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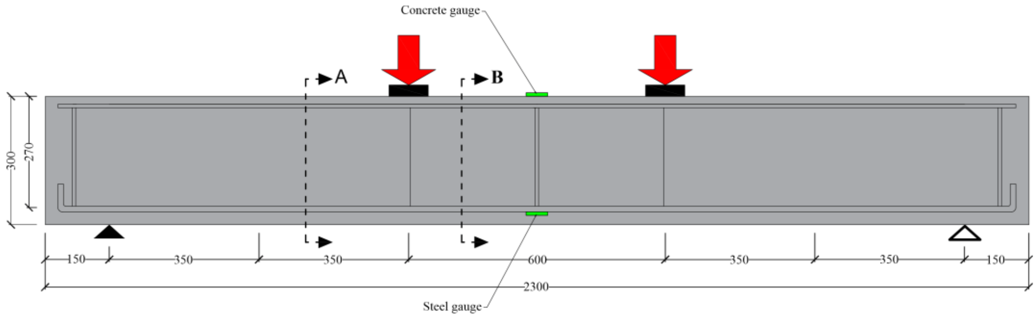
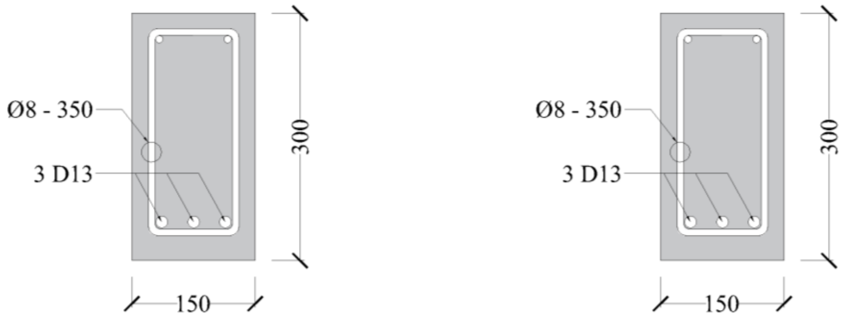
Lampiran 1 Perhitungan Kapasitas Lentur dan Kapasitas Geser Balok Beton Bertulang





Data Balok

- Panjang Balok (*L*) : 2300 mm
- Tinggi Balok (*h*) : 300 mm
- Lebar Balok (*b*) : 150 mm
- Jarak serat tekan ke titik berat tulangan tarik (*d*) : 264 mm
- Kuat tekan beton (*f'c*) : 21.1 N/mm²
- Kuat leleh tulangan geser (f_y) : 336.78 N/mm²
- Kuat leleh tulangan tarik (f_y) : 384.82 N/mm²
- Luas tulangan balok

  -Tulangan tekan (As') : 100.48 mm²

  -Tulangan tarik (As) : 602.88 mm²

a. Kapastias Lentur Balok (Mn)

$\boldsymbol{C_S} + \boldsymbol{C_S} = \boldsymbol{T_S}$

$(0,85\ x\ f'c\ x\ a\ x\ b) + (A_S' \text{ x fy}') = A_S\ x\ fy$

$$a = \frac{(A_S \, x \, fy) - (A_S' \, x \, fy')}{0{,}85 \, x \, f'c \, x \, b}$$

$$= \frac{(602{,}88 \ x \ 384.82\ ) - (100{,}48 \ x \ 336.78)}{0{,}85 \ x \ 21.1 \ x \ 150}$$

$$a = 74.459 \ mm$$

$$M_n = T_S \ x \ \left(d - \frac{a}{2}\right)$$

$$M_n = A_S \ x \ fy \ x \ \left(d - \frac{a}{2}\right)$$

$$M_n = 602{,}88 \ x \ 384.82 \ x \ \left(264 - \frac{74.459}{2}\right)$$

$$= 51{,}450 \ kNm$$

Maka,

$$P_n = \frac{M_n}{0{,}35}$$

$$P_n = \frac{51{,}450}{0{,}35}$$

$$= \mathbf{147 \ kN}$$

b. Kapasitas Geser

$$V_c = \frac{1}{6} \sqrt{f'c}. b_w. d$$

$$= \frac{1}{6} \sqrt{21.1}. 150 \ .259$$

$V_c = \ 29742$ **(29.742 kN)**

$$V_s = \frac{A_v \ . f_y. d}{s}$$

$$V_s = \frac{100.48 \ x \ 384.82 \ x \ 259}{350}$$

$V_s = 28{,}613 \ N$ **(28,613 kN)**

Jadi kuat geser nominal

$V_n = V_c + V_s$

V_n = 29,742 kN + 28.613 kN = 58,355 kN

Sehingga

$P_n = 2V_n$

$P_n = 2\ x\ 58{,}355$

P_n = **116.71 kN**

Berdasarkan hasil perhitungan analitis menunjukkan $P_{nlentur} > P_{ngeser}$. Hal ini menunjukkan bahwa balok beton bertulang mengalami kegagalan geser.

Lampiran 2 Perhitungan Kapasitas Geser Balok SBG

Data balok :

- Panjang Balok (*L*) : 2300 mm
- Tinggi Balok (*h*) : 300 mm
- Lebar Balok (*b*) : 150 mm
- Lebar GFRP (*wf*) : 700 mm
- Tinggi efektif NFRP (*dfv*) : 264 mm
- Jarak serat tekan ke titik berat tulangan tarik (*d*) : 264 mm
- Jarak serat tekan ke titik tulangan tekan (*d'*) : 32 mm
- Kuat tekan beton (*f'c*) : 21.1 N/mm²
- Modulus elastisitas beton; (Ec = $4700 \, . \, f'c^{0.5}$) : 21589.33 N/mm²
- Kuat leleh tulangan geser (f_y) : 336.78 N/mm²
- Jarak antar tulangan geser (*s*) : 350 mm
- Faktor reduksi kuat lentur (Ɵ) : 1,00
- Faktor reduksi kekuatan GFRP (*ψf*) : 0,85
- Tulangan Tekan (As') : 100.48 mm^2
- Tulangan Tarik (As) : 602.88 mm^2

Ketebalan per lembaran (*tf*) : 1.33 mm
Kuat tarik *ultimate* (*f*fu*) : 460 N/mm²
Regangan *ultimate* (*ε*fu*) : 0,02 mm/mm
Modulus elastisitas (*Ef*) : 20900 N/mm²
Jumlah lapisan GFRP/ AbFRP (n) : 1,00
Sudut pemasangan GFRP/ AbFRP : 90 mm
Jarak pemasangan GFRP/ AbFRP : 700 mm

Data Material Tulangan Geser :

Kuat leleh tulangan (*fy*) : 336.78 N/mm²
Regangan leleh (*εy*) : 0,00168390 mm/mm
Modulus elastisitas (*Es*) : 200000 N/mm²

Syarat kuat geser :

$V_u \leq \Phi V_n$

Dimana,

V_u = Gaya geser terfaktor pada penampang

V_n = Kuat geser nominal

$V_n = V_c + V_s$

Dimana,

V_c = Kuat geser beton

V_s = Kuat geser tulangan sengkang

Kekuatan Geser Beton:

$V_u = \Phi V_c + \Phi V_s$

$$V_c = \frac{1}{6}\sqrt{f'c}.b_w.d$$

$$= \frac{1}{6}\sqrt{21.1}.150.264$$

$V_c = 30316.93\ N$ (**30.32 kN**)

Kekuatan Geser Tulangan :

$$V_s = \frac{A_v\ .f_y.d}{s} \qquad A_v = 100{,}48$$

$$V_s = \frac{100{,}48\ x\ 336.78\ x\ 264}{350}$$

$V_s = 25524.77\ N$ (**25.52 kN**)

Maka kuat geser nominal

$V_n = V_c + V_s$

= 30.32 + 25.52

$\boldsymbol{V_n = 55.84}$ **kN**

Kekuatan Geser Perkuatan GFRP:

Berdasarkan persamaan yang diberikan ACI 440, kapasitas geser pada balok beton bertulang yang diperkuat dengan FRP *Composite* dapat dihitung dengan persamaan:

$\Phi V_n = \Phi (V_c + V_s + \Psi\ V_f)$

ACI 440 menjelaskan faktor reduksi untuk kapasitas geser pada balok beton bertulang dengan tiga sisi yang diberi perkuatan FRP sebagai berikut:

$$V_n = 0{,}75\ (V_c + V_s + 0{,}85\ V_f)$$

Terdapat dua kemungkinan kegagalan atau kehancuran yang terjadi pada perkuatan geser yang disumbangkan FRP pada balok beton bertulang, yaitu kegagalan akibat retak atau patahnya FRP dan kegagalan akbat lepasnya rekatan FRP dengan balok beton bertulang.

Untuk perencanaan perkuatan geser berdasarkan kegagalan akibat retaknya (*fractur mechanisme*) FRP, ACI *Committee Report* 440 memberikan persamaan:

$$V_f = \frac{A_f\ f_{fe}(\sin\beta + \cos\beta\ )\ d_f}{s_f}$$

– Regangan efektif FRP

$$\varepsilon_{fe} = K_v \qquad \varepsilon_{fu} \ \leq 0{,}004$$

– Tegangan perkuatan FRP

$$f_{fe} = \varepsilon_{fe}\ .\ E_f$$

– Luas perkuatan FRP

$$A_f = 2\ n.t_f.w_f$$

Dari persamaan regangan efektif FRP (ε_{fe}), koefisien reduksi dapat dihitung menggunakan persamaan:

$$K_v = \left(\frac{k_1\ \ k_2\, L_e}{1190\ \varepsilon_{fu}}\right)$$

$$K_1 = \left(\frac{f'c}{27}\right)^{2/3}$$

$$K_2 = \left(\frac{d_f - 2L_e}{d_f}\right) \text{ Untuk rekatan pada kedua sisi}$$

$$\left(\frac{d_f - L_e}{d_f}\right) \text{ Untuk rekatan yang berbentuk U}$$

$$L_e = \frac{23300}{(n\ .\ t_f\ .\ E_f)^{0{,}58}}$$

Menentukan Regangan Efektif dari Perkuatan FRP

$$\varepsilon_{fe} = K_v \qquad \varepsilon_{fu} \ \leq 0{,}004$$

Dari persamaan regangan efektif FRP (ε_{fe}), koefisien reduksi dapat dihitung menggunakan persamaan:

$$K_v = \left(\frac{k_1 \ \ k_2 \ L_e}{1190 \ \varepsilon_{fu}}\right)$$

Dimana:

$$K_1 = \left(\frac{f'c}{27}\right)^{2/3} \quad = \ \left(\frac{21.1}{27}\right)^{2/3} = 0{,}85$$

$$K_2 = \left(\frac{d_f - L_e}{d_f}\right) \quad = \ untuk \ rekatan \ berbentuk \ U$$

Dimana, $L_e \ = \ \frac{23300}{(n \ . \ t_f \ . \ E_f)^{0{,}58}}$

$$L_e \ = \ \frac{23300}{(1 \ x \ 1{,}33x \ 20900)^{0{,}58}} = 61.64$$

Maka,

$$K_2 = \left(\frac{d_{fv} \ - \ L_e}{d_{fv}}\right) = \left(\frac{264 \ - \ 61.64}{301{,}00}\right) \ = \ 0.77$$

Maka,

$$K_v = \left(\frac{k_1 \ \ k_2 \ L_e}{1190 \ \varepsilon_{fu}}\right) \ = \ \left(\frac{0{,}85 \ x \ 0{,}77 \ x \ 61.64}{1190 \ x \ 0.01}\right)$$

$$= \ 0{,}225 \ \leq \ 0{,}750$$

Maka Regangan Efektif (ε_{fe}):

$$\varepsilon_{fe} = K_v \ x \ \varepsilon_{fu} \ \leq 0{,}004$$

$$= 0{,}2246 \ x \ 0{,}015 \ = \ 0{,}00337 \qquad \leq \quad 0{,}004$$

Menentukan Tegangan Efektif dari Perkuatan FRP

$$f_{fe} = \ \varepsilon_{fe} \ . \ E_f$$

$$= \ 0.0033685 \ x \ 20900$$

$$= \ 70.40$$

$$V_f \ = \ \frac{A_{fV} f_e \ (\sin a + \cos) d_{fv}}{s_f}$$

$$A_f \ = \ 2 \text{ x } 1 \text{ x } 1.33 \text{ x } 700$$

$$V_f \ = \ \frac{1862 \ x \ 70.40 \ x \ (sin \ 90 \ + \ cos \ 90 \ ). \ 264.0}{700}$$

$\boldsymbol{V_f} \ = \boldsymbol{49051.613\ N}$

= **49.05 kN**

Maka Kuat Geser Total adalah:

$V_n = V_c + V_s + V_f$

$= 30.32 \ + \ 25.52 \ + \ 49.05$

$\boldsymbol{V_n}$ **=104.89 kN**