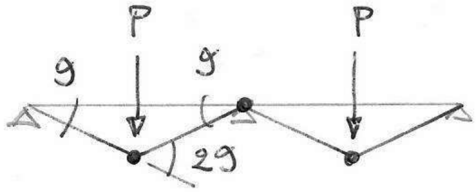
(a)



$$P\left(\theta \frac{L}{2}\right) = 3\theta M_p \Rightarrow P = \frac{6M_p}{L}$$

$$M_p = W_{pl} \cdot f_y / \gamma_{M0} = (7.24)(10^5)(420) = 304 \text{ kNm}$$

$$\Rightarrow P_d = \frac{(6)(304)}{6} = 304 \text{ kN}$$

(b)

$b_f = 141.8$ mm
$t_f = 8.6$ mm
$r = 10$ mm
$h = 398$ mm
$t_w = 6.4$ mm

Flange

$$\frac{c}{t} = \frac{(b_f - t_w - 2r)/2}{t_f} = \frac{141.8 - 6.4 - 20}{(2)(8.6)} = 6.71$$

$\varepsilon = 0.75$

$\frac{c}{t} < 9\varepsilon = 6.75 \rightarrow$ Class 1

Web

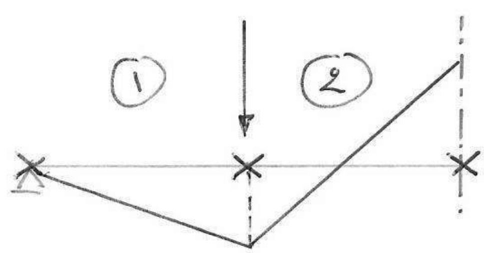
$$\frac{c}{t} = \frac{h - 2t_f - 2r}{t_w} = \frac{398 - 17.2 - 20}{6.4} = 56.4$$

$\frac{c}{t} > 72\varepsilon = 54$

$\frac{c}{t} < 83\varepsilon = 62 \rightarrow$ Class 2 $\rightarrow$ $\boxed{\text{Cross-section is Class 2}}$

A Class 1 cross-section is required for plastic design $\rightarrow$ the analysis method used in (a) is invalid.

(c)



Either segment 1 or segment 2 can be critical for LTB. Segment 2 has the larger moment, but benefits from double curvature.

$\rightarrow$ both need checking

$I_{zz} = (4.10)(10^6)\ mm^4$

$J = (1.07)(10^5)\ mm^4$

$C_w = I_{zz} d^2/4 = (1.55)(10^{11})\ mm^4$

$d = h - t_f = 389.4\ mm$

$L_{cr} = 3000\ mm$

$$M_{cr} = C_1 \frac{\pi^2}{L_{cr}^2} E I_{zz} \sqrt{\frac{C_w}{I_{zz}} + \frac{L_{cr}^2}{\pi^2} \frac{GJ}{EI_{zz}}} = C_1 (205)\ kNm$$

1

$C_1 = 1/0.6$ (data sheets)

$M_{cr} = 342\ kNm$

$\lambda = \sqrt{\frac{M_p}{M_{cr}}} = 0.94$

$\phi = 1.07$

$\chi = 0.63$

Curve b
Rolled
$h/b > 2$
$\alpha = 0.34$

$M_{b,Rd} = 193\ kNm$

$\frac{5}{32} PL = 193\ kNm$

$\Rightarrow P = 206\ kN$

2

$C_1 = 1/0.4$ $(\psi = -\frac{5}{6})$

$M_{cr} = 492\ kNm$

$\lambda = 0.79$

$\phi = 0.91$

$\chi = 0.73$

$M_{b,Rd} = 223\ kNm$

$\frac{3PL}{16} = 223\ kNm$

$\Rightarrow P = 198\ kN$

critical

Q2

(a) $c/t = \frac{164}{3} = 54.7 > 42\varepsilon = 42(0.81) = 34$ Class 4

$b/t = \frac{167}{3} = 55.7$

$\sigma_{cr} = 4 \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = 233$ MPa

$\lambda = \sqrt{\frac{355}{233}} = 1.23 \rightarrow \rho = \frac{1}{\lambda}\left(1 - \frac{0.22}{\lambda}\right) = 0.67$

$b_{eff} = \rho(167) = 111$ mm $\rightarrow A_{eff} = 1335$ mm^2

$A_{eff} \cdot f_y = 474$ kN

$I = \frac{170^4}{12} - \frac{164^4}{12} = 9.32(10^6) \rightarrow N_E = \frac{\pi^2 EI}{L^2} = 435$ kN

$\lambda_c = \sqrt{\frac{A_{eff} \cdot f_y}{N_E}} = 1.04$ curve $\underline{b}$: $\alpha = 0.34$

$\phi = \frac{1}{2}(1 + \alpha(\lambda - 0.2) + \lambda^2) = 1.188 \rightarrow \chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}} = 0.57$

$P = \chi \cdot A_{eff} \cdot f_y = 270$ kN

(b) $A = 4(167)(3) = 2004$ mm^2

$4(ct + t^2) = 2004$ with $\frac{c}{t} = 34 \rightarrow c = 34t$

$34t^2 + t^2 = 501$

$\rightarrow t = 3.78$ mm $\rightarrow c = 128.6$ mm $\rightarrow d = 136.2$ mm

$A \cdot f_y = 711$ kN

$I = \frac{(136.2)^4}{12} - \frac{(128.6)^4}{12} = 5.86(10^6)$ mm^4 $\rightarrow N_E = 273.8$ kN

$\lambda_c = \sqrt{\frac{A f_y}{N_E}} = 1.61 \rightarrow \phi = 2.04 \rightarrow \chi = 0.30$

$P = \chi \cdot A \cdot f_y = 216$ kN

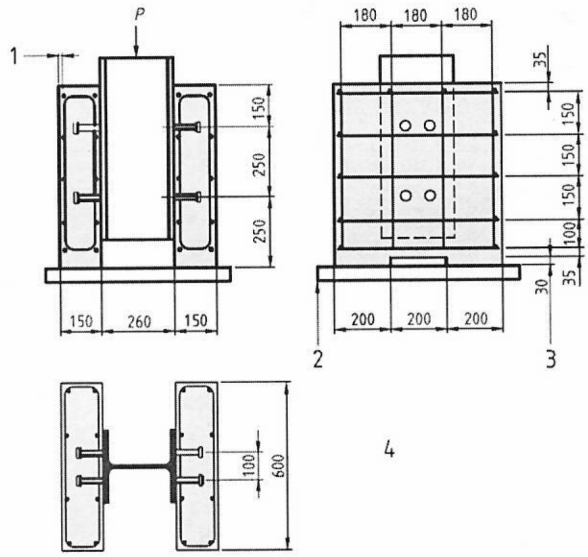
(c) $(a)/(b) = 1.25 \rightarrow 25\%$ higher

$I_{\square} \sim b^3$

As b increases, I increases rapidly (faster than negative influence of loss of effective area).

Q3

(a)



(b) Linear behaviour of the connectors does not allow a redistribution of the connector forces from the ends (maximum slip) towards the middle → not suited for plastic design.

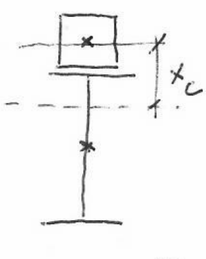
(c)

D.L.	25 kN/m	× 1.35	=	33.8
L.L.	15 kN/m	× 1.5	=	22.5
S.W. slab	7.2 kN/m	× 1.35	=	9.7
S.W. beam	0.92 kN/m	× 1.35	=	1.24
				67.2 kN/m

$$V_{max} = \frac{(67.2)(10)}{2} = 336 \text{ kN}$$

$$n = 2n_0 = 2\,\frac{200}{33} = 12.1 \qquad b_{eff} = \min\left(\frac{10}{4}, 2\right) = 2 \text{ m}$$

$$b_{eff}/n = 165 \text{ mm}$$



$$A = 11700 + (150)(165) = 36450 \text{ mm}^2$$

$$x_c = (11700)\left(\frac{533}{2} + \frac{150}{2}\right)/A = 109.6 \text{ mm} > 75 \text{ mm}$$

N.A. in beam

$$I = I_{UB} + A_{UB}\left(\frac{533}{2} - 34.6\right)^2 + \frac{(150)^3(165)}{12} + (150)(165)(109.6)^2 = 1.53\,(10^9)\text{ mm}^4$$

$$q = V_{max}\frac{Q}{I} = (336)(150)\frac{(165)(109.6)}{(1.53)(10^9)} = \overset{0.60}{\cancel{0.41}} \text{ kN/mm}$$

$$125 / 0.60 = \overset{208}{\cancel{243}\ \cancel{306}} \text{ mm}$$

$$\rightarrow \overset{200}{\cancel{300}} \text{ mm spacing}$$

(d) $0.85 (f_{cd})(h)(b_{eff}) = (0.85)\left(\frac{30}{1.5}\right)(150)(2000) = 5100 \text{ kN}$

$A \cdot f_y = (11\,700)(355) = 4154 \text{ kN} \rightarrow$ N.A. in concrete

$$P_{Rd,1} = \frac{(0.8)(500)\pi(19)^2/4}{1.25} = 90.7 \text{ kN}$$

$$P_{Rd,2} = \frac{(0.29)(19)^2\sqrt{(30)(33000)}}{1.25} = \underline{83.3} \text{ kN}$$

$\frac{4154}{83.3} = 50$ over 5 m $\rightarrow$ rows of 2 @ 200 mm

Q4.

(a) $I_{bolts} = 4\left(70^2 + 210^2 + 350^2\right) = 686\,(10^3)\ mm^2$

$W_{bolts} = I_{bolts}/350 = 1960\ mm$

$M_{Ed}/W_{bolts} = 255\ kN$

$N_{Ed}/12 = 10\ kN$

$\left.\right\}$ 245 kN Tension

$V_{Ed}/12 = 16.7\ kN$

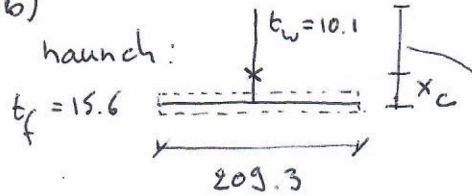
Try M24 : $N_{Rd} = (0.9)(353)(1000)/1.1 = 289\ kN$ <u>ok</u>

$V_{Rd} = (0.6)(353)(1000)/1.1 = 193\ kN$ <u>ok</u>

Interaction : $\dfrac{16.7}{193} + \dfrac{\overset{245}{\cancel{265}}}{(1.4)(289)} = \overset{0.69}{\cancel{0.74}} < 1.0$ <u>ok</u>

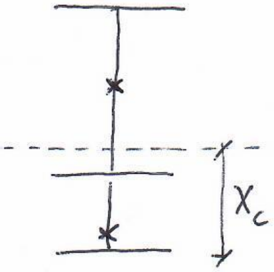
(b)

haunch :



$x_c = \dfrac{(10.1)(267-15.6)\left(\frac{267}{2}\right)}{(10.1)(267-15.6)+(209.3)(15.6)} = 58.4\ mm$

$\rightarrow 267 - 15.6/2 - x_c = 200.8$



$A_{UB} = 11700\ mm^2$ $\qquad I_{UB} = 55230\,(10^4)\ mm^4$

$X_c = \left[A\left(533 - \frac{15.6}{2}\right) + \frac{A}{2}(58.4)\right]\Big/1.5A = 369\ mm$

$I = I_{UB} + A\left(533 - \frac{15.6}{2} - 369\right)^2 + \frac{I_{UB}}{2} + \frac{A}{2}\left[-(200.8)^2 + (369-58.4)^2\right]$

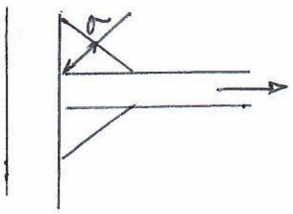
$= 1.44\,(10^9)\ mm^4$

Top flange :

$\sigma = \dfrac{M}{I}\left(800 - 369 - \frac{15.6}{2}\right) - \dfrac{N}{A} = 146.8 - 6.8 = \underline{140\ MPa}$

Bottom flange :

$\sigma = -\dfrac{M}{I}\left(369 + \frac{15.6}{2}\right) - \dfrac{N}{A} = -130.7 - 6.8 = 137.5\ MPa$



$\rightarrow (140)(15.6)$
$= 2.18\ kN/mm$

$\sigma = \left(\dfrac{2180}{2}\right)\dfrac{\sqrt{2}}{2}\Big/a = \dfrac{772}{a}\ MPa$

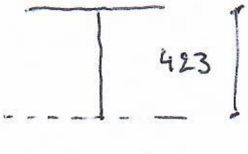
$\tau = \sigma$

$\left(\dfrac{772}{a}\right)\sqrt{1+3} \leq \dfrac{490}{(0.9)(1.1)} \rightarrow a \geq 3.12\ mm \rightarrow$ <u>5 mm leg</u>

$\sigma = \left(\dfrac{772}{a}\right) \leq \dfrac{0.9}{1.1}(490)$? <u>Ok</u>

<u>Web</u>

$q = V\dfrac{A\bar{y}}{I}$



$A\bar{y} = \dfrac{(423-15.6)^2}{2}(10.1) + (15.6)(209.3)\left(423 - \frac{15.6}{2}\right)$

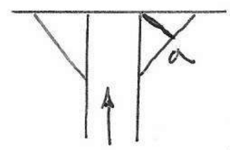
$= 2.19\,(10^6)\ mm^3$

$$q = \frac{(200)(10^3)(2.19)(10^6)}{55\,230\,(10^4)} = 793 \text{ N/mm}$$

$$a = \frac{5}{\sqrt{2}} = 3.54 \text{ mm}$$

$$\tau_v = \left(\frac{793}{2}\right)/a = 112 \text{ MPa}$$

$+$



$$(6.8)(10.1) = 69 \text{ N/mm}$$

$$\tau_h = \frac{(69)}{2}\frac{\sqrt{2}}{2}/a = 6.9 \text{ MPa}$$

$$\sigma = \tau_h$$

$$\sqrt{6.9^2 + 3(6.9^2 + 112^2)}$$

$$= 195 \text{ MPa} < 490 \quad \underline{\text{ok}}$$