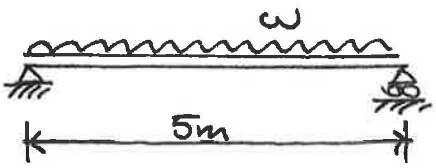
1(a)



w AT ULS $= \left[(5\,kN/m^2 \times 1.6) + (23.54\,kN/m^3 \times 0.25 \times 1.4) \right] \times 4m$

$= 64.96\,kN/m$

w AT SLS $= \left[5\,kN/m^2 + (23.54\,kN/m^3 \times 0.25m) \right] \times 4m$

$= 43.54\,kN/m$

BENDING CAPACITY (ULS)

$M_{app} = wl^2/8 = 64.96 \times 5^2/8 = 203\,kNm$

PLASTIC MOMENT CAPACITY $M_p = Z_p \sigma_y$

$\therefore$ TARGET $Z_p = \dfrac{203 \times 10^6}{355} = 571\,cm^3$

PROVIDE ADDITIONAL 100% FOR L.T.B.

$\therefore$ TARGET $Z_p = 1142\,cm^3$

TRY UB 356x171x67 $\rightarrow$ $Z_p = 1211\,cm^3$
$M_p = 429.9\,kNm$

THEORETICAL ELASTIC CRITICAL MOMENT:

$$M_c = \frac{\pi}{L} \left[EI_{yy} \left(GJ + \frac{\pi^2}{L^2} EC_w \right) \right]^{0.5}$$

$$C_w = \frac{0.3477^2 \times 1362 \times 10^{-8}}{4} = 4.11 \times 10^{-7}$$

$$\therefore M_c = \frac{\pi}{5} \left[210 \times 10^9 \times 1362 \times 10^{-8} \left[(81 \times 10^9 \times 23.8 \times 10^{-8}) + \frac{\pi^2}{25} (210 \times 10^9 \times 4.11 \times 10^{-7}) \right] \right]^{0.5}$$

$= 245.4\,kNm$

$$\therefore \bar{\lambda}_{LT} = \sqrt{\frac{M_p}{M_c}} = \sqrt{\frac{429.9}{245.4}} = 1.3$$

$\chi_{LT} \simeq 0.47$ (FROM L.T.B. CHART IN DATASHEET) (*)

$\therefore M_{MAX} = 0.47 \times 429.9$ kNm $= 202$ kNm $\simeq 203$ kNm

$\therefore$ SATISFACTORY.

DEFLECTION CHECK (SLS)

$\delta_{MAX} = 5000/360 = 13.88$ mm.

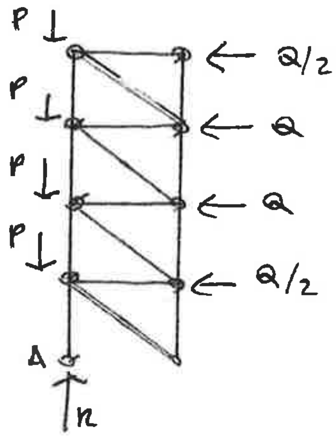
$$\delta = \frac{5 \cdot\cdot w \ell^4}{384 EI} = \frac{5 \times 43.54 \times 5000^4}{384 \times 210 \times 10^3 \times 19460 \times 10^4 \text{ mm}^4}$$

$= 8.67$ mm $<$ 13.88 mm.

$\therefore$ UB 356 x 171 x 67 is SATISFACTORY.

(*) THE ASSUMPTION HERE IS THAT THE BENDING MOMENT IS CONSTANT. THIS IS NOT THE CASE FOR THE BEAM IN QUESTION, BUT THIS IS A SAFE APPROXIMATION.

b)



AT ULS:

$P = 1.2 \times 43.54$ kN $\times \frac{5}{2} = 108.85$ kN

$Q = (1.0 + 1.5) \times 4 \times 3.5 \times 1.2 = 42$ kN

$$R = 4P + \underbrace{\left(\frac{3Q \times 3.5\text{m} \times 2.5}{3\text{m}}\right)}_{A\downarrow}$$

$= 802.9$ kN

$\therefore$ TARGET AREA $A = \frac{802.9 \times 10^3}{355 \text{ N/mm}^2} = 2262 \text{ mm}^2$

PROVIDE ADDITIONAL 100% FOR BUCKLING

$\therefore$ TARGET AREA $A = 4524 \text{ mm}^2$ (45.2 cm^2)

$\therefore$ TRY UC 203 x 203 x 46 ($A = 58.7 \text{ cm}^2$)

PLASTIC SQUASH LOAD $= 5870 \times 355 = 2084$ kN

$\lambda = 350/5.13 = 68.2$

$\lambda_0 = \pi\sqrt{\dfrac{210 \times 10^3}{355}} = 76.4$

$\therefore \bar{\lambda} = 68.2/76.4 = 0.89$

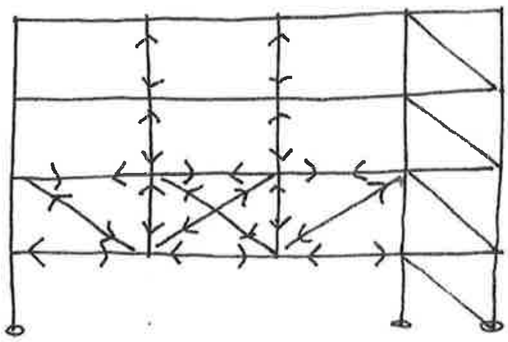
$r/y = 5.13/(20.3/2) = 0.51 \quad \therefore$ USE CURVE B

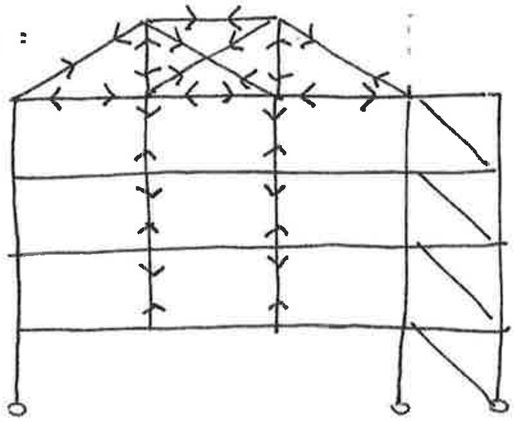
$\chi \simeq 0.65$ (FROM BUCKLING CHART)

$\therefore R_{MAX} = 0.65 \times 2084\ kN$
$= 1354.6\ kN > 802.9\ kN.$

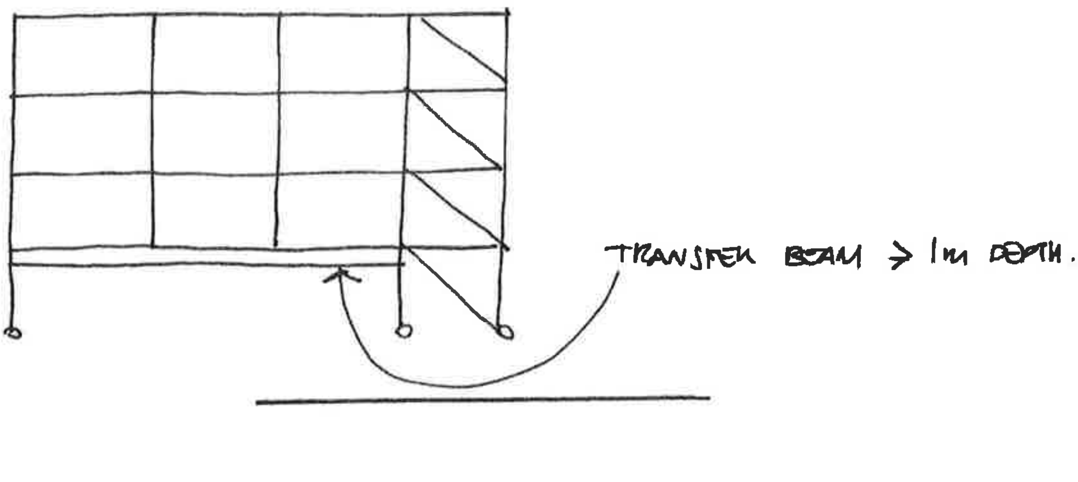
$\therefore$ UC 203 x 203 x 46 is SATISFACTORY.

c) THE TWO PREFERABLE OPTIONS ARE :

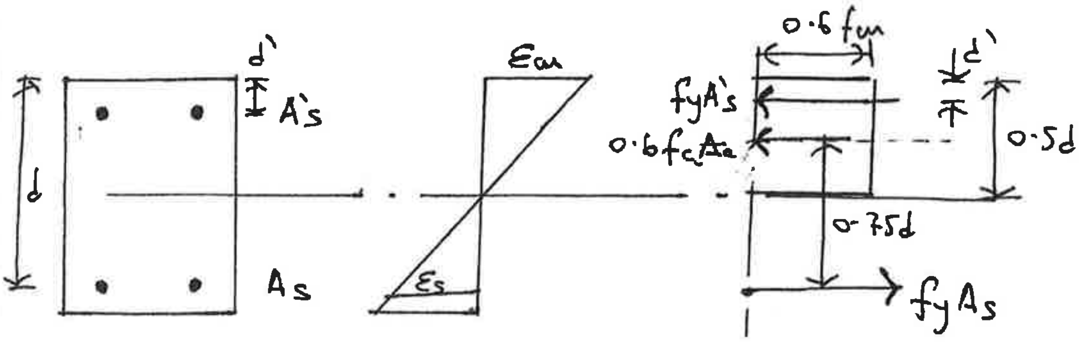




A LESS PREFERABLE OPTION DUE TO THE 15m CLEAR SPAN IS :



2 a)



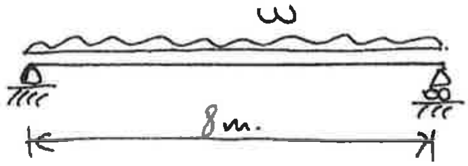
↻ ABOUT TENSION STEEL:

$$M_u = \frac{0.6 f_{cu} A_c}{\gamma_c} \cdot 0.75d + \frac{f_y A'_s}{\gamma_s}(d - d')$$

$$= \frac{0.6 f_{cu} \cdot 0.5d \cdot b \cdot 0.75d}{\gamma_c} + \frac{f_y A'_s}{\gamma_s}(d - d')$$

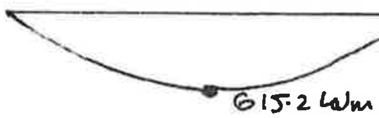
$$= \frac{0.225 f_{cu} b d^2}{\gamma_c} + \frac{f_y A'_s (d - d')}{\gamma_s}$$

b i)



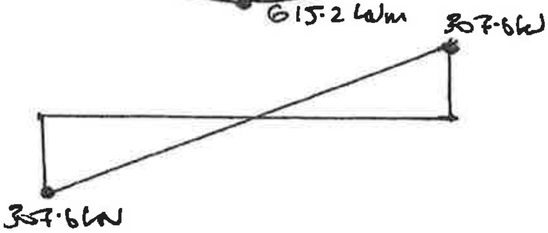
$$\omega = (45 \times 1.6) + \left(\frac{2400 \times 9.81}{1000} \times 0.3 \times 0.5 \times 1.4\right)$$

$$= 76.9 \text{ kN/m}$$



$$M_{MAX} = 76.9 \times 8^2/8$$

$$= 615.2 \text{ kNm}$$



$$V_{MAX} = 76.9 \times 8/2$$

$$= 307.6 \text{ kN}$$

b ii) $M_u = 0.225 f_{cu} bd^2/\gamma_c$

$= 0.225 \times 40 \times 300 \times 447.5^2/1.5$

$= 360.5$ kNm $< M_{MAX}$

∴ COMPRESSION STEEL REQUIRED.

$$\frac{A'_s f_y (d-d')}{\gamma_s} = M_{MAX} - M_u$$

$d = 500 - 40 - 25/2$
$= 447.5$ mm
$d' = 40 + 20/2$
$= 50$ mm

$$\therefore A'_s = \frac{(615.2 - 360.5)\times10^6 \times 1.15}{460 \times (447.5 - 50)}$$

$= 1585 \text{ mm}^2$

∴ PROVIDE 6T20 ($A'_s = 1884 \text{mm}^2$)

FROM EQUILIBRIUM OF LONGITUDINAL FORCES IN FIG 2(a):

$$\frac{A_s f_y}{\gamma_s} = \frac{0.6 f_{cu} bd}{2\gamma_c} + \frac{f_y A'_s}{\gamma_s}$$

$$\therefore A_s = \frac{1.15}{460}\left(\frac{0.6 \times 40 \times 300 \times 447.5}{2 \times 1.5} + \frac{460 \times 1884}{1.15}\right)$$

$= 4569 \text{ mm}^2$

∴ PROVIDE 10T25 ($A_s = 4910 \text{mm}^2$).

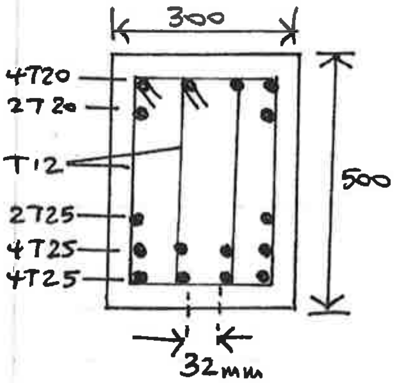
b iii) TAKE STRUT ANGLE $\theta = 45°$; $s = 0.75d$

$$V_{Rd,s} = A_{sv} f_y (0.9d)(\cot\theta)/s\gamma_s$$

$$\therefore A_{sv} = \frac{307.6\times10^3 \times 0.75 \times 447.5 \times 1.15}{460 \times (0.9 \times 447.5) \times \cot 45°}$$

$= 407.8 \text{mm}^2$

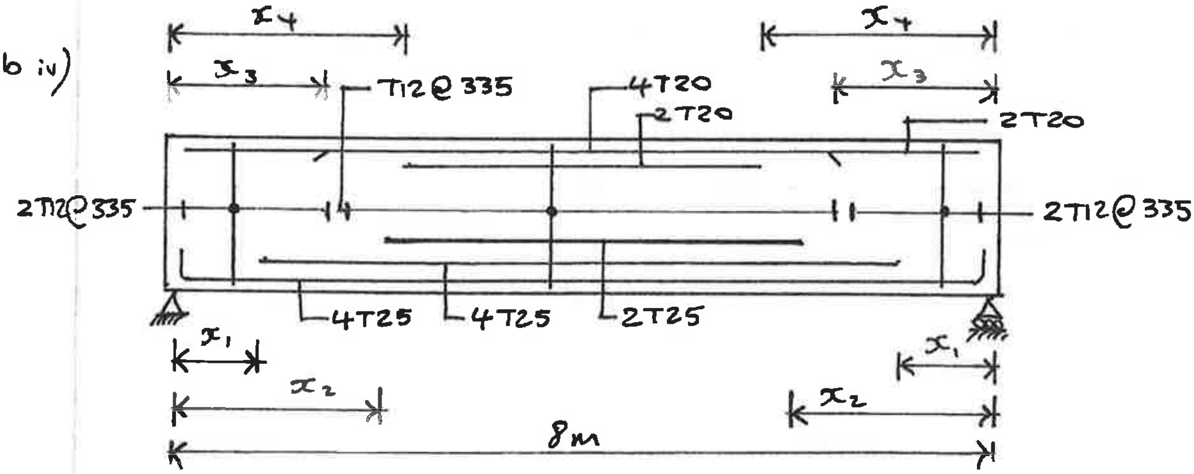
∴ PROVIDE 4T12 LEGS (A_{sv} = 452mm²). @ 335mm



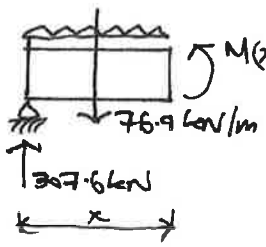
NOTE 1: THE PERCENTAGE REINFORCEMENT ≃ 4.5%. THIS MAY LEAD TO CONGESTION (DIFFICULTIES IN PLACING AND COMPACTING CONCRETE). CONSIDER USING LARGER CROSS-SECTION OF CONCRETE AND/OR PLASTICISER TO AID COMPACTION.

NOTE 2: DUE TO THE MULTIPLE LAYERS OF REINFORCEMENT, $d < 447.5$ AND $d' > 50$ ∴ RE-CALCULATE AND CHECK THAT REINFORCEMENT SPECIFIED IS ADEQUATE.

b iv)



M(x) :



$M(x) = 307.6x - 38.45x^2$

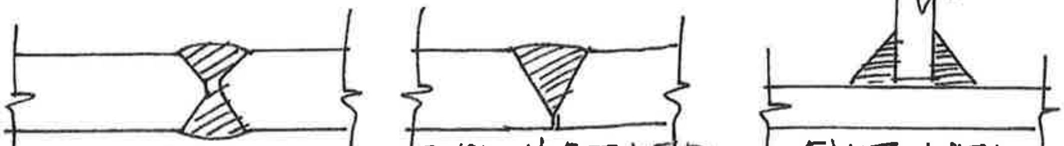
∴ FOR BOTTOM REINFORCEMENT $M(x) \geq 0.75d \cdot f_y A_s / \gamma_s$

$$\therefore\ 38.45x^2 - 307.6x + \frac{f_y A_s \cdot 0.75d}{\gamma_s} \geq 0$$

SOLVING FOR A_s = 4T25 & 8T25 GIVES $x_1 = 1.0m$; $x_2 = 2.5m$

3a) WELDING

- FUSING OF PARENT METAL AND ELECTRODE BY MEANS OF ELECTRIC ARC.
- WELDS CAN BE WITHIN THICKNESS OF PARENT METAL (BUTT WELD) OR EXTERNAL TO THE PARENT METAL (FILLET WELD).

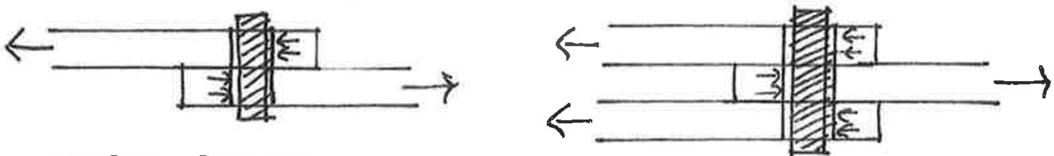


DOUBLE V BUTT WELD — SINGLE V BUTT WELD — FILLET WELD.

- WELDS CAN PROVIDE FULL STRENGTH JOINTS
- LOW MATERIAL COST, BUT SKILLED LABOUR
- MAY CONTAIN DEFECTS LEADING TO FATIGUE FAILURE
- POST-CONSTRUCTION / QUALITY CONTROL INSPECTIONS ARE V. IMPORTANT PARTICULARLY FOR SITE WELDING.

BOLTING

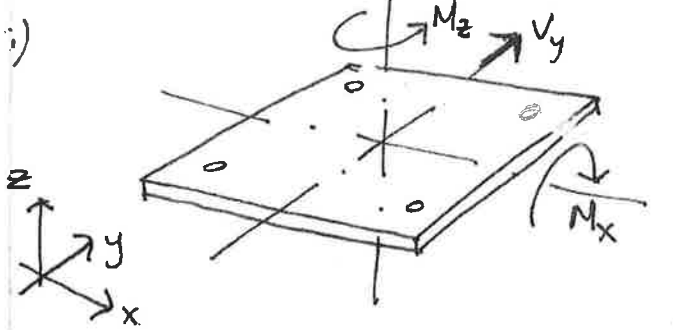
- HOLES DRILLED IN FABRICATION SHOP, JOINT ASSEMBLED / BOLTED ON-SITE.
- BOLTS TRANSFER LOADS IN SHEAR, BEARING AND DIRECT TENSION AND SHOULD BE DESIGNED ACCORDINGLY
- CONNECTIONS MAY BE SINGLE OR DOUBLE SHEAR.



SINGLE SHEAR — DOUBLE SHEAR

- BOLTED CONNECTIONS HAVE LESS QUALITY CONTROL ISSUES AND ARE EASY TO ASSEMBLE
- EDGE AND END DISTANCES, SPACING BETWEEN BOLTS CAN GOVERN STRENGTH ∴ FULL STRENGTH JOINTS CAN BE CUMBERSOME.

b) i)



$$V_y = 5\,kPa \times 1.5m \times 2m = 15\,kN$$

$$M_x = (5\,kPa \times 1.5m \times 2m) \times 5m = 75\,kNm$$

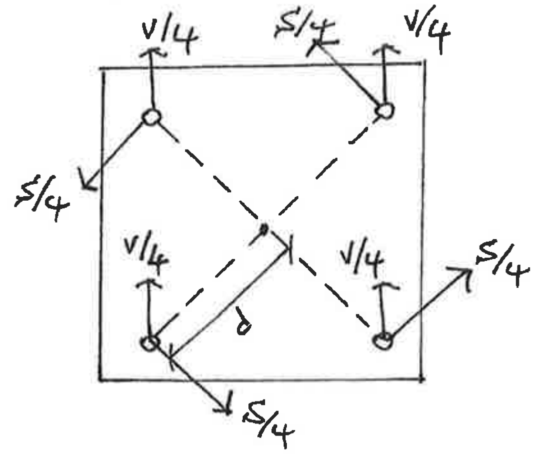
$$M_z = (5\,kPa \times 1.5m \times 2m) \times 1.75m = 26.25\,kNm$$

FOR TOP REINFORCEMENT : $M(x) - M_u - \frac{A'_s f_y (d-d')}{\gamma_s} \geq 0$

$\therefore 38.45x^2 - 307.6x + 360.5 \text{ kNm} + \frac{A'_s f_y (d-d')}{\gamma_s} \geq 0$

SOLVING FOR A'_s = 2T20 & 4T20 GIVES $x_3 = 2m$; $x_4 = 2.8m$

b) ii) FORCES ON BOLTS:



$d = 110\sqrt{2} \times 10^{-3}$ m

$\frac{V}{4} = \frac{15\text{kN}}{4} = 3.75\text{kN}$

$\frac{S}{4} = \frac{M_z}{4d} = \frac{26.25\text{kN}}{110\sqrt{2}\times10^{-3}\times4}$

$= 42.19\text{kN}$

∴ RESULTANT SHEAR FORCE R ON BOLT (WORST CASE):

$$R = \sqrt{\left(3.75 + \frac{42.19}{\sqrt{2}}\right)^2 + \left(\frac{42.19}{\sqrt{2}}\right)^2} = \underline{\underline{44.9\text{kN}}}$$

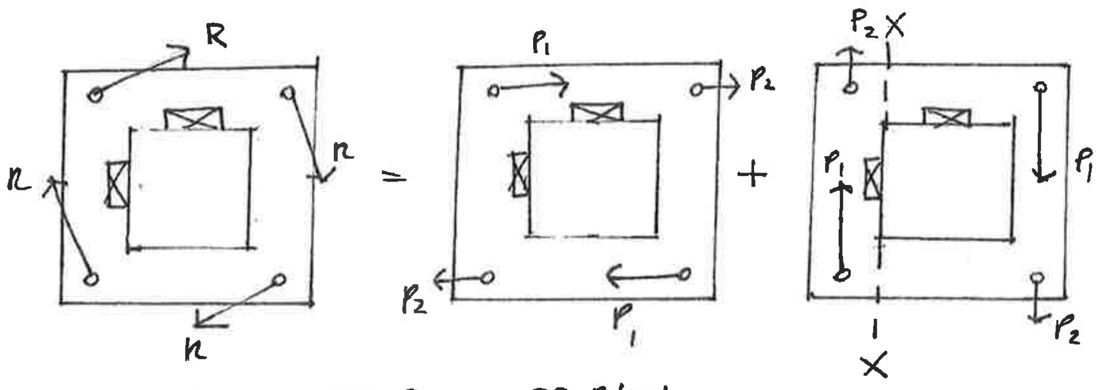
CROSS SECTIONAL AREA REQUIRED:

$A = R/\tau_y$ WHERE $\tau_y = 0.6\sigma_y$

$\therefore A = 44.9\times10^3/(0.6\times460) = 162.8\text{ mm}^2$

∴ BOLT DIAMETER ≥ 14.4mm, SAY 16mm

b) iii)



WHERE $P_1 = \frac{42.19}{\sqrt{2}} = 29.8\text{kN}$

$P_2 = 3.75 + \frac{42.19}{\sqrt{2}} = 33.6\text{kN}$

FOR SHEAR AND BENDING CONSIDER CRITICAL SECTION XX.

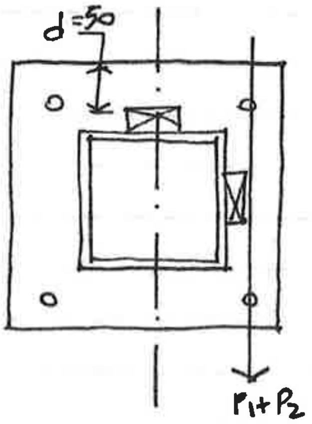
SHEAR STRESS :

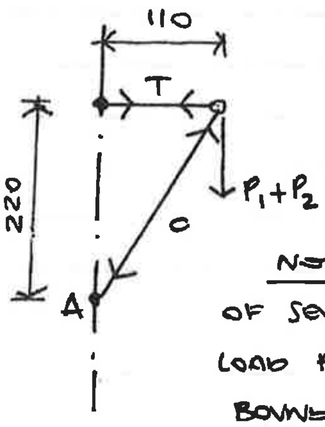
$$\tau_{AV} \leq \tau_y \Rightarrow \frac{33.6kN + 29.8kN}{(300-50)t} \leq 355 \times 0.6$$

$$\therefore t \geq 1.2\text{mm}$$

ELASTIC BENDING STRESS :

THE SPAN / DEPTH RATIO OF THE CRITICAL SECTION XX = 35/300 ≈ 0.12 ∴ THE CANTILEVERING PLATE IS LIKELY TO BEHAVE LIKE A DEEP BEAM ∴ CONSIDER THE FOLLOWING STRUT AND TIE MODEL :





NOTE : THIS IS ONE OF SEVERAL POSSIBLE LOAD PATHS (LOWER BOUND APPROACH).

$$\text{A2} \quad T = (P_1+P_2)\frac{110}{220} \quad , \text{ BUT } \quad T \leq \sigma_y d t$$

$$\therefore t \geq (P_1+P_2)\frac{110}{220} \cdot \frac{1}{\sigma_y d} = (29.8 + 33.6)\times 10^3 \cdot \frac{110}{220} \cdot \frac{1}{355 \cdot 50}$$

$$\therefore t \geq 1.79\text{mm}$$

PLATE BEARING :

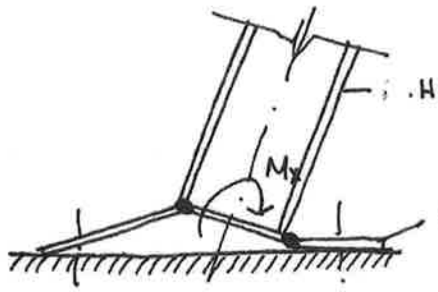
$$\sigma_b \leq \sigma_y \Rightarrow \frac{44.9 \times 10^3}{16 \times t} \leq 355$$

$\therefore t \geq 7.9$mm , SAY 8mm THICK.

- BASEPLATE THICKNESS GOVERNED BY BENDING STRESS FROM BOLTS ∴ REDUCE BASEPLATE SIZE FROM 300 x 300 mm TO SAY, 275 x 275 mm (END-DISTANCE PERMITTING) TO SAVE MATERIAL.
- SERVICE HOLES COULD BE COMBINED INTO ONE LARGER HOLE.

b iv) OTHER CHECKS:

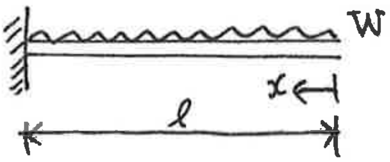
1. PRYING → BENDING IN BASEPLATE



2. ANCHORAGE (PULL-OUT) OF HOLDING DOWN BOLTS

3. VEHICLE IMPACT.

4) a)



$$v_f = \frac{W\ell^3}{8EI} = \frac{3W\ell^3}{2Ebh^3}$$

$$\tau_{NA} = \frac{3W}{2bh} \cdot \frac{x}{\ell} = \gamma_{NA} G \quad -(1)$$

$$dv_s = \gamma_{NA}\, dx \quad -(2)$$

$$(1) \,\&\, (2) \Rightarrow \frac{1}{G}\frac{3W}{2bh}\left(\frac{x}{\ell}\right)dx = dv_s$$

$$\therefore v_s = \left[\frac{3Wx^2}{4Gbh\ell}\right]_0^\ell + A$$

$@\ x=0\ ;\ v_s=0\ ;\ \therefore A=0$

$$\therefore v_s = 3W\ell/4Gbh$$

$$\therefore v_{TOT} = v_f + v_s = \frac{3W\ell^3}{2Ebh^3}\left(1 + \frac{Eh^2}{2G\ell^2}\right)$$

b i) BENDING STRENGTH REQUIREMENTS:

$$M_{MAX} = W\ell/2 = (20\,kN \times 1.5/2) \times \underset{(\gamma_f)}{1.5}$$

$$= 22.5\,kNm$$

$$f_{m,d} = \underbrace{k_{mod} \cdot k_h \cdot k_{crit} \cdot k_{ls}}_{\cdot\cdot 1.0} \cdot f_{m,k}/\gamma_m$$

$$= 1.0 \times 24/1.3$$

$$= 18.46\,MPa$$

$$z \geq \frac{M}{\sigma} \rightarrow h \geq \sqrt{\frac{6M}{b\sigma}}$$

$$\geq \sqrt{\frac{6 \times 22.5\times10^6}{175 \times 18.46}} = 204\ mm$$

SHEAR STRENGTH REQUIREMENTS:

$$\tau_{MAX} = \frac{3}{2}\frac{V_{MAX}}{A} = \frac{3}{2}\frac{V_{MAX}}{bh}$$

$$f_{v,d} = \underbrace{k_{mod} \cdot k_{ls}}_{} \cdot f_{v,k} / \gamma_m$$

$$= 1.0 \times 2.5 / 1.3$$

$$= 1.92 \text{ MPa.}$$

$$\therefore h \geq \frac{3}{2} \cdot \frac{V_{MAX}}{b} \cdot \frac{1}{1.92} = \frac{3}{2} \cdot \frac{20 \times 10^3}{175} \cdot \frac{\overset{(\gamma_f)}{1.5}}{1.92} = 134 \text{ mm}$$

DEFLECTION REQUIREMENTS:

Try $h = 204$ mm.

$$v_{TOT} = \frac{3 \times 20 \times 10^3 \times 3000^3}{2 \times 11 \times 10^3 \times 175 \times 204^3}\left(1 + \frac{11 \times 10^3 \times 204^2}{2 \times 0.69 \times 10^3 \times 3000^2}\right)$$

$$= 51.4 \text{ mm} > \frac{\text{SPAN}}{200} \ (15 \text{ mm}).$$

$$\text{NEW TRIAL SIZE} \approx \left(\frac{51.4}{15}\right)^{1/3} \cdot 204 = 307$$

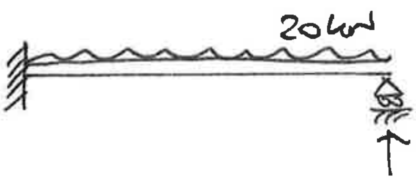
$\therefore$ Try 350 mm

$$v_{TOT} = \frac{3 \times 20 \times 10^3 \times 3000^3}{2 \times 11 \times 10^3 \times 175 \times 350^3}\left(1 + \frac{11 \times 10^3 \times 350^2}{2 \times 0.69 \times 10^3 \times 3000^2}\right)$$

$$= 10.87 \text{ mm} < 15 \text{ mm} \quad \therefore \text{SATISFACTORY.}$$

$\therefore$ PROVIDE $h = 350$ mm (GOVERNED BY DEFLECTION).

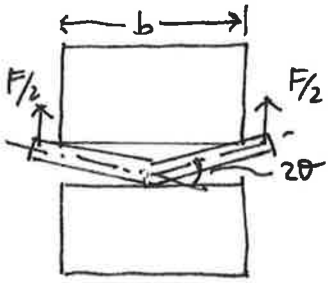
b ii)



$$F = \frac{3}{8} \cdot 20\text{kN} \times 1.5 = 11.25\text{kN}$$

TWO POSSIBLE FAILURE MODES:

PLASTIC HINGE IN BOLT



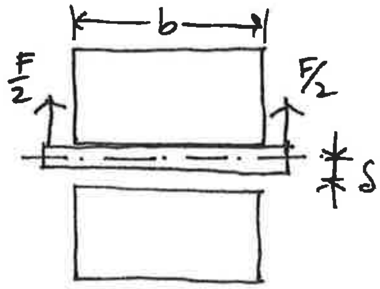
$M_{yd} = 0.8\,\sigma_y\,d^3 / 6\gamma_m$

$Fb/8 = 0.8 \times 355 \times d^3 / 6 \times 1.15$

$\therefore d = \sqrt[3]{\frac{11.25\times10^3 \times 175}{8} \times \frac{6\times1.15}{0.8\times355}}$

$= 18.15\,mm.$

BEARING IN TIMBER.



$F\delta = f_{h1d}\, b\, d\, \delta$

$\therefore d = F / f_{h1d} \cdot b$

$f_{h1d} = f_{h0k} / (k_{90}\sin^2 90 + \cos^2 90)\gamma_m$

$f_{h0k} = 0.082\,(1 - 0.01\times25)\,350$

$= 21.5\,MPa$

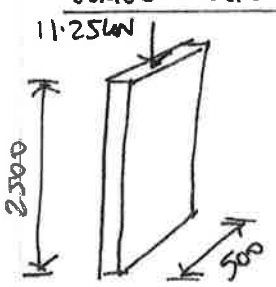
$\therefore f_{h1d} = \frac{21.5}{1.65\times1} \cdot \frac{1}{1.3} = 10.02\,MPa$

$\Rightarrow d = 11.25\times10^3 / 10.02 \times 175$

$= 6.4\,mm.$

$\therefore$ **BOLT ϕ = 20 mm.**

WALL DESIGN



SQUASHING CAPACITY $P = f_k\, t\, l / \gamma_m$

$\therefore t \geq P\gamma_m / f_k l$

$\geq \frac{11.25 \times 10^3 \times 2.8}{5 \times 500}$

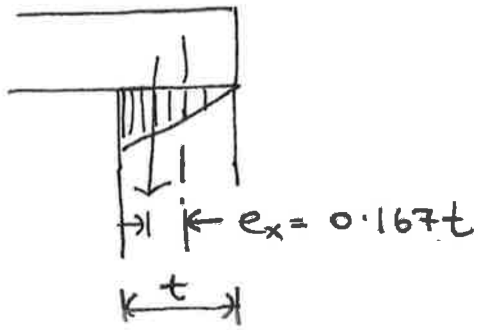
$\geq 12.6\,mm.$

However $h_{ef}/t_{ef} \not> 26$

$\therefore$ Try $t = 100\,mm$ $(h_{ef}/t_{ef} = 25)$.

BUCKLING CAPACITY $P_b = \beta f_k t l / \gamma_m$

CONSIDER ECCENTRICITY e_x



$\frac{h_{ef}}{t_{ef}} = 25$

$\therefore \beta \approx 0.35$

$\therefore P_b = 0.35 \times 5 \times 100 \times 500 / 2.8$

$= 31.25\,kN > 11.25\,kN$

∴ 100mm THICK WALL IS SATISFACTORY, BUT IT IS POSSIBLE TO REDUCE LENGTH FROM 500mm TO 180mm.