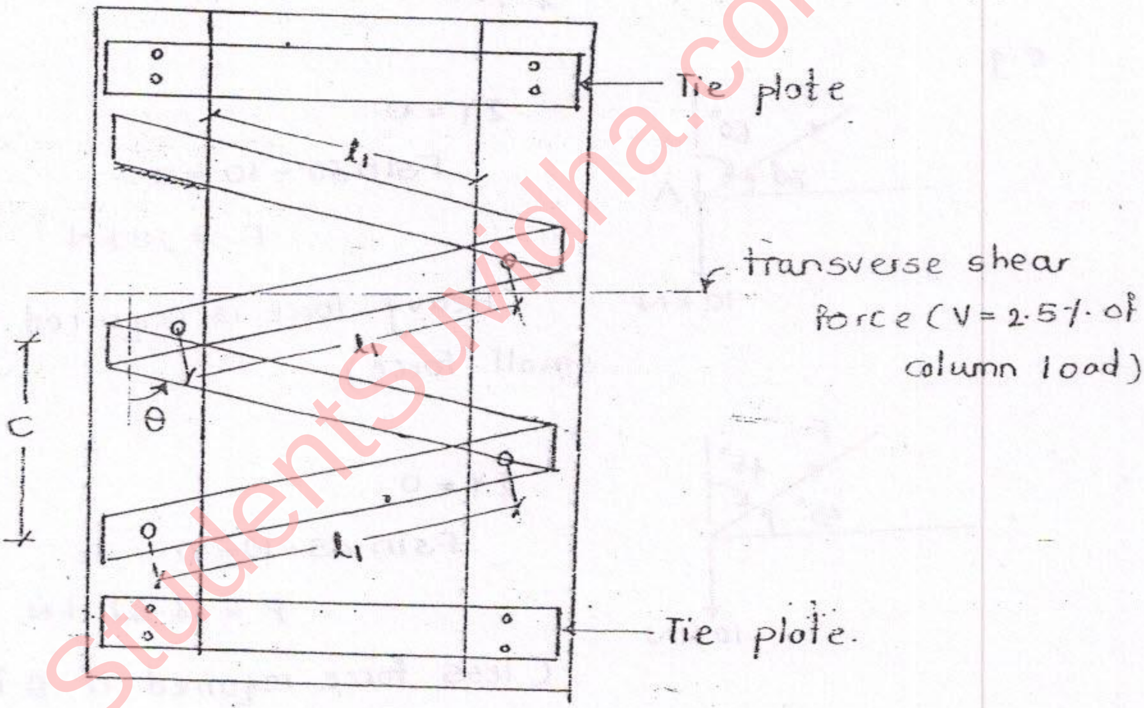
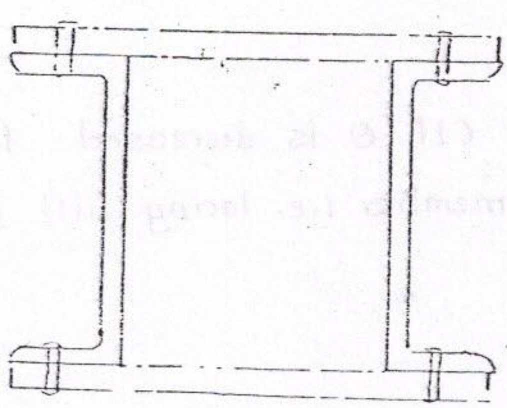
Design of Lacing :

Lacing is system of connecting elements in built up column. Lacing makes the components of a column act as a single unit.

If the components of column are very close to each other then tack rivets are used to make them act as a single unit. If the spacing of components is more, then tack rivets are useless. So we use lacing or battening ......

(inclined member - lacing; horizontal member - batten)





(ii) Lacing members are idealised as truss elements i.e. they are subjected to either tension or compression only. BM. in lacing members is zero. To ensure that B.M. is zero in lacing member, provide only one rivet at each end as far as possible.

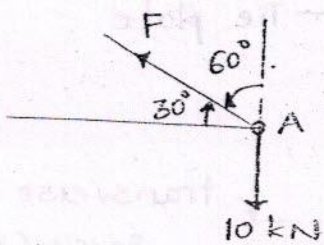
(iii) Maximum slenderness ratio for lacing member is limited to 145. (less value is taken because the length of the lacing member is very less)

(iv) The angle of lacing with respect to vertical (θ) is

$\theta \nless 40^\circ$

$\ngtr 70^\circ$.

e.g.

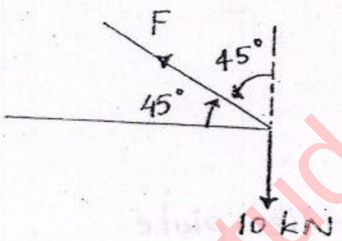


$\Sigma Y = 0$

$F \sin 30 - 10 = 0$

$F = 20\ kN$

(Heavy force is required to balance small force)



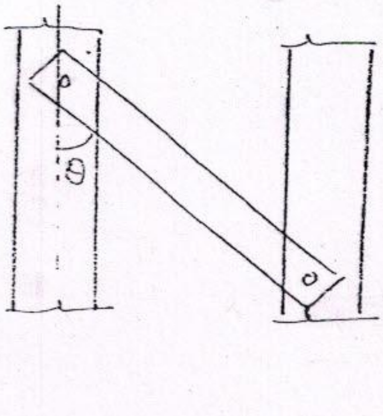
$\Sigma Y = 0$

$F \sin 45 - 10 = 0$

$F = 14.41\ kN$

(less force required if θ is reduced)

$\therefore$ If θ (with vertical) increase F required to balance the load, increases.



(If θ is decreased length of the member i.e. lacing will be increased)

So, if θ is greater than $70°$, force in lacing member will be very high and it may buckle due to excessive compressive force. If θ is less than $40°$, then length of lacing member will be more and lacing member may buckle. Thus,

$$\theta \nless 40° \quad \text{(as per IS code)}$$
$$\ngtr 70°$$

(v) Length of the lacing member (l_1) is taken as the distance between inner ends of rivets or welds as shown in fig.

(vi) Effective length of lacing member:

$$L_{eff} = l_1 \text{, for single lacing}$$
$$= 0.7 \cdot l_1 \text{, for double lacing}$$
$$= 0.7\, l_1 \text{, for welded lacing.}$$

(vii) Width of lacing bar:

It depends on the nominal diameter of rivet provided.

Nominal dia. of rivet (ϕ)	Min. width of lacing bar (mm)
16	50
18	55
20	60
22	65

So, minimum width of lacing member $\simeq$ 3 × nominal dia (ϕ)

(viii) Thickness of lacing member:

$$t_{min} = \frac{l_1}{40} \text{, for single lacing}$$

$$t_{min} = \frac{l_1}{60} \text{, for double lacing.}$$

(ix) If there is possibility of buckling of the column component between lacing connections, then increase angle θ upto $70°$, to reduce the value of 'C'. (spacing of lacing). If there is possibility of buckling even after providing $\theta = 70°$, then double lacing is provided. to prevent buckling of column components between the connections.

(x) To prevent buckling of the column components between lacing connections, the following codal provision should be satisfied.

$$(\lambda)_{component} \ngtr 50$$

$$\ngtr 0.7 \cdot (\lambda)_{column}$$

For tack riveting

$$(\lambda)_{component} \ngtr 40$$

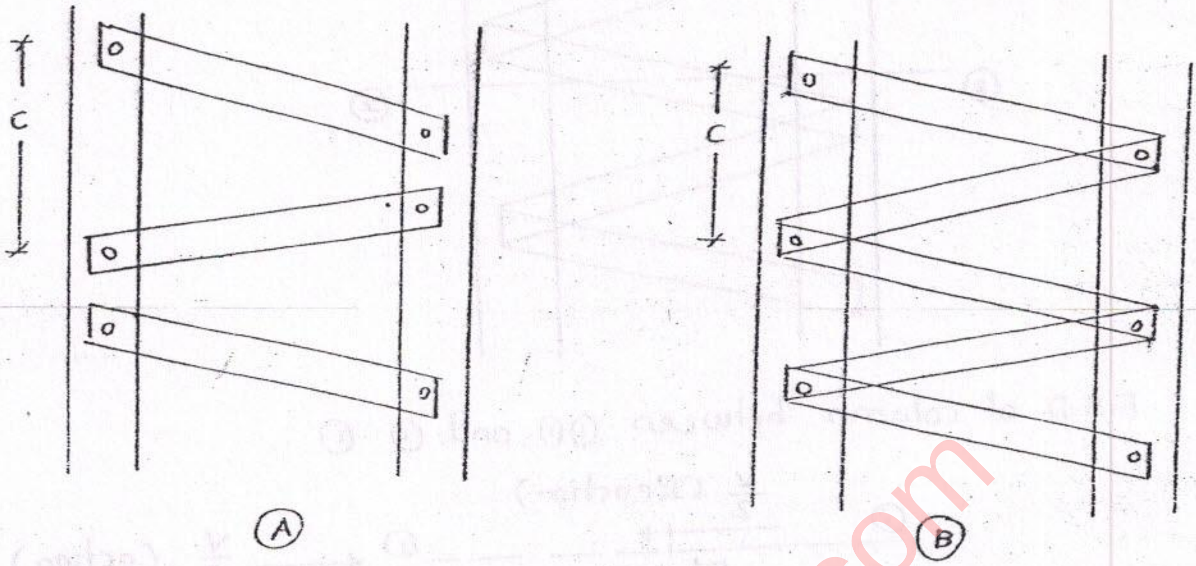
$$\ngtr 0.6 \, (\lambda)_{column}$$

(xi) Lacing system should not vary throughout the length of the column i.e. width, thickness, angle of lacing, of lacing should be same throughout the length of column. (so that analysis will be simple)

(xii) The lacing system on opposite sides of main components should be mirror image of other (so that analysis will be simple).

(xiii) At the ends of lacing system, at top and bottom, tie plates are provided (also called Batten plates). These batten plates are tie plates used to prevent distortion of built-up column cross section.

(xiv) Arrangement of lacing members.



Arrangement of lacing in (A) is better than (B) because even if one rivet fails, spacing of lacing will not change in (A) but spacing will be doubled in the arrangement (B). So there is a possibility of buckling between the connections in (B).

(xv) Forces in lacing members:

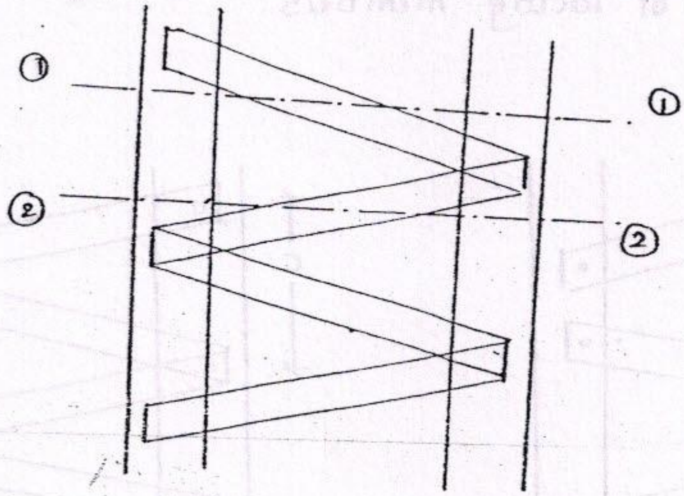
(a) Lacing system is designed to resist a transverse shear force of

$$V = 2.5\% \text{ column loads.}$$

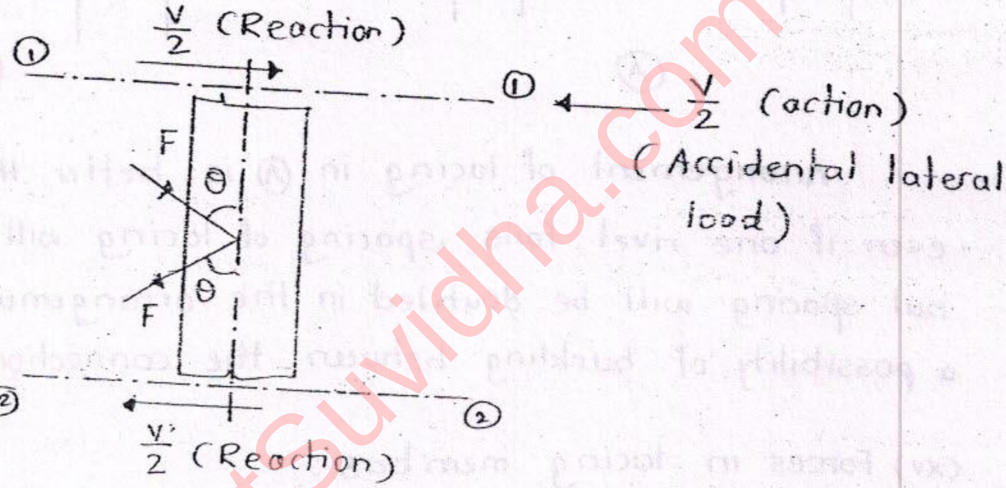
(to take care of eccentricity of axial load and moments arising due to accidental lateral loads)

(b) The transverse shear force 'V' is shared by lacing system on both sides equally. So transverse shear force on each lacing bar is $\frac{V}{2}$.

(c)



F.B.D. of column between ①① and ② -② :



What is the value of F so that its X- component is $\frac{V}{2} = ?$

At top,

$$F \sin\theta = \frac{V}{2}$$

$$F = \frac{V}{2\sin\theta} \quad \text{(compressive force)}$$

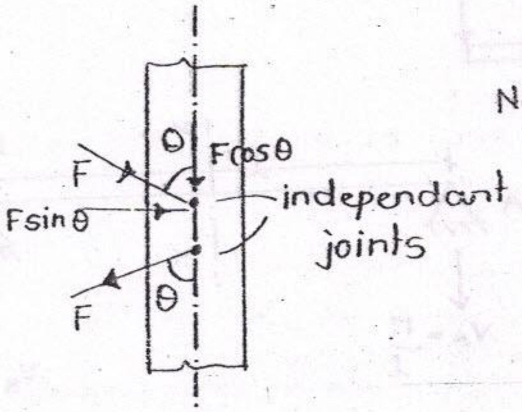
At bottom,

$$F \sin\theta = \frac{V}{2}$$

$$F = \frac{V}{2\sin\theta} \quad \text{(tensile force)}$$

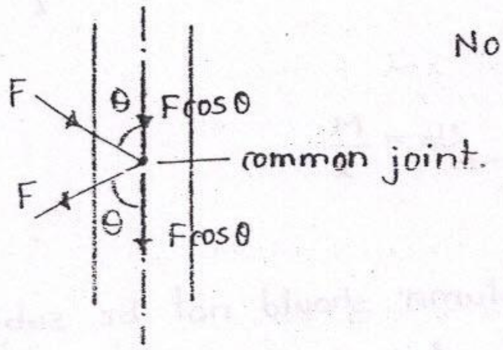
From the above free body diagram, we find that lacing members are subjected to tensile and compressive forces of $\frac{V}{2\sin\theta}$

(d) Design of connection :



No. of rivets required.

$$n = \frac{F}{R_v} \quad \because (F\cos\theta < F)$$

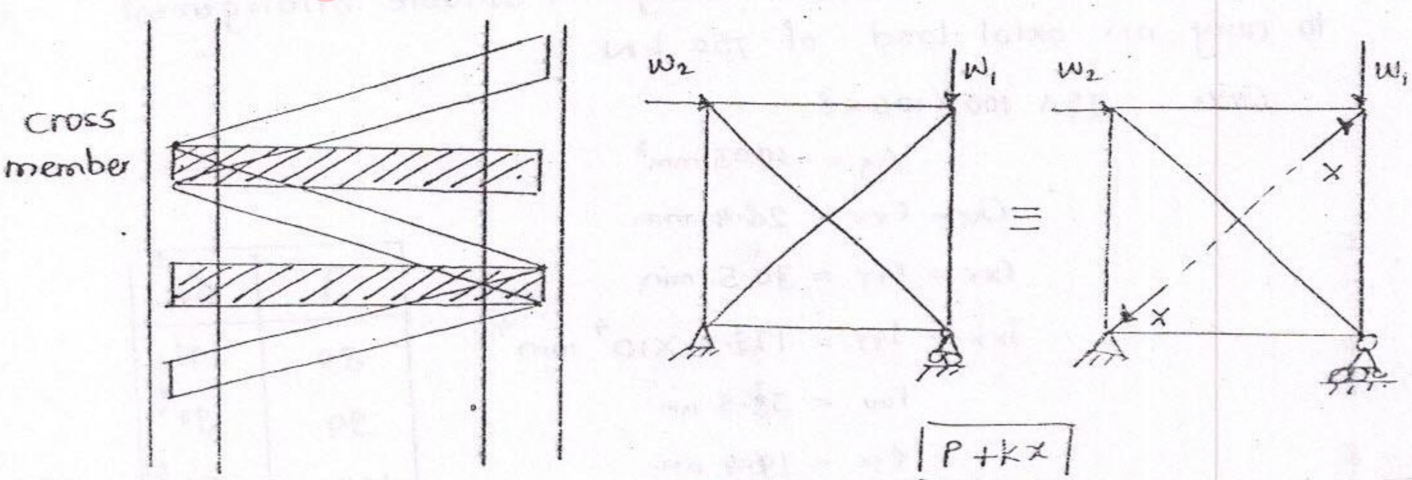


No. of rivets required

$$n = \frac{\text{Max. force} \rightarrow \text{in Y-direction}}{R_v}$$

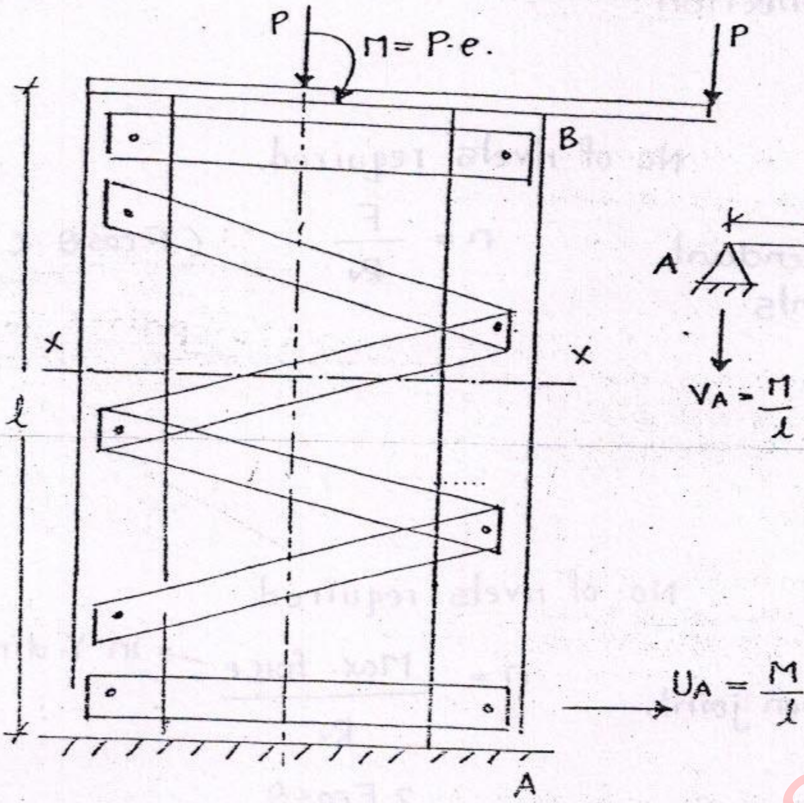
$$= \frac{2F\cos\theta}{R_v} \quad \because (2F\cos\theta > F)$$

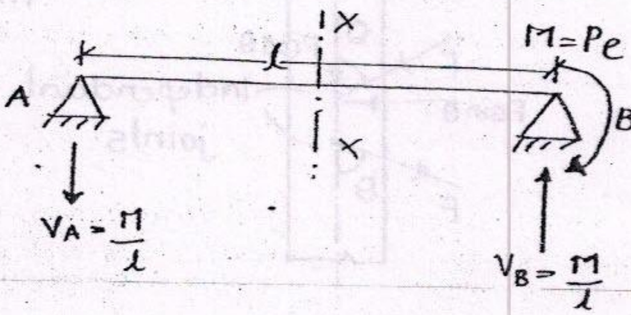
(xvi) As far as possible cross members between lacing system are avoided. Becouse if cross members are provided, the lacing system becomes a statically indeterminate structure. The cross member produces additional forces in the lacing system. Lacing members are designed for these additional forces also, if cross members are provided.



$P + kx$

(XVII)





S.F. @ XX $= -\frac{M}{l}$

As far as possible the column should not be subjected to eccentric loading in the plane of lacing. Because the lacing system must be designed for additional shear forces developed due to moment $(U_A = \frac{M}{l})$

Q. A column of length 9.4 m is effectively held in position at both ends but not restrained against rotation at one end (Fixed at one end and hinged at other end). It is constructed by using 4 ISA 100×100×8. Design a suitable arrangement to carry an axial load of 750 kN

Given ISA 100×100×8

$A_g = 1903 \text{ mm}^2$

$C_{xx} = C_{yy} = 28.4$ mm

$r_{xx} = r_{yy} = 30.5$ mm

$I_{xx} = I_{yy} = 177.0 \times 10^4 \text{ mm}^4$

$r_{uu} = 38.5$ mm

$r_{vv} = 19.4$ mm

λ	σ_{ac}
80	101
90	90
110	80

Note :-

In this problem, P and A_g are given so we don't have to assume σ_{ac}. σ_{ac} value is fixed.

(i) Axial compressive stress in column.

$$\sigma_{ac} = \frac{P}{A_g}$$

$$= \frac{750 \times 10^3}{(4 \times 1903)}$$

$$= 98.52 \ N/mm^2$$

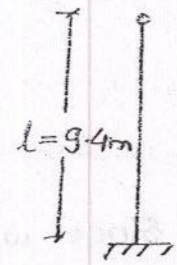
for $\sigma_{ac} = 98.52$ MPa.

$$(\lambda)_{reqd} = 80 + \frac{(101 - 98.52)}{11}(90-80)$$

$$= 82.25$$

$$(\lambda)_{reqd} = \frac{L}{r_{min}}$$

$$82.25 = \frac{0.8 \times 9.4}{r_{min}}$$



$$\therefore (r_{min})_{reqd} = \frac{0.8 \times 9.4}{82.24}$$

$L = 0.8l$

(Recommend)

$$= 91.42 \ mm$$

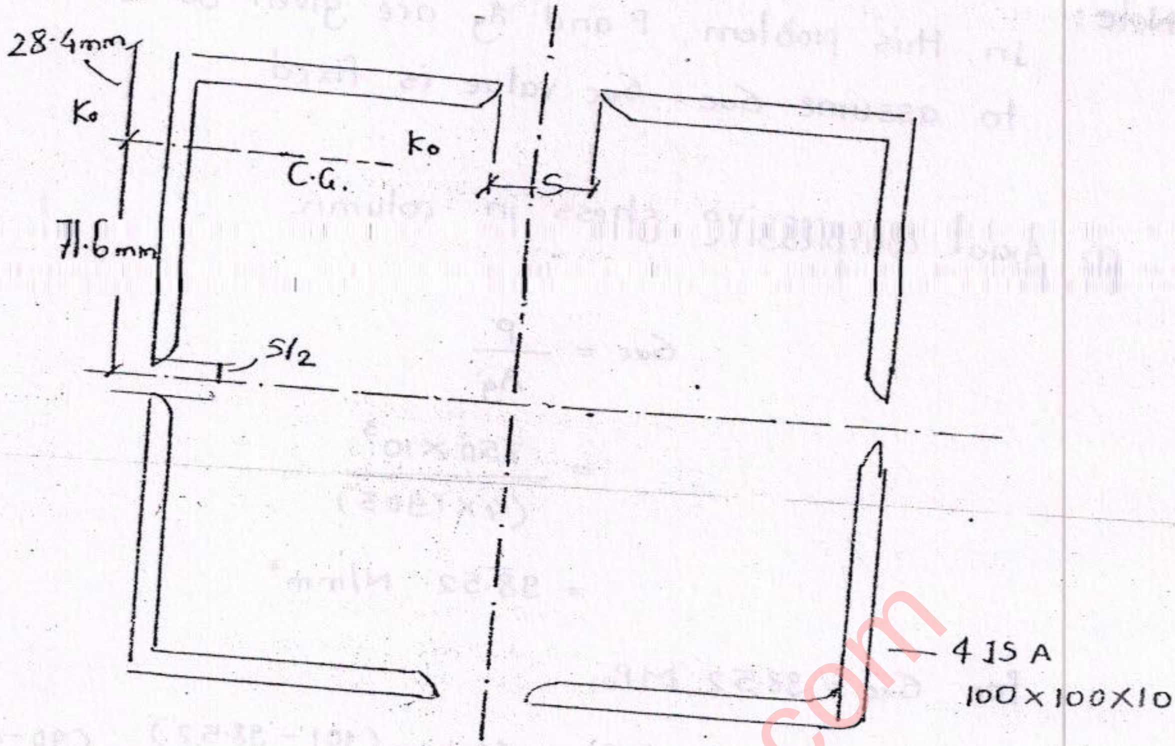
$$\therefore (r_{min}) = \sqrt{\frac{I_{min}}{A_g}}$$

$$(I_{min})_{reqd} = A_g \times (r_{min})^2$$

$$= 4 \times 1903 \times (91.42)^2$$

$$= 63.61 \times 10^6 \ mm^4$$

Note: The most efficient c/s in resisting compression is thin hollow circular section or thin box section. So arrang 4 angles in form of box.



$$(I_{min})_{provided} = 4\left[\underset{I_{k_o k_o}}{177\times10^4} + \underset{A_g}{1903}\times \underset{h^2}{(71.6)^2}\right]$$
(without any spacing)

$$= 46.1\times10^6\ mm^4 < (I_{min})_{reqd.}$$

Hence unsafe section.

Since we cannot change the angles, to increase the moment of inertia of built up column, we have to increase the spacing of angles as shown in fig.

$$(I_{min})_{reqd} = 63.61\times10^6$$

$$= 4\left[\underset{I_{k_o k_o}}{177\times10^4} + \underset{A_g}{1903}\times \underset{h}{\left(71.6+\frac{S}{2}\right)^2}\right]$$

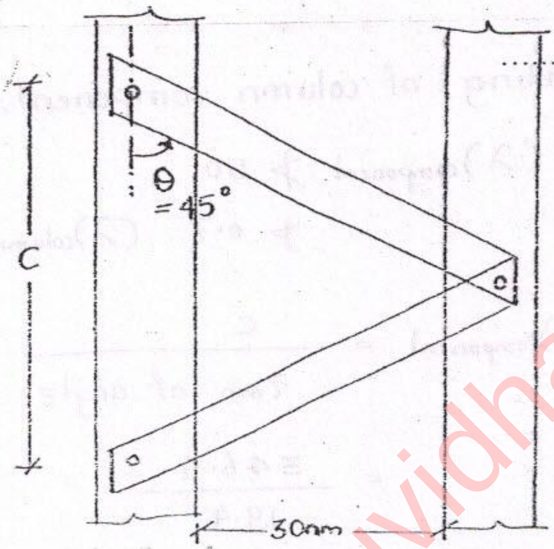
$$S = 29.15\ mm$$

So provide the spacing of $(S) = 30\,mm$ as shown in fig.

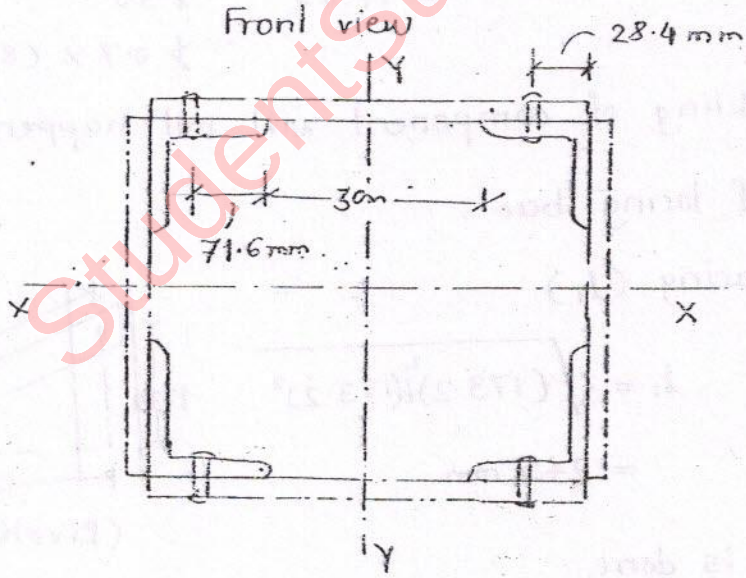
Q. In the above problem. design a suitable lacing system.

Design of lacing means finding spacing of lacing (c). dimensions of lacing. (length, width, thickness) and forces in lacing member.

(i) Spacing of Lacing (c)



Front view



Assume angle of inclination (θ = 45°) for simple calculati

Assume rivets are provided at C.G. level of angles i.e. at 28.4mm from back of angles.

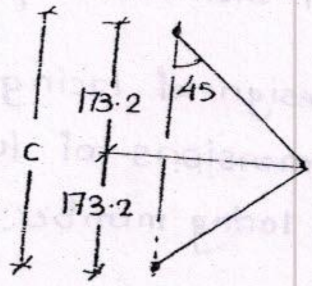
So transverse distance (horizontal distance) between rivet lines

$$= 71.6 + 71.6 + 30 = 173.2 mm$$

∴ Spacing of lacing

$C = 173.2 + 173.2$

$= 346.4$ mm



Check for buckling of column components between the connections :

To prevent buckling of column component.

$(\lambda)_{component} \not> 50$

$\not> 0.7 \ (\lambda)_{column}$

$(\lambda)_{component} = \dfrac{C}{r_{min} \text{ of angle}}$

$= \dfrac{346.4}{19.4}$

$= 17.85 \quad \not> 50$

$\not> 0.7 \times (82.25) = 57.6$

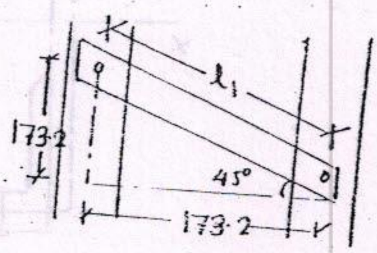
Hence buckling of component will not happen.

(ii) Dimensions of lacing bar :

ⓐ Length of lacing (l_1)

$l_1 = \sqrt{(173.2)^2 + (173.2)^2}$

$= 245$ mm

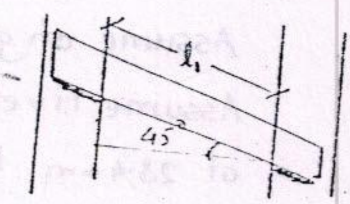


(Rivetted)

If welding is done.

$l_1 = 30\sqrt{2}$

$= 42.42$ mm



(Welded)

(b) Width of lacing bar. (b)

∴ Minimum width ≃ 3 × Nominal dia. of rivet

Assume, $\phi = 20\,mm$.

∴ Minimum width (b) = 3×20

= 60 mm.

If welding is done, assume arbitrary value of the thickness (b) = 50 mm.

(c) Thickness of lacing bar (t)

$$t_{min} = \frac{l_1}{40}$$

$$= \frac{245}{40} = 6.1\,mm$$

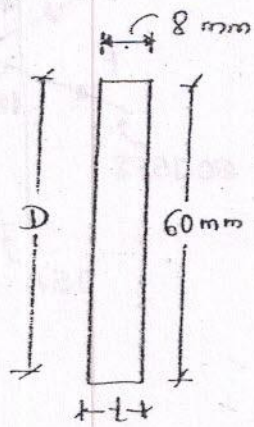
Provide thickness of lacing (t) = 8 mm

So provide 60 ISF 8 as lacing plate.

(d) Check for λ. ($\lambda \not> 145$)

$$\lambda = \frac{L}{r_{min}}$$

L = Eff. length of lacing member (l_1) = 245 mm



$$r_{min} = \sqrt{\frac{I_{min}}{A_g}}$$

$$= \sqrt{\frac{\left(\frac{Dt^3}{12}\right)}{D \cdot t}}$$

$$= \frac{t}{\sqrt{12}} = \frac{8}{\sqrt{12}}$$

$$r_{min} = 2.31\,mm$$

$$\lambda = \frac{245}{2.31} = 106.06 < 145\,mm$$

Hence safe.

Note:

If the slenderness ratio of the lacing member becomes unsafe, then increase the thickness of lacing bar.

(ii) Forces in lacing bar:

ⓐ Transverse S.F.

$$V = 2.5\ \%\ \text{of column load.}$$

$$= \frac{2.5}{100} \times 750$$

$$= 18.75\ kN$$

ⓑ The transverse S.F. is shared by 2 lacing members at any level.

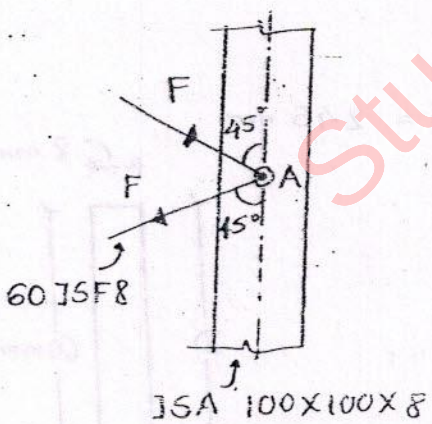
So compressive or tensile force in lacing bar

$$F = \frac{V}{2 \sin \theta}$$

$$= \frac{18.75}{2 \times \sin 45^\circ}$$

$$= 13.25\ kN$$

ⓒ No. of rivets required at connection:



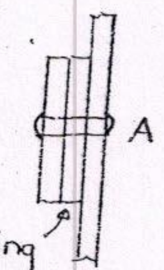
No. of rivets required,

$$n = \frac{2F \cos\theta}{R_v}$$

Rivets are in double shear.

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

$$= 72.6\ kN$$



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

$$= 21.5 \times (10) \times 300 \quad (\text{Assume})$$

$$= 64.5\ kN$$

t - sum of lacing member thickness = 8+8 = 16 mm } less
(bearing force acts in same direction for lacing bars)
or
angle thickness = 10 mm

$$R_v = P_b = 64.5 \text{ kN}$$

∴ No. of rivets required, $n = \frac{2F\cos\theta}{R_v}$

$$= \frac{2 \times 13.25 \cos 45^\circ}{64.5}$$

$$= 0.29 \simeq 1 \text{ rivet.}$$

ⓓ Check for strength of lacing bar:

(i) Tensile strength of lacing bar

$$P_t = (B-d) \cdot t \cdot f_t$$

$$= (60 - 21.5) \times 8 \times 150 \quad \text{(150 Assume.)}$$

$$= 46.2 \text{ kN} \quad > F = 13.25 \text{ kN.}$$

Hence safe.

(ii) Compressive strength of lacing member:

$$P_c = \sigma_{ac} \times A_g$$

$$= \sigma_{ac} \times (B \times t)$$

For $\lambda = 106.1$

$$\sigma_{ac} = 80 - \frac{6.1}{20}(80 - 67.1)$$

$$= 76.01 \text{ N/mm}^2$$

$$P_c = 76.01 \times (60 \times 8)$$

$$= 36.51 \text{ kN} \quad > F = 13.25 \text{ kN}$$

Hence, safe.