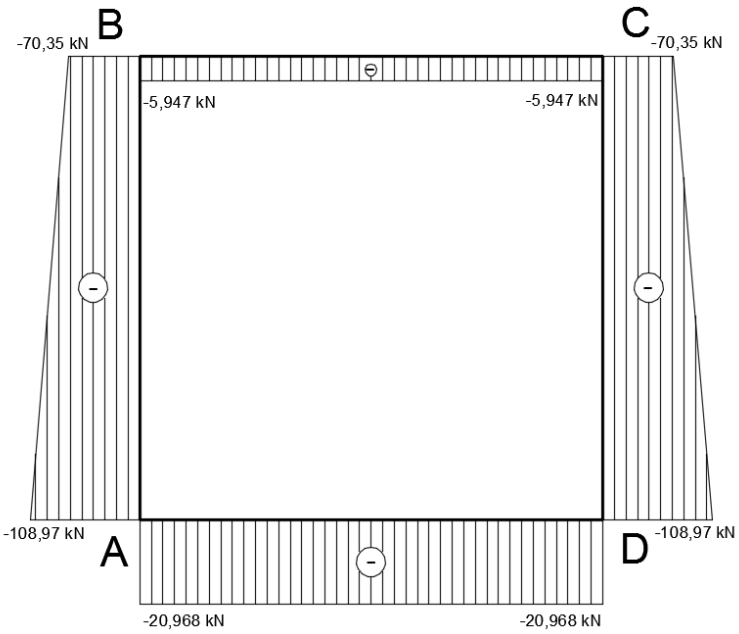
1. Gambar Bidang D (Gaya Lintang)



2. Gambar Bidang M (Momen)



3. Gambar Bidang N (Gaya Normal)



3.4 PERHITUNGAN PENULANGAN STRUKTUR BETON BOX CULVERT

3.4.1 Penulangan Plat Atas (Top Slab)

Diketahui :

- P ult = 5,947 Kn
- M ult = 52,81 kNm
- Fc’ = 20 Mpa
- Fy = 400 Mpa
- ρg = 2 %
- d ‘ = 58 mm

➢ Menghitung momen dan gaya aksial rencana :

P ult = 5,947 Kn

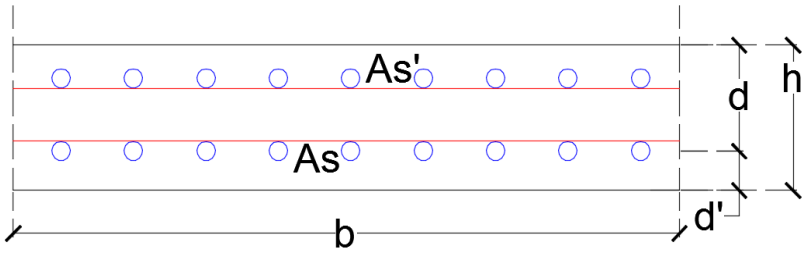
M ult = 52,815 kNm

e = $\frac{Mu}{Pu}$

$$= \frac{52{,}815\ (10^3)}{5{,}947}$$

$$= 8880{,}948 \text{ mm}$$

➢ Menentukan dimensi tulangan pokok top slab :



Menggunakan dimensi top slab 300 mm x 1000 mm, dengan jumlah penulangan 2 % dan tebal selimut beton efektif (d') = 58 mm.

$\rho = \rho' = \frac{As}{b\ .\ d} = 0{,}01 \rightarrow$ karena A_{st} = 2%, maka As = As' = $\frac{1}{2}$ x 2% = 1% = 0,01

- d = h - d'

  = 300 - 58

  = 242 mm

- As = As' = 0,01 . b . d

  = 0,01 x 1000 x 242

  = 2420 mm²

Dicoba menggunakan tulangan D16 – 250 mm (As = 2614 mm^2) tiap sisi plat

- $\rho = \rho' = \frac{As}{b\ .\ d}$

  $= \frac{2614}{1000\ x\ 242}$

  = 0,01 mm

➢ Pemeriksaan kondisi seimbang (P ub)

- Cb $= \frac{600\ (d)}{600+fy}$

  $= \frac{600\ (242)}{600+400}$

  = 145,2 mm

- $\beta 1$ = 0.81 → **ketentuan pasal 3.3.2 ayat 7 SK SNI T-15**

- αb $= \beta 1\ .\ Cb$

  = 0,81 x 145,2

  = 117,61 mm

- ε_s' $= \frac{(Cb-d')}{Cb}\ \varepsilon_{cu}$

  $= \frac{(145,2-58)}{145,2}$ (0,003)

  = 0,0018

  $\frac{fy}{Es}$ $= \frac{400}{200000}$

  = 0,002

ε_s' = 0,0018 < 0,002 → maka tulangan belum mencapai luluh saat beton hancur

- fs' $= Es\ .\ \varepsilon_s'$

  = 200000 x 0,0018

  = 360 Mpa

- P ub $= 0,65\ (0,85\ fc'\ \alpha b\ b + As\ fs' - As\ fy)$

  $= 0,65\ [0,85(20)(117,61)(1000)+(2614)(360) - (2614)(400)]$

  $= 0,65\ [1999370 + 941040 - 1045600] \times 10^{-3}$

  = 1231,63 kN

Persamaan Whitney untuk penampang persegi dengan hancur tekan :

$$Pn = \frac{As.fy}{\frac{e}{(d-d')}+0{,}50} + \frac{bh.fc}{\frac{3he}{d^2}+1{,}18}$$

$$= \frac{2614.\ 400}{\frac{8880{,}948}{(242-58)}+0{,}50} + \frac{300.1000.20}{\frac{3.300.8880{,}948}{242^2}+1{,}18}$$

= 21441,16 + 43585,44 = 65026,6 kN

$\phi Pn = 0{,}65\ Pn$

= 0,65 (65026,6)

= 42267,29 kN

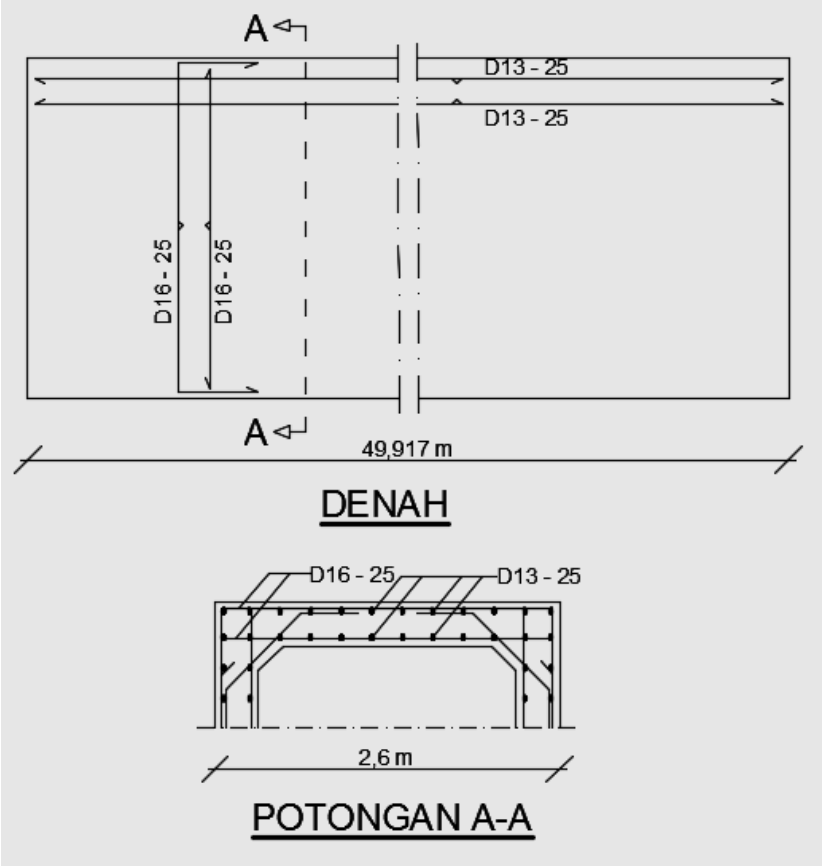
ϕPn = 42267,29 kN > Pu = 5,947 kN, maka top slab memenuhi syarat

- Merencanakan tulangan pembagi

Sesuai dengan ketentuan yang terdapat pada SK SNI-T-15-1991-03. Digunakan tulangan pembagi D13, dengan jarak spasi ditentukan dengan nilai terkecil dari :

a. 16 kali diameter tulangan pokok memanjang D16 = 16(16) ≈ 250 mm
b. 48 kali diameter tulangan sengkang D13 = 48(13) ≈ 620 mm
c. Dimensi terkecil (tebal plat) = 300 mm

Sehingga digunakan tulangan pembagi D13 dengan jarak 250 mm



Gambar 3.23 *Penulangan Top Slab*

3.4.2. Penulangan Plat Bawah (Bottom Slab)

Diketahui :

- P ult = 20,968 Kn
- M ult = 64,297 kNm
- Fc’ = 20 Mpa
- Fy = 400 Mpa
- ρg = 2 %
- d’ = 58 mm

➢ Menghitung momen dan gaya aksial rencana :

P ult = 20,968 Kn

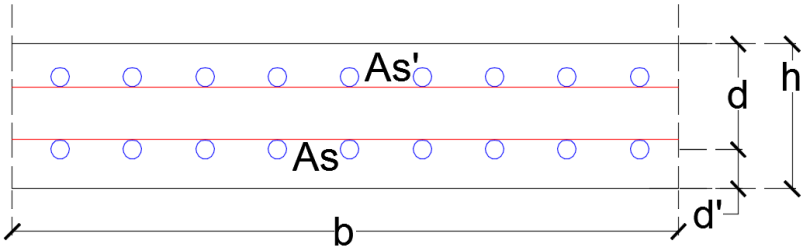
M ult = 64,297 kNm

e = $\frac{Mu}{Pu}$

= $\frac{64{,}297\ (10^3)}{20{,}968}$

= 3066,435 mm

➢ Menentukan dimensi tulangan pokok bottom slab :



Menggunakan dimensi tulangan bottom slab 300 mm x 1000 mm, dengan jumlah penulangan 2 % dan tebal selimut beton efektif (d') = 58 mm.

ρ = ρ' = $\frac{As}{b\ .\ d}$ = 0,01 ⟶ karena A_{st} = 2%, maka As = As' = $\frac{1}{2}$ x 2% = 1% = 0,01

- d = h - d'

  = 300 - 58

  = 242 mm

- As = As' = 0,01 . b . d

  = 0,01 x 1000 x 242

  = 2420 mm²

Dicoba menggunakan tulangan D16 – 250 mm (As = 2614 mm^2) tiap sisi plat

- ρ = ρ' = $\frac{As}{b\ .\ d}$

$= \frac{2614}{1000\ x\ 242}$

= 0,01 mm

- Pemeriksaan kondisi seimbang (P ub)

  - *Cb* $= \frac{600\ (d)}{600+fy}$

    $= \frac{600\ (242)}{600+400}$

    = 145,2 mm

  - β1 = 0.81 → **ketentuan pasal 3.3.2 ayat 7 SK SNI T-15**

  - αb = β1 . *Cb*

    = 0,81 x 145,2

    = 117,61 mm

  - ε_s' $= \frac{(Cb-d')}{Cb}\ \varepsilon_{cu}$

    $= \frac{(145,2-58)}{145,2}$ (0,003)

    = 0,0018

    $\frac{fy}{Es}$ $= \frac{400}{200000}$

    = 0,002

ε_s' = 0,0018 < 0,002 → maka tulangan belum mencapai luluh saat beton hancur

  - fs' = Es . ε_s'

    = 200000 x 0,0018

    = 360 Mpa

- P ub = 0,65 (0,85 fc' αb b + As fs' - As fy)

  = 0,65 [0,85(20)(117,61)(1000)+(2614)(360) - (2614)(400)]

  = 0,65 [1999370 + 941040 - 1045600] x 10^{-3}

  = 1231,63 kN

Persamaan Whitney untuk penampang persegi dengan hancur tekan :

$$Pn = \frac{As.fy}{\frac{e}{(d-d')}+0{,}50} + \frac{bh.fc}{\frac{3he}{d^2}+1{,}18}$$

$$= \frac{2614.\ 400}{\frac{3066{,}435}{(242-58)}+0{,}50} + \frac{300.1000.20}{\frac{3.300.3066{,}435}{242^2}+1{,}18}$$

= 60913,2 + 124212,37 = 185125,57 kN

ϕPn = 0,65 Pn

= 0,65 (185125,57)

= 120331,62 kN

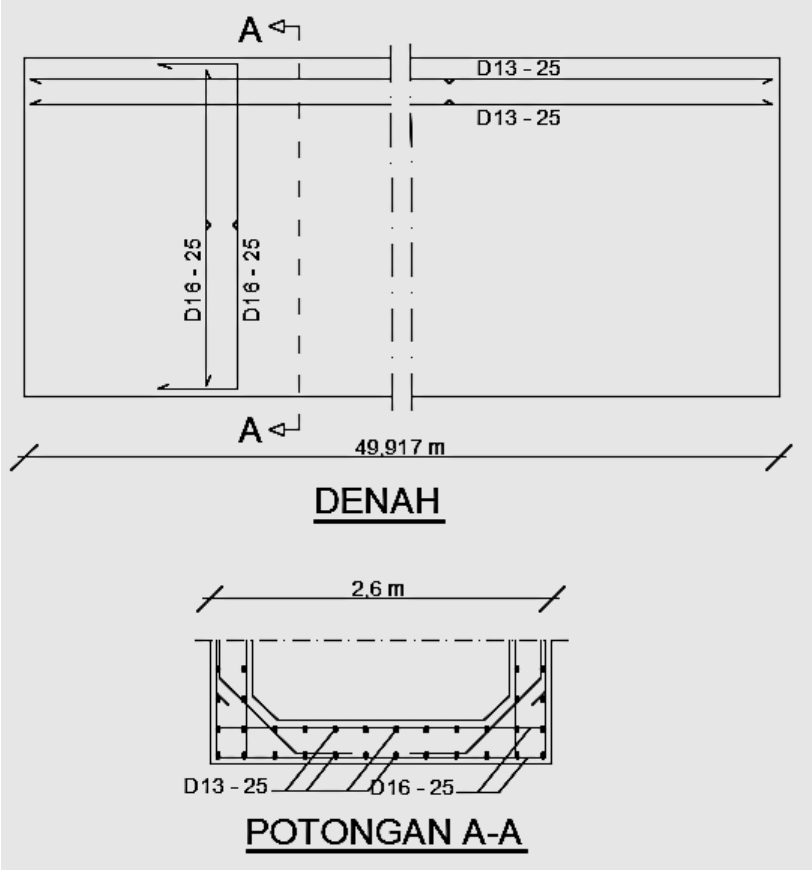
ϕPn = 120331,62 kN > Pu = 20,968 kN, maka bottom slab memenuhi syarat

- Merencanakan tulangan pembagi

Sesuai dengan ketentuan yang terdapat pada SK SNI-T-15-1991-03. Digunakan tulangan pembagi D13, dengan jarak spasi ditentukan dengan nilai terkecil dari :

a. 16 kali diameter tulangan pokok memanjang D16 = 16(16) ≈ 250 mm
b. 48 kali diameter tulangan sengkang D13 = 48(13) ≈ 620 mm
c. Dimensi terkecil (tebal plat) = 300 mm

   Sehingga digunakan tulangan pembagi D13 dengan jarak 250 mm



Gambar 3.24 *Penulangan Bottom Slab*

3.4.3. Penulangan Plat Dinding (Wall Slab)

Diketahui :

- P ult = 108,97 Kn
- M ult = 38,812 kNm
- Fc’ = 20 Mpa
- Fy = 400 Mpa
- ρg = 2 %
- d‘ = 58 mm

➢ Menghitung momen dan gaya aksial rencana :

P ult = 108,97 Kn

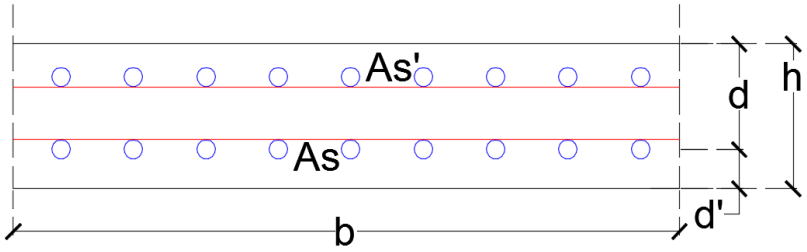
M ult = 38,812 kNm

$$e = \frac{Mu}{Pu}$$

$$= \frac{38{,}812\ (10^3)}{108{,}97}$$

$$= 356{,}171 \text{ mm}$$

➢ Menentukan dimensi tulangan pokok wall slab :



Menggunakan dimensi tulangan wall slab 300 mm x 1000 mm, dengan jumlah penulangan 2 % dan tebal selimut beton efektif (d') = 58 mm.

$\rho = \rho' = \frac{As}{b \,.\, d} = 0{,}01 \rightarrow$ karena A_{st} = 2%, maka As = As' = $\frac{1}{2}$ x 2% = 1% = 0,01

- d = h - d'

  = 300 - 58

  = 242 mm

- As = As' = 0,01 . b . d

  = 0,01 x 1000 x 242

  = 2420 mm²

Dicoba menggunakan tulangan D16 – 250 mm (As = 2614 mm^2) tiap sisi plat

- $\rho = \rho' = \frac{As}{b \,.\, d}$

  $= \frac{2614}{1000\ x\ 242}$

  = 0,01 mm

➢ Pemeriksaan kondisi seimbang (P ub)

- Cb $= \frac{600\ (d)}{600+fy}$

  $= \frac{600\ (242)}{600+400}$

  = 145,2 mm

- $\beta 1$ = 0.81 → **ketentuan pasal 3.3.2 ayat 7 SK SNI T-15**

- αb $= \beta 1\ .\ Cb$

  = 0,81 x 145,2

  = 117,61 mm

- ε_s' $= \frac{(Cb-d')}{Cb}\ \varepsilon_{cu}$

  $= \frac{(145,2-58)}{145,2}$ (0,003)

  = 0,0018

  $\frac{fy}{Es}$ $= \frac{400}{200000}$

  = 0,002

ε_s' = 0,0018 < 0,002 → maka tulangan belum mencapai luluh saat beton hancur

- fs' $= Es\ .\ \varepsilon_s'$

  = 200000 x 0,0018

  = 360 Mpa

- P ub $= 0,65\ (0,85\ fc'\ \alpha b\ b + As\ fs' - As\ fy)$

  $= 0,65\ [0,85(20)(117,61)(1000)+(2614)(360) - (2614)(400)]$

  $= 0,65\ [1999370 + 941040 - 1045600] \times 10^{-3}$

  = 1231,63 kN

Persamaan Whitney untuk penampang persegi dengan hancur tekan :

$$Pn = \frac{As.fy}{\frac{e}{(d-d')}+0{,}50} + \frac{bh.fc}{\frac{3he}{d^2}+1{,}18}$$

$$= \frac{2614.400}{\frac{356{,}171}{(242-58)}+0{,}50} + \frac{300.1000.20}{\frac{3.300.356{,}171}{242^2}+1{,}18}$$

$$= 429279 + 901772{,}12 = 1331051{,}12 \text{ kN}$$

$$\phi Pn = 0{,}65\ Pn$$

$$= 0{,}65\ (1331051{,}12)$$

$$= 865183{,}23 \text{ kN}$$

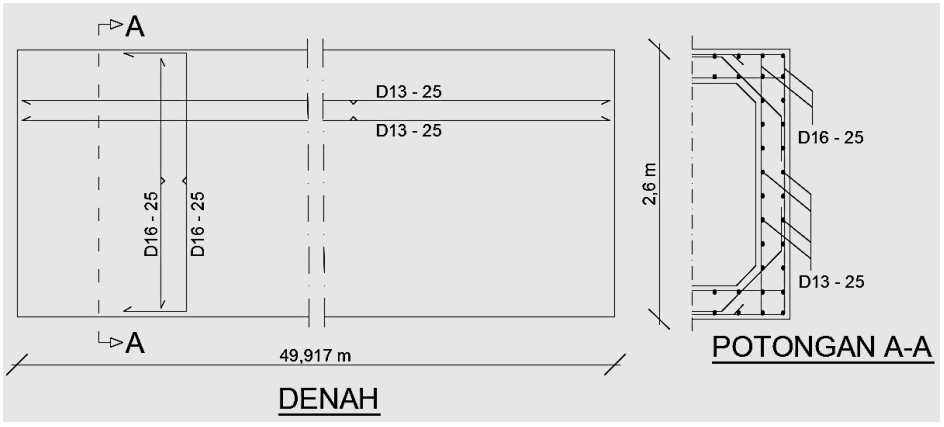
$\phi Pn = 865183{,}23$ kN > Pu = 108,97 kN, maka wall slab memenuhi syarat

- Merencanakan tulangan pembagi

Sesuai dengan ketentuan yang terdapat pada SK SNI-T-15-1991-03. Digunakan tulangan pembagi D13, dengan jarak spasi ditentukan dengan nilai terkecil dari :

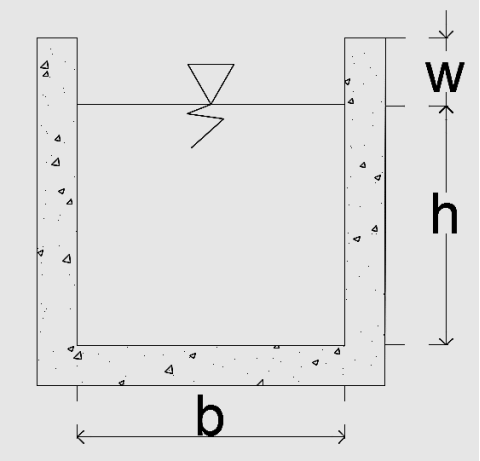
a. 16 kali diameter tulangan pokok memanjang D16 = 16(16) ≈ 250 mm
b. 48 kali diameter tulangan sengkang D13 = 48(13) ≈ 620 mm
c. Dimensi terkecil (tebal plat) = 300 mm

   Sehingga digunakan tulangan pembagi D13 dengan jarak 250 mm



Gambar 3.25 *Penulangan Wall Slab*

3.5 ANALISA KAPASITAS ALIRAN BOX CULVERT



Gambar 3.26 *Penampang Melintang Box Culvert*

Diketahui :

w = 0,2 m

h = 1,8 m

b = 2,0 m

- Menghitung luas penampang saluran box culvert (A)

$$A = b \,.\, h$$

$$A = 2 \,.\, 1{,}8$$

$$\mathbf{A = 3{,}6\ m^2}$$

- Menghitung keliling basah saluran (P)

$$P = b + 2\,.h$$

$$P = 2 + 2\,.1{,}8$$

$$\mathbf{P = 5{,}6\ m}$$

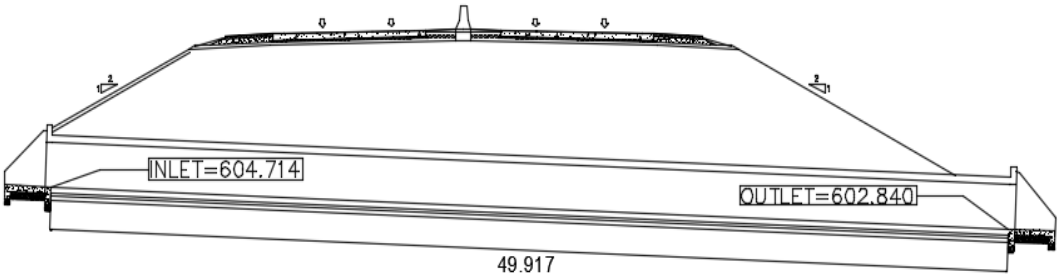
- Menghitung jari – jari hidrolis (R)

$$R = \frac{A}{P}$$

$$R = \frac{3{,}6\ m^2}{5{,}6\ m}$$

$$\mathbf{R = 0{,}643\ m}$$

- Menghitung kemiringan memanjang dasar saluran (I)



Gambar 3.27 *Penampang memanjang box culvert*

Diketahui :

Elevasi inlet (t1) = 604,714 m

Elevasi outlet (t2) = 602,840 m

Panjang saluran (L) = 49,917 m

$$I = \frac{t1 - t2}{L} \text{ x } 100\%$$

$$I = \frac{604{,}714 - 602{,}840}{49{,}917} \text{ x } 100\%$$

$$I = \frac{1{,}874}{49{,}917} \text{ x } 100\%$$

$$\mathbf{I = 0{,}0375\ \% = 0{,}000375}$$

- Menghitung kecepatan aliran dengan persamaan manning (V)

$$V = \frac{1}{n} .\ R^{2/3} .\ I^{1/2}$$

***Tabel 3.5** Harga Koefisien Kekasaran Manning*

Bahan	n
Kaca, plasitik, kuningan	0,010
Plesteran semen	0,011
Pipa pembuangan	0,013
Pipa pembuangan	0,013
Saluran beton	0,013
Kayu	0,011 – 0,014
Besi tuang dilapis	0,014
Batu bata	0,014
Bata dilapisi mortar	0,015
Saluran tanah bersih	0,022
Pasangan batu disemen	0,025
Saluran tanah	0,030
Saluran dengan dasar batu dan tebing rumput	0,040
Saluran pada galian batu padas	0,040

Dari tabel di atas diketahui bahwa harga koefisien kekasaran manning untuk saluran beton = 0,0013, maka kecepatan aliran box culvert adalah sebagai berikut:

$$V = \frac{1}{0{,}013} \cdot\ 0{,}643^{2/3} \cdot\ 0{,}000375^{1/2}$$

$$\mathbf{V = 1{,}102\ m/detik}$$

- <u>Menghitung debit saluran box culvert (Q)</u>

$$Q = V \cdot\ A$$

$$Q = 1{,}102 \cdot\ 3{,}6$$

$$\mathbf{Q = 3{,}97\ m^3/\ detik}$$

Jadi debit aliran box culvert yang dapat dilewatkan adalah sebesar

$$\mathbf{Q = 3{,}97\ m^3/\ detik}$$