MODUL – 4

LENTUR PADA BALOK PERSEGI
(Tulangan Rangkap)

CAPAIAN PEMBELAJARAN MATAKULIAH:

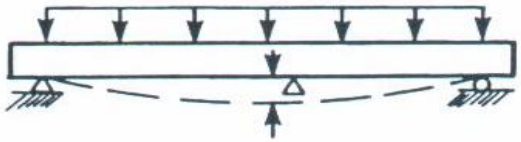
- **Mahasiswa mampu memahami momen nominal dan ultimit pada balok persegi**
- **Mahasiswa mampu menganalisis & mendesain balok bertulangan rangkap akibat momen lentur**

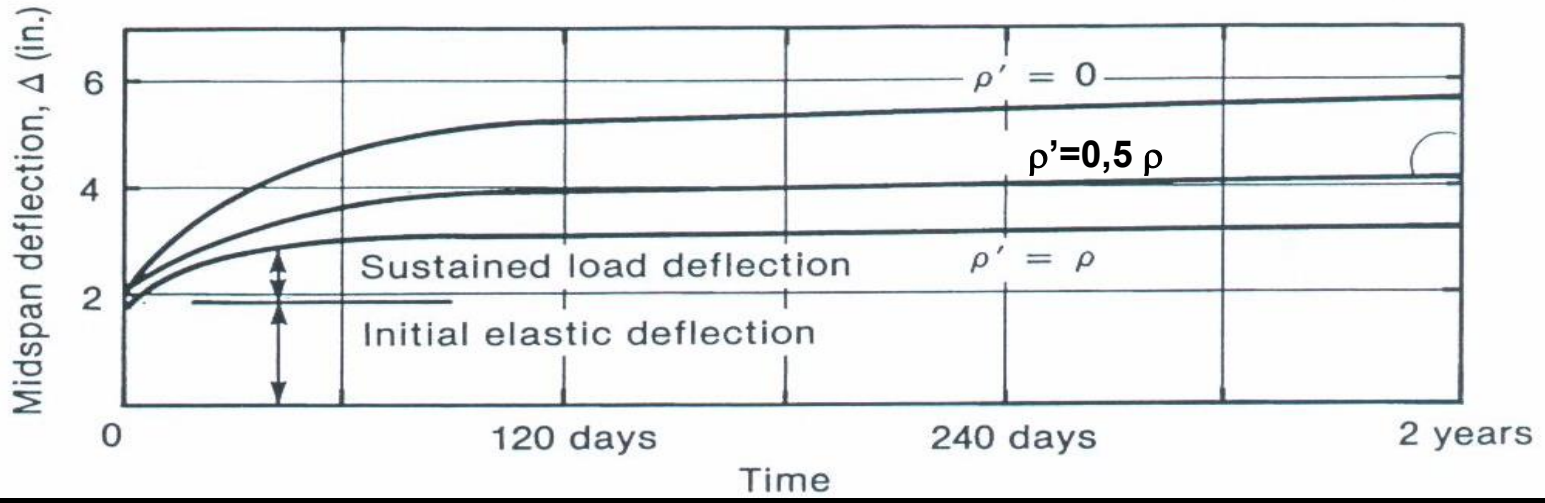
Keuntungan pemakaian tulangan tekan

1. **Mengurangi Lendutan Jangka Panjang, khususnya balok yang dibebani konstan dalam jangka panjang**

$$\rho' \approx \frac{1}{\Delta_{cp+sh}} \;;\; \Delta_{cp+sh} = \frac{T}{1+50\cdot\rho'}\cdot\Delta_{DL}$$

Washa (1952)





Keuntungan pemakaian tulangan tekan

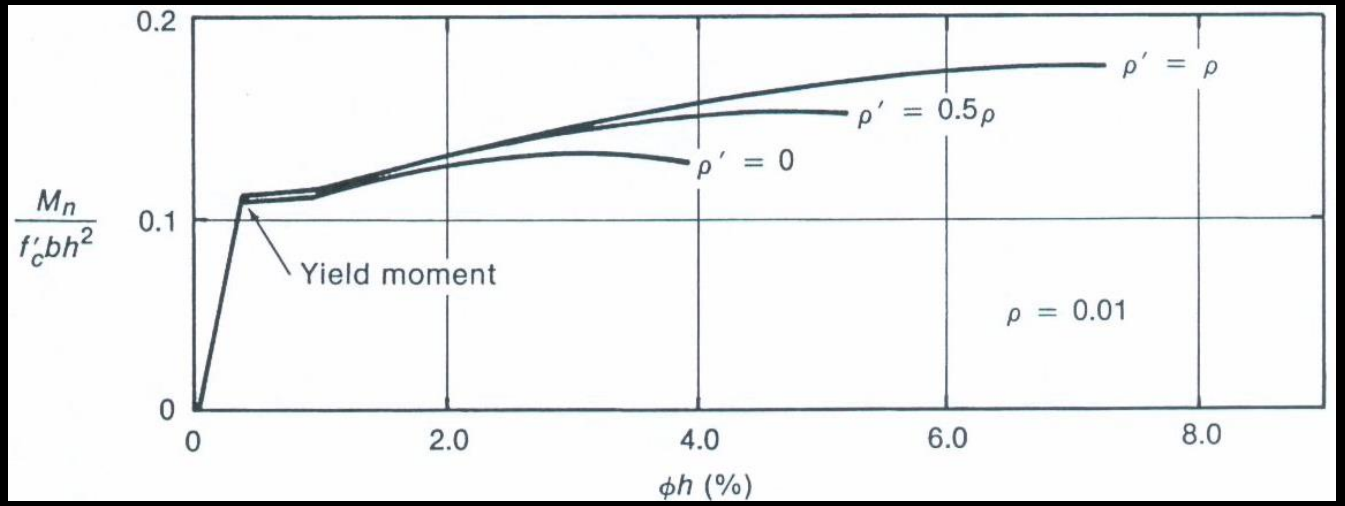
2. Meningkatkan Daktilitas

- Mengurangi tinggi blok stress (a)---garis netral (c) juga mengecil
- Regangan pada serat tarik bertambah– keruntuhan dimulai dari tulangan tarik

$$\varphi = kapasitas\ rotasi = \frac{\varepsilon_c}{c} = \varepsilon_c \frac{\beta_1}{k \cdot d} = \frac{1}{k} \cdot \frac{\varepsilon_c \cdot \beta_1}{d}$$

$$\mu_\varphi = \text{daktilitas kurvatur} = \frac{\varphi_u}{\varphi_y}$$

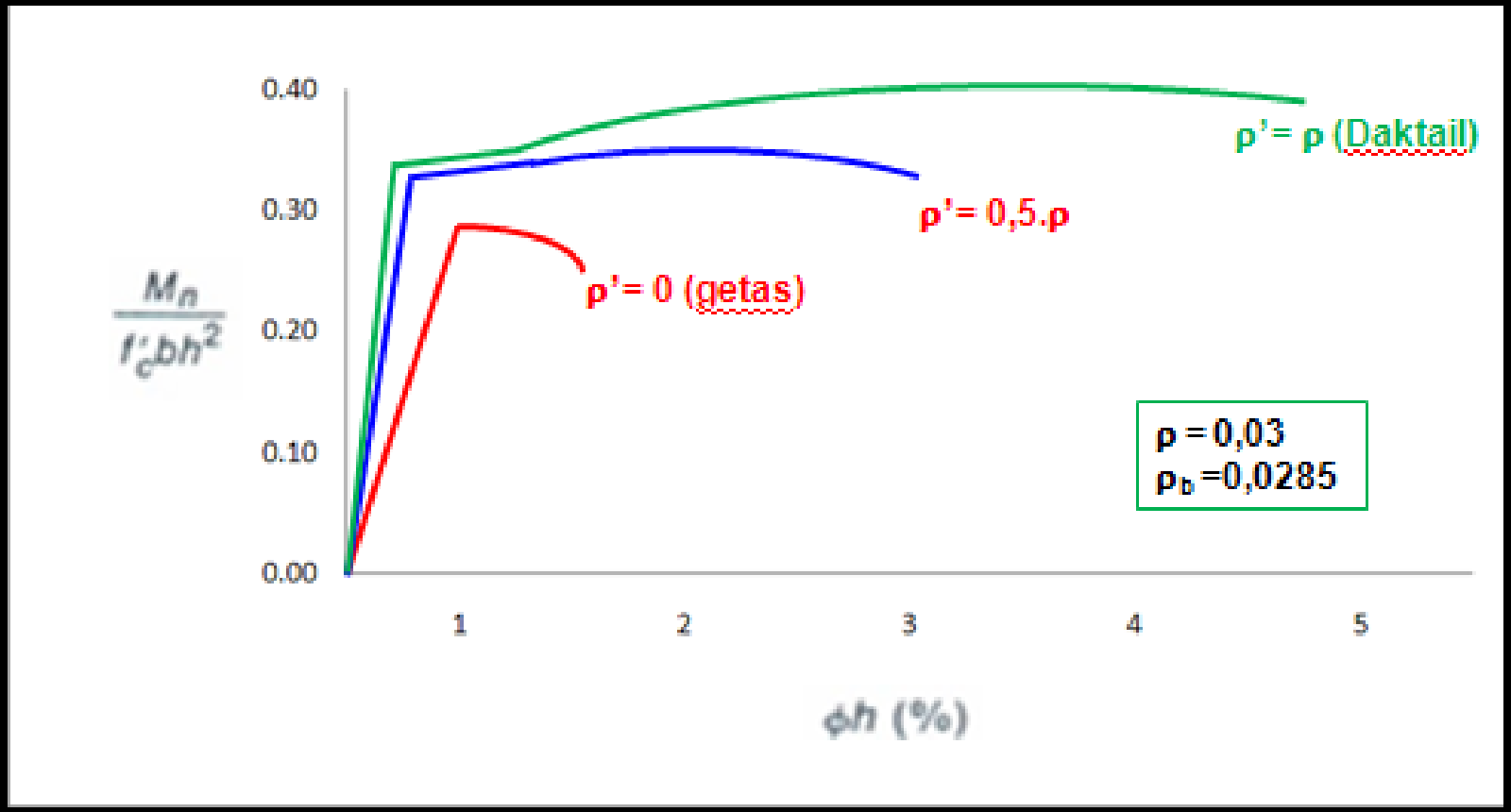
$\rho < \rho_b$



Keuntungan pemakaian tulangan tekan

3. Mengubah Tipe Keruntuhan

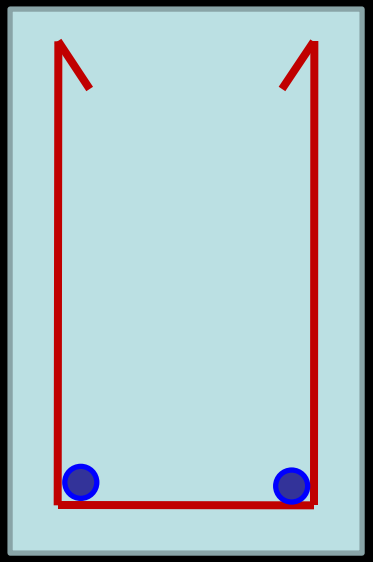
- Penampang dgn keruntuhan over Reinforced menjadi under Reinforced

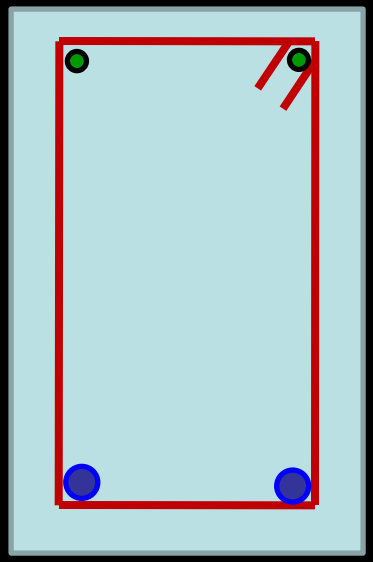


Keuntungan pemakaian tulangan tekan

4. Kemudahan dalam Perakitan Tulangan

- Tulangan geser dapat dipasang dengan baik – menjadi pegangan tul. geser.



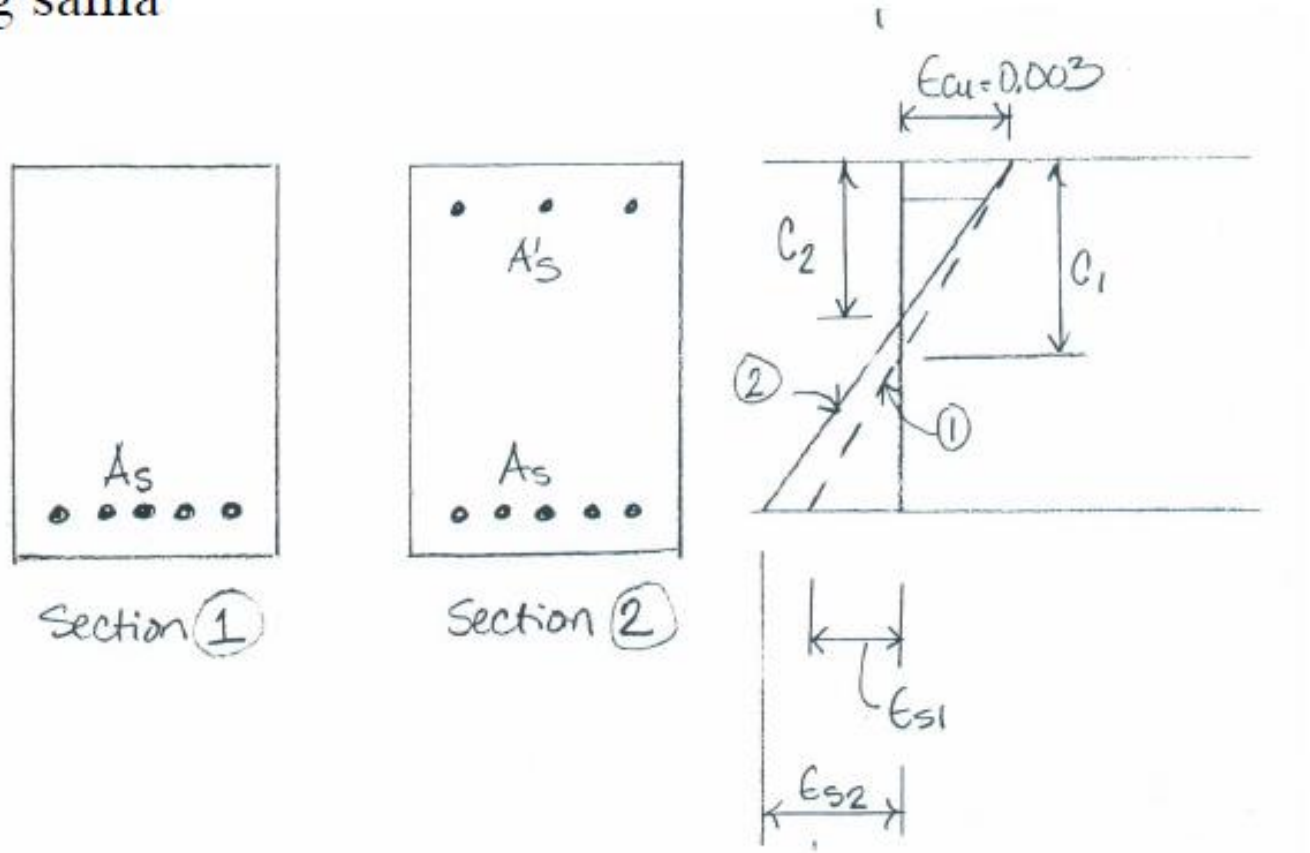


Alasan Penggunaan Tulangan Tekan

- Mengurangi defleksi akibat beban yang tetap (sustained).
  - Rangkak pada beton didaerah tekan
  - Transfer beban ke tulangan tekan.
  - Mengurangi tegangan pada beton.
  - Rangkak menjadi lebih kecil.
  - Defleksi akibat beban tetap juga lebih kecil.

Efek Tulangan Tekan

Bandingkan distribusi regangan pada dua balok dengan A_s yang sama



Efek Tulangan Tekan

Section 1:

$$T = A_s f_s$$

$$T = C_{c1} = 0.85 f_c' ba = 0.85 f_c' b \beta_1 c_1$$

$$c_1 = \frac{A_s f_s}{0.85 f_c' b \beta_1}$$

Section 2:

$$T = A_s f_s$$

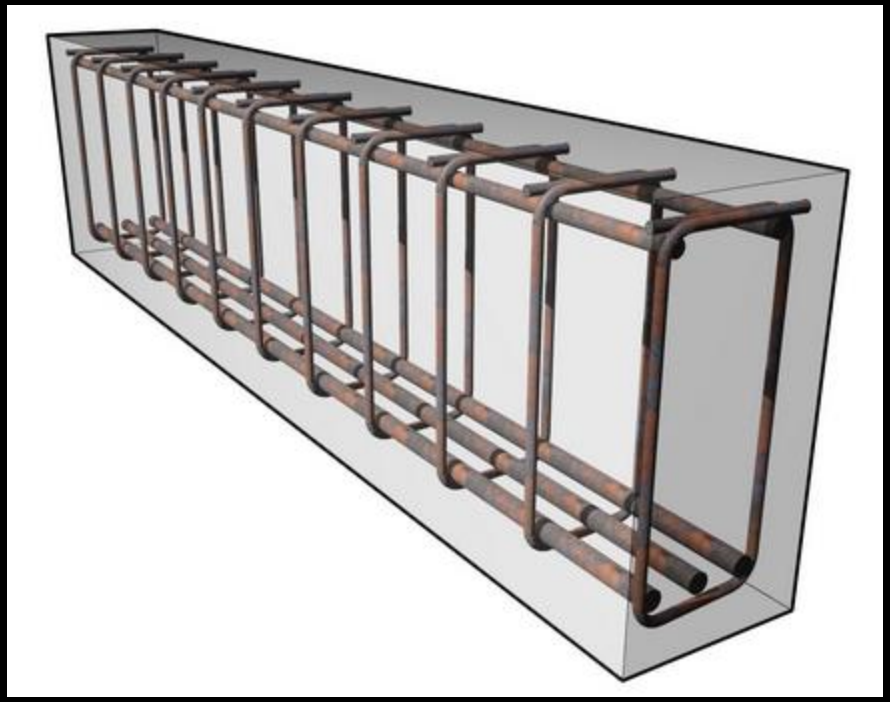
$$T = C_s' + C_{c1}$$

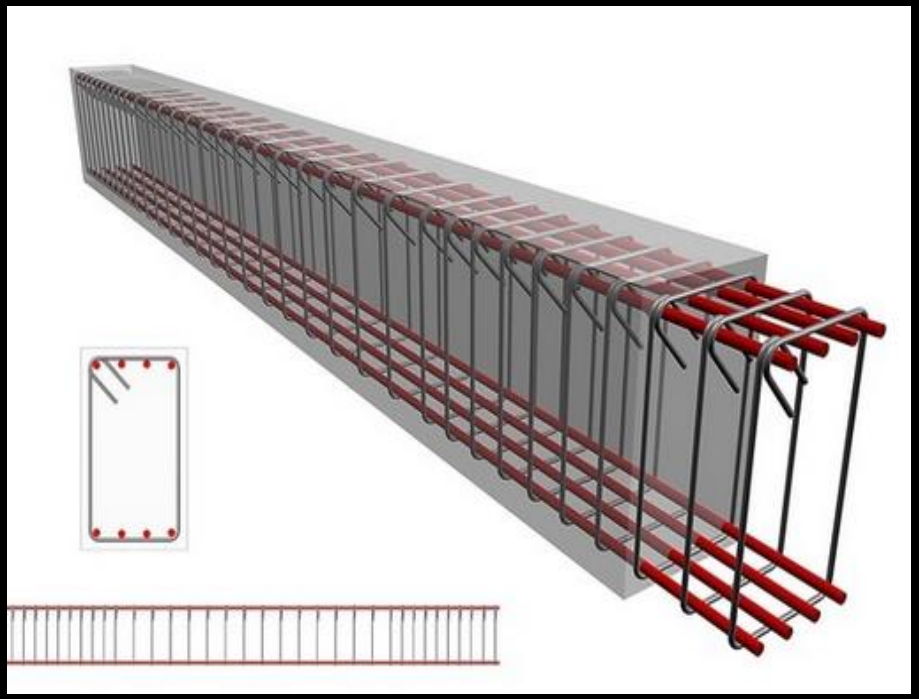
$$= A_s' f_s' + 0.85 f_c' b a_2$$

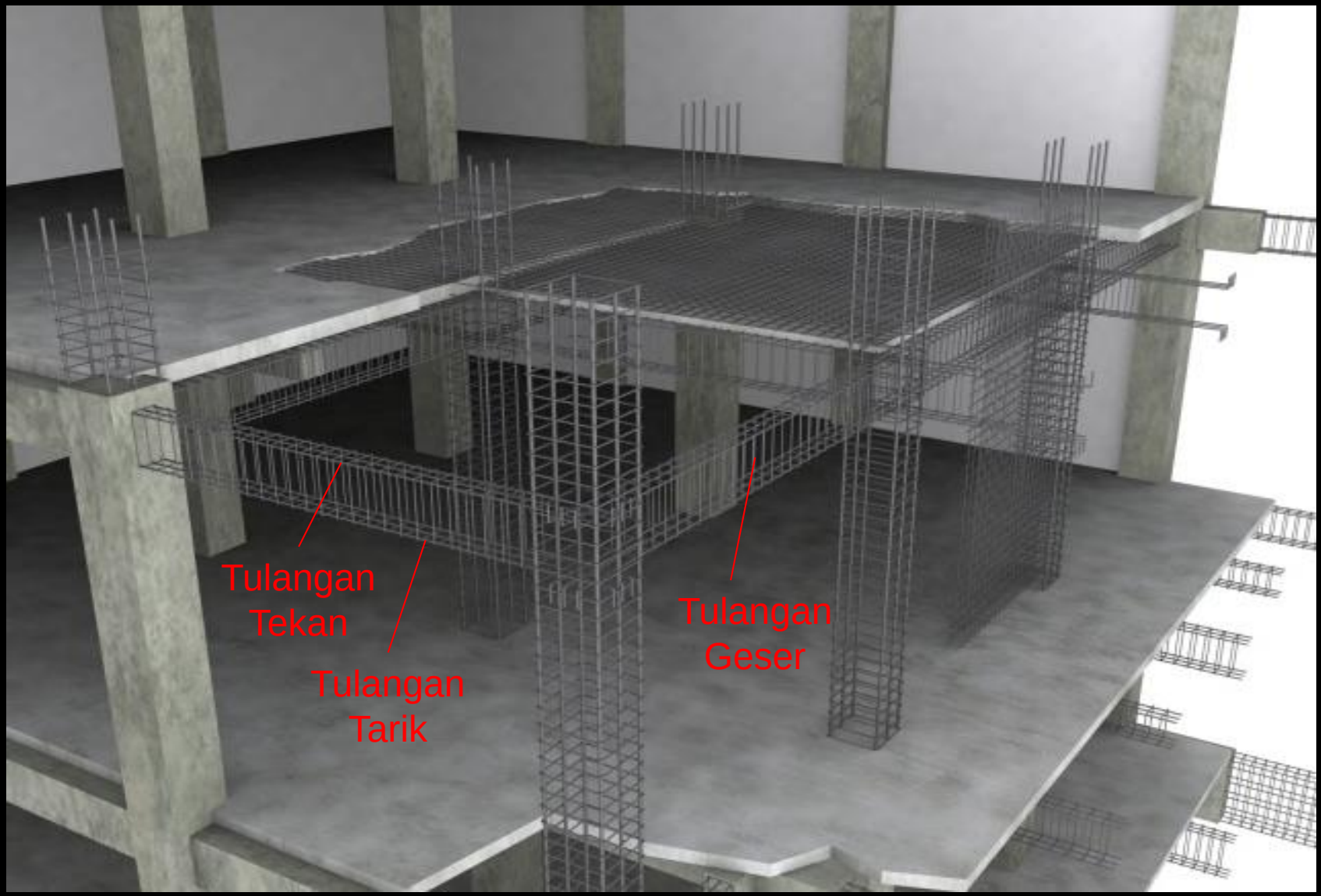
$$= A_s' f_s' + 0.85 f_c' b \beta_1 c_2$$

$$c_2 = \frac{A_s f_s - A_s' f_s'}{0.85 f_c' b \beta_1}$$

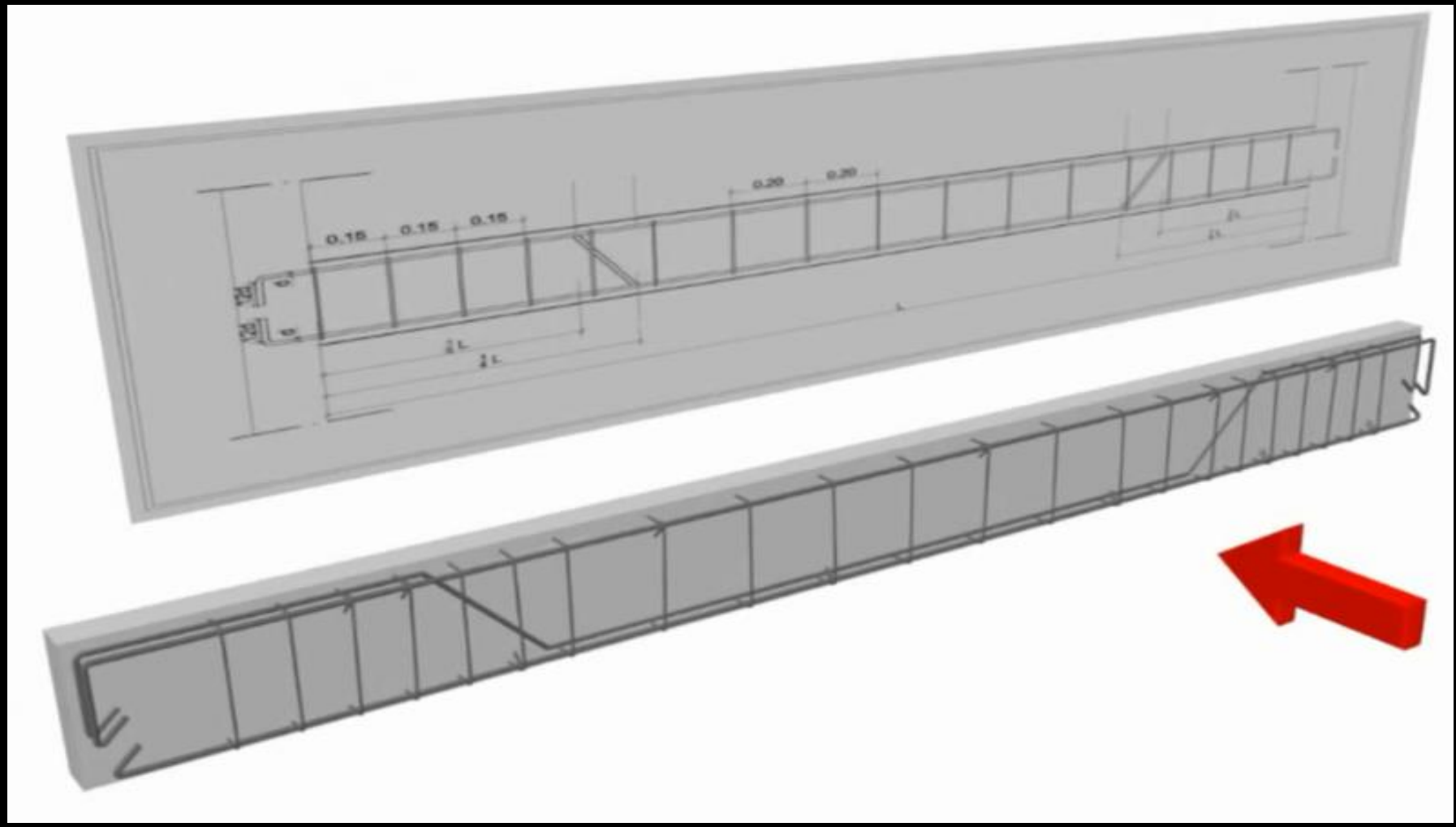
Penambahan tulangan tekan A_s' akan mengurangi luas daerah tekan pada beton. ⟶ Sumbu netral akan naik ($c_2 < c_1$) dan nilai ε_s akan naik pula($\varepsilon_{s2} > \varepsilon_{s1}$).



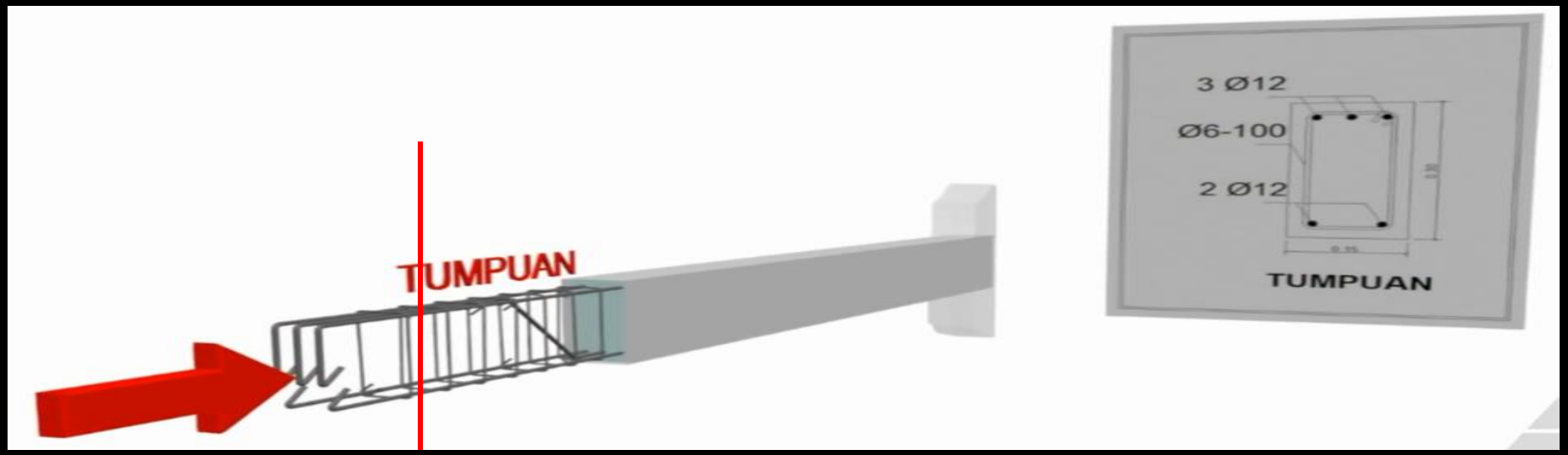


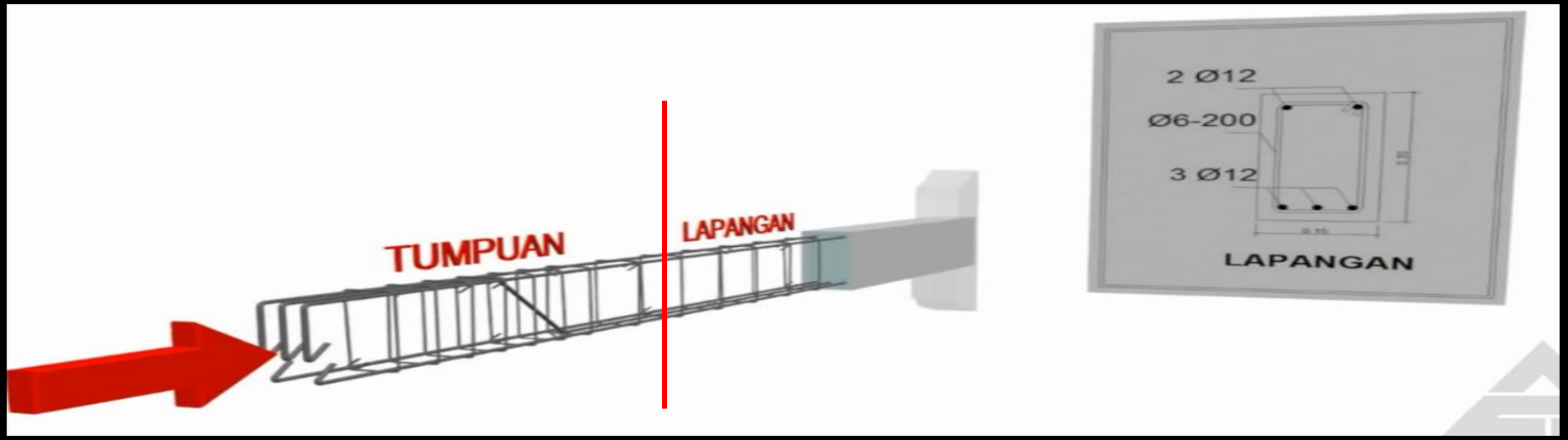

Tulangan
Tekan
Tulangan
Tarik
Tulangan
Geser

GAMBAR TULANGAN MEMANJANG

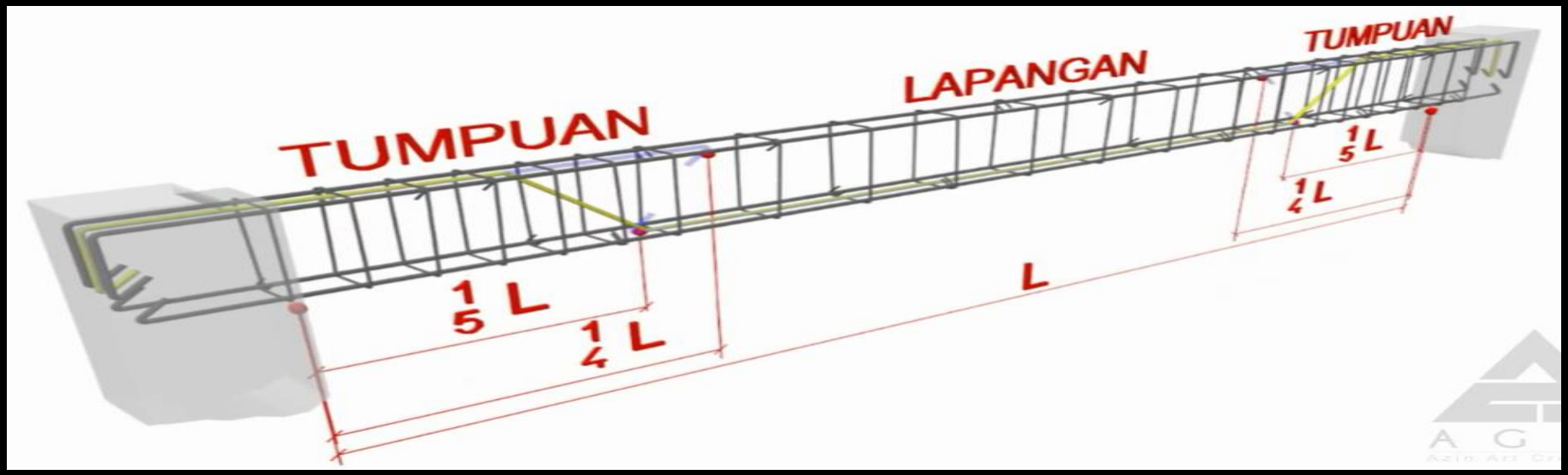


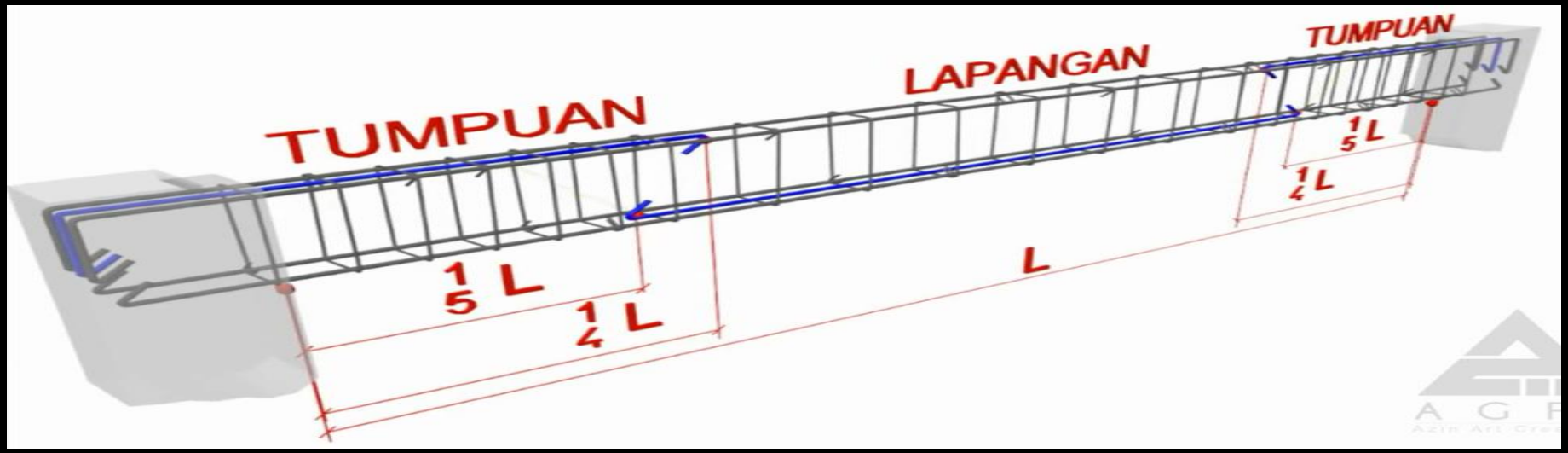
GAMBAR TULANGAN MELINTANG/POT



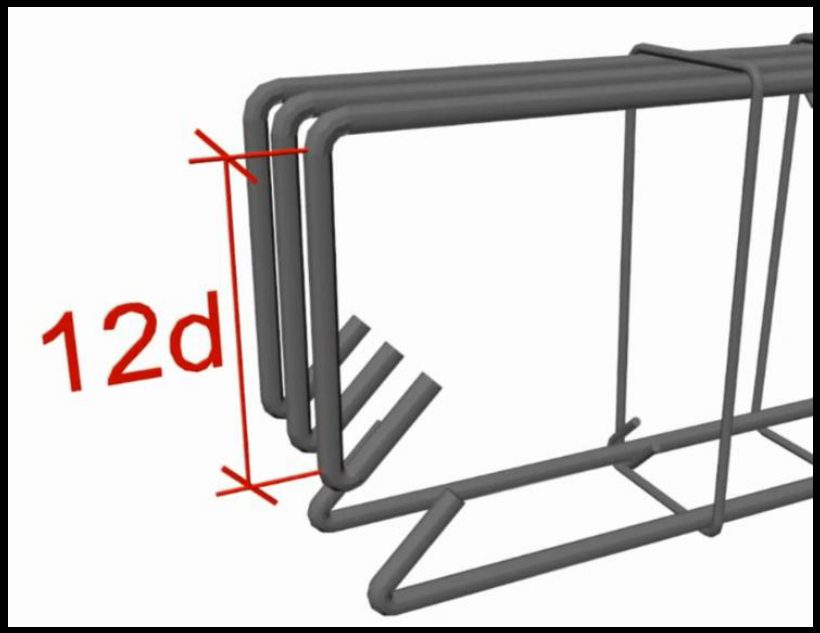


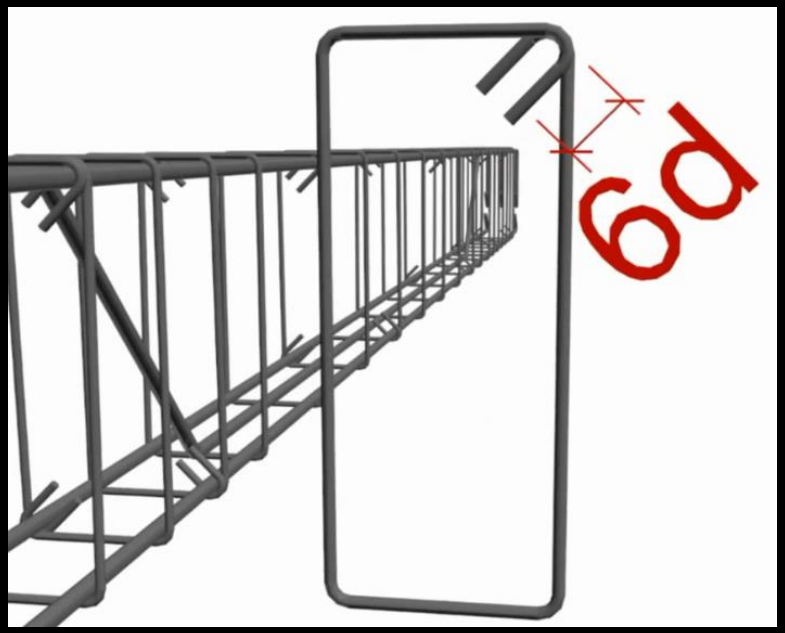
GAMBAR PEMUTUSAN TULANGAN MEMANJANG





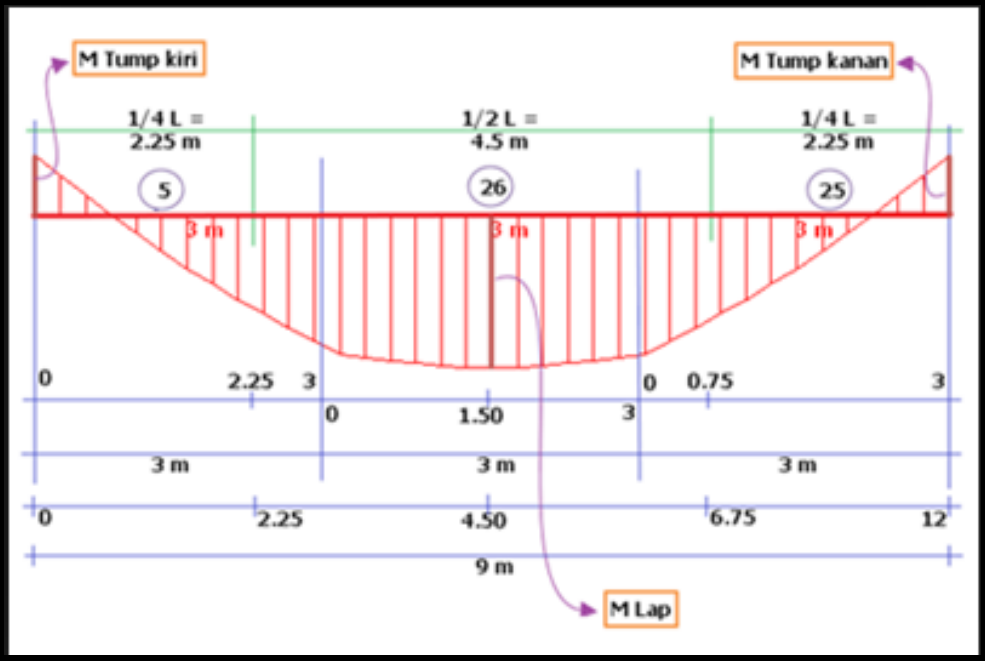
GAMBAR KAIT TULANGAN



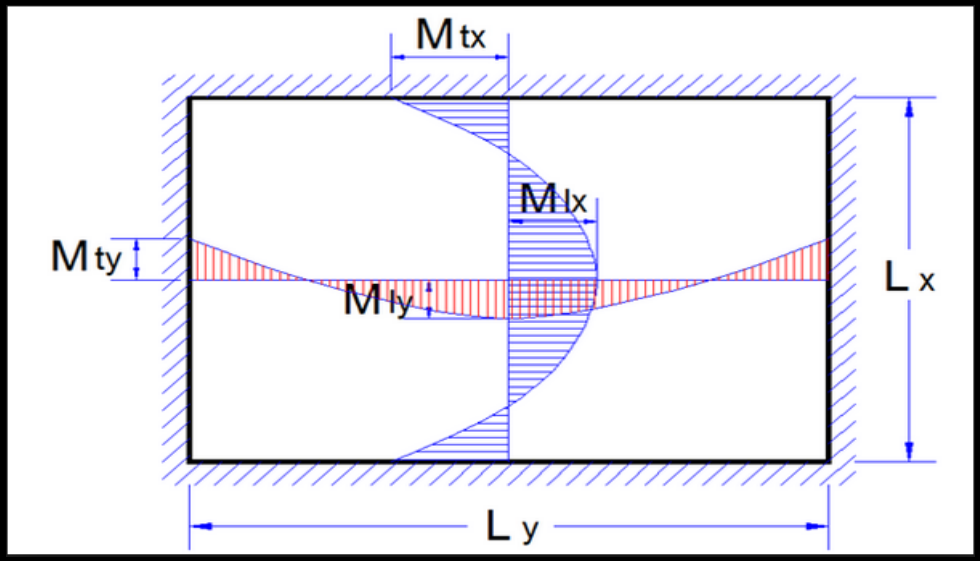


MOMEN DESAIN ULTIMIT

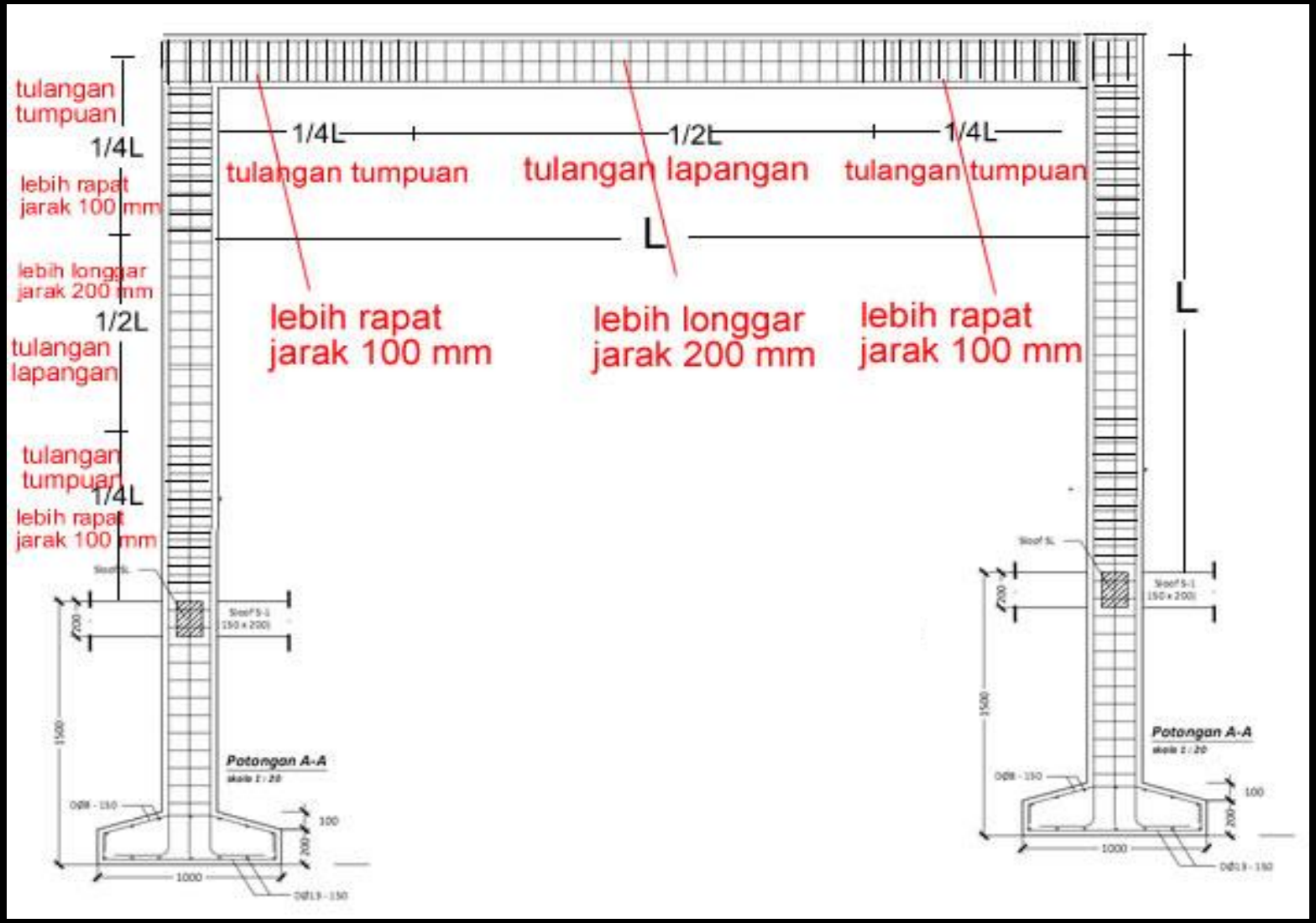
BALOK



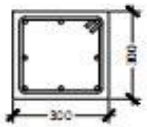
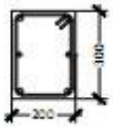
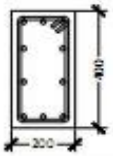
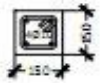
PLAT LANTAI



GAMBAR PENULANGAN BALOK



GAMBAR PENULANGAN BALOK

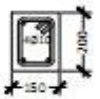
NOTASI	K-1	K-2	K-3	Kp
GAMBAR				
DIMENSI	300 X 300	200 X 300	200 X 400	150 X 150
TULANGAN	8D13	6D13	10D13	4Ø10
SENGKANG	2PØ10 - 100/200	2PØ10 - 100/200	2PØ10 - 100/200	2PØ10 - 100/200

tul dimeter 10 jarak 100 mm pada 1/4L kolom

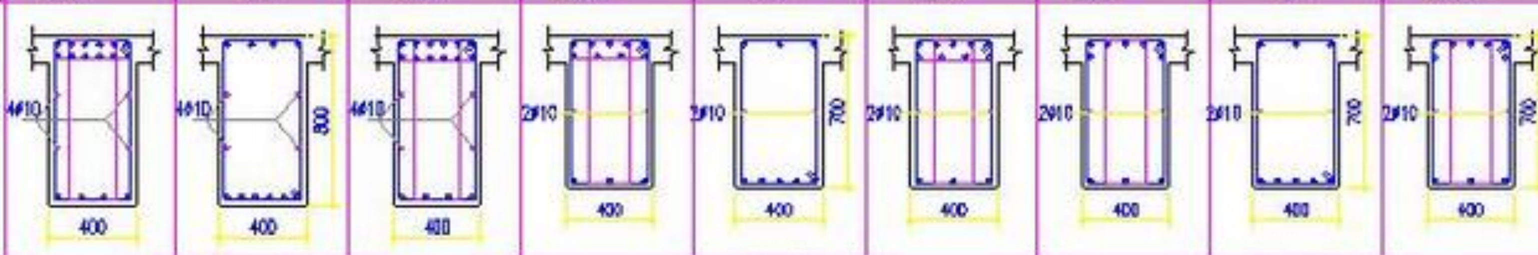
tul dimeter 10 jarak 200 mm pada 1/2L Kolom

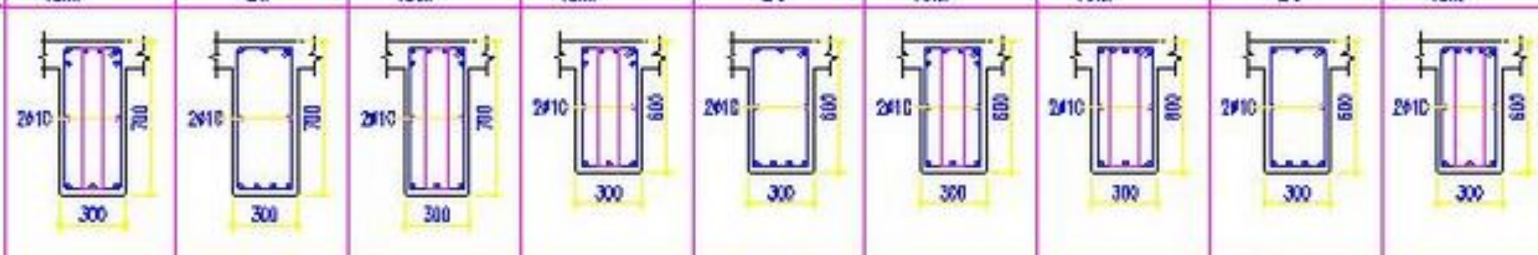
tul dimeter 10 jarak 100 mm pada 1/4L tumpuan Balok

tul dimeter 10 jarak 200 mm pada 1/2L lapangan Balok

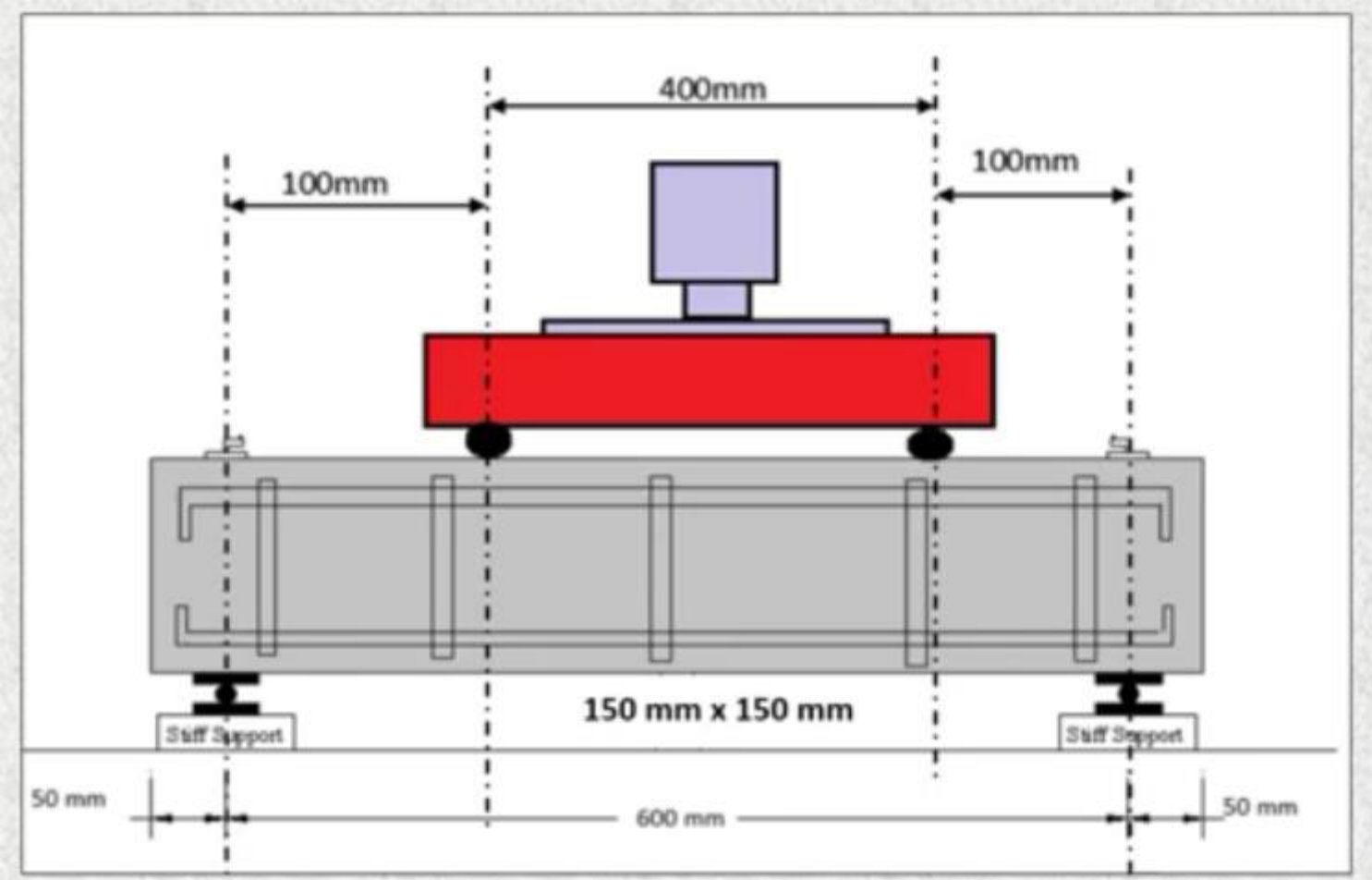
NOTASI	SL	B1		B2		RB
		TUMPUAN	LAPANGAN	TUMPUAN	LAPANGAN	TUMPUAN/ LAPANGAN
GAMBAR						
DIMENSI	150 X 200	200 X 400	200 X 400	200 X 300	200 X 300	150 X 200
TULANGAN ATAS	2P Ø 10	5D13	3 D 13	4D13	2 D 13	12P Ø 10
TULANGAN TENGAH		2Ø8	2Ø8	2Ø8	2Ø8	
TULANGAN BAWAH	2P Ø 10	3 D 13	5D13	2 D 13	4D13	2P Ø 10
SENGKANG	2PØ10 - 150	2PØ10 - 100	2PØ10 - 200	2PØ10 - 100	2PØ10 - 200	2PØ10 - 150

GAMBAR PENULANGAN BALOK

TYPE BALOK / LANTAI	G.0			G1.a			G1.b		
	TUMP	LAP	TUMP	TUMP	LAP	TUMP	TUMP	LAP	TUMP
									
UKURAN BALOK	400 X800			400 X700			400 X700		
TULANGAN ATAS	12 D22	4 D22	12 D22	8 D22	3 D22	9 D22	7 D22	3 D22	7 D22
TULANGAN BAWAH	4 D22	8 D22	4 D22	3 D22	5 D22	3 D22	3 D22	5 D22	3 D22
SENGKANG	2ø10–100	ø10–150	2ø10–100	2ø10–100	ø10–150	2ø10–100	2ø10–100	ø10–150	2ø10–100

TYPE BALOK / LANTAI	G2.b			G3.a			G3.b		
	TUMP	LAP	TUMP	TUMP	LAP	TUMP	TUMP	LAP	TUMP
									
UKURAN BALOK	300 X700			300 X 600			300 X 600		
TULANGAN ATAS	6 D22	3 D22	6 D22	6 D22	3 D22	6 D22	6 D22	3 D22	6 D22
TULANGAN BAWAH	3 D22	4 D22	3 D22	3 D22	4 D22	3 D22	3 D22	4 D22	3 D22
SENGKANG	2ø10–100	ø10–150	2ø10–100	2ø10–100	ø10–150	2ø10–100	2ø10–100	ø10–150	2ø10–100

CONTOH PENGUJIAN BALOK TULANGAN RANGKAP

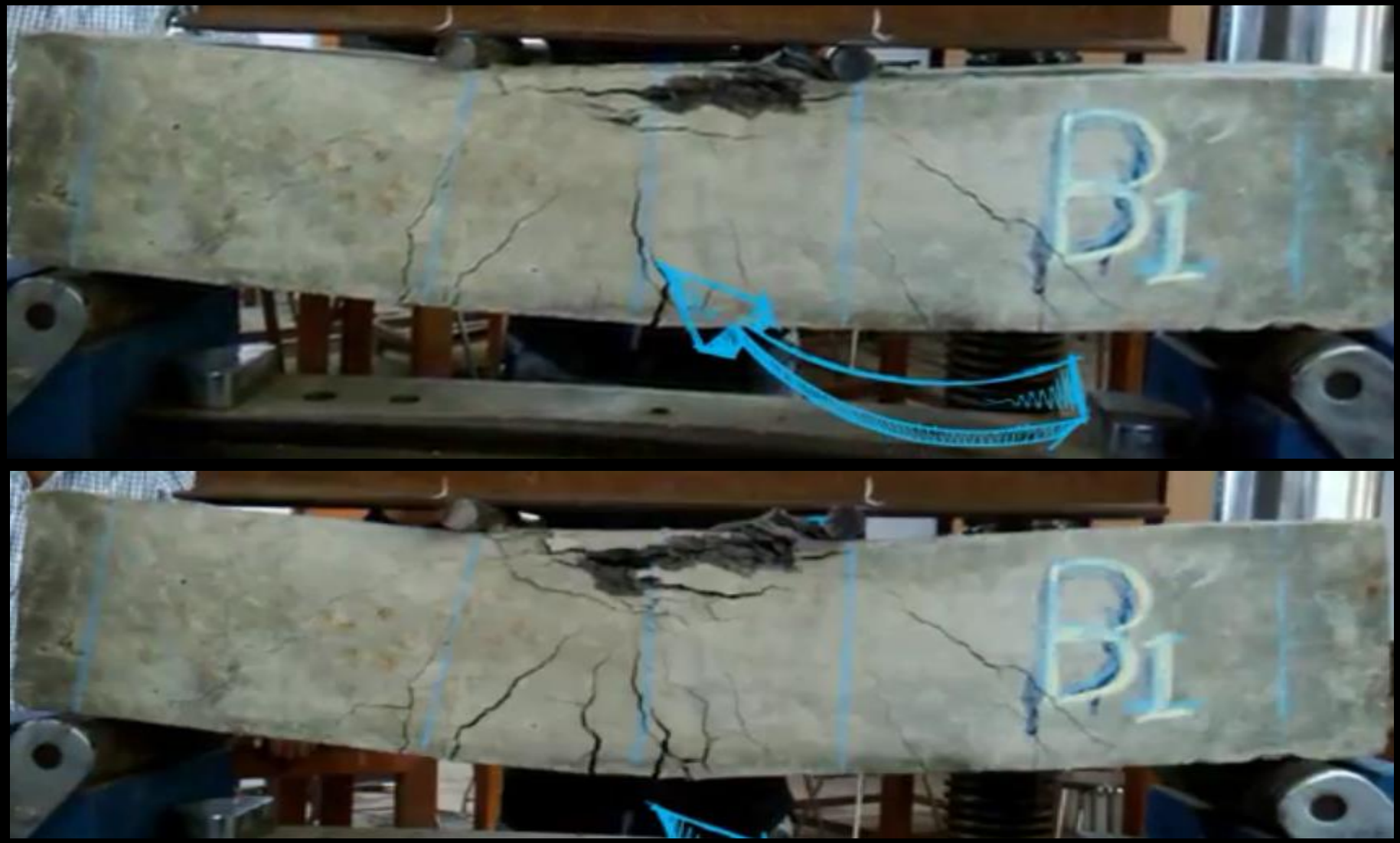


Experimental Set-up for Beam Testing

CONTOH PENGUJIAN BALOK TULANGAN RANGKAP

CONTOH PENGUJIAN BALOK TULANGAN RANGKAP

CONTOH PENGUJIAN BALOK TULANGAN RANGKAP



Kuat Nominal, Kuat Rencana, dan Kuat Perlu

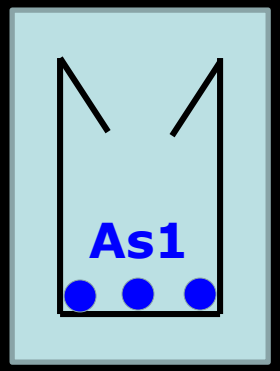
Kuat Nominal adalah kekuatan suatu komponen struktur penampang yang dihitung berdasarkan ketentuan dan asumsi metode perencanaan sebelum dikalikan dengan faktor reduksi kekuatan yang sesuai.
Kuat Nominal berupa Mn, Vn, Tn, dan Pn.

Kuat Rencana adalah kekuatan suatu komponen struktur atau penampang yang diperoleh dari hasil perkalian antara kuat nominal dengan faktor reduksi kekuatan yang sesuai.
Kuat Rencana berupa Mr, Vr, Tr, dan Pr.

Kuat Perlu adalah kekuatan gaya luar yang bekerja pada struktur akibat beban berfaktor.
Kuat Perlu berupa Mu, Vu, Tu, dan Pu.

KONSEP DESAIN BALOK SEGIEMPAT BERTULANGAN RANGKAP (Doubly Reinforced Section)

Momen Ultimit
Akibat beban
berfaktor hasil
Analisis Struktur



Mu

Mn1 < Mn

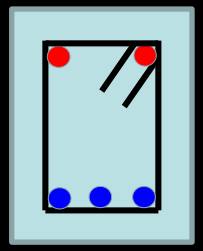
Perbesar
dimensi --- h

Menambah
Tulangan Tekan

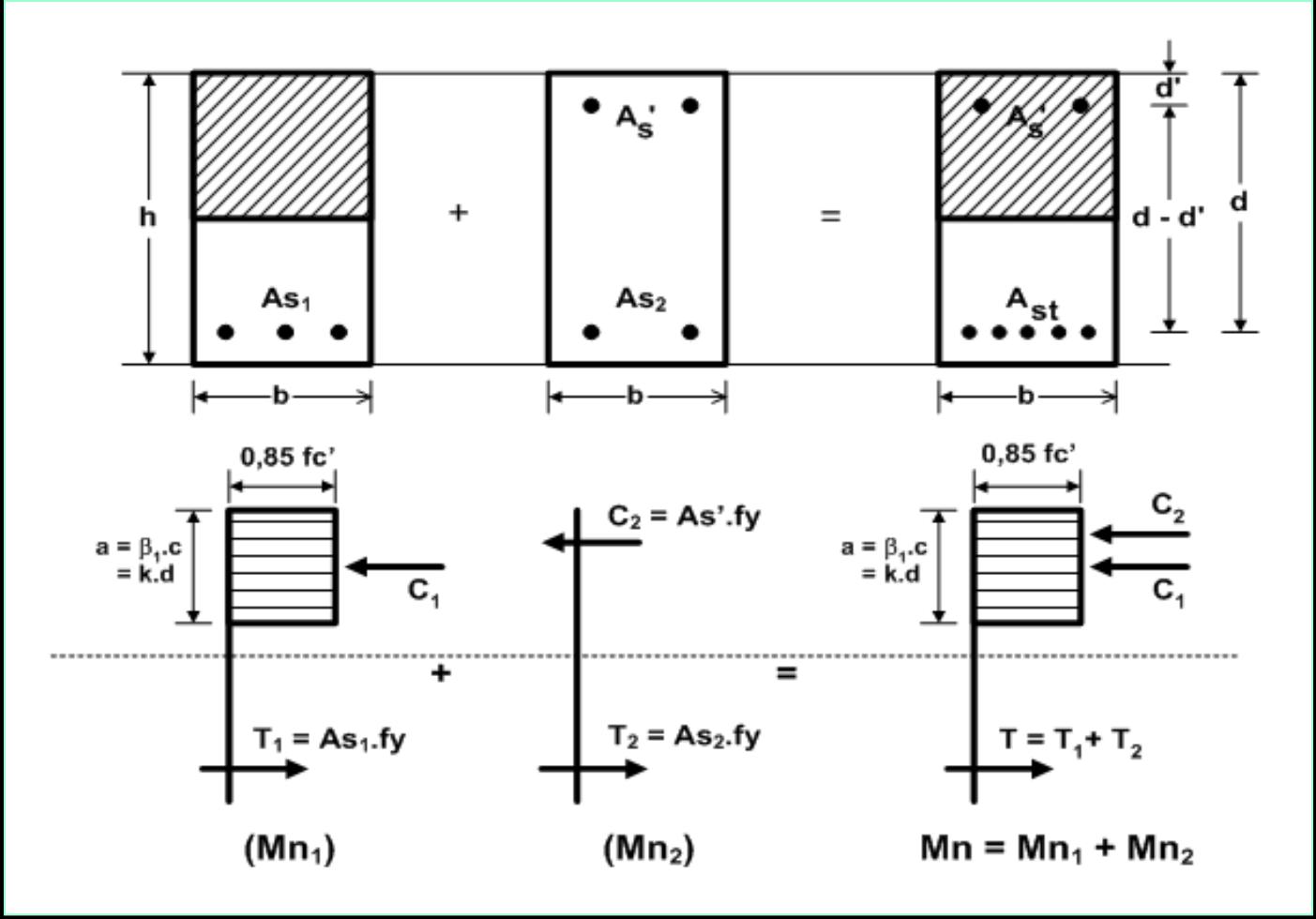
Mn1 > Mn = Mu/ϕ

Cukup
Tulangan Tunggal

Kapasitas Momen
Nominal dgn
tulangan tunggal
maksimum



DESAIN BALOK SEGIEMPAT BERTULANGAN RANGKAP (Doubly Reinforced Section)



Desain Balok Bertulangan Rangkap

a. Tentukan Momen Nominal Maksimum (M_{n1})

$$Hitung : k_{maks} = 0{,}75\ k_b = 0{,}75 \cdot \left(\beta_1 \cdot \frac{600}{600 + f_y} \right)$$

Hitung kapasitas momen M_{n1}:

$M_{n1} = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k_{maks} \cdot (1 - \frac{1}{2} \cdot k_{maks})$

Tentukan tulangan As_1 untuk memikul M_{n1}

$$A_{s1} = \frac{M_{n1}}{f_y \cdot d \cdot \left(1 - \frac{k_{maks}}{2} \right)}$$

b. Menghitung Tulangan Rangkap

Hitung selisih momen: $M_{n2} = \Delta M = M_n - M_{n1}$

- **Jika $M_{n2} > 0$ diperlukan tulangan rangkap**
- **Jika tulangan rangkap diperlukan, maka harus ada tulangan tekan**
- **Jika $M_{n2} < 0$ cukup dipakai tulangan tunggal**

c. Jika diperlukan tulangan rangkap

$$Luas\ tulangan\ tekan: A_s' = \frac{M_{n_2}}{(d - d') \cdot f_y'}$$

Luas Total Tulangan Tarik:

$$A_{s2} = A_s' \Rightarrow A_{st} = A_{s1} + A_{s2}$$

$$A_{st} = \frac{M_{n_1}}{f_y \cdot d \cdot \left(1 - \frac{k_{maks}}{2}\right)} + \frac{M_{n2}}{(d - d')\, f_y'}$$

d. Pembatasan rasio tulangan baja

- **Tulangan tekan belum leleh, $f_s' = E_s \cdot \varepsilon_s'$**

$$\varepsilon_{s'} = \varepsilon_{cu} \cdot \frac{k - \beta_1 \cdot \left(d'/d \right)}{k} \quad maka:$$

$$\rho_{maks} = 0{,}75 . \rho_b + \rho' . \frac{f_s'}{f_y'}$$

- Tulangan tekan leleh, $f_s' = f_y$ *maka*:

$$\rho_{maks} = 0{,}75 \cdot \rho_b + \rho'$$

Contoh soal 1:

Desainlah balok segiempat dengan momen ultimit Mu = 290 kN.m, dimensi balok dibatasi b = 25 cm, h = 50 cm, dan d = 45 cm. Jika semua mutu baja f_y = 400 MPa dan mutu beton f_c' = 25 MPa. Hitung luas tulangan yg diperlukan.

Penyelesaian:

Hitung momen yg dapat ditahan oleh tulangan tunggal dgn kondisi rasio tul. maksimum:

β_1 = 0,85 → $f_c' \leq$ 30 MPa, ϕ = 0,80 untuk balok yang menahan lentur.

$$k_{maks} = 0{,}75 \cdot \left(\beta_1 \cdot \frac{600}{600 + f_y} \right) = 0{,}75 \cdot \left(0{,}85 \cdot \frac{600}{600 + 400} \right) = 0{,}3825$$

$M_{n1} = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k_{maks} \cdot (1 - ½ \cdot k_{maks})$

$M_{n1} = 0{,}85 \cdot 25 \cdot 250 \cdot 450^2 \cdot 0{,}3825 \cdot (1 - ½ \cdot 0{,}3825) \cdot (10^{-6})$

$= 332{,}790$ kN.m

$$A_{s1} = \frac{M_{n1}}{f_y \cdot d \cdot \left(1 - \frac{k_{maks}}{2}\right)} = \frac{332{,}790 \cdot \left(10^6\right)}{400 \cdot 450 \cdot \left(1 - \frac{0{,}3825}{2}\right)}$$

$$= 2286\ mm^2$$

Hitung selisih momen:

$M_{n2} = M_n - M_{n1} = 290/0{,}80 - 332{,}790 = 29{,}710$ kN.m > 0

$M_{n2} = 29{,}71$ kN.m ⇨ perlu tulangan rangkap

- *Hitung tulangan tekan(asumsi tul. tekan leleh):*

$$A_{s'} = \frac{M_{n2}}{(d - d') \cdot f_y'} = \frac{29{,}71.(10^6)}{(450 - 50).400} = 185{,}70\, mm^2$$

$$A_{s2} = A_{s'} = 185{,}70 \text{ mm}^2$$

- **Hitung luas total tulangan tarik :**

$A_{st} = A_{s1} + A_{s2}$; A_{st} = 2286 + 185,70

= 2471,70 mm²

Maka dipakai:

Tulangan tekan : 3D-10 (A_s' = 235,50 mm²)

Tulangan tarik : 6D-25 (A_{st} = 2946 mm²)

- Check kondisi leleh tula ngan tekan :

$$A_s' = 235{,}50\ \text{mm}^2 \Rightarrow \rho' = \frac{A_s'}{b \cdot d} = \frac{235{,}50}{250 \cdot 450} = 0{,}0021$$

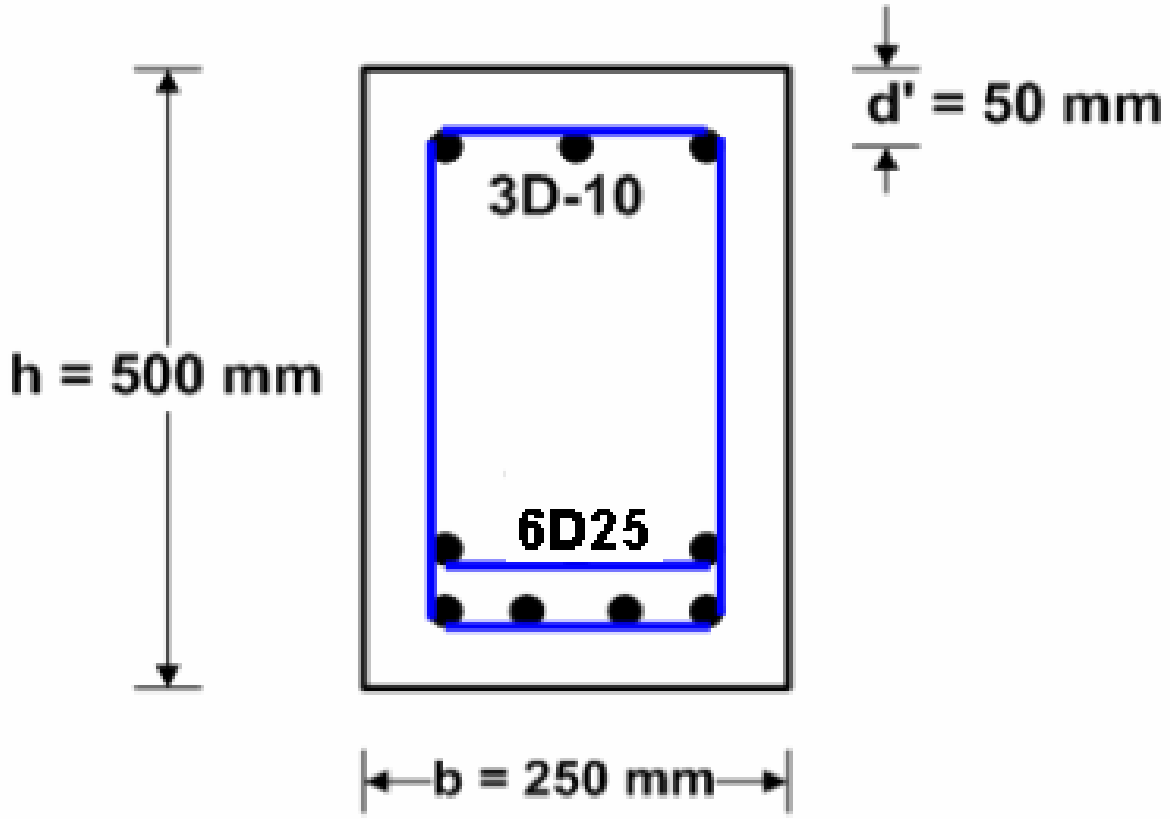
$$A_{st} = 2946\ \text{mm}^2 \Rightarrow \rho = \frac{A_{st}}{b \cdot d} = \frac{2946}{250 \cdot 450} = 0{,}0262$$

$$\rho - \rho' \geq \left(\frac{0{,}85 \cdot f_c'}{f_y \cdot d}\right) \cdot \left(\frac{600}{600 - f_y}\right) \cdot \beta_1 \cdot d' \Rightarrow$$

$$0{,}0262 - 0{,}0021 \geq \left(\frac{0{,}85 \cdot 25}{400 \cdot 450}\right) \cdot \left(\frac{600}{600 - 400}\right) \cdot 0{,}85 \cdot 50$$

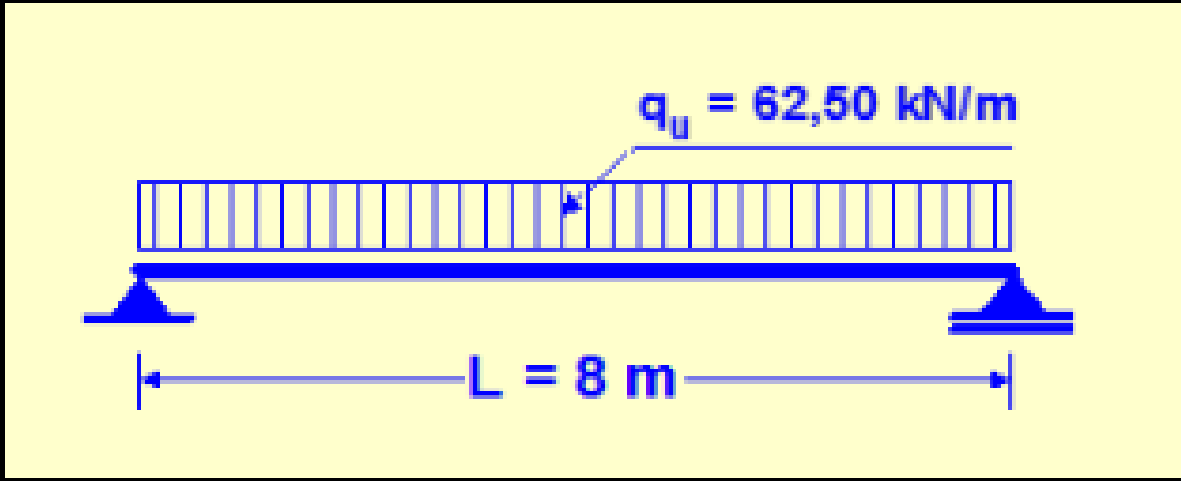
$$0{,}0241 > 0{,}0151 \Rightarrow \text{tulangan tekan leleh}$$

Sketsa
Penulangan Balok



Contoh soal 2:

Sebuah balok segiempat diatas 2 tumpuan, bentang L = 8 m, memikul beban merata terfaktor total (q_u) = 62,50 kN/m. Desainlah tulangan balok untuk menahan momen ultimit struktur jika dimensi balok dibatasi b = 300 mm, h = 500 mm, f_y = 350 MPa, f_c' = 28 MPa., selimut beton 50 mm, diameter sengkang 8 mm dan jarak min. antar tulangan utama 20 mm. Diameter baja utk tulangan tekan = 18 mm & tulangan tarik = 27 mm.



Penyelesaian:

Hitung momen nominal akibat beban terfaktor:

$$M_u = \frac{1}{8} \cdot q_u \cdot L^2 = \frac{1}{8} \cdot 62{,}50 \cdot 8^2 = 500 \ kN.m$$

$$M_n = \frac{M_u}{\phi} = \frac{500}{0{,}80} = 625 \ kN.m$$

Hitung titik tangkap tulangan tarik dan tekan terhadap serat tekan beton:

Asumsi tulangan tarik 1 lapis:

$d = h - (d_s + \phi_s + \frac{1}{2} \cdot \phi_t)$

$d = 500 - (50 + 8 + \frac{1}{2} \cdot 27) = 428{,}50$ mm

Asumsi tulangan tekan 1 lapis:

$d' = d_s + \phi_s + \frac{1}{2} \cdot \phi_t$`

$d' = 50 + 8 + \frac{1}{2} \cdot 18 = 67$ mm

Hitung Momen yang dapat ditahan oleh tulangan tunggal (kmaks):

$\beta_1 = 0,85 \rightarrow f_c' \leq 30$ MPa

$\phi = 0,80$ untuk balok yang menahan lentur

$$k_{maks} = 0,75 \cdot \left(\beta_1 \cdot \frac{600}{600 + f_y} \right) = 0,75 \cdot \left(0,85 \cdot \frac{600}{600 + 350} \right)$$

$$= 0,4026$$

$M_{n1} = 0,85 \cdot f_c' \cdot b \cdot d^2 \cdot k_{maks} \cdot (1 - ½ \cdot k_{maks})$

$M_{n1} = 0,85 \cdot 28 \cdot 300 \cdot 428,50^2 \cdot 0,4026 \cdot (1 - ½ \cdot 0,4026) \cdot (10^{-6})$

$= 421,583$ kN.m

$$A_{s1} = \frac{M_{n_1}}{f_y \cdot d \cdot (1 - k_{maks}/2)} = \frac{421,583}{350 \cdot 428,50 \cdot (1 - 0,4026/2)} = 3519,564 \ mm^2$$

- **Hitung selisih momen:**

  $M_{n2} = M_n - M_{n1} = 625 - 421{,}583 = 203{,}417$ kN.m > 0

  $M_{n2} = 203{,}417$ kN.m (maka perlu tulangan rangkap)

- *Hitung tulangan tekan:*

$$A_s' = \frac{M_{n2}}{(d-d')\cdot f_y'} = \frac{203{,}417\cdot(10^6)}{(429-67)\cdot 350} = 1607{,}724\ mm^2$$

$$A_{s2} = A_s' = 1607{,}724\ \text{mm}^2$$

Hitung luas total tulangan tarik:

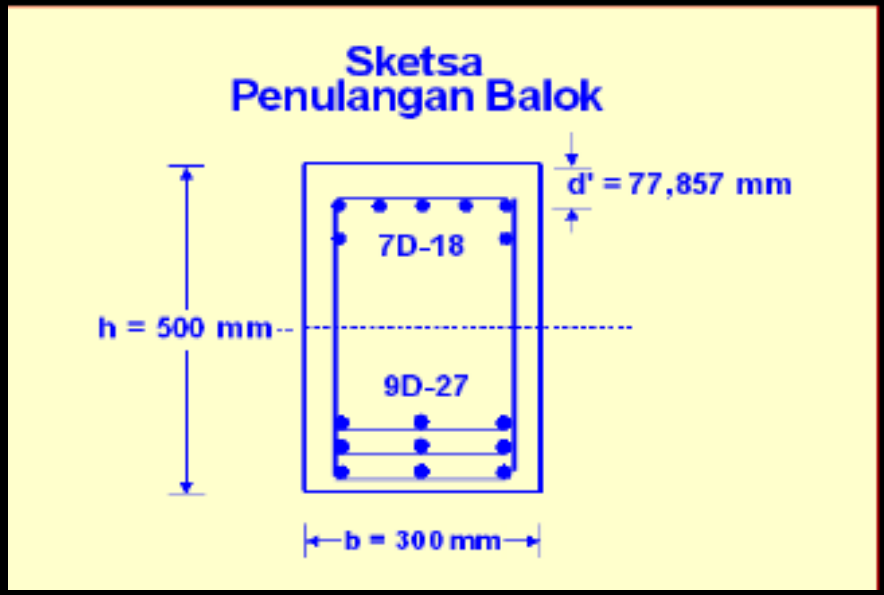
$A_{st} = A_{s1} + A_{s2}$

$A_{st} = 3519{,}564 + 1607{,}724 = 5127{,}288\ mm^2$

Dipakai :

Tulangan tekan : 7D-18 (A_s' = 1781,283 mm^2)

Tulangan tarik : 9D-27 (A_{st} = 5152,997 mm^2)



- Lebar balok dgn. tulangan terpasang (Tekan)

$$b_t = 2 \cdot d_s + 2 \cdot \phi_s + n \cdot \phi_t' + (n-1) \cdot s_t$$

$$b_t = 2 \cdot 50 + 2 \cdot 8 + 5 \cdot 18 + (5-1) \cdot 20$$

$$= 286\ mm < b = 300\ mm \ldots\ldots Ok!$$

- Lebar balok dgn. tulangan terpasang (Tarik)

$$b_t = 2 \cdot d_s + 2 \cdot \phi_s + n \cdot \phi_t + (n-1) \cdot s_t$$

$$b_t = 2 \cdot 50 + 2 \cdot 8 + 3 \cdot 18 + (3-1) \cdot 20$$

$$= 237\ mm < b = 300\ mm \ldots\ldots Ok!$$

- **Perhitungan Titik Tangkap Tulangan**:

Titik Berat Tul. Tekan Thd Serat Tekan				
Lapis	**n**	**A_s**	**x**	**A_s.x**
1	5	1272,345	67	85247,12
2	2	508,938	105	53438,49
Total	7	1781,283		138685,60

$$d' = \frac{\sum A_s' \cdot x}{\sum A_s'}$$

$$= 77{,}857\ mm$$

Titik Berat Tulangan Tarik thd. Serat Tekan

Titik Berat Tulangan Tarik thd. Serat Tekan				
Lapis	**n**	**A_s**	**x**	**A_s.x**
1	3	1717,666	72,0	122813,1
2	3	1717,666	118,5	203543,4
3	3	1717,666	165,5	284273,7
Total	6	5152,997		610630,2

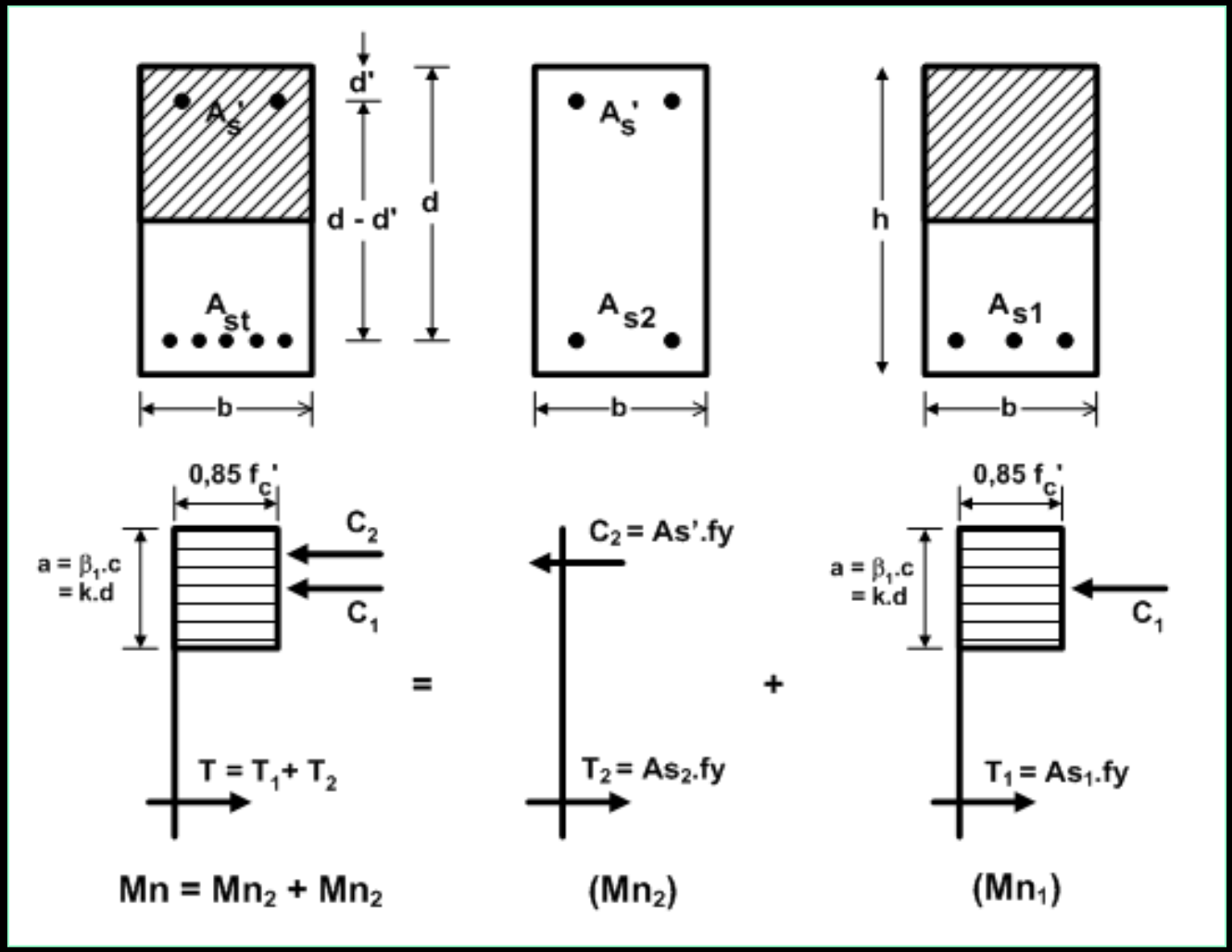
$$d = \frac{\sum A_s \cdot x}{\sum A_s} = 381{,}50 \ mm$$

$$\rho - \rho' \geq \left(\frac{0{,}85 \cdot f_c'}{f_y \cdot d} \right) \cdot \left(\frac{600}{600 - f_y} \right) \cdot \beta_1 \cdot d'$$

$$0{,}04502 - 0{,}01556 \geq \left(\frac{0{,}85 \cdot 28}{350 \cdot 381{,}5} \right) \cdot \left(\frac{600}{600 - 350} \right) \cdot (0{,}85 \cdot 77{,}857)$$

$$0{,}02946 > 0{,}02831 \rightarrow \text{tulangan tekan} - \text{meleleh}$$

ANALISIS BALOK SEGIEMPAT BERTULANGAN RANGKAP



Balok dengan Tulangan Ganda

Empat mode keruntuhan yang mungkin

- Keruntuhan *Under reinforced*
  - (Case 1) Tulangan tekan dan tulangan tarik leleh
  - (Case 2) Hanya tulangan tarik yang leleh
- Keruntuhan *Over reinforced*
  - (Case 3) Hanya tulangan tekan yang leleh
  - (Case 4) Tidak terjadi leleh pada tulangan, beton hancur

Kasus-1:

Tulangan Tarik meleleh dan Tekan meleleh

1. Persamaan Keseimbangan Gaya:

$C_1 = 0{,}85 \cdot f_c' \cdot k \cdot d \cdot b$

$C_2 = A_s' \cdot f_y'$

$T = A_s \cdot f_y$

$C_1 + C_2 = T$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_y' = A_s \cdot f_y$$

$$k = \frac{A_s \cdot f_y - A_s' \cdot f_y'}{0{,}85 \cdot f_c' \cdot b \cdot d} = \frac{\rho \cdot f_y - \rho' \cdot f_y'}{0{,}85 \cdot f_c'}$$

$$\text{dimana}: \quad \rho = \frac{As}{b \cdot d} \quad ; \quad \rho' = \frac{As'}{b \cdot d}$$

2. Regangan Tulangan Tarik:

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) \geq \varepsilon_y$$

3. Regangan Tulangan Tekan:

$$\varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) \geq \varepsilon_y'$$

4. Momen Nominal penampang:

$$Mn = Mn_1 + Mn_2$$

$$Mn = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - \tfrac{1}{2} \cdot k) + A_s' \cdot f_y' \cdot (d - d')$$

NB: $\rho_{maks} = 0{,}75 \cdot \rho_b + \rho'$

Kasus-2:

Tulangan Tarik meleleh dan Tekan belum meleleh

1. Persamaan Keseimbangan Gaya:

$C_1 = 0{,}85 \cdot f_c' \cdot k \cdot d \cdot b$

$C_2 = A_s' \cdot f_s'$

$T = A_s \cdot f_y$

$C_1 + C_2 = T$

$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_s' = A_s \cdot f_y$

$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot (\varepsilon_s' \cdot E_s) = A_s \cdot f_y$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot \left[\varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) \right] \cdot E_s = A_s \cdot f_y$$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot \left[0{,}003 \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) \right] \cdot 200.000 = A_s \cdot f_y$$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot 600 \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) = A_s \cdot f_y \quad ----xk$$

$$0{,}85 \cdot f_c' \cdot b \cdot d \cdot k^2 + A_s' \cdot 600 \cdot k - A_s' \cdot 600 \cdot \beta_1 \cdot (d'/d) - A_s \cdot f_y \cdot k = 0$$

$$\left(0{,}85 \cdot f_c' \cdot b \cdot d\right) \cdot k^2 + \left(A_s' \cdot 600 - A_s \cdot f_y\right) \cdot k - A_s' \cdot 600 \cdot \beta_1 .(d'/d) - A_s \cdot f_y = 0$$

$$A = 0{,}85 \cdot f_c' \cdot b \cdot d$$

$$B = A_s' \cdot 600 - A_s \cdot f_y$$

$$C = -A_s' \cdot 600 \cdot \beta_1 .(d'/d)$$

$$k = \frac{-B + \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}$$

2. Regangan Tulangan Tarik:

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) \geq \varepsilon_y$$

3. Regangan Tulangan Tekan:

$$\varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) < \varepsilon_y'$$

4. Momen Nominal penampang:

$$f_s' = E_s \cdot \varepsilon_s'$$

$$M_n = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot \left(1 - \frac{1}{2} \cdot k \right) + A_s' \cdot (d - d') \cdot f_s'$$

$$\text{NB} : \rho_{maks} = 0{,}75 \cdot \rho_b + \rho' \cdot \left(\frac{f_s'}{f_y'} \right)$$

Kasus-3:

Tulangan Tarik belum meleleh dan Tekan meleleh

1. Persamaan Keseimbangan Gaya:

$C_1 = 0{,}85 \cdot f_c' \cdot k \cdot d \cdot b$

$C_2 = A_s' \cdot f_y'$

$T = A_s \cdot f_s$

$C_1 + C_2 = T$

$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_y' = A_s \cdot f_s$

$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_y' = A_s \cdot (\varepsilon_s \cdot E_s)$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_y' = A_s \cdot \left[\varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) \right] \cdot E_s$$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_y' = A_s \cdot 0{,}003 \cdot \left(\frac{\beta_1 - k}{k} \right) \cdot 200.000$$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_y' = A_s \cdot 600 \cdot \left(\frac{\beta_1 - k}{k} \right) ----xk$$

$$\left(0{,}85 \cdot f_c' \cdot b \cdot d \right) \cdot k^2 + \left(A_s' \cdot f_y' + A_s \cdot 600 \right) \cdot k - A_s \cdot 600 \cdot \beta_1 = 0$$

$$A = 0{,}85 \cdot f_c' \cdot b \cdot d$$

$$B = A_s' \cdot f_y' + A_s \cdot 600$$

$$C = -A_s \cdot 600 \cdot \beta_1$$

$$k = \frac{-B + \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}$$

2. Regangan Tulangan Tarik:

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) < \varepsilon_y$$

3. Regangan Tulangan Tekan:

$$\varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) \geq \varepsilon_y'$$

4. Momen Nominal penampang:

$Mn = Mn_1 + Mn_2$

$Mn = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - \frac{1}{2} \cdot k) + A_s' \cdot f_y' \cdot (d - d')$

NB: $\rho_{maks} = 0{,}75 \cdot \rho_b + \rho'$

Kasus-4:

Tulangan Tarik belum meleleh dan Tekan belum meleleh

1. Persamaan Keseimbangan Gaya:

$C_1 = 0{,}85 \cdot f_c' \cdot k \cdot d \cdot b$

$C_2 = A_s' \cdot f_s'$

$T = A_s \cdot f_s$

$C_1 + C_2 = T$

$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot f_s' = A_s \cdot f_s$

$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot (\varepsilon_s' \cdot E_s) = A_s \cdot (\varepsilon_s \cdot E_s)$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot \left[\varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) \right] \cdot E_s = A_s \cdot \left[\varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) \right] \cdot E_s$$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot \left[0{,}003 \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) \right] \cdot 200.000 = A_s \cdot 0{,}003 \cdot \left(\frac{\beta_1 - k}{k} \right) \cdot 200.000$$

$$0{,}85 \cdot f_c' \cdot k \cdot d \cdot b + A_s' \cdot 600 \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) = A_s \cdot 600 \cdot \left(\frac{\beta_1 - k}{k} \right) ----xk$$

$$0{,}85 \cdot f_c' \cdot b \cdot d \cdot k^2 + A_s' \cdot 600 \cdot k - A_s' \cdot 600 \cdot \beta_1 \cdot (d'/d) - A_s \cdot 600 \cdot \beta_1 + A_s \cdot 600 . k = 0$$

$$\left(0{,}85 \cdot f_c' \cdot b \cdot d\right) \cdot k^2 + \left(A_s' \cdot 600 + A_s \cdot 600\right) \cdot k - A_s' \cdot 600 \cdot \beta_1 .(d'/d) - A_s \cdot 600 \cdot \beta_1 = 0$$

$$A = 0{,}85 \cdot f_c' \cdot b \cdot d$$

$$B = 600 \cdot \left(A_s' + A_s\right)$$

$$C = -600 \cdot \beta_1 \cdot \left(A_s' .(d'/d) + A_s\right)$$

$$k = \frac{-B + \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A}$$

3. Regangan Tulangan Tarik:

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) < \varepsilon_y$$

4. Regangan Tulangan Tekan:

$$\varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot (d'/d)}{k} \right) < \varepsilon_y'$$

5. Momen Nominal penampang:

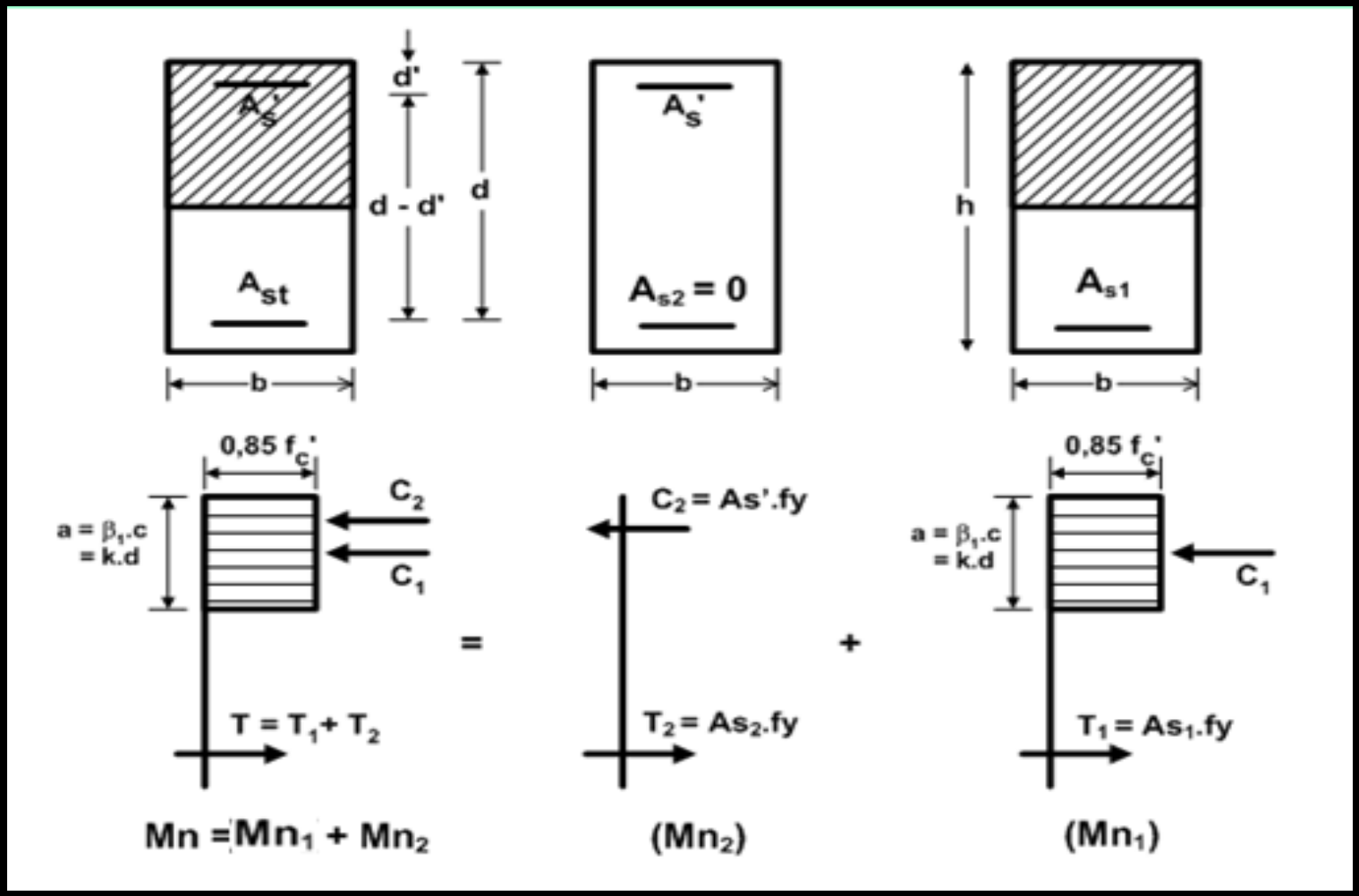
$$Mn = Mn_1 + Mn_2$$

$$Mn = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - \tfrac{1}{2} \cdot k) + A_s' \cdot f_s' \cdot (d - d')$$

NB:

$$\rho_{maks} = 0{,}75 \cdot \rho_b + \rho' \cdot \left(\frac{f_s'}{f_y'} \right)$$

ANALISIS BALOK PERSEGI BERTULANGAN RANGKAP SIMETRIS (As = As')



Prosedur:

1. **Asumsi tulangan tekan meleleh: $\varepsilon_s' \geq \varepsilon_y$**
2. **Hitung:**

   $T_2 = 0$; $T_2 = C_2 = 0$

   $Mn_2 = C_2 \cdot (d - d') = 0$
3. **Hitung:**

   $T_1 = T - T_2 = A_s \cdot f_y - 0 = A_s \cdot f_y$

   $C_1 = T_1 = A_s \cdot f_y$
4. *Hitung* :

$$k = \frac{C_1}{0{,}85 \cdot f_c' \cdot b \cdot d} = \frac{A_s \cdot f_y}{0{,}85 \cdot f_c' \cdot b \cdot d} \Rightarrow k = \frac{f_y}{0{,}85 \cdot f_c'} \cdot \rho$$

$$\rho = \frac{A_s}{b.d} \quad ; \quad \rho' = \frac{A_s'}{b.d}$$

5. Hitung regangan Tulangan Tekan (ε_s')

$$\varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{k - \beta_1 \cdot \left(d'/d \right)}{k} \right)$$

6. Hitung Tegangan Tulangan Tekan (f_s')

Jika $\varepsilon_s' \geq \varepsilon_y'$, maka: $f_s' = f_y'$

Jika $\varepsilon_s' < \varepsilon_y'$, maka: $f_s' = E_s \cdot \varepsilon_s'$

7. Hitung Rasio Tulangan Seimbang (ρ_b)

$$\rho_b = \frac{0{,}85 \cdot f_c'}{f_y} \cdot \beta_1 \cdot \left(\frac{600}{600 + f_y} \right)$$

8. Hitung Rasio Tulangan Minimum (ρ_{min})

Untuk beton fc' < 30 MPa maka :

$$\rho_{min} = \frac{1{,}4}{fy}$$

Untuk beton fc' > 30 MPa maka :

$$\rho_{min} = \frac{\sqrt{fc'}}{4 \cdot fy}$$

tapi tidak boleh kurang dari

$$\rho_{min} = \frac{1{,}4}{fy}$$

9. Hitung rasio tulangan maksimum

$$\rho_{maks} = 0{,}75 \cdot \rho_b + \rho' \cdot \frac{f_s'}{f_y}$$

10. Momen nominal yang ditahan tulangan tarik

$$M_{n1} = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - \tfrac{1}{2}.k)$$

11. Momen nominal kapasitas penampang

$$Mn = Mn1 + Mn2$$

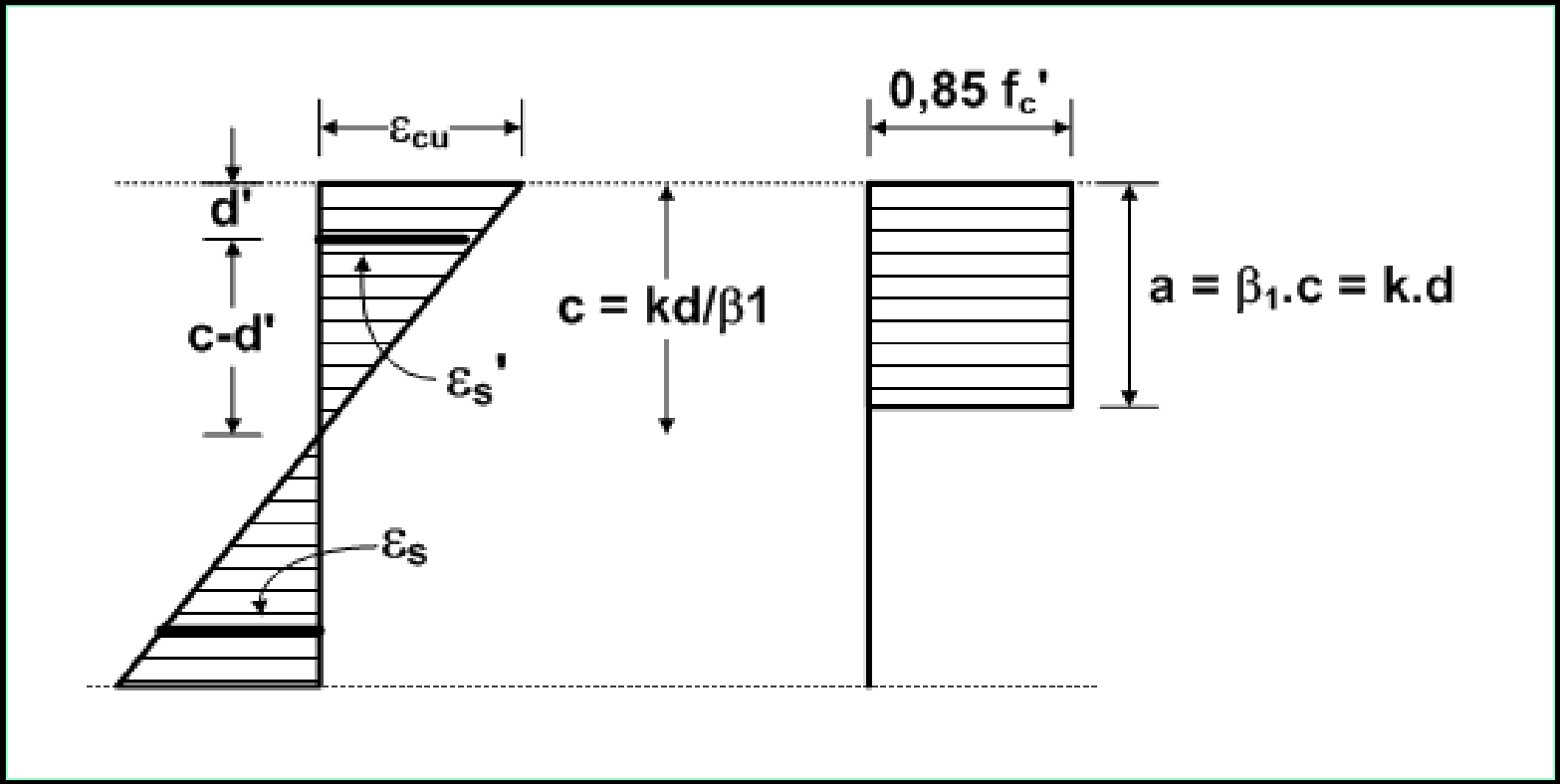
$$Mn = 0{,}85 \,.\, fc' \,.\, b \,.\, d^2 \,.\, k \,.\, (1 - \tfrac{1}{2}.k)$$

12. Momen Rencana Ultimit penampang

$$Mr = \phi \,.\, Mn$$

ANALISIS DIAGRAM REGANGAN PADA TULANGAN TEKAN

Asumsi : tulangan tekan meleleh ($\varepsilon_s' \geq \varepsilon_y$)



$$\frac{\varepsilon_s'}{c-d'} = \frac{\varepsilon_{cu}}{c}$$

$$\varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{c-d'}{c}\right) = \varepsilon_{cu} \cdot \left(\frac{k.d/\beta_1 - d'}{k.d/\beta_1}\right) \quad ; \quad \varepsilon_s' = \varepsilon_{cu} \cdot \left(\frac{k-\beta_1 \cdot (d'/d)}{k}\right)$$

$$\text{Jika} \quad \varepsilon_s' = \varepsilon_y \text{ (leleh) maka}: \; k_y = \beta_1 \cdot \left(\frac{\varepsilon_{cu}}{\varepsilon_{cu} - \varepsilon_y}\right) \cdot \left(\frac{d'}{d}\right)$$

Kontrol tulangan tekan:

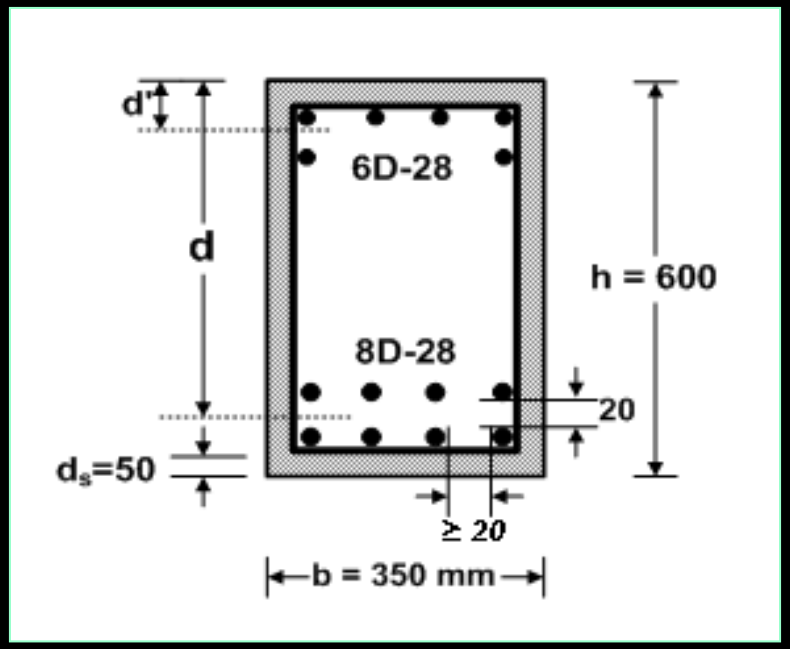
- **Jika $k < k_y$ tulangan tekan belum leleh $f_s' = E_s \cdot \varepsilon_s'$**
- **Jika $k \geq k_y$ maka tulangan tekan leleh atau:**

$$\frac{f_y}{0{,}85 \cdot f_c'} \cdot (\rho - \rho') \geq \beta_1 \cdot \frac{\varepsilon_{cu}}{\varepsilon_{cu} - \varepsilon_y} \cdot \left(\frac{d'}{d}\right) \; ; \; \varepsilon_{cu} = 0{,}003 \; ; \; E_s = 2 \times 10^5 \; MPa$$

$$(\rho - \rho') \geq \left(\frac{0{,}85 \cdot f_c'}{f_y \cdot d}\right) \cdot \left(\frac{600}{600 - f_y}\right) \cdot \beta_1 \cdot d'$$

Contoh soal 3:

Sebuah balok segiempat diatas 2 tumpuan bentang (L) = 10 m dan memikul beban merata berfaktor total sebesar q_u, dimensi lebar 350 mm, tinggi 600 mm, diameter sengkang 8 mm dan jarak minimum antar tulangan 20 mm.



Tulangan tarik 8D-28,
Tulangan tekan 6D-28,
Selimut beton 50 mm,
f_y = 350 MPa, dan f_c' = 22 MPa.

Hitunglah besarnya beban q_u yang dapat dipikul balok!

Penyelesaian:

- Perhitungan titik tangkap tulangan:

Titik Berat Tulangan Tekan thd. Serat Tekan				
Lapis	n	A_s'	x	$A_s'.x$
1	4	2463,009	72	177336,6
2	2	1231,504	120	147780,5
Total	6	3694,513		325117,1

$$d' = \frac{\sum A_s' \cdot x}{\sum A_s'} = 88 \ mm$$

Titik Berat Tulangan Tarik thd. Serat Tekan				
Lapis	**n**	**A_s**	**x**	**A_s.x**
1	4	2463,009	72	177336,6
2	4	2463,009	120	295561,0
Total	8	4926,017		472897,7

$$d = h - \frac{\sum A_s \cdot x}{\sum A_s} = 504\ mm$$

- **Nilai β_1, f_c' = 22 MPa --------- β_1 = 0,85**
- **Faktor Reduksi Kekuatan ----- ϕ = 0,80 (lentur)**
  - *Hitung rasio tulangan*:

$$A_s' = 6 \cdot 615{,}752 = 3694{,}513\ mm^2$$

$$\Rightarrow \rho' = \frac{A_s'}{b \cdot d} = \frac{3694{,}513}{350 \cdot 504} = 0{,}02094$$

$$A_s = 8 \cdot 615{,}752 = 4926{,}017\ mm^2$$

$$\Rightarrow \rho = \frac{A_s}{b \cdot d} = \frac{4926{,}017}{350 \cdot 504} = 0{,}02793$$

- *Check batasan rasio tulangan*

  (asumsi tulangan tekan leleh)

$$\rho_b = \frac{0{,}85 \cdot f_c'}{f_y} \cdot \beta_1 \cdot \left(\frac{600}{600 + f_y} \right) = \frac{0{,}85 \cdot 22}{350} \cdot 0{,}85 \cdot \left(\frac{600}{600 + 350} \right)$$

$$= 0{,}02868$$

$$\rho_{maks} = 0{,}75 \cdot \rho_b + \rho' = 0{,}75 \cdot 0{,}02868 + 0{,}02094 = 0{,}04246$$

$$\rho = 0{,}02793 < \rho_{maks} = 0{,}04246 \Rightarrow \text{ker untuhan tarik}$$

- *Check kondisi leleh tulangan tekan*

$$\rho - \rho' \geq \left(\frac{0{,}85 f_c'}{f_y \cdot d} \right) \cdot \left(\frac{600}{600 - f_y} \right) \cdot \beta_1 \cdot d'$$

$$0{,}02793 - 0{,}02094 \geq \left(\frac{0{,}85 \cdot 22}{350 \cdot 504} \right) \cdot \left(\frac{600}{600 - 350} \right) \cdot 0{,}85 \cdot 88$$

$$0{,}00698 \leq 0{,}01903 \Rightarrow \textit{tidak memenuhi artinya}$$

tul. tekan belum meleleh

- *Tulangan tekan belum leleh*

$$k = -\left(\frac{\rho'\cdot\varepsilon_{cu}\cdot E_s - \rho\cdot f_y}{1{,}7\cdot f_c'}\right) + \sqrt{\left(\frac{\rho'\cdot\varepsilon_{cu}.E_s - \rho\cdot f_y}{1{,}7\cdot f_c'}\right)^2 + \left(\frac{\rho'\cdot\varepsilon_{cu}.E_s.\beta_1.d'/d}{0{,}85\cdot f_c'}\right)}$$

$$k = -\left(\frac{0{,}02094\cdot 0{,}003\cdot 2\cdot 10^5 - 0{,}02793\cdot 350}{1{,}7\cdot 22}\right)$$

$$+\sqrt{\left(\frac{0{,}02094\cdot 0{,}003\cdot 2\cdot 10^5 - 0{,}02793\cdot 350}{1{,}7\cdot 22}\right)^2 + \left(\frac{0{,}02094\cdot 0{,}003\cdot 2\cdot 10^5\cdot 0{,}85\cdot 88/504}{0{,}85\cdot 22}\right)}$$

$$k = -\ 0{,}07466 + 0{,}32451 = 0{,}24985$$

- Re *gangan tulangan tekan yang terpasang* :

$$\varepsilon_s' = \varepsilon_{cu} \cdot \frac{k - \beta_1 \cdot (d'/d)}{k} = 0{,}003 \cdot \frac{0{,}24985 - 0{,}85 \cdot (88/504)}{0{,}24985}$$

$$= 0{,}00122 < \varepsilon_y = 0{,}0018$$

$$f_s' = E_s \cdot \varepsilon_s' = 200000 \cdot 0{,}00122$$

$$= 243{,}590 \ MPa$$

- Re *gangan tulangan tarik yang terpasang* :

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) = 0{,}003 \cdot \left(\frac{0{,}85 - 0{,}24985}{0{,}24985} \right)$$

$$= 0{,}00721 > \varepsilon_y = 0{,}0018 \ (leleh)$$

- *Koreksi rasio tulangan tarik maksimum karena tulangan tekan belum leleh*

$$\rho_{maks} = 0{,}75 \cdot \rho_b + \rho' \cdot \frac{f_s'}{f_y} = 0{,}75 \cdot 0{,}02868 + 0{,}02094 \cdot \frac{243{,}590}{350} = 0{,}0361$$

$$\rho = 0{,}02793 < \rho_{maks} = 0{,}0361 \rightarrow \text{keruntuhan tarik}$$

Hitung Momen Nominal:

Momen Nominal Akibat Tulangan Tarik:

$M_{n1} = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - \frac{1}{2} \cdot k)$

$M_{n1} = 0{,}85 \cdot 22 \cdot 350 \cdot 504^2 \cdot 0{,}24985 \cdot (1 - \frac{1}{2} \cdot 0{,}24985) \cdot 10^{-6}$

$= 363{,}487$ kN.m

Momen Nominal Akibat Tulangan Tekan:

$M_{n2} = A_s' \cdot (d - d') \cdot f_s'$

$= 3694{,}513 \cdot (504 - 88) \cdot 243{,}590 \cdot 10^{-6}$

$= 374{,}377$ kN.m

Momen Nominal Total (M_n):

$M_n = M_{n1} + M_{n2} = 363{,}487 + 374{,}377 = 737{,}864$ kN.m

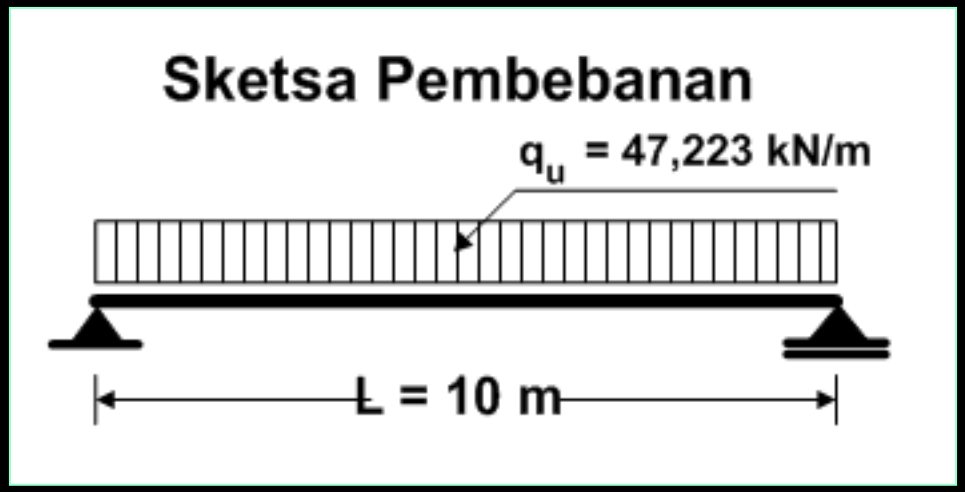
Momen Rencana ultimit (M_r):

$M_r = \phi \cdot M_n$

$M_r = 0{,}80 \cdot 737{,}864 = 590{,}291$ kN.m

Beban merata berfaktor yang mampu dipikul balok (qu):

$$M_r = \frac{1}{8} \cdot q_u \cdot L^2 \; ; \; q_u = \frac{8 \cdot M_r}{L^2} = \frac{8 \cdot 590{,}291}{10^2} = 47{,}223 \; kN/m$$



Contoh soal 4:

Sebuah balok lebar 300 mm dan tinggi 550 mm, mutu beton f_c' = 20 MPa dan mutu baja f_y = 300 MPa. Tulangan tarik 4D-25, selimut beton 50 mm. Hitung kapasitas momen nominal & momen desain dari penampang ini bila:

a. Tulangan tekan 2D-13

b. Tulangan tekan 3D-19

Penyelesai an :

a. Tulangan tekan 2D-13

- Hitung rasio tulangan :

$$A_s' = 2.133 = 266\ \text{mm}^2 \Rightarrow \rho' = \frac{As'}{b \cdot d} = \frac{266}{300 \cdot 500} = 0{,}00177$$

$$A_s = 4.490 = 1960\ \text{mm}^2 \Rightarrow \rho = \frac{A_s}{b \cdot d} = \frac{1960}{300 \cdot 500} = 0{,}013$$

- Check batasan rasio tulangan

(asumsi tulangan tekan leleh) :

$$\rho_b = \frac{0{,}85 \cdot f_c'}{f_y} \cdot \beta_1 \cdot \left(\frac{600}{600 + f_y} \right)$$

$$= \frac{0{,}85 \cdot 20}{300} \cdot 0{,}85 \cdot \left(\frac{600}{600 + 300} \right) = 0{,}0321$$

$$\rho_{maks} = 0{,}75 \cdot \rho_b + \rho' = 0{,}75 \cdot 0{,}0321 + 0{,}00177 = 0{,}0258$$

$$\rho = 0{,}013 < \rho_{maks} = 0{,}0258 \Rightarrow \text{ker}\textit{untuhan tarik}$$

- *Hitung nilai k*

$$k = \frac{f_y}{0{,}85 \cdot f_c'} \cdot [\rho - \rho'] = \frac{300}{0{,}85 \cdot 20} \cdot [0{,}013 - 0{,}00177]$$

$$= 0{,}1982$$

- Check regangan tulangan baja :

$$\varepsilon_y = f_y / E_s = 300/200000 = 0{,}0015$$

$$\varepsilon_s' = \varepsilon_{cu} \cdot \frac{k - \beta_1 \cdot \left(d'/d\right)}{k} = 0{,}003 \cdot \frac{0{,}1982 - 0{,}85 \cdot \left(50/500\right)}{0{,}1982}$$

$$= 0{,}0017 \geq \varepsilon_y \ (leleh)$$

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k}\right) = 0{,}003 \cdot \left(\frac{0{,}85 - 0{,}1982}{0{,}1982}\right) = 0{,}0099 \geq \varepsilon_y \ (leleh)$$

- Tulangan baja tekan meleleh :

$$M_{n1} = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - ½ \cdot k)$$

$$M_{n1} = 0{,}85 \cdot 20 \cdot 300 \cdot 500^2 \cdot 0{,}1982 \,.\, (1 - ½ \cdot 0{,}1982) \cdot 10^{-6} = 227{,}66 \ \text{kN.m}$$

$$M_{n2} = A_s \cdot (d - d') \cdot f_y = 266 \cdot (500 - 50) \cdot 300 \cdot 10^{-6} = 35{,}91 \ \text{kN.m}$$

Momen Nominal (Mn):

$M_n = M_{n1} + M_{n2} = 227,66 + 35,91 = 263,57$ kN.m

Momen Rencana Ultimit (Mr):

$M_r = \phi \cdot M_n$; $M_r = 0,80 \cdot 263,57 = 210,856$ kN.m

b. Tulangan tekan 3D-19

- Hitung ratio tulangan

$$A_s' = 3 \cdot 284 = 852\ mm^2 \Rightarrow \rho' = \frac{As'}{b \cdot d} = \frac{852}{300 \cdot 500} = 0,00568$$

$$A_s = 4 \cdot 490 = 1960\ mm^2 \Rightarrow \rho = \frac{A_s}{b \cdot d} = \frac{1960}{300 \cdot 500} = 0,013$$

- *Hitung nilai k*

$$k = \frac{f_y}{0,85 \cdot fc'} \cdot [\rho - \rho'] = \frac{300}{0,85 \cdot 20} \cdot [0,013 - 0,0056] = 0,129$$

- Check regangan tulangan baja

$$\varepsilon_y = f_y / E_s = 300/200000 = 0{,}0015$$

$$\varepsilon_s' = \varepsilon_{cu} \cdot \frac{k - \beta_1 \cdot (d'/d)}{k} = 0{,}003 \cdot \frac{0{,}129 - 0{,}85 \cdot (50/500)}{0{,}129}$$

$$= 0{,}0010 < \varepsilon_y \ (belum \ \ leleh)$$

$$\varepsilon_s = \varepsilon_{cu} \cdot \left(\frac{\beta_1 - k}{k} \right) = 0{,}003 \cdot \left(\frac{0{,}85 - 0{,}129}{0{,}129} \right) = 0{,}0168 \ > \varepsilon_y \ (leleh)$$

Tulangan tekan belum meleleh

$$k = -\left(\frac{\rho' \cdot \varepsilon_{cu} \cdot E_s - \rho \cdot f_y}{1{,}7 \cdot f_c'} \right) + \sqrt{\left(\frac{\rho' \cdot \varepsilon_{cu} \cdot E_s - \rho \cdot f_y}{1{,}7 \cdot f_c'} \right)^2 + \left(\frac{\rho' \cdot \varepsilon_{cu} \cdot E_s \cdot \beta_1 \cdot d'/d}{0{,}85 \cdot f_c'} \right)}$$

$$k = -\left(\frac{0{,}00568 \cdot 0{,}003 \cdot 2 \cdot 10^5 - 0{,}013 \cdot 300}{1{,}7 \cdot 20}\right) + \sqrt{\left(\frac{0{,}00568 \cdot 0{,}003 \cdot 2 \cdot 10^5 - 0{,}013 \cdot 300}{1{,}7 \cdot 20}\right)^2 + \left(\frac{0{,}00568 \cdot 0{,}003 \cdot 2 \cdot 10^5 \cdot 0{,}85 \cdot 50/500}{0{,}85 \cdot 20}\right)}$$

$$\mathrm{k} = -(-0{,}0145) + 0{,}1313 = 0{,}1458$$

$$\varepsilon_s' = \varepsilon_{cu} \cdot \frac{k - \beta_1 \cdot (d'/d)}{k}$$

$$= 0{,}003 \cdot \frac{0{,}1458 - 0{,}85 \cdot (50/500)}{0{,}1458} = 0{,}0013 < \varepsilon_y$$

$$\mathrm{f_s'} = \mathrm{E_s} \,.\, \varepsilon_s' = 2.105.0{,}0013 = 260\ MPa$$

Hitung Momen Nominal:

$M_{n2} = A_s' \cdot (d - d') \cdot f_s' = 852 \cdot (500 - 50) \cdot 260 \cdot 10^{-6}$

$= 99{,}68$ kN.m

$M_{n1} = 0{,}85 \cdot f_c' \cdot b \cdot d^2 \cdot k \cdot (1 - \frac{1}{2} \cdot k)$

$M_{n1} = 0{,}85 \cdot 20 \cdot 300 \cdot 500^2 \cdot 0{,}1458 \cdot (1 - \frac{1}{2}.0{,}1458) \cdot 10^{-6}$

$= 172{,}34$ kN.m

Momen Nominal Total (M_n):

$M_n = M_{n1} + M_{n2} = 172{,}34 + 99{,}68 = 272{,}02$ kN.m

Momen Rencana Ultimit (M_r):

$M_r = \phi \, . \, M_n$

$M_r = 0{,}80 \cdot 272{,}02 = 217{,}62$ kN.m

Kesimpulan:

Tul. Tekan	ρ'	Rasio ρ'	Mn	Rasio Mn	k
2D-13	0,00177	1,00	263,57	1,00	0,1982
3D-19	0,00568	3,20	272,02	1,03	0,1458

- Peningkatan tulangan tekan sampai sebesar 3,2 x hanya memberikan sedikit kenaikan nilai momen nominal.
- Semakin besar rasio tulangan tekan akan menyebabkan nilai k semakin kecil ($\rho' \sim 1/k$)
- Semakin besar rasio tulangan tekan akan menyebabkan nilai kapasitas rotasi balok akan semakin besar pula ($\rho' \sim \varphi$) sehingga balok akan semakin daktail ($\varphi \sim \mu_\varphi$).

$$\varphi = kapasitas\ rotasi = \frac{\varepsilon_c}{c} = \varepsilon_c \frac{\beta_1}{k \cdot d} = \frac{1}{k} \cdot \frac{\varepsilon_c \cdot \beta_1}{d}$$

$$\mu_\varphi = \text{daktilitas kurvature} = \frac{\varphi_u}{\varphi_y}$$

$$\rho' \approx \frac{1}{\Delta_{cp+sh}} \; ; \; \Delta_{cp+sh} = \frac{T}{1 + 50 \cdot \rho'} \cdot \Delta_{DL}$$

- **Semakin besar rasio tulangan tekan akan mengurangi lendutan akibat creep dan susut.**

Kontrol Kapasitas Minimum Momen

Kapasitas Minimum Momen Positif dan Momen Negatif

SNI 03-2847-02 Pasal 23.3.2.2

(2) Kuat lentur positif komponen struktur lentur pada muka kolom tidak boleh lebih kecil dari setengah kuat lentur negatifnya pada muka tersebut. Baik kuat lentur negatif maupun kuat lentur positif pada setiap penampang di sepanjang bentang tidak boleh kurang dari seperempat kuat lentur terbesar yang disediakan pada kedua muka kolom tersebut.

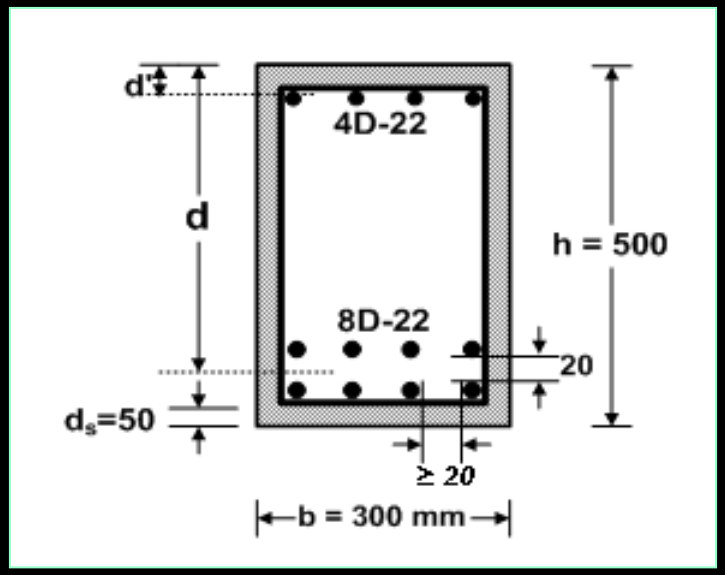
Momen positif-negatif terbesar pada bentang	= **391**	kN-m.
1/4 momen negatif terbesar	= **98**	kN-m.

Maka nilai dari kapasitas momen positif dan negatif dari tulangan yang terpasang nilainya tidak boleh kurang dari 98 kN-m.

Umpan Balik Modul 4

Soal 1:

Sebuah balok segiempat diatas 2 tumpuan bentang (L) = 10 m dan memikul beban merata berfaktor total sebesar q_u, dimensi lebar 300 mm, tinggi 500 mm, diameter sengkang 8 mm dan jarak minimum antar tulangan 20 mm.



Tulangan tarik 8D-22,
Tulangan tekan 4D-22,
Selimut beton 50 mm,
f_y = 240 MPa, dan f_c' = 20 MPa.

Hitunglah besarnya beban q_u yang dapat dipikul balok.

Umpan Balik Modul 4

Soal 2:

Desainlah balok segiempat dengan momen ultimit Mu = 400 kN.m, dimensi balok dibatasi b = 30 cm, h = 50 cm, dan d = 45 cm. Jika mutu baja f_y = 400 MPa dan mutu beton fc' = 32 MPa. Hitung luas tulangan yang diperlukan.