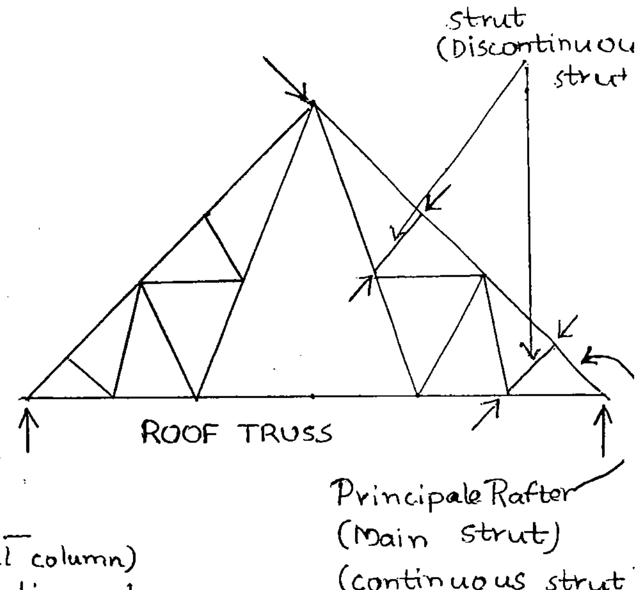
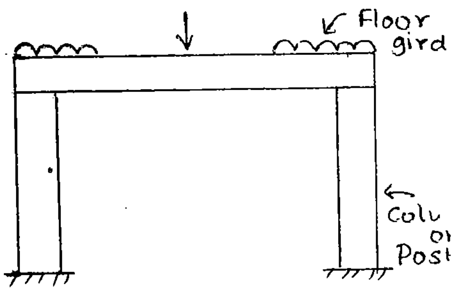
12th Sept,
FRIDAY

6. COMPRESSION MEMBERS

- Principale Rafter – normally used in roof truss as a main strut.
- Strut – generally used in roof truss (or) in a bracing system.



- Column (or) Post (or) Stanction – (steel column) used in industrial building to support floor (or) floor girders.



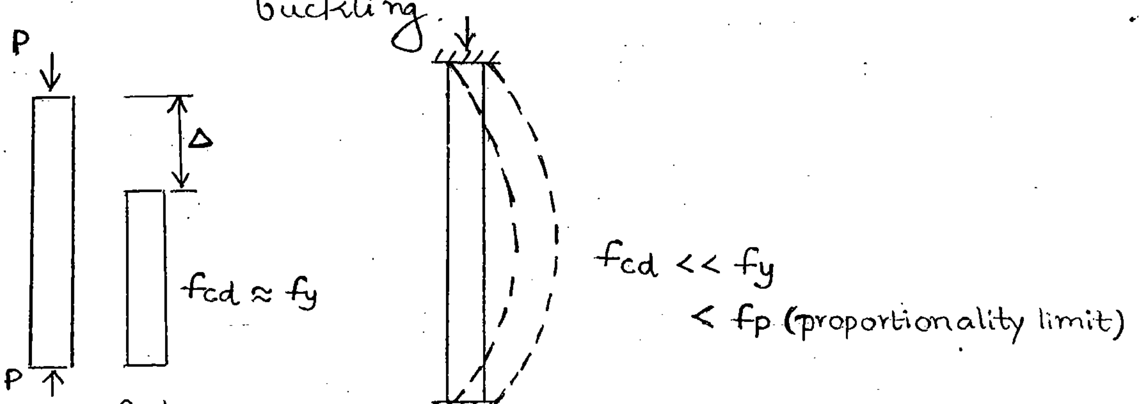
- Boom – Principle compression member in a crane system.

→ Types of Failures in a Compression Member

(i) Short Column or short strut – Normally fail by yielding or crushing of a material.

(ii) Intermediate Column or Intermediate strut – generally fail by inelastic buckling.

(iii) Long Column or Long strut – generally fail by elastic buckling.



(Yielding failure in Short Column)

(Elastic buckling failure in long column)

– Compressive strength of a column or strut is influenced by:

(i) Initial imperfection in the member (due to handling, transportation & erection).

(ii) Residual stress in the c/s (developed due to cooling from high temp while moulding to ambient temp.)

(iii) Eccentricity of loading (creating additional moments)

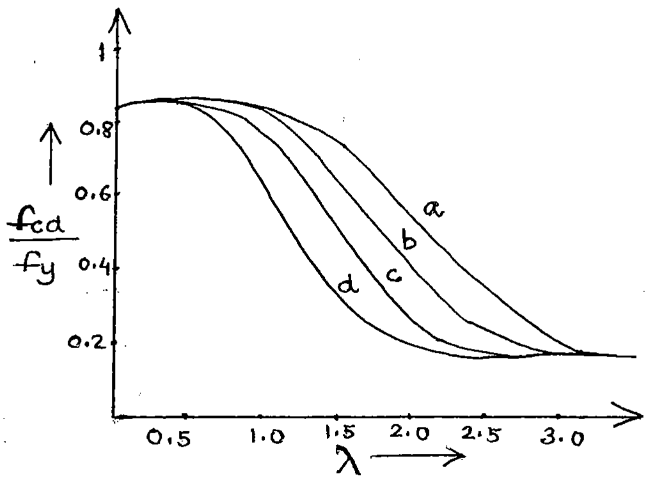
→ Design Compression Strength of a Member (P_d)

$$P_d = f_{cd} \cdot A_e$$

f_{cd} → design stress in axial compression

A_e → effective sectional area.

⊙ IS 800:2007 proposes multiple curves a, b, c & d based on PERRY ROBERTSON'S Approach.



λ = non-dimensional effective slenderness ratio.

$$\lambda = \sqrt{\frac{f_y}{f_{cc}}} = \sqrt{\frac{f_y \left(\frac{KL}{r}\right)^2}{\pi^2 E}}$$

f_{cc} = elastic buckling stress

$$= \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

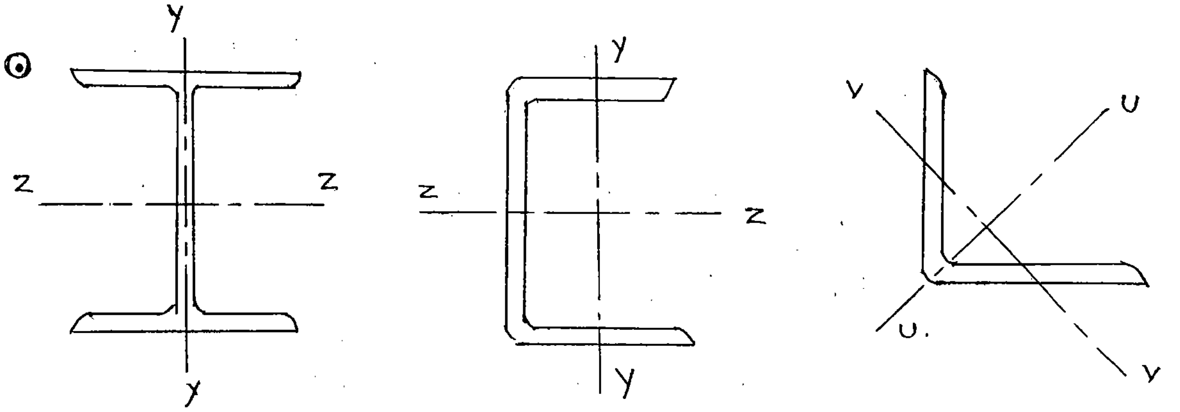
⊙ As per IS 800:1984,

$$P_d = \sigma_{ac} \cdot A_e$$

$$\sigma_{ac} = \frac{0.6 f_y f_{cc}}{\left((f_y)^n + (f_{cc})^n\right)^{1/n}} \leq 0.6 f_y$$ (MERCHENT RANKINE FORMULA)

⊙ Class a (tubular sections) members have more compressive strength compared to class c (solid circular sections). Both class a & c members are initially straight and free from eccentric loading. But residual stresses will be more in class c compared to class A as uniform cooling takes place in the interior and exterior of tubular sections.

⊙



$r_{zz} > r_{yy}$ $\quad$ $r_{zz} > r_{yy}$ $\quad$ $r_{uu} > r_{vv}$.

$$\lambda = \sqrt{\frac{f_y \left(\frac{KL}{r}\right)^2}{\pi^2 E}}$$

∴ λ will be more for bending along y-y axis. Higher λ means lower $\frac{f_{cd}}{f_y}$ value from the curve.

$$\therefore (P_d)_{z-z} > (P_d)_{y-y}.$$

Economic sections or best sections are those in which

$(P_d)_{zz} = (P_d)_{yy}$. (tubular circular sections).

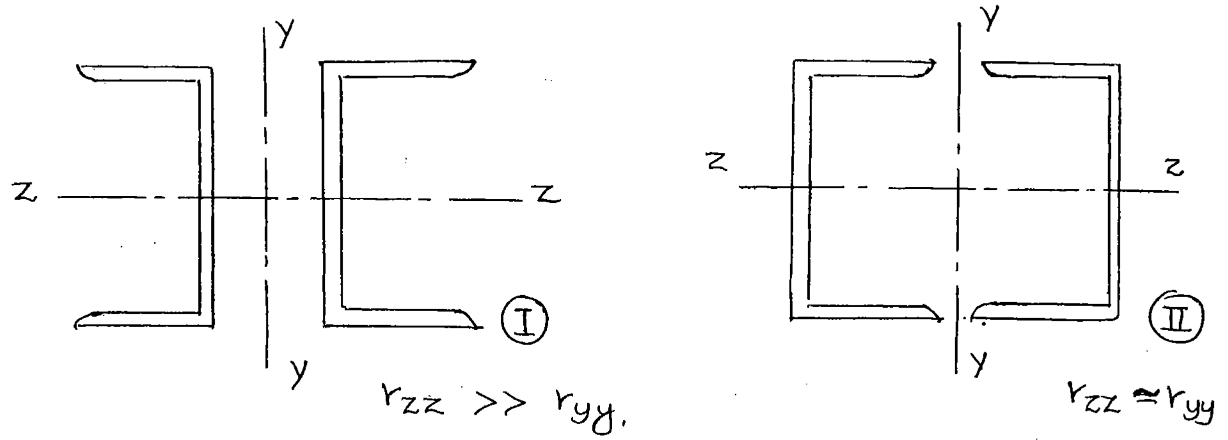
* Perry Robertson's Equation

$$f_{cd} = \frac{f_y / \gamma_{mo}}{\phi + (\phi^2 - \lambda^2)^{0.5}} \leq \frac{f_y}{\gamma_{mo}}$$

$\lambda \rightarrow$ non dimensional effective slenderness ratio $= \sqrt{\frac{f_y}{f_{cc}}}$

$$= \sqrt{\frac{f_y \left(\frac{KL}{r}\right)^2}{\pi^2 E}}$$

II^{nd} section will be subjected to eccentric loading wrt y axis
However for I^{st} section, loading will be CG of section.



For same area of section, II^{nd} section will be more economical and effecient than I^{st} section.

- For struts, tacking bolts, or tacking welds or tacking rivets are used to connect different sections.
- For columns, bracings or lacing systems are used.

* Connecting Systems for Built up Columns are:
- Lacing System (preferred for eccentric loaded column)
- Batten system (generally used for axially loaded columns)

* Lacing System

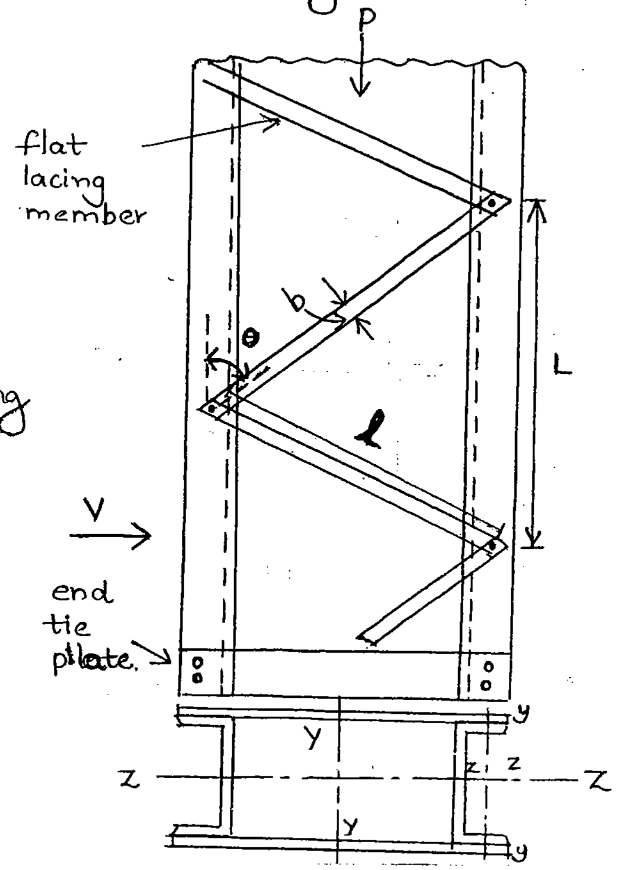
- Flats, angles, channels or tube sections are mostly used as section for lacing member.

$\theta \rightarrow$ angle of inclination of lacing with longitudinal axis.

$L \rightarrow$ spacing of lacing member

$b \rightarrow$ width of flat lacing

$l \rightarrow$ length of lacing member.



Step 3 : Select a trial section with approximate area equal to area required with higher minimum radius of gyration.

Step 4: Based on end condition, KL and effective slenderness ratio (KL/r) and fcd of a trial section may be calculated.

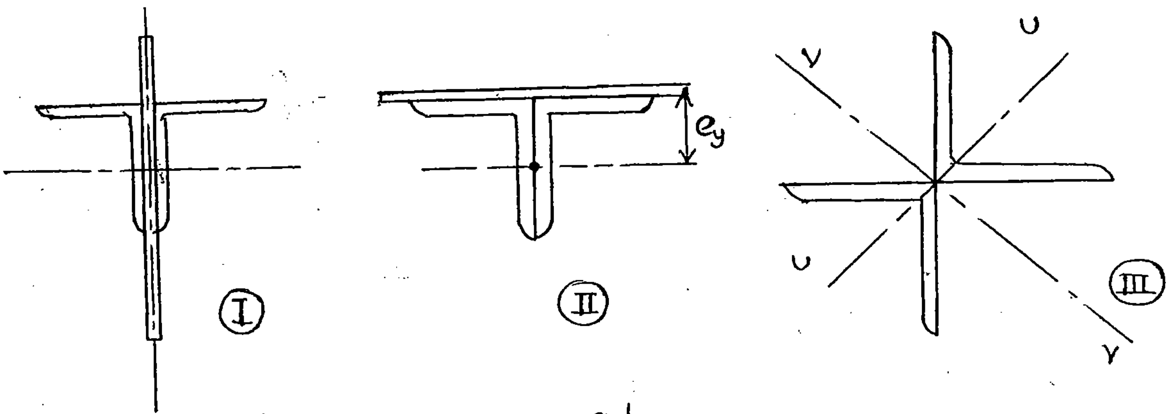
Step 5: $(P_d)_{trial} = (f_{cd})_{trial} \times A_e$

If $P \leq (P_d)_{trial}$; section is safe. Otherwise same procedure is repeated with higher c/s area.

* Limiting Slenderness Ratio.

	Limiting λ
A compression member subjected to compressive loads resulting from <u>DL + LL</u> combination.	≤ 180
A member subjected to compressive loads resulting from wind load or earthquake loads, <u>WL / EQL</u>	≤ 250
For compression flange of beam.	≤ 300

→ Built up Sections (Built up Coloumns)



Out of three sections, IIIrd one is most effecient as more area thrown away from buckling axis and hence more r

$\frac{KL}{r}$ → effective slenderness ratio.

KL → effective length of a compression member.

K → effective length constant ; L → unsupported length.

$$\phi = 0.5\left(1 + \alpha(\lambda - 0.2) + \lambda^2\right)$$

α → imperfection factor.

Buckling Class	a	b	c	d
α	0.21	0.36	0.49	0.76

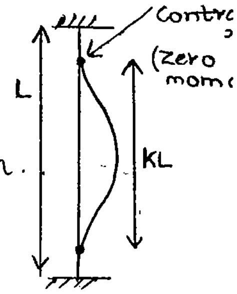
It considers —

a) Eccentricity of a load.
b) Initial straightness.
c) Residual stress present in c/s

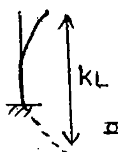
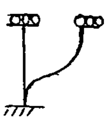
→ Effective Length of a Compression Member : (KL)

KL depends upon :—

(i) type of end condition
(ii) No: of members meeting at a joint location.
(iii) No: of rivets or bolts used at a joint.



* Effective Length of a Column (KL)

Type of End Condition	Effective Length (KL)	Effective length constant (K)
Fixed — Fixed. 	0.65L	0.65
Fixed — Pinned (or hinged) 	0.80L	0.80
Pinned — Pinned (Hinged — Hinged) 	1.0L	1.0
Fixed — Free 	2.0L	2.0
Fixed — Moment Roller. 	1.2 L	1.2

Pinned-moment roller		2.0L	2.0

18th Sept,

THURSDAY

→ Design of Axially Loaded Compression Members.

* Design Requirement for Safety of Compression Members:

- Design compressive load (P) ≤ Design compression strength of a member.

- $\left(\frac{KL}{r}\right)_0$ of section ≤ Limiting Slenderness Ratio. (to take care of erection loads)

⊙ Design of compression member is an indirect method of design as the failure stress, f_{cd}, depends on lot of factors.

$$f_{cd} = f\left(\frac{KL}{r}, \alpha, \phi = \sqrt{\frac{f_y}{f_{cc}}}\right)$$

⊙ For a tension member, section is dependent on A_g.

For a compression member, section is dependent on A_e & r

For a beam, section is dependent on moment of inertia.

Step 1: Assume design stress in axial compression (f_{cd})

f_{cd} = 90 MPa (for angle struts)

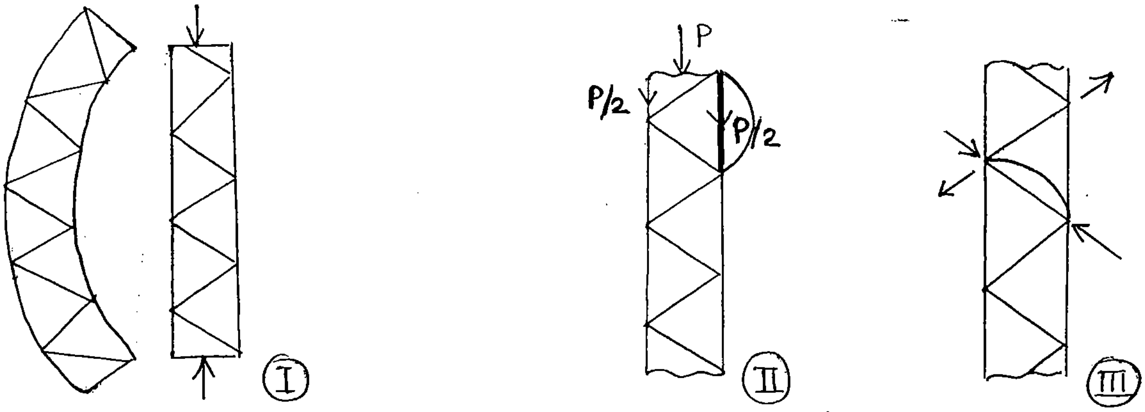
= 135 MPa (for I-section columns)

= 200 MPa (for heavily loaded columns)

Step 2: Effective sectional area required for factored compressive load, P is :

$$(A_e)_{req} = P/(f_{cd})_{assumed}$$

- Failure of lacing system



(I) → buckling of whole component

(II) → local buckling of column component.

(III) → local buckling of lacing member

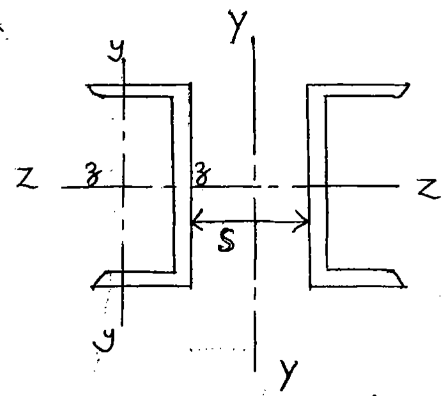
- General Specifications:

⊙ The radius of gyration normal to the plane of lacing not less than parallel to the plane of lacing

ie, $r_{yy} \nless r_{zz}$

To have economy in design, condition must be

$$r_{yy} = r_{zz} \Rightarrow I_{yy} = I_{zz}$$

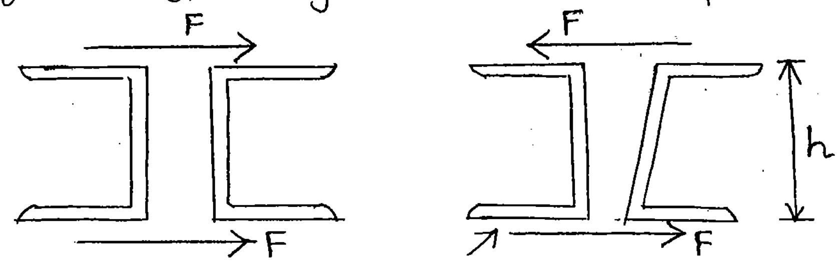


$$I_{zz} = I_{yy}$$

$$2 I_{zz} = 2\left(I_{yy} + A z^2\right)$$

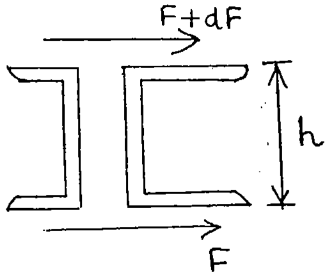
$$= 2\left(I_{yy} + A\left(\frac{S}{2} + C_{yy}\right)^2\right)$$

⊙ For single lacing system, lacing on one plane should reflect mirror image to the other plane.



$$M = F \times h$$

⊙ There should not be any variation in lacing system



$M = dF \times h$

– Design Specifications: (important)

⊙ $40^\circ \leq \theta \leq 70^\circ$

Optimum angle for lacing member, $\theta = 45^\circ$ to 50°

If $\theta < 40^\circ$, lacing member may chance to carry some of the the column load and same load may transfer from one column component to another column component like truss member.

If $\theta > 70^\circ$, the tieing force carrying capacity of lacing member is decreased.

⊙ Effective slenderness ratio of lacing member should be less than or equal to 145.

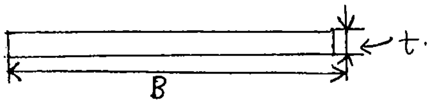
$$\left(\frac{KL}{r}\right)_{lacing} \leq 145$$

Above condition is required to avoid local buckling of Lacing member b/w individual column components.

	Kl
(i) For single lacing system with one bolt or one rivet.	1.0 l
(ii) For single lacing with welds.	0.7 l
(iii) For double lacing system	0.7 l

where Kl → effective length of lacing member (Kl

For flat lacing ($B \times t$)



$$I_{min} = \frac{Bt^3}{12}$$

$$r_{min} = \sqrt{\frac{I_{min}}{A}} = \sqrt{\frac{Bt^3}{12 \cdot Bt}} = \frac{t}{\sqrt{12}}$$

$$\frac{\sqrt{12}\, Kl}{t} \leq 145$$

Min width of flat lacing member, $B_{min} \simeq 3 \ast$ shank diameter of bolt.

Shank diameter of bolt	M_{16}	M_{18}	M_{20}	M_{22}
B (min) (mm)	50	55	60	65

- Min thickness of lacing member

$t_{min} \not< \frac{l}{40}$; for single lacing system

$\not< \frac{l}{60}$; for double lacing member.

- $\frac{L}{r^c_{min}} \leq 50$

$\leq 0.7 \times$ effective slenderness ratio of whole built up column $\left(\frac{KL}{r}\right)_0$

whichever is less.

$r^c_{min} \rightarrow$ min. radius of individual column component.

The above condition is required to eliminate local buckling of individual column component b/w lacings.

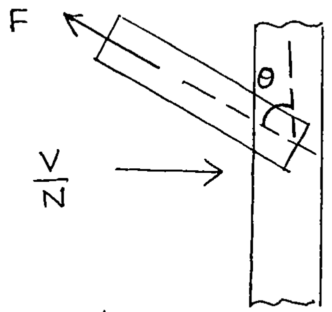
Lacing members ~~may~~ should be designed for a transverse shear of 2.5 % factored column load.

Transverse shear, V = 2.5 * factored column load

$$V = \frac{2.5\ P}{100}$$

$$\frac{V}{N} - F\sin\theta = 0$$

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



- Design axial force in lacing member (F)

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

$$F = \frac{V}{2\sin\theta} \quad \text{(for single lacing, } N = 2$$

$$= \frac{V}{4\sin\theta} \quad \text{(for double lacing system } N = 4)$$

- Effective slenderness ratio of lacing column should be increased by 5% in order to take care shear deformations due to unbalanced horizontal forces in lacing members.

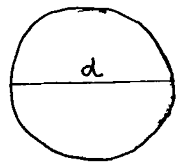
LEVEL-2
P-52
9th SEPT, FRIDAY

1. Effective slenderness ratio, $\frac{KL}{r} = 200$

$\frac{l}{d} = ?$

$KL = 1.0\,L$ (Ends are hinged)

$\frac{KL}{r} = 200$



$\therefore \frac{L}{r} = 200$

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{\pi d^4/64}{\pi/4\ d^2}} = \frac{d}{4}$$

$$\frac{L}{d/4} = 200 \Rightarrow \frac{l}{d} = 50$$

4. Transverse shear, $V = \frac{2.5P}{100}$

$P \rightarrow$ Factored load. ; $P_s \rightarrow$ Service load.

$P = \gamma_L \times P_s$

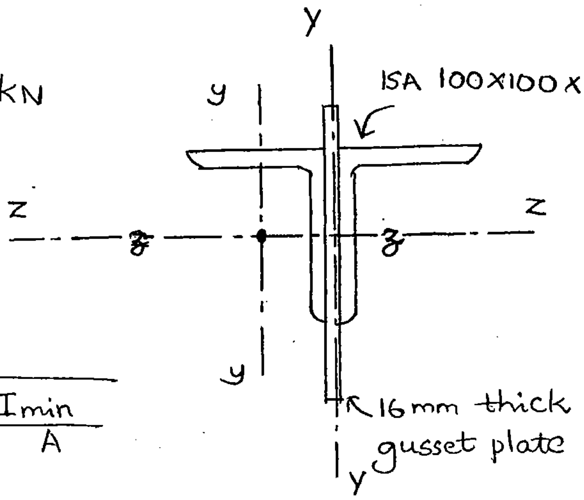
$= 1.5 \times 1000 = 1500$ kN.

$\therefore V = \frac{2.5 \times 1500}{100} = 37.5$ kN

5. Axial force in lacing, $F = \frac{V}{N \sin\theta}$

$\theta = 45^0$; $N = 2$.

$F = \frac{37.5}{2 \sin 45} = 26.52$ kN



6. $A = 1903\ mm^2$

$I_{zz} = I_{yy} = 177 \times 10^4\ mm^4$

Min radius of gyration, $r_{min} = \sqrt{\frac{I_{min}}{A}}$

I_{min} = min of I_{yy} or I_{zz}.

$$I_{zz} = 2(I_{GG} + Ay^2)$$

$$= 2(I_{zz} + A0^2) = 2 I_{zz}.$$

Gusset plates are provided only at points of junctions.

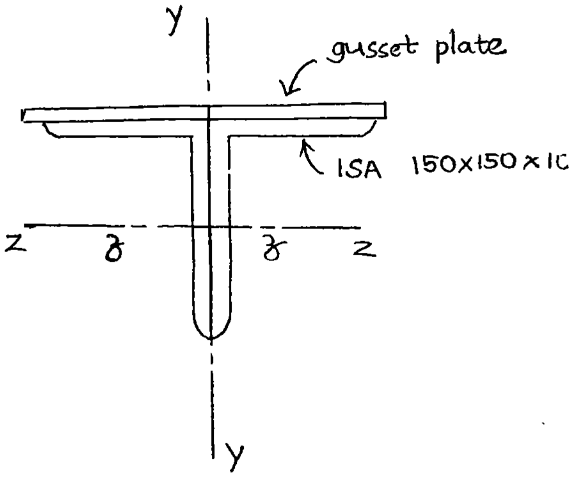
$\therefore$ I & A of gusset plates are not included

$$I_{yy} = 2(I_{yy} + A(t/2 + C_{zz})^2).$$

$$\Rightarrow I_{zz} < I_{yy} \quad \therefore I_{min} = I_{zz}.$$

$$r_{min} = \sqrt{\frac{2 I_{zz}}{2A}} = \underline{\underline{30.6 \text{ mm}}}$$

8. $I_{min} = \min \; I_{zz} \text{ or } I_{yy}$



$$I_{zz} = 2(I_{zz} + \cancel{Ay^2}^{\,0})$$

$$= 2 I_{zz}$$

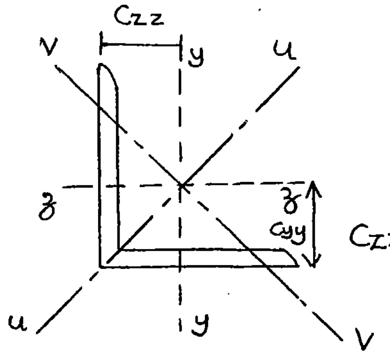
$$I_{yy} = 2(I_{yy} + Az^2)$$

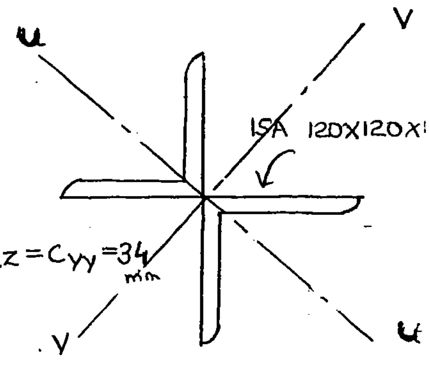
$$= 2 I_{yy} + 2A(40.8)^2$$

$$I_{min} = I_{zz}.$$

$$r_{min} = \sqrt{\frac{I_{min}}{A}} = \sqrt{\frac{2 I_{zz}}{2A}} = \sqrt{\frac{6.335 \times 10^6}{2921}} = \underline{\underline{46.57 \text{ mm}}}$$

9. $r_{min} = \sqrt{\frac{I_{min}}{A}}$





I_{min} = min of I_{vv} or I_{uu}

$$I_{uu} = 2(I_{uu} + Av^2).$$

$$= 2(584 \times 10^4 + 2750 \times 0^2)$$

$$= 1168 \times 10^4 \text{ mm}^4$$

$$I_{vv} = 2(I_{vv} + Au^2).$$

$$= 2(151 \times 10^4 + 2750 \times 2312).$$

$$= 1573.6 \times 10^4$$

$A = 2750 \text{ mm}^2$

$I_{zz} = I_{yy} = 368 \times 10^4$

$I_{uu} = 584 \times 10^4$

$I_{vv} = 151 \times 10^4.$

$$u^2 = C_{zz}^2 + C_{yy}^2 = 34^2 + 34^2 = 2312.$$

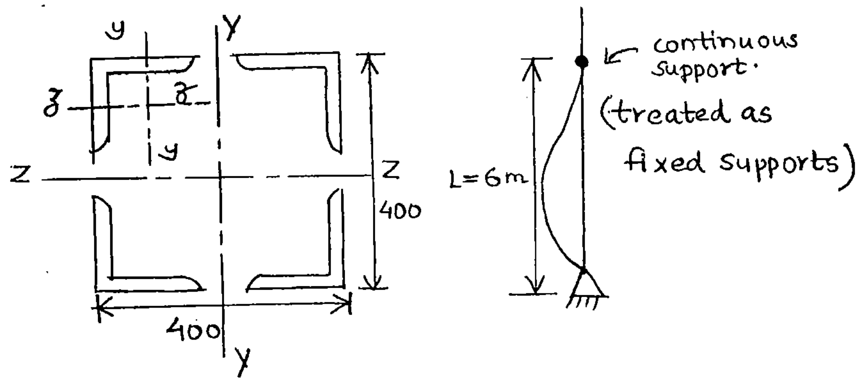
$$I_{min} = I_{uu} = 1168 \times 10^4 \text{ mm}^4.$$

$$r_{min} = \sqrt{\frac{I_{uu}}{A}} = \sqrt{\frac{1168 \times 10^4}{2 \times 2750}} = \underline{\underline{46.08 \text{ mm}}}$$

10. $A = 1903$, $I_{33} = I_{yy} = 177 \times 10^4 \text{ mm}^4$.

$C_{yy} = C_{zz} = 28.4$ mm.

$r_{yy} = r_{zz} = 30.5$ mm.



P-47 : 6 th Point.

Buckling about any axis of built-up member → class C

Design axial compressive load, $P = f_{cd} \times A_e$.

f_{cd} = Design axial compressive stress

A_e = Effective sectional area $= 4 \times 1903 \text{ mm}^2$

$$f_{cd} = \frac{f_y/\gamma_{mo}}{\phi + (\phi^2 - \lambda^2)^{0.5}} \leq \frac{f_y}{\gamma_{mo}}$$

Assume grade of steel, Fe 410

$\Rightarrow f_y = 250$ MPa, $\gamma_{mo} = 1.10$

Built up members — class C $\Rightarrow$ Imperfection factor, $\alpha = 0.49$

λ = non dimensional effective slenderness ratio

$$= \sqrt{\frac{f_y \left(\frac{KL}{r}\right)^2}{\pi^2 E}}$$

$KL = 0.8L$ (one end hinged & other end fixed).

$= 0.8 \times 6000 = 4800$ mm.

MI of built up section : $I_{zz} = I_{yy} = (I_{GG} + Ay^2)\,4$

$$= 4\left(177\times10^4 + 1903\times\left(\frac{400}{2} - 28.4\right)^2\right)$$

$$= 231.227\times10^6\ mm^4.$$

$$r_{min} = r_{yy} = r_{zz} = \sqrt{\frac{I_{zz}\ \text{or}\ I_{yy}}{4A}}$$

$$= \sqrt{\frac{231.227\times10^6}{4\times1903}} = 174.28\ mm.$$

Effective slenderness ratio $= 1.05\ \frac{KL}{r}$ (5% ↑ for built up column).

$$\lambda = \sqrt{\frac{f_y\left(\frac{KL}{r}\right)^2}{\pi^2 E}} = \sqrt{\frac{250\times\left(\frac{1.05\times4800}{174}\right)^2}{\pi^2\times2\times10^5}} = \underline{\underline{0.325}}$$

$$\phi = 0.5\left(1+\alpha(\lambda-0.2)+\lambda^2\right).$$

$$= 0.5\left(1+0.49(0.325-0.2)+0.325^2\right).$$

$$= 0.5834$$

$$f_{cd} = \frac{f_y/\gamma_{mo}}{\phi+(\phi^2-\lambda^2)^{0.5}} = \frac{250/1.10}{0.58+\left(0.58^2-0.325^2\right)}.$$

$$f_{cd} = 214.33 < \frac{250}{1.1}\ N/mm^2$$

$$P_d = f_{cd}\times A. = 214\ (4\times1903).$$

$$= 1628\times10^3\ N = \underline{\underline{1628\ kN}}$$