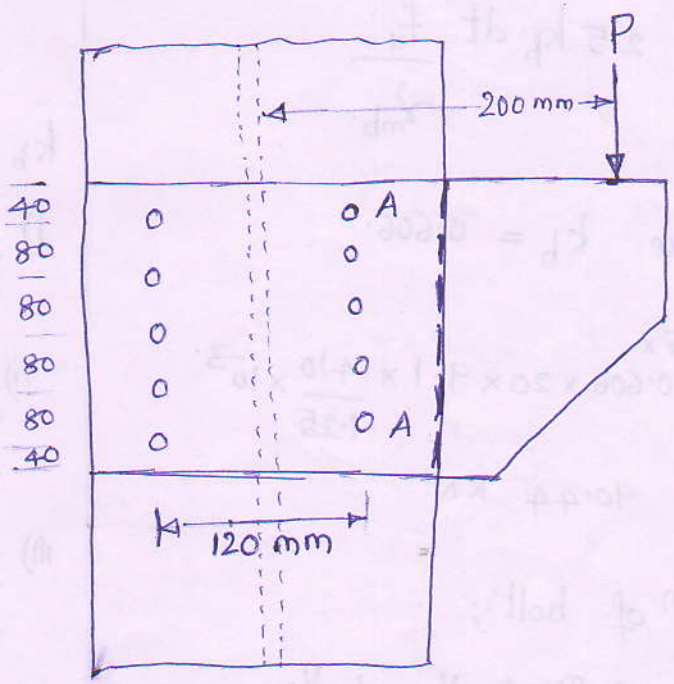
DESIGN OF ECCENTRIC CONNECTIONS

Prob: Determine the safe load 'P' that can be carried by the joint shown in figure. The bolts used are 20 mm of grade 4.6. The thickness of flange of I-section is 9.1 mm and that of bracket plate is 10 mm.

Soln:



For Fe 410 grade of steel;

$f_u = 410\ N/mm^2$

For bolts of grade 4.6;

$f_{ub} = 400\ N/mm^2$

Partial safety factor for material of bolt;

$\gamma_{mb} = 1.25$

Stress area of 20 mm dia bolt $A_{nb} = 0.78 \times \frac{\pi}{4} (20)^2$

$= 245\ mm^2$

$d = 20$ mm (Dia of bolt)

$d_o = 20 + 2 = 22$ mm (Dia of bolt hole)

Pitch $p = 80$ mm;

Edge distance $e = 40$ mm

Strength of bolt in single shear;

$$V_{dsb} = A_{nb} \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} \quad (pg: 75)$$

$$= 245 \times \frac{400}{\sqrt{3} \times 1.25} \times 10^{-3} = 45.26 \text{ kN}$$

Strength of bolt in bearing,

$$V_{dpb} = 2.5\, k_b\, dt \frac{f_u}{\gamma_{mb}}$$

Hence $k_b = 0.606$

$$V_{dpb} = 2.5 \times 0.606 \times 20 \times 9.1 \times \frac{410}{1.25} \times 10^{-3}$$

$$= 90.44 \text{ kN}$$

So, V_{sd} = Min^m of V_{dpb} & V_{dsb}

$= 45.26$ kN

k_b is least of;

i) $\frac{e}{3d_o} = \frac{40}{3 \times 22} = 0.606$

ii) $\frac{p}{3d_o} - 0.25 = \frac{80}{3 \times 22} - 0.25 = 0.96$

iii) $\frac{f_{ub}}{f_u} = \frac{400}{410} = 0.975$

iv) 1

Let P_1 be the factored load.

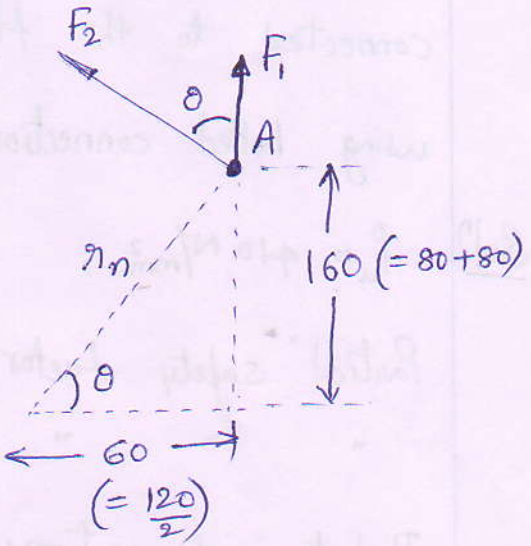
Service ~~load~~; $P = \frac{P_1}{\text{~~load factor~~}} = \frac{P_1}{1.5}$

Total no. of bolts in joint $n = 10$.

Direct force $F_1 = \frac{P_1}{n} = \frac{P_1}{10}$

Force in bolt due to torque $F_2 = \dfrac{P e r_n}{\Sigma r^2}$

Extreme bolt A, will be highly stressed.



$$r_n = \sqrt{(60)^2 + (160)^2} = 170.88 \text{ mm}$$

$$\Sigma r^2 = 4(160^2 + 60^2) + 4(80^2 + 60^2) + 2(60^2)$$

$$= 164{,}000 \text{ mm}^2$$

$$F_2 = \frac{P_1 \times 200 \times 170.88}{164{,}000} = 0.20839\, P_1$$

$$\cos\theta = \frac{60}{170.88} = 0.3511$$

Resultant force on the bolt should be less than or equal to strength of bolt.

$$45.26 \leq \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$$

$$\sqrt{\left(\frac{P_1}{10}\right)^2 + (0.20839P_1)^2 + 2 \times \frac{P_1}{10} \times 0.20839P_1 \times 0.3511}$$

$$P_1 = 173.49 \text{ KN}$$

$$\text{Service load} = \frac{173.49}{\text{load factor}} = \frac{173.49}{1.5} = 115.65 \text{ KN}.$$

2 Prob: Design a seat connection for a factored beam end reaction of 110 kN. The beam section is ISMB 250 @ 365.9 N/m connected to the flange of column; ISHB 200 @ 365.9 N/m using bolted connection. Use Fe410 grade steel & bolts of grade 4.6.

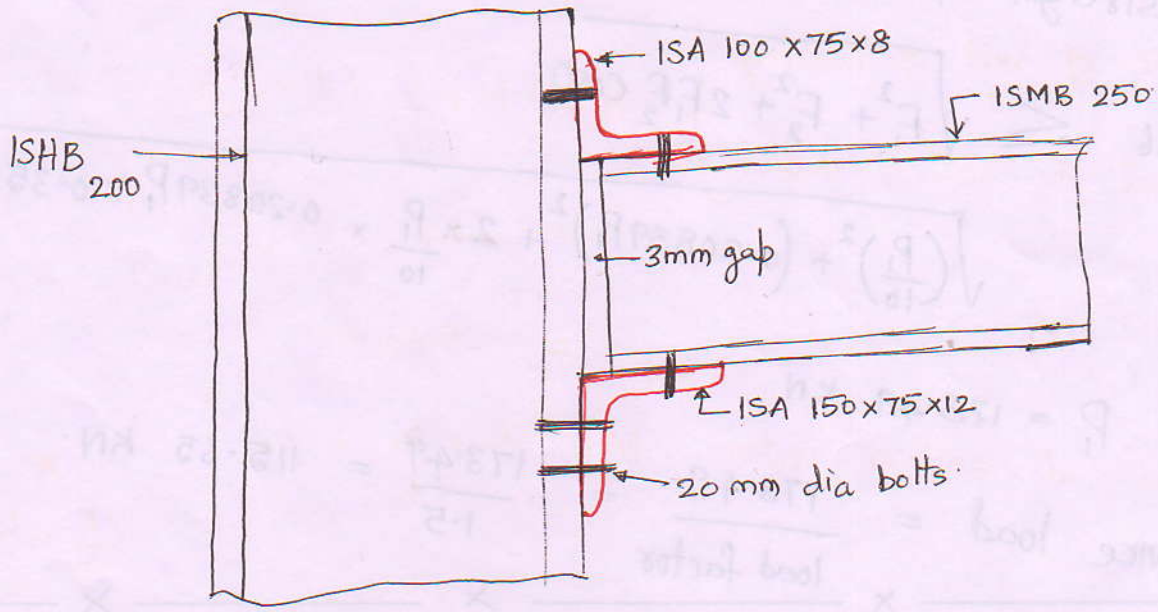
Soln $f_u = 410\ N/mm^2$; $f_y = 250\ N/mm^2$ $f_{ub} = 400\ N/mm^2$

Partial safety factor for material of bolt $\gamma_{mb} = 1.25$

" " " " " $\gamma_{m0} = 1.1$

Properties of sections:

Property	ISMB 250	ISHB 200
Depth of section h	~~300~~ 250 mm	~~450~~ 200 mm
Width of flange b_f	~~150~~ 125 mm	~~150~~ 200 mm
Thickness of flange t_f	~~10.4~~ 12.5 mm	~~17.4~~ 9.00 mm
t_w	~~7.6~~ 6.9 mm	~~9.4~~ 6.1 mm
Gauge g	~~90~~ 65 mm	~~90~~ 55 mm
Radius @ root R_1	13 mm	



The length of seat angle, B = width of beam flange

= 125 mm (i.e b_f = 125 mm)

Bearing length of the seat leg (i.e length of web bearing) $b = \frac{R\gamma_{mo}}{t_w f_{yw}}$ (This is calculated on the basis of web crippling of beam)

$= \frac{110 \times 10^3 \times 1.1}{6.9 \times 250} = 70.14$ mm.

Provide an angle section with leg length of 75 mm.

Provide a clearance of 3 mm bet^n the beam and column flange.

Req^d length of outstanding leg = 70.14 + 3 = 73.14 mm.

< 75 mm. (OK).

Length of bearing on seat, $b_1 = b - (t_f + R_1)$

R_1 = root radius = 13 mm
t_f = 12.5 mm

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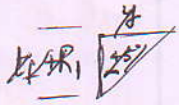
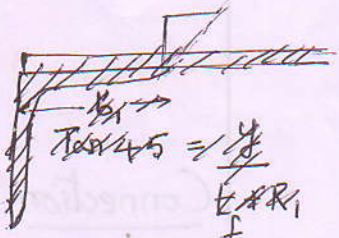
$= 70.14 - (12.5 + 13)$

$= 44.64$ mm.





$y = (t_f + R_1)$

c = clearance

Try a seat angle 150 × 75 × 12 mm.

Radius at root of seat angle R_a = 10 mm.

Distance of end of bearing on seat to root of angle $b_2 = b_1 + c - (t_a + R_a)$

$= 44.64 + 3 - (12 + 10)$

$= 25.64$ mm.

Moment at critical section $M = R \times \frac{b_2}{b_1} \times \frac{b_2}{2}$

(Reaction is assumed to be uniformly distributed over bearing length b_1) $\therefore \frac{R}{b_1}$

* $\left(\frac{R}{b_1}\right) b_2 \cdot \frac{b_2}{2}$

similar to $w \cdot l \cdot \frac{l}{2}$

$$= 110 \times \frac{25.64}{44.64} \times \frac{25.64}{2} = 809.98 \text{ kN-mm}$$

Moment capacity of angle ~~section~~ leg;

$B = 125$ mm
$t = 12$ mm

$$M_d = 1.2 Z_e \frac{f_y}{\gamma_{mo}} = 1.2 \times \frac{125 \times 12^2}{6} \times \frac{250}{1.1} \times 10^{-3}$$

$$= 818.18 \text{ kN·mm} > 809.98 \text{ kN·mm} \quad \text{(OK)}$$

So, provide a seat angle $150 \times 75 \times 12$

Shear capacity of outstanding leg (seating leg)

$$V_{dp} = B t_a \frac{f_y}{\sqrt{3}\,\gamma_{mo}}$$

$$= 125 \times 12 \times \frac{250}{\sqrt{3} \times 1.1}$$

$$= 196.82 \text{ kN} > 110 \text{ kN} \quad \text{(OK)}$$

Connection of seat angle leg with column flange

Provide 20 mm diameter 4.6 grade bolts

Bolts will be in single shear & bearing.

$$A_{nb} = 0.78 \times \frac{\pi}{4} d^2 = 245 \text{ mm}^2$$

Strength of bolt in single shear,

$$V_{dsb} = A_{nb} \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} = 245 \times \frac{400}{\sqrt{3} \times 1.25} \times 10^{-3}$$

$$= 45.26 \text{ kN}$$

Assume st^n of bolt in bearing $>$ st^n of bolt in shear; st^n of bolt $= 45.26$ kN

No. of bolts req^{d} $n = \dfrac{\text{Reaction}}{\text{S}^{t^n}\text{ of bolt}}$

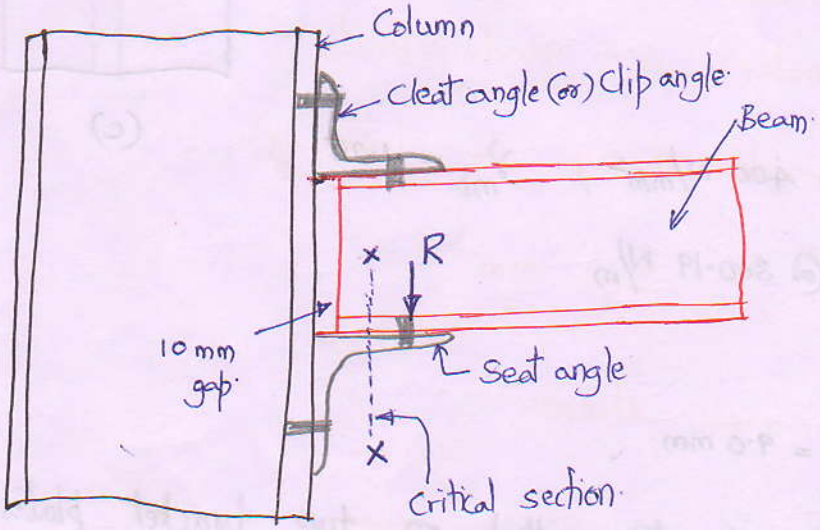
$= \dfrac{110}{45.26} = 2.43 \simeq 4$

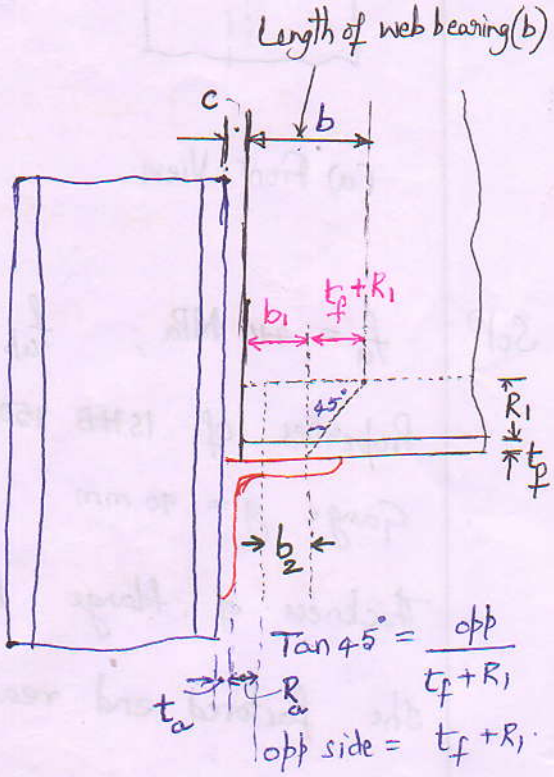
Provide 20 mm dia bolts; 4 in numbers, in two rows at a pitch of 60 mm.

Provide 20 mm dia bolts; 2 in numbers, to connect seat leg with beam flange.

Provide a nominal cleat angle ISA 100 x 75 x 8 mm over the top of the beam flange.

Connect the legs of this angle with flanges of beam and column with 2 no. of 20 mm dia bolts each.



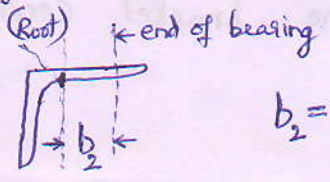


1) $b = \dfrac{R}{t_w} \cdot \dfrac{\gamma_{mo}}{f_{yw}}$

2) $b_1 = b - (t_f + R_1)$

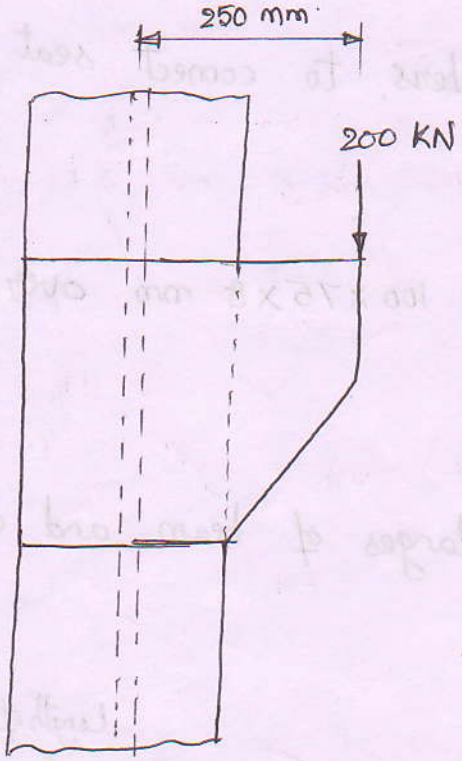
R_1 = root radius of beam flange.

3) Distance bet^{n} end of bearing on seat to root of angle

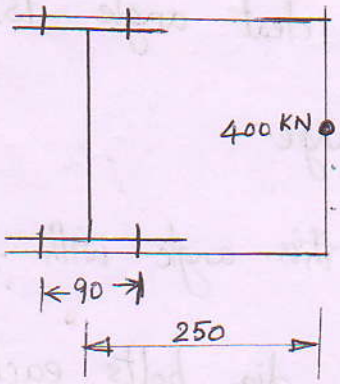


$b_2 = b_1 + c - (t_a + R_a)$

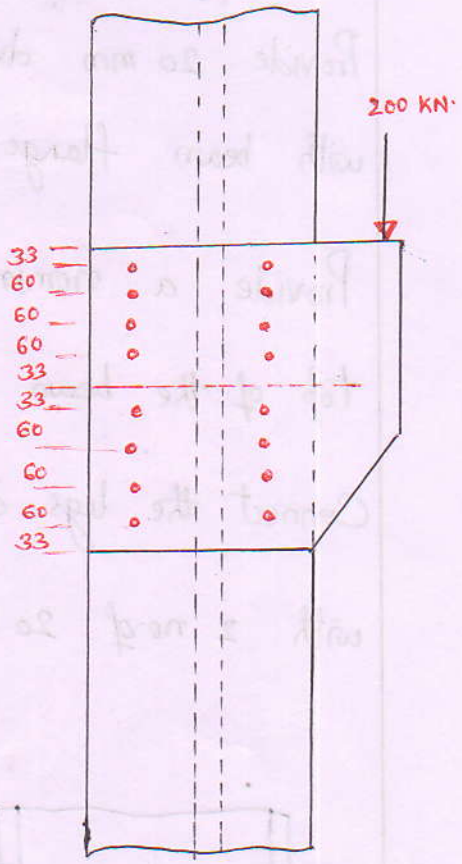
Prob: Design a bolted bracket connection to support an end reaction of 400 kN because of the factored loads supported by the beam. The eccentricity of end reaction is shown in figure. Thickness of bracket plate may be taken as 10 mm. Column section is ISHB 150 @ 300.19 N/m. Use Fe 410 steel & 4.6 grade of bolts



(a) Front View



b) Plan



(c)

Soln $f_u = 410$ MPa ; $f_{ub} = 400$ N/mm^2 ; $\gamma_{mb} = 1.25$

Properties of ISHB 150 @ 300.19 N/m

Gauge $g = 90$ mm

Thickness of flange $t_f = 9.0$ mm

The factored end reaction is transmitted on two bracket plates.

Load on one bracket connection $P = \frac{400}{2} = 200$ KN.

Provide 20 mm diameter bolts. $d = 20$ mm

$d_o = 20 + 2 = 22$ mm

Edge distance $e = 33$ mm

Stress area $A_{nb} = 0.78 \times \frac{\pi}{4} (20)^2 = 245 \text{ mm}^2$

Min^m pitch $p = 2.5d = 2.5 \times 20 = 50$ say 60 mm

St^n of bolt in single shear $V_{dsb} = \frac{A_{nb} \cdot f_{ub}}{\sqrt{3}\, \gamma_{mb}}$

$$V_{dsb} = 245 \times \frac{400 \times 10^{-3}}{\sqrt{3} \times 1.25} = 45.26 \text{ kN}$$

St^n of bolt in bearing $V_{dpb} = 2.5\, k_b\, dt\, \frac{f_u}{\gamma_{mb}}$

k_b is least of

i) $\frac{e}{3d_o} = \frac{33}{3 \times 22} = 0.50$

ii) $\frac{p}{3d_o} - 0.25 = \frac{60}{3 \times 22} - 0.25 = 0.659$

iii) $\frac{f_{ub}}{f_u} = \frac{400}{410} = 0.95$

iv) 1.0

$\therefore k_b = 0.5$

$V_{dpb} = 2.5 \times 0.5 \times 20 \times 9 \times \frac{410}{1.25} \times 10^{-3}$

$= 73.8$ KN

$\therefore$ St^n of bolt $V_{sd} = 45.26$ KN

Providing bolts in two vertical rows;

No. of bolts in one row $n = \sqrt{\frac{6M}{p\, n'\, V_{sd}}}$

M : moment

p : pitch of bolts

n' : no. of vertical rows of bolts

V_{sd} : St^n of bolt

$= \sqrt{\frac{6 \times 200 \times 250}{60 \times 2 \times 45.26}} = 8.$

Provide 8 bolts in one vertical row.

So provide 16 no of bolts on each bracket plate.

Critical bolt will be bolt A (bolt whose radial distance is max^m from cg of bolt group)

Force on Critical bolt A;

Direct force $F_1 = \frac{P}{n} = \frac{200}{16} = 12.5$ KN.

Force in bolt due to twisting moment $F_2 = \frac{Pe\, r_n}{\Sigma r^2}$

$P = 200$ KN; $e = 250$ mm; $r_n = \sqrt{213^2 + 45^2} = 217.70$ mm

$$\Sigma r^2 = 4\left[(213^2+45^2) + (153^2+45^2) + (93^2+45^2) + (33^2+45^2)\right]$$

$$= 346,464 \text{ mm}^2$$

$$F_2 = \frac{200 \times 250 \times 217.7}{346,464} = 31.417 \text{ KN}$$

$$\cos\theta = \frac{45}{\sqrt{213^2+45^2}} = 0.206$$

Resultant force on critical bolt $F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$

$$= \sqrt{12.5^2 + 31.417^2 + 2 \times 12.5 \times 31.417 \times 0.20}$$

$$= 36.12 \text{ KN} < 45.26 \text{ KN}$$

(OK).

Prob: Design a stiffened seat connection for an ISMB 350 @ 574 N/m transmitting an end reaction of 320 kN (due to factored loads) to a column section ISHB 300 @ 576.8 N/m. Use Fe410 grade steel & bolts of grade 4.6

Soln:

$f_u = 410\ N/mm^2$

$f_{yw} = 250\ N/mm^2$

$f_{ub} = 400\ N/mm^2$

Partial safety factor for material of bolt $\gamma_{mb} = 1.25$

" " " " " $\gamma_{mo} = 1.1$

" " " " " $\epsilon = \sqrt{\frac{250}{f_y}} = 1$

Properties of sections to be connected :

Property	ISMB 350 (Beam)	ISHB 300 (column)
Width of flange b_f	140 mm	250 mm
t_f	14.2 mm	10.6 mm
t_w	8.1 mm	7.6 mm
Gauge g	80 mm	
Radius @ root R_1	14 mm	

Length of seat angle B = width of beam flange

= 140 mm

Bearing length of seat leg $b = \frac{R}{t_w} \cdot \frac{\gamma_{mo}}{f_{yw}}$

$$b = \frac{320 \times 10^3}{8.1} \times \frac{1.10}{250} = 173.82 \text{ mm}$$

Provide a clearance 'c' of 5 mm bet^n beam & column flange.

Req^d length of outstanding leg = 173.82 + 5 = 178.82 mm ≃ 200 mm

Provide seat angle 200 x 150 x 10 mm; with seating leg of 200 mm connected to the flange of beam with 2, - 24 mm diameter bolts of grade 4.6.

Radius at root of angle $R_a = 13.5$ mm.

Stiffener angles

Bearing area req^d by stiffener angles $A = R \cdot \frac{\gamma_{mo}}{f_y}$

$$= 320 \times 10^3 \times \frac{1.1}{250}$$

$$= 1408 \text{ mm}^2$$

Provide two angles ISA 90x60x8

Area provided by stiffening legs of the angles $= 2(90 \times 8)$

$= 1440 \text{ mm}^2$

Length of outstanding leg = 90 - 8 = 82 mm.

Length of outstand of stiffener $\nrightarrow 14 t_a \epsilon$ $(\epsilon = 1)$

$= 14 \times 8 \times 1 = 112$ mm

t_a (thickness of angle) should be more than t_w (=8.1)

Since the difference is very less; it may be used.

Distance of end reaction from column flange $e_x = \frac{200}{2} = 100$ mm.

200 is the length of seating leg connected to flange of beam.

Stiffener angles provide some rigidity to the seat angle and the reaction is assumed to act @ middle of seat angle.

Design of Connections:

Use 24-mm dia bolts @ a pitch of 60 mm.

For 24-mm dia bolts; $A_{nb} = 0.78 \times \frac{\pi}{4}(24)^2 = 353 \text{ mm}^2$

Min^m pitch $p = 2.5\, d_o = 2.5 \times 24 = 60$ mm

Edge distance $e = 39 \text{ mm} \simeq 40$ mm.

Dia of bolt hole $d_o = 24 + 2 = 26$ mm.

st^n of bolt in single shear $V_{dsb} = A_{nb} \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}$

$= 353 \times \frac{400}{\sqrt{3} \times 1.25} \times 10^{-3}$

$= 65.22$ KN.

st^n of bolt in bearing $V_{dpb} = 2.5\, k_b\, d\, t\, \frac{f_u}{\gamma_{mb}}$

k_b is least of;

$\frac{e}{3d_o} = \frac{40}{3 \times 26} = 0.513$.

$\frac{p}{3d_o} - 0.25 = \frac{60}{3 \times 26} - 0.25 = 0.519$

$f_{ub}/f_u = 400/410 = 0.95$

1

$\therefore k_b = 0.513$.

$V_{dpb} = 2.5 \times 0.513 \times 24 \times 8 \times \frac{410}{1.25} \times 10^{-3}$

$= 80.76$ KN.

So st^n of bolt $= 65.22$ KN.

There will be two vertical rows of bolts, connecting legs of two stiffener angles with the column flange.

No. of bolts in one row: $n = \sqrt{\frac{6M}{p n' V_{sd}}}$

$$= \sqrt{\frac{6 \times 320 \times 10^3 \times 100}{60 \times 2 \times 6522 \times 10^3}} = 4.95 \simeq 5.$$

Depth of stiffener angle = $(4 \times 60) + (2 \times 40) = 320$ mm

$h = 320 - 40 = 280$ mm

$h/7 = 280/7 = 40$ mm

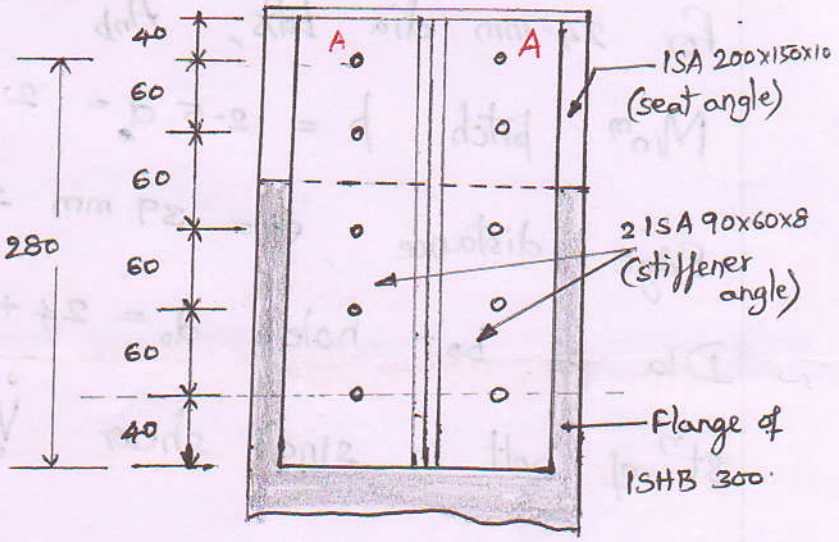
Critical bolt will be A.

$\Sigma y_i = 2[0 + 60 + 120 + 180 + 240]$

$= 1200$ mm.

$\Sigma y_i^2 = 2[0 + 60^2 + 120^2 + 180^2 + 240^2]$

$= 216{,}000$ mm^2



Moment shared by critical bolt;

$$M' = \frac{M}{1 + \frac{2h}{21}\frac{\Sigma y_i}{\Sigma y_i^2}} = \frac{320 \times 100}{1 + \frac{2 \times 280}{21} \times \frac{1200}{216{,}000}}$$

$= 27.87 \times 10^3$ kN mm.

Tensile force in critical bolt

$$T_b = \frac{M' y_n}{\Sigma y_i^2} = \frac{27.87 \times 10^3 \times 240}{216{,}000} = 30.96 \text{ kN}$$

Shear force in critical bolt;

$$V_{sb} = \frac{P}{\text{no. of bolts}} = \frac{320}{2 \times 5} = 32 \text{ kN}.$$

Check: $\left(\frac{V_{sb}}{V_{dsb}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2 \leq 1$

Strength of bolt in tension $T_{db} = \frac{T_{nb}}{\gamma_{mb}}$

$T_{nb} = 0.9 f_{ub} A_{nb} \not> f_{yb} \frac{\gamma_{mb}}{\gamma_{mo}} A_{sb}$

$= 0.9 \times 400 \times 353 \times 10^{-3} = 127.08$ KN

$\not> 250 \times \frac{1.25}{1.1} \times 452 \times 10^{-3} = 128.40$ kN

$T_{nb} = 127.08$ kN

$T_{db} = \frac{127.08}{1.25} = 101.66$ kN

$\left(\frac{32}{65.22}\right)^2 + \left(\frac{30.96}{101.66}\right)^2 = 0.333 < 1.0$ (OK)

Prob: An ISLB 300 @ 369.8 N/m transmits an end reaction of 385 KN, under factored loads, to the web of ISMB 450 @ 710.2 N/m. Design a bolted framed connection. Use Fe410 steel & 4.6 grade bolts.

Sol^n $f_u = 410$ N/mm^2 $f_y = 250$ N/mm^2 $f_{ub} = 400$ N/mm^2

$\gamma_{mb} = 1.25$ $\gamma_{mo} = 1.1$

Properties of sections:

Property	ISLB 300	ISMB 450
Depth of section h	300 mm	450 mm
Width of flange bf	150 mm	150 mm
Thickness of flange t_f	9.4 mm	17.4 mm
Thickness of web t_w	6.7 mm	9.4 mm
Gauge 'g'	90 mm	90 mm

Connection of web of ISLB 300 with framing angle leg.

Provide 24 mm dia bolts.

Bolts will be in double shear.

Stress area $A_{nb} = 0.78 \times \frac{\pi}{4}(24)^2 = 353\ mm^2$

Min^m pitch $p = 2.5d = 2.5 \times 24 = 60\ mm \simeq 65\ mm$.

Edge distance $e = 39\ mm \simeq 40\ mm$

Dia of bolt hole $d_o = 24 + 2 = 26\ mm$

St^n of bolt in double shear; $V_{dsb} = 2 \cdot A_{nb} \cdot \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}}$

$= 2 \times 353 \times \frac{400}{\sqrt{3} \times 1.25} \times 10^{-3}$

$= 130.43\ kN$

St^n of bolt in bearing $V_{dpb} = 2.5\, k_b\, d\, t\, \frac{f_u}{\gamma_{mb}}$

k_b is least of;

i) $\frac{e}{3d_o} = \frac{40}{3 \times 26} = 0.513$

ii) $\frac{p}{3d_o} - 0.25 = \frac{65}{3 \times 26} - 0.25 = 0.58$

$\therefore k_b = 0.513$

iii) $\frac{f_{ub}}{f_u} = \frac{400}{410} = 0.975$

iv) 1.0

$\therefore V_{dpb} = 2.5 \times 0.513 \times 24 \times 6.7 \times \frac{410}{1.25} \times 10^{-3} = 67.64\ kN$.

St^n of bolt = $67.64\ kN$.

No. of bolts for making connections $n = \frac{385}{67.64} = 6$ $\left\{ n = \frac{R}{\text{Bolt value}} \right\}$.

Two framing angles, one on each side of the web will be provided.

Provide the bolts in two vertical rows.

Min^m size of angle leg $= 2 \times 40 + 65 = 145$ mm $\simeq 150$ mm

Connection of web of ISMB 450 with framing angle leg.

Let us provide 24 mm dia bolts.

Bolts will be in single shear.

Assuming thickness of angle leg to be more than the thickness of web of ISMB 450; the bolts will bear on web of ISMB 450.

St^n of bolt in single shear $V_{dsb} = \frac{A_{nb} f_{ub}}{\sqrt{3}\, \gamma_{mb}}$

$= 353 \times \frac{400}{\sqrt{3} \times 1.25} \times 10^{-3} = 65.22$ kN

St^n of bolt in bearing $V_{dpb} = 2.5\, k_b\, dt\, \frac{f_u}{\gamma_{mb}}$

$= 2.5 \times 0.513 \times 24 \times 9.4 \times \frac{410}{1.25} \times 10^{-3}$

$= 94.90$ kN

So st^n of bolt $= 65.22$ kN.

No. of bolts for making the connection $n = \frac{R}{\text{st}^n \text{ of bolt}}$

$= \frac{385}{65.22} = 6.$

Provide 3 bolts each on the legs of the two framing angles as shown in figure.

~~Min^m depth of framing leg~~

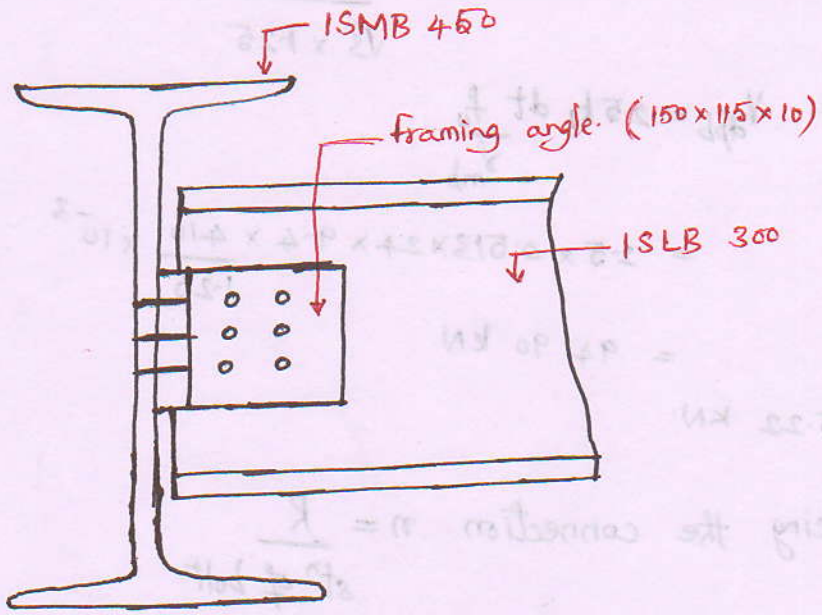
Min^m size of angle leg = $2 \times 40 = 80$ mm $\simeq$ 115 mm

Min^m depth of framing angle leg $h = 2\times40 + 2\times65$

$= 210$ mm.

Thickness of angle section can be determined by equating the SF (end reaction) to the shear capacity of angle leg.

$$V = V_d = \frac{f_y}{\sqrt{3}\,\gamma_{mo}}\, h\,(2\,t_w) \quad (\because \text{there are two angles})$$

$$385 \times 10^3 = \frac{250}{\sqrt{3} \times 1.1} \times 210 \times (2 \times t_w) \Rightarrow t_w = 6.89 \simeq 10 \text{ mm}.$$

So provide 2 framing angles 150 x 115 x 10 mm in size.