Analysis of Flanged Sections:

$$b_e = min\begin{cases} b_w + 16h_f \\ b_w + s_w \\ b_w + \frac{l_n}{4} \end{cases} \quad \rightarrow Effective\ Flange\ width\ for\ T - section, SBC304 - 18, 6.3.2.1$$

$$b_e = min\begin{cases} b_w + 6h_f \\ b_w + \frac{s_w}{2} \\ b_w + \frac{l_n}{12} \end{cases} \quad \rightarrow Effective\ Flange\ width\ for\ L - section, SBC304 - 18, 6.3.2.1$$

$$h_f \geq \frac{b_w}{2} \quad b_e \leq 4b_w \quad \rightarrow T\ section\ dimensions\ limitations, SBC304 - 18, 6.3.2.2$$

$$A_{s,min} = Max\left(\frac{\sqrt{f_c'}}{4f_y}b_w d, \frac{1.4}{f_y}b_w d\right) \quad \rightarrow minimum\ steel\ area, SBC304 - 9.6.1.2$$

$$a = \frac{A_s f_y}{0.85 f_c' b_e} \quad \rightarrow depth\ of\ equiv. stress\ block, steel\ yielding, a \leq h_f$$

$$c = \frac{-\beta \pm \sqrt{\beta^2 - 4\alpha\beta d}}{2\alpha} \quad \rightarrow neutrial\ axix\ depth, steel\ not\ yielding, a \leq h_f$$

$$\alpha = 0.85 f_c' b\beta_1 \quad , \quad \beta = A_s E_s \varepsilon_{cu} \quad \rightarrow factors$$

$$M_n = T\left(d - \frac{a}{2}\right) \quad \rightarrow nominal\ moment\ capacity, a \leq h_f$$

$$C_{cf} = 0.85 f_c'(b_e - b_w)h_f \quad \rightarrow Compression\ force\ in\ overhanging\ flange, a > h_f$$

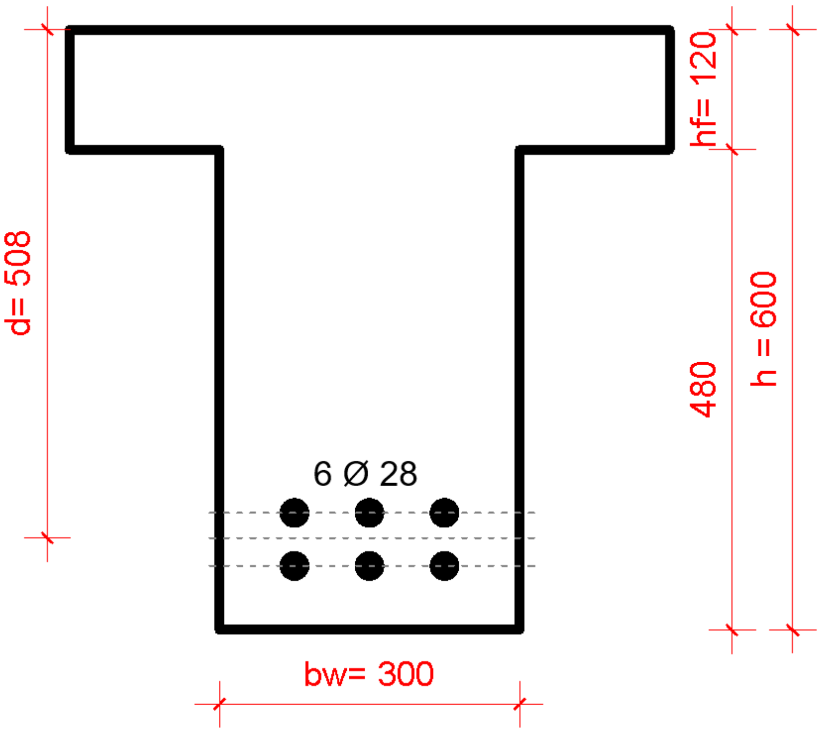
$$C_{cw} = 0.85 f_c' b_w a \quad \rightarrow Compression\ force\ in\ web, a > h_f$$

$$a = \frac{T - C_{cf}}{0.85 f_c' b_w} \quad \rightarrow depth\ of\ equiv. stress\ block, steel\ yielding, a > h_f$$

$$c = \frac{A + B}{2}\left(\sqrt{1 + \frac{4Ad}{(A + B)^2}} - 1\right) \quad \rightarrow neutrial\ axix\ depth, steel\ not\ yielding, T\ beam\ a > h_f$$

$$A = \frac{600 A_s}{0.85 f_c' b_w 0\beta_1} \quad , \quad B = \frac{(b_f - b_w)h_f}{b_w \beta_1} \quad \rightarrow factors$$

$$M_n = C_{cf}\left(d - \frac{h_f}{2}\right) + C_w\left(d - \frac{a}{2}\right) \quad \rightarrow nominal\ moment\ capacity, a > h_f$$



Determine the design moment and check minimum steel and tension control conditions. Use f'_c = 22 MPa, f_y = 420 MPa, d_s=10 mm, Agg. Size = 18 mm.

1- Find, A_s and $A_{s\ min}$:

$$A_s = 6 \times \pi \frac{28^2}{4} = 3694.5\ mm^2$$

$$A_{s,min} = Max\left(\frac{\sqrt{f_c'}}{4f_y}b_w d, \frac{1.4}{f_y}b_w d\right) = Max\left(\frac{\sqrt{22}}{4 \times 420} \times 300 \times 508, \frac{1.4}{420} \times 300 \times 508\right)$$

$$A_{s,min} = 508\ mm^2$$

$A_s \geq A_{s\ min}$ ➔ ✓

2- Find Neutral axis depth (c) from top fibers assuming steel is yielding and $a \leq h_f$:

$$a = \frac{A_s f_y}{0.85 f_c' b_e} = \frac{3694.5 \times 420}{0.85 \times 22 \times 600} = 276.6\ mm$$

276.6 < 120 ➔ assumption not satisfied. Use decomposition method.

3- Calculate T, C_{cf}, a, c, and C_{cw}

$$T = A_s f_y = 3694.5 \times 420 = 1551690\ N = 1551.69\ kN$$

$$C_{cf} = 0.85 f_c'(b_e - b_w)h_f = 0.85 \times 22 \times (600 - 300) \times 120 = 673200\ N = 673.2\ kN$$

$$a = \frac{T - C_{cf}}{0.85 f_c' b_w} = \frac{1551690 - 673200}{0.85 \times 22 \times 300} = 156.59\ mm$$

f'_c = 22 MPa < 28 ➔ β_1 = 0.85

$$c = \frac{a}{\beta_1} = \frac{156.59}{0.85} = 184.22\ mm$$

$$C_{cw} = 0.85 f_c' b_w a = 0.85 \times 22 \times 300 \times 156.59 = 878469.9\ N = 878.4699\ kN$$

4- Check assumption (steel is yielding) at most top steel layer, d_{min}

$$S_l = max\left(\frac{4}{3}Agg, 25\right) = 25\ mm$$

$$d_t = h - cover - d_s - \frac{d_b}{2} = 600 - 40 - 10 - 14 = 536\ mm$$

$$d_{min} = d_t - S - d_b = 536 - 25 - 28 = 483\ mm$$

$$\varepsilon_{min} = \left(\frac{d_{min} - c}{c}\right)\varepsilon_{cu} = \left(\frac{483 - 184.22}{184.22}\right) \times 0.003 = 0.00487 \geq \varepsilon_y$$

0.00487 ≥ 0.0021 ➔ steel is yielding

5- Find Ø:

Check strain at bottom layer

$$\varepsilon_t = \left(\frac{d_t - c}{c}\right)\varepsilon_{cu} = \left(\frac{536 - 184.22}{184.22}\right) \times 0.003 = 0.00573 \geq 0.005 \geq \varepsilon_y$$

0.00573 ≥ 0.005 ➔ tension control ➔ Ø = 0.9

5- Find design moment capacity $ØM_n$

$$M_n = C_{cf}\left(d - \frac{h_f}{2}\right) + C_w\left(d - \frac{a}{2}\right)$$

$$M_n = 673200\left(508 - \frac{120}{2}\right) + 878469.9\left(508 - \frac{156.59}{2}\right) = 679.08\ \times 10^6\ N.mm$$

$$\emptyset M_n = 0.9 \times 679.08 = 611.17\ kN.m$$

Alternative Solution:

1- Find, A_s and $A_{s\,min}$:

$$A_s = 6 \times \pi \frac{28^2}{4} = 3694.5\, mm^2$$

$$A_{s,min} = Max\left(\frac{\sqrt{f_c'}}{4f_y} b_w d, \frac{1.4}{f_y} b_w d\right) = Max\left(\frac{\sqrt{22}}{4 \times 420} \times 300 \times 508, \frac{1.4}{420} \times 300 \times 508\right)$$

$$A_{s,min} = 508\, mm^2$$

$A_s \geq A_{s\,min}$ ➔ ✓

2- Find Neutral axis depth (*c*) from top fibers assuming steel is yielding and $a \leq h_f$:

$$a = \frac{A_s f_y}{0.85 f_c' b_e} = \frac{3694.5 \times 420}{0.85 \times 22 \times 600} = 276.6\, mm$$

276.6 < 120 ➔ assumption not satisfied. Use decomposition method.

3- Find A_{sf} and A_{sw}

$$A_{sf} = \frac{0.85 f_c' (b_e - b_w) h_f}{f_y} = \frac{0.85 \times 22 \times (600 - 300) \times 120}{420} = 1602.86\, mm^2$$

$$A_s = A_{sf} + A_{sw} \rightarrow A_{sw} = A_s - A_{sf} = 3694.5 - 1602.86 = 2091.64 mm^2$$

4- Find Neutral axis depth (*c*) from top fibers assuming steel is yielding and $a > h_f$:

$$a = \frac{A_{sw} f_y}{0.85 f_c' b_w} = \frac{2091.64 \times 420}{0.85 \times 22 \times 300} = 156.59\, mm$$

f'_c = 22 MPa < 28 ➔ $\beta_1 = 0.85$

$$c = \frac{a}{\beta_1} = \frac{156.59}{0.85} = 184.22\, mm$$

Check assumption (steel is yielding) at most top steel layer, d_{min}

$$S_l = max\left(\frac{4}{3} Agg, 25\right) = 25\, mm$$

$$d_t = h - cover - d_s - \frac{d_b}{2} = 600 - 40 - 10 - 14 = 536\, mm$$

$$d_{min} = d_t - S - d_b = 536 - 25 - 28 = 483\, mm$$

$$\varepsilon_{min} = \left(\frac{d_{min} - c}{c}\right) \varepsilon_{cu} = \left(\frac{483 - 184.22}{184.22}\right) \times 0.003 = 0.00487 \geq \varepsilon_y$$

0.00487 ≥ 0.0021 ➔ steel is yielding

4- Find Ø:

Check strain at bottom layer

$$\varepsilon_t = \left(\frac{d_t - c}{c}\right)\varepsilon_{cu} = \left(\frac{536 - 184.22}{184.22}\right) \times 0.003 = 0.00573 \geq 0.005 \geq \varepsilon_y$$

0.00573 ≥ 0.005 ➔ tension control ➔ Ø = 09

5- Find design moment capacity $ØM_n$

$$M_n = A_{sf} f_y \left(d - \frac{h_f}{2}\right) + A_{sw} f_y \left(d - \frac{a}{2}\right)$$

$$M_n = 1602.86 \times 420 \left(508 - \frac{120}{2}\right) + 2091.64 \times 420 \left(508 - \frac{156.59}{2}\right) = 679.08 \times 10^6 N.mm$$

$$ØM_n = 0.9 \times 679.08 = 611.17\ kN.m$$

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