# Q16 (Edge M.G. of Roadway Bridge)

## * Loads:

$$w_{D.L1} = O.W_{steel} + O.W_{R.C} + \text{metal Deck}$$

$$= \overset{\text{assumed}}{2.0} + 0.25 \times 2.5 \times 5.2 + \frac{15}{1000} \times \overset{1.2+\frac{8}{2}}{5.2}$$

$$= 5.33 \; t/m'$$

$$w_{D.L2} = \text{wearing surface} + \text{Piping} + \text{Hand Rail}$$

$$= 0.08 \times 2.2 \times 5.2 + \overbrace{0.25 + 0.15}^{\text{assumed}}$$

$$= 1.32 \; t/m'$$

$w_{L.L} = 2.98 \; t/m'$ & $P = 35 \; t$ [Ref. to Q5]

## * Straining Actions:

$$M_{D.L1} = \frac{5.33 \times 36^{2}}{8} \times \overset{\text{cont. beam}}{0.9} = 777.1 \; t.m. \quad (+ve\ Mt)$$

$$M_{D.L2} = \frac{1.32 \times 36^{2}}{8} \times 0.9 = 192.3 \; t.m.$$

$M_{L.L+I} = 982.7 \; t.m.$ [Ref. to Q5]

$$Q_{D.L1} = \frac{5.33 \times 36}{2} = 96.0 \; t$$

$$Q_{D.L2} = \frac{1.32 \times 36}{2} = 23.8 \; t$$

$Q_{L.L+I} = 122.5 \; t$ [Refer to Q5]

* Sections Properties :

i) Steel Sec. Alone

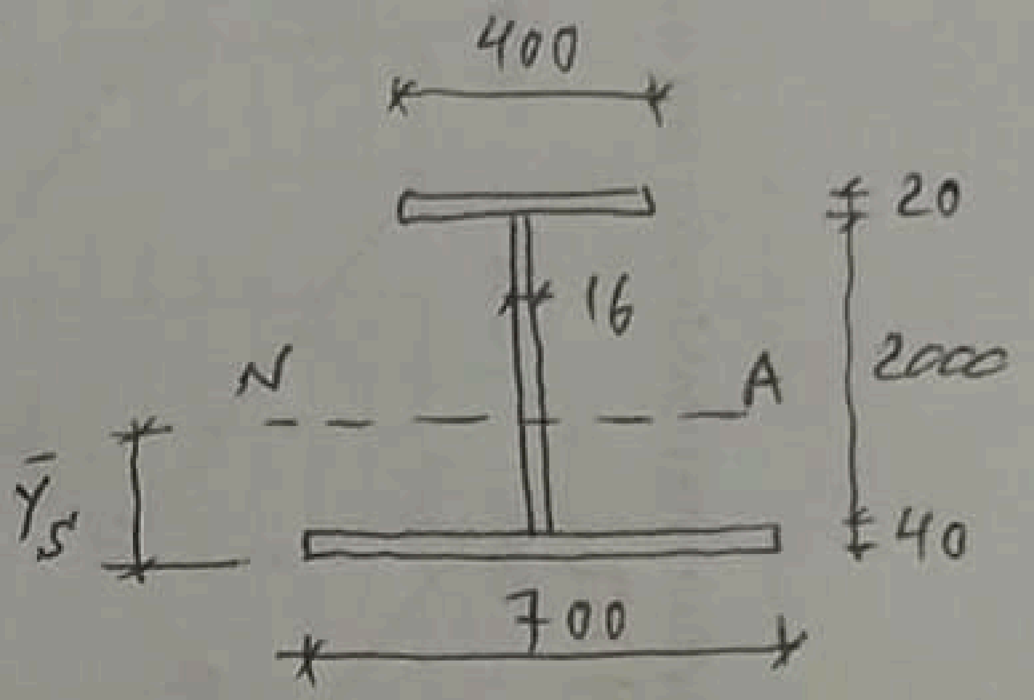
$$h = \frac{L}{16\to22} = \frac{36000}{16\to22} = 1640 \to 2250 \text{ m/m}$$ (including R.C slab)

take $d_w = 2000$ m/m , $t_w = 16$ m/m

Steel top flange $b_{tf} = 400$ m/m , $t_{tf} = 20$ m/m (Comp. Flange)

steel bot. flange $b_{bf} = 700$ m/m , $t_{bf} = 40$ m/m (Tens. Flange)

check for comp. flange local buckling :



assumed Steel Sec.

$$\frac{b_{tf}-t_w}{2\,t_{tf}} = \frac{400-2\times16}{2\times20}$$

$$= 9.2 < \frac{21}{\sqrt{F_y}} = 11.07$$

$F_y \sim 3.6$ t/cm$^2$ ST 52

$$\bar{Y}_s = \frac{70\times4\times2 + 40\times2\times(1+200+4) + 200\times1.6\times(\frac{200}{2}+4)}{70\times4 + 40\times2 + 200\times1.6}$$

$$= 73.88 \text{ cm}$$

$$I_{x_s} = \frac{70\times\bar{4}^3}{12} + 70\times4\,(73.88-2)^2 + \frac{40\times\bar{2}^3}{12} + 40\times2\,(1+200+4-73.88)$$

$$+ \frac{1.6\times\overline{200}^3}{12} + 1.6\times200\,(100+4-73.88)^2$$

$$= 4179457 \text{ cm}^4$$

$$Y_{us} = 4+200+2-73.88 = 132.12 \text{ cm}$$

$$Y_{ls} = 73.88 \text{ cm}$$

$$Z_{us} = \frac{I_s}{Y_{us}} = \frac{4179457}{132.12} = 31633.8 \text{ cm}^3$$

$$Z_{ls} = \frac{I_s}{Y_{ls}} = \frac{4179457}{73.88} = 56570.9 \text{ cm}^3$$

## ii) Virtual Section :

Use concrete $F_{cu} = 400\ kg/cm^2$ , $E_c = 280\ t/cm^2$

$\therefore$ modular ratio $n = 8$

$t_s = t_{slab} = 25\ cm$ (given)

$b_E = b_{EL} + b_{ER}$

$b_{EL} = $ smaller of $\left\langle \begin{array}{l} \frac{L}{8} = \frac{3600}{8} = 450\ cm \\ b^* = 120\ cm \end{array} \right.$

$= 120\ cm$

$b_{ER} = $ smaller of $\left\langle \begin{array}{l} \frac{L}{8} = 450\ cm \\ b = \frac{800}{2} = 400\ cm \end{array} \right.$

$= 400\ cm$

$b_E = 120 + 400 = 520\ cm$

$\ngtr 12\ t_s = 12 \times 25 = 300\ cm$

$\therefore\ b_E = 300\ cm$

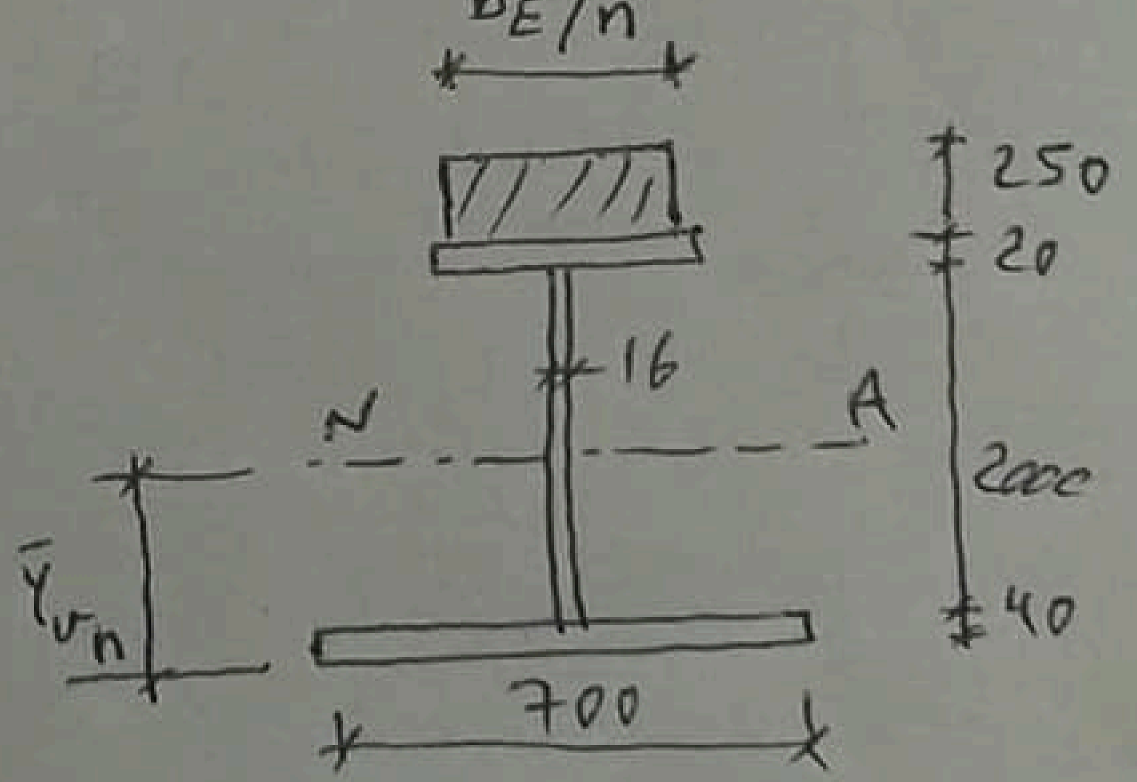
### a) Virtual Section Properties Neglecting Creep

$n = 8$ , $b_E/n = \frac{300}{8} = 37.5\ cm$

$\bar{Y}_{vn} = (A_s \cdot \bar{Y}_s + A_c \cdot Y_c) / (A_s + A_c)$

$$= \frac{680 \times 73.88 + 937.5\left(\frac{25}{2} + 206\right)}{680 + 937.5}$$

$= 157.7\ cm$



$$I_{x_{vn}} = \overset{I_s}{4179457} + \overset{A_s}{680}(157.7 - 73.88)^2 + \frac{37.5 \times 25^3}{12} + 37.5 \times 25\left(\frac{25}{2} + 206 - 157.7\right)^2$$

$= 12471424\ cm^4$

$A_s = 70 \times 4 + 40 \times 2 + 200 \times 1.6$

$= 680\ cm^2$

$A_c = 37.5 \times 25$

$= 9[illegible].5\ cm^2$

$Y'_{us} = 206 - 157.7 = 48.3$ cm

$Y'_{es} = 157.7$ cm

$Y'_{c} = 25 + 206 - 157.7 = 73.3$ cm

$$Z'_{us} = \frac{I_{xvn}}{Y'_{us}} = \frac{12471424}{48.3} = 258208 \text{ cm}^3$$

$$Z'_{es} = \frac{I_{xvn}}{Y'_{es}} = \frac{12471424}{157.7} = 79083 \text{ cm}^3$$

$$Z'_{uc} = \frac{I_{xvn}}{Y'_{c}} = \frac{12471424}{73.3} = 170142 \text{ cm}^3$$

### b) Virtual sec. Prop. C-sidering Creep

$n = 3 \times 8 = 24$ , $b_E/3n = \frac{300}{24} = 12.5$ cm

$$\bar{Y}_{v3n} = \frac{680 \times 73.88 + 312.5\,(12.5 + 206)}{680 + 312.5} = 119.42 \text{ cm}$$

$A_c = 12.5 \times 25$
$= 312.5$ cm$^2$

$$I_{xv3n} = 4179457 + 680\,(119.42 - 73.88)^2 + \frac{12.5 \times 25^3}{12} + 12.5 \times 25\,(12.5 + 206 - 119.42)^2 = 8673744 \text{ cm}^4$$

$Y''_{us} = 206 - 119.42 = 86.58$ cm , $Y''_{es} = 119.42$ cm

$$Z''_{us} = \frac{I_{xv3n}}{Y''_{us}} = \frac{8673744}{86.58} = 100182 \text{ cm}^3$$

$$Z''_{es} = \frac{I_{xv3n}}{Y''_{es}} = \frac{8673744}{119.42} = 72632 \text{ cm}^3$$

$Z''_{c} \equiv$ No Need

## * Check of Stresses ;

i) for Unshored Construction (Case I or method I)

(neglecting creep)

$$f_{us} = \frac{M_{D.L_1}}{Z_{us}} + \frac{M_{D.L_2} + M_{L.L+I}}{Z'_{us}}$$

$$= \frac{777.1 \times 100}{31633.8} + \frac{192.3 \times 100 + 982.7 \times 100}{258208} = 1.65\ t/cm^2$$

$$< 0.58\,F_y = 2.1\ t/cm^2$$

o.k.

$$f_{es} = \frac{M_{D.L_1}}{Z_{es}} + \frac{M_{D.L_2} + M_{L.L+I}}{Z'_{es}}$$

$$= \frac{777.1 \times 100}{56570.9} + \frac{192.3 \times 100 + 982.7 \times 100}{79083} = 2.86\ t/cm^2$$

$> 2.1$ Unsafe

increase steel dimens.

$$f_{uc} = \frac{M_{D.L_2} + M_{L.L+I}}{n \cdot Z'_{uc}} = \frac{192.3 \times 100 + 982.7 \times 100}{8 \times 170142} = 0.086 \times 1000$$

$= 86.3\ kg/cm^2$

$< 95\ kg/cm^2$

o.k.

During Construction

Comp. flange ; $f_{us} = \dfrac{M_{D.L_1}}{Z_{us}} = \dfrac{777.1 \times 100}{31633.8} = 1.19\ t/cm^2$

Use temporary Hz. bracing ; $L_u = 3.0\ m$ spacing bet.w. X.G.

$$L_{u_1} = \frac{20 \times 40}{\sqrt{3.6}} = 421.6\ cm$$

$$L_{u_2} = \frac{1380 \times (40 \times 2) \times 1.0}{\underset{h_s}{206} \times 3.6} = 148.9\ cm < L_u$$

$$f_{L.T.B_1} = \frac{800 \times (40 \times 2) \times 1.0}{300 \times 206} = 1.036\ t/cm^2$$

$$r_T = \sqrt{\frac{2 \times 40^3/12}{2 \times 40 + \frac{200 \times 1.6}{6}}} = 8.94\ cm \ ; \quad \frac{L_u}{r_T} = \frac{300}{8.94} = 33.54$$

$$\frac{L_u}{r_T} < 84\sqrt{\frac{C_b}{F_y}} = 84\sqrt{\frac{1}{3.6}} = 44.27 \Rightarrow F_{L.T.B_2} = 0.58\,F_y$$

$= 2.1\ t/cm^2$

$\therefore f_{us} < F_{L.T.B.}$ o.k.

ii) for Shored Construction (case II or method II)

Considering Creep (for steel only)

$$f_{us} = \frac{M_{D.L_1} + M_{D.L_2}}{Z''_{us}} + \frac{M_{L.L+I}}{Z'_{us}}$$

$$= \frac{(777.1 + 192.3) \times 100}{100182} + \frac{982.7 \times 100}{258208} = 1.35 \ t/c^2 < 2.1$$

o.k.

$$f_{es} = \frac{M_{D.L_1} + M_{D.L_2}}{Z''_{es}} + \frac{M_{L.L+I}}{Z'_{es}}$$

$$= \frac{(777.1 + 192.3) \times 100}{72632} + \frac{982.7 \times 100}{79083} = 2.58 \ t/c^2 > 2.1 \ t/c^2$$

Unsafe

increase steel dimensions

$$f_{uc} = \frac{M_{D.L_1} + M_{D.L_2} + M_{L.L+I}}{n \cdot Z'_{uc}}$$

$$= \frac{(777.1 + 192.3 + 982.7) \times 100}{8 \times 170142} = 0.143 \ t/c^2$$

$$= 143 \ kg/c^2$$

$$> 95 \ kg/c^2$$ Unsafe

increase steel dim.

* Check of shear stress (for both shored & Unshored)

$$Q_t = Q_{D.L_1} + Q_{D.L_2} + Q_{L.L+I}$$

$$= 96.0 + 23.8 + 122.5 = 242.3 \ t$$

$$q = \frac{242.3}{0.85 \times 200 \times 1.6} = 0.89 \ t/c^2 < 0.35 F_y = 1.26 \ t/c^2$$

o.k.

* Check of Deflection (Due to L.L ONLY)

assume $M_{L.L} = 0.8 \, M_{L.L+I} = 0.8 \times 982.7$

$= 786 \ t.m.$

$$w_{L.L} = \frac{8\,M_{L.L}}{L^2} = \frac{8 \times 786}{\overline{36}^2} = 4.85 \ t/m' = 0.0485 \ t/cm'$$

$$\delta_{all} = \frac{L}{600} = \frac{3600}{600} = 6.0 \ cm$$

$$\delta_{act} \text{ (Unshored) neglecting creep} = \frac{5 \times 0.0485 \times \overline{3600}^4}{384 \times 2100 \times 12471424} = 4.05 \ cm < \delta_{all} \quad \underline{o.k.}$$

$$\delta_{act} \text{ (shored) considering creep} = \frac{5 \times 0.0485 \times \overline{3600}^4}{384 \times 2100 \times 8673744} = 5.83 \ cm < \delta_{all} \quad \underline{o.k.}$$

## * Shear Connectors

### 1) Using Stud Connectors

#### i) Unshored Construction (neglecting creep)

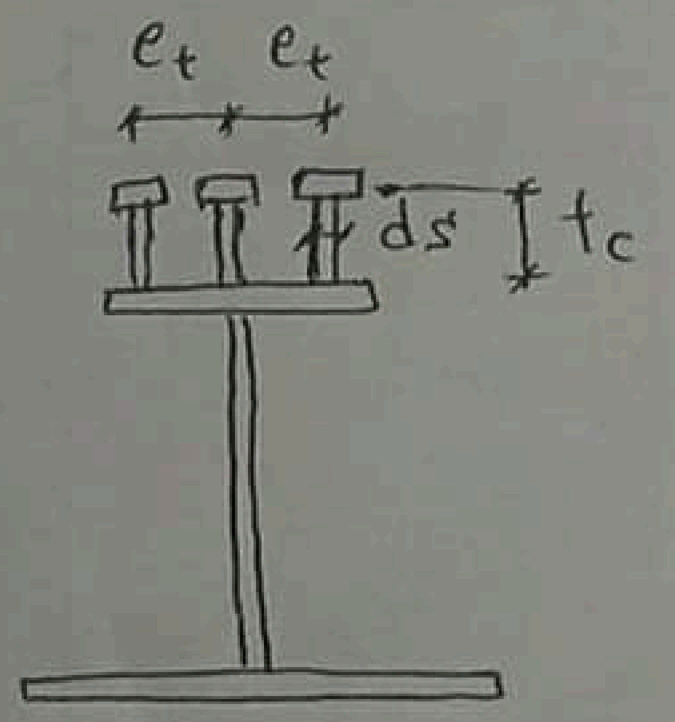
$$Q_c = 0.5\,Q_{D.L_1} + Q_{D.L_2} + Q_{L.L+I}$$

$$= 0.5 \times 96 + 23.8 + 122.5$$

$$= 194.3 \ t$$

$$\tau_{sc} = \frac{Q_c \cdot A_c \cdot Y_c}{I_{x_{vn}}} = \frac{194.3 \times (37.5 \times 25) \times (206 + \frac{25}{2} - 157.7)}{12471424}$$

$$= 0.888 \ t/cm'$$



use 3 studs M20 per row ; ST52

$d_s = 20$ mm ($\leq 2\, t_{tf}$) o.k.

$e_t \geq 4\, d_s$ o.k.

take $t_c = 120$ mm ($\geq 4\, d_s$) o.k.

$$R_{sc} = 5.4 \times 10^{-3} A_{sc} \left( \overset{kg/cm^2}{f_{cu}} \underset{t/cm^2}{E_c} \right)^{\frac{1}{2}} \leq 0.58\, F_y\, A_{sc}$$

$$= 5.4 \times 10^{-3} \times \frac{\pi (2)^2}{4} \times (400 \times 280)^{\frac{1}{2}} \qquad = 0.58 \times 3.6 \times \frac{\pi (2)^2}{4}$$

$$= 5.68 \ t \qquad = 6.56 \ t$$

$$\tau_{sc} \cdot e = \overset{\text{No/row}}{3} \cdot R_{sc}$$

$$\therefore \quad e_1 \leq \frac{3 \times 5.68}{0.888} = 19.2 \text{ cm}$$

$$e_{min} = 6\, d_s = 6 \times 2 = 12 \text{ cm} \quad \text{o.k.}$$

$$e_{max} = \text{smaller of} \begin{cases} 60 \text{ cm} \\ 3\, t_s = 3 \times 25 = 75 \text{ cm (including haunch)} \\ 4\, t_c = 4 \times 12 = 48 \text{ cm} \end{cases}$$

$$= 48 \text{ cm}$$

o.k.

check for fatigue :

No of cycles = 2,000,000 , class "F"

$$F_{sr} = 0.4 \ t/cm^2$$

$$\tau_{sc} = \frac{0.5\, Q_{L.L+I} \cdot A_c \cdot Y_c}{I_{x_{vn}}} = \frac{0.5 \times 122.5 \times (37.5 \times 25) \times (206 + \frac{25}{2} - 157.7)}{12471424}$$

$$= 0.28 \ t/cm^2$$

$$R_{sc}' = \underset{\text{as before}}{5.68 \ t} \leqslant F_{sr}\, A_{sc} = 0.4 \times \frac{\pi (2)^2}{4} = 1.26 \ t$$

$$e_2 \leq \frac{3 \times 1.26}{0.28} = 13.5 \text{ cm}$$

from $e_1$ & $e_2$ take $e = 13.5$ cm

$(e_{min} = 12 \text{ cm} , \ e_{max} = 48 \text{ cm})$ o.k.

ii) Shored Construction

The same as case (i) ; but take

$$\tau_{sc} = \frac{(Q_{D.L_1} + Q_{D.L_2})\, A_c'' \cdot Y_c''}{I_{x_{v3n}}} + \frac{Q_{L.L+I} \cdot A_c \cdot Y_c}{I_{x_{vn}}}$$

& for Fatigue :

$$\tau_{sc} = \frac{0.5\, Q_{L.L+I} \cdot A_c \cdot Y_c}{I_{x_{vn}}}$$

## 2) Using Channel Connectors

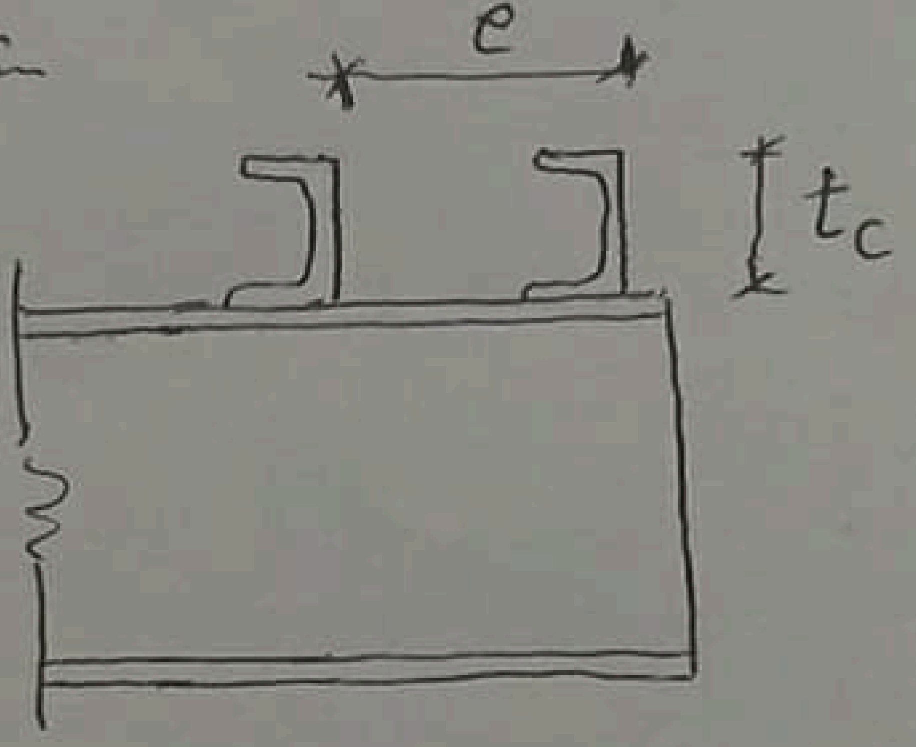
### i) Unshored Constr. (neglecting creep)

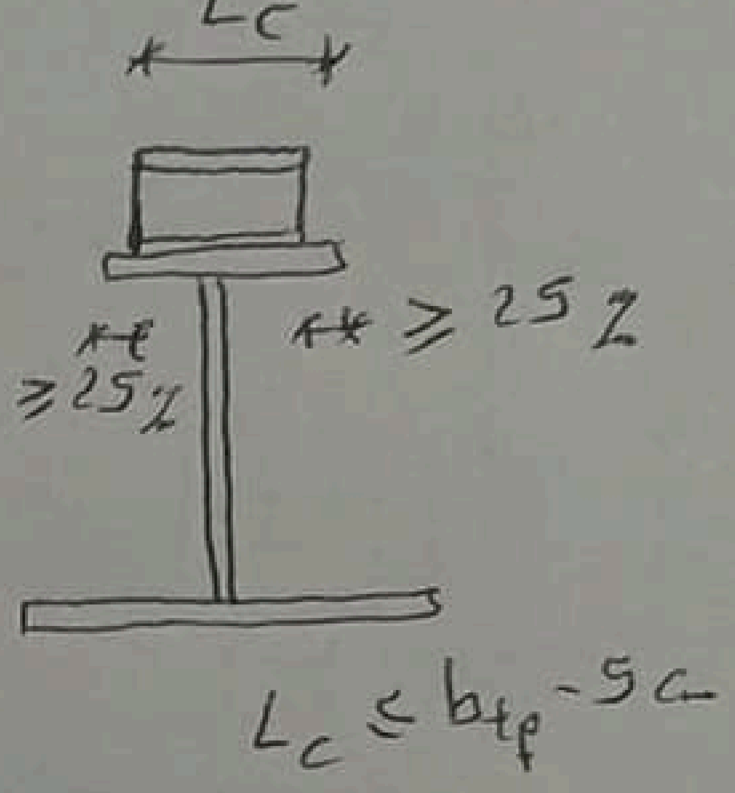
$Q_c = 194.3\ t$ (as for stud)

$\tau_{sc} = 0.888\ t/cm'$ (as calculated for stud connector)

assume UPN 100, $L_c = 20$ cm

$\therefore\ t_c = 10$ cm





$$\underset{t}{R_{sc}} = 3.8\times10^{-3}\,(\overset{cm}{t_f} + 0.5\,\overset{cm}{t_w}) \times \underset{cm}{L_c}\,(\underset{kg/c^2}{f_{cu}}\ \underset{t/c^2}{E_c})^{\frac{1}{2}}$$

$$= 3.8\times10^{-3}\,(0.85 + 0.5\times0.6)\times 20\,(400\times280)^{\frac{1}{2}}$$

$$= 29.25\ t$$

$\tau_{sc}\cdot e = R_{sc}$

$\therefore\ e_1 \le \dfrac{29.25}{0.888} = 32.9$ cm

$e_{min} = t_s = 25$ cm

$e_{max} = $ smaller $\begin{cases} 60\ cm \\ 3\,t_s = 75\ cm \\ 4\,t_c = 40\ cm \end{cases}$

$= 40$ cm

check for fatigue (connection)

No. of cycles = 2,000,000

class E'

$F_{sr} = 0.41\ t/c^2$

assume fillet weld all around with $s_w = 5$ mm

$A_w = 2\,(\underset{L_c}{20} + \underset{b}{5}) \times \underset{s_w}{0.5} = 25\ cm^2$

$R_w = A_w \cdot F_{sr} = 25 \times 0.41 = 10.25\ t$

$\tau_{sc} = 0.28\ t/cm'$ (as calculated for stud)

$\tau_{sc}\cdot e = R_w \Rightarrow e_2 \le \dfrac{10.25}{0.28} = 36.6$ cm

from $e_1$ & $e_2$ take spacing $e = 30$ cm ($e_{min} = 25$ cm, $e_{max} = 40$ cm)