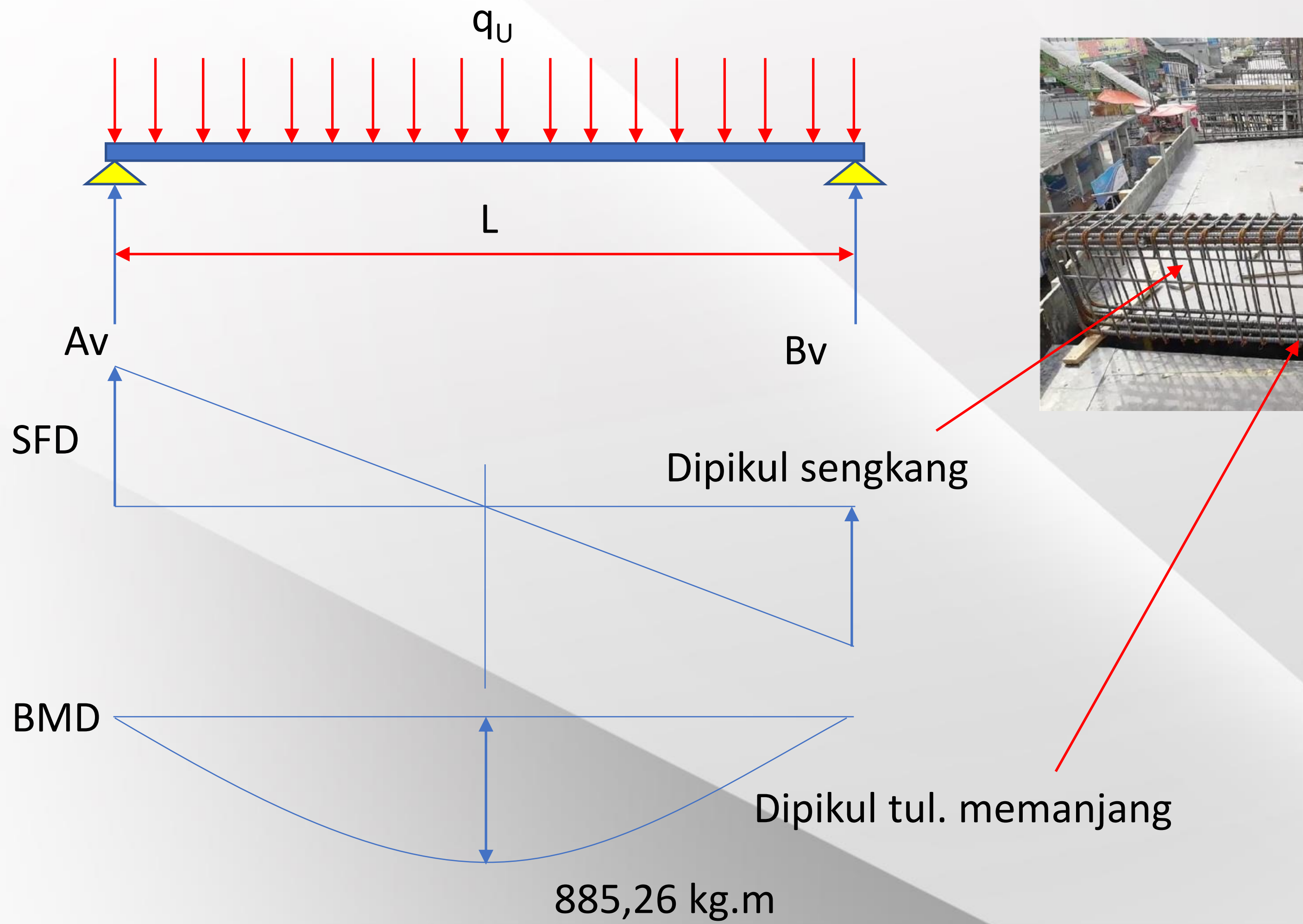
Mata Kuliah : Perancangan Struktur Beton
Kode : TSI-303
SKS : 3 sks

Analisis Lentur Pada Balok Persegi Tulangan Tunggal

Pertemuan - 3

- Sub Pokok Bahasan :
  - Asumsi Dasar Analisis Lentur Pada Balok
  - Analisis Lentur Penampang Balok Persegi

- Activity 1
- Watching video

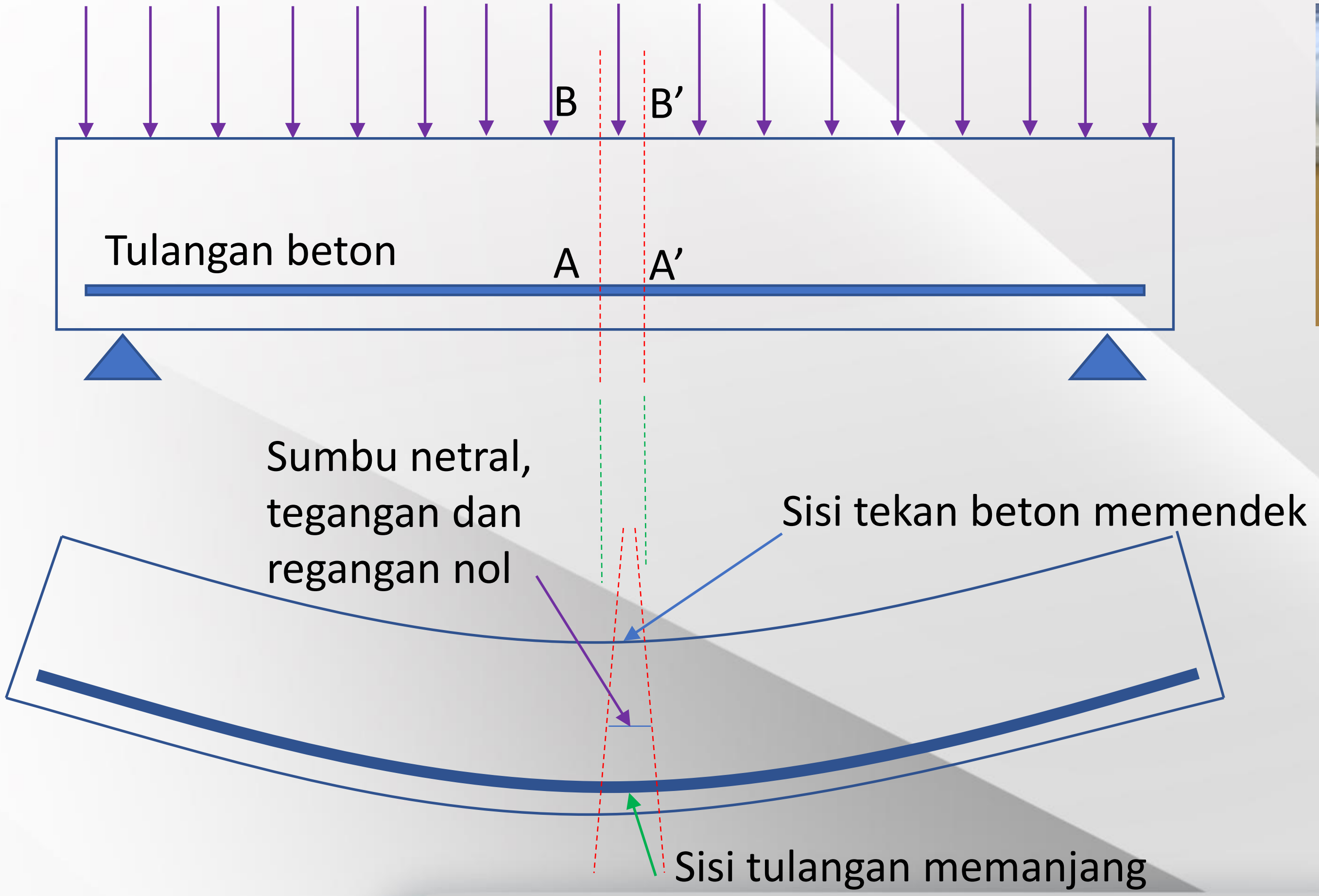

q_U
L
Av
Bv
SFD
Dipikul sengkang
BMD
Dipikul tul. memanjang
885,26 kg.m

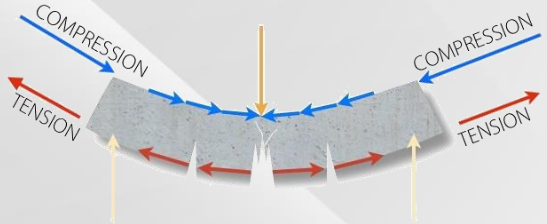
Asumsi Dasar

Metode kekuatan (*Strength Design Method*) atau **metode ultimit** :

- Distribusi regangan pada beton adalah **linear**
- Modulus Elastistisitas baja, **E_s = 200.000 MPa**
- Penampang datar akan tetap datar setelah terjadi lentur
- Kuat tarik dari beton diabaikan
- regangan maksimum serat tekan beton terluar = **ε'_{cu} = 0,003**
- bentuk dari distribusi tegangan tekan beton diasumsikan berupa persegi empat

Asumsi Dasar





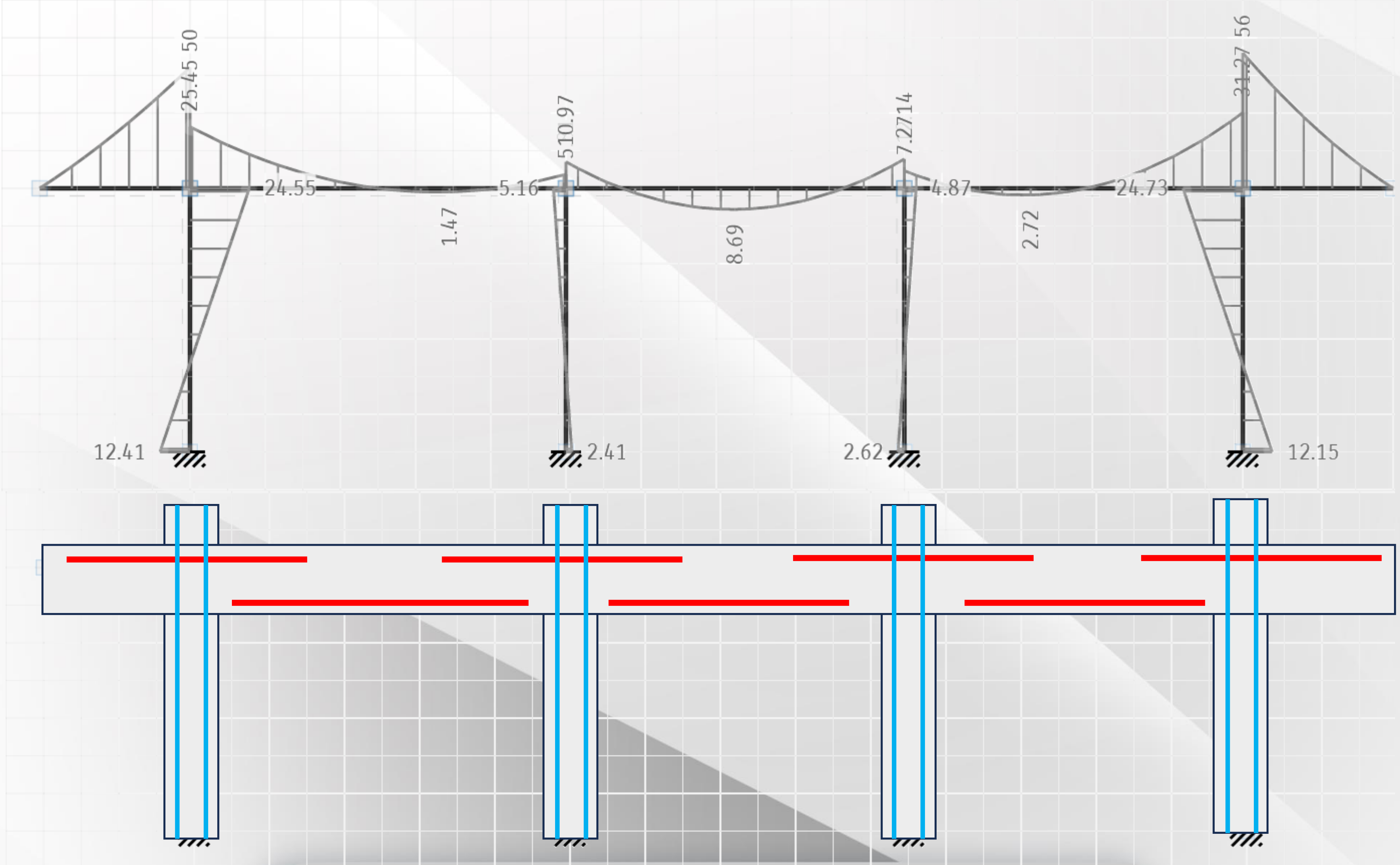

24.55
1.47
5.16
8.69
4.87
2.72
24.73
12.41
2.41
2.62
12.15

Diagram regangan

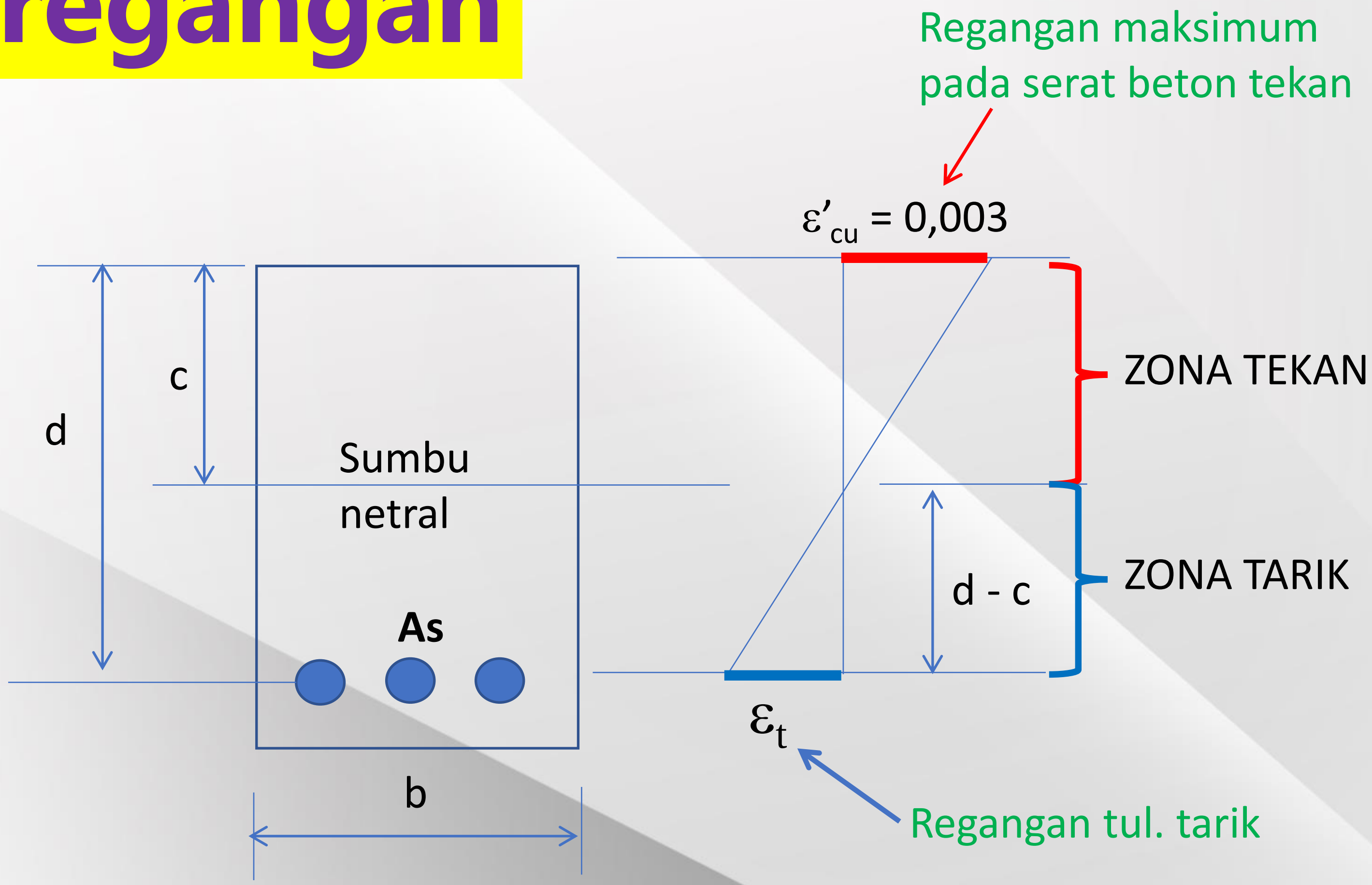
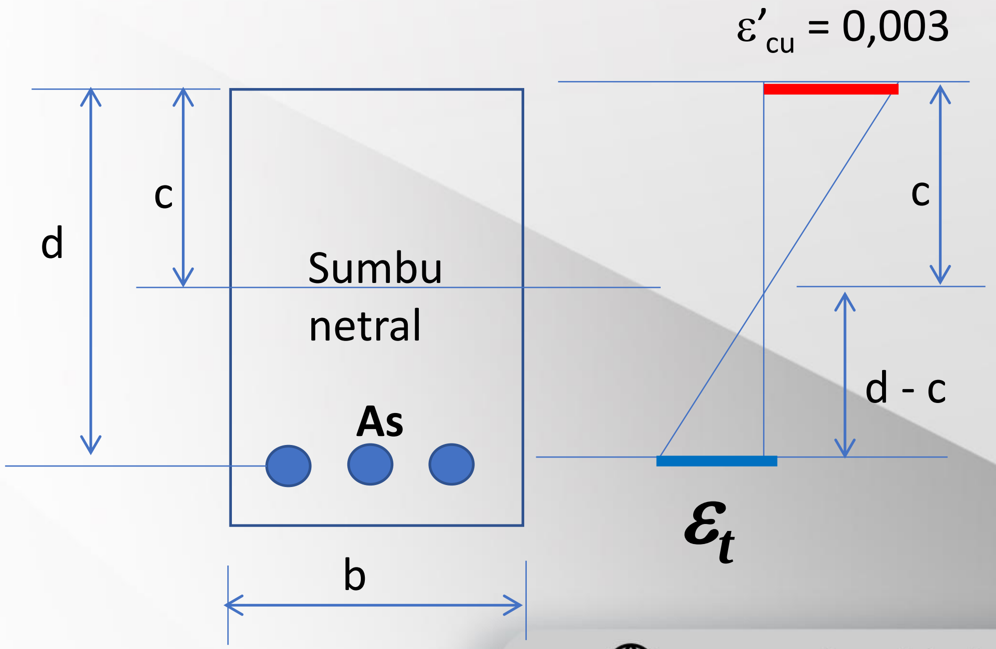


Diagram regangan

- **Kondisi regangan seimbang (*balanced strain condition*), $\varepsilon_t = \varepsilon_y$**
- **Penampang terkendali tekan (*compression controlled section*), $\varepsilon_t \leq \varepsilon_{ty}$**
- **Penampang terkendali tarik (*tension controlled section*), $\varepsilon_t \geq 0{,}005$**



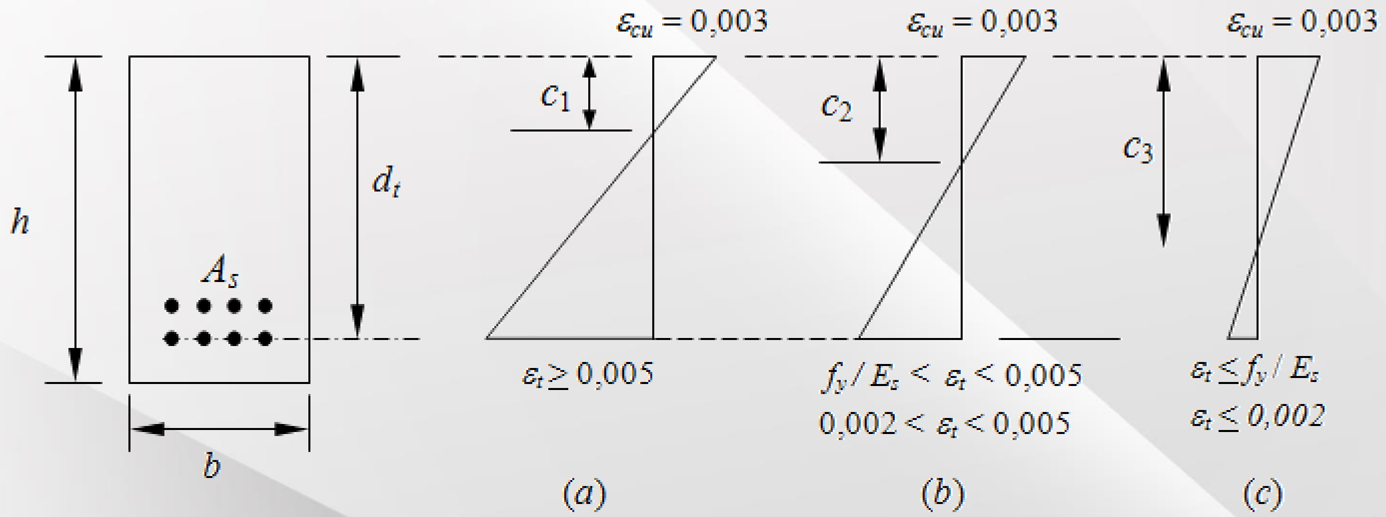
$$\varepsilon_t = \frac{d-c}{c}0{,}003$$

$\varepsilon_{ty} = f_y/E_s$

Untuk f_y = 400 MPa, maka ε_y = 400/200.000 = **0,002**

ε_t tidak boleh kurang dari 0,004

Diagram regangan



Terkendali Tarik   Transisi   Terkendali Tekan

*) ε_t diukur hingga **<u>tulangan terluar</u>**

Diagram Tegangan

- SNI 2847:2019 **ps. 22.2.2.4.1 :** distribusi blok tegangan ekuivalen berbentuk **empat persegi panjang** (Blok Tegangan Whitney, 1937)

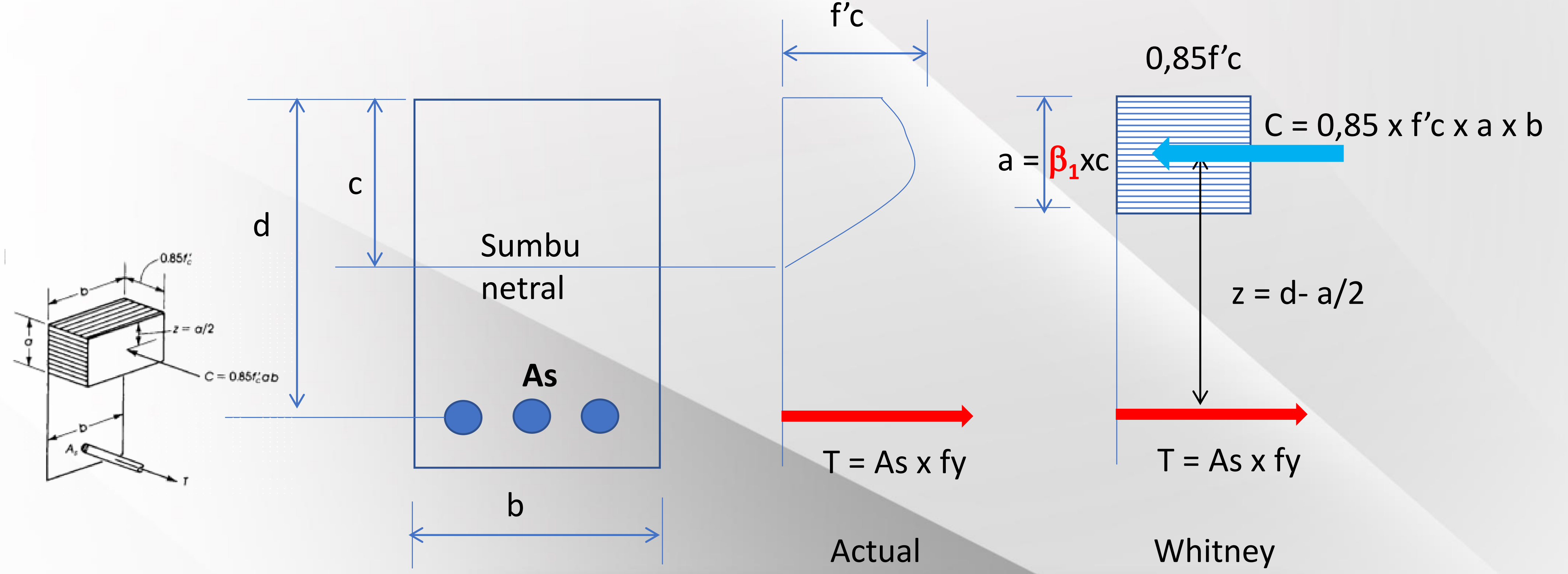
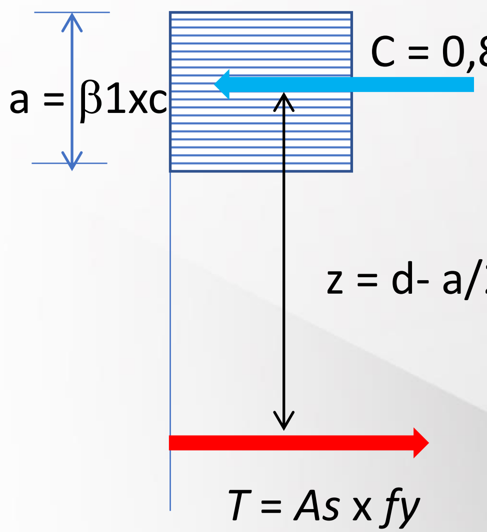


Diagram Tegangan

- Faktor β_1 dapat dihitung sebagai berikut :
  - untuk kuat tekan beton, 17 $\leq f'_c \leq$ 28 MPa $\beta_1 = 0{,}85$
  - untuk 28 MPa < f'_c < 55 MPa $\beta_1 = 0{,}85 - 0{,}05\dfrac{f'_c - 28}{7}$
  - Untuk f'_c lebih dari 55 Mpa $\beta_1 = 0{,}65$

Momen Nominal



$\Sigma H = 0$ $\quad C = T$

$$0{,}85 \times f'_c \times a \times b = A_s \times f_y$$

$$a = \frac{0{,}85\, f_c'.b}{A_s\, f_y}$$

Setelah ***a*** diperoleh maka M_n dapat dihitung

$$M_n = 0{,}85\, f_c' a \cdot b \left(d - \frac{a}{2} \right) = A_s \cdot f_y \left(d - \frac{a}{2} \right)$$

Rasio tulangan, ρ, dinyatakan dalam bentuk

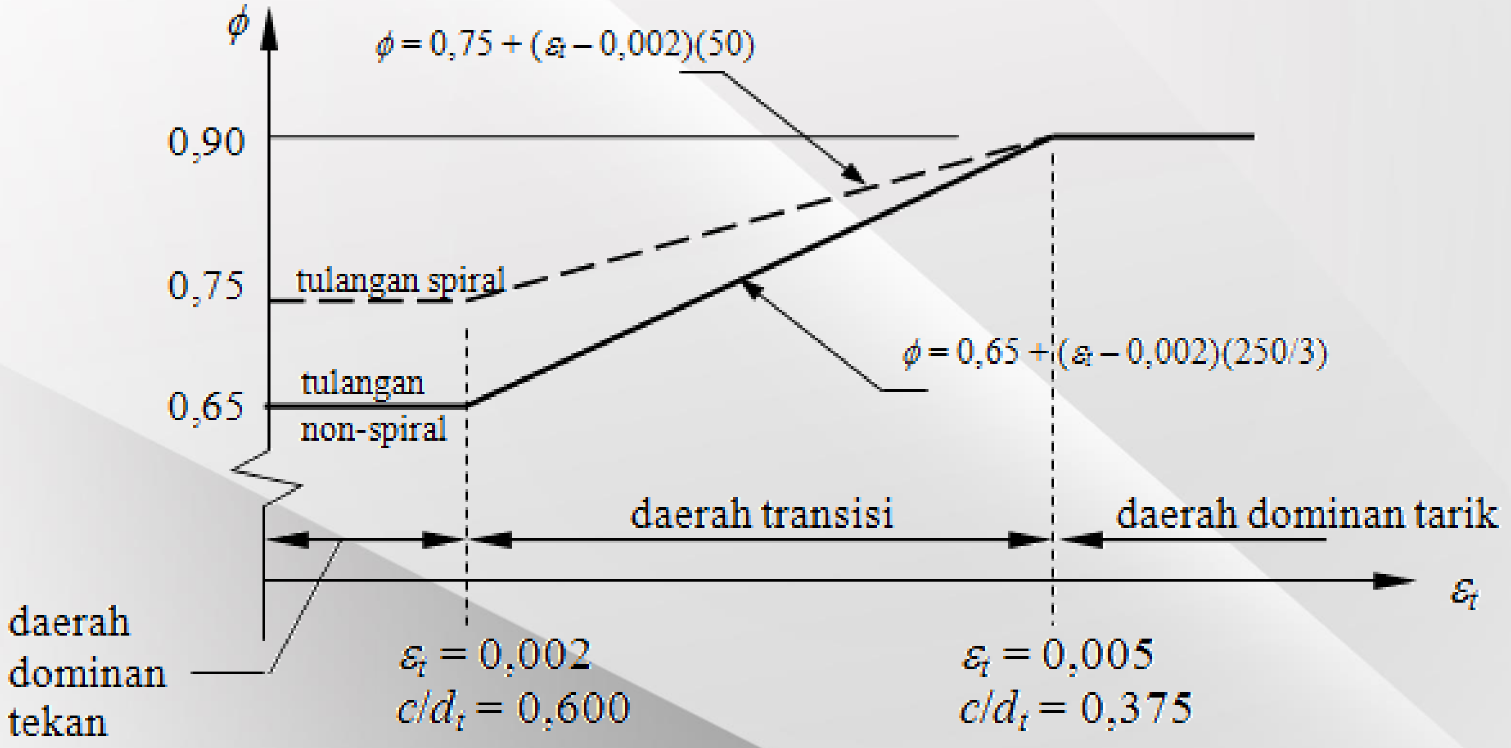
$$\rho = \frac{A_s}{b \times d}$$

Faktor Reduksi Kekuatan

Dalam SNI 2847:2019, pasal 21.2.1 digunakan beberapa nilai faktor reduksi kekuatan, ϕ, sebagai berikut :

- untuk penampang terkontrol tarik $\phi = 0{,}90$
- untuk penampang terkontrol tekan
  - dengan tulangan spiral $\phi = 0{,}75$
  - tulangan non-spiral $\phi = 0{,}65$
- untuk geser dan puntir $\phi = 0{,}75$
- untuk tumpu pada beton $\phi = 0{,}65$

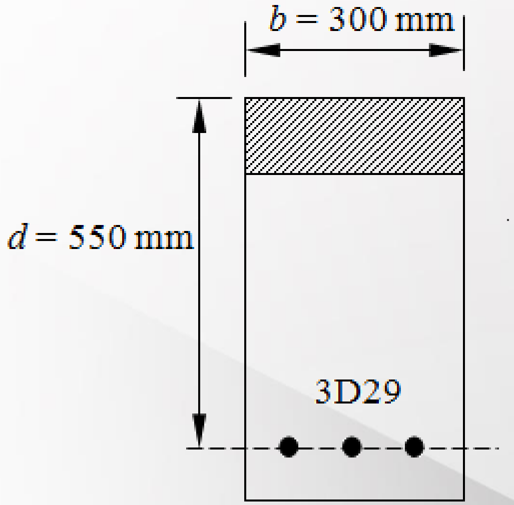
Faktor Reduksi Kekuatan



Untuk komponen struktur lentur beton bertulang, nilai ε_t harus sama atau lebih besar daripada 0,004 !

Contoh 1 *(tension controlled section)*

Tentukan besarnya kuat momen rencana, ϕM_n



$$A_s = 3 \times \frac{1}{4} \pi 29^2 = 1981{,}6 mm^2$$

f'_c = 20 MPa dan f_y = 400 MPa

$a = A_s.f_y/(0{,}85f'c.b)$
$= 1981{,}6(400)/(0{,}85x20x300) = 155{,}42$ mm

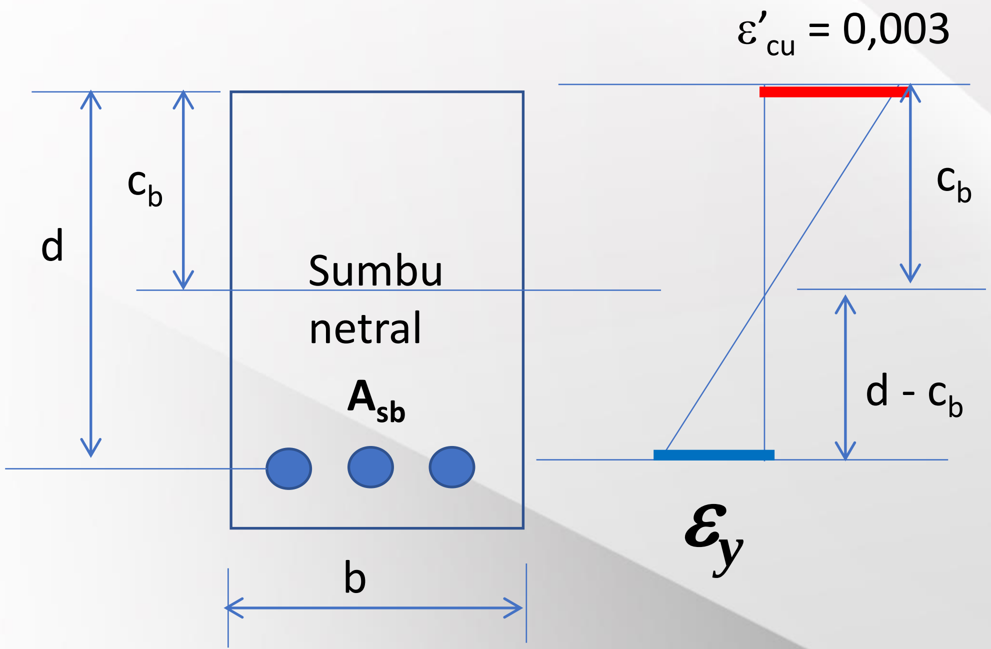
$c = a/\beta_1 = 155{,}42/0{,}85 = 182{,}85$ mm
$c/d_t = 182{,}85/550 = 0{,}3324 < 0{,}375$
(*tension controlled*) –> $\phi = 0{,}90$

$M_n = A_s.f_y\,(d-a/2) = 1981{,}6(400)(550 - (155{,}42/2))$
= 374.355.945,6 N.mm = 374,35 kN.m

ϕM_n = 0,90(374,35) = **336,91 kN.m**

Balanced Section

$\varepsilon_t = \varepsilon_y$ (=0,002)



$\varepsilon_y = f_y/E_s = fy/200.000 = 0,002$

$$\frac{\varepsilon'_{cu}}{\varepsilon_y} = \frac{c_b}{d - c_b}$$

$$(d - c_b)0,003 = c_b \frac{f_y}{200.000}$$

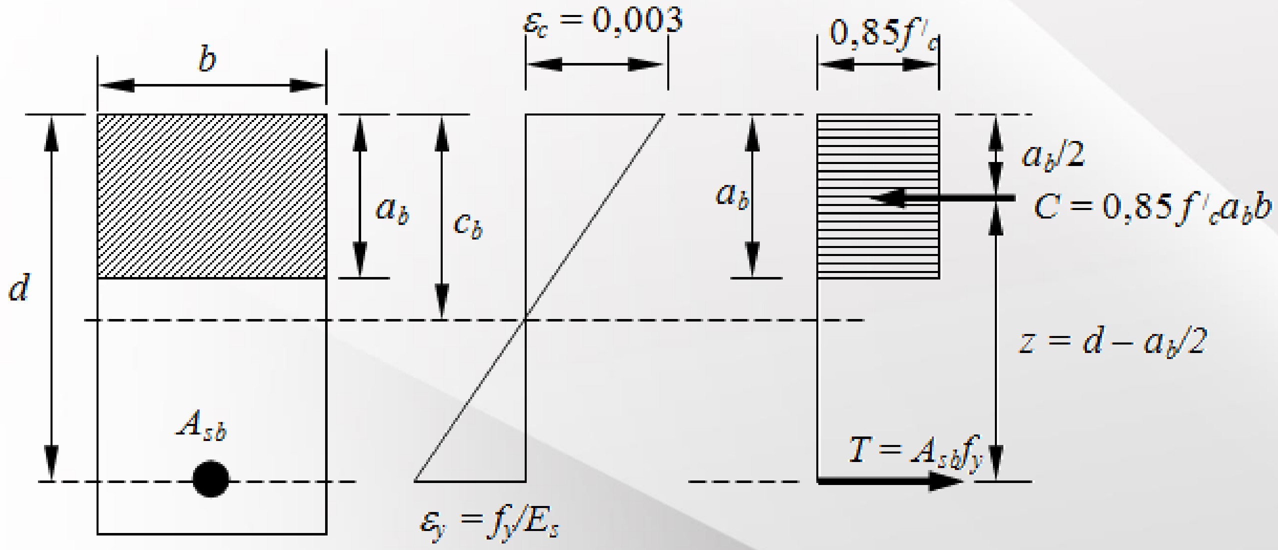
$$(d - c_b)600 = c_b f_y$$

$$600d - 600c_b = c_b f_y$$

$$600d = (600 + f_y)c_b$$

$$c_b = \left(\frac{600}{600 + f_y}\right)d$$

Balanced Section



Penampang Persegi Pada Kondisi Seimbang

$$C = T$$
$$0{,}85\, f'_c a_b b = A_{sb} f_y$$

$$A_{sb} = \frac{0{,}85\, f'_c a_b b}{f_y}$$

$$A_{sb} = \frac{0{,}85\, f'_c \beta_1 c_b b}{f_y}$$

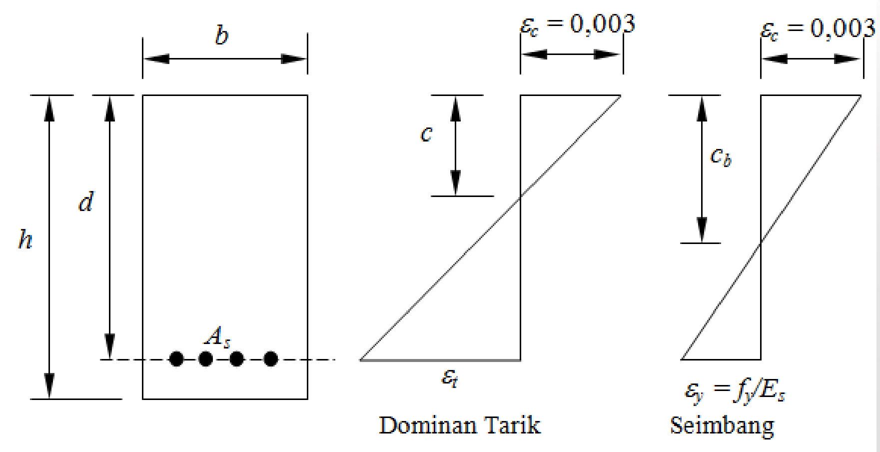
$$\rho_b = \frac{A_{sb}}{bd} = \frac{0{,}85\, f'_c \beta_1 b}{bd}\left(\frac{600}{600 + f_y}\right)d$$

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

Parameter ρ disebut sebagai rasio tulangan tarik yang besarnya sama dengan Luas Tulangan dibagi luas penampang beton efektif

Batas regangan tulangan

- **SNI 2847:2019 pasal 9.3.3.1** mensyaratkan bahwa nilai ε_t pada kondisi kuat lentur nominal harus lebih besar atau sama dengan 0,004.



$$c_b = \frac{a_b}{\beta_1} = \frac{A_{sb}\cdot f_y}{0{,}85 f'_c \beta_1 b} = \frac{\rho_b f_y d}{0{,}85 f'_c \beta_1}$$

$$c = \frac{\rho \cdot f_y d}{0{,}85 f'_c \beta_1}$$

$$\frac{c}{c_b} = \frac{\rho}{\rho_b}$$

$$\frac{c}{d} = \frac{\rho}{\rho_b}\frac{c_b}{d} = \left(\frac{\rho}{\rho_b}\right)\left(\frac{0{,}003}{0{,}003 + f_y/E_s}\right)$$

karena $\dfrac{c}{d} = \dfrac{0{,}003}{0{,}003+\varepsilon_t}$

$$\frac{0{,}003}{0{,}003+\varepsilon_t} = \left(\frac{\rho}{\rho_b}\right)\left(\frac{0{,}003}{0{,}003 + f_y/E_s}\right)$$

sehingga $\dfrac{\rho}{\rho_b} = \dfrac{0{,}003 + f_y/E_s}{0{,}003+\varepsilon_t}$

Batas regangan tulangan

Jika nilai ε_t = **0,005** (tension controlled)

$$\rho_{maks} = \left(\frac{0{,}003 + f_y / E_s}{0{,}008} \right) \rho_b$$

Jika tulangan baja mempunyai f_y = 400 MPa dan E_s = 200.000 MPa, maka

ρ_{maks} = 0,625ρ_b

Jika nilai ε_t = **0,004** (transition zone)

$$\rho_{maks} = \left(\frac{0{,}003 + f_y / E_s}{0{,}007} \right) \rho_b$$

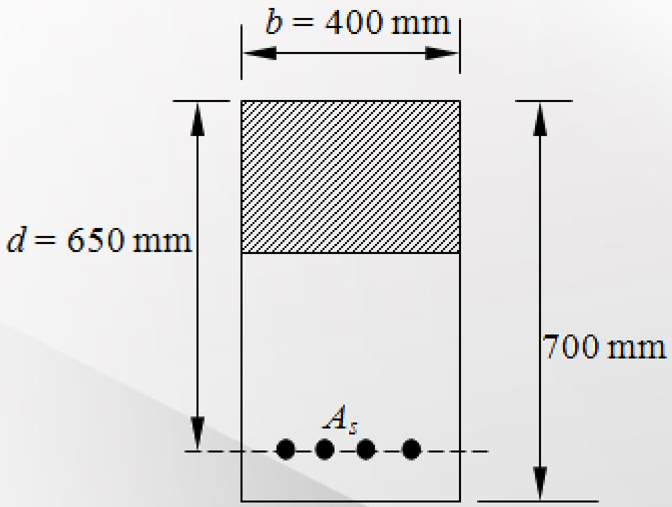
Jika tulangan baja mempunyai f_y = 400 MPa dan E_s = 200.000 MPa, maka

ρ_{maks} = 0,714ρ_b

Notes :

$$\frac{\rho}{\rho_b} = \frac{0{,}003 + f_y / E_s}{0{,}003 + \varepsilon_t}$$

Contoh 2 *(balanced, tension and transition section)*



f'_c = 25 MPa dan f_y = 400 MPa

Hitunglah :

1. luas tulangan baja pada kondisi seimbang, A_{sb}
2. luas tulangan maksimum yang diijinkan agar penampang merupakan penampang dominan tarik serta penampang pada daerah transisi
3. posisi sumbu netral, *c*, dan tinggi blok tegangan tekan ekuivalen, *a*, untuk penampang dominan tarik pada soal b

1. Menghitung A_{sb}

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

$$\rho_b = 0,85 \cdot 0,85 \frac{25}{400}\left(\frac{600}{600+400}\right) = 0,0271$$

$$A_{sb} = \rho_b bd = 0,0271 \times 400 \times 650 = 7.046 \text{ mm}^2$$

2.a. Penampang terkendali tarik

$$\rho_{\text{maks}} = 0,625\rho_b = 0,625 \times 0,0271 = 0,01693,$$

$$A_{s\text{ maks}} = \rho_{\text{maks}} bd = 0,01693 \times 400 \times 650 = 4.401,8 \text{ mm}^2$$

2.b. Penampang pada zona transisi

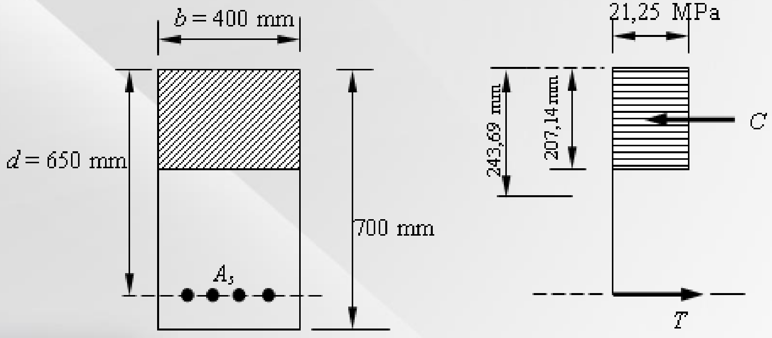
$$\rho_{\text{maks } t} = 0,714\rho_b = 0,714 \times 0,0271 = 0,01935$$

$$A_{s\text{ maks } t} = 0,01935 \times 400 \times 650 = 5.031 \text{ mm}^2$$

3. Penampang pada zona terkendali tarik

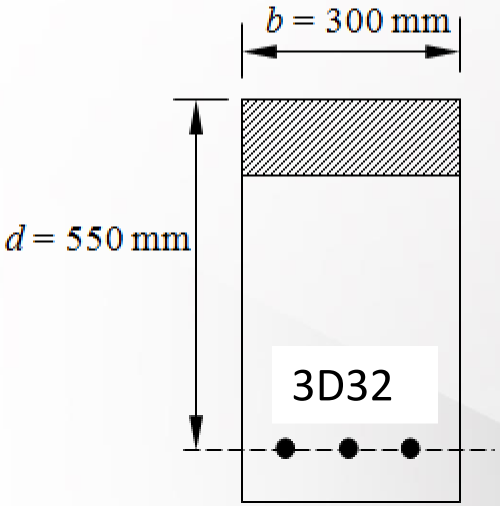
$$a = \frac{A_{smaks} f_y}{0,85 f'_c b} = \frac{4.401,8 \times 400}{0,85 \times 25 \times 400} = 207,14 \text{ mm}$$

$$c = \frac{a}{\beta_1} = \frac{207,14}{0,85} = 243,69 \text{ mm}$$



Contoh 3 : *(transition zone)*

Hitung nilai ϕM_n penampang balok dengan tulangan lentur 3D32 (A_s = 2.412,74 mm^2)



$$a = \frac{A_s f_y}{0{,}85 f'_c b} = \frac{2.412{,}74 \times 400}{0{,}85 \times 20 \times 300} = 189{,}23 \text{ mm}$$

$$c = \frac{a}{0{,}85} = 222{,}62 \text{ mm}$$

$d_t = d = 550$ mm $\qquad c/d_t = 0{,}40476 > 0{,}375$

$$\varepsilon_t = \left(\frac{d-c}{c}\right)0{,}003 = \left(\frac{550-222{,}62}{222{,}62}\right)0{,}003 = 0{,}00441$$ **Transition zone**

$$\phi = 0{,}65 + (\varepsilon_t - 0{,}002)\left(\frac{250}{3}\right) = 0{,}851$$

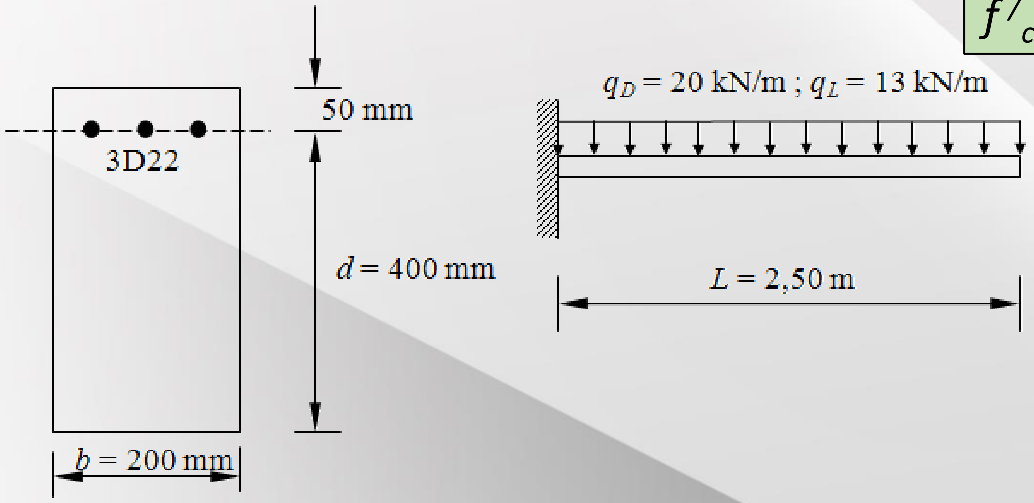
$\phi M_n = \phi A_s \cdot f_y (d - a/2) = 0{,}851 \times 2.412{,}74 \times 400\ (550 - (189{,}23/2))$

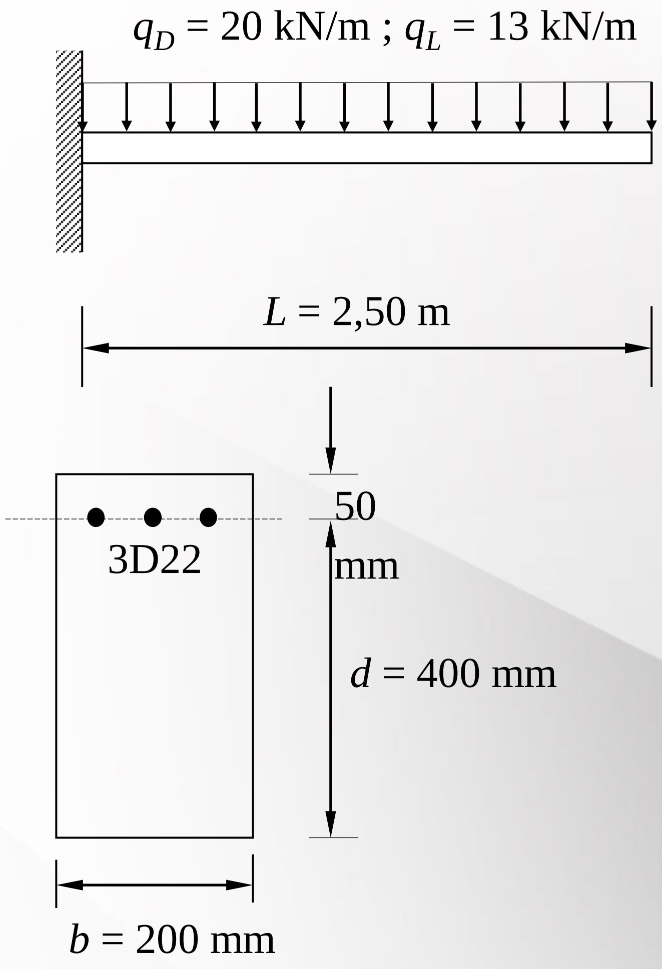
$= 374.006.195{,}91$ N·mm = **374,01 kN·m**

Contoh 4 : *(case study)*

Sebuah balok kantilever beton bertulang sepanjang 2,5 m memiliki penampang persegi dengan penulangannya seperti ditunjukkan pada Gambar. Balok memikul beban mati (termasuk berat sendiri balok) sebesar 20 kN/m, dan beban hidup sebesar 13 kN/m. Periksalah apakah balok cukup untuk memikul beban yang bekerja.

f'_c = 25 MPa dan f_y = 400 MPa





$$A_s = 3 \times \frac{1}{4} \pi 22^2 = 1.140 mm^2$$

$$q_u = 1{,}2q_D + 1{,}6q_L = 1{,}2(20) + 1{,}6(13) = 44{,}8 \text{ kN/m}$$

$$M_u = \tfrac{1}{2} q_u L^2 = \tfrac{1}{2}(44{,}8)(2{,}5)^2 = 140 \text{ kN·m}$$

$$a = \frac{A_s f_y}{0{,}85 f'_c b} = \frac{1140 \times 400}{0{,}85 \times 25 \times 200} = 107{,}29 \text{ mm}$$

$$c = \frac{a}{0{,}85} = 126{,}22 \text{ mm} \qquad d = 400 \text{ mm}$$

$$c/d = 0{,}3155 < 0{,}375$$

$$\varepsilon_t = (d-c)/c \times 0{,}003 = \left(\frac{400 - 126{,}22}{126{,}22}\right) 0{,}003$$

$$= 0{,}00651 > 0{,}005 \qquad \phi = 0{,}90$$

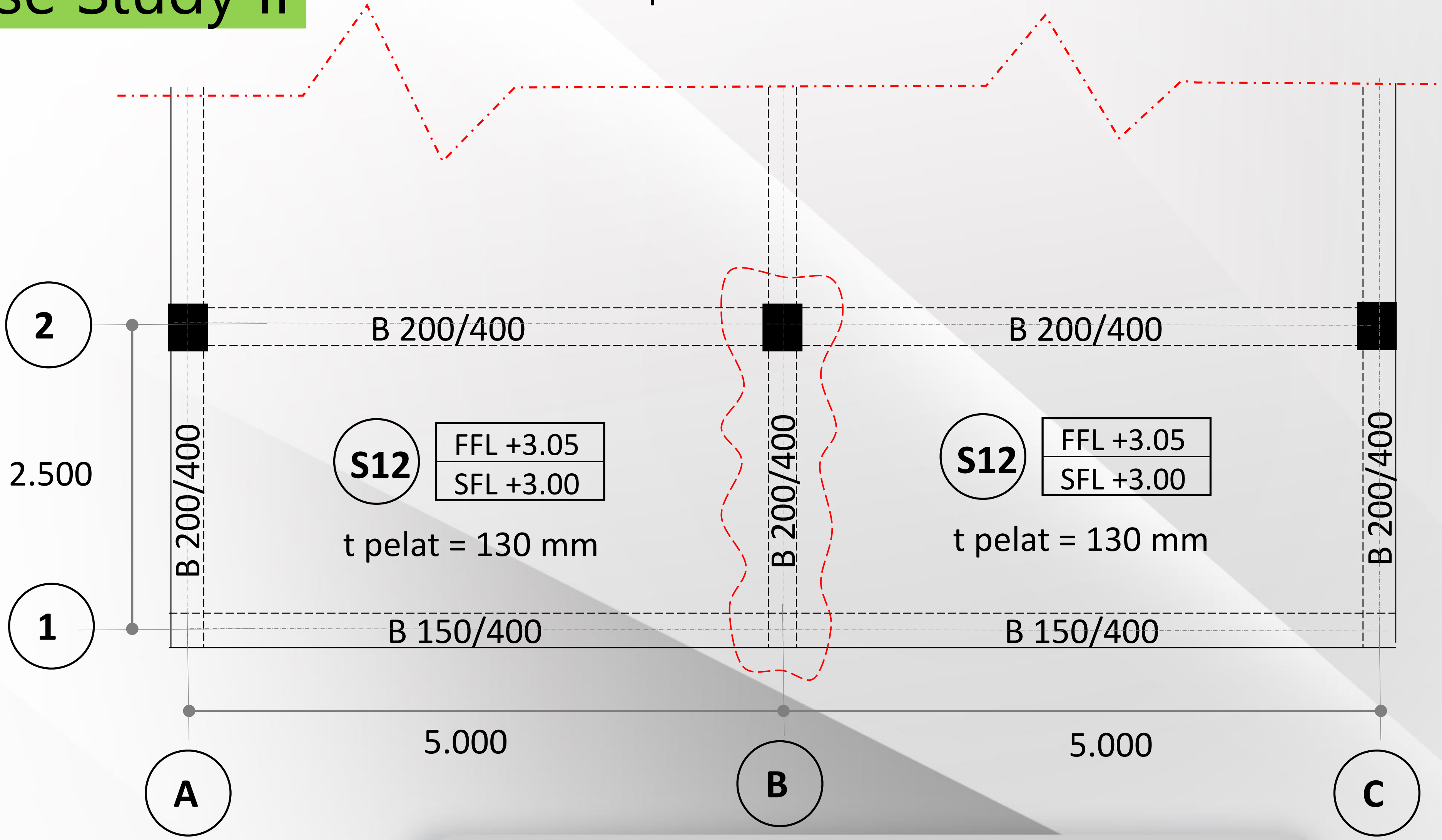
Tension controlled section

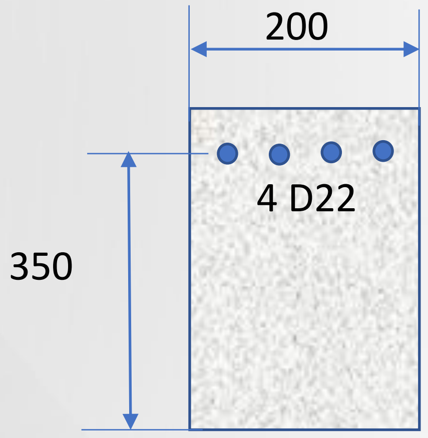
$$\phi M_n = \phi A_s \cdot f_y \left(d - \frac{a}{2}\right) = 0{,}90 \times 1140 \times 400 \left(400 - \frac{107{,}29}{2}\right)$$

$$= 142.144.092 \text{ N·mm} = 142{,}14 \text{ kN·m} > M_u \quad \textbf{o.k.}$$

Case Study II

Periksalah kecukupan balok as B1-B2





Step 1 : Hitung beban pelat

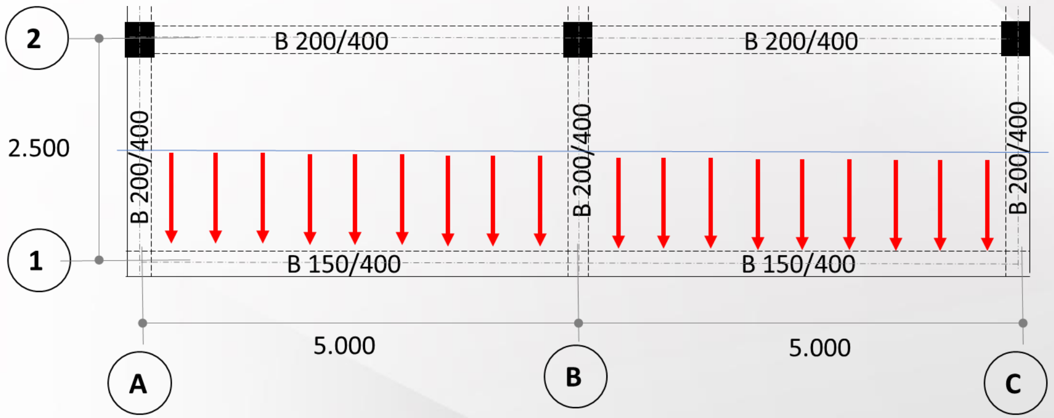
	Beban Mati (DL)									
			Concrete slab	0,13	x	23,6	kN/m^3	=		kN/m^2
			Mortar, cement	0,02	x	20,4	kN/m^3	=		kN/m^2
			Ceramic tile	0,01	x	23,6	kN/m^3	=		kN/m^2
			Gypsum board 10 mm	10	x	0,008	kN/m^2	=		kN/m^2
			Suspended steel channel system							kN/m^2
			Ducting/ ME					=		kN/m^2
			Total DL					=		kN/m^2
	Beban Hidup (LL)									
			Hunian					=	1,92	kN/m^2

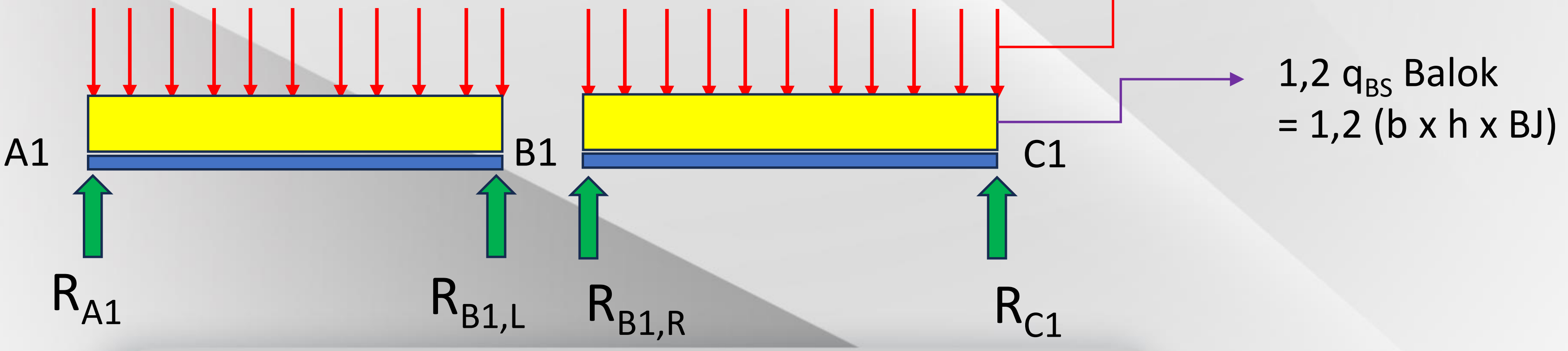
q_{DL} (fr slab) = kN/m^2

q_{LL} = 1,92 kN/m^2

Step 2 : Hitung beban Balok Anak

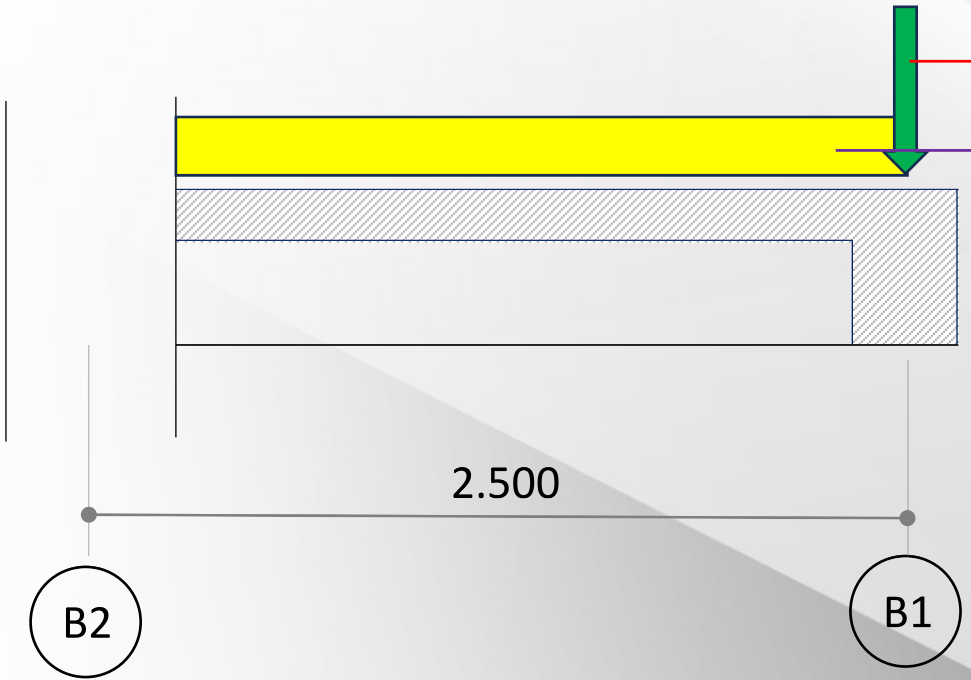
$$q_{u\ slab} = 1{,}2q_{DL} + 1{,}6\ q_{LL}$$





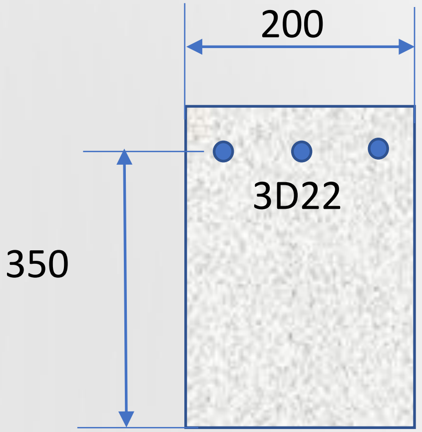
Step 3 : Hitung beban Balok Kantilever

Hitung Nilai BMD titik B2 (M_u)



$R_{B1, L} + R_{B1, R}$

1,2 q_{BS} Balok
= 1,2 (b x h x BJ)



Hitung ϕM_n Balok

f'_c = 25 MPa dan f_y = 400 MPa

Step 4 : Bandingkan M_u dan ϕM_n

Apabila M_n dikalikan dengan faktor reduksi ϕ, maka diperoleh bentuk

$$\phi M_n = \phi A_s \cdot f_y \left(d - \frac{a}{2} \right)$$

karena $a = \frac{0{,}85 f_c'.b}{A_s f_y}$ ⇨ $\phi M_n = \phi A_s \cdot f_y \left(d - \frac{A_s \cdot f_y}{1{,}7 f_c' \cdot b} \right)$

$\rho = A_s/bd$ $A_s = \rho bd$ ⇨ $\phi M_n = \phi \rho f_y b d^2 \left(1 - \frac{\rho \cdot f_y}{1{,}7 \cdot f_c'} \right)$

atau $\phi M_n = \phi \rho f_y \left(1 - \frac{\rho \cdot f_y}{1{,}7 \cdot f_c'} \right) b d^2$ $\phi M_n = R_u b d^2$

$$R_u = \phi \rho f_y \left(1 - \frac{\rho \cdot f_y}{1{,}7 \cdot f_c'} \right)$$

Saat ρ maks, maka R_u akan maks

Kapan ρ akan maksimum??

Tabel Nilai ρ dan R_u ($=M_u/bd^2$) Untuk Penampang Dominan Tarik, $\varepsilon_t = 0{,}005$ dan $\phi = 0{,}90$

f'_c (MPa)	f_y (MPa)	β_1	ρ_b	ρ_{maks}	R_u(MPa)
20	400	0,850	0,0217	0,01355	4,100
25	400	0,850	0,0271	0,01693	5,125
30	400	0,836	0,0320	0,01998	6,065
35	400	0,800	0,0357	0,02231	6,828
40	400	0,764	0,0390	0,02436	7,513

Tabel Nilai ρ dan R_u ($=M_u/bd^2$) Untuk Penampang Daerah Transisi, $\varepsilon_t = 0{,}004$ dan $\phi = 0{,}817$

f'_c (MPa)	f_y (MPa)	β_1	ρ_b	ρ_{maks}	R_u(MPa)
20	400	0,850	0,0217	0,01548	4,138
25	400	0,850	0,0271	0,01935	5,173
30	400	0,836	0,0320	0,02283	6,126
35	400	0,800	0,0357	0,02550	6,905
40	400	0,764	0,0390	0,02784	7,609