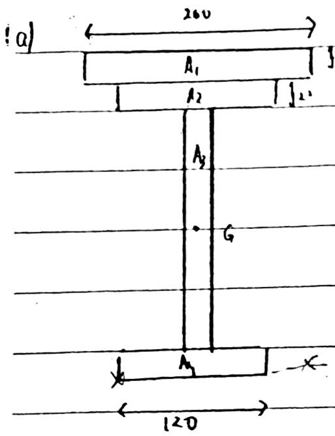
CV4102 14/15 S1

iCave
Development Office

1(a)



$A_1 = 200(20) = 4000$

$A_2 = 120(20) = 2400$

$A_3 = 200(20) = 4000$

$A_4 = 120(20) = 2400$

$= 12800 mm^2$

distance btw centroid of web to bottom

$12800(L_G) = 200(20)(250) + 120(20)(230) + 200(20)(120) + 120(20)(10)$.

a) $L_G = \dfrac{4000)[250) + 2400(230) + 4000(120) + 2400(10)}{4000 + 2400 + 4000 + 2400}$

$L_G = 160.625$ from bottom

b) I_{yy} about y-y axis

$250-160.625$ $230-160.625$ $120-160.625$ $10-160.625$

$I_{yy} = \left[\frac{1}{12} 200\ 20^3 + 4000(89.375)^2\right] + \left[\frac{1}{12} 120\ 20^3 + 2400\ 69.375^2\right] + \left[\frac{1}{12} 20\ 200^3 + 4000(40.625)^2\right] + \left[\frac{1}{12} 120\ 20^3 + 2400(150.625^2)\right]$

$I_{yy} = 118181666.7\ mm^3$

c) $W_{ely} = I_{yy}/z$

$= \dfrac{118181666.7}{160.625}$

$= 735761.3489$

D. Area above plastic neutral axis = Area below plastic neutral axis

$200(20) + 120(20) + 20(220 - x) = 20(x-20) + \cancel{120(20)}$

$4000 + 4400 - 20x = 20x - 400$

$8800 = 40x$

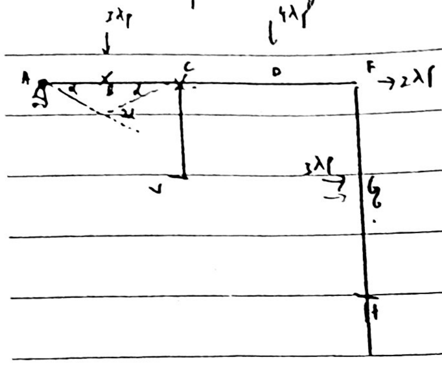
$x = 220\ mm$ X = distance btw the bottom fibre and the plastic neutral axis, PNA

Area above PNA = area below PNA

$W_{pl} = 200(20)(30) + 120(20)\ 20 + 20(200)(100) + 120(20)(210)$

$= 1072000\ mm^3$

(i) Beam mechanism with plastic hinges at BC



$W_{ext} = W_{int}$

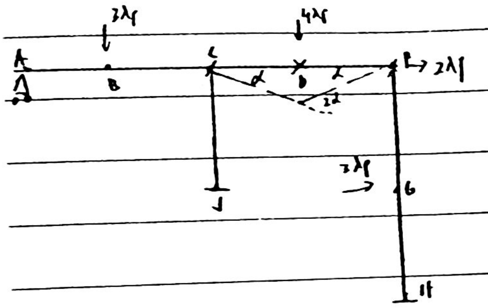
$3\lambda P \, 4\alpha = M_p(2\alpha) + M_p(\alpha)$

$12\lambda P\alpha = 3M_p\alpha$

$\lambda P = \frac{1}{4} M_p$

$\lambda = \frac{1}{4}\frac{M_p}{P}$

(ii) Beam Mechanism with plastic hinges at CDF



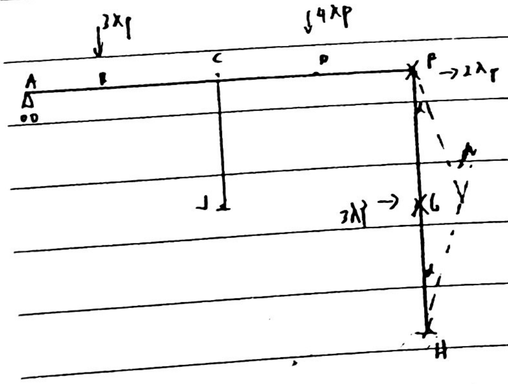
$W_{ext} = W_{int}$

$4\lambda P \, 4\alpha = M_p\alpha + M_p(2\alpha) + M_p\alpha$

$16\alpha\lambda P = 4M_p\alpha$

$\lambda = \frac{1}{4}\frac{M_p}{P}$

(iii) Column mechanism with plastic hinges at FGH



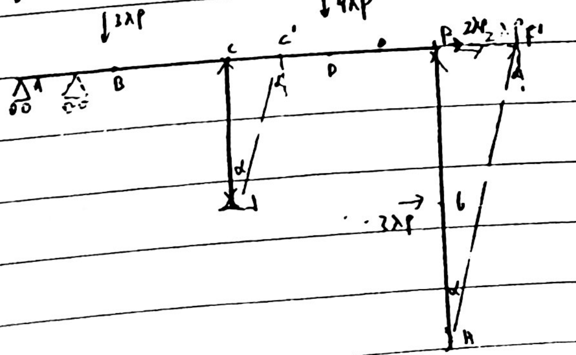
$W_{ext} = W_{int}$

$3\lambda P \; 6\alpha = M_p\alpha + M_p 2\alpha + M_p\alpha$

$18\lambda P\alpha = 4M_p\alpha$

$\lambda = \frac{2}{9}\frac{M_p}{P}$

(iv) Sway mechanism with plastic hinges at CJFH



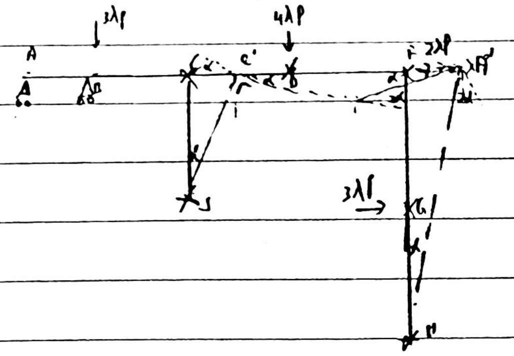
$W_{ext} = W_{int}$

$2\lambda P(12\alpha) + 3\lambda P(6\alpha) = M_p\alpha + M_p\alpha + M_p\alpha + M_p\alpha$

$42\lambda P\alpha = 4M_p\alpha$

$\lambda = \frac{2}{21}\frac{M_p}{P}$

v) Combined mechanism with plastic hinges at C D F J H



$W_{ext} = W_{int}$

$2\lambda P(12\alpha) + 3\lambda P(6\alpha) + 4\lambda P(4\alpha) = M_p\alpha + M_p(\alpha) + M_p(2\alpha) + M_p(\alpha) + M_p\alpha$

$58\lambda P\alpha = 7M_p\alpha$

$\lambda = \frac{7}{58}\frac{M_p}{P}$

Mechanism 1 $\rightarrow \lambda = \frac{1}{4}\frac{M_p}{P}$

Mechanism 2 $\rightarrow \lambda = \frac{1}{4}\frac{M_p}{P}$

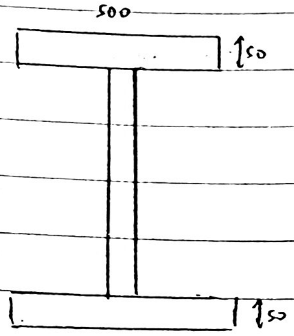
Mechanism 3 $\rightarrow \lambda = \frac{2}{9}\frac{M_p}{P}$

Mechanism 4 $\rightarrow \lambda = \frac{2}{21}\frac{M_p}{P}$

Mechanism 5 $\rightarrow \lambda = \frac{7}{58}\frac{M_p}{P}$

Mechanism 4 has the lowest load factor (λ)
therefore it is the correct mechanism

2 (i)



$f_y = 335$

$\varepsilon = 0.84$

- for flange

$c_f/t_f = \dfrac{(500-20)/2}{50} = 4.8$

class 1 limit $\rightarrow 9\varepsilon = 7.56$

class : $c_f/t_f < 9\varepsilon \rightarrow$ class 1

- For web

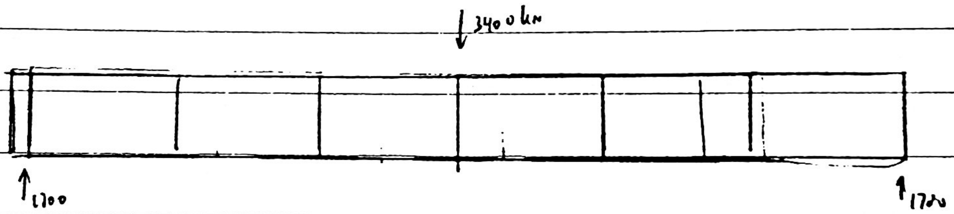
$h_w/t_w = \dfrac{3400}{20} = 170$

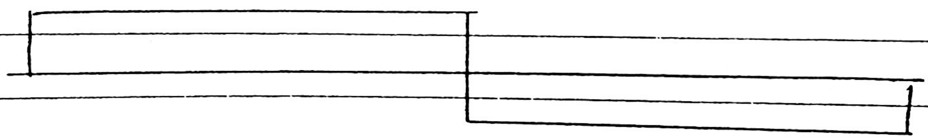
class 3 limit $= 124\varepsilon = 104.16$

$h_w/t_w > 124\varepsilon \rightarrow$ class 4

$\therefore$ flange class 1, web class 4 $\rightarrow$ overall $\Rightarrow$ class 4

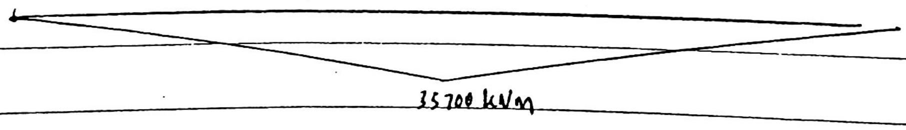
(ii)





$V_{max} = 1700$

$M_{max} = 35700$



(iii) Flange only method

Use resistance from flange only

$M_{f,rd} = W_{pl,f} \times f_y = A_f (h_w + t_f) f_y$

$= 500(50)(3400+50)(335)\ 10^{-6}$

$= 28893.75$ not sufficient

(iii)

$A_{gross} = 500(50) \times 2 + 3400(20) = 118000 mm^2$

$I_{gross} = [\frac{1}{12} 500\ 50^3 + 500(50)\ 1725^2] \times 2 + \frac{1}{12} 20\ 3400^3$

$= 21429833.33$

Calculation of effective width and 6'

use gross section → $\psi = 1$ and $k\sigma = 23.9$

$\bar{\lambda}_p = \frac{h_w/t_w}{28.4 \varepsilon \sqrt{k\sigma}} = \frac{\frac{3400}{20}}{28.4(0.84)(\sqrt{23.9})} = 1.458 > 71.08$

$\bar{\lambda}_p = 1.458 > 0.5 + \sqrt{0.085 - 0.055(-1)} = 0.874$

$\rho = \frac{\bar{\lambda}_p - 0.055(3+\psi)}{\lambda_p^2} = \frac{1.458 - 0.055(3-1)}{1.458^2}$

$\rho = 0.634$

$b_c = \frac{3400}{2} = 1700$

$b_{eff} = 0.634 \times 1700 = 1077.8$

$b_{e1} = 0.4(1077.8) = 431.12$

$b_{e2} = 0.6(1077.8) = 646.68$

$x = 1700 - 1077.8 = 622.2$

$\Delta A = 622.2(20) = 12444 mm^2$

$A_{eff} = 118000 - 12444 = 105556 mm^2$

$r = \frac{x}{2} + b_{e2} = \frac{622.2}{2} + 646.68$

$r = 957.78$

therefore $\Delta r = 957.78 \times \frac{12444}{105556}$

$\Delta r = 112.913$

$I_{eff} = I_{gross} + A(\Delta r)^2 - \left(\frac{x^3 t_w}{12} + \Delta A(r + \Delta r)^2\right)$

$= 21429833.33\ 10^4 mm^4 + 118000(112.913^2) - \left[\frac{622.2^3(20)}{12} + 12444(957.78 + 112.913)^2\right]$

$= 20113570.3\ cm^4$

Distance between G' and centroid of compression flange

$d_1 = 1700 + 25 + 112.913$

$= 1837.913$

$d_2 = 1700 + 25 - 112.913$

$= 1612.087$

new stress ratio $\psi = \dfrac{-1612.087}{1837.913}$

$= -0.87713$

$W_{el,eff} = \dfrac{I_{eff}}{d_1} = \dfrac{2011\,3570.3109}{1837.913}$

$= 109437.01\ cm^3$

$M_{y,rd} = 109437.01 \times 10^3 \times 335$

$= 36661\ kNm \quad > 35700 \rightarrow$ sufficient

(iv) shear resistance

$V_{max} = 1700kN$

$a = 7000mm^2 > h_w$

$k_\tau = 5.34 + 4\left(\dfrac{3400}{7000}\right)^2$

$k_\tau = 6.284$

$h_w/t_w = \dfrac{3400}{20} = 170 \leq 31 \dfrac{\varepsilon}{\eta}\sqrt{k_\tau} = 31 \dfrac{(0.84)}{1}\sqrt{6.284} = 65.277 \rightarrow 1$

hence, the web is not sturdy

$\bar{\lambda}_w = \dfrac{h_w}{37.4 t_w \varepsilon \sqrt{k_\tau}} = \dfrac{3400}{37.4(20)(0.84)\sqrt{6.284}} = 2.159$

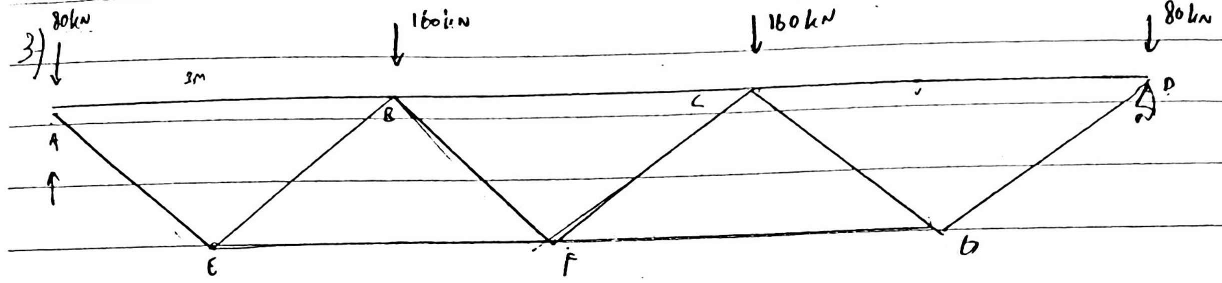
$\chi_w = \dfrac{1.37}{0.7 + 2.159} = 0.47925$

thus $V_{bw,rd} = \dfrac{\chi_w f_{yw} h_w t_w}{\sqrt{3}\,\gamma_{M1}} = \dfrac{0.47925(335)(3400)(20)}{\sqrt{3}}$

$= 6303.115kN > 1700\ kN$

No need to check flange contribution as shear resistance from web is sufficient

3)



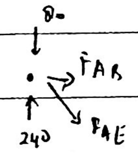
$M_A = 0$

$160(3) + 160(6) + 80(9) = R_D(9)$

$R_D = 240$ kN

$R_A = 240$ kN

At Point A

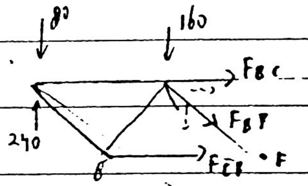


$80 + F_{AE}\sin 45 = 240$

$F_{AE} = 226.2742$ kN

$F_{AE}\cos 45 + F_{AB} = 0$

$F_{AB} = -160$ kN



$M_F = 0$

$160(1.5) + 80(4.5) = F_{BC}\,1.5 + 240(4.5)$

$F_{BC} = -320$ kN

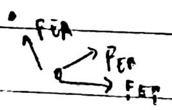
$M_E = 0$

$160(1.5) + F_{BC}(1.5) + F_{BF}(1.5\sqrt{2}) + 240(1.5) = 80(1.5)$

$240 - 480 + F_{BF}\,1.5\sqrt{2} + 360 = 120$

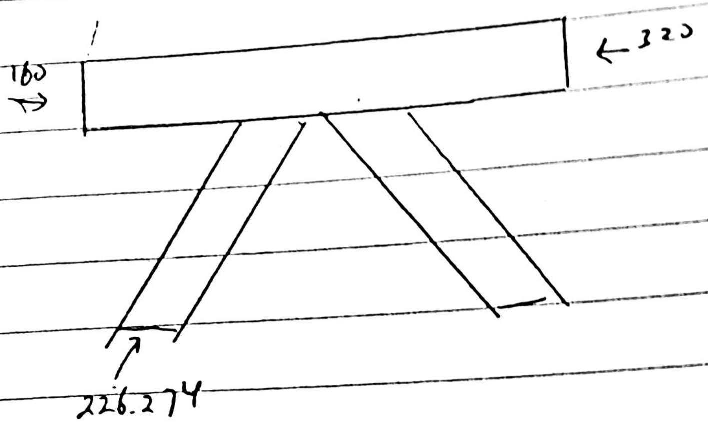
$F_{BF} = 0$ kN

At Point E



$F_{EA}\sin 45 + F_{EB}\sin 45 = 0$

$F_{EB} = -226.274$ kN



Chord ϕ 114.3 × 6.3

brac ϕ : 88.9 × 5

$f_{yo} = f_{yi} = 275\ N/mm^2$

$\gamma = \frac{d_0}{2t_0} = \frac{114.3}{2(6.3)} = 9.0714$

$\beta = d_1/d_0 = \frac{88.9}{114.3} = 0.78$

check range of validity

$d_1/d_0 = d_2/d_0 = 0.78$

$0.2 \leq \frac{d_1}{d_0} = \frac{d_2}{d_0} = 0.78 \leq 1$

$10 \leq \frac{d_0}{t_0} = 9.0714 \leq 50$

$\frac{d_0}{t_0} = 9.0714 \leq 46.3$ (class 2) } ok

$10 \leq \frac{d_1}{t_1} = \frac{88.9}{5} = 17.78 \leq 50$

$\frac{d_1}{t_1} = 17.78 \leq 46.3$ (class 2) } ok

$10 \leq \frac{d_2}{t_2} = \frac{88.9}{5} = 17.78 \leq 50$

$d_2/t_2 = 17.78 \leq 46.3$ (class 2) } ok

(c) $\sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} + \frac{M_{0,Ed}}{W_{el,0}}$

As $M_{0,Ed} = 0$

$\sigma_{p,Ed} = \frac{N_{p,Ed}}{A_0} = \frac{160 \cdot 10^3}{1099.942mm^2} = 145.462 \, N/mm^2$

$n_p = \frac{145.462}{275} = 0.529$

check for chord face failure

$N_{1,rd,compression} = \frac{k_g \, k_p \, f_{y0} \, t_0^2}{\sin\theta_1} \left(1.8 + 10.2 \frac{d_1}{d_0}\right) / \gamma_{M5}$

$N_{2,rd} = \frac{\sin\theta_1}{\sin\theta_2} N_{1,rd}$

$k_g = \gamma^{0.2} \left[1 + \frac{0.024 \, \gamma^{1.2}}{1 + \exp(0.5 \frac{g}{t_0} - 1.33)} \right]$

$k_g = 9.0714^{0.2} \left[1 + \frac{0.024 \; 9.0714^{1.2}}{1 + \exp(0.5 \frac{30}{6.3} - 1.33)} \right]$

$k_g = 1.691$

Since $n_p > 0$

$k_p = 1 - 0.3 n_p (1 + n_p)$

$k_p = 1 - 0.3 (0.529)(1.529) = 0.7573$

therefore

$N_{1,rd} = \frac{(1.691)(0.7573)(275)(6.3)^2}{\sin 45} \left[1.8 + 10.2 \frac{88.9}{114.3} \right]$

$N_{1,rd} = 192.4 kN$

$N_{2,rd} = N_{1,rd} = 192.4 kN$

Punching shear failure

Brace 1

$$N_{1,Rd} = \frac{f_{y0}}{\sqrt{3}}\, t_0\, \pi\, d_1 \left(\frac{1+\sin\theta_1}{2\sin^2\theta_1}\right) / \gamma_{M5}$$

$$= \frac{275}{\sqrt{3}}(6.3)\pi(88.9)\left[\frac{1+\sin 45}{2\sin^2 45}\right]$$

$N_{1,Rd} = 476.897$

Brace 2 → No need to check

Brace capacity

$$W_{el} = \frac{\pi}{32(88.9)}\left(88.9^4 - 78.9^4\right)$$

$W_{el} = 26180.85\ mm^3$

$I_y = 1163738.633$

$$N_{cr} = \frac{\pi^2 EI}{L_{cr}^2} = \frac{\pi^2 (210000)(1163738.633)}{(1.5\sqrt{2}\ 10^3)^2}$$

$N_{cr} = 535.997$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \sqrt{\frac{\frac{1}{4}\pi(88.9^2 - 78.9^2) \times 275}{535.997 \cdot 10^3}}$$

$= 0.8223$

Use buckling curve a $= \alpha = 0.21$

$$\phi = 0.5\left[1 + 0.2(0.8223 - 0.2) + 0.8223^2\right]$$

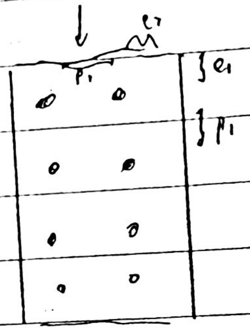
$\phi = 0.9$

$$\chi = \frac{1}{0.9 + \sqrt{0.9^2 - 0.8223^2}} = 0.7895$$

$$N_{b,Rd} = \frac{0.7895 \times \frac{1}{4}\pi(88.9^2 - 78.9^2) \times 275}{1}$$

$= 286.1374\ kN$

4 a)



$e_1 = 60$

$p_1 = 70$

$e_2 = 50$

$p_2 = 154$

for e_1 : $1.2 d_0 \le e_1 \le 4t + 40$

$1.2(22) \le 60 \le 4(13) + 40$

$26.4 \le 60 \le 92 \rightarrow$ ok

for e_2 : $1.2 d_0 \le e_2 \le 4t + 40$

$26.4 \le 50 \le 92 \rightarrow$ ok

for p_1 : $2.2 d_0 \le p_1 \le \min(28t, 400)$

$2.2(22) \le 70 \le \min(28(13), 400)$

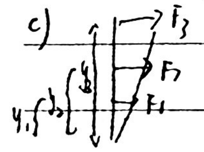
$48.4 \le 70 \le 364 \rightarrow$ ok

for p_2 : $2.4 d_0 \le p_2 \le \min(14t, 400)$

$2.4(22) \le 154 \le \min(14(13), 400)$

$52.8 \le 154 \le 182 \rightarrow$ ok

c)



$$F_3 = \frac{P(160)(210)}{2(210^2 + 140^2 + 70^2)}$$

$F_3 = 0.245 P$

Tension resistance

From the table $= F_{t,rd} = 141 kN$

$F_3 = F_{t,rd} = 0.245 P = 141$

$P = 575.5 kN$

Slip resistant at serviceability

$$F_{s,rd,ser} = \frac{k_s\ n\ \mu\ (F_{p,c} - 0.8\ F_{t,Ed,ser})}{\gamma_{M3,ser}}$$

$k_s = 1$ $F_{pc} = 0.7 f_{ub} A_s = 0.7(800)(245$

$= 137.2\ kN$

$n = 1$

$\mu = 0.5$ $\gamma_{M3,ser} = 1.1$

$$F_{s,rd,ser} = \frac{1(1)(0.5(137.2 - 0.8 F_3)}{1.1}$$

$= 62.364 - 0.364\ F_3$

Shear force $= P/8$

$F_{s,rd,ser} = P/8$

$62.364 - 0.364(0.245P) = P/8$

$62.364 - 0.0891P = P/8$

$P = 291.3\ kN$

- at ultimate limit state

shear capacity

$$F_{v,rd} = \frac{\alpha_v\ f_{ub}\ A}{\gamma_{M2}} = \frac{0.6(800)(245)}{1.25}$$

$= 94.08$

$F_{v,rd} = P/8$

$P = 752.64\ kN$

Bearing capacity $\rightarrow F_b = \frac{k_1\ \alpha_b\ f_u\ d\ t}{\gamma_{M2}}$

For end bolts $= \alpha_d = \frac{e_1}{3d_0} = \frac{60}{3(22)} = 0.91$

Inner bolts $= \alpha_d = \frac{p_1}{3d_0} - \frac{1}{4} = \frac{70}{3(22)} - \frac{1}{4} = 0.811$

$\alpha_b = \min(\alpha_d, \frac{f_{ub}}{f_u}, 1) = \min(0.811, \frac{800}{430}, 1)$

$= 0.811$

Perpendicular to direction of load

for end bolts $= k_1 = \min\left(2.8\frac{e_2}{d_0} - 1.7, 2.5\right)$

$= \min\left(2.8\frac{50}{22} - 1.7, 2.5\right)$

$= 2.5$

For inner bolts: $k_1 = \min\left(1.4\frac{p_2}{d_0} - 1.7; 2.5\right)$

$= \min\left(1.4\frac{154}{22} - 1.7, 2.5\right)$

$= 2.5$

hence, $F_{b,rd} = \dfrac{2.5(0.811)(430)(22)(13)}{1.25}$

$= 199.474\ kN$

$F_{b,rd} = P/8$

$P = 1595.788\ kN$

Max load that can be applied to satisfy serviceability and ultimate limit state =

$P = 291.3\ kN$

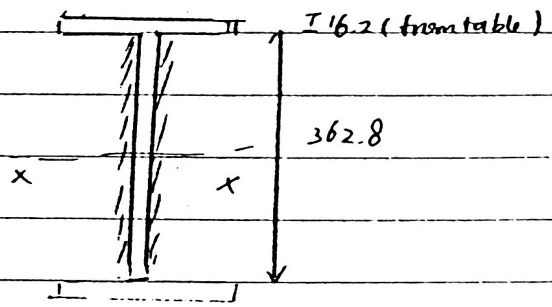
D) $a = 0.707 \times 15$

$a = 10.605$

Total area of 15mm fillet welds:

$= 2(362.8) \times 10.605$

$= 7694.988\ mm^2$



max vertical shear stress $= F_s = P/\text{Area of weld} = \dfrac{291.3 \times 10^3}{7694.988} = 37.856\ N/mm^2$

Second moment of the weld group

$I_{xx} = \left[\frac{1}{12}\ 10.605\ 362.8^3\right] \times 2$

$= 84403655.78\ mm^4$

Sh[illegible] force [illegible]

$$Z_{xx} = \frac{I_{xx}}{y}$$

$$= \frac{84403655.78}{\frac{362.8}{2}}$$

$$Z_{xx} = 465290.2744$$

Max. bending stress is equal to

$$f_b = \frac{P \times e}{Z_{xx}} = \frac{291.3 \; 10^3 \times 160}{465290.2744} = 100.17 \; N/mm^2$$

max stress is equal to

$$F_T = \sqrt{37.856^2 + 100.17^2}$$

$$= 107.0843 \; N/mm^2$$

$$f_{vw,d} = \frac{f_u / \sqrt{3}}{\beta_w \times \gamma_{M_2}}$$

$$= \frac{430/\sqrt{3}}{0.85 \times 1.25} = 233.657 \; N/mm^2$$

$F_{vw,d} > F_T \rightarrow$ sufficient