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1 (a) $n = 1.35 \times 40 + 1.5 \times 35 = 106.5\ kN/m$.

$M_{Ed} = \frac{WL^2}{8} = \frac{106.5 \times 6.4^2}{8} = 545.28\ kNm$.

$d = 550 - 30 - 10 - \frac{32}{2} = 494mm$.

$F_{cf} = 0.567 f_{ck} b_f h_f = 0.567 \times 30 \times 600 \times 150 = 1530.9kN$.

$M_{cf} = F_{cf} \times z = F_{cf} \times (d - \frac{h_f}{2}) = F_{cf} \times (494 - \frac{150}{2}) = 641.45kNm$

since $M_{cf} > M_{Ed}$, all flange contribution.

$M_{Ed} = 0.567 f_{ck} b_f (0.8x)(d - 0.4x) \rightarrow 545.28 \times 10^6 = 0.567 \times 30 \times 600 \times 0.8x \times (494 - 0.4x)$.

$\hookrightarrow x = 154.53\ mm$.

$C = T \rightarrow 0.567 f_{ck} b_f (0.8x) = A_s (0.87 f_{yk}) \rightarrow A_s = 2900.5mm^2$, provide 4H32 ($3218mm^2$).

$\frac{A_{s,req}}{bd} = \frac{2900.5}{600 \times 494} \times 100\% = 0.98\% \approx 1.0\% \rightarrow$ From Table, basic $\frac{L}{D} \approx 17$.

$F_1 = 1$, $F_2 = 1$, $F_3 = \frac{A_{s,prov}}{A_{s,req}} = \frac{3218}{2900.5} = 1.1095$

Allowable L/D = basic $L/D \times F_1 \times F_2 \times F_3 = 17 \times 1 \times 1 \times 1.1095 = 18.862$.

Actual $L/D = \frac{6.4}{0.494} = 12.96$.

Since actual < allowable L/D, span effective ratio is acceptable.

(b) $V_{max} = (106.5 \times 6.4)/2 = 340.8\ kN$

① At support face, $V_{Ef} = V_{max} - w \times \frac{width}{2} = 340.8 - 106.5 \times \frac{0.4}{2} = 319.5kN$

$V_{Rd,max(22)} = 0.124 b_w d f_{ck} (1 - \frac{f_{ck}}{250}) = 0.124(250)(494)(30)(1 - \frac{30}{250}) = 404.29kN > V_{Ef} = 319.5kN$

$\hookrightarrow \theta = 22°$, $\cot\theta = 2.5$

② At 1.0d from support face, $V_{E,1d} = V_1 - w(\frac{width}{2} + d) = 340.8 - 106.5(\frac{0.4}{2} + 0.494) = 266.89kN$

$\frac{A_{sw}}{S_2} = \frac{V_{E1d}}{0.87 d f_{yk} \cot\theta} = \frac{266.89 \times 10^6}{0.87(494)(500)(2.5)} = 0.554$

$\hookrightarrow$ provide $\phi 10$ @ 275 spacing (0.571).

Spacing check : $S = 275 < 0.75d = 370.5$ OK!

③ For minimum stirrup,

$\frac{A_{sw,min}}{S} = \frac{0.08 f_{ck}^{0.5} b_w}{f_{yk}} = 0.219 \rightarrow$ provide $\phi 10$ @ 350 spacing (0.449)

$V_{min} = \frac{A_{sw}}{S}(0.78) f_{yk} d \cot\theta \times 10^{-3} = 216.26kN$

For zone ① & ②,

$x = (V_{Ef} - V_{min})/w = 0.96938$

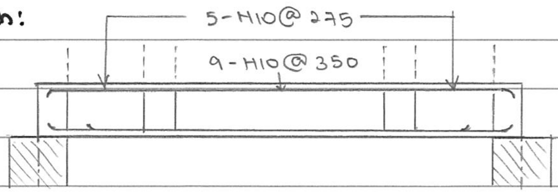
no. of links $= 1 + (\frac{0.96938}{0.275}) = 4.525 \approx 5$

$L_{1/2} = (5-1) \times 0.275 = 1.1m$

$L_3 = L - (\frac{0.4}{2} \times 2) - 1.1 - 1.1 = 6.4 - 0.4 - 1.1 - 1.1 = 3.4m$.

no. of links $= \frac{3.4}{0.35} - 1 = 8.7 \approx 9$.

Sketch:



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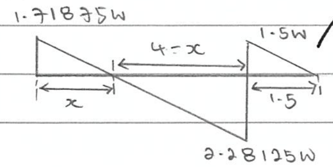
2. Let left support and right support be A & B respectively.

$\Sigma M_A = 0$, $5.5w(2.75) = R_B(4) \rightarrow R_B = 3.78125w$

$R_A = 5.5w - 3.78125w = 1.71875w$.

SFD:

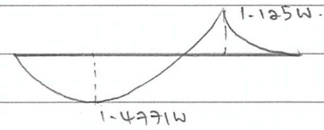


$\frac{1.71875w}{x} = \frac{2.28125w}{4-x} \rightarrow x = 1.71875\,m$

$M_{2,max} = \frac{1}{2}(1.71875w)(1.71875) = 1.4771w$.

$M_{1,max} = \frac{1}{2}(1.5w)(1.5) = 1.125w$.

BMD:



For section 2:

5T16 $\rightarrow 1006mm^2$, 3T32 $\rightarrow 2414mm^2$

Assuming top flange contribution only,

$F_{st} = 0.87A_sf_{yk} = 0.87(2414)(460) \times 10^{-3} = 966.083kN$

$F_{sc} = 0.87A_sf_{yk} = 0.87(1006)(460) \times 10^{-3} = 402.601kN$.

$F_{cc} = 0.567f_{ck}(0.8x)b = 0.567(40)(0.8x)(400) \times 10^{-3} = 7.2576x\,kN$.

$F_{st} = F_{sc} + F_{cc} \rightarrow x = 77.64mm < 150mm$, assumption correct.

$M = Tz = 966.083(d - 0.4x) = 966.083(460 - 0.4 \times 77.64) \times 10^{-3}$

$= 414.40\,kNm = M_{2,max} = 1.4771w$

$\hookrightarrow w_2 = 280.5\,kN/m$.

For section 1:

5T20 $\rightarrow 1571mm^2$, 2T16 $\rightarrow 402mm^2$

Assuming contribution below flange,

$F_{st} = 0.87A_sf_{yk} = 0.87(1571)(460) \times 10^{-3} = 628.714kN$

$F_{sc} = 0.87A_sf_{yk} = 0.87(402)(460) \times 10^{-3} = 160.880kN$

$F_{cc} = 0.567f_{ck}(0.8x)b = 0.567(40)(0.8x)(250) \times 10^{-3} = 4.536x\,kN$

$F_{st} = F_{sc} + F_{cc} \rightarrow x = 103.14mm < 300mm$, assumption correct.

$M = Tz = 628.714(d - 0.4x) = 628.714(465 - 0.4 \times 103.14) \times 10^{-3}$

$= 266.41\,kNm = M_{1,max} = 1.125w$

$\hookrightarrow w_1 = 236.8\,kN/m$.

$\therefore$ Take more critical w_1 value of 236.8kN/m

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3 (a) $b = 350$, $h = 400$, $f_{ck} = 40$, $N = 2000\ kN$, $M = 300\ kNm$.

$\frac{N}{bhf_{ck}} = 0.357$, $\frac{M}{bh^2 f_{ck}} = 0.134$, from Table, $\frac{A_s f_{yk}}{bhf_{ck}} = 0.27 \rightarrow A_s = 3024 mm^2$

(b) Assume compression steel yields and tension steel doesn't yield,

$F_{cc} = 0.567 f_{ck}(0.8x)b = 0.567(40)(0.8x)(350) = 6.3504x\ kN$

$F_{sc} = 0.87 f_{yk} A_{sc} = 0.87(500)(2414) = 1050.9\ kN$

$F_{st} = f_s \cdot A_s = E_s \varepsilon_s A_s = 200\times10^3 (\frac{d-x}{x})(0.0035)(A_s)$

$= 1689.8(\frac{340-x}{x})\ kN$

$N = F_{cc} + F_{sc} - F_{st} \rightarrow 2000 = 6.3504x + 1050.9 - 1689.8(\frac{340-x}{x})$

$\hookrightarrow x = 248.07 mm.$

Check assumptions:

$\frac{\varepsilon_{sc}}{0.0035} = \frac{x-d'}{x} = \frac{248.07-60}{248.07} \rightarrow \varepsilon_{sc} = 0.00265 > \varepsilon_y = 0.00217 \rightarrow$ compression steel yields (OK!)

$\frac{\varepsilon_{st}}{0.0035} = \frac{d-x}{x} = \frac{340-248.07}{248.07} \rightarrow \varepsilon_{st} = 0.00130 < \varepsilon_y = 0.00217 \rightarrow$ tension steel doesn't yield (OK!)

Assumptions are correct, proceed with calculation,

$F_{cc} = 6.3504(248.07) = 1575.3 kN$, $F_{st} = 1689.8(\frac{340-248.07}{248.07}) = 626.21 kN$

$M_{yy} = [F_{cc}(200-0.4x) + F_{sc}(340-200) + F_{st}(340-200)]\times10^{-3}$

$= 393.43 kNm$

4 (a) Assuming moment of resistance is same in both directions,

$M = T\cdot z = (0.87 A_s f_{yk})(d-0.4x)$

condition(s): 1. A_s is same for both directions

Assumption(s): 1. Assume d is the same in both directions.

$\Big\}$ $(d-0.4x)$ must be minimized

Determining neutral axis:

$C = T \rightarrow 0.567 f_{ck}(0.8x)(L) = 0.87 f_{yk} A_s \rightarrow x = \frac{0.87 f_{yk} A_s}{0.567 f_{ck}(0.8x)(L)}$

From above, we conclude x is inversely proportional to L. To minimize $(d-0.4x)$, we need greater x value.

$L_y > L_x > a \rightarrow L_y - L_x > a \rightarrow L_x$ smaller than L_y.

As x is inversely proportional to L, L_x gives a larger x value and is the more critical value to be considered for bending check.

∴ Check along L_y direction.

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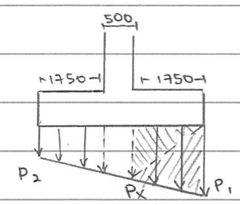
4 (b) Check for base (SLS)

$N+W = 1500 + (4 \times 4 \times 0.8 \times 24) = 1807.2\,kN$

$p_1 = \frac{N+W}{A} + \frac{6M}{BL^2} = \frac{1807.2}{4 \times 4} + \frac{6 \times 400}{4 \times 4 \times 4} = 150.45\,kN/m^2 < q_a = 250\,kN/m^2$ OK!

Design Reinforcement



Design pressure $= \frac{N_u}{L^2} \pm \frac{6M_u}{L^3} = \frac{1800}{4^2} \pm \frac{6(500)}{4^3} = \begin{cases} 159.375\,kN/m^2 \rightarrow P_1 \\ 65.625\,kN/m^2 \rightarrow P_2 \end{cases}$

Using $\phi 20$ bars, $d = 800 - 80 - \frac{20}{2} = 710mm$

$P_x = \frac{1750+500}{4000} \times (P_1 - P_2) + P_2 = 118.36\,kN/m^2$

$M = \frac{1}{2} \times P_x \times 1.75 \times 4 \times (\frac{1.75}{3}) + \frac{1}{2} \times P_1 \times 1.75 \times 4 \times (\frac{1.75 \times 2}{3}) = 892.43\,kNm$

$K = \frac{M}{f_{ck} b d^2} = \frac{892.43 \times 10^6}{40 \times 4000 \times 710^2} = 0.0110$

$z = d(0.5 + \sqrt{0.25 - \frac{K}{1.134}}) = 703.01mm > 0.95d = 674.5mm$

$\therefore z = 0.95d = 674.5mm.$

$A_{s,req} = \frac{M}{0.87 f_{yk} z} = \frac{892.43 \times 10^6}{0.87 \times 500 \times 674.5} = 2889.5mm^2$

$A_{s,min} = \max(0.26(\frac{f_{ctm}}{f_{yk}})bd, 0.0013bd) = \max(5168.8, 3692) = 5168.8mm^2$

↳ provide 17H20 ($5340mm^2$).

Punching Shear Check (at 2.0d from column face)

$u_1 = 4 \times 500 + 4\pi d_m = 2000 + 4\pi(700) = 10796mm.$

area within $u_1 = \pi(2d_m)^2 + (2 \times d_m \times c \times 4) + c^2 = 9.2075m^2$

$V_{Ed} = \frac{159.375 + 65.625}{2}(4^2 - 9.2075) = 764.15kN$

$\rho_l = \sqrt{\frac{5340}{4000 \times 710} \times \frac{5340}{4000 \times 690}} \times 100 = 0.19073\%$

$v_{Rd,c} = \frac{0.18}{\gamma_c} k(100 \rho_l f_{ck})^{1/3} = 0.12(1 + \sqrt{\frac{200}{700}})(0.19073 \times 40)^{1/3} = 0.363$

$v_{Rd,c} \leq v_{min} = 0.035\, k^{3/2} f_{ck}^{1/2} = 0.0035(1 + \sqrt{\frac{200}{700}})^{3/2} \times 40^{1/2} = 0.420 \rightarrow$ take v_{min}

$V_{Rd,c} = v_{Rd,c}\, u_1 d_m = 0.420 \times 10796 \times 700 \times 10^{-3}$

$= 3174kN > V_{Ed} = 764.15kN$ OK!