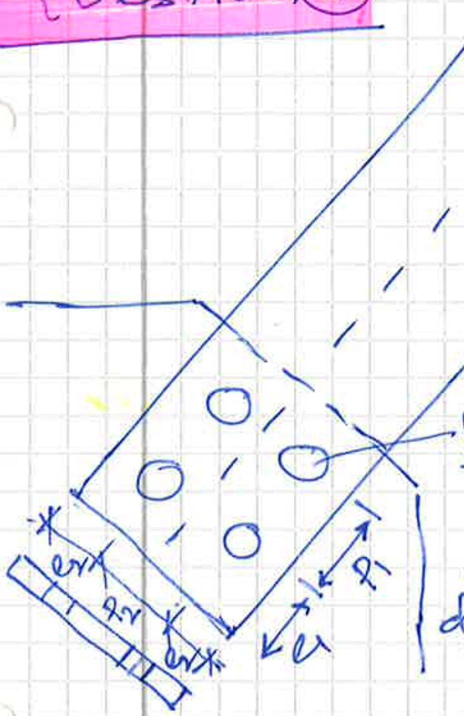
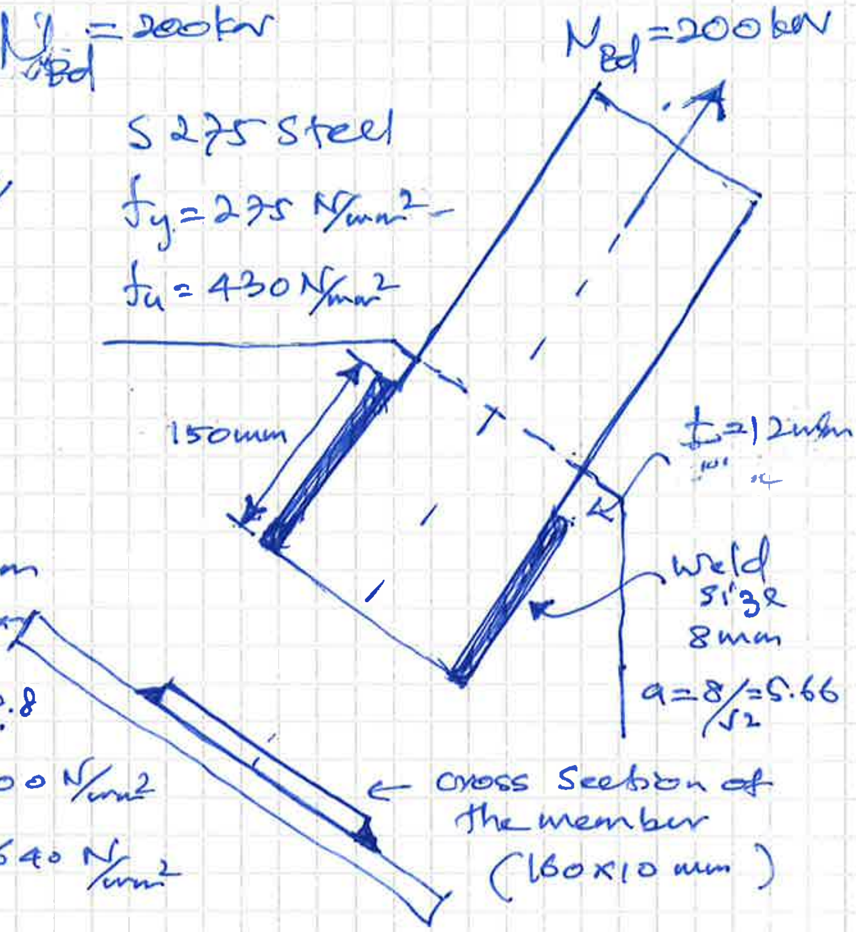
Question ①



bolts
M 16
d = 16 mm
$d_0 = 18$ mm
Grade 8.8
$f_{ub} = 800\ N/mm^2$
$f_{yb} = 640\ N/mm^2$

S 275 Steel
$f_y = 275\ N/mm^2$
$f_u = 430\ N/mm^2$



$P_1 = 100$ mm
$e_1 = 50$ mm
$P_2 = 80$ mm
$e_2 = 40$ mm

(a).(i). check for c/s yielding.

$$N_{pl,Rd} = \frac{A f_y}{\gamma_{m0}} = \frac{160 \times 10 \times 275}{1.05} = 419\ kN > N_{Ed} = 200\ kN \quad ok$$

No cross sectional yielding.

Check for local fracture near holes.

$$N_{u,Rd} = \frac{0.9 A_{net} f_u}{\gamma_{m2}} = \frac{0.9 [A - 2 d_0 t] f_u}{\gamma_{m2}}$$

$$= \frac{0.9 [160 \times 10 - 2 \times 18 \times 10]\, 430}{1.25 \times 10^3}$$

$$= 383.9\ kN > N_{Ed} = 200\ kN \quad ok$$

No fracture near holes.

Member shown in figure 1(a) can withstand the design load //

(ii). Yes. Member shown in Figure 1(b) can carry the loads.

This member symmetrically (Concentrically) welded and (A_{net} < A (as there is no bolt holes).
in 1(a)   in 1(b).

$N_{pl,Rd}$ is same as case a(i).

$$\therefore \quad N_{u,Rd} = \frac{0.9 A f_u}{\gamma_{m2}} > \frac{0.9 A_{net} f_u}{\gamma_{m2}}$$

$N_{u,Rd}$ in Section a(i).

as $A = 160 \times 10 > A_{net} = 160 \times 10 - 2 \times 18 \times 10$

(b)(i). Bolts are subjected to shear.

$$F_{v,Ed} = \left(\frac{200}{4}\right) kN = 50\,kN$$

(class of bolt M 8.8.)

(Shear force per bolt)

M16 bolts shear planes passing through threaded portions;

$$F_{v,Rd} = \frac{0.6 f_{ub} A_s}{\gamma_{m2}} = F^*_{d,v} = 60.3\,kN$$

$\therefore \quad F_{v,Ed} = 50\,kN < F_{v,Rd} = 60.3\,kN$ ok//

Bolt size are suitable//

(ii). Check the tension member for bearing failure.

$$F_{b,Ed} = F_{v,Ed} = 50\,kN$$

$$F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{m_2}}$$

$d = 16 mm$
$d_0 = 18 mm$
$t = 10 mm$
$f_u = 430 N/mm^2$
$\gamma_m = 1.25$

$$\alpha_b = Min\left[\frac{e_1}{3d_0} ; \left(\frac{p_1}{3d_0} - \frac{1}{4}\right) ; \frac{f_{ub}}{f_u} ; 1.0\right]$$

$$= Min\left[\frac{50}{3\times18} ; \left(\frac{100}{3\times18} - \frac{1}{4}\right) ; \frac{800}{430} ; 1.0\right]$$

$$= Min\left[0.925 ; 1.601 ; 1.86 ; 1.0\right] = 0.925$$

$$k_1 = Min\left[\left(2.8\frac{e_2}{d_0} - 1.7\right) ; \left(1.4\frac{p_2}{d_0} - 1.7\right) ; 2.5\right]$$

$$= Min\left[\left(\frac{2.8\times40}{18} - 1.7\right) ; \left(\frac{1.4\times80}{18} - 1.7\right) ; 2.5\right]$$

$$= Min\left[4.52 ; 4.52 ; 2.5\right] = 2.5$$

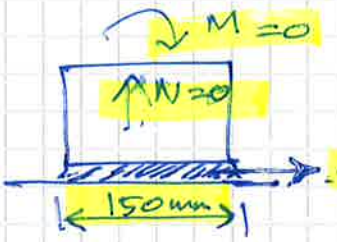
$$F_{b,Rd} = \frac{2.5\times0.925\times430\times16\times10}{1.25\times10^3} = 127.28 kN$$

$F_{b,Rd} = 127.28 kN > F_{b,Ed} = 50 kN$ Ok //

Tension Member is not subjected to bearing failure. //

(iii). Fillet weld ; $a = 8/\sqrt{2} = 5.66$ mm

$a = 5.66\text{mm} > 0.5t_p = 5\text{mm} > 3\text{mm}$ ok.



$2V = 200\text{kN}$ $V = 100\text{kN}$

weld legth $L = 150 - 2a = 138.68$ mm

$\tau_\perp = \sigma_\perp = 0$; $\tau_{\parallel} = \dfrac{V}{La} = \left(\dfrac{100\times10^3}{138.68\times5.66}\right)$

$= 127.47\ \text{N/mm}^2$

Design check;

$$\sqrt{\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_\parallel^2)} = \sqrt{3}\,\tau_\parallel = \sqrt{3}\times127.47\ \text{N/mm}^2$$
$$= 220.78\ \text{N/mm}^2$$

$$\frac{f_u}{\beta_w \gamma_{M_2}} = \frac{430}{1.25\times0.85} = 404\ \text{N/mm}^2$$

$$\sqrt{\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_\parallel^2)} = 220.78\ \text{N/mm}^2 < \frac{f_u}{\beta_w \gamma_{M_2}} = 404\ \text{N/mm}^2$$

ok//

Size of the weld is Suitable //

Question (2)

(a)(i) RHS 250x150x10

$i_y = 90.4\,mm$

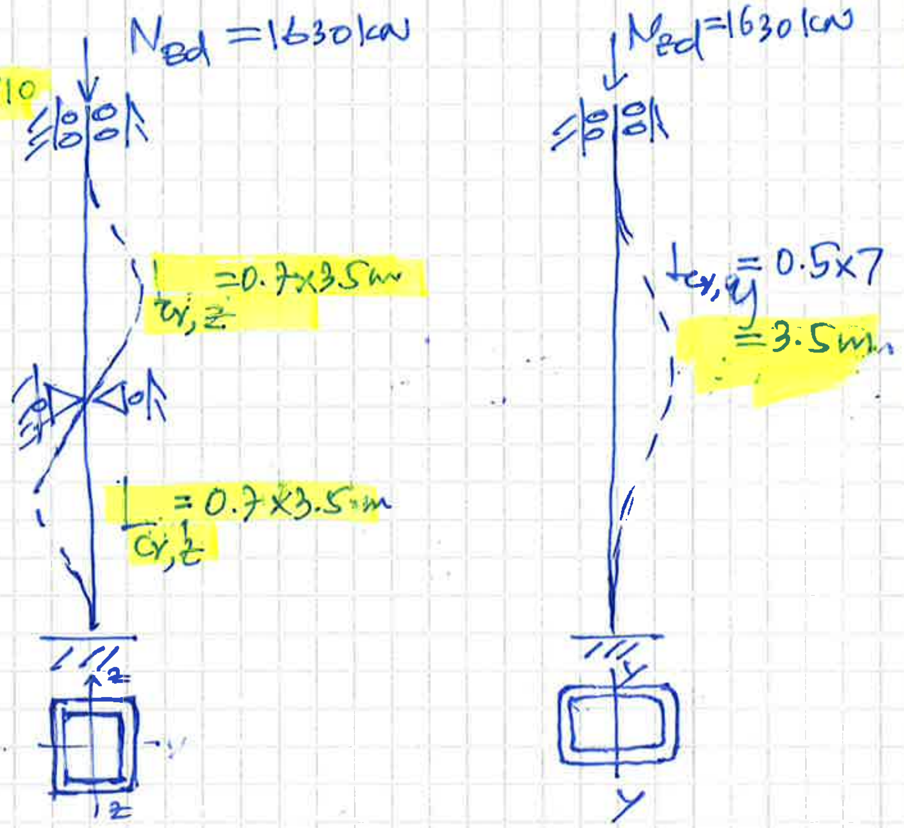
$i_z = 60.5\,mm$

$A = 7450\,mm^2$

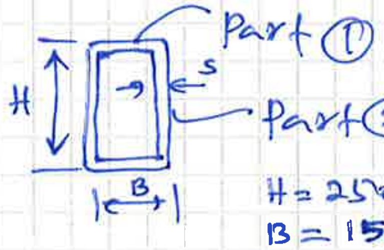
S355 Steel

$f_y = 355\,N/mm^2$

$\varepsilon = 0.81$



Class classification.



$H = 250\,mm$
$B = 150\,mm$
$s = 10\,mm$

Part (1). Compression

$$c_1/s\varepsilon = \left(\frac{B - 3s}{s\varepsilon}\right) = \frac{150 - 3\times10}{10\times0.81} = 14.81 < 33 \text{ class (1)}$$

Part (2). Compression

$$c_2/s\varepsilon = \left(\frac{H - 3s}{s\varepsilon}\right) = \frac{250 - 3\times10}{10\times0.81} = 27.16 < 33 \text{ class (1)}$$

Cross section is class (1).

Check for Cross Sectional yielding.

$$N_{c,Rd} = \frac{Af_y}{\gamma_{m0}} = \frac{7450\times355}{1.05\times10^3} = 2518.8\,kN$$

$< N_{Ed} = 1630\,kN$

ok ✓

Check for overall flexural buckling.

$$N_{b,Rd} = \chi \frac{Af_y}{\gamma_{m1}}$$

$$\bar{\lambda}_y = \frac{l_{cr,y}}{i_y} \cdot \frac{1}{93.9 \times 0.81} = \frac{3500}{90.4} \cdot \frac{1}{93.9 \times 0.81} = 0.509$$

$$\bar{\lambda}_z = \frac{l_{cr,z}}{i_z} \cdot \frac{1}{93.9 \times 0.81}$$

$$\bar{\lambda}_z = \frac{0.7 \times 3500}{60.5} \cdot \frac{1}{93.9 \times 0.81}$$

$$\bar{\lambda}_z = 0.5324$$

hot finished Curve "a" Select $\alpha_z = 0.21$

as $\bar{\lambda}_z > \bar{\lambda}_y$; Buckling axis is about z-z axis.

$$\phi_z = 0.5\left[1 + \alpha_z(\bar{\lambda}_z - 0.2) + \bar{\lambda}_z^2\right]$$

$$= 0.5\left[1 + 0.21(0.5324 - 0.2) + 0.5324^2\right]$$

$$= 0.677$$

$$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z^2 - \bar{\lambda}_z^2}} = \frac{1}{0.677 + \sqrt{0.677^2 - 0.5324^2}}$$

$$= 0.914$$

$$N_{b,Rd} = \frac{\chi_z A f_y}{\gamma_{M_1}} = \frac{0.914 \times 7450 \times 355}{1.05 \times 10^3} = 2301 \text{ kN}$$

$N_{b,Rd} = 2301$ kN $>$ $N_{Ed} = 1630$ kN

ok//

RHS 250x150x10 is Suitable//

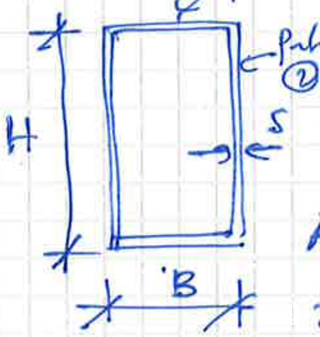
(ii). A ↓ Reducing $N_{c,Rd}$ ↓

$i = \sqrt{\frac{I\downarrow}{A\downarrow}}$; Due to Corrosion; material loss; hence C/S Area gradually reducing. then I ↓ and A ↓ ;

∴ i – Radius of gyration ?

$\bar{\lambda} = \frac{l_{cr}}{i \updownarrow}$; $N_{b,Rd} \updownarrow$? it difficult to say increase or decrease.

(b)(i) RHS 300×200×6.3



$H = 300\,mm$
$B = 200\,mm$
$S = 6.3\,mm$
$A = 6080\,mm^2$
$i_y = 113\,mm$
$i_z = 82.8\,mm$

Class classification

Part ① : Compression

$$\frac{c_1}{s\varepsilon} = \frac{(B - 3s)}{s\varepsilon} = \frac{(200 - 3\times 6.3)}{6.3\times 0.81}$$

$$= 35.48 < 38 \quad \text{Class ②}$$

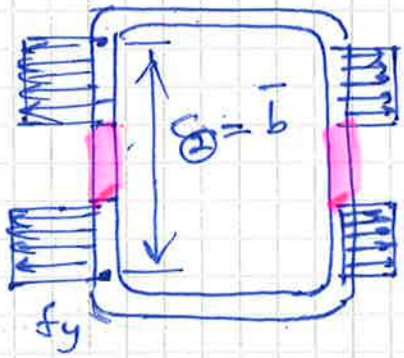
Part ② : Compression

$$\frac{c_2}{s\varepsilon} = \frac{(H - 3s)}{s\varepsilon} = \frac{(300 - 3\times 6.3)}{6.3\times 0.81} = 55.08 > 42 \quad \text{Class ④}$$

$$c_2 = (300 - 3\times 6.3) = 281.1\,mm$$

C/S is Class ④. Part ② only subjected to local buckling.

From Table 4.1 : Internal Compression elements



$$\psi = \frac{\sigma_2}{\sigma_1} = 1.0$$

$$k_\sigma = 4.0$$

$$\bar{\lambda}_p = \frac{\bar{b}/t}{28.4\varepsilon\sqrt{k_\sigma}}$$

$$= \frac{c_2/s}{28.4\varepsilon\sqrt{k_\sigma}} = \frac{281.1/6.3}{28.4\times 0.81\times\sqrt{4}}$$

$$= 0.97 > 0.673$$

$$\rho = \frac{\bar{\lambda}_p - 0.055(3+\psi)}{\bar{\lambda}_p^2} = \frac{0.97 - 0.055(3+1)}{0.97^2}$$

$$= 0.797$$

$$A_{eff} = A - 2(1-\rho)c_2 s$$

$$= 6080 - 2(1 - 0.797)281.1\times 6.3 = \underline{\underline{5360\,mm^2}}$$

(ii). $N_{c,Rd} = \dfrac{A_{eff} f_y}{\gamma_{M0}} = \dfrac{5360 \times 355}{1.05 \times 10^3} = 1812 \text{ kN}$

$> N_{Ed} = 1630 \text{ kN}$

Column can withstand the axial load without cross sectional yielding.

$\therefore$ ok //

(iii). Design buckling resistance [Class 4]

$N_{b,Rd} = \chi \dfrac{A_{eff} f_y}{\gamma_{M1}}$

Determination of χ;

$\bar{\lambda}_y = \dfrac{L_{cr,y}}{i_y} \cdot \dfrac{\sqrt{A_{eff}/A}}{93.9 \times 0.81}$

$= \dfrac{3500}{113} \cdot \dfrac{\sqrt{5360/6080}}{93.9 \times 0.81}$

$= 0.382$

$\bar{\lambda}_z = \dfrac{L_{cr,z}}{i_z} \cdot \dfrac{\sqrt{A_{eff}/A}}{93.9 \times 0.81}$

$\bar{\lambda}_z = \dfrac{0.7 \times 3500}{82.8} \cdot \dfrac{\sqrt{5360/6080}}{93.9 \times 0.81}$

$= 0.365$

$\therefore \bar{\lambda}_y > \bar{\lambda}_z$; Buckling y-y axis.

Hot finished RHS cross sections; buckling curve "a" from Table 6.2; $\alpha = 0.21$;

$\phi_y = 0.5\left[1 + \alpha(\bar{\lambda}_y - 0.2) + \bar{\lambda}_y^2\right]$

$= 0.5\left[1 + 0.21(0.382 - 0.2) + 0.382^2\right] = 0.592$

$\chi_y = \dfrac{1}{\phi_y + \sqrt{\phi_y^2 - \bar{\lambda}_y^2}} = \dfrac{1}{0.592 + \sqrt{0.592^2 - 0.382^2}}$

$= 0.958$

$N_{b,Rd} = \dfrac{\chi_y A_{eff} f_y}{\gamma_{M0}} = \dfrac{0.958 \times 5360 \times 355}{1.05 \times 10^3} = 1735 \text{ kN}$

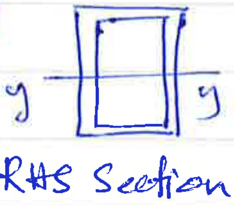
$> N_{Ed} = 1630 \text{ kN}$

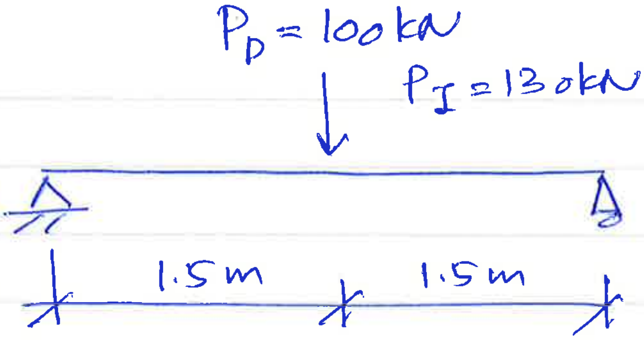
ok //

Column can withstand the axial load without overall flexural buckling //

Question 3

(a)





S 355 steel

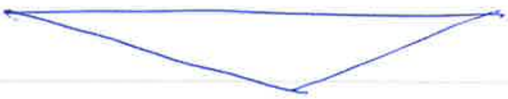
$f_y = 355 \, N/mm^2$ $\quad \varepsilon = 0.81 \quad L = 3m$

(i). Design for ULS

Design load $P_{Ed} = 1.35(P_D) + 1.5(P_I)$
$= 330$ kN

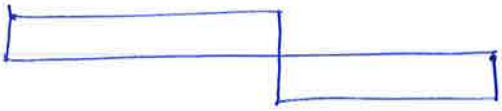
$M_{ed} = \frac{P_{Ed} L}{4} = 247.5$ kNm

BMD



$V_{ed} = P_{ed}/2 = 165$ kN

SFD



Trail Section; $W_{pl,y} \geq \frac{\gamma_{mo} M_{ed}}{f_y}$

$W_{pl,y} \geq \frac{1.05 \times 247.5 \times 10^6}{355}$

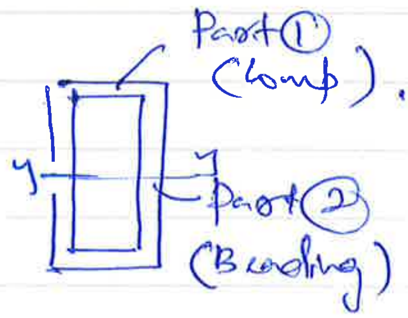
$W_{pl,y} \geq 732.04 \times 10^3 \ mm^3$

Select RHS 300x200x8 as a trail Section.

$W_{pl,y} = 775 \times 10^3 mm^3 \quad A = 7650 \, mm^2$

$I_y = 96.5 \times 10^3 \, mm^4$

Class classification



Part (1); Compression.

$c/t\varepsilon = (200 - 3\times 8)/8 \times 0.81 = 27.16 < 33$
Class (1)

Part (2); Bending

$c/t\varepsilon = \frac{(300 - 3\times 8)}{8 \times 0.81} = 42.59 < 72$ class (1).

Cross Section is class (1)

Checking for bending Moment

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl,y} f_y}{\gamma_{M0}} = \frac{775\times10^3 \times 355}{1.05\times10^6} = 262\ kNm$$

$M_{Ed} = 247.5\ kNm < M_{c,Rd} = 262\ kNm$ ok

No cross sectional yielding //

RHS Section negligible effect on LTB.

No LTB.

$\therefore$ Bending check is ok.

Checking for shear force.

$$V_{c,Rd} = V_{pl,Rd} = \frac{A_v f_y/\sqrt{3}}{\gamma_{M0}}$$

$$A_v = \left(\frac{Ah}{b+h}\right) = \frac{7650\times300}{(200+300)} = 4590\ mm^2$$

$$V_{c,Rd} = \frac{4590\times 355/\sqrt{3}}{1.05\times10^3} = 895.96\ kN$$

$\therefore V_{Ed} = 165\ kN < V_{c,Rd} = 895.96\ kN$ ok

No cross sectional shear yielding //

Checking for Combined effect.

$V_{Ed} = 165\ kN < 0.5 V_{c,Rd} = 447.98\ kN$

$\therefore$ No effect of V_{Ed} to $M_{c,Rd}$ //

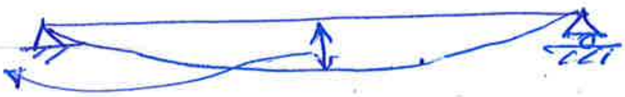
$\therefore$ RHS 300x200x8 is Suitable Design Section.

(ii). Design for SLS (check)

$P_{SLS} = 1.0(P_P) + 1.0(P_I) = 230\ kN$

$$\delta_{SLS} = \frac{1}{48}\frac{P_{SLS} L^3}{EI}$$

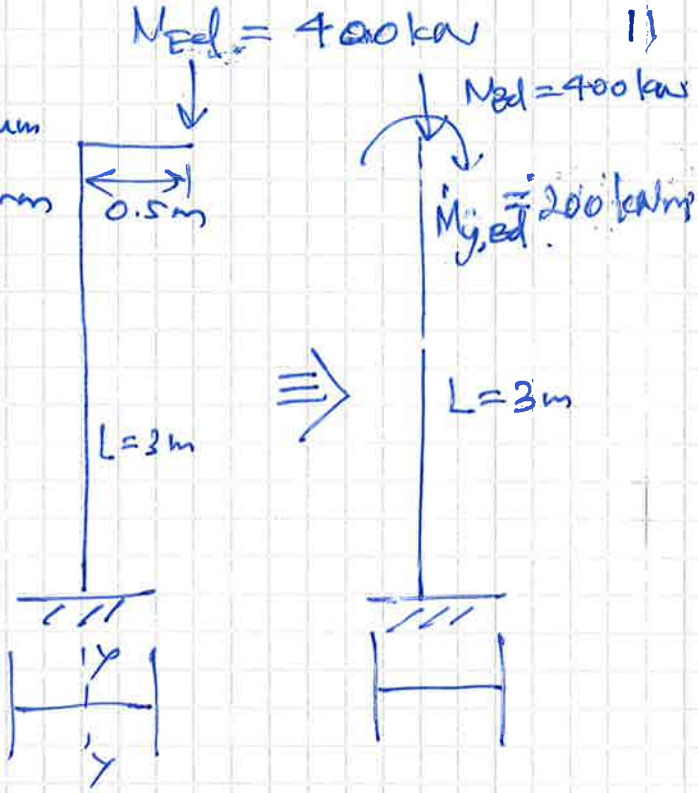
δ_{SLS}



$$= \frac{1}{48}\times\frac{230.0\times10^3\times3000^3}{210000\times96.5\times10^6} = 6.385\ mm < \delta_{all} = L/200 = 15\ mm$$

$(\delta_{SLS})_{actual} < \delta_{allowable}$ // SLS check is OK //

(b). HE 300B



$A = 14900\ mm^2$ $\quad i_y = 130\ mm$

$S_y = 934 \times 10^3\ mm^3$ $\quad i_z = 75.8\ mm$

$h = b = 300mm$ $\quad t_f = 19mm$

$t_w = 11mm$ $\quad r = 27mm$

S 355 Steel

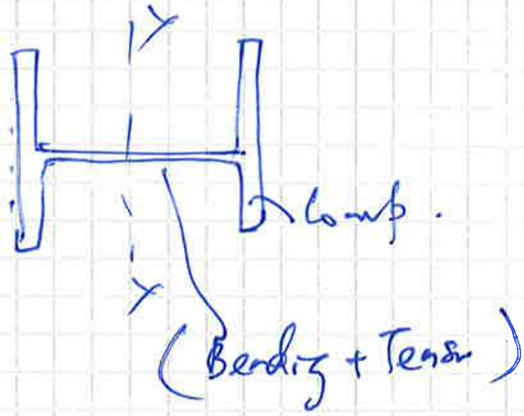
$f_y = 355\ N/mm^2$ $\quad \varepsilon = 0.81$

$M_{cr} = 1105\ kNm$

$k_{yy} = 1.058$

$k_{zy} = 0.968$

(i). Cross Section Class



Flange (Compression)

$$\frac{c_f}{t_f \varepsilon} = \frac{(b - 2r - t_w)/2}{t_f \varepsilon} = 7.63 < 9$$

Class 1

Web (Bending + Compression)

$$\frac{c_w}{t_w \varepsilon} = \frac{(h - 2r - 2t_f)}{t_w \varepsilon} = 23.34 < 33$$

Class 1.

Lower bound of cl 1

$$\left[33 \leq \frac{396}{13\alpha - 1} < 72 \right]$$

∴ Cross Section is Class 1

Checking for Buckling

$M_{y,Ed} = 200\text{ kNm}$
$M_{z,Ed} = 0$
$N_{Ed} = 400\text{ kN}$

$$\frac{N_{Ed}}{\chi_y \frac{N_{Rk}}{\gamma_{m1}}} + k_{yy} \frac{M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{m1}}} \leq 1$$

$$\frac{N_{Ed}}{\chi_z \frac{N_{Rk}}{\gamma_{m1}}} + k_{zy} \frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{m1}} \leq 1$$

$$N_{Rk} = A f_y = \frac{14900 \times 355}{10^3} = 5289.5\text{ kN}$$

$$M_{y,Rk} = W_{pl,y} f_y = 2 S_y f_y = \frac{2 \times 934 \times 10^3 \times 355}{10^6} = 663.14\text{ kNm}$$

χ_y , χ_z ;

$$\bar{\lambda}_y = \frac{L_{cr,y}}{i_y} \cdot \frac{1}{\lambda_1} = \frac{2 \times 3000}{130} \cdot \frac{1}{93.9 \times 0.81} = 0.606$$

$$\bar{\lambda}_z = \frac{L_{cr,z}}{i_z} \cdot \frac{1}{\lambda_1} = \frac{2 \times 3000}{75.8} \cdot \frac{1}{93.9 \times 0.81} = 1.04$$

$h/b = 1.0$, S355 Steel hot Rolled, $t_f < 100$ mm.

y-y axis Curve "b" — $\alpha_y = 0.34$

z-z axis curve "c" — $\alpha_z = 0.49$

$$\phi_y = 0.5\left[1 + \alpha_y(\bar{\lambda}_y - 0.2) + \bar{\lambda}_y^2\right]$$
$$\phi_y = 0.752$$

$$\phi_z = 0.5\left[1 + \alpha_z(\bar{\lambda}_z - 0.2) + \bar{\lambda}_z^2\right]$$
$$\phi_z = 1.25$$

$$\chi_y = \frac{1}{\phi_y + \sqrt{\phi_y^2 - \bar{\lambda}_y^2}}$$
$$\therefore \chi_y = 0.835$$

$$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z^2 - \bar{\lambda}_z^2}}$$
$$\therefore \chi_z = 0.52$$

χ_{LT} ; $\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} f_y}{M_{cr}}} = \sqrt{\frac{2 S_y f_y}{M_{cr}}} = \sqrt{\frac{2 \times 934 \times 10^3 \times 355}{1105 \times 10^6}}$

$= 0.775$

$h/b = 1.0 < 2$ curve "a" $\alpha_{LT} = 0.21$

$\phi_{LT} = 0.5 \left[1 + \alpha_{LT} (\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2 \right]$
$= 0.86$

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \lambda_{LT}^2}} = 0.81$$

$$\frac{N_{Ed}}{\chi_y \frac{N_{Rk}}{\gamma_{m1}}} + k_{yy} \frac{M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{m1}}} = \frac{400}{\left(\frac{0.835 \times 5289.5}{1.05}\right)} + \frac{1.058 \times 200}{\left(\frac{0.81 \times 663.14}{1.05}\right)} = 0.509 < 1$$

ok

No buckling about y-y axis.

$$\frac{N_{Ed}}{\chi_z \frac{N_{Rk}}{\gamma_{m1}}} + k_{zy} \frac{M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{m1}}} = \frac{400}{\left(\frac{0.52 \times 5289.5}{1.05}\right)} + \frac{0.968 \times 200}{\left(\frac{0.81 \times 663.14}{1.05}\right)} = 0.532 < 1$$

ok

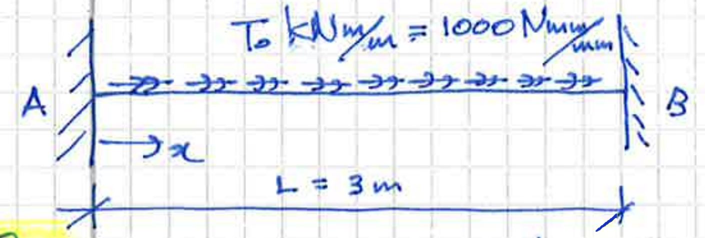
No buckling about z-z axis.

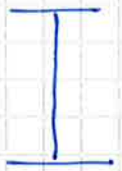
No buckling failure of Member

Member is Suitable against Overall or lateral torsional buckling

(ii). BC beam has not been sufficiently laterally braced, BC beam may subjected Lateral Torsional buckling. Due to this, point B subjected to out of plane Bending Moment ($M_{z,Ed}$) in addition to $M_{y,Ed}$. Hence Reduce the buckling capacity.

Question (4)



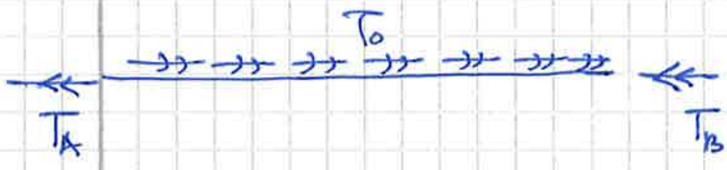


IPE 500

at $x = 0$
$\phi = 0$
$\frac{d\phi}{dx} = 0$

at $x = L$
$\phi = 0$
$\frac{d\phi}{dx} = 0$

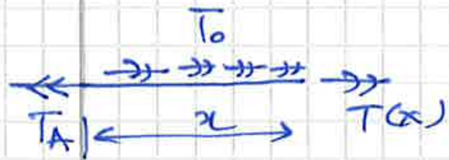
Neglect the effect of St. Venant torsion.
$GI_T \ll EC_w$



$\Sigma T = 0; \quad T_A + T_B = T_0 L$

By symmetricity of BC's, loading & Geometry;

$T_A = T_B = T_0 L/2$



$$T(x) = T_A - T_0 x = T_0 L/2 - T_0 x$$

$$-EC_w \frac{d^3\phi}{dx^3} = T(x) = T_0 L/2 - T_0 x$$

$$-EC_w \frac{d^2\phi}{dx^2} = T_0 \frac{L}{2} x - T_0 \frac{x^2}{2} + C_1$$

$$-EC_w \frac{d\phi}{dx} = T_0 \frac{L}{2}\frac{x^2}{2} - T_0 \frac{x^3}{6} + C_1 x + C_2$$

$$-EC_w \phi(x) = T_0 \frac{L}{2}\frac{x^3}{6} - T_0 \frac{x^4}{24} + C_1 \frac{x^2}{2} + C_2 x + C_3$$

Boundary Conditions;

at $x = 0$; $\phi(x) = 0$; $C_3 = 0$

$\frac{d\phi}{dx} = 0$; $C_2 = 0$

at $x = L$; $\frac{d\phi}{dx} = 0$; $T_0 \frac{L}{2} \cdot \frac{L^2}{2} - T_0 \frac{L^3}{6} + C_1 L = 0$

$$C_1 = \frac{T_0 L^2}{6} - \frac{T_0 L^2}{4} = \frac{-T_0 L^2}{12}$$

$$\therefore -EC_w \frac{d^3\phi}{dx^3} = \frac{T_0 L}{2} - T_0 x$$

$$\frac{d^3\phi}{dx^3} = -\frac{T_0}{EC_w}\left[\frac{L}{2} - x\right]$$

$$-EC_w \frac{d^3\phi}{dx^2} = T_0 \frac{L}{2} x - T_0 \frac{x^2}{2} - T_0 \frac{L^2}{12}$$

$$\frac{d^2\phi}{dx^2} = \frac{T_0}{2EC_w}\left[x^2 - Lx + \frac{L^2}{6}\right]$$

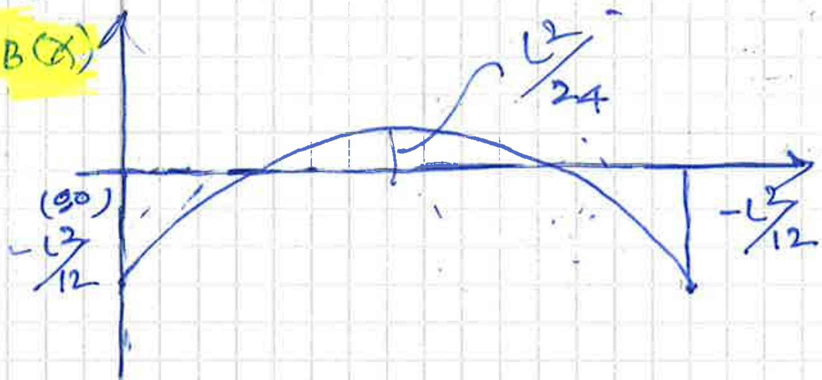
$$= \frac{T_0}{2EC_w}\left[\left(x - \frac{L}{2}\right)^2 + \frac{L^2}{6} - \frac{L^2}{4}\right]$$

$$= \frac{T_0}{2EC_w}\left[\left(x - \frac{L}{2}\right)^2 - \frac{L^2}{12}\right]$$

$T_w(x)$

$\left[\begin{array}{c}\text{at}\\ x=0\\ \text{and}\\ x=L\end{array}\right]$ $\left(\frac{d^3\phi}{dx}\right)_{max} = \phi_{xxx} = \pm \frac{T_0 L}{2EC_w}$

$B(x)$

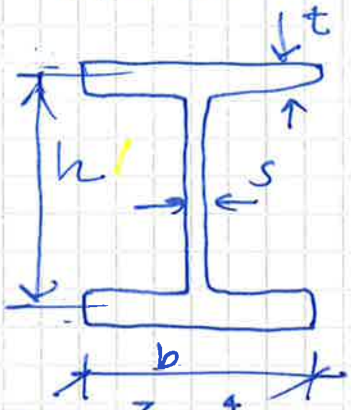


$\left[\begin{array}{c}\text{at}\\ x=0\\ \text{and}\\ x=L\end{array}\right]$ $\left(\frac{d^2\phi}{dx^2}\right) = \frac{T_0 L^2}{12EC_w} = \phi_{xx}$

Critical Cross Sections are $x=0$ & $x=L$

(i). $h = 500 - t = 484$ mm

IPE 500



$b = 200$ mm

$t = t_f = 16$ mm

$s = t_w = 10.2$ mm

$C_w = 1249 \times 10^9$ mm^6

$$I_f = \frac{1}{12} b^3 t = \frac{1}{12} \times 200^3 \times 16 = 1.0667 \times 10^7 \text{ mm}^4$$

$$A_f = bt = 200 \times 16 = 3200 \text{ mm}^2$$

$$M_f = E I_f \, h/2 \, \phi_{xx} \quad ; \quad \sigma_w = M_f \frac{b}{2 I_f}$$

$$\therefore \sigma_{w,max} = E \frac{hb}{4} (\phi_{xx})_{max}$$

For $x = 0$ & $x = L$

$$\sigma_{w,max} = \frac{\cancel{E} hb}{4} \cdot \left(\frac{T_o L^2}{12 \cancel{E} C_w} \right)$$

$$= \frac{T_o L^2}{48 C_w} \cdot hb = \frac{1000 \times 3000^2 \times 484 \times 200}{12 \times 1249 \times 10^9}$$

$$\sigma_{w,max} = 14.53 \text{ N/mm}^2$$

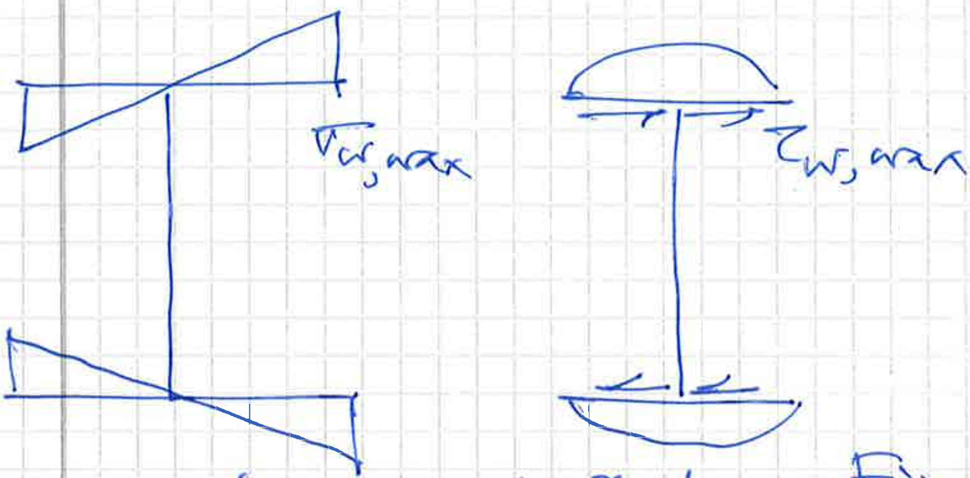
$$V_f = E I_f \, h/2 \, \phi_{xxx} \quad ; \quad \tau_w = V_f \frac{3}{2 A_f}$$

$$\tau_{w,max} = E I_f \, h/2 \cdot \frac{3}{2 A_f} \cdot (\phi_{xxx})_{max}$$

For $x = 0$ & $x = L$

$$\tau_{w,max} = \frac{3 \cancel{E} I_f \, h/2}{2 A_f} \cdot \left(\frac{T_o L}{2 \cancel{E} C_w} \right) = \frac{3 I_f}{8 A_f} \cdot \frac{T_o L}{C_w} \cdot h$$

$$= \frac{3 \times 1.0667 \times 10^7}{8 \times 3200} \times \frac{1000 \times 3000}{1249 \times 10^9} \times 484 = 1.453 \text{ N/mm}^2$$



at $x=0$; $x=L$ Fixed ends

(ii). Check for the ULS ;

$$\sigma_{w,max} = 14.53\ N/mm^2 < f_y/\gamma_{m0} = \frac{355}{1.05} = 338\ N/mm^2$$

Ok No warping Tensile failure.

$$\tau_{t,max} + \tau_{w,max} < \tau_y/\gamma_{m0} = f_y/\sqrt{3}\gamma_{m0}$$

$\tau_{t,max} \rightarrow 0$

$$\tau_{w,max} = 1.453\ N/mm^2 < \frac{355}{\sqrt{3} \times 1.05} = 195\ N/mm^2$$

Ok. No warping shear failure //

(iii).

$T_A + T_B = T_0 L$

Compared to previous case T_A is larger value.

$|T_A| > |T_B|$

More stress concentration at support B.

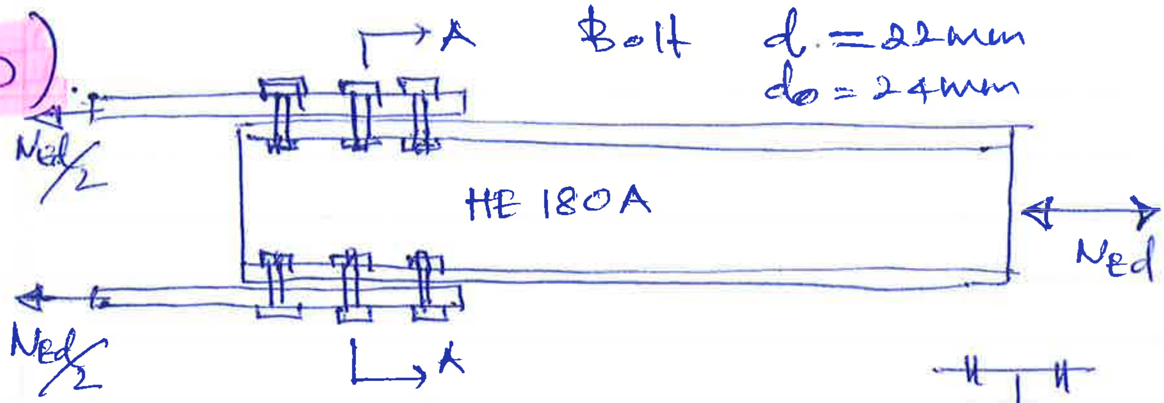
at $x=0$; $T_w \uparrow \rightarrow \left(\frac{d^3\phi}{dx^3}\right)\uparrow$; $\tau_w \uparrow$ shear stress increasing.

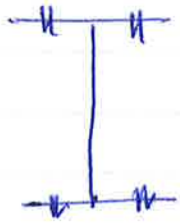
also $B_w \uparrow \rightarrow \left(\frac{d^2\phi}{dx^2}\right)\uparrow$; $\sigma_w \uparrow$

Warping Normal stress will increase //

(b)

Bolt $d = 22mm$
$d_0 = 24mm$





$t_f = 9.5mm$
$A = 4530mm^2$

Section A–A
S275 Steel.

$$\Delta F = F_{max} - F_{min} = 210 \text{ kN}$$

No of cycles per day $= 200$ cycles/day

Safe life ; low Consequence $\Rightarrow$ $\gamma_{Mf} = 1.35$
$\gamma_{Ff} = 1.0$

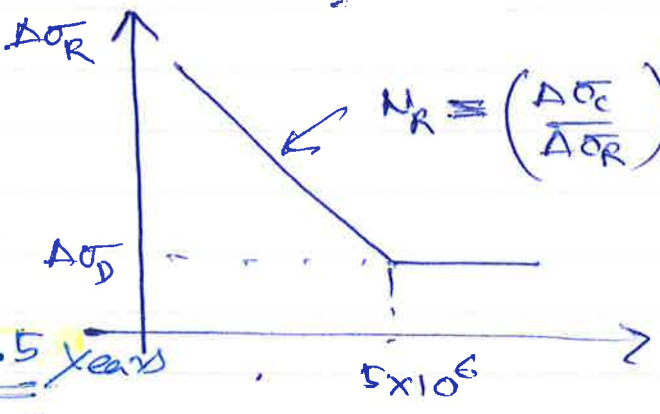
(b)(i). Detail category is 90 for HE 180A Member;

$$\Delta\sigma_C = 90 \text{ N/mm}^2 \qquad \Delta\sigma_D = 0.737\,\Delta\sigma_C = 66.33 \text{ N/mm}^2$$

$$\Delta\sigma_E = \frac{\Delta F}{A_{net}} = \frac{210\times10^3}{(4530 - 4\times24\times9.5)} = 58.04 \text{ N/mm}^2$$

$$\Delta\sigma_R = \gamma_{Mf}\gamma_{Ff}\,\Delta\sigma_E = 1.35\times1.0\times58.04 = 78.358 \text{ N/mm}^2 > \Delta\sigma_D.$$

$$N_R = \left(\frac{90}{78.358}\right)^3 2\times10^6$$
$= 3030{,}453$ cycles



$$N_R = \left(\frac{\Delta\sigma_C}{\Delta\sigma_R}\right)^3 2\times10^6$$

$$\text{Fatig life} = \frac{N_R}{200\times365} = \underline{\underline{41.5 \text{ Years}}}$$

(b)(ii). Detail category is 50 for one sided covered connection with non-preloaded bolts in normal clearance holes.
(No load Reversals) $F(t) \geq 0$

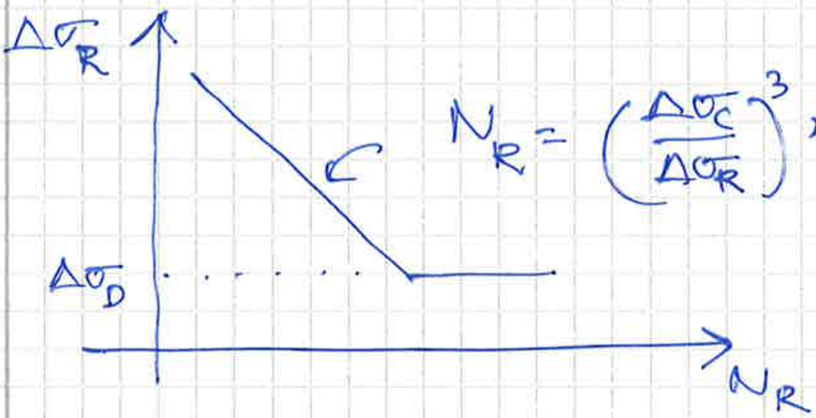
$\Delta\sigma_C = 50 \, N/mm^2$

for one plate.

$$\Delta\sigma_E = \frac{\Delta F/2}{A_{net}}$$

$$= \frac{(210 \times 10^3/2)}{(180 \times 20 - 2 \times 24 \times 20)} = 39.77 \, N/mm^2$$

$$\Delta\sigma_R = \gamma_{mf}\gamma_{Ff}\Delta\sigma_E = 1.35 \times 39.77 = 53.7 \, N/mm^2$$



$$N_R = \left(\frac{\Delta\sigma_C}{\Delta\sigma_R}\right)^3 2 \times 10^6$$

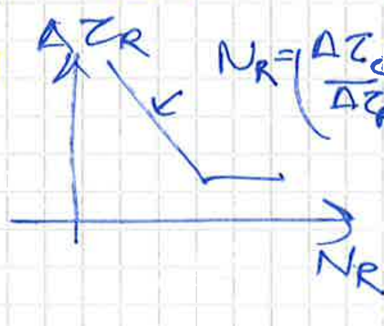
$\Delta\sigma_D = 0.732 \Delta\sigma_C$
$= 36.85 \, N/mm^2$

$$N_R = \left(\frac{50}{53.7}\right)^3 2 \times 10^6 = 1614422 \text{ cycles}.$$

$$\text{Fatigue life} = \left(\frac{N_R}{200 \times 365}\right) = 22.1 \text{ Years}$$

(iii). Detail category is 100 for bolts subjected to SINGLE SHEAR. M 22 bolts
Figure (15).
Thread not in the shear planes.

$\Delta\tau_C = 100 \, N/mm^2$



$$N_R = \left(\frac{\Delta\tau_C}{\Delta\tau_R}\right)^5 2 \times 10^6$$