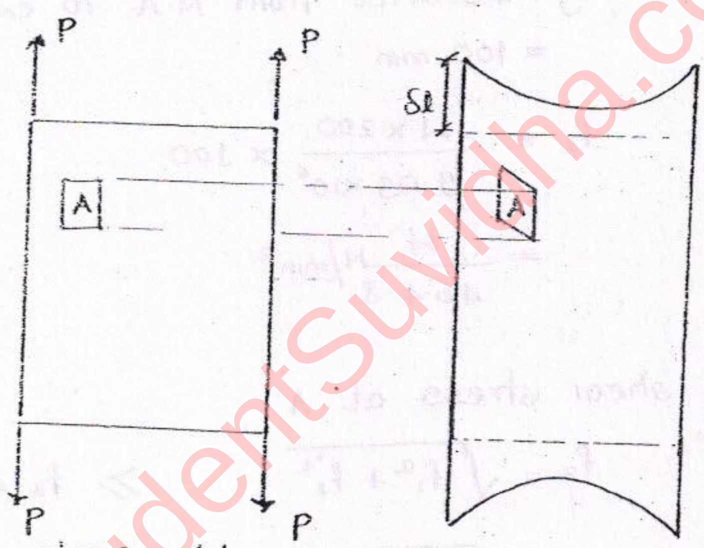
Q. In the above problem, find factored load Wu., if ultimate tensile stress in weld metal $f_u = 410$ MPa & $\gamma_m = 1.25$.

$$f_R = \sqrt{\left(\frac{W_u}{1344}\right)^2 + \left(\frac{W_u}{454.8}\right)^2} \leq \frac{f_u}{\sqrt{3} \times 1.25}$$

$$W_u = 81.61 \text{ kN}.$$

Design of tension members:

(1) Shear log :

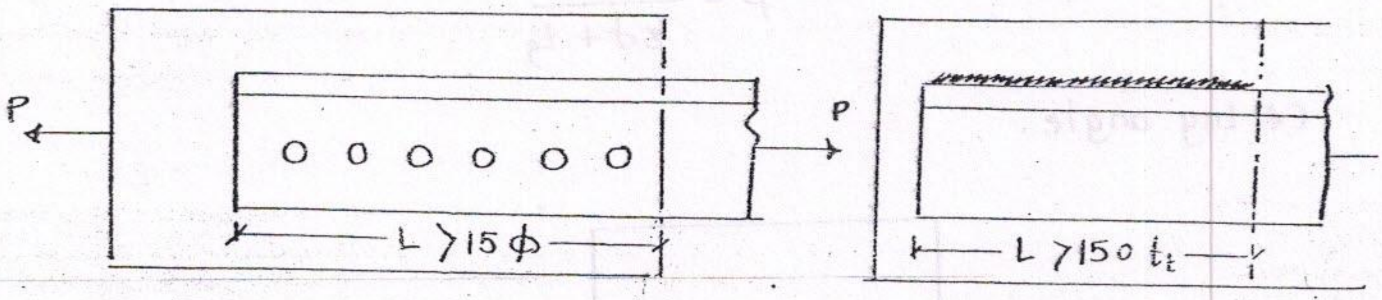


plane rubber plate. Loded rubber (deformed shape)

(i) Non-uniform straining of a member due to tension is called shear log. Shear log reduces the efficiency of the tension member components that are not connected directly to the gusset plate.

(ii) To strain the member uniformly the section will be cracked at the connected part (where the δL is already more)

(2) Long joints :

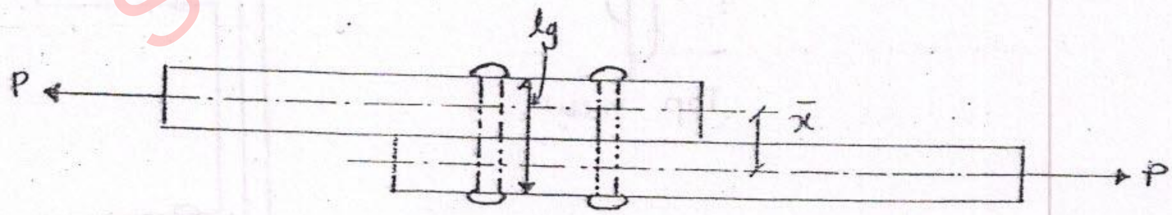


(i) If length of joint is greater than 15 φ or (150 × t), then joint is called long joint.

(ii) It is assumed that applied axial load is shared by all the rivets equally. But in long joints, outer rivets take more load than inner rivets. So failure of rivets in long joints is sequencial, begenining with those at ends and progressing towards centre. This type of failure is called 'Unbuttoning'.

(iii) If the length of joint is more the efficiency of member will be less.

(3) Grip length (l_g) :



Grip length (l_g) ≯ 8d in WSM

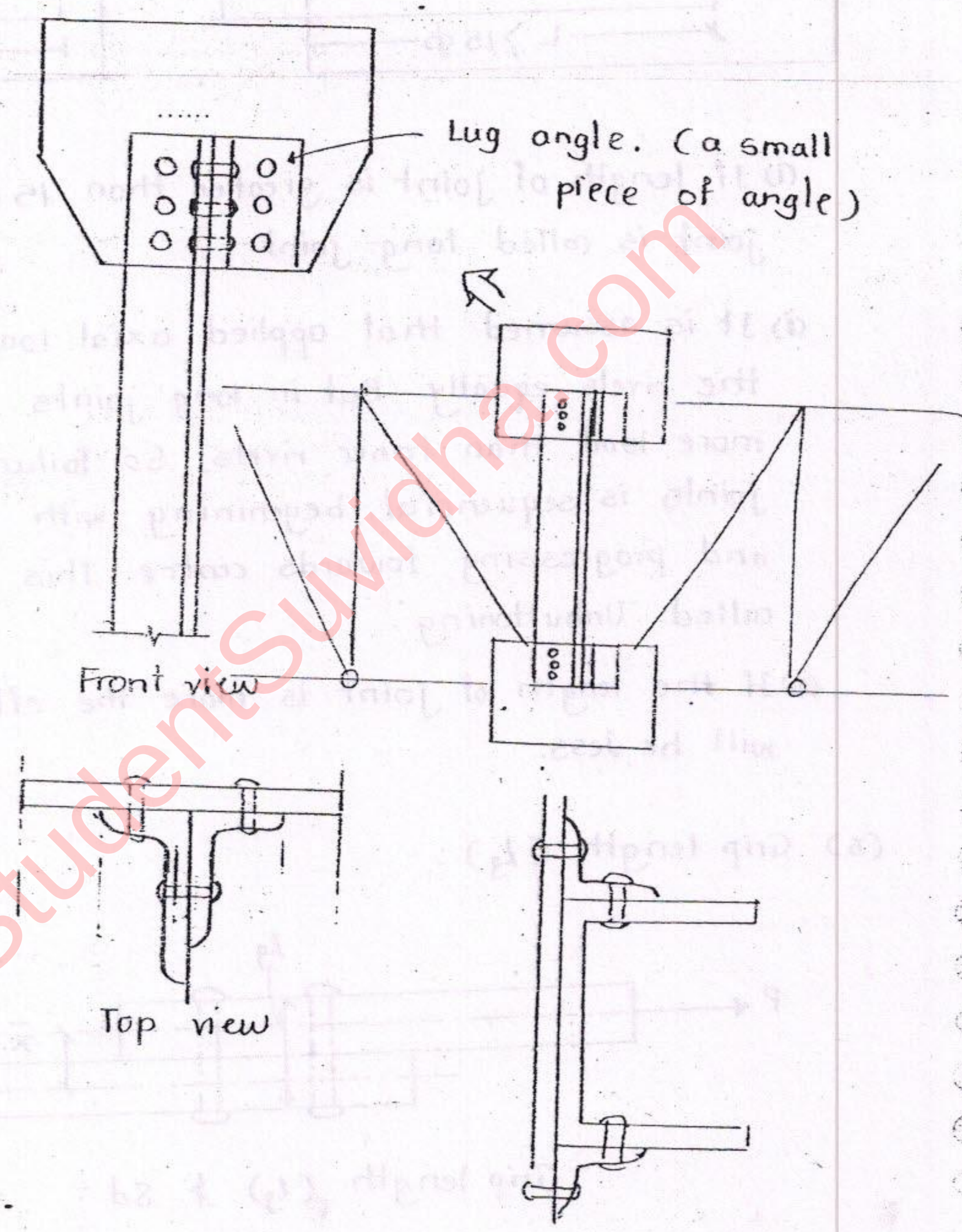
≯ 5d in LSM.

(i) If the grip length increases then the efficiency of joint decreases (due to additional bending stresses developed in the rivets)

(ii) If $l_g > 5d$, shear carrying capacity of the rivet is reduced by the factor,

$$\beta = \frac{8d}{3d + l_g}$$

(4) Lug angle :

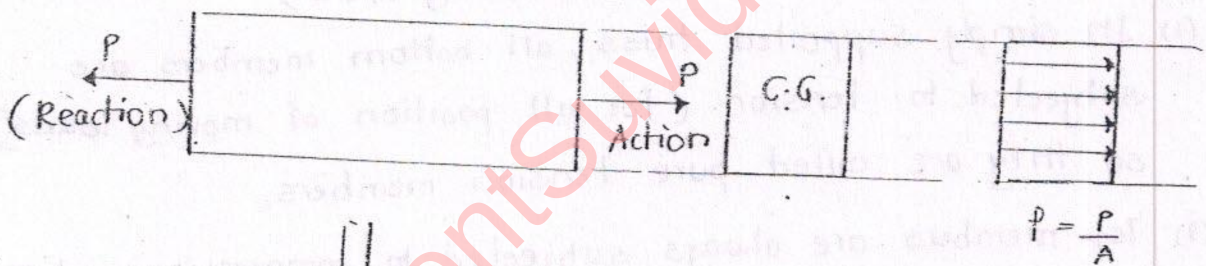


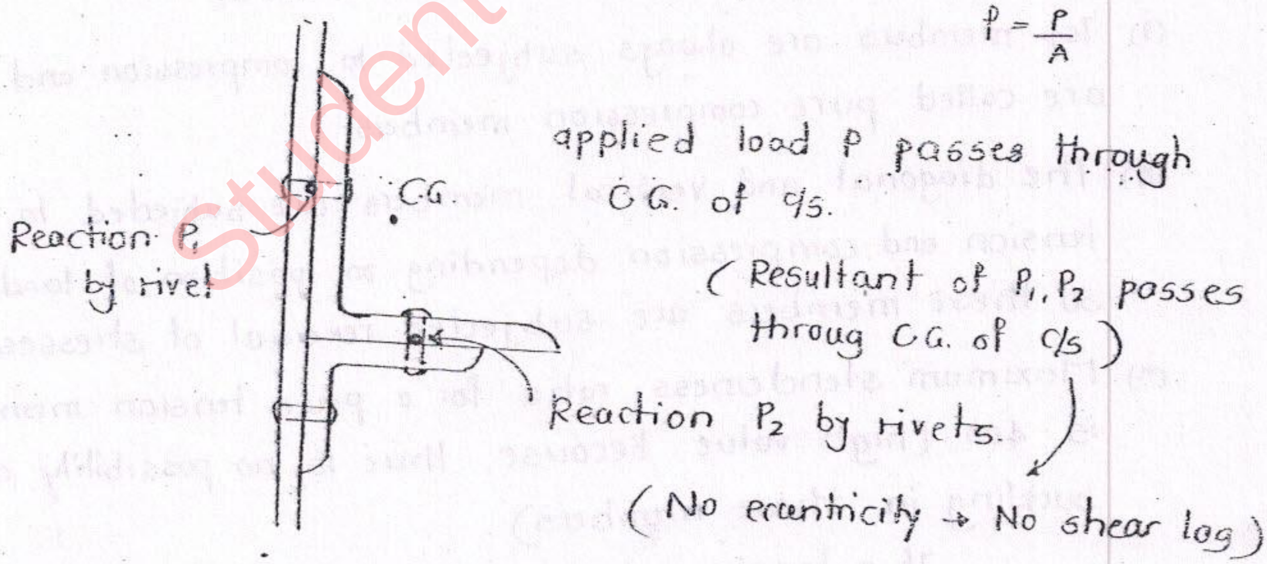
(i) Lug angle is small piece of angle used to connect the outstand legs of structural members to the gussel plate.

(ii) The purpose of lug angle is to reduce length of connection to gusset plate and to reduce shear lag effect.

(Both the legs are connected to gusset plate directly and indirectly, thus the uniform stress is developed. Thus there will be no shear lag. as there will be no non-uniform strain)

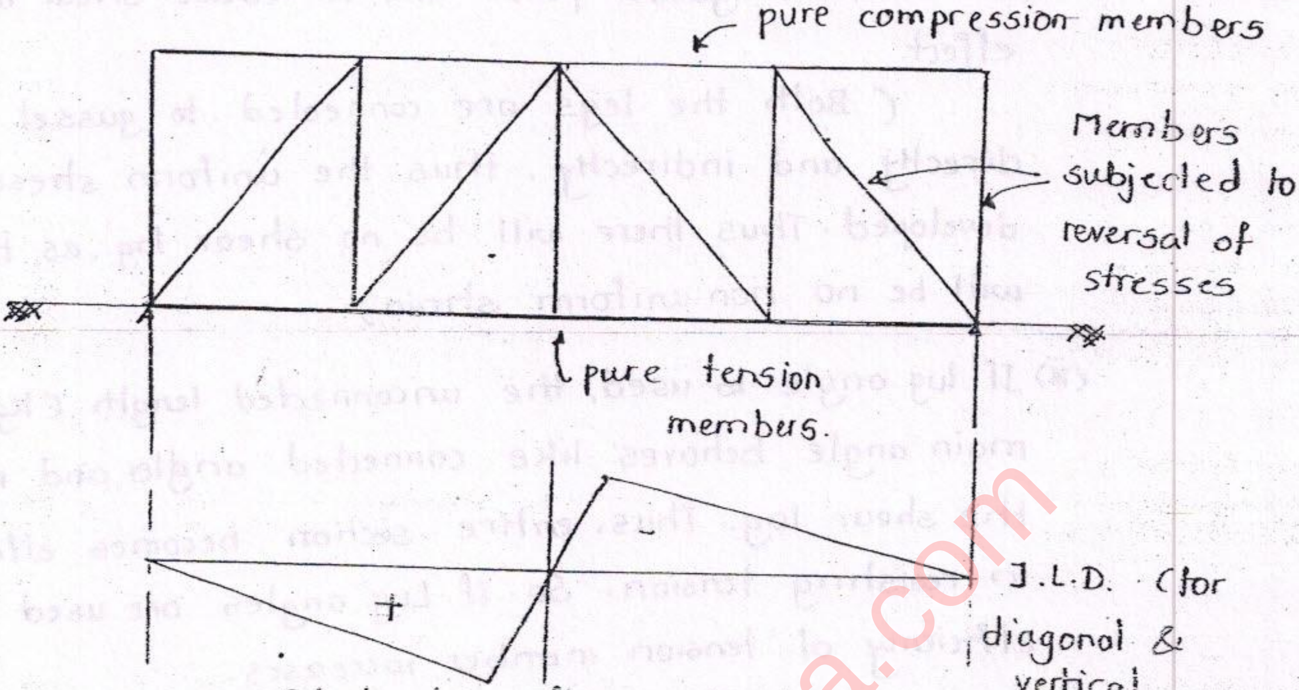
(iii) If lug angle is used, the unconnected length (leg) of main angle behaves like connected angle and reduce the shear lag. Thus, entire section becomes effective in resisting tension. So if Lug angles are used the efficiency of tension member increases.





(iv) As long as action and reaction pass through C.G. of c/s, tensile and compressive stress distribution over that c/s are uniform. So strain is also uniform.

(5) Maximum slenderness ratio for tension members.



(behaviour after application of unit moving load)

(i) In simply supported truss, all bottom members are subjected to tension (for all position of moving loads) so they are called pure tension members.

(ii) Top members are always subjected to compression and they are called pure compression members.

(iii) The diagonal and vertical members are subjected to tension and compression depending on position of loading. So these members are subjected reversal of stresses.

(iv) Maximum slenderness ratio for a pure tension member is 400 (high value because, there is no possibility of buckling in these members).

If a tension member is subjected to reversal of stress max. slenderness ratio is 180. (less value because of the possibility of buckling due to compression)

(v) For a tension member subjected to reversal of stresses in roof trusses, the maximum slenderness ratio is

(λ) 350.

(6) Load carrying capacity of tension member:

ⓐ Safe load carrying capacity.

$$P_t = \sigma_{at} \cdot A_{net} \quad \text{(in WSM)}$$

where.

σ_{at} - permissible tensile stress $= 0.6 f_y$.

A_{net} - net effective c/s area.

ⓑ load carrying capacity.

$$P_t = A_g \times \left(\frac{f_y}{1.1}\right) \quad \text{(in LSM)}$$

(if yielding decides the strength

or

$$P_t = A_{net} \times \left(\frac{0.9 f_u}{1.25}\right) \quad \text{(in LSM)}$$

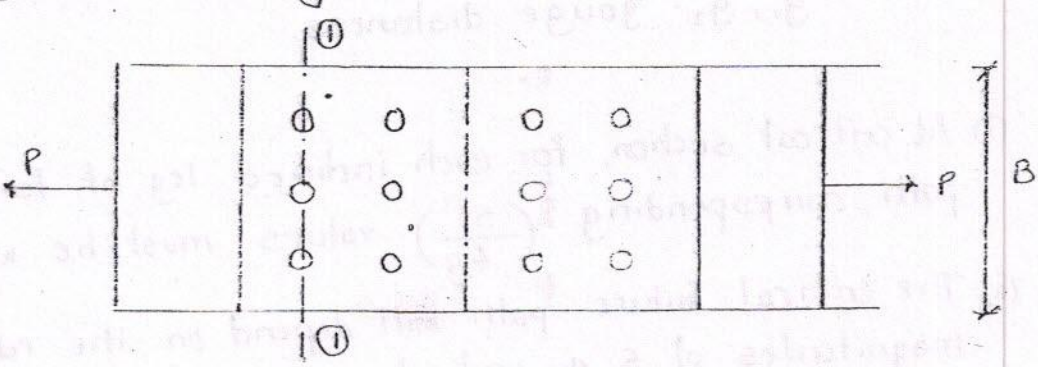
(if cracking decides strength)

The lesser value of the above two is taken as the tensile strength of the member.

(7) Calculation of A_{net}:

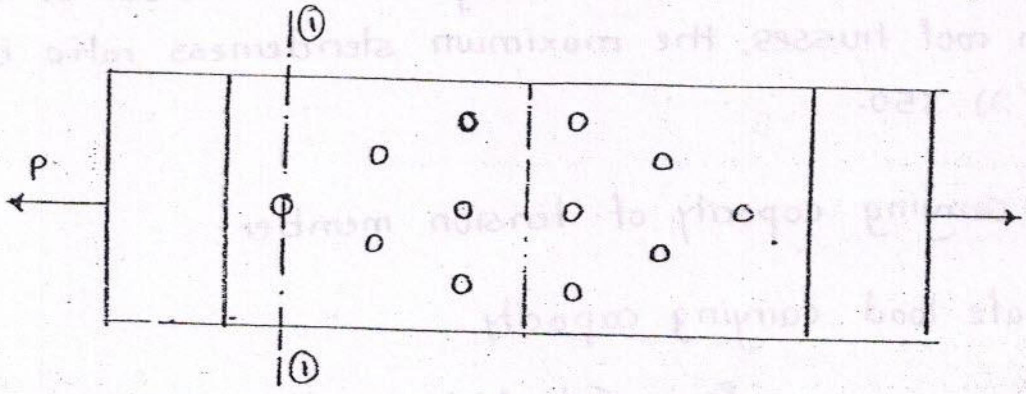
(1) For plate:

ⓐ Chain riveting:



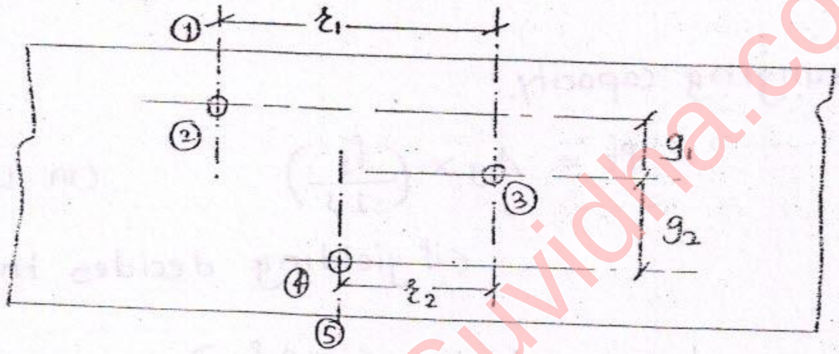
A_{net} @ ①-① $= (B - 3d) \cdot t$

(b) Diamond riveting :



A_{net} @ (1)-(1) = $(B-d).t$.

(c) Staggered riveting :



A_{net} along any critical path (1), (2), (3) (4) (5).

$$= \left[B - n_1 . d + \frac{s_1^2}{4 g_1} + \frac{s_2^2}{4 g_2} \right] t$$

$$- \left(\frac{s^2}{4g} \text{ rule - empirical formula} \right)$$

where,

n_1 - no. of rivets along critical section.

s_1, s_2 - staggered pitches.

g_1, g_2 - gauge distances.

Note:

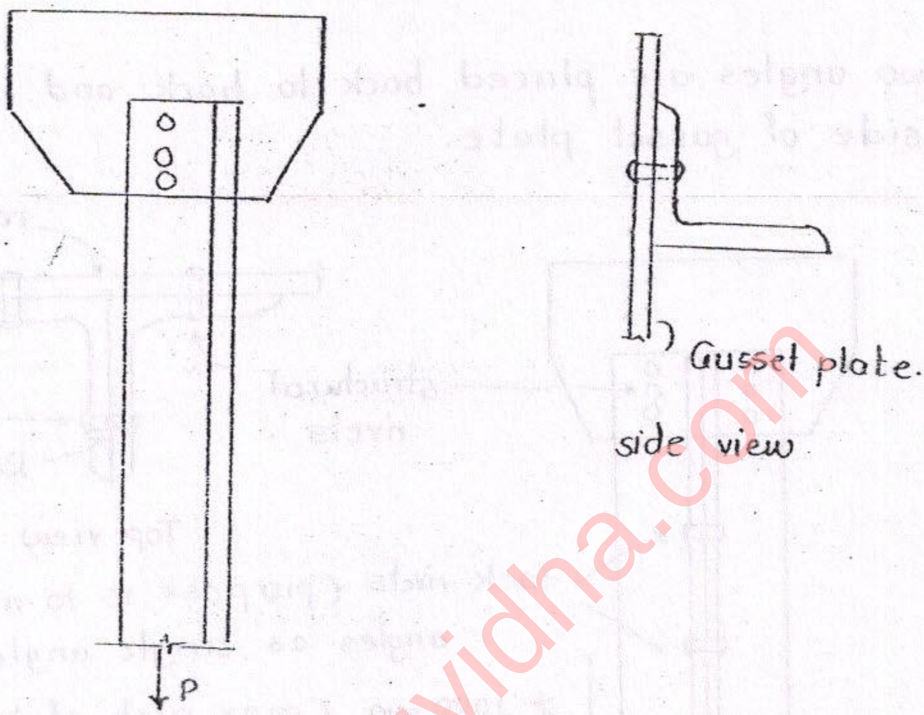
(i) At critical section, for each inclined leg of failure path, corresponding $\left(\frac{s^2}{4g}\right)$ values must be written.

(ii) The critical failure path will depend on the relative magnitudes of s, g, and d. (hole diameter)

Monday
14th October 2013

(II) Anet for angles

(i) If single angle tension member is connected to gusset plat



$$A_{net} = A_1 + k \cdot A_2$$

where
$$k = \frac{3A_1}{3A_1 + A_2}$$

A_1 - net area of connected leg.
= gross area of connected leg - area of rivet holes

A_2 - gross area of unconnected or outstand leg.

Note:

(i) K is factor used to take care of shear lag effect which is produced due to eccentricity of connection.

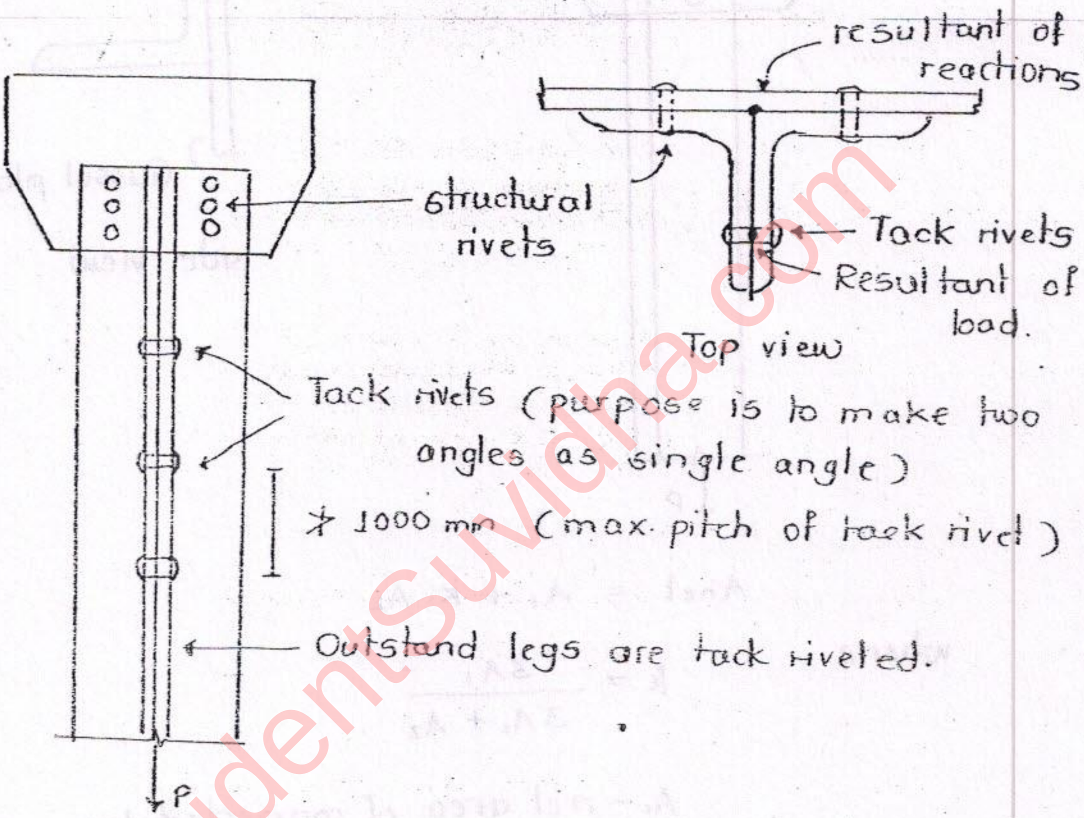
(ii) If lug angle is used to connect single angle to gusset plate then k is taken as 1 so that.

$$A_{net} = A_1 + A_2$$

= cross section area of angle - Area of rivet holes

(ii) A_{net} is called net effective c/s area because we deducted area of holes in the connected leg and factor k is used for unconnected leg to find the effective area of unconnected leg.

(2) If two angles are placed back to back and connected to one side of gusset plate.



$$A_{net} = A_1 + K \cdot A_2$$

where

$$k = \frac{5A_1}{5A_1 + A_2}$$

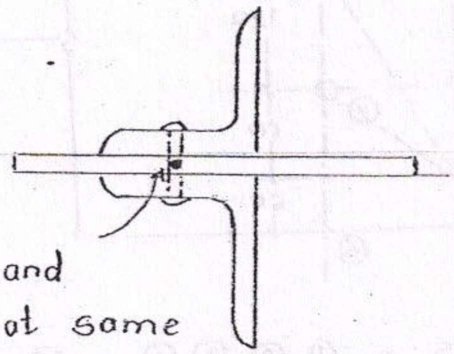
Note:

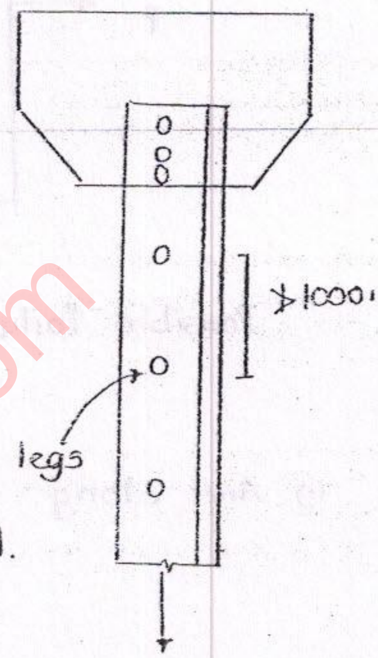
(i) In this case the effect of shear lag is less, because the line of action of resultant load and resultant reaction is relatively less. So the factor k is more.

(ii) If tack rivets are not provided along there lengths each angle will behave independently. and the factor k is $\left(\frac{3A_1}{3A_1 + A_2}\right)$ is considered for calculating A_{net}.

(3) If two angles are placed back to back and connected to both sides of gusset plate.

It is the most efficient way of connecting. Thus the load carrying capacity is maximum.



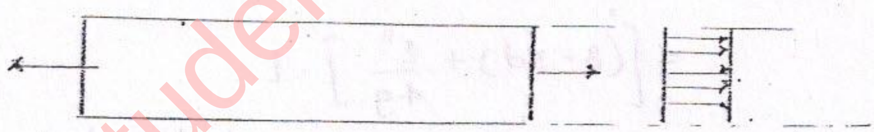


C.G. of angle and connection are at same location. So no eccentricity. No shear lag.

$$A_{net} = A_1 + A_2$$

$$= \text{Gross area of angles} - \text{area of rivet holes.}$$

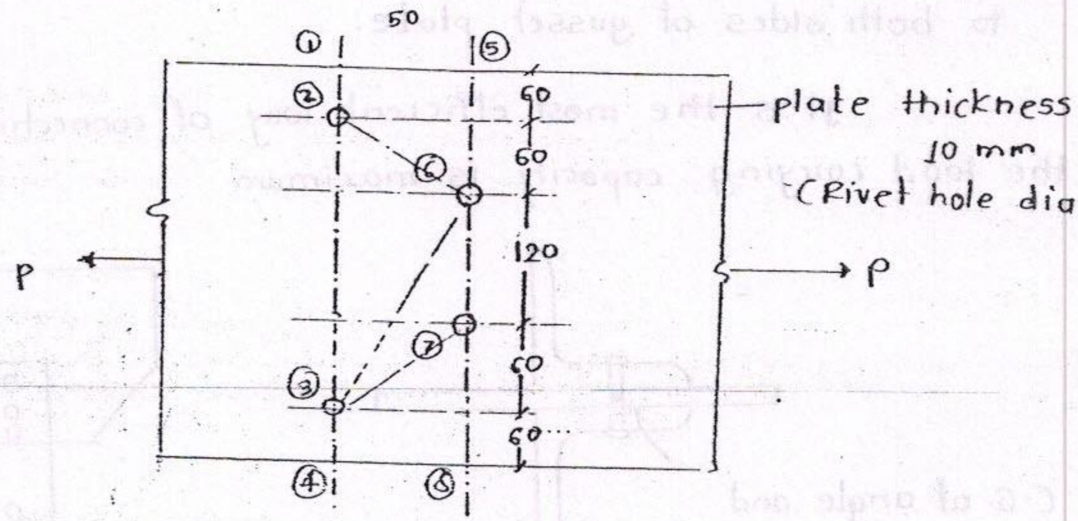
$\therefore\ k = 1$



Note:

In this case also if two angles are not tack riveted then each angle behaves independently and factor k is $\left(\frac{3A_1}{3A_1 + A_2}\right)$ is considered for each angle to calculate A_{net}

Q. Find the Anet for the [illegible] shown in fig



Possible failure paths - ①.②③④ , ⑤.⑥⑦.⑧ are same so ⑤⑥⑦⑧ need not be checked.

(i) Anet along: ①②③④

$= (B - 2d) \times t$

$= (360 - 2\times22) \times 10$

$= 3160\ mm^2$

(No. of inclined paths = 0
Rivet holes = 2)

(ii) Anet along ①②⑥⑦⑧

$= \left[(B - 3d) + \frac{s^2}{4g}\right] \cdot t$

$= \left[(360 - 3\times22) \times \frac{50^2}{4\times60}\right] \times 10$

$= 3044 \cdot 16\ mm^2$

Inclined legs = 1
$s_1 = 50$, $g = 60$
rivet holes = 3

(iii) Anet along ①②⑥③④

$= \left[(360 - 3\times22) + \frac{50^2}{4\times60} + \frac{50^2}{4\times180}\right] \times 10$

$= 3078\ mm^2$

Inclined legs = 2
Rivet holes = 3
$s_1 = 50$, $g_1 = 60$
$s_2 = 50$, $g_2 = 180$

(iv) A_{net} along ① ② ⑥ ⑦ ③ ④

$$= \left[(360 - 4 \times 22) + \frac{50^2}{4 \times 60} + \frac{50^2}{4 \times 60} \right] \times 10$$

$= 2928 \text{ mm}^2$

Inclined legs = 2

Rivets holes = 4.

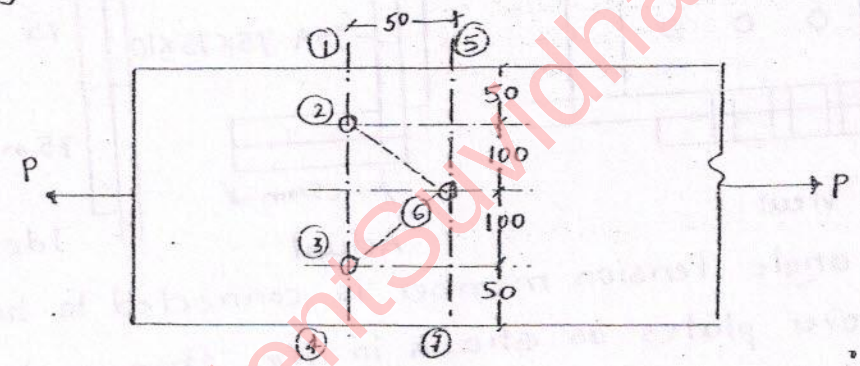
$s_1 = 50$. $g_1 = 60$

$s_2 = 50$. $g_2 = 60$.

So correct failure path for the plate is ① ② ⑥ ⑦ ③ ④

correct $A_{net} = 2928 \text{ mm}^2$

Q. What is the net effective width of the plate shown in fig. carrying tension.



hole dia = 25 mm

Possible failure paths.

① ② ③ ④ – 2 rivet holes.

⑤ ⑥ ⑦ - 1 rivet hole

① ② ⑥ ⑦ - 2 rivet holes. 1 inclined leg. ($\frac{s^2}{4g}$ extra

① ② ⑥ ③ ④ - 3 rivet holes. 2 inclined legs

B_{net} along ① ② ③ ④

$= B - 2d$

$= 300 - 2(25)$

$= 250$ mm

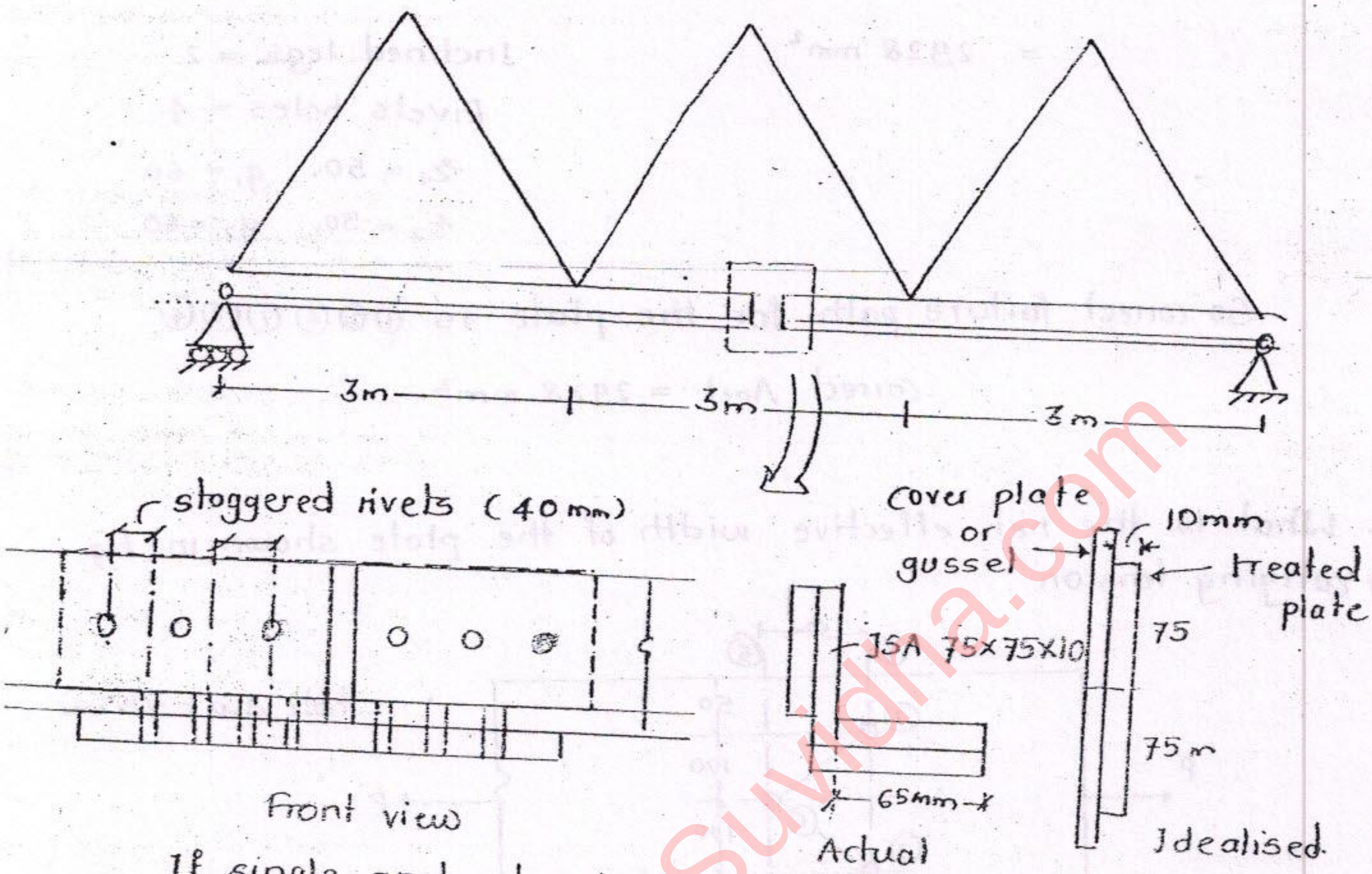
B_{net} along ① ② ⑥ ③ ④

$$= (300 - 3 \times 25) + \frac{50^2}{4 \times 100} + \frac{50^2}{4 \times 100}$$

$= 237.5$ mm

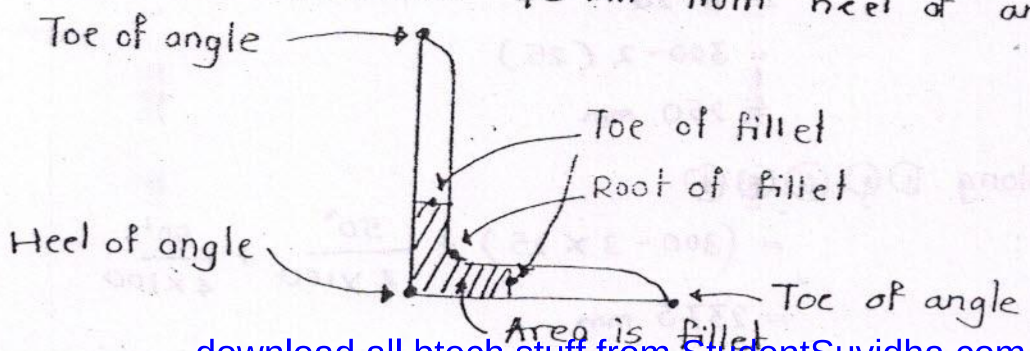
So minimum B_{net} = 237.5 mm

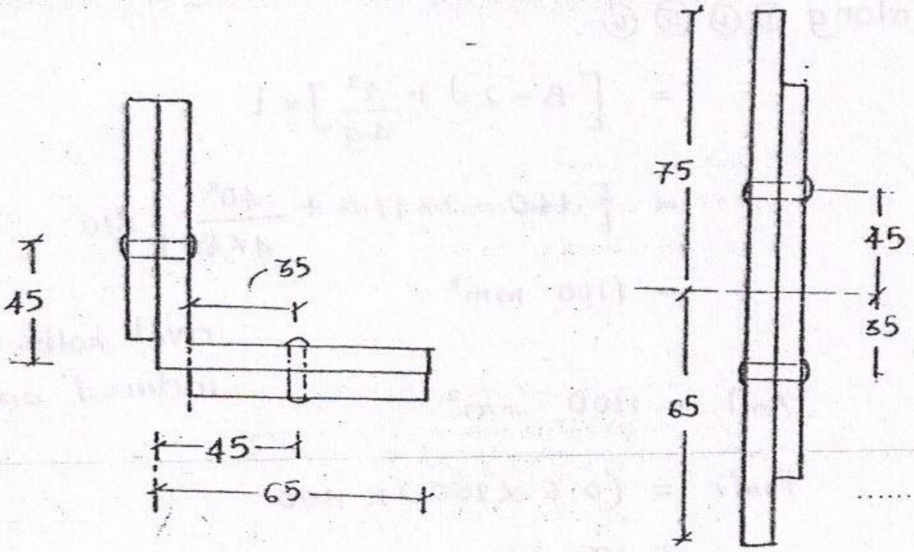
Note :

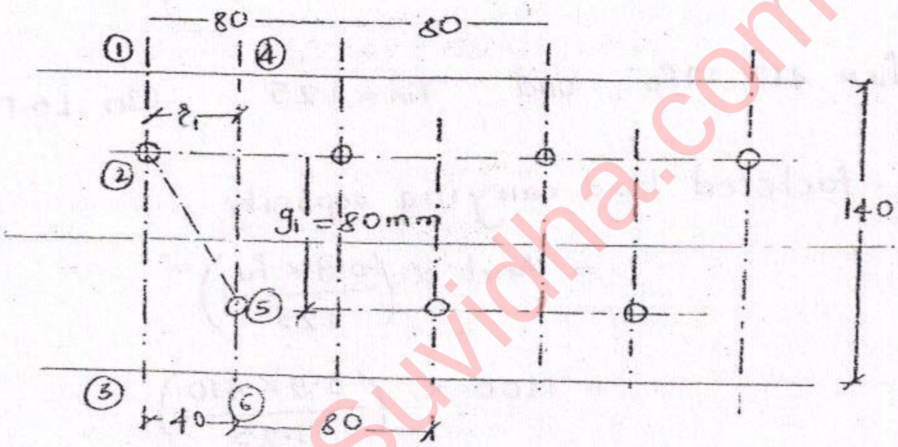


If single angle tension member is connected to two gussel plates or cover plates as shown in fig. then angle section can be treated as a plate and net width is calculated by taking $\left(\frac{s^2}{4g}\right)$ rule.

Q. An ISA 75×75×10 is connected to two cover plate by 16 mm dia. rivet through both legs. The pitch of each rivet is 80 and rivets in one leg are staggered by 40 mm w.r.t. other. Find Load carrying capacity of angle. The rivets are connected at a distance 45 mm from heel of angle.







Since both legs are connected legs, angle section can be treated as plate section as shown in fig.

Analysis :

($\phi = 16mm$ $\therefore d = 17.5\ mm$)

Tension carrying capacity of angle .

$P_t = \sigma_{at} \times A_{net}$ $\sigma_{at} = 0.6 f_y$

A_{net} :

A_{net} along ① ② ③ .

$= (B - d) \cdot t$

$= (140 - 17.5) \times 10$

$= 1225\ mm^2$

A_{net} along ① ② ⑤ ⑥.

$$= \left[B - 2d + \frac{s^2}{4g}\right] \times t$$

$$= \left[140 - 2 \times 17.5 + \frac{40^2}{4 \times 80}\right] \times 10$$

$$= 1100 \ mm^2$$

rivet holes = 2
inclined angle leg - 1.

$\therefore$ $A_{net} = 1100 \ mm^2$

$\therefore$ $P_{safe} = (0.6 \times 250) \times 1100$

$= 165$ kN

If $f_u = 410$ MPa and $\gamma_m = 1.25$ (In LS.M.)

P_u - factored load carrying capacity

$$= A_{net} \times \left(\frac{0.9 \times f_u}{1.25}\right)$$

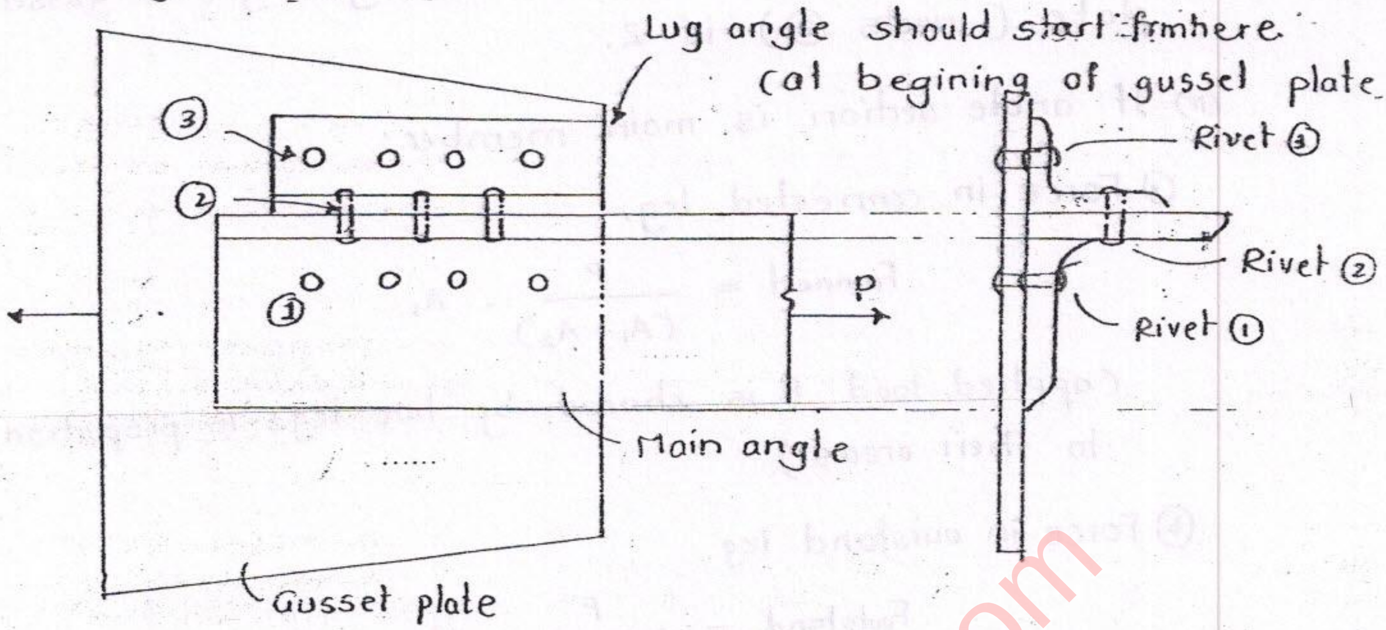
$$= 1100 \times \left(\frac{0.9 \times 410}{1.25}\right)$$

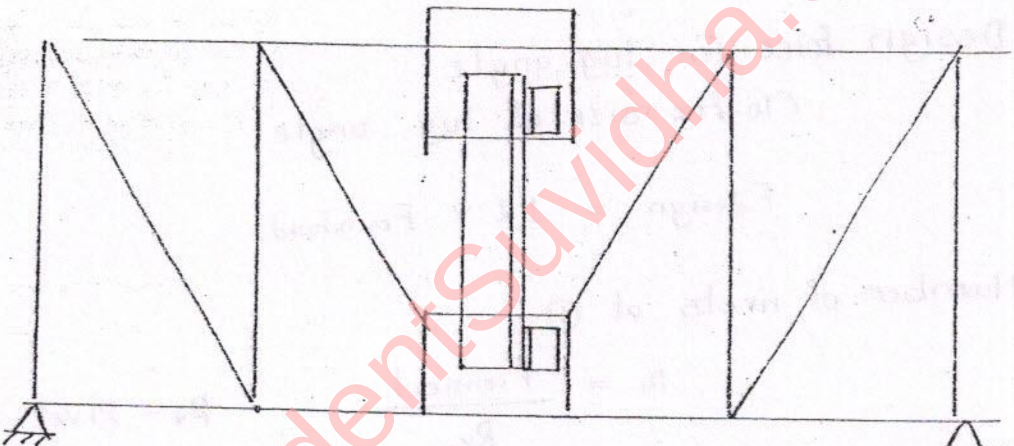
$= 325$ kN

Safe load or working load $= \dfrac{325}{1.5}$ ← As in concrete structures.

$= 216.7$ kN.

Design of Lug angle :





Rivet ① - Rivets connecting main angle and gusset plate

Rivet ② - Rivets connecting outstand leg of main angle and lug angle

Rivet ③ - Rivets connecting lug angle and gusset plate.

(i) Since lug angle is used the Anet for main angle and lug angle.

$$A_{net} = A_1 + A_2 \qquad (k = 1)$$

* (ii) The rivets connecting outstand leg of main angle and lug angle (Rivets ②.) should start in advance of all other rivets. To ensure that outstand leg of main angle transfers load

(iii) Minimum no. of rivets to connect lug angle to gussel plate (rivets ③) is 2.

(iv) If angle section is main member:

ⓐ Force in connected leg.

$$F_{connect} = \frac{P}{(A_1 + A_2)} \cdot A_1$$

(applied load P is shared by two legs in proportion to their areas)

ⓑ Force in outstand leg.

$$F_{outstand} = \frac{P}{(A_1 + A_2)} \cdot A_2$$

ⓒ Design force for lug angle:

(To fix size of lug angle

$$F_{design} = 1.2 \times F_{outstand}$$

ⓓ Number of rivets at ①.

$$n_1 = \frac{F_{connect}}{R_v}$$ R_v - Rivet value.

ⓔ Number of rivets at ②

$$n_2 = \frac{1.4 \times F_{outstand}}{R_v}$$

ⓕ Number of rivets at ③

$$n_3 = \frac{1.2 \times F_{outstand}}{R_v}$$

Q. ISA 100 × 70 ×10 is used as tension member with longer leg connected to 10 mm thick gusset plate. The connection is made with the help of Lug angle. Design the connection and sketch the rivet details. Use 20 mm dia. rivets. Take $f_t = 150$ MPa. $f_s = 100$ MPa. $f_b = 300$ MPa. Sections available for lug angle are.

(a) ISA 60 × 60 × 8 ($A_g = 896\ mm^2$)

(b) ISA 60 × 60 ×10 ($A_g = 1100\ mm^2$)

(c) ISA 70 × 70 × 8 ($A_g = 1200\ mm^2$)

(i) Always longer leg is connected to gusset plate because they are most effective in transferring the tension. Due to shear log effect. outstand legs are less effective in transferring the tension. So shorter legs are kept as an outstand.

(ii) Design of lug angle means fixing the size of lug angle and finding the number of rivets required at locations ①, ② and ③.

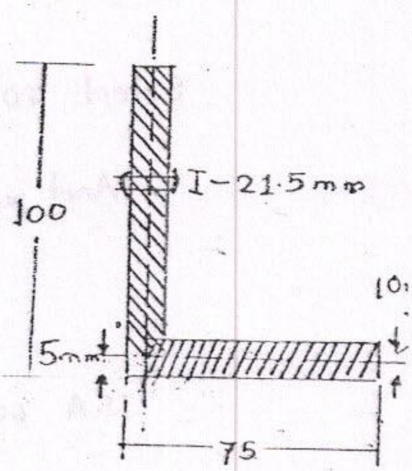
Analysis:

(Finding $F_{connect}$, $F_{outstand}$)

If P is given it will be shared by two legs. otherwise find load carrying capacity of angle.

$$P_{safe} = \sigma_{at} \times A_{net}$$

$$A_{net} = A_1 + A_2 \text{ (due to lug angle)}$$



$\phi = 20$ mm $d = 21.5$ mm

$$A_1 = (100-5-21.5) \times 10$$

$$= 735\ mm^2$$

A_2 - gross area

$$= (75-5) \times 10 = 700\ mm^2$$

$$A_{net} = A_1 + A_2$$
$$= 735 + 700$$
$$= 1435 \text{ mm}^2$$

$$\therefore P_{safe} = 150 \times 1435$$
$$= 215.25 \text{ kN.}$$

$$F_{connect} = \frac{P}{A_1 + A_2} \times A_1$$
$$= \frac{215.25}{1435} \times 735$$
$$= 110.25 \text{ kN}$$

$$F_{outstand} = 215.25 - 110.25$$
$$= 105 \text{ kN}$$

(ii) Design:

(fix size of lug angle, find n_1, n_2, n_3)

ⓐ Size of lug angle:

It is designed for a force of $(1.2 \times F_{outstand})$

$$\therefore A_{net \text{ requird}} = \frac{1.2 \times F_{outstand}}{\sigma_{at}}$$
$$= \frac{1.2 \times 105 \times 10^3}{150}$$
$$= 840 \text{ mm}^2$$

Select $60 \times 60 \times 8$ $(A_g - 896 \text{ mm}^2)$

$$A_{net \text{ provided}} = A_g - \text{area of rivet hole}$$
$$= 896 - (21.5 \times 8)$$
$$= 724 \text{ mm}^2 \quad (< 840 \text{ mm}^2)$$

$\therefore$ ISA $60 \times 60 \times 8$ is unsafe as lug angle

Select ISA $60 \times 60 \times 10$ ($A_g = 1100 \; mm^2$)

$$A_{net} \text{ provided} = 1100 - (21.5 \times 10)$$
$$= 885 > (840)$$

Hence ISA $60 \times 60 \times 10$ can be provided as Lug angle.

ⓑ No. of rivets at ①, ②, ③.

Rivet value :

Rivets at all locations are subjected to single shear.

$$P_s = \frac{\pi}{4} \times d^2 \times f_s$$
$$= \frac{\pi}{4} \times 21.5^2 \times 100$$
$$= 36.3 \; kN$$

$$P_b = d \times t \times f_b$$
$$= 21.5 \times 10 \times 300$$
$$= 64.5 \; kN.$$

∴ Rivet value. $(R_v) = P_s = 36.3 \; kN$

∴ No. of rivets at ①,

$$n_1 = \frac{F_{connect}}{R_v}$$
$$= \frac{110.25 \; kN}{36.3} = 3.04 \simeq 4 \text{ rivets}$$

No. of rivets at ②

$$n_2 = \frac{1.4 \times F_{outstand}}{R_v}$$
$$= \frac{1.4 \times 105}{36.3} = 4.05 \simeq 5 \text{ rivets}$$

No. of rivets at ③

$$n_3 = \frac{1.2 \times 105}{36.3} = 3.44 \simeq 4 \text{ rivets}$$

(iii) Arrangement of rivets.

Min. pitch $= 2.5\,\phi = 2.5 \times 20 = 50$ mm

Min. end distance $= 1.5\, d = 1.5 \times 21.5 = 32.25$

$\simeq 35$ mm

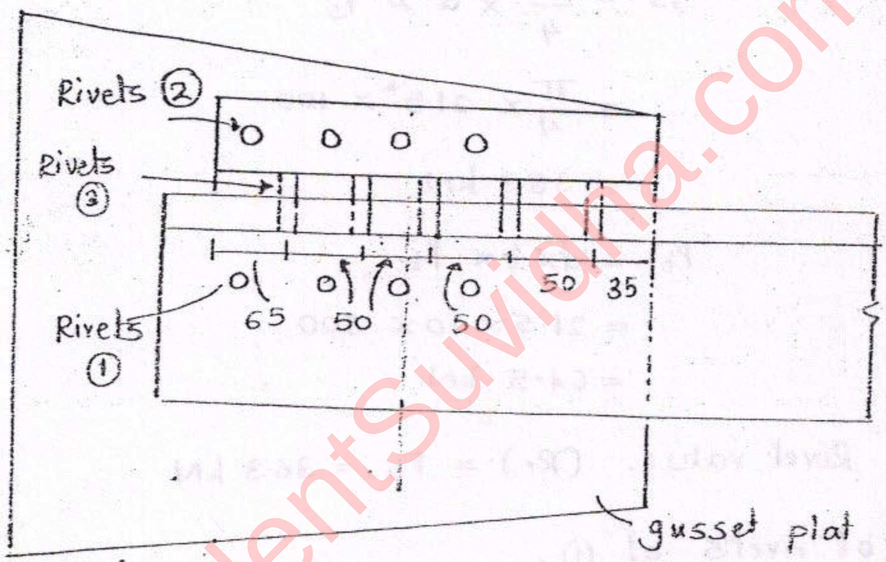
So length of lug angle

$= 4 \times 50 + 2 \times 35$

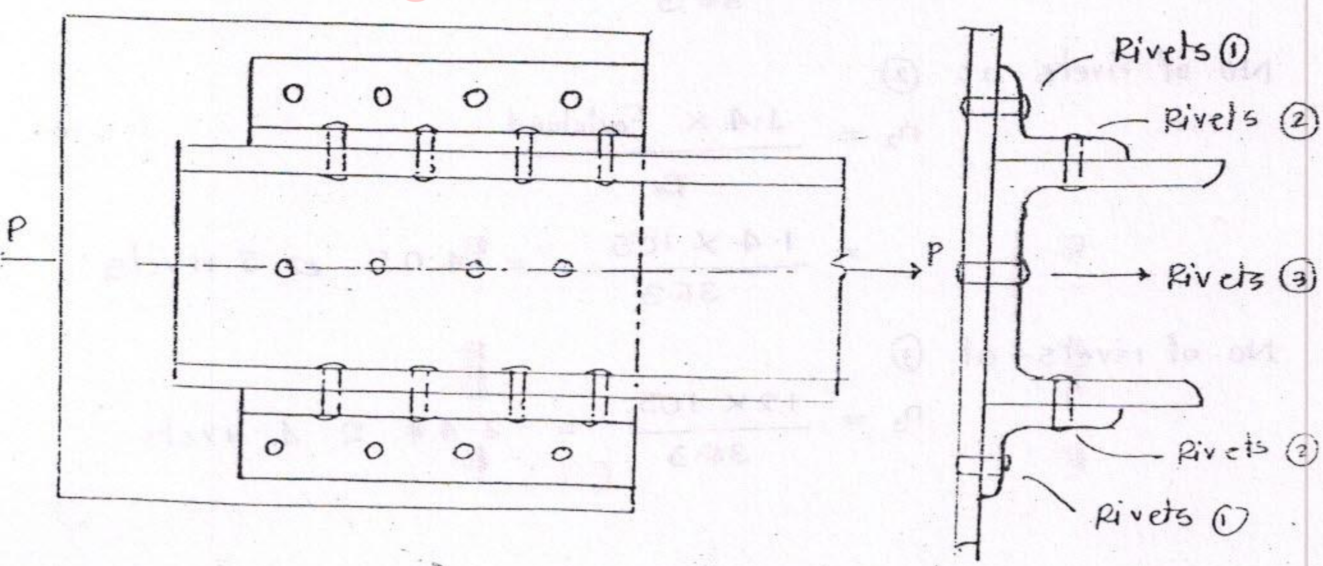
$= 270$ mm.

∴ Provide length of lug angle $= 300$ mm

(to accomodate staggering of rivets)



(v) If Channel section is used as Main member:



(i) Two lug angles are used and they should be kept symmetrical w.r.t. centreline of channel section.

(ii)
$$F_{connect} = \frac{P}{A_1 + A_2 + A_3} \times A_1$$

where. A_1 - net area of connected leg.

A_2, A_3 - gross area of each outstand leg.

(iii)
$$F_{outstand} = \frac{P}{A_1 + A_2 + A_3} \times (A_2 \text{ or } A_3)$$

(iv)
$$F_{design} = 1.1 \times F_{outstand}$$

(v) No. of rivets at ①

$$n_1 = \frac{1.1 \times F_{outstand}}{R_v}$$

At ②

$$n_2 = \frac{1.2 \times F_{outstand}}{R_v}$$

At ③

$$n_3 = \frac{F_{connect}}{R_v}.$$

Design of tension member:

P and σ_{at} are given we have to fix the size of meml

Procedure:

(i) To find $(A_{net})_{reqd.} = \frac{P}{\sigma_{at}}$

Increase Anet by 40-50% to get $(A_g)_{reqd.}$

(to take care of rivet holes and k-factor)

Increase Anet by 20% (approximately) to get (A_g)..

(to take care of k-factor only i.e. when welding is done)

(ii) Select a suitable section from a given set and find number of rivets required

If

$$(A_{net})_{provided} > (A_{net})_{required}$$

– design is safe.

(iii) Check slenderness ratio. (λ)

Q. A single angle tie (tension member) in a welded steel truss in a shed is required to be designed for an axial tension of 50 kN. If σ_{at} = 150 MPa. Most suitable section is

Marks

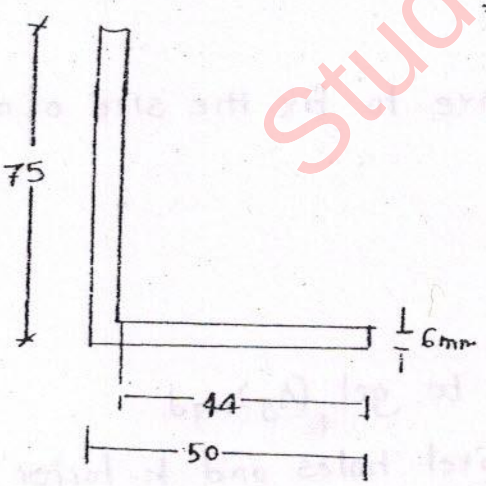
a) ISA 75 × 50 × 6 b) ISA 60 × 40 × 5

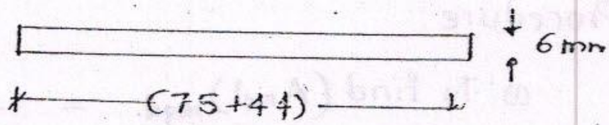
(c) ISA 50 × 30 × 4 (d) ISA 45 × 30 × 5

$$(A_{net})_{reqd} = \frac{P}{\sigma_{at}}$$

$$= \frac{50 \times 10^3}{150}$$

$$= 333.33 \text{ mm}^2$$





For ISA 75 × 50 × 6

$\therefore A_g = (75 \times 44 \times 6) = 720 \text{ mm}^2$

for ISA 60 × 40 × 5 = $A_g = (60 \times 35 \times 5) = 475 \text{ mm}^2$

for ISA 50 × 30 × 4 = $A_g = (50 \times 26 \times 4) = 304 \text{ mm}^2$

for ISA 45 × 30 × 5 $A_g = (45 \times 25 \times 5) = 350 \text{ mm}^2$

Take ISA 60×40×5 $(A_g = 475\ mm^2)$

Increase by 20% to get A_g

$\therefore A_g = 1.2 \times 333$

$= 400 < (A_g)$ provided $= 475\ mm^2$

OK.

Tuesday
15th October 2013

Q. Design a single angle tension member for a roof truss to carry a pull of 100 kN. The member is subjected to possible reversal of stresses due to action of wind. The length of member between c/c connections is 3.5 m. Take $f_y = 250$ MPa. Available sections are.

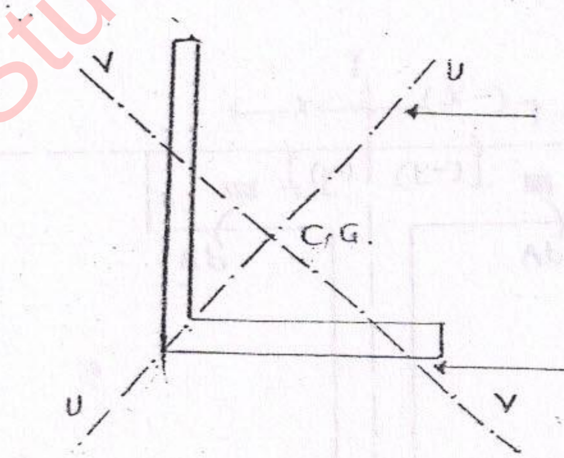
(i) ISA 75×50×8 $(A_g = 936\ mm^2,\ r_{uu} = 23.5\ mm,\ r_{vv} = 14\ mm)$

(ii) ISA 100×100×10 $(A_g = 1900\ mm^2)$

Note:

(i) Principal axes:

These are the axes about which product of inertia is zero and M.I. is minimum and maximum.

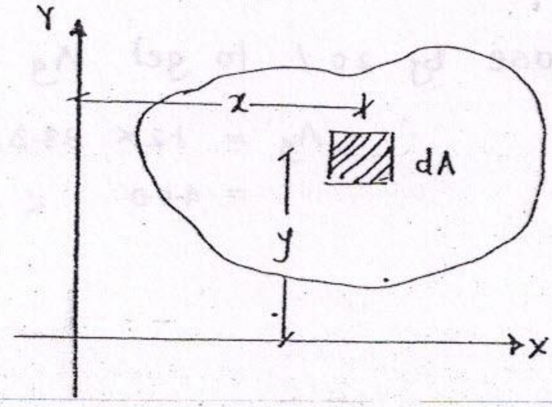


I_{uv} - product of inertia $= 0$

I_{uu} - maximum M.I. . r_{uu} is max.

I_{vv} - minimum M.I. . r_{vv} is min

(ii) Product of inertia :



$y \cdot dA$ is called First moment of area

$y^2 \cdot dA$ is called Second moment of area

$$J_{xx} = M.I. = \int y^2 \cdot dA$$

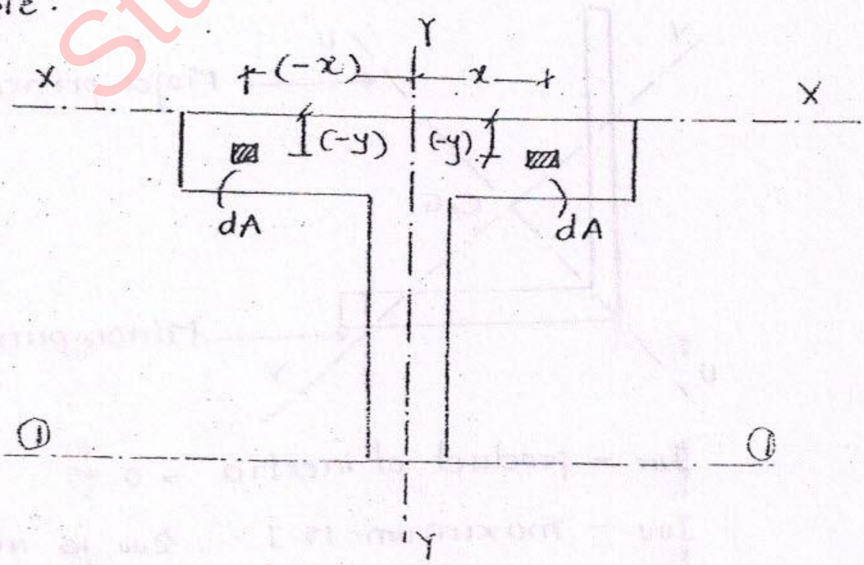
∴ $x \cdot y \cdot dA$ is called Product of inertia.

$$J_{xx} = P.I. = \int x \cdot y \cdot dA.$$

(iii) Moment of inertia is always a positive quantity but product of inertia can be positive or negative or zero, depending on the position of the area w.r.t. XY axes

(iv) Product of inertia of an area w.r.t a symmetric axis and any other perpendicular axis is always zero.

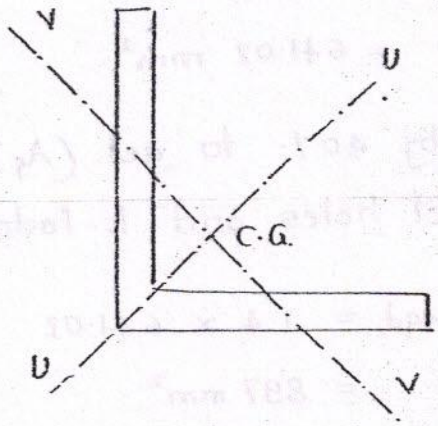
Example :



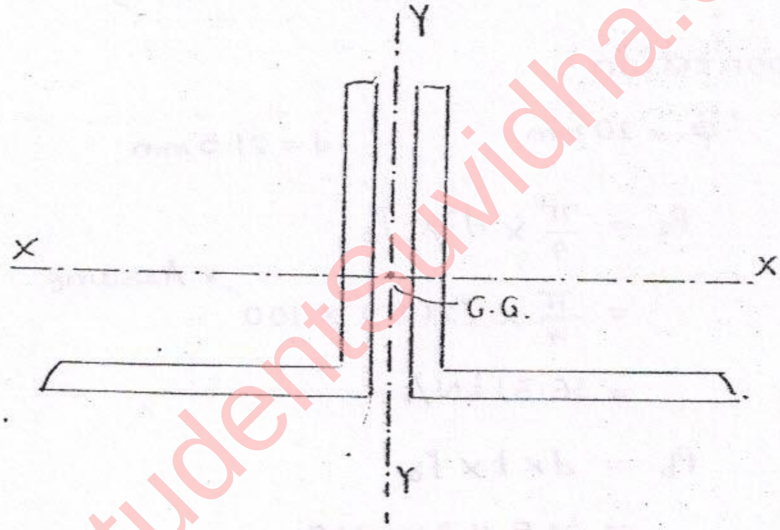
$$J_{XY} = dA(-x)(-y) + dA(x)(-y) = 0$$

$$J_{XY} = I_{1\text{-}Y} = 0$$

(v) With the symmetric axis and perpendicular axis passing through C.G. of section. Then the axes are called principal axes.



For single angle section, U and V are Principal axes.



For double angle section, X and Y are principal axes. (Y-Y is axis of symmetry)

$\therefore$ $I_{XY} = 0$

I_{XX} is minimum. r_{xx} is minimum

I_{YY} is maximum, r_{YY} is maximum.

(i) $(A_{net})_{reqd.}$

$$= \frac{P}{\sigma_{at}}$$

$$= \frac{100 \times 10^3}{0.6 \times 260}$$

$$= 641.02 \ mm^2$$

Increase A_{net} by 40% to get $(A_g)_{reqd}$. (for rivet holes and k-factor)

$\therefore$ $(A_g)_{reqd} = 1.4 \times 641.02$

$$= 897 \ mm^2$$

$\therefore$ Select ISA 75 × 50 × 8 ($A_g = 936 \ mm^2$)

(ii) Design of connection:

$\phi = 20 \ mm$ $\therefore$ $d = 21.5 \ mm$

$$P_s = \frac{\pi}{4} \times d^2 \times P_s$$

$$= \frac{\pi}{4} \times (21.5)^2 \times 100 \quad \rightarrow \text{Assume}$$

$$= 36.31 \ kN/r$$

$$P_b = d \times t \times f_b$$

$$= 21.5 \times 8 \times 300$$

$$=$$

$\therefore$ Rivet value, $R_v = P_s = 36.31 \ kN$

$\therefore$ No. of rivets required $= \frac{P}{R_v} = \frac{100 \times 10^3}{36.31 \times 10^3} = 2.71 \approx 3$

(iii) $(A_{net})_{provided}$:

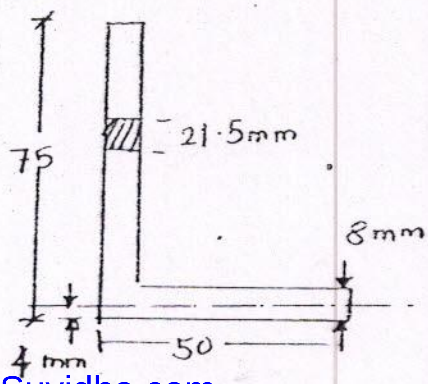
$$A_{net} = A_1 + k.A_2$$

$$A_1 = (75 - 4 - 21.5) \times 8$$

$$= 396 \ mm^2$$

$$A_2 = (50 - 4) \times 8$$

$$= 368 \ mm^2$$



$$k = \frac{3A_1}{3A_1 + A_2}$$

$$= \frac{3(396)}{3(396) + 368}$$

$$= 0.76.$$

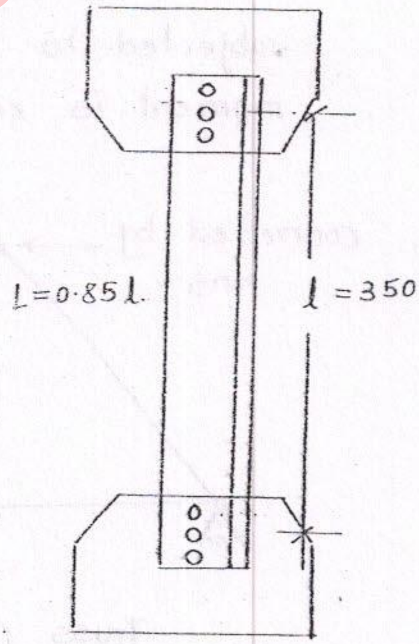
$$\therefore \quad (A_{net})_{provided} = 396 + 0.76\,(368)$$

$$= 675.56 \text{ mm}^2 \quad (> 641.02 \text{ mm}^2)$$

Hence ISA 75×50×8 is safe as required angle section

(iv) Check slenderness ratio :

$$\lambda = \frac{L}{r_{min}} \not> 350$$



Effective length,

$$L = 0.85\, l$$

$$= 0.85 \times 3500$$

$$= 2975 \text{ mm}$$

$$r_{min} = \text{Minimum of } r_{uu} \,\&\, r_{vv}$$

$$= 14 \text{ mm}$$

$$\lambda = \frac{2975}{14}$$

$$= 212.5 \not> 350$$

Hence safe.

Note :

(i) If angle section is connected by more than one rivet or welds, effective length of member is

$$L = 0.85\, l.$$

(ii) Effective length of a member is the distance between points of zero moments.