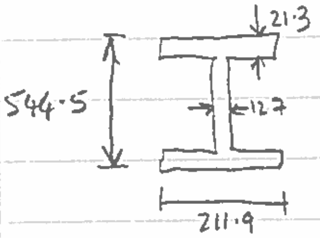
2016, 4D10 Structural Steelwork.

1 a). 533 x 210 x 122 UB., S275



$$\text{maj. } I_{xx} = 76040 \times 10^{-8}\ m^4$$
$$\text{min } I_{yy} = 3388 \times 10^{-8}\ m^4$$
$$\text{maj } Z_p = 3196 \times 10^{-6}\ m^3$$
$$J = 178 \times 10^{-8}\ m^4$$
$$A = 155 \times 10^{-4}\ m^2$$

Compact? (DS4)

Ext. plate in compression: $\frac{b}{t}\sqrt{\frac{\sigma_y}{355}} = \frac{(211.9 - 12.7)}{2(21.3)}\sqrt{\frac{275}{355}} = 4.1 < 8$ OK ✓

Int. plate in bending $\frac{b}{t}\sqrt{\frac{\sigma_y}{355}} = \frac{544.5 - 2(21.3)}{12.7}\sqrt{\frac{275}{355}} = 34.8 < 56$ OK ✓

(but ≥ 24 in compression)
(need later)

∴ Compact for bending.

Calc. plastic: $M_{pl,maj} = Z_p \sigma_y = [3196 \times 10^{-6} m^3][275 \times 10^6 N/m^2]$
$= \underline{878.9 \text{ kNm}}$

Calc. elastic $M_{LT} = \pi/L \sqrt{GJEI_{min}}\left(1 + \frac{\pi^2}{L^2}\frac{E\Gamma}{GJ}\right)^{1/2}$

$$\text{Basic} = \frac{\pi}{4}\sqrt{\frac{210 \times 10^9}{2.6}(178 \times 10^{-8})\, 210 \times 10^9 (3388 \times 10^{-8})}$$

$$= \frac{\pi}{4}\ 210 \times 10 \sqrt{\frac{(178)(3388)}{2.6}} = \underline{794.3 \text{ kNm}}$$

$$\Gamma = \frac{ID^2}{4} = \frac{(3388 \times 10^{-8})(0.5232)^2}{4} = 231.9 \times 10^{-8}\ m^6$$

$D = 544.5 - 21.3 = 523.2$ mm

$$1 + \frac{\pi^2}{L^2}\frac{E\Gamma}{GJ} = 1 + \frac{\pi^2}{4^2}(2.6)\frac{231.9 \times \cancel{10^{-8}}}{178 \times \cancel{10^{-8}}} = 3.089$$

$$\sqrt{} = \underline{1.7576}$$

$$\therefore M_{LT,BASIC} = 794.3 \times 1.7576 = \underline{1396 \text{ kNm}}$$

4D10 1a) cont'd.

$C_{unequal} = 0.6$ as $\psi = 0$  (DS3)

$$M_{cr} = \frac{M_{LT}}{C_{unequal}} = \frac{1396}{0.6} = 2327 \text{ kNm}$$

Sausage: $\lambda = \sqrt{\frac{\text{Plastic}}{\text{Elastic}}} = \sqrt{\frac{878.9}{2327}} = 0.6146$

Which curve? $\frac{h}{b} = \frac{544.5}{211.9} = 2.57 > 2$ $\therefore$ Curve b) (DS3)

Curve b), DS1 $\rightarrow \chi = 0.83$ @ $\lambda = 0.615$

$$M_{design} = 0.83(878.9) = \underline{\underline{729 \text{ kNm}}}$$

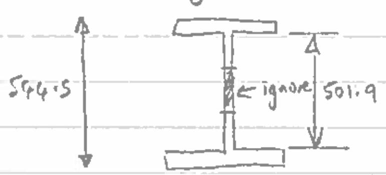
$$M_{applied} = \frac{WL}{4} \quad (L = 8m)$$

$$\therefore 729 \text{ kNm} = \frac{W(8m)}{4} \Rightarrow W = \frac{729}{2} = \underline{\underline{365 \text{ kN}}}$$

b) Beam column. Not compact for axial in web, so ignore part of web

$\lambda = 34.8$ part a) > 24 $\Rightarrow K_c = 0.8$ (DS4)

$\therefore$ Ignore $(1 - K_c) = 0.2$ of the web.



$\therefore$ Reduce area by $(0.2 \times 501.9) \times 12.7 = 1275 \text{ mm}^2$

$$A_{basic} = 15{,}500 \text{ mm}^2$$
$$A_{eff} = 15{,}500 - 1275 = 14{,}225 \text{ mm}^2$$
$$= \underline{\underline{142.3 \times 10^{-4} \text{ m}^2}}$$

<u>Axial:</u> Calc. plastic: $N_{pl} = (142.3 \times 10^{-4} \text{ m}^2)(275 \times 10^6 \text{ N/m}^2)$
$$= \underline{\underline{3912 \text{ kN}}}$$

Calc. elastic $N_{el} = \frac{\pi^2 E I_{min}}{L^2} = \frac{\pi^2 (210 \times 10^9)(3388 \times 10^{-8})}{16} (\text{N/m}^2)\text{m}^4$

$$= \underline{4389 \text{ kN}}$$

(Minor only, and no need to reduce I_{minor} due to non-compact web)

1 b) cont'd.

$$\lambda = \sqrt{\frac{\text{Plastic}}{\text{Elastic}}} = \sqrt{\frac{3912}{4389}} = 0.89$$

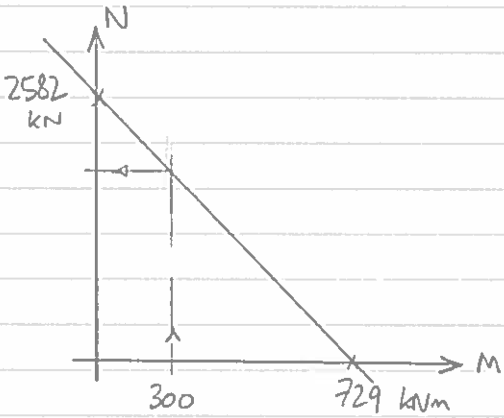
Which curve? $\frac{h}{b} = 2.57 > 1.2$

$t < 40$, buckling about z-z, S275
→ curve b) (DS2)

$\rightarrow \chi = 0.66$ (DS1)

$\therefore N_{design} = 0.66(3912) = \underline{\underline{2582\ kN}}$

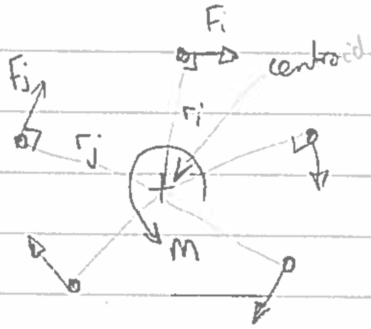
M_{design} (as per part a)) $= \underline{\underline{729\ kNm}}$



$$N_{max} = 2582 - 2582\left(\frac{300}{729}\right) = \underline{\underline{1519\ kN}}$$

4D10 2016

Q2 a).



$$M = \sum_{i=1}^{N} F_i r_i$$

Main assumption is the elastic one, that $F_i \propto r_i$

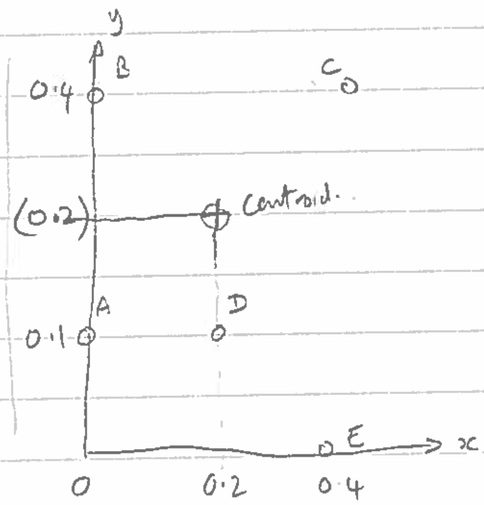
so say $F_i = k r_i$ k = some constant.

Then $M = \sum_{i=1}^{N} F_i r_i = \sum_{i=1}^{N} k r_i^2 = k \sum r_i^2$

$\therefore \quad k = \left(\dfrac{M}{\sum r_i^2} \right)$

So $F_j = k r_j = \dfrac{M r_j}{\sum r_i^2} = \dfrac{M}{\sum (r_i^2 / r_j)}$

LD10, 2016, Q2.



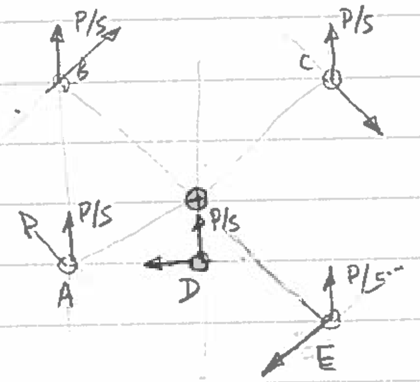
$= (x_i-\bar{x})^2+(y_i-\bar{y})^2$

Bolt	x_i	y_i	$(x_i-\bar{x})$	$(y_i-\bar{y})$	r_i^2	r_i
A	0	0.1	−0.2	−0.1	0.05	0.2236
B	0	0.4	−0.2	0.2	0.08	
C	0.4	0.4	0.2	0.2	0.08	0.2828
D	0.2	0.1	0	−0.1	0.01	
E	0.4	0	0.2	−0.2	0.08	
	$\Sigma = 1$	$\Sigma = 1$			$\Sigma r_i^2 = 0.30$	

$A\bar{x} = \int x\,dA \quad \therefore \quad \bar{x} = 1/5 = 0.2$

$\therefore\ 5\bar{x} = (\Sigma x_i)1 \qquad \bar{y} = 1/5 = 0.2$

$\therefore$ Worst cases are bolts B, C, E due to moment.



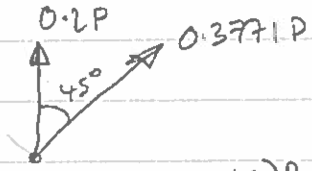
$\therefore$ Bolt $\underline{\underline{B}}$ critical.

$$F_{max} = \frac{Pe}{\Sigma r_i^2/r_{max}}$$

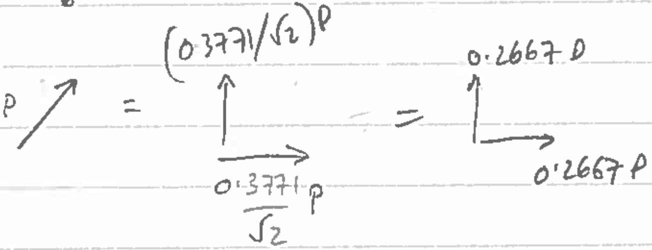
$$= \frac{P(0.4)}{(0.30/0.2828)}$$

$$= 0.3771\,P$$

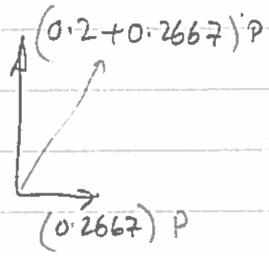
Q2 b) cont'd



and



∴ Resultant



Resultant force

$$= \sqrt{(0.4667)^2 + (0.2667)^2}$$

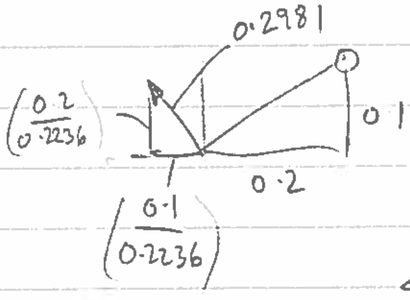
$$= \underline{\underline{0.5375\ P}}.$$

Max shear on M36 grade 8.8 $\approx$ 285 kN (DS5)

$$\therefore \quad 0.5375\ P = 285\ \text{kN}$$

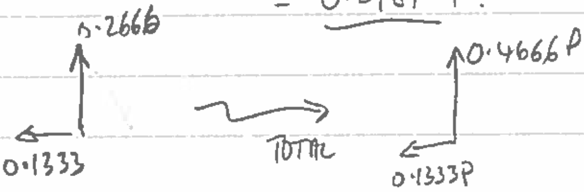
$$\therefore \quad P = \frac{285}{0.5375} = \underline{\underline{530\ \text{kN}}}$$

[check bolt A, force is smaller (due to moment) but it aligns better.



$$F_A = \frac{Pe}{\sum r_i^2 / r_{max}} = \frac{P(0.4)}{0.3/0.2236}$$

$$= \underline{0.2981\ P}.$$



(∴ B is worse).]

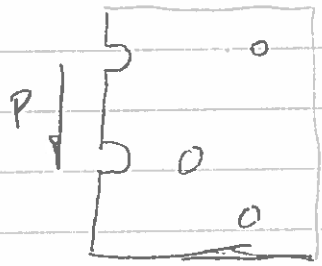
4D10 (cont'd).

Q2 b) Need to check edge distances

Need to check plates in bearing at bolt holes.

Need to check plates in shear

eg



4D10 Structural Steelwork, 2016.

Q3. a) Check compactness

Flange: $b = 200 - 12 - 10 = 178$, $t = 12$

$$\frac{b}{t}\sqrt{\frac{275}{355}} = 13.1 < 24 \quad \therefore \text{Compact in compression}$$

Web: $b = 1000 - 24 = 976$, $t = 12$

$$\frac{b}{t}\sqrt{\frac{275}{355}} = 71.5 > 56 \quad \therefore \text{NOT compact in bending.}$$

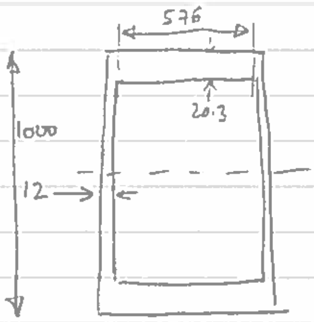
Stiffeners: $b = 120$, $t = 20$

$$\frac{b}{t}\sqrt{\frac{275}{355}} = 5.3 < 8 \quad \therefore \text{Compact.}$$

(2 marks).

b). Smeared section

$$h = \frac{(576)(12) + 2(120)(20)}{576} = 12 + \frac{2(120)}{576} = \underline{\underline{20.3 \text{ mm}}}$$

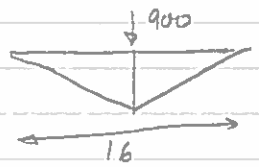


$$I_{maj} = \frac{2(576)(20.3)^3}{12} + 2(576)(20.3)\left(500 - \frac{20.3}{2}\right)^2 + \frac{2(12)(1000)^3}{12}$$

$$= 803{,}000 + 5.611 \times 10^9 + 2 \times 10^9$$

$$= \underline{\underline{7.612 \times 10^9 \text{ mm}^4}}$$

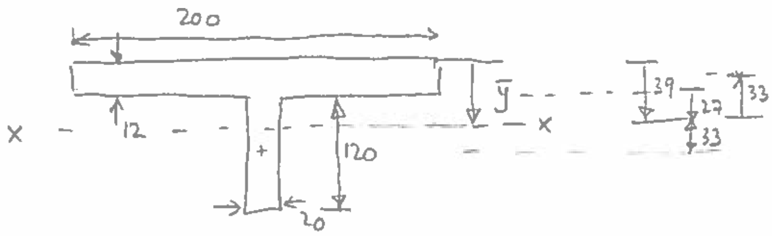
c)



$$M = \frac{WL}{4} = \frac{(900)(16)}{4} = 3600 \text{ kNm}$$

$$\sigma = \frac{My}{I} = \frac{(3600 \times 10^3)(0.5)}{7.612 \times 10^{-3}} = \underline{236 \text{ MPa}}$$

c)



$$A = 200(12) + 120(20) = 4800 \text{ mm}^2$$

$$A\bar{y} = 200(12)(6) + (120)(20)(72) = 187\,200 \text{ mm}^3$$

$$\bar{y} = \frac{187200}{4800} = \underline{\underline{39 \text{ mm}}}$$

$$I_{xx} = \frac{(200)(12^3)}{12} + (200)(12)(39-6)^2 + \frac{(20)(120)^3}{12} + (20)(120)(33)^2$$

$$= 28{,}800 + 2.614 \times 10^6 + 2.880 \times 10^6 + 2.614 \times 10^6$$

$$= \underline{\underline{8.136 \times 10^6 \text{ mm}^4}}$$

Calc. Plastic. $N_{pl} = 275 \text{ N/mm}^2 \times 4800 \text{ mm}^2 = \underline{\underline{1320 \text{ kN}}}$

Calc. Elastic $N_{elas} = \frac{\pi^2 E I}{L^2} = \frac{\pi^2 (210 \times 10^3 \text{ N/mm}^2)(8.136 \times 10^6 \text{ mm}^4)}{(4000)^2 \text{ mm}^2} = \underline{\underline{1054 \text{kN}}}$

$$\lambda = \sqrt{\frac{N_{pl}}{N_{el}}} = \sqrt{\frac{1320}{1054}} = 1.12$$ Use curve c) (Welded) $\rightarrow \chi = 0.47$

$$N_{Design} = (0.47)(1320 \text{ kN}) = \underline{\underline{620 \text{ kN}}}$$

but require $\sim \sigma A \approx (236 \text{ N/mm}^2)(4800 \text{ mm}^2) = \underline{\underline{1132 \text{ kN}}}$

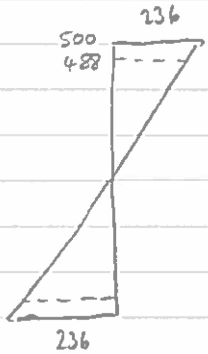
$\therefore$ Not adequate

(Need to put in more cross-frames).

Q3 d).

Shear force $= \frac{W}{2} = 450$ kN

Shear stress $\tau = \frac{450 \times 10^3}{2 \times 12 \times 976} = 19.2$ MPa



$\leftarrow 236 \times \frac{488}{500} = 230 \text{ MPa} = \sigma_b$

$\sigma_c = 0$

Strength: $\sigma^2 \leq \sigma_y^2 - 3\tau^2$ DS4

$\therefore \sqrt{\sigma^2 + 3\tau^2} < \sigma_y$?

$\sqrt{(230)^2 + 3(19.2)^2} = 232 < 275$ MPa

$\therefore$ strength OK.

Stability

$\lambda = 71.5$ (part a).

$\sigma_c = 0$

$\sigma_b = 230$ MPa, $\lambda = 71.5 \rightarrow K_b \simeq 1.1$ (DS4)

$\tau = 19.2$ MPa, $\phi = 4/1 \geq 3$, $\lambda = 71.5 \rightarrow K_q \simeq 0.74$ (DS4)

$$\frac{0}{275} + \left(\frac{230}{1.1(275)}\right)^2 + \left(\frac{19.2}{0.74(275/\sqrt{3})}\right)^2$$

$$0 + 0.58 + 0.027 = 0.607 < 1$$

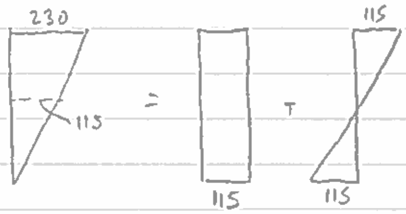
$\therefore$ Stability OK

Q3.

d) Conundrum? (Not needed for exam).

Say we add a stiffener at the midheight of each web

 We now have to check the top half of the panel.



+ shear of 19.2 MPa

$\sigma_c = 115$ MPa, $\lambda = \frac{488}{12}\sqrt{\frac{275}{355}} = 35.8 \geq 24$ ∴ Not compact in compression

$\rightarrow K_c = 0.8$ DS4

$\sigma_b = 115$ MPa $\lambda = 35.8 \leq 56$ ∴ Compact in compression

$\rightarrow K_b = 1.2$ DS4

$\tau = 19.2$ MPa, $\phi = \frac{4}{0.5} = 8 \geq 3$, $\lambda = 35.8 \rightarrow K_q = 1$

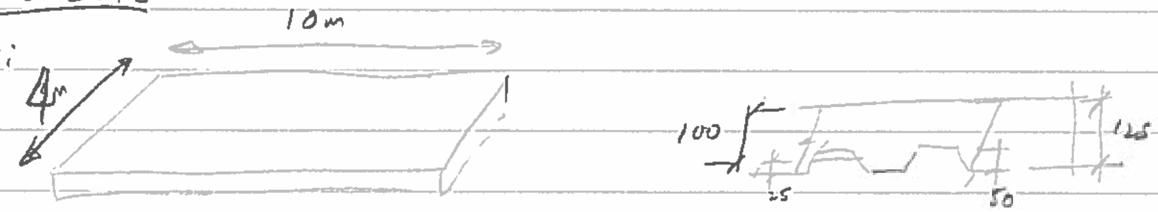
Stability: $\frac{115}{0.8(275)} + \left(\frac{115}{1.2(275)}\right)^2 + \left(\frac{19.2}{1(159)}\right)^2$

$= 0.52 + 0.12 + 0.01 = 0.66 < 1$ ∴ OK.

(i.e. it is still OK).

4D10 2016

Q4:



a). Loads -

Concrete $= 3m \times 0.1m \times (2400 \times 9.81)\ kN/m^3 = 7.06\ kN/m$.

Steel: $457 \times 152 \times 67 \rightarrow 67.2 \times 9.81 = 659\ N/m = 0.66\ kN/m$.

$7.72\ kN/m$

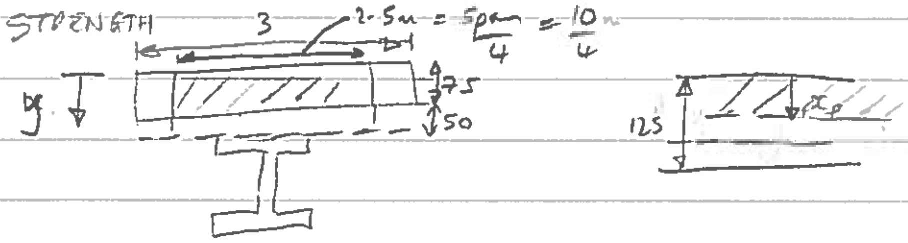
3 kPa permanent services $\times$ 3m $\rightarrow$ 9 kN/m

16.72 kN/m permanent

7 kPa live load $\times$ 3m $\rightarrow$ 21 kN/m live

Total factored $= 1.35(16.72) + 1.5(21) = \underline{54.26\ kN/m}$

$$M_{max} = \frac{wl^2}{8} = \frac{(54.26) \times (10)^2}{8} = \underline{\underline{678.3\ kNm}}$$



Assume N/A in concrete, a depth x_p below top surface

Axial equilib. $A_s \sigma_y = 0.6 f_{cd} b_e x_p$

$A_s = 85.6 \times 10^2\ mm^2$

$\sigma_y = 355\ MPa$ [check compactness

flanges $\frac{b}{t}\sqrt{1} = \frac{(153.8 - 9)}{2(15)} = 4.8 < 8$ OK.

web $\frac{b}{t}\sqrt{1} = \frac{458 - 2(15)}{9} = 47 < 56$ OK for bending

NOT OK for compression

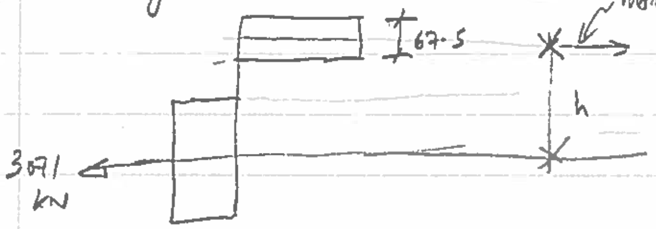
(but it's in TENSION + bending, so OK).]

Q4 a) cont'd

$$x_p = \frac{(8560\ \text{mm}^2)(355\ \text{N/mm}^2)}{0.6(30\ \text{N/mm}^2)(2500\ \text{mm})} \qquad \left[\cancel{8850}^{\,56} \times 355 = \cancel{3071}^{\,3039}\ \text{kN} \right.$$

$$= 67.5\ \text{mm} < 75\ \text{mm} \qquad \therefore \underline{\text{In concrete}}. ✓$$

Strength.



$$M = \cancel{3071}^{\,3039}\ \text{kN} \times h$$

$$h = \left(125 - \frac{67.5}{2}\right) + \frac{458}{2}$$

$$= 320.25\ \text{mm} = 0.320\ \text{m}$$

$$\therefore M_{strength} = \cancel{3071}^{\,3039}\ \text{kN} \times 0.320\ \text{m} = \underline{\underline{\cancel{983}^{\,972.4}\ \text{kNm}}}$$

$\therefore$ Very adequate. (cf 678 kNm req'd)

b)

Shear studs 100 × 25 mm → 154 kN each DS6

Axial force = $\cancel{3071}^{\,3039}$ kN → 20 studs per half span
→ 40 studs total.

$$\text{Spacing} = \frac{10\ \text{m}}{40} = 0.25\ \text{m}. ✓$$

(Could we paired studs → 80% → (but no...)

$\therefore$ ... May as well put single stud in each trough,
→ 200 mm spacing.

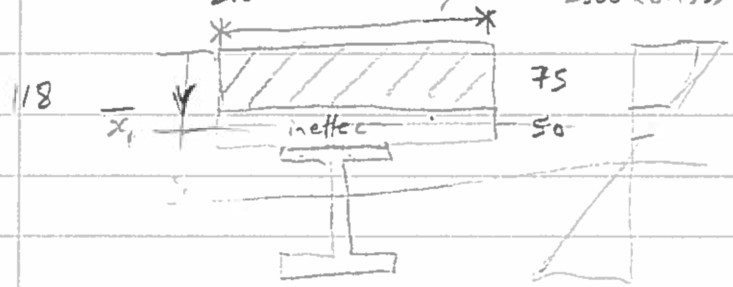
c). Short term deflection

Load $= 7\text{kPa} \times 3 = 21 \text{ kN/m}$.

Need EI:

Modular ratio: $E_c = 28$ GPa (short term) D56

$\frac{28}{210} = 0.133$ ~~2500 x 0.133~~ = 333mm



$A\bar{x} = \int x \, dA$

$$\left[(333 \times 75) + 8560\right] \bar{x} = 333 \times 75 \times \frac{75}{2} + 8560\left[125 + \frac{458}{2}\right]$$

$$= 936.6 \times 10^3 + 3030 \times 10^3$$

$$33.5 \times 10^3 \ \bar{x} = 3967 \times 10^3$$

$$\bar{x} \doteq 118 \text{ mm}$$

$$I = \frac{(333)(75)^3}{12} + (333)(75)\left[118 - \frac{75}{2}\right]^2 + 28930 \times 10^4 + 8560 \times \left[h\right]^2$$

$h = \frac{458}{2} + 125 - 118$
$= 236$

$$= 11.7 \times 10^6 + 161.8 \times 10^6 + 289.3 \times 10^6 + 476.7 \times 10^6$$

$$= 939.4 \times 10^6 \text{ mm}^4 = 939.4 \times 10^{-6} \text{ m}^4$$

$$\Delta = \frac{5wL^4}{384EI} = \frac{5(21 \times 10^3)(10)^4}{384(210 \times 10^9)(939.4 \times 10^{-6})} = 14\text{mm}.$$

$\frac{\text{span}}{250} = 40$ mm 14mm < 40mm $\therefore$ OK