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4

-: HAND WRITTEN NOTES:-
OF
CIVIL ENGINEERING

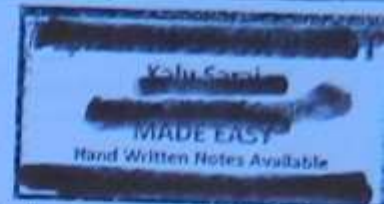
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-: SUBJECT:-
DESIGN OF STEEL
STRUCTURE

4

2

Design of Steel Structures



Rivelled connection

Welded connection

Eccentric connection { Rivelled
Welded

Tension member

Compression members

Beams

Plate girders

Industrial building

Plastic Analysis - Most imp

}

obj

③

IS : 800 - 1984 ✓

IS : 800 - 2007

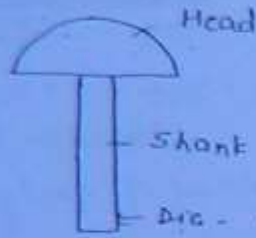
based on limit state
method of analysis

Although W-3 is given in
appendix

is 875 - loading

By - Kanchan Thakur

Riveted Connection



Rivets are —

Generally made of mild steel. and for normal construction purposes Fe 410S grade of steel. 410 N/mm² ultimate strength of steel. This grade

Cold Rivetting

Hot Rivetting

is suitable for rivetting for all thicknesses but for welding it is suitable only upto 20mm thickness of member.

For thicknesses more than 20 mm welding, grade of steel is used for member, they are Fe 410 Wb
WB
Wc

(4)

The other grades of steel are Fe 570 HT

HT = high tension

High tension grade of steel has higher strength and they are more resistant to atmospheric corrosion hence this grade is adopted when reduction in dead wt is desired and when str. is prone to atm corrosion

$$\text{Sp gravity} = 7.85$$

$$\text{weight density} = 7850 \text{ kg/m}^3$$

$$\text{unit wt } \rho = 78.5 \text{ kN/m}^3$$

$$E = 2 - 2.15 \times 10^5 \text{ N/mm}^2$$

$$\alpha = 1.2 \times 10^{-6} / ^\circ\text{C}$$

Advantage of steel structure over aluminium str.

Strength per unit wt. of aluminium is much greater than that of steel.

However $E_{al} = \frac{1}{3} E_{st}$

Hence Al. structure is more prone to buckling. To overcome this crosssectional area of Al str. needs to be increased. Even then a saving of 50% in wt. results by the use of Al str.

However Al is almost 8 times costlier than steel. Thus a greater economy is achieved by the use of steel str.

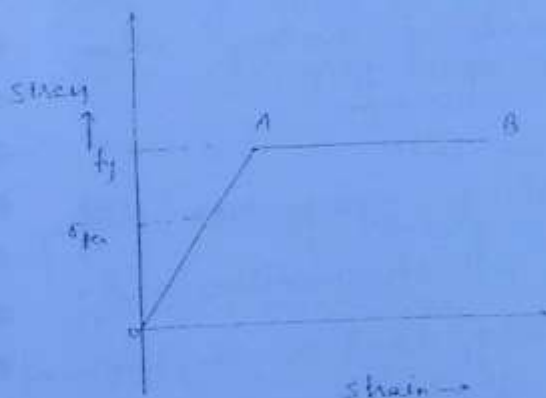
$$d_{al} = 2 d_{st} \quad \textcircled{5}$$

Hence it can not be encased in concrete as steel is normally done.

Note Encasing is normally done for aesthetic & fire resistance. Maintenance cost of Al. structure is less as it is not prone to corrosion.

Method of Design

Elastic Method of design is used



$$\sigma_{ps} = \frac{f_y}{F.O.S}$$

Simplified mild steel stress-strain curve

The structure is designed in such a way that stress in the member do not exceed permissible stress.

To design the structure we need to access the loading to which the structure will be subjected to. Hence there is uncertainty in loading. Similarly there is uncertainty in material property.

Also to simplify the analysis certain assumptions are made because of which error will be introduced in the result, to account for all these we use F.O.S. (6)

$$\text{F.O.S. for tension} = 1.67 = \frac{1}{0.6} \quad f_t = 0.6f_y$$

$$\text{F.O.S. for bending} = 1.5 = \frac{1}{0.66} \quad f_b = 0.66f_y$$

Note: In case of bending there is a margin to resist additional loading beyond the point of first yield. However in tension there is no margin beyond the point of first yield. Hence FOS in tension is more as compared to bending.

• Nominal Dia of rivet

It is the dia of shank of rivet in cold condition.
Cold and Hot rivetting.

Cold and hot rivettings are methods of rivetting. Cold rivetting is not adopted for dia $> 10\text{mm}$.

In hot rivetting rivets are heated to $550 - 1000^\circ\text{C}$. They are inserted in the hole made in the members and hammering is done so as to make head on the hammer side. The diameter of hole in the member should be more than the nominal dia of rivet so that the rivets can be easily inserted in heated condition.

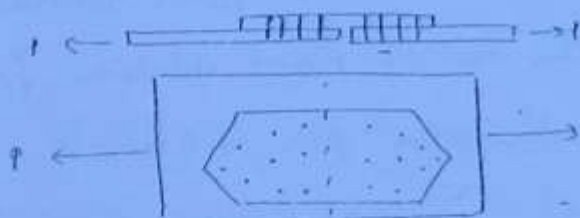


(7)

In comp. gross area is effective and in tension net area is effective in resisting loads.

Rivets in group subjected to direct load share the load equally (if they are of the same diameter).

Actually stress is assumed to be equally shared.



$$P \text{ force taken by one rivet} = \frac{P}{9}$$

The outer rivet will be stressed more as compare to the inner rivet hence in one line we do not adopt more than 5 rivets otherwise unbuckling effect will occur and rivets will start breaking one by one.

Bending stress in rivet is neglected under normal situation but if grip length is more the bending can not be neglected in that case additional precautions are taken as follows. If packing is of larger depth, additional rivets are provided on packing extension. This additional rivets absorbs the effect of (reduces the effect of) bending stress.

Recommendation: If the grip of rivet exceeds 6 times the dia of rivet hole, no. of rivets required by normal calculation should be increased by not less than 1/2 for each additional grip of 1/2 in.

provided on parking extension.

Ex. Dia of hole = 20 mm
grip length = 152 mm
load = 100 kN



Strength of 1 rivet = 20 kN

Calculate the no. of rivets required.

$$6 \times \text{dia of hole} = 6 \times 20 = 120 \text{ mm}$$

$$\text{grip over } 120 \text{ mm} = 152 - 120 = 32 \text{ mm}$$

So additional no. of rivets (over and above from normal calc.)
= 1% of the no. of rivet obtained from normal calculation per 1.6 mm

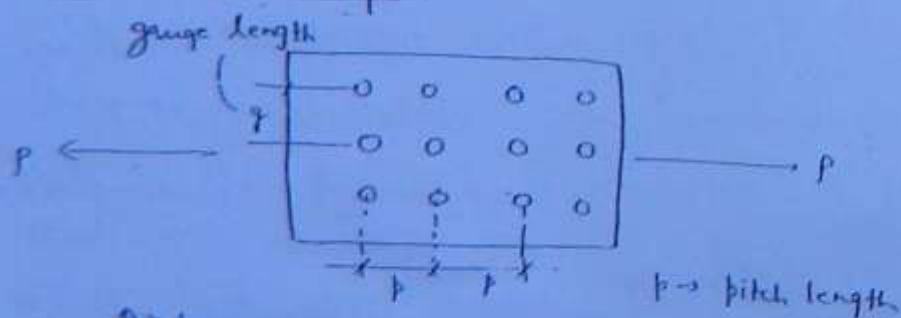
$$\text{no. of rivet req. by normal cal} = \frac{100}{20} = 5$$

$$\text{So Add. no. of rivet required} = \frac{32 \times 20}{1.6} \times \frac{1}{100} \times 5 = 1$$

$$\text{Total no. of rivet} = 5 + 1 = 6$$

- Rivet fills the hole completely. i.e. to calculate strength of rivet we use the gross dia of rivet i.e. the hole dia.

Pitch & Gauge



Distance b/w centre line of two rivets in the dir of force is called pitch & dis b/w centre of two rivets at right angle to the dir of force is called gauge

$$\begin{aligned} \text{Dia of hole} &= \text{Nominal dia of rivet} + 1.5 \text{ mm} && \text{for dia} \leq 25 \text{ mm} \\ \text{Dia of hole} &= \text{Nominal dia of rivet} + 2 \text{ mm} && \text{for dia} > 25 \text{ mm} \end{aligned}$$

Dia of hole is also called as gross dia of rivet (This is under the assumption that rivet fills the hole completely)

Unwin's formula

(9)

Dia of rivet to suit the thickness of member

$$d_{\text{mm}} = 6.05 \sqrt{t_{\text{mm}}} \quad \left(\begin{array}{l} \text{Not recommended by} \\ \text{IS code} \end{array} \right)$$

↓
Nominal dia

It is a guideline

t is the thickness of thinner member being joined

Normally adopted dia of rivets are in (mm)

10	12	16	18	20	22
25	30	36	42	48	56

Assumptions in Rivetted connection-

Friction b/w the plates is neglected

In hot rivetting because of gripping friction develops b/w the plates. So long as the external force overcomes the frictional force, rivets will not be subjected to any stress. Once the friction is overcome, the rivets will deform and hence will start sharing loads but it is difficult to quantify the amount of friction hence it is neglected and all the forces are assumed to be resisted by rivets only.

Shear stress is uniform over the x-section of rivet



Actual variation of

Assumed shear stress

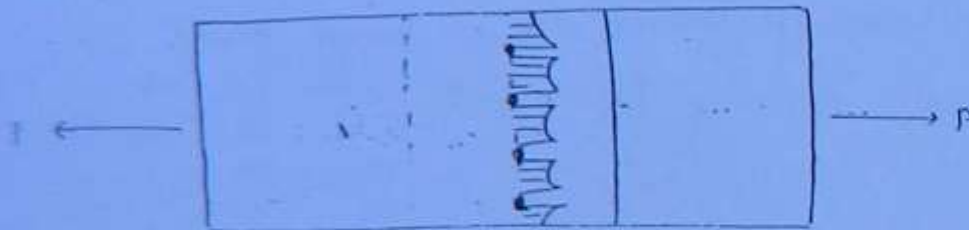
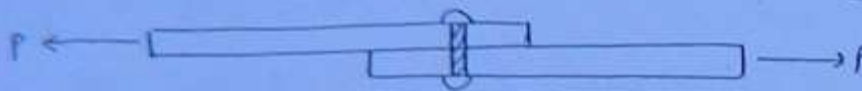
$$\text{Max s.f. resisted by 1 rivet} = \left\{ \sigma_{\text{perm}} \times \frac{\pi d_{\text{hole}}^2}{4} \right\}$$

Note: Shear failure is a sudden failure hence FOS for shear is large.

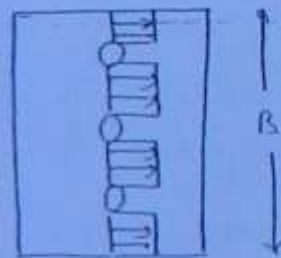
Above assumption is a simplifying assumption. No

∴ Distribution of direct stress on the portion of plate b/w the rivet hole is uniform

(10)



Actual stress variation



Assumed stress variation

B, t thickness of plate

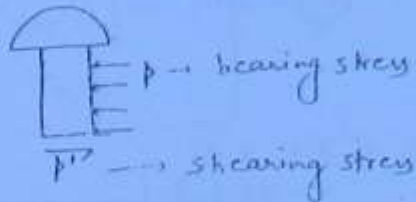
d' dia of hole

σ_t per. tensile stress

$$P_{\text{max}} = \underbrace{(B - 3d')}_{A_{\text{net}}} \times t \times \sigma_t$$

Note Because of stress concentration stress is normally 2-3 times that of av. stress

Transmission of load through rivets



$$P = p \times \pi d' t_1$$

$$P = \frac{p' \pi d'^2}{4}$$

(//)



hole dia = d'

Max bearing force resisted by top portion of rivet

$$= (d' t_1) \sigma_{br}$$

by bottom

$$(d' t_2) \sigma_{br}$$

Max force resisted by rivet in bearing = $d' \times t \times \sigma_{br}$

t = min thickness

Max force resisted by rivet in shearing = $\frac{\pi d'^2}{4} \sigma_s$

σ_s = permissible shearing stress

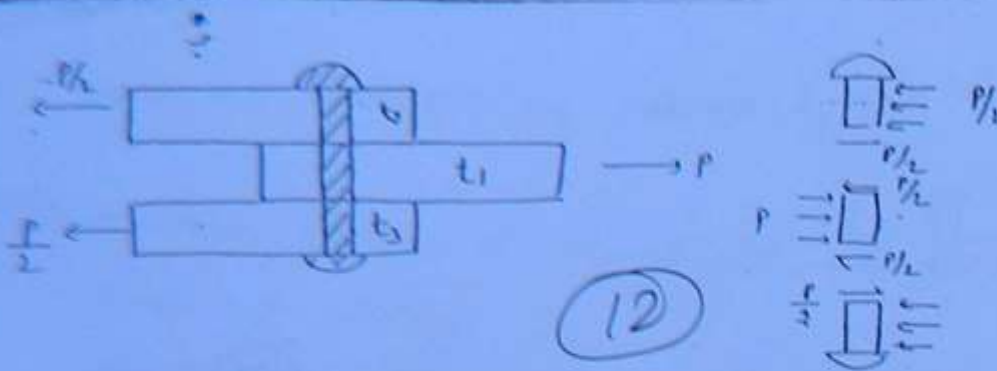
The strength of rivet is min of shearing and bearing strength
this is called rivet value of the rivet

$\therefore$ strength of rivet

R_v

If the rivet fails in shear by shearing on one plane
the rivet is said to be in single shear

$\therefore$



d' $\rightarrow$ Dia of hole

Bearing strength of rivet $= d' \times t \times \sigma_{bt}$

$$t \rightarrow \min \left(t_1, (t_2 + t_3) \right)$$

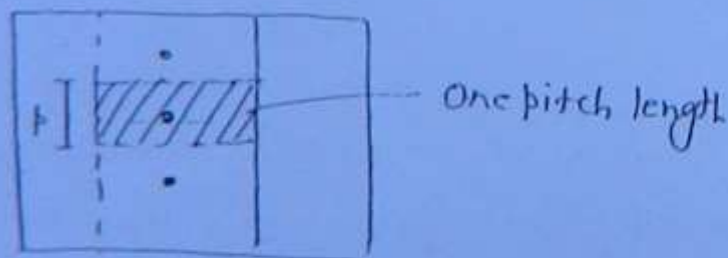
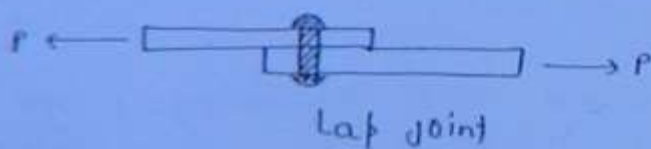
Shearing strength of rivet $= 2 \frac{\pi d'^2}{4} \times \sigma_s$

In this case rivet is said to be in double shear.

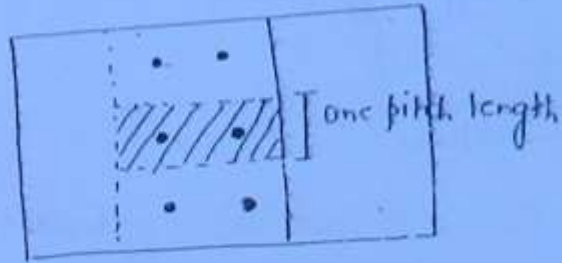
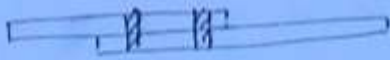
Note

Max. strength of rivet is taken as that corresponding to double shear.

Type of Joints



Single Rivetted lap joint

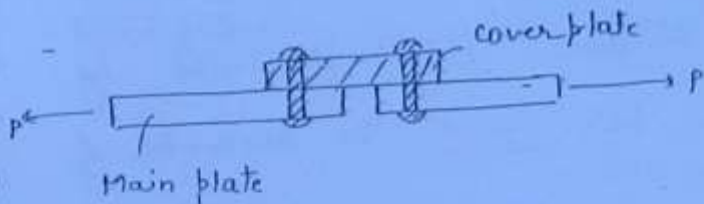


Double rivetted lap joint

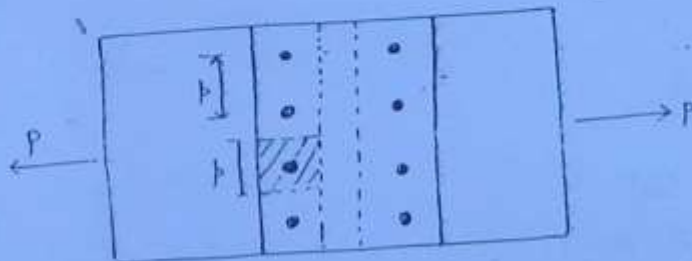
(13)

similarly when in one pitch length there are 3 rivets

Triple rivetted lap joint



single rivetted single cover butt joint



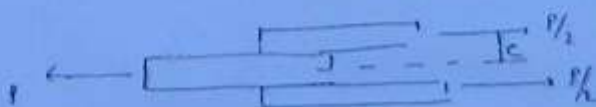
Double rivetted double cover butt joint



Double rivetted single cover butt joint

Note: whenever we concentrate on butt joint we concentrate on one side of butt joint of connection.

Eccentricity is eliminated in the case of double cover butt joint.

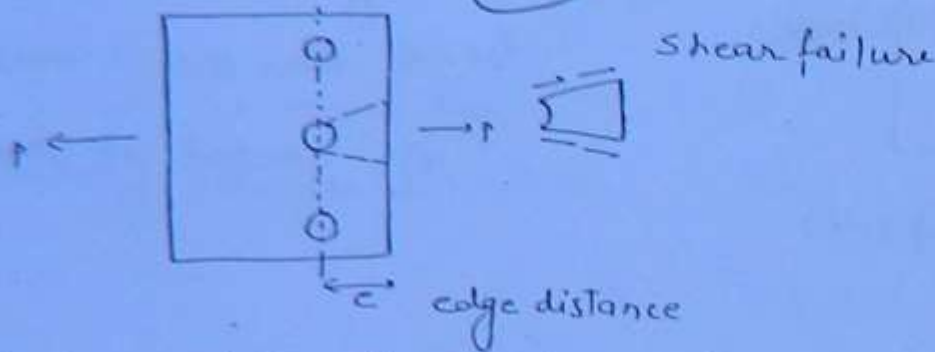


$$M = \frac{P}{2}c - \frac{P}{2}c = 0$$

Failure of Rivet Joint

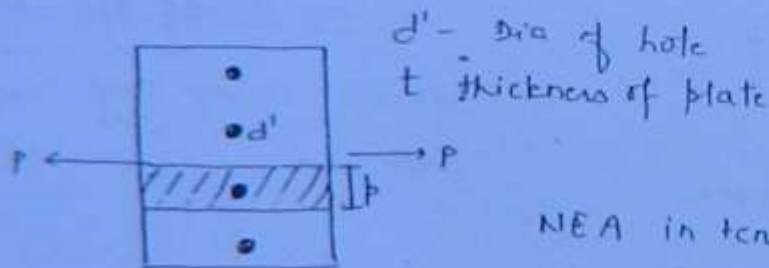
- 1) By tearing of plate b/w rivet hole and edge of plate

(14)



It is a type of shearing failure of plate at ends and occurs due to insufficient edge distance. It is prevented by keeping the edge distance to be twice the diameter of rivet hole.

- 2) By tearing of plate b/w rivet

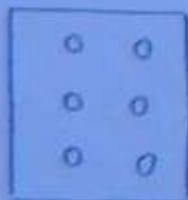


$$NEA \text{ in tension} = (B - 4d')t$$

$$\text{Strength of main plate in tearing} = (B - 4d')t\sigma_{at}$$

σ_{at} - permissible stress in axial tension

$$\text{Strength of main plate / pitch length} = (p - d')t\sigma_{at}$$



In case of double rivetted butt joint strength of joint per pitch length will be



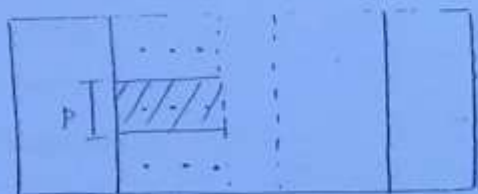
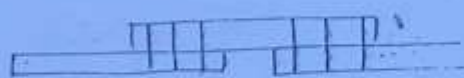
(15)

$$(p-d') t \sigma_{at}$$

shearing failure of joint by shearing of rivets
Strength of joint in shearing is equal to summation of shearing strength of all rivets in the joint



$$\begin{aligned} \text{strength of joint in shearing} &= \frac{[\pi d']^2}{4} \times \sigma_s \times 3 \\ &= \frac{3}{4} \sigma_s \pi d'^2 \end{aligned}$$



Rivets are in single shear No. of rivet/pitch length = 3

Strength of joint in shearing per pitch length

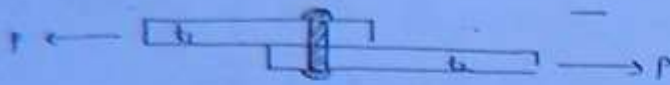
$$= \frac{\pi}{4} (d')^2 \sigma_s \times 3$$

Strength of triple rivetted double cover butt joint in

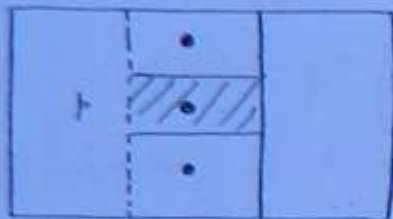
$$\text{shearing per pitch length} = 2 \times \frac{\pi}{4} (d')^2 \sigma_s \times 3$$

St. of one rivet in double shear.

Bearing or crushing of rivet.

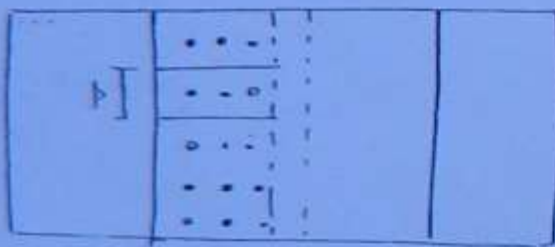
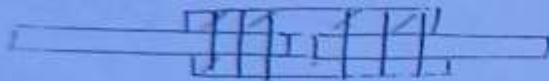


(16)



Strength of joint per pitch length
in bearing = $d' \times t \times \sigma_{br}$

t min thickness of plate



St. of joint per pitch length in bearing

$$= (d' \times t \times \sigma_{br}) \times 3$$

b area of hole

$t \rightarrow$ combined thickness of two cover plate or thickness of main plate whichever is min

* Bearing failure of plate.



bearing failure in



Bearing failure of rivet

Bearing failure of plate

Strength of joint is the minimum of shearing, bearing and tearing strength of joint.

(17)

Efficiency of Joint

$$\eta = \frac{\text{Strength of joint (min of shearing, bearing, tearing)}}{\text{Strength of main ~~hole~~ plate without deduction for hole}}$$

Note For efficient utilization of material rivets and plates should fail simultaneously

IS Code Recommendation

1) Permissible stress in rivets

		axial tension	shearing	bearing
shop rivet	Power driven	100 MPa	100 MPa	300 MPa
	Hand driven	80 MPa	80 MPa	250 MPa

For field rivetting, the above permissible values are reduced by 10%

Permissible stress values are increased by 25% in case of wind or earthquake loading

(18)

Note

Wind and/or EQ forces act for very short duration for that short duration member force will increase and hence the no. of rivet requirement will increase significantly if permissible stresses are kept constant low over there is a margin between permissible stress and yield stress and if that margin is utilised for that short duration no. of rivet requirement will not increase significantly hence economy will result thus for that short duration FOS is reduced and hence permissible stress is increased.

NC

Min Pitch

Min pitch = 2.5 times the nominal dia of rivet

Max pitch

a) Dis b/w the centres of two consecutive rivets in the dir of stress should not exceed $16t$ or 200mm whichever is less in tension member. where t is the thickness of thinner plate

b) In comp. it is

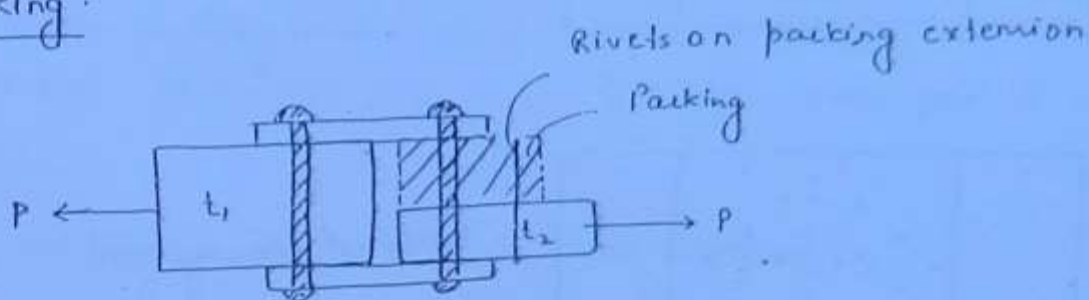
$12t$ or 200mm

whichever is less

for tacking rivets its max pitch is $32t$ or 300 mm whichever ever is less. (19)

Tacking rivets are used to ensure that the two members being joined along the length behave as a single unit

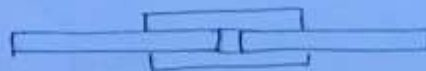
Packing

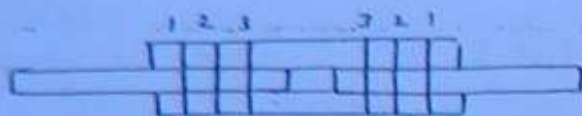


If the difference of thickness b/w two plates being joined ($t_1 - t_2$) is greater than 6 mm , then additional rivets shall be provided on packing extension.

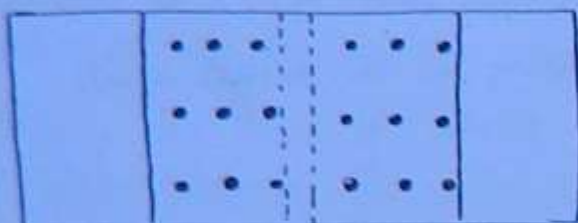
No. of additional rivets will be 2.5% of actual no. of rivet obtained from normal calculation per 2 mm thickness of packing

Arrangement of rivets

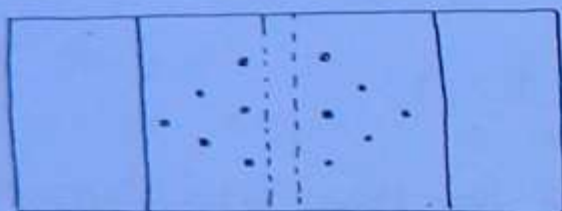




(20)



Chain Arrangement



Diamond Arrangement

Force in the main plate ^{beyond} before 1-1 is less than that before 1-1 because rivets at section 1-1 absorb some force and transmits it to the cover plate. The same thing holds for 2-2 and 3-3 therefore main plate required max^m net area at section 1-1 than at other sections. Thus it is desirable to have max^m minimum no. of rivets at section 1-1 providing max^m NEA. No. of rivets can be increased in inner row that is 2-2 & 3-3. Thus diamond rivetting is better as compare to chain rivetting.

Tearing strength of main plate

Diamond

Chain

1-1

$$(B-d')t\sigma_{at} + R_v = P$$

$$(B-2d)t\sigma_{at} = P$$

2-2

$$(B-2d')t\sigma_{at} + R_v = P$$

$$(B-2d)t\sigma_{at} + 2R_v = P$$

3-3

$$(B-3d')t\sigma_{at} + 3R_v = P$$

$$(B-2d)t\sigma_{at} + 4R_v = P$$

if

$$R_v - d' \times t \times \sigma_{ot} \leq 0$$

secn 2-2 will fail in tearing

2-2 more critical as compare to 1-1

(21)

At

for chain rivetting most critical section is section 1-1. If plate does not fail at secn 1-1 it will never fail at secn 2-2 & 3-3.

for cover plate secn 3-3 is most critical.

Q. A member of a truss consists of 2 angles 6 mm thick placed back to back. It carries a direct load of 100 kN and is connected to a gusset plate 8 mm thick. Determine the no. of power driven field rivet of 18 mm dia required for the joint:

$$d' = 18 + 1.5 = 19.5$$



Strength of rivet in shearing = $\frac{2 \times d'^2 \times 90}{4}$

$$= \frac{2 \times 19.5^2 \times 90}{4} = 53.757 \text{ kN}$$

in bearing

$$= \frac{19.5 \times 8 \times 300 \times 0.9}{1} = 42.12 \text{ kN}$$

rivet value R_v

$$= \frac{53.757 \text{ kN}}{42.12 \text{ kN}} = 1.27$$

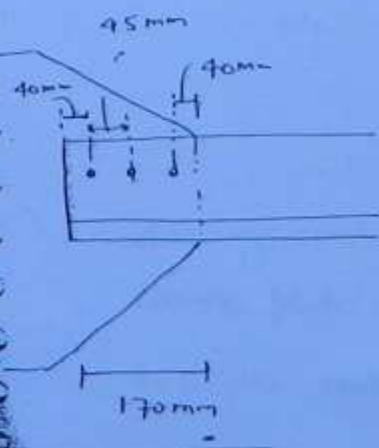
No. of rivet

$$= \frac{100}{53.757} = 1.87$$

$$= \frac{100}{42.12} = 2.37$$

$$= \approx 3 \text{ rivet}$$

$$= \approx 3 \text{ rivet}$$



Note

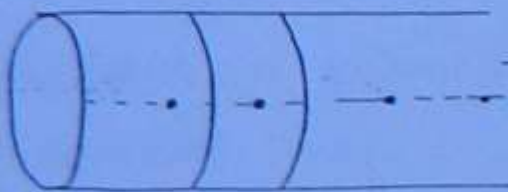
Shearing strength of rivet $\propto d^2$

Bearing strength of rivet $\propto d$

(22)

Hence when shearing governs the design it is better to use small no. of large dia rivets. If however bearing governs the design it is better to use large no. of small dia rivets.

Q: The plate of a boiler 6 mm thick is connected by single rivetted lap joint with 16 mm dia power driven shop driven at 50 mm pitch. Calculate the efficiency of joint.



$$d' = 16 + 1.5 = 17.5$$

$$F_t = 50 \times 6 \times 150 = 45 \text{ kN}$$

$$\text{Tearing strength of plate} = (50 - 17.5) \times 6 \times 150 =$$

$$29.25 \text{ kN}$$

$$\text{Strength of rivet in shearing} = \frac{\pi d^2}{4} \times 100 = \frac{24.053 \text{ kN}}{24.648 \text{ kN}}$$

$$\text{bearing} = 17.5 \times 6 \times 270 = 28.95 \text{ kN}$$

$$n R_v = 24.648 \quad 24.053 \text{ kN}$$

$$\eta = \frac{24.053 \times 100}{45} = 53.45\%$$

Q. A tie member has to transmit a pull of 400 kN. Design a butt joint to connect two no. of 12-mm thick plate and also find its efficiency use power driven shop rivet.

Sol.

No. of rivets and its dia

Arrangement of rivets

Width of main and cover plate

Thickness of cover plate

Efficiency

23

$$\text{Dia of rivet} = 6.05\sqrt{t} = 20.95 \text{ mm} =$$

$$\text{Let us adopt } 20 \text{ mm dia rivet. } \Rightarrow d' = 20 + 1.5 = 21.5 \text{ mm}$$

$$\text{Rivet value} = \text{Min of (shearing strength, Bearing strength)}$$

$$\text{Shearing strength} = \frac{2 \times \pi \times (21.5)^2 \times 100}{4} = 72.61 \text{ kN}$$

$$\text{Bearing strength} =$$

Assuming that combined thickness of two cover plate is more than main plate

$$\text{Bearing strength} = d' \times t \times 300 = 77.4 \text{ kN}$$

$$\text{rivet value} = 72.61 \text{ kN}$$

$$\text{No. of rivets} = \frac{400}{72.61} = 5.5$$

Adopt 6 no. of 20 mm ϕ rivet

Arrangement of rivets will decide the dimensions of main & cover plate.

Let us adopt diamond rivetting pattern



Width of main plate will be provided such that the main plate does not tear at any section 1, 2 & 3

Tearing strength of main plate at section 1-1

$$(B - d') \times 12 \text{ mm} \times 150 > 400 \times 10^3$$

$$B - d' > 222.22$$

$$B > 222.22 + 21.5$$

$$> 243.72 \text{ mm}$$

Tearing strength at 2-2

$$(B - 2d') \times 12 \times 150 + R_v > 400 \times 10^3$$

$$B > 224.88 \text{ mm}$$

At 3-3

$$(B - 3d') \times 12 \times 150 + 3R_v > 400 \times 10^3$$

$$B > 165.7 \text{ mm}$$

Let us adopt width of main plate = 250 mm

Adopting the width of cover plate same as that of main plate

Tearing strength of cover plate at section 3-3

$$(250 - 3d') \times 2t \times \sigma_{at} > 400$$

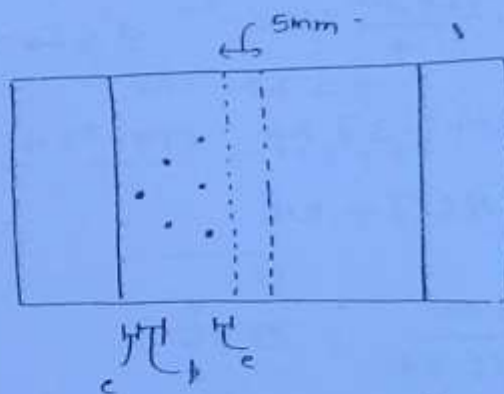
$$t > 7 + 81 - 7.187 \text{ mm}$$

Recommendation - Min thickness of plate in steel structure should be adopted 6mm when it is not exposed to atm. and 8 mm if it is exposed to atm.

Let us adopt $t = 8 \text{ mm}$

(25)

Arrangement — Diamond
No of rivet — 6
Width of main plate — 250mm
Width of cover — 250mm
Thickness of cover plate — 8mm



$$e = 2 \times 21.5 = 43$$

$$p = 2.5 \times 20 = 50$$

$$4e + 4p + 5 \text{ mm} = 4 \times 43 + 4 \times 50 + 5 = 377 \text{ mm}$$

$$\text{Efficiency} = \frac{\text{Min of shearing, bearing, tearing st. of joint}}{\text{Strength of main plate without deduction for hole}}$$

$$\begin{aligned} \text{Min } \left\{ \begin{array}{l} \text{Shearing st. of joint} \\ \text{Bearing st. of joint} \end{array} \right. &= 6 R_v = 6 \times 72.61 \\ &= 435.66 \text{ KN} \end{aligned}$$

$$\text{Tearing strength of main plate} = (250 - 3 \times 21.5) \times 8 \times 150 = 411.3 \text{ KN}$$

$$\text{cover plate} = (250 - 3 \times 21.5) \times 8 \times 150 = 411.3 \text{ KN}$$

hence strength of joint = 411.3 kN

$$\eta = \frac{411.3 \times 10^3 \times 100}{250 \times 12 \times 150} = 91.4\% \quad (26)$$

Q. Design a rivetted splice for a tie of a steel bridge
20 cm wide 20mm thick carrying an axial load of 5000 kg
Use 12mm thick cover plate and 22mm dia rivet

$\sigma_{at} = 150 \text{ mpa}$, $\sigma_s =$ permissible stress in shear = 100 MPa

$\sigma_{br} = 300 \text{ MPa}$

Sol. $d' = 22 + 7.5 = 23.5 \text{ mm}$

Shearing

$$\text{Rivet value} = \min \left(\frac{2 \times \pi d'^2 \times 100}{4}, d' \times 20 \times 300 \right)$$

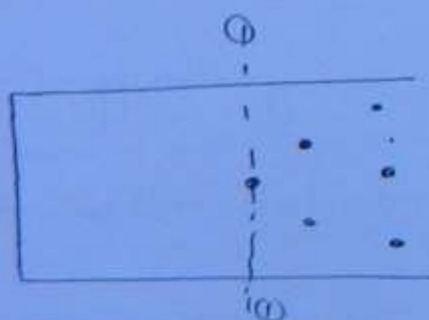
$$= 2 \times 43.37 \text{ kN}, 141 \text{ kN}$$

$$\text{Rivet value} = 86.74 \text{ kN}$$

$$\text{No. of rivet} = \frac{5000}{86.74} = 5.76$$

Adopt 6 rivet of 22 mm dia

Arrangement



$$\text{tearing strength of section 1-1} = (B - d') \times 20 \times 150$$

$$= 529.5 \text{ kN} > 5000 \text{ safe}$$

$$2-2 = (B - 2d') \times 20 \times 150 + 86.74$$

$$3-3 = (B - 3d') \times 20 \times 150 + 3 \times 86.74$$

$$= 648.72 \text{ kN} \quad (27)$$

for cover plate (Adopting width of cover plate = width of main plate)

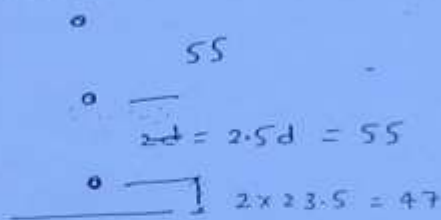
$$= (200 - 3d') \times 24 \times 150$$

$$= 466.2 \text{ kN} < 500 \text{ kN}$$

So cover plate is not safe in tearing.

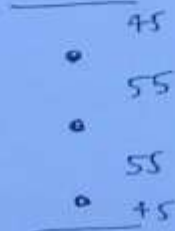
After adopting diamond arrangement connection will

See 3-3



$$55 \times 2 + 47 \times 2 = 204$$

So take



$$e = 1.6 \text{ to } 1.7 \text{ time } d'$$

So 3 rivets can be accommodated

Hence we can ^{not} apply 3 rivet at secⁿ 3-3 b/cov cover plate is not safe

Let us adopt chain rivetting



Check tearing strength of main plate at secⁿ 1-1

$$(B - 2d') \times 20 \times 150 = 454 \text{ kN} < 500$$

Not safe

Hence let us adopt

(i) or (ii)

(28)

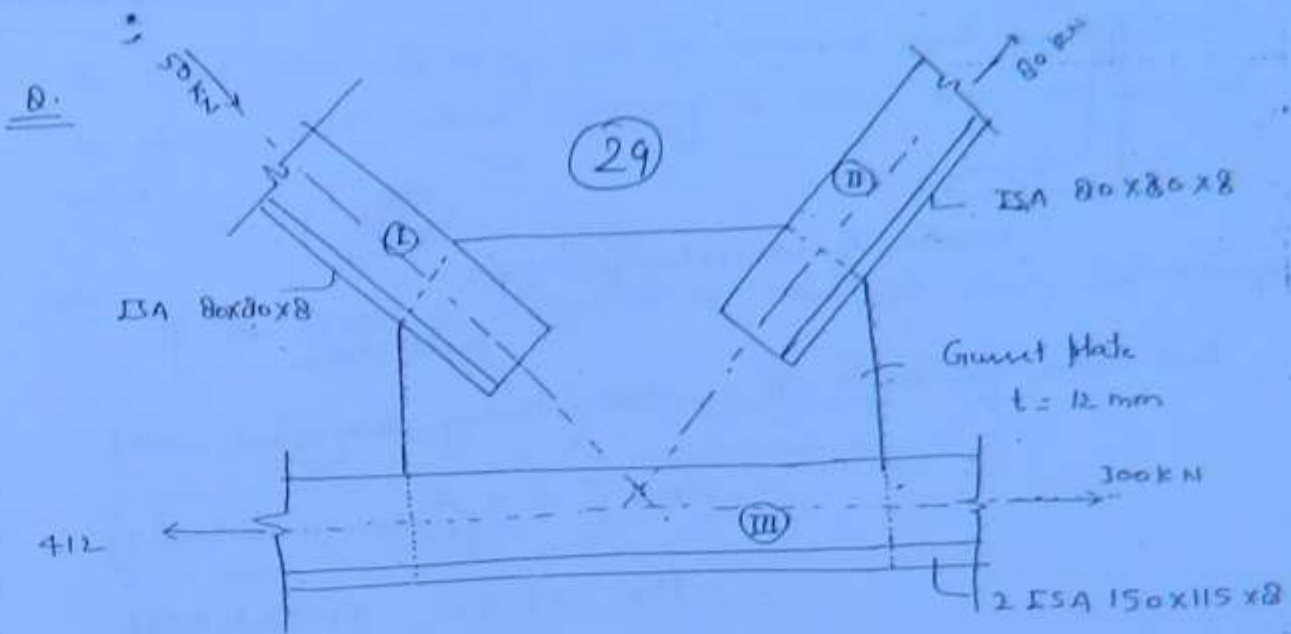
• • •
• • •

(1)

or

• • •
• • •

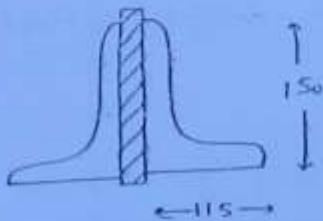
(11)



Determine the no. and pattern of 20 mm dia rivet used for connection

permissible stress in shearing in rivet = 102.5 N/mm^2

$\sigma_{br} = 236 \text{ N/mm}^2$



for connection of angle I & II rivet is in single shear but for connect of angle III with gusset rivet is in double shear

Hence rivet value for I, II = $\min(\text{shearing strength, Bearing st.})$

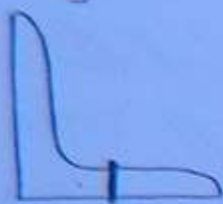
$$= \min \left(\frac{\pi \cdot 21.5^2}{4} \times 102.5, 21.5 \times 8 \times 236 \right)$$

$$= \min (37.213 \text{ kN}, 40.59 \text{ kN})$$

$$\text{Rivet value} = 37.2 \text{ kN}$$

$$\text{No. of rivet for I} = \frac{50}{37.2} = 2 \text{ rivet adopt}$$

$$\text{for II} = \frac{80}{37.2} = 3 \text{ rivet adopt}$$



(36)

L Location of connection for angle

$$\begin{aligned}
 \text{Rivet value for angle III} &= \text{Min} \left(\overset{\text{Double shear}}{\text{shearing}}, \text{Bearing} \right) \\
 &= \text{Min} \left(\frac{2 \pi d^2 \times 102}{4}, d' \times t \times 236 \right) \\
 &= \text{Min} \quad 74.72, \quad 21.5 \times 12 \times 236 \\
 &= \quad \quad \quad , \quad 60.89 \\
 &= 60.89 \text{ kN}
 \end{aligned}$$

Net force needs to be transferred to the gusset

$$= 412 - 300 = 112 \text{ kN}$$

$$\text{No. of rivet} = \frac{112}{60.89} = \text{Adopt 2 rivet}$$

For thin shells

For thin shells the connection will be done per pitch length, force in one pitch length will be stress $\times$ pitch length $\times$ thickness

Stress will be for cylindrical shell

$$a) \text{ hoop stress} = \frac{pd}{2t\eta}$$

$$b) \text{ Long stress} = \frac{pd}{4t\eta}$$

$$F = \frac{pd}{2t\eta} (s \times t)$$

The force for which connection will be designed

$$F = \text{Stress} \times s \times t \text{ --- thickness}$$

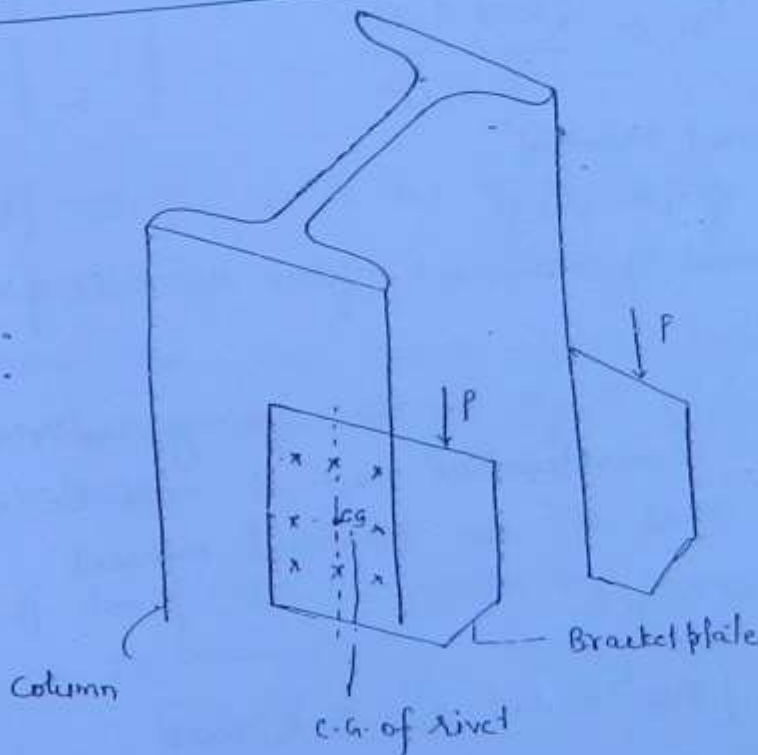
To start with efficiency will be assumed and finally it will be shown that actual efficiency is more than the assumed value.

(3)

Note If the rivet is subjected to combined shear and tension

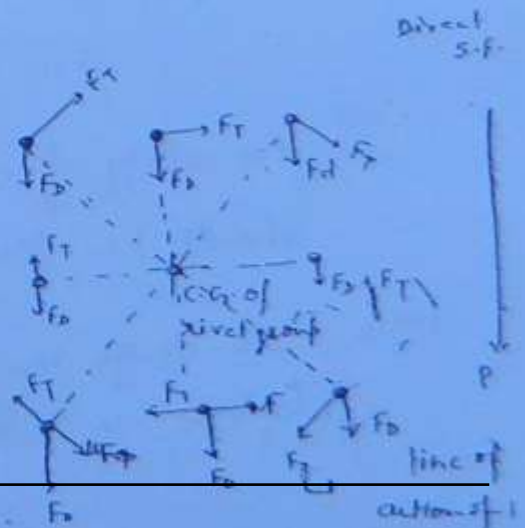
$$\frac{(\text{Shear stress})_{\text{calc.}}}{\left(\begin{array}{c} \text{Permissible shear stress} \\ \text{in rivet} \end{array} \right)} + \frac{\text{Tensile stress calc.}}{\text{Per.}} \leq 1.4$$

Eccentric Connection -



F_{di} = force on the i th rivet due to direct loading

$$= \frac{P \cdot A_i}{\sum_{i=1}^n A_i}$$



Under the assumption that direct shear stress is equally shared.

Direction of this force will be parallel to the line of action of force

(32)

We know that torsional shear stress = $\tau_{ti} = \frac{T r_i}{J}$

$$\text{Torsional shear force} = \frac{T r_i}{J} A_i$$

$$F_{ti} = \frac{(P e) A_i r_i}{J}$$

for discrete area $J = \sum A_i r_i^2$

$$F_{ti} = \frac{(P e) A_i r_i}{\sum A_i r_i^2}$$

$(P e) \rightarrow$ Torsional Moment

$A_i \rightarrow$ Area of i^{th} rivet

$r_i \rightarrow$ Distance of i^{th} rivet from the C.G. of rivet group

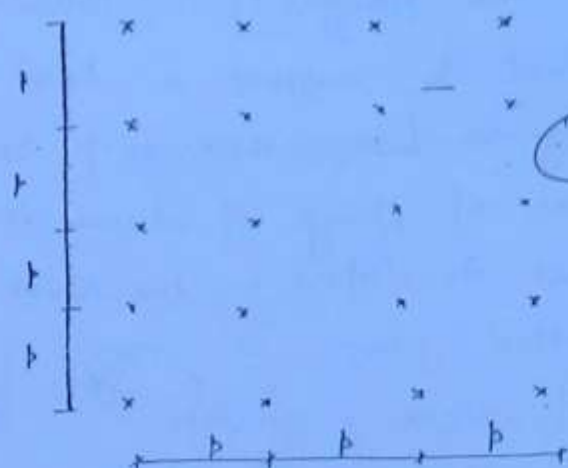
The direction of this S.F. is $\perp$ to line joining the C.G. and the rivet under consideration and it will be in the same sense as that of the torsional moment

Resultant force on i^{th} rivet

$$F_{ri} = \sqrt{F_{di}^2 + F_{ti}^2 + 2 F_{di} F_{ti} \cos \theta}$$

For safety of connection resultant force in all rivets should be less than their rivet value.

Note - To design the connection no. of rivets are chosen as follows



n - no. of rivets in one column

m - no. of such columns

$$n = \sqrt{\frac{6(Pe)}{mp R_v}} \quad \text{Torsional moment}$$

Make



If all the rivets are of same dia then most critical rivet is the one which is farthest from the C.G. If there are more than one rivets equally distant from C.G. then the rivet in which angle b/w $F_0 + F_t$ ^{is least} is the most critical rivet.

If dia of all the rivets are same

$$F_{di} = \frac{P}{n}$$

$$F_{Ti} = \frac{(Pe)r_i}{\sum d_i^2}$$



1, 2, 3 & 4 have same value of F_0 and F_T but angle b/w $F_0 + F_T$ is smaller in ① & ② hence they are the most critical rivet.

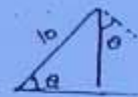
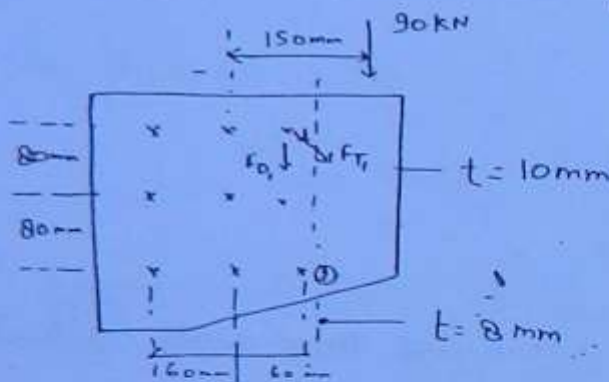


1 & 2 are most critical rivet

Q. A bracket connected to the flange of a column through a group of rivet to support a load of 90 kN as shown in figure below thickness of bracket plate is 10 mm and that of flange of column is 8 mm determine the max force developed in the rivet and design a suitable rivetted joint.

Allowable stress in single shear = 100 MPa
in double shear = 200 MPa

$$\sigma_{br} = 180 \text{ MPa}$$



Assume size of rivets to be same. Hence rivet 1 & 2 will become most critical rivet.

Sol. $F_{D_i} = \frac{90}{9} = 10 \text{ kN}$

Hence let us calculate force in rivet 1 which is max

$$F_{D_1} = \frac{90}{9} = 10 \text{ kN}$$

$$F_{T_1} = \frac{P e x_1}{\sum x_i^2} = \frac{90 \times 150 \times 100}{(4 \times 100^2 + 2 \times 80^2 + 2 \times 60^2)} = 22.5 \text{ kN}$$

$\cos \theta$

$$\frac{12}{13} = \frac{3}{5}$$

$$F_{R_1} = \sqrt{F_T^2 + F_D^2 + 2 F_T F_D \cos \theta} = 29.6 \text{ kN}$$

$$\frac{\pi}{4} (d + 1.5)^2 \times 100 \geq 29.6 \times 10^3$$

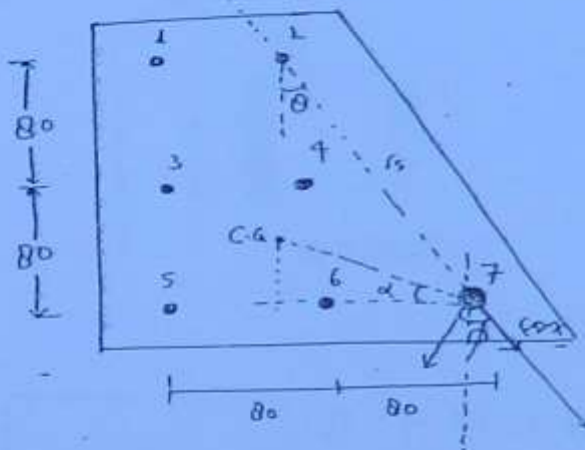
$$\text{www.FirstRanker.com} \geq 19.41 \text{ mm } 17.9 \text{ mm}$$

Bearing strength of rivet $= d + 1.5 \times 8 \times 180 > 29.6 \times 10^3$
 $d > 19.05 \text{ mm}$

hence adopt rivet dia = 20 mm

(35)

Q.



Rivet 1-6 are of dia d'
 & rivet 7 is of dia $1.2d'$

Find force in 7th rivet

$$\cos \theta = \frac{2}{\sqrt{5}}$$

$$\sin \theta = \frac{1}{\sqrt{5}}$$

$$P = 100 \text{ kN} = 100 \text{ kN}$$

$$\tan \alpha = 2$$

$$\alpha = 33.69^\circ$$

$$A = 26.565$$

$$\phi = (\alpha + \theta) = 60.255^\circ$$

$$\bar{X} = \frac{A_1 x_1 + A_2 x_2 + A_3 x_3 + \dots + A_n x_n}{A_1 + A_2 + \dots + A_n}$$

$$= \frac{0 + 0 + 0 + 3 \times A \times 80 + 1.44 A \times 160}{7.44 A}$$

$$= 63.226 \text{ mm}$$

$$\bar{Y} = \frac{0 + 0 + 0 + 2 A \times 80 + 2 A \times 160}{7.44 A}$$

$$= 64.516 \text{ mm}$$

$$F_{D7} = \frac{100 \times 1.44 A}{7.44 A} = 19.355 \text{ kN}$$

$$(P.C) = 100 \times 1000 \left(80 + 80 - 63.226 \right) + \frac{100}{\sqrt{5}} \left(64.516 \right)$$

$$= 115.41 \text{ mm}$$

$$C = 57.7 \text{ mm}$$

$$P.C = 115.41 \text{ mm}$$

$$P.C = 57.70 \text{ kN/mm} = 5.77 \text{ kN}$$

$$r_1 = 114.51 \text{ mm}$$

$$r_2 = 96.94 \text{ mm}$$

$$r_3 = 65.08 \text{ mm}$$

$$r_4 = 22.83 \text{ mm}$$

$$r_5 = 90.33 \text{ mm}$$

$$r_6 = 66.67 \text{ mm}$$

$$r_7 = 110.31 \text{ mm}$$

(36)

$$\frac{(P_c) A r_7}{\sum A r_i^2}$$

$$= \frac{(P_c) A (r_1 + \dots + r_6) + 1.44 A \times r_7}{A (r_1^2 + \dots + r_6^2) + 1.44 A \cdot r_7^2}$$

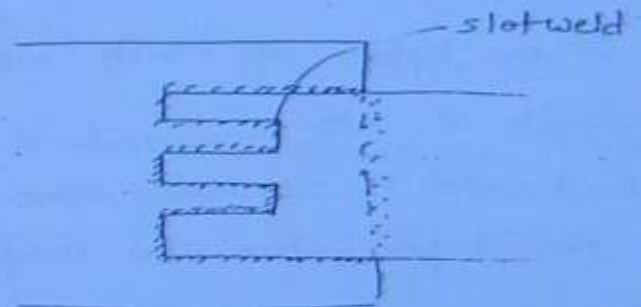
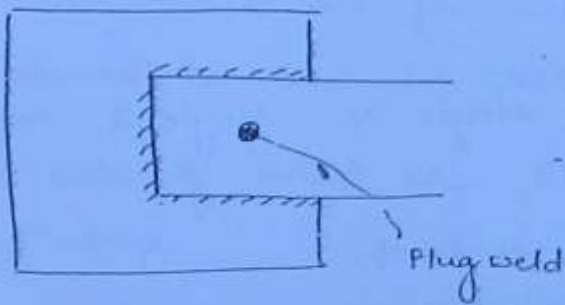
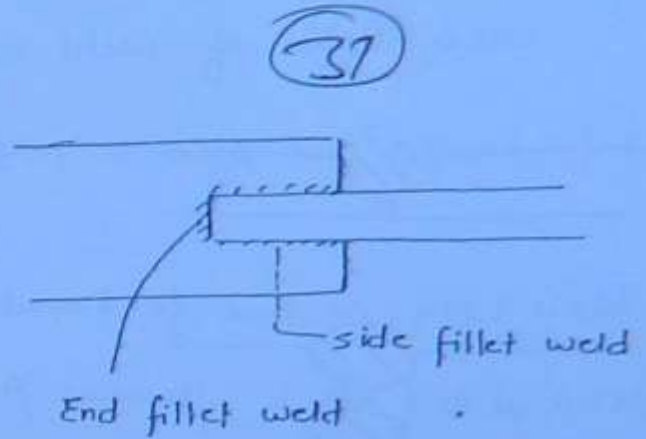
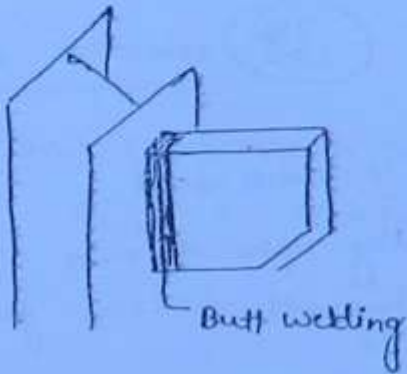
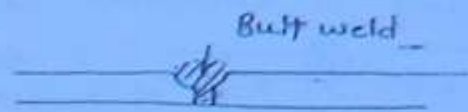
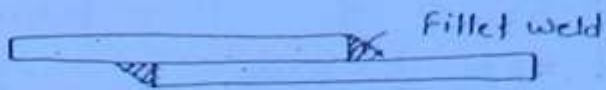
$$F_{L_7} = 16.28 \text{ kN}$$

$$F_{L_7} = \sqrt{F_{D_7}^2 + F_{T_7}^2 + 2 F_D F_T \cos(60.25^\circ)}$$

$$= 30.86 \text{ kN}$$

22/09/11

Welded Connection



Types of weld.

- i) Butt weld or groove weld
- ii) Fillet weld
- iii) Plug weld
- iv) slot weld

Welding is done by electric arc welding

Butt weld -

The various types of butt welds are square butt weld



Adopted upto $t \leq 8\text{mm}$

Other types of weld are

(38)



single U butt weld

Normally upto 40mm



Double U - butt weld

> 40mm

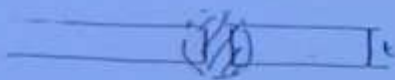
Other types of butt weld are single V, single J, single double V, etc.

Butt weld is normally done in the workshop.

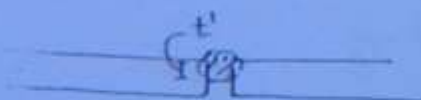
Partial penetration and complete penetration.

When weld metal does not penetrate to the complete depth of the plate.

Weld metal penetrates completely to the full ^{depth} length is known as complete penetration.



complete penetration $P_{max} = B \times t \times \sigma_{at}$



Partial or incomplete penetration

$$P_{max} = B \times t' \times \sigma_{at}$$

If the thickness of penetration is not given t' can be taken

as $\frac{5}{8}$ times of t_{min} but it is not IS code recommendation.

Fillet weld

Can be done in the field as lesser precision is required in it. It is cheaper as compared to butt weld.

Fillet weld is almost always assumed to fail in shear.

(39)

Permissible stresses

Tension and compression on section through the throat of butt weld

$$\sigma_{term} = 0.6 f_y$$

Shear of section through the throat of butt or fillet weld

$$= 0.4 f_y \quad (\text{Normally it is } 108 \text{ to } 110 \text{ N/mm}^2)$$

Then values are for welding done in workshop they are reduced to 80%. In case of field welding.

In case of wind or ER the permissible values are increased by 25%.

Design of butt weld

- Butt weld or groove weld is more suitable for alternating stress provided that full penetration of weld is achieved.
- Reinforcement is good for static load condition. It is not suitable for alternating stress condition due to huge stress conc. at this location leading to onset of crack.

However even in this case reinforcement of 0.6 to 0.75 to 3m is kept.

- The strength of weld in tension and compression is given by

$$l_{eff} \times t_{eff} \times 0.6 f_y$$

l_{eff} - Actual length of weld - length of full size of weld

t_{eff} - Thickness of thinner part being joined (mean of complete penetration)

For incomplete penetration t_{eff} is min thickness of weld metal common to the parts being joined excluding reinforcement.

When two plates are of different thickness



t_1 - thicker

(40)

If $(t_1 - t_2) > \frac{t_2}{4}$ or 3mm whichever is greater then we provide tapering in the thickness. The tapering should not be greater than 1 in 5.



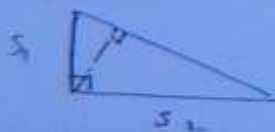
If the thickness of weld common b/w the plates is not given in incomplete penetration weld t_{eff} can be taken as $\frac{5}{8}$ times t_{min} .

Design of Fillet weld.

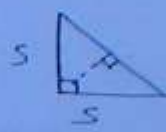
Size of the weld

Size of the weld is decided on the basis of largest right angle that can be inscribed in the weld for normal fillet weld size is taken as the minimum weld leg size.

Note

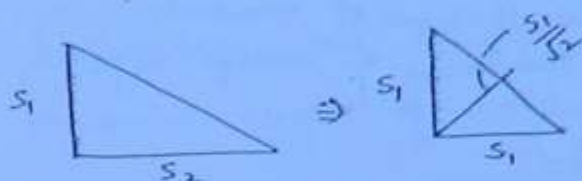


Size of weld = s_1



Size of weld = s

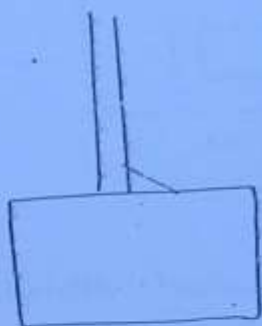
For right angle fillet weld minimum throat size will be $\frac{s_1 s_2}{\sqrt{s_1^2 + s_2^2}}$. However as per IS code it is taken as $\left(\frac{s}{\sqrt{2}}\right)$



(41)

see

Minimum size of weld.



Thickness of thicker part

min size

0-10

3 mm

10-20

5 mm

20-32

6 mm

32-50

8 mm first run, 10 mm final

For thickness > 50 mm

Special technique like pre heating is required. Preheating is done so that plate does not extract heat from the weld.

Min size however should not be more than thickness of thinner plate being joined

If the weld size is small it will cool faster due to heat extracted by the thicker plate. Hence rapid cooling leads to brittleness in the weld hence there should be min size of the weld controlled by the thickness of thicker plate.

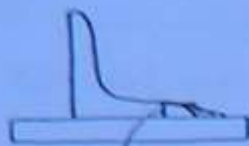
Max size of weld.

For square edge, Max size = thickness of thinner plate being joined - 1.5 mm



Square edge

For round edge



max size of weld = $\frac{3}{4}$ nominal thickness of round edge

(42)

Note

From economy point of view it is better to use smaller size of large length of weld and longer.

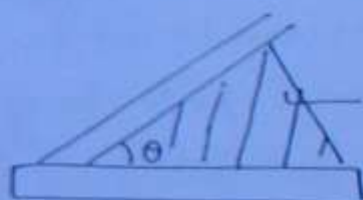
$$\text{quantity of steel} = \frac{1}{2} \times s \times s \times L$$

$$\propto L s^2$$

$$\text{Force} \propto L \times s$$

Throat of fillet weld.

Effective throat thickness is given by = $k \times \text{size of weld}$



weld = $k s$

Eff. throat thickness = $k (\text{size of weld})$
= $k s$

θ	60-90	91-100	101-106	107-113	114-120
k	0.7	0.65	0.6	0.55	0.5

Area resisting shear in fillet weld is $L \times t$

where L is the length of weld t is the eff. throat thickness hence force resisted by fillet weld

$$L \times t \times 0.4 f_y \rightarrow \text{Permissible shear}$$

throat thickness

Effective length of fillet weld.

$$L_{eff} = L_{overall} - 2s$$

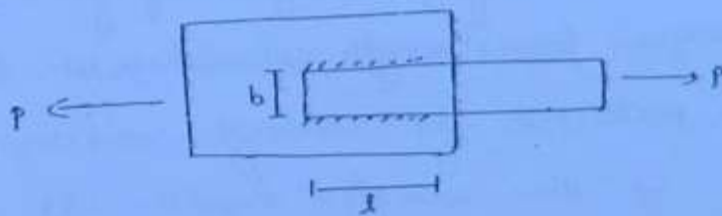
$s \rightarrow$ size of weld

In drawings the length shown is the effective length.

Minimum length of weld = $4s$ (for weld to be 100% effective in load transfer)

Side Fillet weld

(43)



$l \neq b$

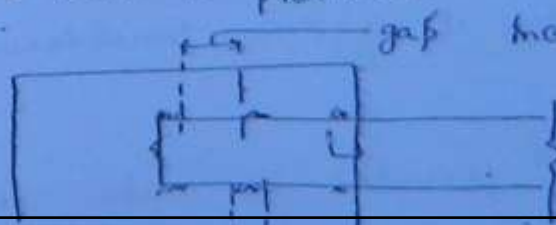
As width increases non-uniformity in stress in the plate increases to make it more uniform plug or slot weld can be used



Stress variation on the plate

Intermittent Fillet weld

When the length of smallest size weld required to transmit in load is less than the continuous length of joint. Intermittent fillet weld is provided.

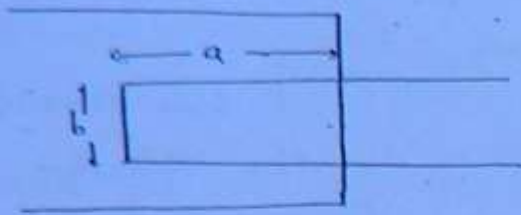


mean of knick - max gap

let $a \geq 200 \text{ mm}$

whichever is smaller

$t \rightarrow$ thickness of thinner plate



(44)

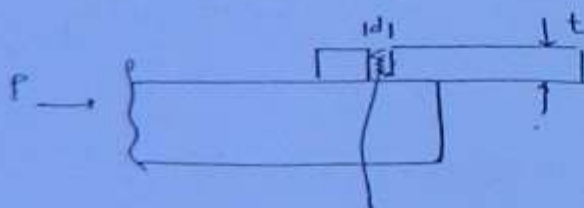
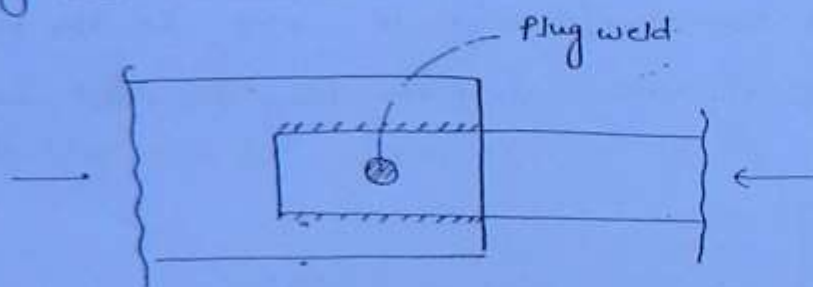
$$P = l \times t \times 4f_y \Rightarrow \text{find } l \text{ if } l < (2a + b)$$

b choose min

we provide intermittent fillet weld.

The strength of end fillet weld is generally larger than that of side fillet weld however for strength calculation we take the strengths of the two welds to be same.

Plug and slot weld.



$d \neq 3t$ or 25 mm which ever greater

t is the thickness of plate in which slot is made.

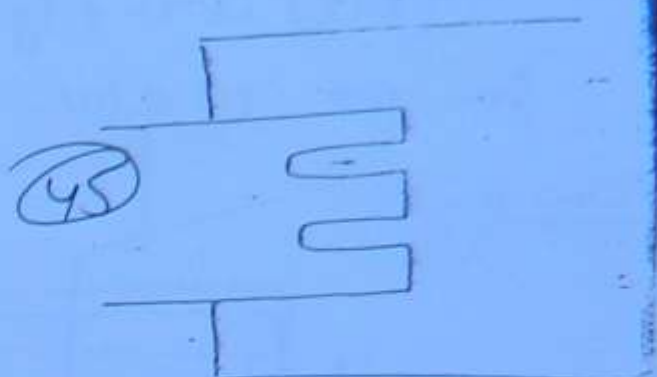
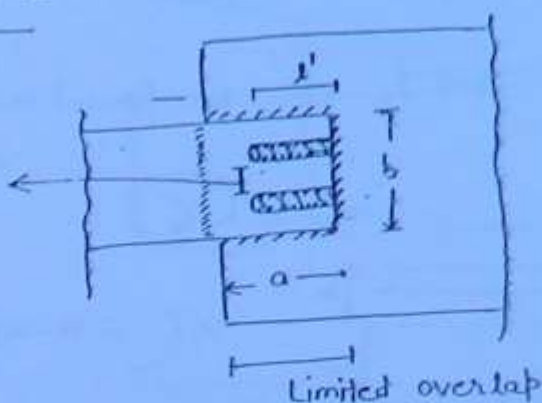
Effective connection b/w
top & bottom plate

Plug weld is capable of resisting shear however as per code recommendation it is not considered to be contributing to the strength.

- Plug weld is also provided to make stress variation in top plate more uniform.

slot weld -

gap b/w
slots should be
 $2t$



If the overlap is limited and even by providing the largest size of weld all along the available length, if P force can not be resisted then we provide additional length of connection by making slot. - The additional length of connection in the above figure will be $4l'$

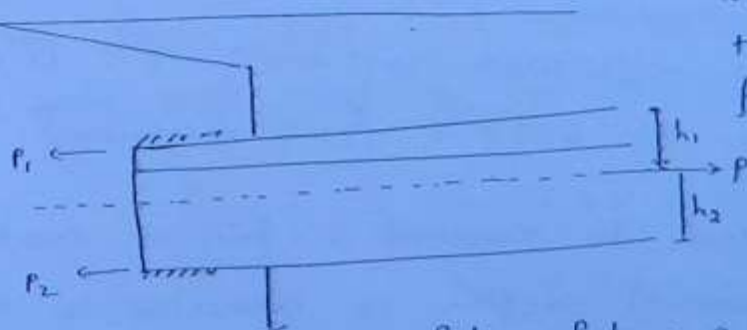
Width of slot $\neq 3t$ or 25 mm whichever is greater

$\gamma \neq 1.5t$ or 12 mm

Note Min overlap in lap joint $\neq 4t$ or 40 mm whichever is more

Fillet weld for truss member

Truss joint should be such that it should be moment free



$$P_1 h_1 - P_2 h_2 = 0$$

$$\frac{P_1}{P_2} = \frac{h_2}{h_1}$$

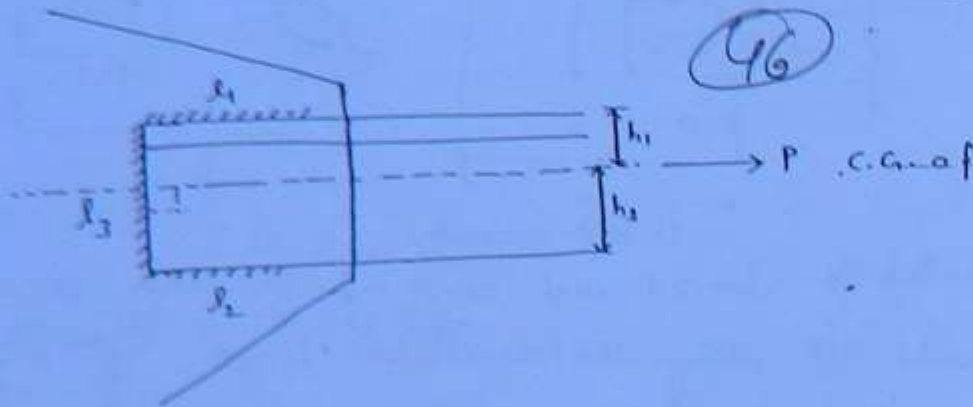
$$\frac{l_1 \times t \times 0.4 f_y}{l_2 \times t \times 0.4 f_y} = \frac{h_2}{h_1}$$

$$\frac{l_1}{l_2} = \frac{h_2}{h_1} \quad \text{--- (1)}$$

$$(l_1 + l_2) \times t \times 0.7 f_y = P \quad \text{--- (ii)}$$

from eq (i) + (ii) $l_1 + l_2$ can be found out

Case-II



$$P = (l_1 + l_2 + l_3) \times t \times 0.7 f_y \quad \text{--- (i)}$$

$\hookrightarrow$ Throat thickness

$$P_1 h_1 - P_2 h_2 - P_3 \left\{ \frac{h_1 + h_2}{2} - h_1 \right\} = 0$$

$$P_1 = l_1 \times t \times 0.7 f_y$$

$$P_2 = l_2 \times t \times 0.7 f_y$$

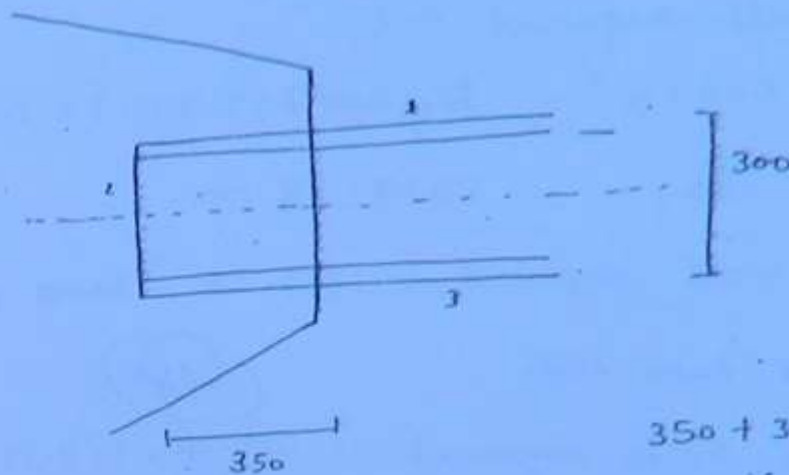
$$P_3 = l_3 \times t \times 0.7 f_y$$

Indian standard light channel

Q An ISLC 300 with area 4211 mm^2 , $T = 11.6 \text{ mm}$ (flange thickness), $t = 6.7 \text{ mm}$ (web thickness) is



used to transmit a pull of 600 kN. The channel section is connected to a gusset plate 10 mm thick. Design a fillet weld if overlap is limited to 350 mm and welding can be provided only on 3 sides. Use slot weld if required.



$$350 + 350 + 300 = 1000 \text{ mm}$$

Max size of fillet weld on side 1 = Thickness of thinner part
- 1.5 mm (2f edge)

$$= 10 - 1.5 = 8.5 \text{ mm}$$

Min size

$$= 5 \text{ mm}$$

Max size of fillet on side 2 = $6.7 - 1.5 = 5.2 \text{ mm}$

$$\text{min} = 3 \text{ mm}$$

If uniform size of weld is to be provided we will adopt 5 mm size.

Max force that can be resisted by providing weld on 3 side and adopting the max. possible size.

$$P_{\text{max possible}} = 350 \times 2 \times t_1 \times 0.7 f_y + 300 \times t_2 \times 0.7 f_y$$

$$t_1 = 0.7 S_1 = 0.7 \times 8.5$$

$$t_2 = 0.7 \times 5.2$$

$$P_{\text{max}} = 525.7 \text{ kN} < 600 \text{ kN}$$

Hence we need to provide slot welding.

Hence we will provide slots by adopting a uniform size of weld = 5 mm

length of weld required = l

$$600 \times 10^3 = l_{req} \times 0.7 \times 5 \times 0.9 \times 250$$

$$l_{req} = 1714.28 \text{ mm}$$

$$\text{Length of slot weld required} = 1714.28 - 1000 = 714.28 \text{ mm}$$

providing two slots

$$\text{length of slots required} = \frac{714.28}{2} = 357.14$$

Adopt 180 mm

Width of slot = $3t$ or 25 mm whichever is more

$$= 3 \times 6.7 \text{ or } 25$$

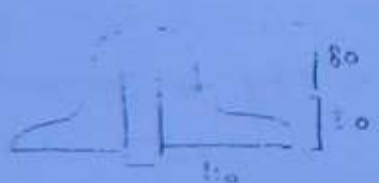
$$= 20.1 \text{ or } 25$$

$$\text{take } b = 25 \text{ mm}$$

Q. In an industrial shed and edge support consisting of two angles $110 \times 110 \text{ mm}$ is to be connected to 16 mm gusset plate for a tensile load of 650 kN

Design the moment free welded connection.

Assuming both the angles are placed back to back and connected by a single gusset plate.



Net area of each angle

$$2 \left(A - \frac{t}{2} \right) t$$

$$= \left(110 - \frac{t}{2} \right) t$$

$$(110 - t) t$$

$$(110 - t) t \times 150 \geq 3.75 \times 10^5$$

$$220t - t^2 - 2500 \geq 0$$

$$t > 10.73 \text{ mm}$$

$$\text{take } t = 12 \text{ mm}$$

3

$$S_{max} = \frac{3}{4} t \quad \text{or} \quad 1.5 \text{ mm}$$

$$= \frac{3}{4} \times 1.5 = 1.125$$

$$S_{min} = 1.125$$

$$S_{max} = 1.125$$

$$S_{min} = 1.125$$

$$T_{max} = 1.125$$

$$T_{min} = 1.125$$

Length of weld = 49

$$21.66 \times 1.125 = 24.41$$

$$21.66 \times 1.125 = 24.41$$

$$L = \frac{24.41}{0.16}$$

$$L = 152.56$$

$$\left(\frac{24.41}{0.16} \right) L = 152.56$$

$$L = 166.71$$

$$L = 413.63$$

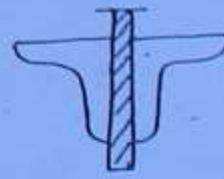


Weld
 1.125

170 mm

413 mm

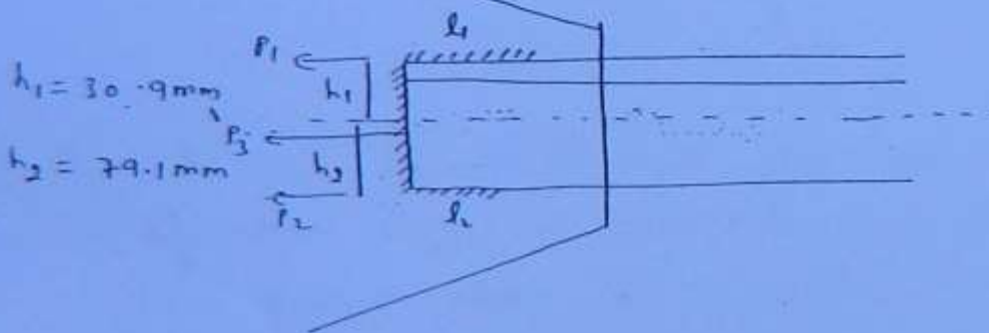
The best arrangement for transfer of loading to the gusset plate will be when two angles are connected on opp. side of gusset plate.



(B)

Hence each angle will carry 325 kN load

Hence we have to decide length of weld, size of weld and arrangement of weld.



As the thickness of angle is not given we will proceed on the basis of min size of weld decided on the basis of thickness of gusset plate

Min size = 5 mm adopted

$$\text{length of weld req.} = \frac{325000}{5 \times 0.7 \times 100} = 928.57 \text{ mm}$$

Note: i) Max. thickness available for angle

ii) Max. size available for angle

a) equal angle

b) Unequal angle

iii) Max depth of I section available

(iv) Gauge location for I-section

(v) Min thickness of plate

vi) Max thickness of plate

$$\text{Strength of weld} = 0.7 \times 5 \times 100 = \frac{NC}{350 \text{ N/mm}}$$

$$l_1 + l_2 = 928.57 - 110 = 818.57 \text{ mm}$$

$$P_1 = l_1 \times 0.75 \times 0.4 f_y$$

$$P_2 = l_2 \times 0.75 \times 0.4 f_y$$

$$P_3 = l_3 \times 0.75 \times 0.4 f_y$$

$$= 110 \times 0.75 \times 100 = 38.5 \text{ kN}$$

For moment free connection

$$P_1 \overset{30.9}{h_1} - P_2 \overset{79.1}{h_2} - P_3 \left(\frac{h_1 + h_2}{2} - h_1 \right) + 0 = 0$$

$$P_1 + P_2 = 325 - 38.5 = 286.5$$

$\therefore M = 0$ about centroidal axis

$$350 l_1 \times 30.9 - 350 l_2 \times 79.1 - 38.5 \times 10^3 \times 24.1 = 0$$

$$l_1 + l_2 = 818.57$$

$$30.9 l_1 - 79.1 l_2 = 2651$$

$$l_1 + l_2 = 818.57$$

$$l_1 = 612.72 = 615 \text{ mm}$$

$$l_2 = 205.84 = 210 \text{ mm}$$

Weld Notations



Fillet weld



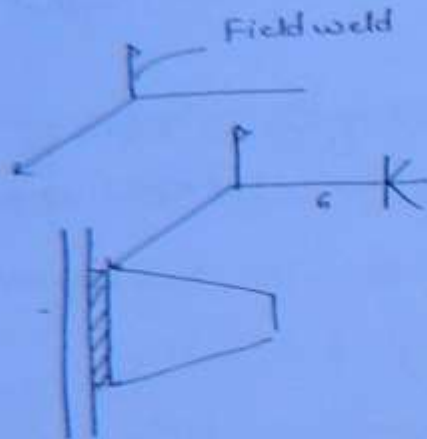
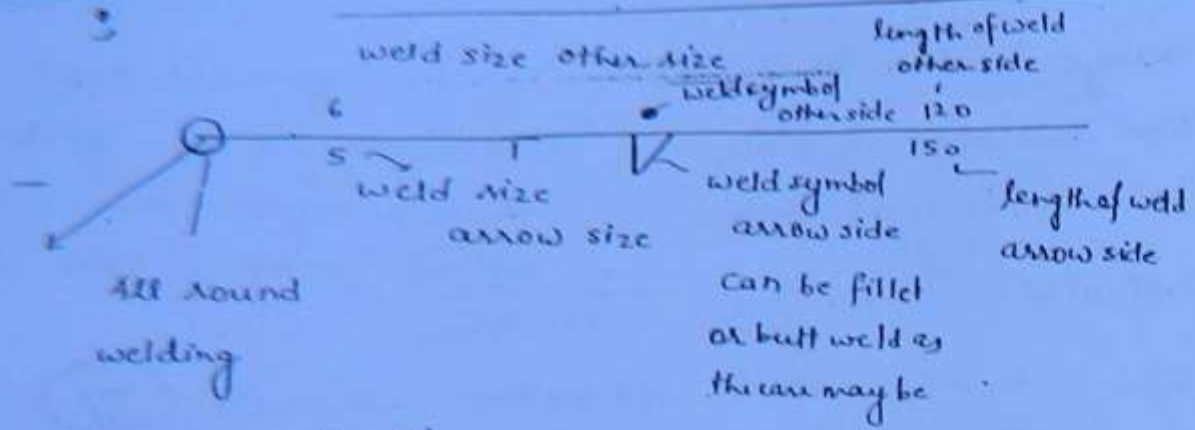
Square butt weld



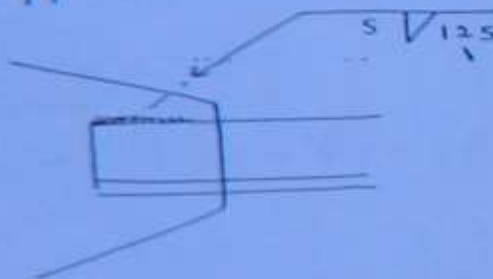
single V



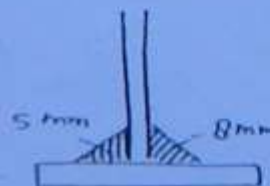
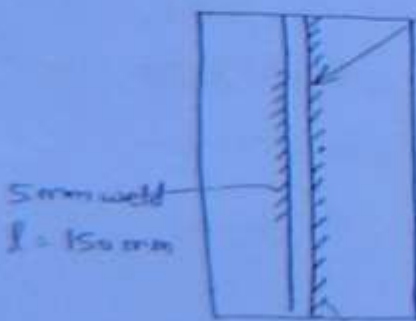
Double V



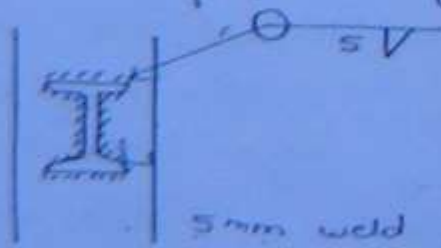
Field butt weld of throat thickness = 6 mm and weld is double bevel.

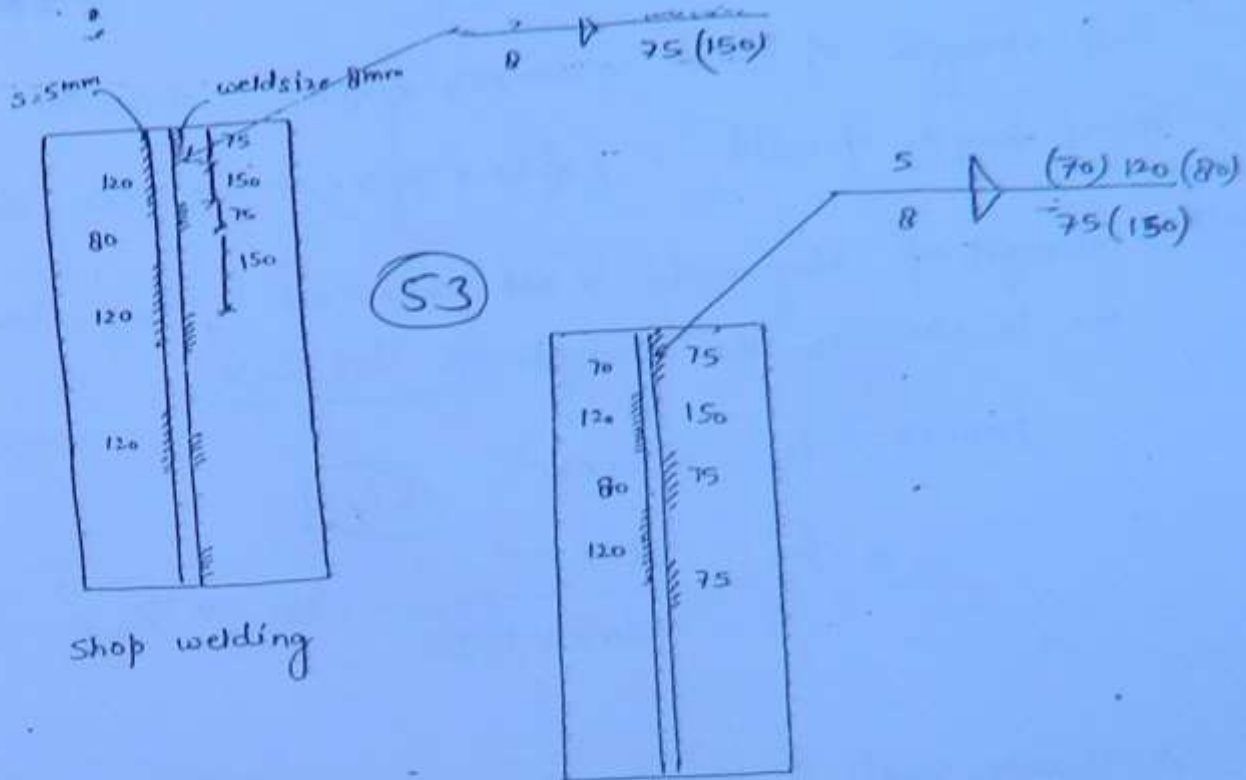


5 mm shop fillet weld of length 125 mm

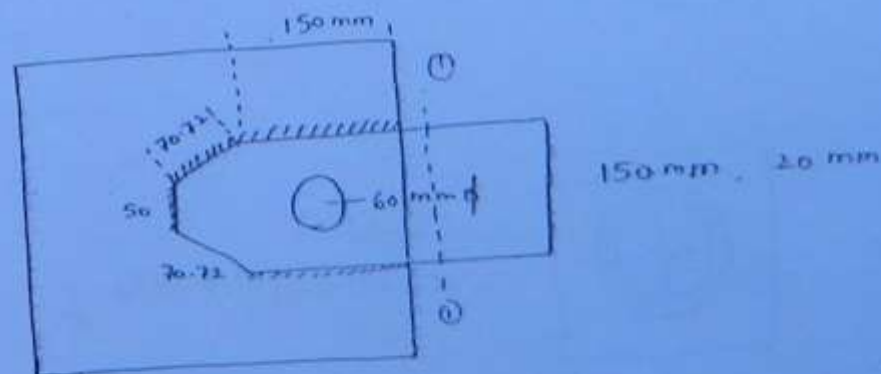


8 mm weld length 200 mm





Q. A plate of 150 mm width and 20 mm thickness is welded to another plate by fillet weld as shown in figure the size of weld is 12 mm throughout compute the av. shear stress produced in the weld for the full strength of plate if the allowable stress is 150 N/mm^2 in axial tension.



Note: As in this case the location of slot is not given the strength of plate can not be decided hence we will work on full strength of plate at sec 1-1

$$\text{Full strength of plate} = 150 \times 120 \times 150 = 450 \text{ kN}$$

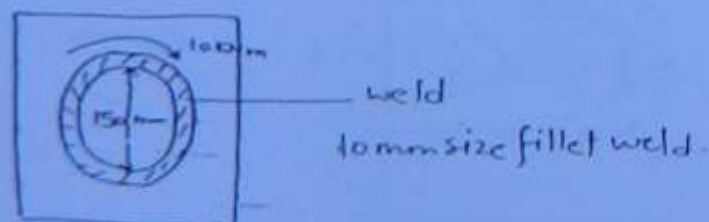
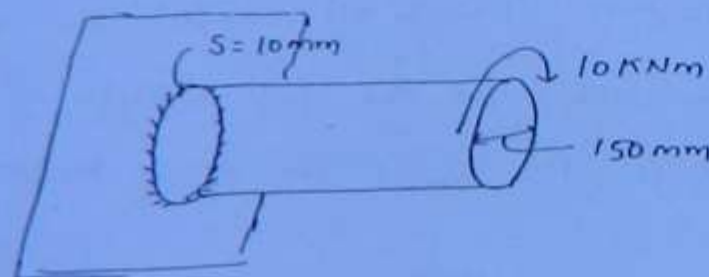
$$\text{total length of weld} = 2 \times (150 + 70.72) + 50 + 7 \times 60 = 680 \text{ mm}$$

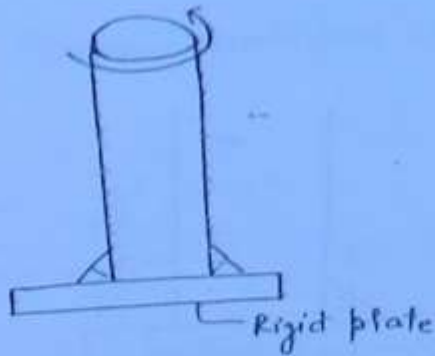
Note: strength of plug weld is not considered in design but we can consider the strength of slot weld.

$$0.75 \times f_t = 450 \times 10^3 \quad (54)$$

$$f_t = \frac{450 \times 10^3}{680 \times 0.7 \times 12} = 78.78 \text{ N/mm}^2$$

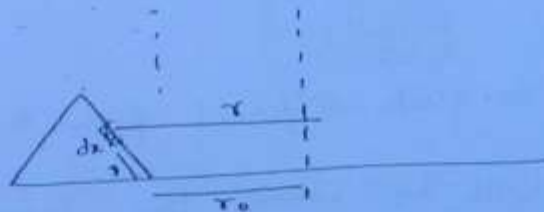
Q9 A circular shaft of diameter 150 mm is welded to a rigid plate by an external all round fillet weld of size 10 mm if a torque of 10 kNm is applied to the shaft find the maximum stress in the weld.





Shear stress = $\frac{T r}{J}$ → Polar moment of inertia of twisting section

Exact Calc. of J



$$\int_0^{75} 2\pi r dx r^2$$

$$r = 75 \text{ mm}$$

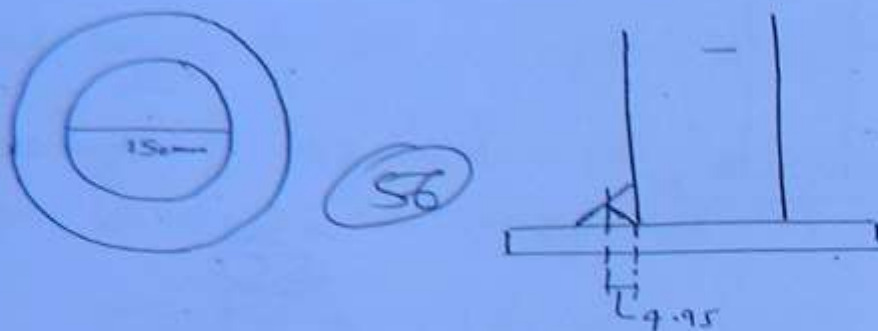
$$r = r_0 + \frac{x}{\sqrt{2}}$$

$$J = \int_0^{7 \times 10} 2\pi \left(r_0 + \frac{x}{\sqrt{2}} \right)^3 dx = 20.474 \times 10^6 \text{ mm}^4$$

$$r_{\text{max}} = r_0 + \frac{0.7 \times 10}{\sqrt{2}} = 79.949 \text{ mm}$$

$$\text{Max. Shear stress} = \frac{10 \times 10^6 \times 79.95}{20.474 \times 10^6} = 39.05 \text{ N/mm}^2$$

Ans. Approximate calc.



$$J = \frac{\pi}{32} \left[(150 + 2 \times 4.95)^4 - 150^4 \right]$$

$$= 14.3177 \times 10^6 \text{ mm}^4$$

(x) quite less as compared to actual value.

$$\tau = \frac{T \cdot r}{J} = \frac{10 \times 10^6 \times 79.95}{14.31 \times 10^6} = 55.83 \text{ N/mm}^2$$

$$J = \frac{\pi}{32} \left[(150 + 14)^4 - 150^4 \right] = 21.318 \times 10^6 \text{ mm}^4$$

Approximate calc. is quite different from the actual value a logical calculation will be when the projected width is taken as the actual width of resisting section and it is assumed that the stress is uniform over the cross section of throat



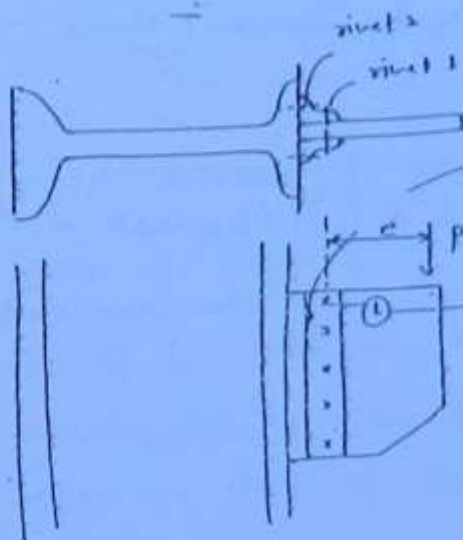
To: Shear stress on throat assuming constant

$$T_o \times 2\pi r \times 0.75 \times r = 10$$

$$T_o = \frac{10 \times 10^6}{2\pi \left(20 + \frac{7.5}{\sqrt{2}} \right)^2 \times 0.75}$$

$$= 35.57 \text{ N/mm}^2$$

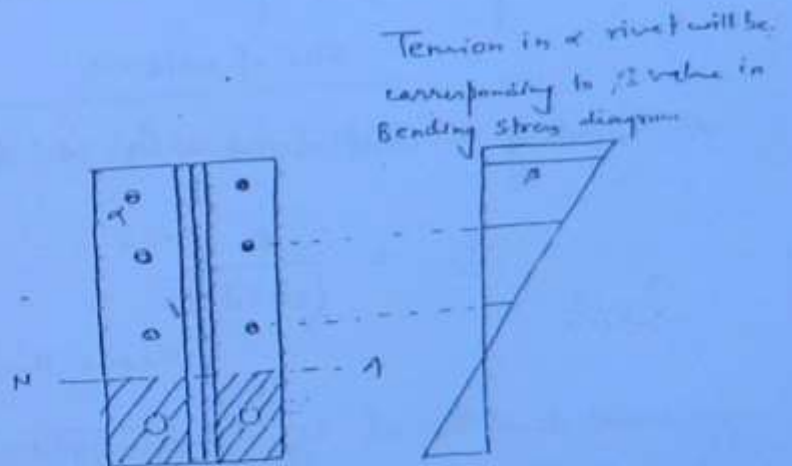
Eccentric connection using weld.



Rivet ② is subjected to shear and axial tension

subjected to direct shear + Torsional moment

(S7)



Tension in a rivet will be corresponding to σ value in Bending stress diagram

Bending stress variation

In rivet 2 check for safety is done as follows

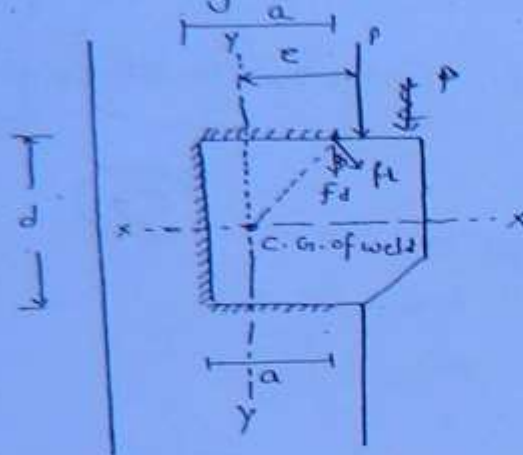
$$\frac{\text{Calculated axial force}}{\text{Permissible axial force}} + \frac{\text{Calc. Shear force}}{\text{Perm. shear force}} \leq 1.4$$

NH

Eccentric connection using welding.

Case-1

Weld subjected to direct shear + Torsional shear —



$$f_r = \sqrt{f_d^2 + f_t^2} + f_d f_t \cos \theta \leq \text{per.}$$

Shear stress in weld

(SP)

Size of weld = s

As welding is continuous area we will work in terms of stress

$$f_d = \frac{P}{(2a+d)t}$$

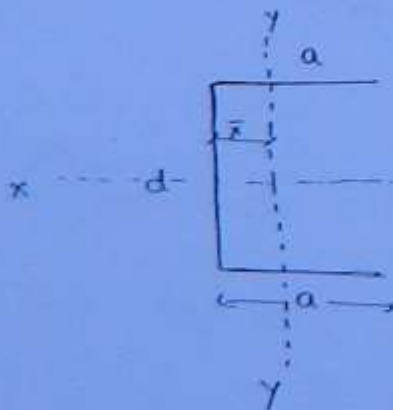
Throat thickness

$$f_d = \frac{P}{(2a+d)(0.7s)}$$

direct shear on throat of weld.

Direction of f_d is taken along the line of action of force P

$$f_t = \frac{Tx}{J}$$



Weld will be considered as a line area as shown above. Thickness of the line will be assumed as throat thickness

$$I_x = I_{xx} + I_{yy}$$

$$I_{xx} = \frac{t d^3}{12} + (a \times t) \left(\frac{d}{2} \right)^2 \times 2$$

$$I_{yy} = (t \times d) \bar{x}^2 + \left[\frac{t a^3}{12} + a t \left(\frac{a}{2} - \bar{x} \right)^2 \right] \times 2 \quad (54)$$

r is distance of point under consideration from c.g. of weld
 e is $\perp$ distance of line of action of P from the c.g. of weld.
 Dir. of f_t will be $\perp$ to the line joining point under consideration to the c.g. of weld and it will be in the same sense as that of the torsional moment.

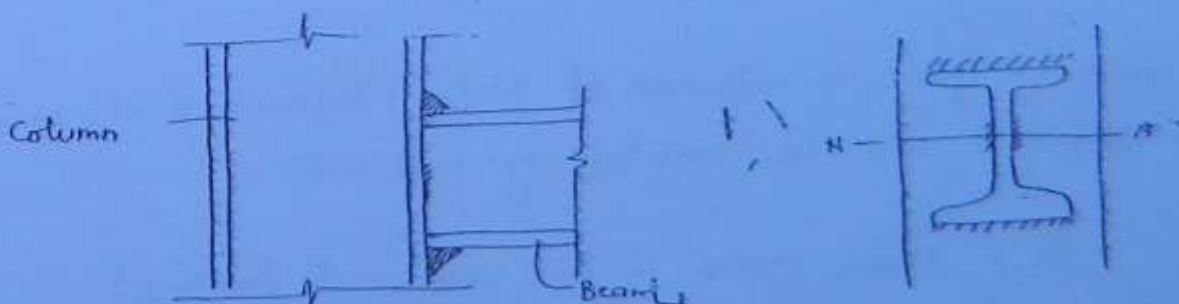
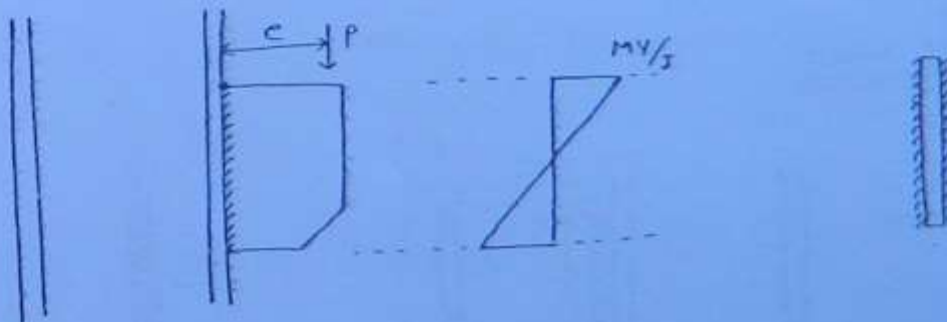
Resultant shear stress

$$f_r = \sqrt{f_d^2 + f_t^2 + 2f_d f_t \cos \theta}$$

for safety

Case-II

fillet weld subjected to direct load and bending.



Direct shear stress
vertical

$$f_v = \frac{P}{2dt}$$



(60)

$$= \frac{P}{2d(0.75)}$$

At any point along the length of weld the bending stress will be resisted by the fillet weld through shearing action on its throat hence horizontal shear stress in fillet weld (f_h)

$$f_h = \left(\frac{My}{I_w} \right)$$

$$I_w = 2 \left(\frac{td^3}{12} \right) = \frac{2(0.75)d^3}{12}$$

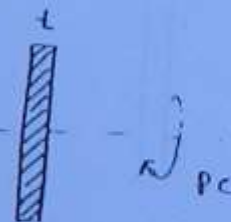
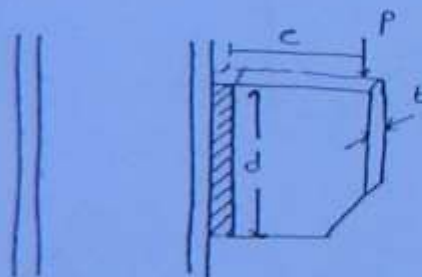
$$f_s = \sqrt{f_h^2 + f_v^2}$$

for safety of connection $f_s < \text{permissible shear stress in weld}$

Case - III

Butt Weld

Case



Butt weld is just an extension of plate whatever is the stress in the plate, it will be resisted by butt weld

$$f_s = \text{shear stress in butt weld} = \frac{P}{td} \text{ (vertical)}$$

$$f_b = \text{bending stress in butt weld} = \frac{PE y_{max}}{I_{xx}} = \frac{PE (d/2)}{\frac{td^3}{12}}$$

(61)

checking safety using interaction formula

$$\left(\frac{f_s}{\text{shear stress in butt weld}} \right)^2 + \left(\frac{f_b}{\text{perm. bending stress in butt weld}} \right)^2 \leq 1.0$$

Equivalency Method -

$$\sqrt{f_b^2 + 3f_s^2} \leq 0.9f_y$$

based on max distortion energy theorem

permissible bending stress for flanged section = 165 N/mm^2
= $(0.67 f_y)$

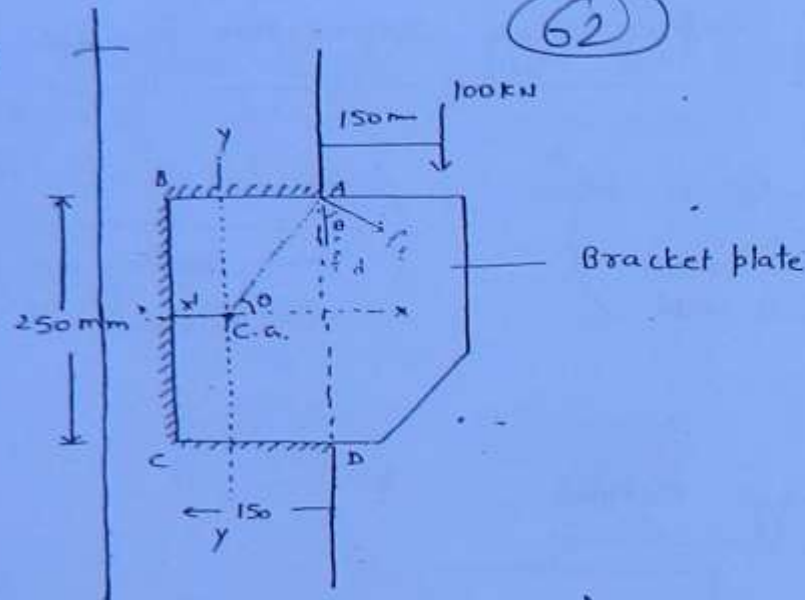
for solid sections. (, , ) permissible

bending stress is 185 N/mm^2

is connected

Q. A welded bracket connects the a plate to a column flange as shown in the fig. below determine the size of weld if the allowable stress in the weld is 110 N/mm^2

ISMB 300



(62)

$$\begin{aligned} X' &= \frac{A_1 X_1 + A_2 X_2}{A_1 + A_2 + A_3} \\ &= \frac{2(150 \times t \times 75) + 0}{550 \times t} = 40.91 \text{ mm} \end{aligned}$$

Maximum stress will be either at A or at D

$$\text{At A} \quad f_d = \frac{100 \times 10^3}{550 \times t} = \frac{181.818}{t} \text{ N/mm}^2$$

$$f_t = \frac{T r}{J} = \frac{T r_A}{I_{xx} + I_{yy}}$$

$$I_{xx} = 2(150 \times t \times 125^2) + \frac{t \times 250^3}{12} = 5.9896 \times 10^6 t \text{ mm}^4$$

$$\begin{aligned} I_{yy} &= 250 t \times 1^2 + \left[\frac{150^3 t}{12} + (t \times 150)(75 - 40.91)^2 \right] \times 2 \\ &= 1.3295 \times 10^6 t \text{ mm}^4 \end{aligned}$$

$$T = 100 \times 10^3 (300 - 40.91) = 25.9 \times 10^6 \text{ N mm}$$

$$r_A = \sqrt{(150 - 40.91)^2 + 125^2} = 165.908 \text{ mm}$$

$$f_t = \frac{T r_A}{J} = \frac{507.2096}{t} \text{ N/mm}^2$$

(63)

$$\cos \theta = 0.657$$

$$f_r^2 = f_d^2 + f_t^2 + 2 f_d f_t \cos \theta$$

$$f_r = \frac{720.009}{t} \text{ N/mm}^2$$

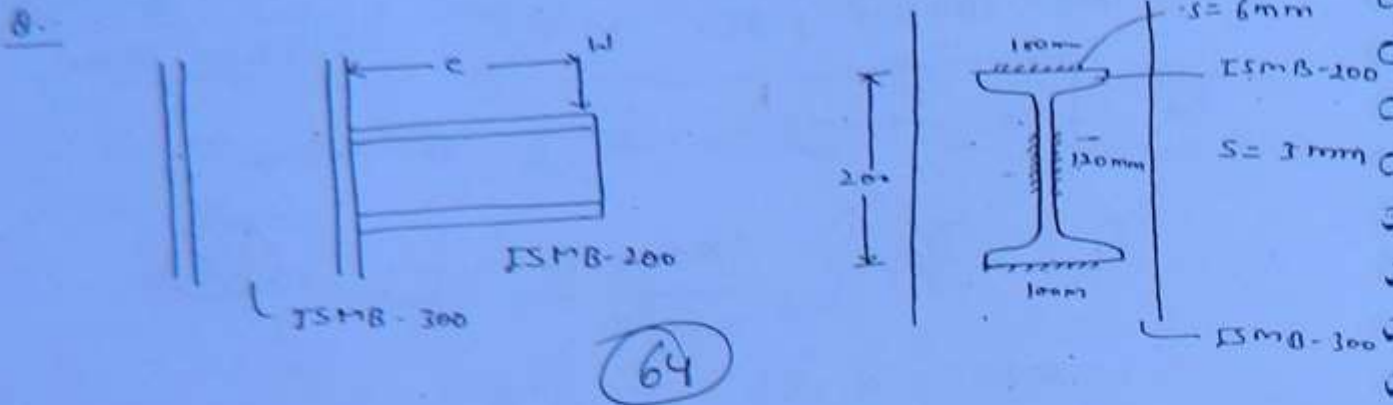
for safety of connection $f_r < \text{per. shear stress}$

$$\frac{720.009}{t} < 110$$

$$t > 6.545 \text{ mm}$$

$$s > \frac{6.545}{.7}$$

$$> \underline{\underline{9.35 \text{ mm}}}$$



Weld is subjected to direct shear W
and BM $= W L$

These external things are resisted by fillet weld through shearing action.

$$\text{Direct shear stress} = \frac{W L}{(100 \times 7 \times 6 + 120 \times 7 \times 3) \times 2} \times \frac{N}{\text{mm}^2}$$

$$= \frac{W L}{1344} \times \frac{N}{\text{mm}^2}$$

$$\text{Bending shear stress} = \frac{M y}{I} = \frac{W L (200) \times 100}{I}$$

$$I = 2 \times (100 \times 7 \times 6) 100^2 + \frac{7 \times 3 \times 120^3 \times 2}{12}$$

$$= 9.0048 \times 10^6 \text{ mm}^4$$

$$f_1 = \frac{W L}{450.24 \times 10^3} \times \frac{N}{\text{mm}^2}$$

$$f_r = \sqrt{f_1^2 + f_2^2} = \sqrt{\left(\frac{W L}{1344}\right)^2 + \left(\frac{W L}{450.24}\right)^2}$$

$$= 2.342 \times 10^{-3} W L \leq 100$$

$$W \leq 42.69 \text{ kN}$$

Note Gearing system resist lateral loads.

Tension Member

Comparison between tension and compression member.

Tension member

Compression member

- 1) In tension net area is effective
- 2) There is no stability problem.
- 3) Permissible stress
 $\sigma_{at} = 0.6 f_y$
- 4) Design is straight forward.

- 1) Gross area is effective.
- 2) There is stability problem b/c member may buckle before achieving full strength
- 3) $\sigma_{ac} < 0.6 f_y$
- 4) Design is based on trial and error.

Note Theoretically there is no limitation on slenderness ratio of tension member since stability is of little concern. However the member may be subjected to compressive load during transportation and erection hence in order to provide adequate rigidity to prevent undesirable lateral buckling and excessive vibration IS code limits the slenderness ratio values as follows

$$\text{Slenderness ratio } \lambda = \frac{l_{eff}}{r_{min}}$$

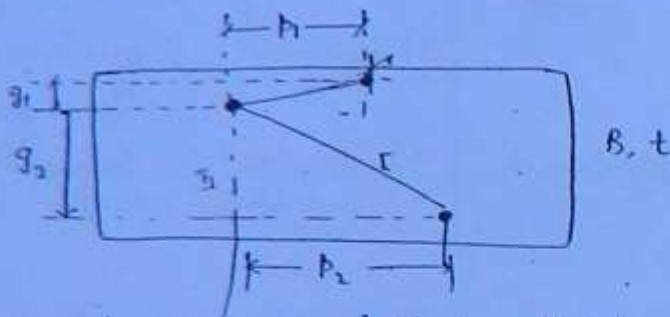
S.No.	Description	Max S.R.	Max S.R.
1)	A tension member in which reversal occurs due to load other than wind or EQ	180	
2)	A member normally acting as a tie in a roof truss or bracing system but subjected to compression due to wind or EQ	350	

S.No	Description	Max. S.F.
------	-------------	-----------

Net Sectional Area

For plates -

A plate may have various modes of failure in tension hence all the modes are required to be examined and the mode which gives the min net area will be the most critical mode.



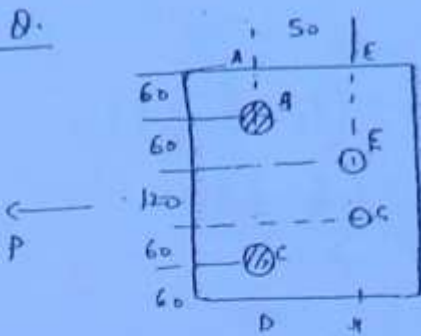
The member may fail in tearing, either along 1-1 or 1-2 or may be 2-3. Net area for all of these failure modes will be calculated and the minimum of it will be the most critical.

$$A_{net} = Bt - nd't + \left(\frac{p_1^2}{4g_1} + \frac{p_2^2}{4g_2} \right) t = B_{eff} \times t$$

↓
No. of rivets along failure line

for each inclined line $\left(\frac{p^2}{4g} \times t \right)$ is added

$$A_{net} = Bt - 2d't + \frac{p^2}{4g} t$$



The thickness of plate is 10 mm
hole dia 22 mm find the min net
Area provided by the plate.

(67)

$$NEA_{ABCD} = 360 \times 10 - 2 \times 22 \times 10 = 3160 \text{ mm}^2$$

$$NEA_{ABFCD} = 360 \times 10 - 3 \times 22 \times 10 + \left(\frac{50^2}{4 \times 60} + \frac{50^2}{4 \times 180} \right) \times 10$$

$$= 3078 \text{ mm}^2$$

$$NEA_{ABFGCD} = 360 \times 10 - 4 \times 22 \times 10 + \left(\frac{50^2}{4 \times 60} + 0 + \frac{50^2}{4 \times 180} \right) \times 10$$

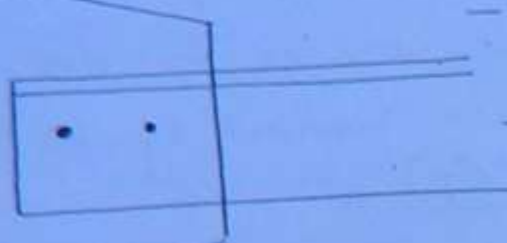
$$= 2928.33 \text{ mm}^2$$

$$NEA_{ABFGH} = 360 \times 10 - 3 \times 22 \times 10 + \frac{50^2}{4 \times 60} \times 10 = 3044.17$$

★ In this case for calculation of force we have to add the
rivet value of c

Hence the most critical section is ABFCD

Net Area for angles



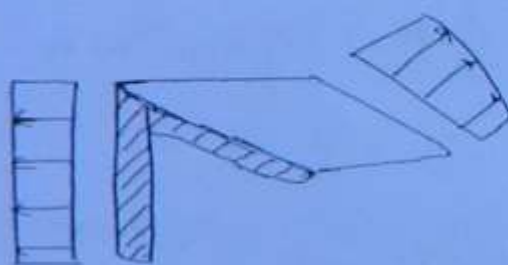
$$A_1 = \left(l_1 - d' - \frac{t}{2} \right) t$$

$$A_2 = \left(l_2 - \frac{t}{2} \right) t$$

→ P



Force is transferred in the member through the gusset plate. Location of transfer is at the location of rivets/welds. This force is then distributed in the whole member through shearing. The connected leg leads over the outstanding leg in the distribution through shear stress. Thus there is a shear lag existing between connected and outstanding leg. The stresses in the angle at the location of joint can be shown as follows.

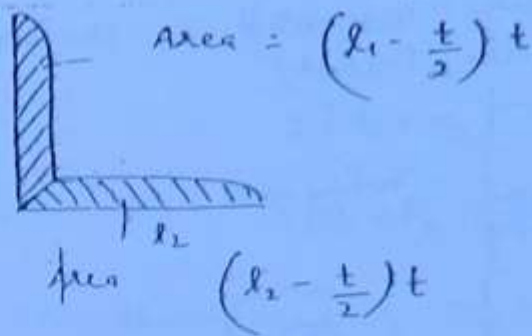


As the stress in outstanding leg is less, the force carried by it, will be less. To account for this, net area is taken as $(A_1 + K A_2)$

where K is a reduction factor for outstanding leg

$A_1 \rightarrow$ Area of connected leg

$A_2 \rightarrow$ outstanding leg



Total area
= $(l_1 + l_2 - t)t$

(69)

single ^{angle} leg connected w/ through one leg only

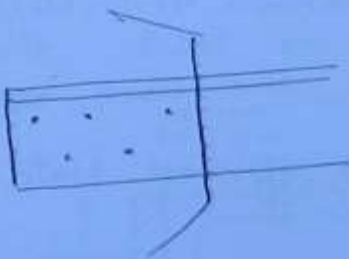


$A_{net} = A_1 + kA_2$

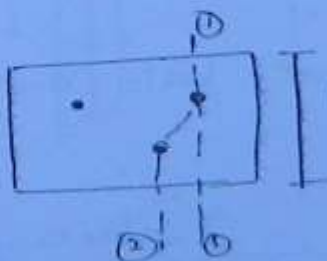
$k = \frac{3A_1}{3A_1 + A_2}$

$A_1 = (l_1 - d' - t/2)t$

$A_2 = (l_2 - t/2)t$

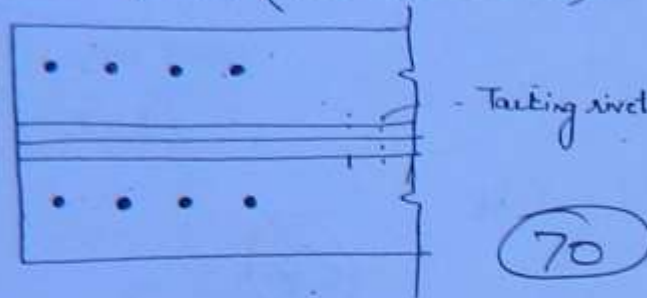


$A_{net} = A_1 + kA_2$
= $(l_2 - \frac{t}{2})t$



$A_{net} = \min \left\{ \begin{aligned} &(l_1 - \frac{t}{2} - d')t, \\ &(l_1 - \frac{t}{2} - 2d' + \frac{P^2}{4g})t \end{aligned} \right\}$

Case-19 (a) When two angles are connected on the same side of gusset plate (and are tacked)



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

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

$A_1 \rightarrow$ Area of connected legs

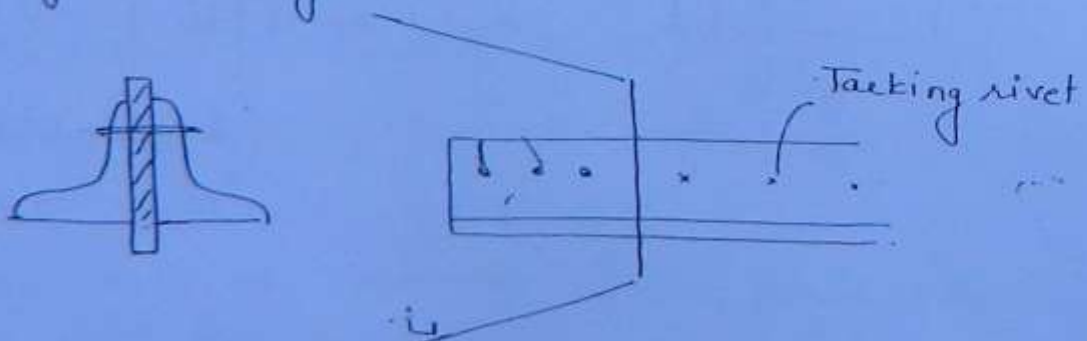
$A_2 \rightarrow$ " " outstanding legs

(b) When two angles are connected on the same side of gusset plate and not tack rivetted.

In this case two angles will behave individually hence net area would be twice the area corresponding to single ^{angle} ~~area~~ connected to a gusset plate.

Case-II (a)

Two angles connected on the ^{opposite side of} gusset plate and tacked along the length.



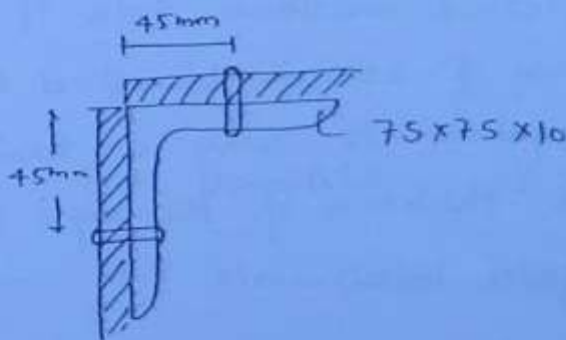
$$\begin{aligned}
 A_{net} &= (A_{gross} - \text{Area of hole}) \\
 &= 2(A_1 + A_2) - \text{Area of hole} \\
 &= 2(l_1 + l_2 - t)t - 2d't
 \end{aligned}$$

(71)

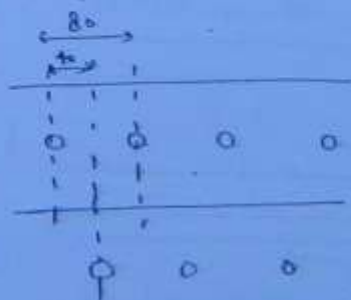
(b) When there is no tack rivetting along the length the two angles will behave individually and net area would be twice that corresponding to single angle connected to gusset plate.

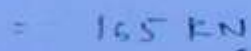
Note Shear lag effect is non existing in this case (can be)

Q. 04E3 An ISA 75x75x10 is connected to gusset plate by 16 mm diameter rivet through both legs the pitch on each leg is 80 mm and the rivets on one leg are staggered by 40 mm w.r.t. those on other. Find allowable tensile load on the angle.



Sol



$$d' = 16 + 1.5 = 17.5$$


Sol.

$$115 - 2 \times 23.5 - \frac{t}{2} = 109.67$$

(73)

$$150 - 2 \times 23.5 - \frac{t}{2} = \frac{40^2}{4 \times 60} \cdot \frac{t}{2} = 109.67$$

$$A_{net \text{ req.}} = \frac{320}{0.6 f_y} = \frac{320 \times 10^3 \text{ N}}{150 \text{ N/mm}^2} = 2133.33 \text{ mm}^2$$

$$A_{net \text{ available}} = A_{1 \text{ net}} + k A_2$$

$$A_2 = \left(115 - \frac{t}{2}\right) \times t$$

$$A_{1 \text{ net}} = \left[150 - \frac{t}{2} - 2 \times 23.5 + \frac{40^2}{4 \times 60}\right] \times t$$

$$= \left(109.67 - \frac{t}{2}\right) t$$

The thickness will be assumed in such a way that area available should be more than Net area required.

$$\text{Assume } t = 8 \text{ mm}$$

$$A_{1 \text{ net}} = 845.336 \text{ mm}^2$$

$$A_2 = 888$$

$$k = 0.74$$

$$A_{net \text{ available}} = 1734.08 < A_{net \text{ req.}} \text{ not safe}$$

$$\text{Assume } t = 10 \text{ mm} \Rightarrow \text{unsafe}$$

$$t = 12 \text{ mm} \Rightarrow \text{safe}$$

$$k = \frac{3A_1}{3A_1 + A_2} = \frac{3\left(109.07 - \frac{t}{2}\right)}{3\left(109.07 - \frac{t}{2}\right) + \left(115 - \frac{t}{2}\right)}$$

(24)

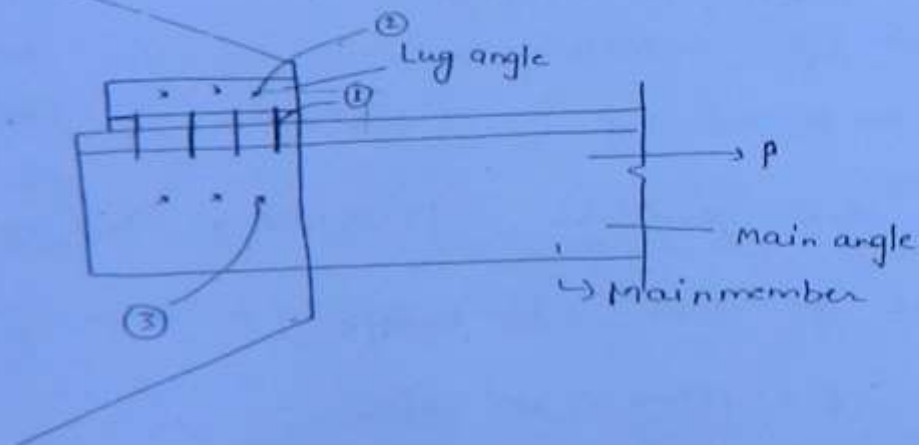
$$NEA = A_1 + kA_2$$

$$2133.33 = \left(109.07 - \frac{t}{2}\right)t + \frac{327.21 - 1.5t}{442.21 - 2t} \cdot \left(115 - \frac{t}{2}\right)t$$

$$t = 11.59 \text{ mm}$$

$$\text{take } t = 12 \text{ mm}$$

Lug Angles



Lug angle is a short length of angle section used at a joint to connect the outstanding leg of main member thereby reducing the length of joint.

The rivet connecting the outstanding leg of main member with the lug angle should start in advance of all other rivets. This is done to ensure that force in the outstanding leg is effectively transferred to the lug angle.

When angle members are main members →



connection with the gusset plate are designed for forces greater than equal to 1.2 times the force in outstanding leg of the main member.

$$\text{Force in the outstanding leg} = \frac{F A_2}{(A_1 + A_2)}$$

$A_2 \rightarrow$ Area of outstanding leg

$A_1 \rightarrow$ Area of connected leg

Hence designed force for lug angle and rivet 2 is

$$F_{D2} = 1.2 \left(\frac{F A_2}{A_1 + A_2} \right)$$

Connection of outstanding leg of main member with the lug angle should be designed for force $\geq 1.4 \times$ force in outstanding leg

Rivet 1 will be designed for

$$F_{D0} = 1.4 \left(\frac{F A_2}{A_1 + A_2} \right)$$

When channel sections are main members.

- Lug angles and it's connection with the gusset plate should be designed for the force 1.1 times force in out standing legs. (76)
- Connection of lug angles with the out standing legs of channel should be designed for a force greater than equal to 1.2 times the force in the outstanding legs.
- Minimum no. of rivets in lug angles should be 2.

Rivet 3 should be designed for force in connected leg.

ES-95 Q.2 Page 75

Ans

As force is not given the maximum force that the angle can resist will be found out under the assumption that, at any section main angle is reduced by 1 rivet hole.

$$F_{max} = (A_{gross} - A_{hole}) \times \sigma_{at}$$

$$A_{gross} = (75 + 100 - 10) \times 10 = 1650 \text{ mm}^2$$

$$A_{hole} = d' \times t = 21.5 \times 10 = 215 \text{ mm}^2$$

$$F_{max} = (1650 - 215) \times 150 = 215.25 \text{ kN}$$

$$A_1 = \left(100 - \frac{t}{2}\right) \times t = 950$$

$$A_2 = (75 - 5) \times 10 = 700$$

$$F_{\text{out standing}} = \frac{F A_2}{A_1 + A_2} = \frac{215.25 \times 700}{1650} = 91.318 \text{ kN}$$

$$A_1 = (100 - 5) \times 10 = 950 \text{ mm}^2$$

$$A_2 = 700 \text{ mm}^2$$

(77)

$$F_{\text{connected}} = 123.932 \text{ kN}$$

$$\text{Rivet value} = \min \left(\overset{10 \text{ mm}}{\text{shearing}}, \overset{8 \text{ mm}}{\text{bearing}} \right)$$

$$R_v = \min \left(\frac{\pi d^2}{4} \times 100, d' t \times 300 \right)$$

$$= \left(\frac{\pi 21.5^2}{4} \times 100, 21.5 \times 10 \times 300 \right)$$

$$= (36.305 \text{ kN}, 64.5 \text{ kN}), 36.305 \text{ kN}$$

$$R_v = 36.305 \text{ kN}$$

$$\text{No. of rivet } 3 = \frac{123.932}{36.305} = 3.41$$

Adopt 4 no.

No. of rivet 2

Design of lug angle

$$F_{\text{design lug angle}} = 91.318 \times 1.2 = 109.582 \text{ kN}$$

$$A_{\text{net req.}} = \frac{109.582 \times 10^3}{150} = 730.55 \text{ mm}^2$$

Let us adopt ISA 60x60x8

$$A_{\text{net}} = 896 - 21.5 \times 8 = 724 \text{ mm}^2 < A_{\text{net req.}}$$

Not safe

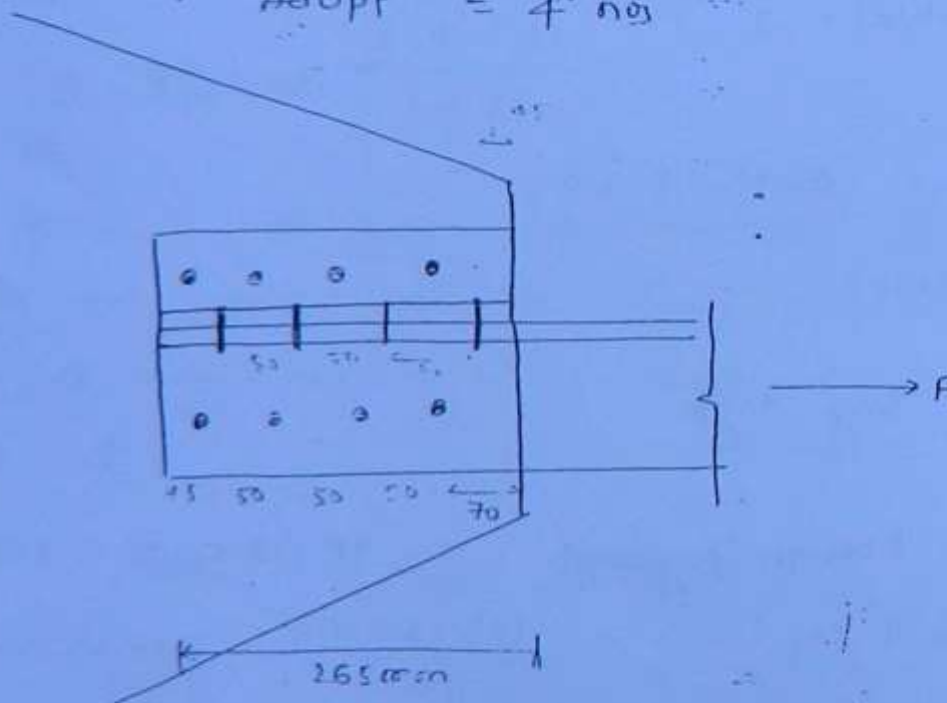
Hence adopt a bigger section

Let us adopt BA $60 \times 60 \times 10$

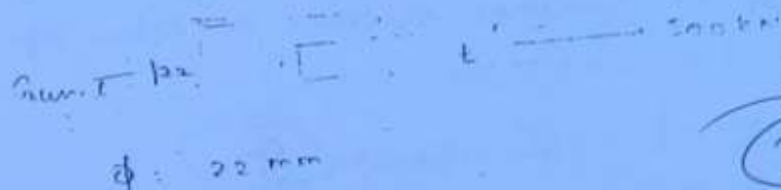
$$\text{Area provided} = 1100 - 21.5 \times 10 = 885 \text{ mm}^2 > \text{Area req.} \\ \text{o.k.}$$

$$\begin{aligned} \text{No. of rivet 1} &= \frac{1.4 \times F_{wt}}{R_v} \quad (78) \\ &= \frac{1.4 \times 91.318}{36.305} = 3.52 \\ &\text{adopt 4 no} \end{aligned}$$

$$\begin{aligned} \text{No. of rivet 2} &= \frac{1.2 \times F_{wt}}{R_v} \\ &= \frac{1.2 \times 91.318}{36.305} = 3.018 \\ &\text{Adopt 4 no} \end{aligned}$$



Sol. 3



The thickness of main plate depends on the tearing strength of the main plate that is

$$\text{tearing strength} \geq 500 \text{ kN}$$

Tearing strength can be known only if arrangement of rivet is known.

Arrangement of rivet is known only when no. of rivets are known.

No. of rivets are known only when rivet value is known

Rivet value is known only when we know whether shearing or bearing govern.

The rivets are in double shear hence shearing strength is known.

Bearing strength will depend on the thickness of main plate. By equating shearing and bearing strength of rivet we get the thickness of main plate under the assumption that combined thickness of cover plate is more than that of main plate.

If thickness is not capable of resisting 500 kN load, thickness has to be increased. If thickness is increased bearing strength will become more than the shearing str. of rivet thing

Hence the rivet value will be governed by shearing strength of rivet. Hence no. of rivet will be $= \frac{500}{22}$

No. of rivet will be arranged and tearing strength will be calculated at various sections in terms of thickness t

allowing per shear = 100 N/mm^2 (8)

Sol. Rivet is in double shear

$$\text{Shearing st. of rivet} = 2 \times \frac{\pi}{4} \times (23.5)^2 \times 100$$

$$= 86.75 \text{ kN}$$

Assuming the the combined thickness of cover plate to be more than main plate

Bearing strength = $d' \times t \times \sigma_{br}$

$$= 23.5 \times 300 \times t = 7.05 t \text{ kN}$$

$$86.747 = 7.05 t$$

$$t = 12.305 \text{ mm}$$

Max. force that gross area corresponding to this thickness

$$\text{can resist} = 6 \times 12.305 \times 250 \times 260 = 480.5 \text{ kN} < 500 \text{ kN}$$

Hence thickness of main plate has to be 9

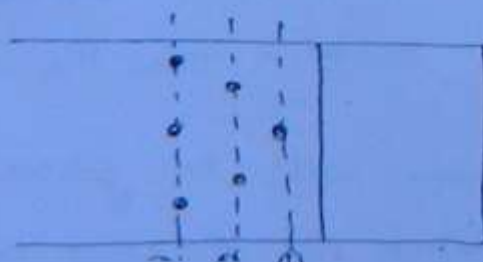
thus shearing strength govern the rivet value.

$$\Rightarrow R_v = 86.748 \text{ kN}$$

$$n = \frac{500}{86.748} = 5.7$$

adopt $n = 6$ rivet

The 6 no. of rivet can be arranged in diamond pattern



Tearing strength of secⁿ 1-1

$$= (250 - 23.5) \times t \times 0.6 \times 260 \geq 500 \times 10^3$$

$$t \geq 14.716 \text{ mm } 14.151 \text{ mm}$$

at 2-2

$$(250 - 2 \times 23.5) \times t \times 0.6 \times 260 + 86.748 \times 10^3 \geq 500 \times 10^3$$

$$t \geq 13.572 \text{ mm}$$

$$\geq 13.05 \text{ mm}$$

Hence we will adopt thickness 15 mm

Let us adopt 16 mm thickness of main plate

& check for strength of cover plate

For cover plate secⁿ 3-3 is critical

$$(250 - 3d') \times t \times 0.6 \times 260 \geq 500$$

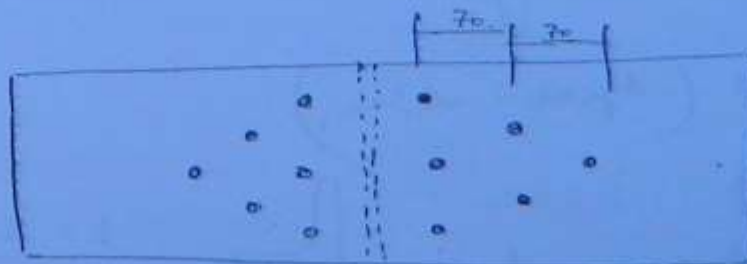
$$t \geq 17.85 \text{ mm}$$

Adopting thickness of cover plate as 10 mm each

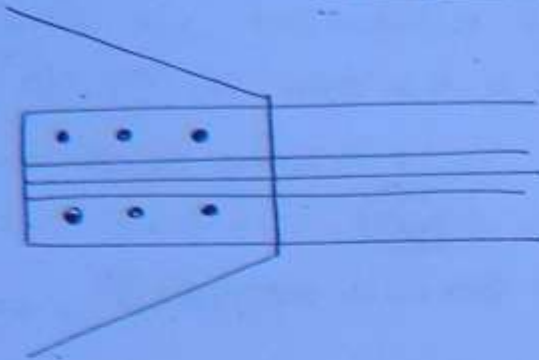
For gusset plates as the thickness of main gusset plate as well as combined thickness of two cover plate are more than 12.3 mm hence shearing will govern the rivet value.

$$\text{hence } = \frac{500}{86.74} = 5.7$$

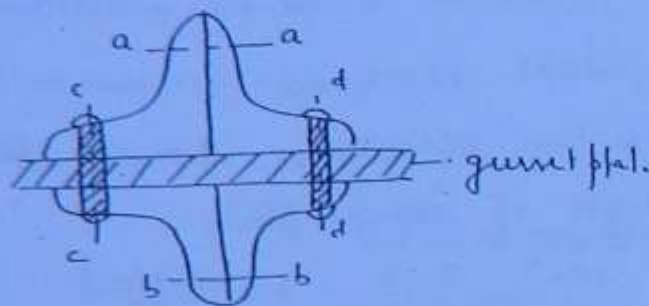
adopt 6 rivet



Compression Member



(82)

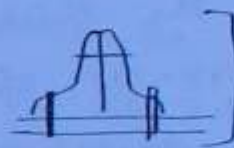


1) Tacking along a, b, c, d

$$A_{net} = (A_{gross} - 4 A_{hole})$$

2) Tacking along a & b

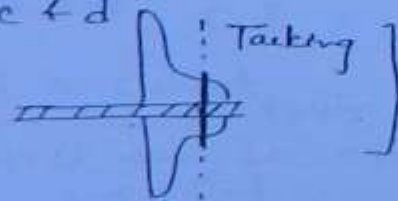
$$A_{net} = \left[2 \times \right]$$



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

3) Tacking along c & d

$$A_{net} = \left[2 \times \right]$$



$$k = 5A_1$$

$$= 2 \times 2 (A_{gross} - A_{hole})$$

4) No tacking

$$A_{net} = 1 \times$$



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

Ex. Angle $60 \times 60 \times 10$

$$A_{gross} = (60 + 60 - 10) \times 10 = 1100 \text{ mm}^2$$

(83)

Can 1

$$4 \times 1100 - 4 \times 21.5 \times 10 = 3540 \text{ mm}^2$$

Can 2

$$k = \frac{SA_1}{SA_1 + A_2} = \frac{5 \times 670}{5 \times 670 + 1100} = 0.7528$$

$$A_{net} = 2 (670 + 0.7528 \times 1100) = 2996.16 \text{ mm}^2$$

Can 3

$$2 \times \left[\text{Diagram of a hole in a plate} \right] = 2 \times (2 \times 1100 - 2 \times 21.5 \times 10)$$

$$= 3 \times 3540 \text{ mm}^2$$

Can 4

$$4 \times \left[\text{Diagram of a hole in a plate} \right] = 4 (A_1 + kA_2)$$

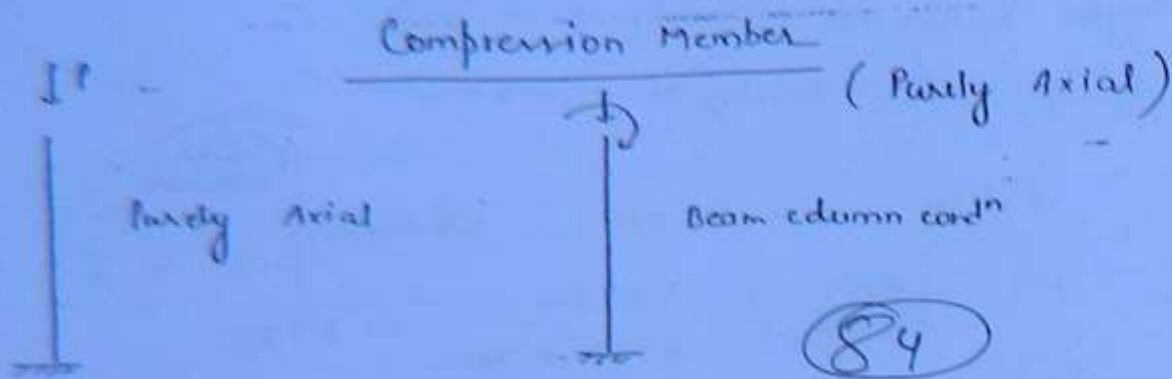
$$A_1 = 335$$

$$A_2 = \left(60 - \frac{t}{2} \right) t = 550$$

$$k = \frac{3A_1}{3A_1 + A_2} = 0.6463$$

$$A_{net} = 2761.86 \text{ mm}^2$$

Note Max. deduction due to web hole at any section along the length of member should never be more than max deduction of hole at any secⁿ at the joint. This is done to ensure that if the joint is not failing member will not fail.



For long columns under purely axial loading the failure is always by buckling and buckling load is given by Euler's load

$$P = \frac{\pi^2 EI}{L^2}$$

The buckling stress is given by Euler's stress

$$\text{Euler stress} = - \frac{\pi^2 E}{\lambda^2}$$

$$\lambda = \frac{l_{eff}}{r_{min}}$$

$r_{min} \rightarrow$ Min radius of gyration of the section and l_{eff} is eff. length of compression member which depend on end support condition. However the IS code takes into account the failure by buckling and crushing simultaneously through the use of Merchant Rankine formula

$$\sigma_{ac} = \text{Res. stress for axial comp} = \frac{0.6 f_{cc} \cdot f_y}{\left[(f_{cc})^{1.4} + (f_y)^{1.4} \right]^{1/1.4}}$$

$f_{cc} \rightarrow$ Euler stress

$f_y \rightarrow$ Yield stress.

For a given grade of steel $\sigma_{ac} = f(\lambda)$

As σ_{ax} decreases

$\frac{1}{E} \cdot \sigma_{ax}$

Effective length. (for columns)

As b/w point of inflection

S. No.

Description

(left) $\frac{l_{eff}}{theoretical}$

(1)



0.65l

(2)



0.8l

0.707l

(3)



l

l

(4)



Fixed at one end and at other end restrained against rotation but fixed in position

1.2l

(5)



Fixed at one end but at other end partially restrained against rotation but not fixed in position

1.5l

Note

Length adopted by IS code is more than the theoretical value because it is impossible to simulate perfect fixity of support. So we $l_{eff} \geq l \geq \sigma_{ax}$

(6)



2l

(7)



2l

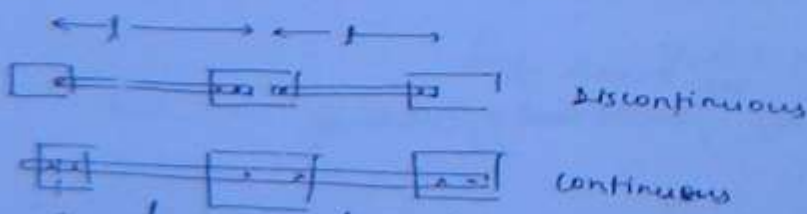
The above values are $\uparrow$ by 10% increase of battered column

Effective length of angle strut

used in trusses and bracing system

	Description	leff	Allowable compressive stress (correct)
1. Continuous	Single or double angle	$.7l$	σ_{ac} <u>86</u>
2. Discontinuous	Single angle connected with one rivet only	l	$.8 \sigma_{ac}$
3. "	Single angle with more than one rivet or weld	$.85l$	σ_{ac}
4. "	Double angle back to back on opposite side of gusset plate	$.7 \text{ to } .85l$	σ_{ac}
5. "	Double angle on same side of gusset plate	l	$.8 \sigma_{ac}$

* Actual value of effective length depend on the rigidity of joint



As rigidity of joint $\uparrow$
leff $\downarrow$ & vice versa

Maximum slenderness ratio

(87)

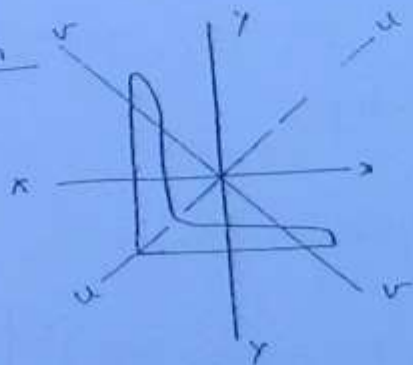
λ_{max}

S.No.

Description

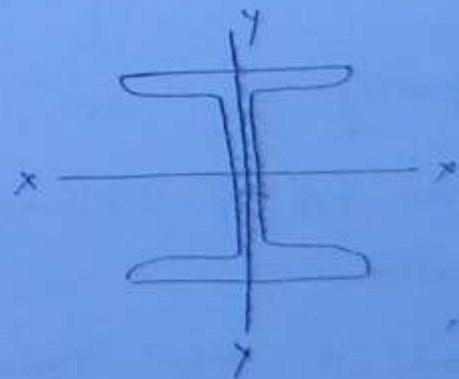
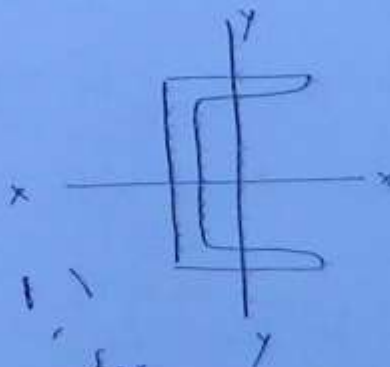
- | | | |
|-----|--|-----|
| (1) | Member carrying compressive load due to dead & live load only | 180 |
| (2) | Member subjected to compression due to wind or EQ. | 250 |
| (3) | For compression flange of beam | 300 |
| (4) | Member normally acting as a tie in a roof truss or bracing system but subjected to reversal of stress due to wind or EQ. | 350 |

Rolled Section



$$I_{min} = I_{uv}$$

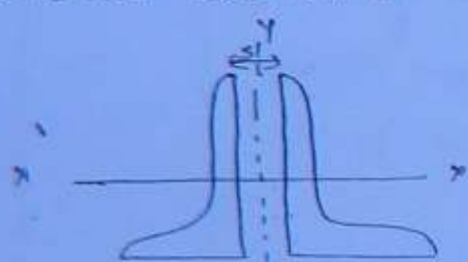
$$r_{min} = r_{uv}$$



L_{min}
or
 L_{xy}

for rolled sections M.O.I. can not be changed. Hence to find out the load carrying capacity I_{min} needs to be located. If the section is having at least one axis of symmetry, $r_{min} = \sqrt{\frac{I_{min}}{A}}$ will be about the axis of symmetry or about an axis $\perp$ to the axis of symmetry. If however the section is having no axis of symmetry then major and minor principal axis needs to be located.

In case of built up sections we can change the M.O.I. of combined section as



Axis of symmetry

(88)

$I_{min} < \begin{matrix} I_{xx} \text{ combination} \\ I_{yy} \text{ combination} \end{matrix}$

$$I_{xx \text{ comb.}} = 2 \times I_{xx} \text{ of one section}$$

$$I_{yy \text{ comb.}} = 2 \left[I_{yy \text{ one}} + A \left(c_{yy} + \frac{s}{2} \right)^2 \right]$$

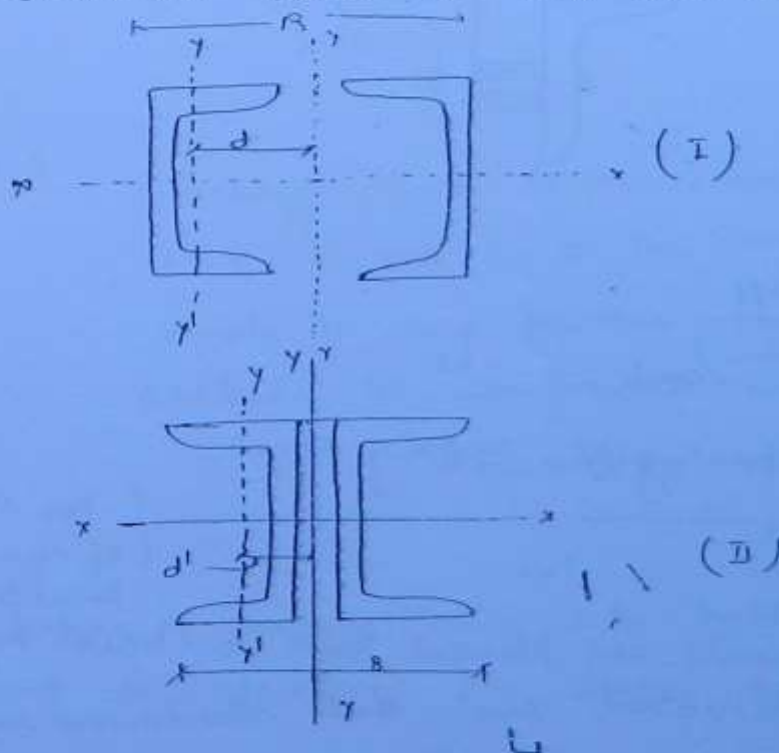
If spacing b/w secⁿ is zero $I_{yy \text{ comb.}}$ in this case will be less than I_{xx} of combination hence I_{min} will be I_{yy} of combination.

If I_{min} is less r_{min} will be less for this λ will be more and hence σ_{ac} will be less.

Thus load carrying capacity will be less.
To increase the load carrying capacity for the given area, I_{yy} of combination needs to be increased. This can be achieved by increasing the spacing. For a given spacing s , I_{xx} of combination will become I_{yy} of comb. For $s > s_0$, $I_{min} = I_{xx}$ of comb. which is fixed. Hence load carrying capacity becomes fixed for all $s > s_0$ and this spacing corresponds to maximum load carrying capacity for a given sectional area. Thus for best utilization of material I_{xx} of comb = I_{yy} of comb.

(89)

Radius of gyration of a sections will not change when put in combination when the axis does not shift



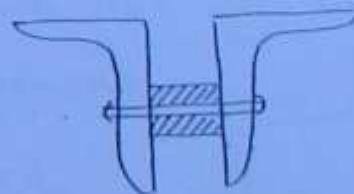
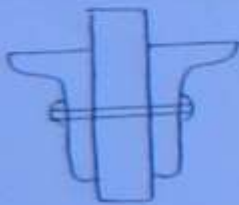
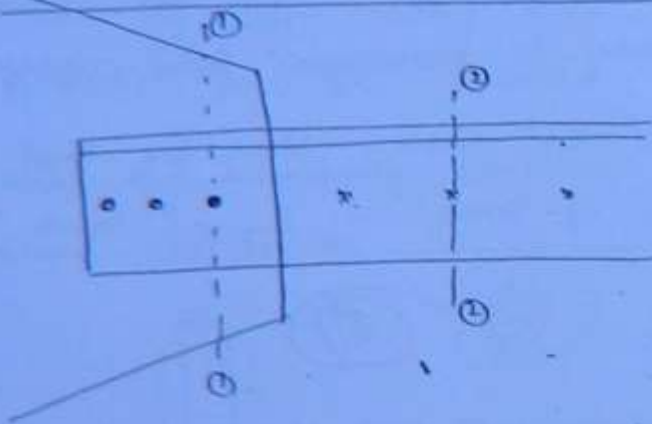
for a given overall size of column strength of I will be more than the strength of II because shifting of axis will be more in (I) than in (II) -

$$d > d'$$

for maintenance point of view II will be better.

IS code Recommendation.

90



$$\lambda_{wholesen} = \frac{L_{eff}}{(\gamma_{min})_{comb}}$$

$$\lambda_{one} = \frac{\text{spacing b/w tanking rivets}}{\gamma_{vv}}$$

for the point of view of local buckling

When two components are placed back to back they should be tank rivetted such that slenderness ratio of individual section b/w tanking rivet should not be

more than 40 nor more than $0.6 \times$ slenderness ratio of whole secⁿ

$$\lambda_{one} \neq 40$$

$$\neq 0.6 \lambda_{whole\ sec^n}$$

This recommendation safeguards against local buckling of individual sections between tacking rivets.

The spacing b/w tacking rivet ^{in line} however should not be more than 600 mm.

The dia of tacking rivet ~~is~~ should not be ^{less} ~~more~~ than the min dia given below.

Thickness of member

upto 10 mm

10 - 16 mm

> 16 mm

Dia of tacking rivet ^{upto}

18 mm

20 mm

22 mm

Note:

Tacking rivet recommendation given before 32 t or 300 mm is the max. spacing b/w tacking rivets in any position. However the limiting criteria in compression will become

$$\lambda_{one} \neq 40$$

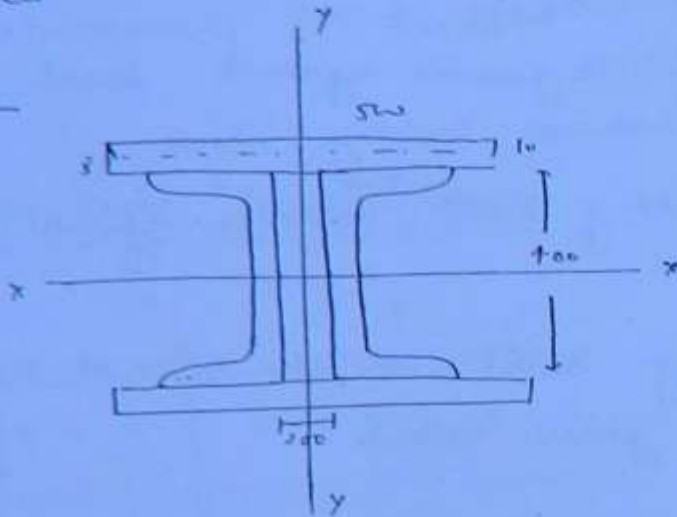
$$\neq 0.6 \lambda_{whole\ sec^n}$$

1 \

- Purpose of tacking rivet is to hold the two member together and to equalize the stress ⁱⁿ ~~the~~ the component memb^r

If the web of channel is > 150 mm in depth, two rows of tacking rivet can be provided. If angles are 125 mm or more two rows of tacking rivet can be provided

8.10 1.49



(90)

$$I_{xx} = 2 \times 150 \times 828 \times 10^3 + \left[\frac{500 \times 10^3}{12} + 500 \times 10 \times 205^2 \right] \times 2$$

$$= 721.9893 \times 10^6 \text{ mm}^4$$

$$I_{yy} = 2 \left[5048 \times 10^3 + (100 + 27.2)^2 \times 6.293 \times 10^3 \right]$$

$$+ 2 \times \frac{10 \times 500^3}{12}$$

$$= 412.5764 \times 10^6 \text{ mm}^4$$

I_{yy} is min

$$r_{min} = \sqrt{\frac{I_{yy}}{A_{channel}}} = \sqrt{\frac{412.5764 \times 10^6}{2 \times (6.293 \times 10^3 + 5000)}}$$

$$= 135.155 \text{ mm}$$

$$r_{max} = 500$$

$$\lambda = \frac{l_{eff}}{r_{min}} = \frac{5000}{135.155} = 36.995$$

$$\sigma_{ac} = 145 - \frac{(145 - 132) \times 6.295}{20}$$

$$(93) \quad = 140.453 \text{ N/mm}^2$$

$$\begin{aligned} \text{safe load} &= 140.453 \times 2 (6293 + 5000) \\ &= 3172.277 \text{ kN} \end{aligned}$$

if effective length is 6m

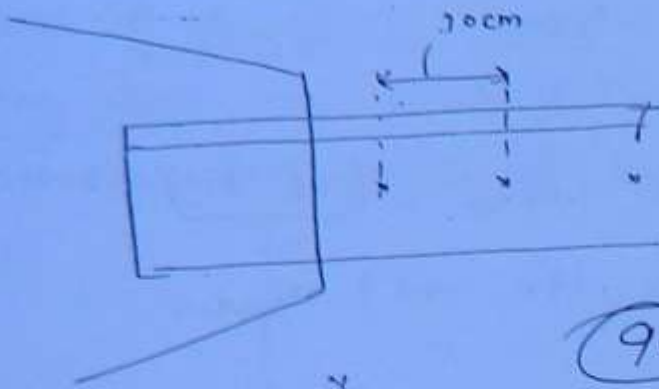
$$\lambda = \frac{6000}{135.155} = 44.393$$

$$\sigma_{ac} = 145 - \frac{(145 - 132) \times 44.393}{20}$$

$$= 135.645 \text{ N/mm}^2$$

$$\begin{aligned} \text{Safe load} &= 135.645 \times 2 (6293 + 5000) \\ &= 3063.667 \text{ kN} \end{aligned}$$

Q.9

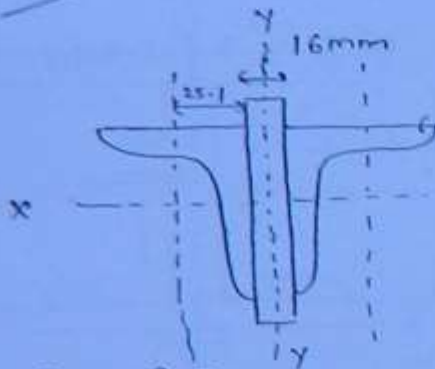


2 ISA 90x90x8

(94)

$$r = \sqrt{\frac{I}{A}}$$

$$I = Ar^2$$



ISA 90x90x8

$$A = 1379 \text{ mm}^2$$

$$C_{xx} = C_{yy} = 25.1 \text{ mm}$$

$$r_{xx} = 27.5 \text{ mm}$$

$$l_{eff} = 3 \times 85 = 255 \text{ mm}$$

$$I_{xx} = 2Ar_{xx}^2 +$$

$$r_{xx} = 27.5 \text{ mm}$$

$$I_{yy} = [Ar^2 + A \times 33.1^2] \times 2$$

$$= A [27.5^2 + 33.1^2] \times 2 = 5.107429 \times 10^6$$

$$r_{yy} = \sqrt{\frac{I_{yy}}{A}} = 43.03 \text{ mm} \quad (\text{sl. need})$$

r_{xx} is min

$$\lambda = \frac{l_{eff}}{r} = \frac{2550}{\frac{43.03}{27.5}} = 59.257 = 92.727$$

$$\lambda_{one} = \frac{300}{17.5} = 17.143$$

$$f = \frac{1320}{20} = \frac{1320 - 1120 \times 9.257}{20} = 1227.43 \text{ N/mm}^2$$

$$P = 120.288 \text{ N/mm}^2$$

$$f = 9900 - \frac{900 - 720}{20} \times 2.727$$

$$= 875.45 \text{ N/cm}^2 = 85.882 \text{ N/mm}^2$$

$$P = 85.882 \times 2 \times 1379 = 236.863 \text{ kN}$$

(95)

if $g = 10 \Rightarrow P = 241.325 \text{ kN}$

Note

As the angle is equal angle $I_{xx} = I_{yy}$

$$r_{xx} = r_{yy}$$

When put in combination x axis does not shift but y axis shifts such that

$$I_{yy} \text{ of comb} > I_{xx} \text{ of comb.}$$

hence

$$I_{\min} \text{ of comb.} = I_{xx} \text{ of comb.}$$

check for local buckling.

$$\lambda_{one} = \frac{30}{r_{uv}} = \frac{30}{1.75} = 17.143$$

$$\lambda_{whole} > \lambda_{one}$$

$$\left. \begin{array}{l} 17.14 \neq 92.7270.6 \\ \neq 40 \end{array} \right\} \Rightarrow \text{safe in local buckling.}$$

local buckling will only be checked least can not be calculated on the basis of this

Q. A ^{ch} section of eff. length 6 m consists of twin box secⁿ using on ISMB 250 with two plates 260x10 mm/side welded each to the tips of two flanges of ISMB 250 on both sides with 4 mm fillet weld continuous through out the height properties of ISMB 250 are

$$D = 250 \text{ mm}$$

$$B = 125 \text{ mm}$$

$$A = 40.4755 \text{ cm}^2$$

$$I_{xx} = 5131.6 \text{ cm}^4$$

$$I_{yy} = 334.5 \text{ cm}^4$$

(96)

Calculate the load carrying capacity of the section.



$$I_{xx_{\text{new}}} = 5131.6 + 2 \times \frac{1 \times 26^3}{12} = 8060.933 \text{ cm}^4$$

$$I_{yy} = 334.5 \times 10^4 + 2 \left[\frac{260 \times 10^3}{12} + 67.5^2 \times 260 \times 10 \right]$$

$$= 27.08 \times 10^6 \text{ mm}^4$$

$$I_{\min} = 27.08 \times 10^6$$

$$r_{\min} = \sqrt{\frac{I_{\min}}{A}} = \sqrt{\frac{27.08 \times 10^6}{(47.55 + 260 \times 10 \times 2)}}$$

$$= 52.1567 \text{ mm}$$

$$d = \frac{L_{\text{eff}}}{r_{\min}} = \frac{6000}{52.1567} = 115.038$$

$$\begin{array}{l} 110 \text{ --- } 70.75.3 \text{ N/mm}^2 \\ 45 \\ 120 \text{ --- } 67.1 \text{ N/mm}^2 \end{array}$$

$$\sigma_{ac} = 71.168 \text{ N/mm}^2$$

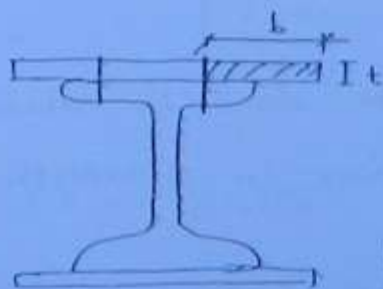
$$\begin{aligned} P &= \sigma_{ac} \times A = 71.168 \times (4755 + 260 \times 20) \\ &= 708.47 \text{ kN} \end{aligned}$$

(97)

Local buckling Phenomenon in cover plates and web plates.

Local buckling phenomenon in webs and cover plate of compression member occurs in the form of waves or wrinkles. The critical stress at which local buckling in the form of waves or wrinkle starts is given by

$$f_{cr} = \frac{K \pi^2 E}{12(1-\nu^2) \left(\frac{b}{t}\right)^2}$$

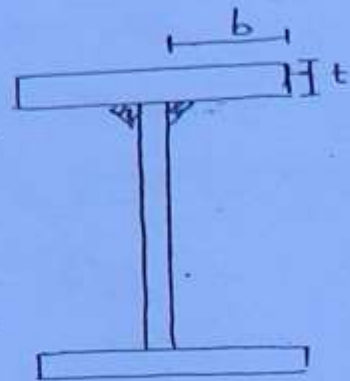
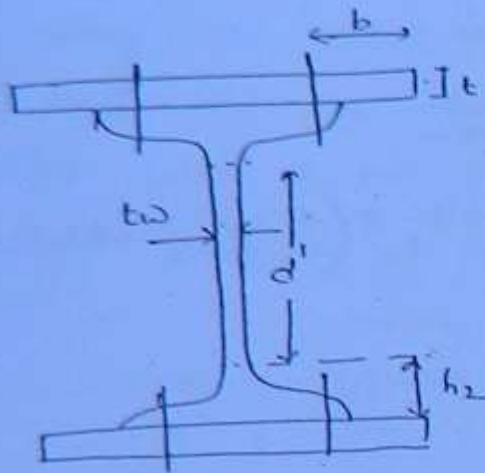


$$f_{cr} \propto \frac{1}{\left(\frac{b}{t}\right)^2}$$

Larger the value of b/t smaller is the stress at which local buckling starts in the form of waves or wrinkles.

if $\left(\frac{b}{t}\right)$ is so adjusted that critical stress for local buckling becomes more than the stress corresponding to overall failure of column, then local buckling will not occur before overall failure of column on this

basis IS code has given the following recommendation



(98)

$$\left(\frac{b}{t}\right) \neq 16$$

Any portion of b greater than $16t$ should not be taken into account in strength calculation

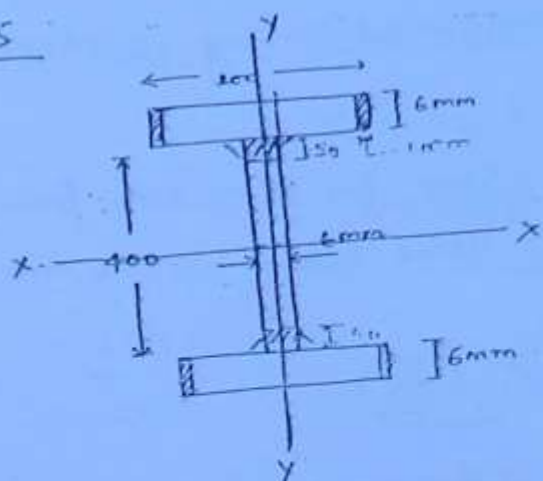
for web $\left(\frac{d'}{t_w}\right) \neq 50$

Any portion of $d' > 50 t_w$ should not be taken into account in strength calculation.

Note →

The area reduction should be done in such a way that it leads to maximum reduction in strength.

Q.5



$$\frac{b}{t} = \frac{300}{6} = 15.166$$

$$\frac{b}{t} \leq 16$$

H = 200

100 mm

100 mm $\Rightarrow$ 100 mm for 100 mm

for 100 mm = 100 mm

99

100 mm

$$I_{yy} = 2 \times \frac{198^3 \times 6}{12} + \frac{6^3 \times 300}{12} = 7.7677 \times 10^6 \text{ mm}^4$$

$$I_{xx} = \frac{6 \times 300^3}{12} + 2 \left[\frac{198 \times 6^3}{12} + 198 \times 6 \times 203^2 \right]$$

$$= 111.42 \times 10^6 \text{ mm}^4$$

$$r_{min} = \sqrt{\frac{I_{min}}{A}} = \sqrt{\frac{7.7677 \times 10^6}{2 \times 198 \times 6 + 300 \times 6}} = 43.29 \text{ mm}$$

$$\lambda = 81.15$$

$$\sigma_{ac} = 997.91 \text{ N/cm}^2 = 0$$

$$P_{safe} = 997.91 \times (2 \times 198 \times 6 + 300 \times 6) \times 10^{-2}$$

$$= 41672.17 \text{ N}$$

$$= 416.727 \text{ kN}$$

Q.6 Page 97

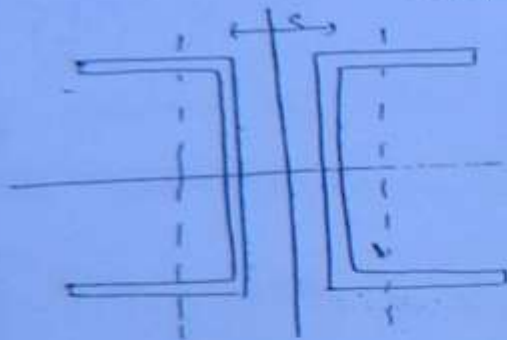
A compression is to be constructed using 2 ISMC 300 placed back to back

$$\sigma_{ax} = \frac{f_c / f_{o.s}}{1 + a_d^2}$$

Rankine constant

(100)

$$= \frac{3200/3}{1 + \frac{1}{7500} d^2} = \frac{8000000}{7500 + d^2} = 759.79 \frac{19}{cm^2}$$



ISMC-300

For max. effice

$$f_{xx} = f_{yy}$$

$$I_{xx} = 2 \times 6362 \cdot 2 \times 10^4 =$$

$$I_{yy} = \left[310.8 \cdot 4 \times 10^4 + 4564 \times \left(23.6 + \frac{s}{2} \right)^2 \right] \times 2$$

$$s = 183.095 \text{ mm}$$

$$r_{min} = (r_{xx})_{comb} = (r_{yy})_{one} = 118.1 \text{ mm}$$

$$l_{eff} = 0.65 \times l = 6.5 \text{ m} = 6500$$

$$d = 55.038$$

σ

$$\begin{aligned}
 P_{safe} &= \sigma_{ac} \times Area \\
 &= 759.79 \times 4564 \times 2 \\
 &= 69353.63 \text{ kg}
 \end{aligned}$$

$$\frac{1 \text{ kgf}}{\text{cm}^2} = \dots \frac{\text{N}}{\text{mm}^2}$$

(1st)

use this conversion

f → force

Design of compression member required

Design of compression member required finding out area of cross secⁿ which depend on σ_{ac} (area req^d = $\frac{P}{\sigma_{ac}}$)
but σ_{ac} ~~also~~ also depends on the section hence we will not have a direct solⁿ as in the case of tension member where permissible stress was constant hence we will go for a trial and error solution.

Step 1 Assume the value of σ_{ac}

- For rolled secⁿ choose σ_{ac} between 60 — 80 MPa
- For built up section choose σ_{ac} 110 MPa

Step 2

$$\frac{P}{(\sigma_{ac})_{\text{chosen}}} = \text{Area required}$$

choose sec trial secⁿ and find the slenderness ratio and hence σ_{ac} for the chosen area

Calculate safe load carrying capacity of the chosen section

$$P' = \text{area}_{\text{chosen}} \times \sigma_{ac, \text{chosen}}$$

$$P' = \text{area}_{\text{provided}} \times \sigma_{ac}$$

P' - safe load carrying capacity of trial secⁿ

- If $P' > P$ secⁿ is sufficient otherwise chose another larger section and repeat. (102)
- check for max. limit of slenderness ratio
- check for slenderness ratio can be done at the time when slenderness ratio of chosen secⁿ was found out.

Q Design a built up column 10 m long to carry an axial load of 750 kN. Use 2 channels placed back to back $l_{eff} = 10$ m. The section available are

ISM C 250

$$A = 3867 \text{ mm}^2$$

$$r_{xx} = 99.4 \text{ mm}$$

$$r_{yy} = 23.8 \text{ mm}$$

$$C_{yy} = 23 \text{ mm}$$

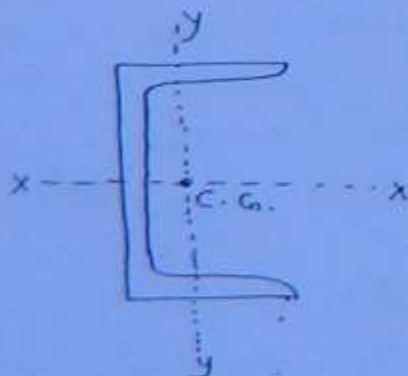
ISM C 300

$$4564 \text{ mm}^2$$

$$118.1 \text{ mm}$$

$$26.1 \text{ mm}$$

$$23.6 \text{ mm}$$



1 - chose

$$\sigma_{all} = 110 \text{ N/mm}^2$$

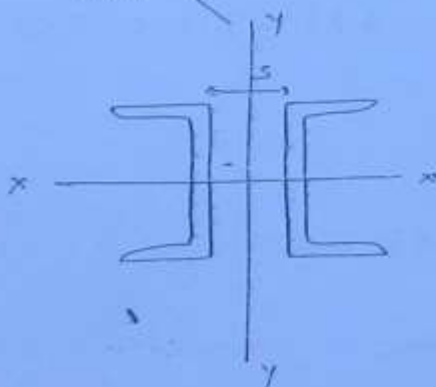
$$A_{req.} = \frac{P}{\sigma_{all}} = \frac{750 \times 10^3}{110} = 6818 \text{ mm}^2$$

chose 2 no of ISMC 250

$$A_{provided} = 2 \times 3867 = 7734 \text{ mm}^2$$

for the chosen area find $r_{min} \rightarrow d \rightarrow \sigma_{all}$

r_{min} min of r_{xx} & r_{yy}



(103)

r_{xx} of combination : r_{xx} of 1 secⁿ b/cor x axis has not shifted and only 2 similar rolled secⁿ has been used.

r_{yy} of combination depends on spacing between the secⁿ for most efficient design

$$r_{xx \text{ comb}} = r_{yy \text{ comb}}$$

thus spacing is so chosen that $r_{xx} \text{ of comb} = r_{yy} \text{ of comb}$ and under the situation

$$r_{min} = (r_{xx} \text{ of comb})$$

$$r_{min} = r_{xx} \text{ of one sec}^n = 99.4 \text{ mm}$$

$$l_{eff} = 10 \text{ m}$$

$$\lambda = \frac{l_{eff}}{r_{min}} = 100.6 < 180 \quad \text{ok from the table}$$

A	σ_{ax}
60	100.7
90	92.8
100	84
110	75.3

104

$$\sigma_{ax} = 83.478 \text{ N/mm}^2$$

$$P' = \sigma_{ax} \text{ provided} \times A_{\text{area pro}} \\ = 84.478 \times (2 \times 3867) = 645.6 \text{ kN} < 750 \text{ not safe}$$

Choose 2 ISMC 300

$$A_{\text{provided}} = 2 \times 4564 = 9128 \text{ mm}^2$$

$$r_{\text{min}} = r_{\text{of ax}} = 118.1 \text{ mm}$$

$$\lambda = \frac{l_{\text{eff}}}{r_{\text{min}}} = \frac{10000}{118.1} = 84.67 < 180 \text{ ok}$$

$$\sigma_{ax} = 100.7 - \frac{100.7 - 92.8}{30} \times 24.67 \\ = 94.2 \text{ N/mm}^2$$

$$P' = \sigma_{ax} \times A_{\text{pro}} \\ = 94.2 \times 9128 = 859.89 \text{ kN} > 750 \text{ kN ok}$$

spacing calculation

$$I_{xx})_c = I_{yy})_c \\ 2 I_{xxm} = 2 \left[I_{yy} + A \left(c_{yy} + \frac{s}{2} \right)^2 \right] \\ 2 A r_{xx}^2 = 2 \left[A \times r_{yy}^2 + A \left(c_{yy} + \frac{s}{2} \right)^2 \right]$$

$$\sigma_{xx}^2 = \sigma_{yy}^2 + \left(c_{yy} + \frac{s}{2} \right)^2$$

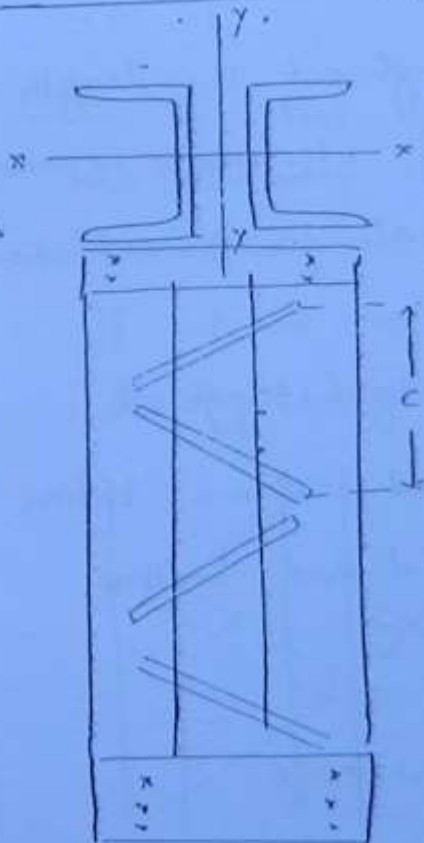
$$s = 183.1 \text{ mm}$$

(105)

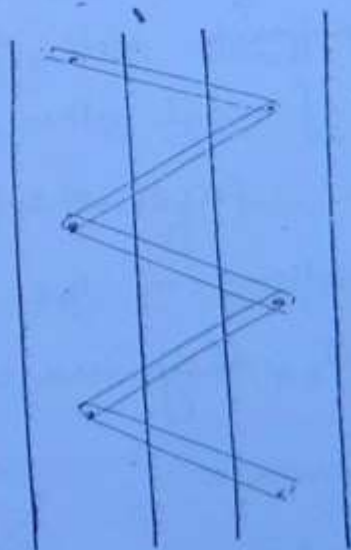
spacing should be chosen 105 mm

under this spacing σ_{min} will remain γ_{xx}

Design of lacing and batten



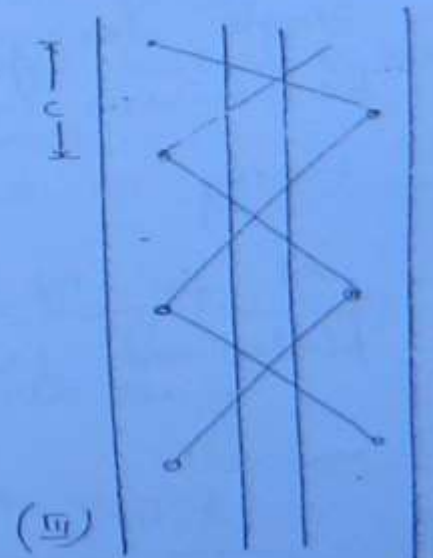
(I)



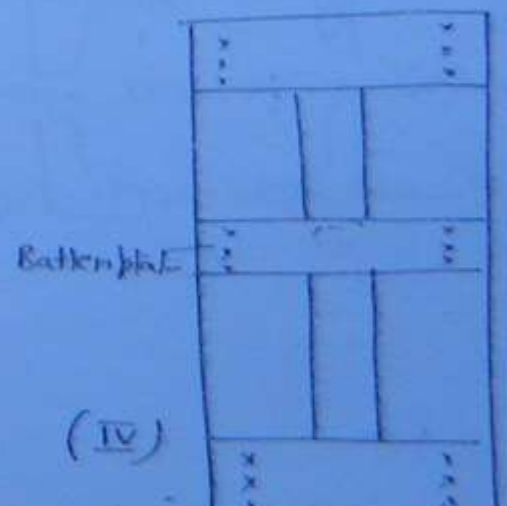
single lacing

(II)

double lacing



(III)



(IV)

- 1) Out of (i) & (ii) I is better because accidental failure of π joint will not decrease the distance b/w intermediate connection significantly.
- 2) If the single lacing is not sufficient to safeguard against local buckling, double lacing will be provided.

(106)

Lacing

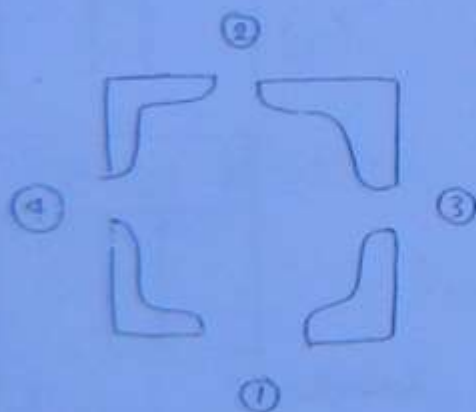
Lacing is in the form of a flat plate or angle. r_{yy} is kept slightly more than r_{xx} .

Lacing should not be varied throughout the length of compression member (angle, r_{xx} , etc should be same).

Single lacing on opposite side of main component should be mirror image of each other.

Lacing on adjacent face should be staggered.

At the top and bottom in the laced column batten plates are provided they are called end battens.



1-2 mirror image

3-4 mirror image

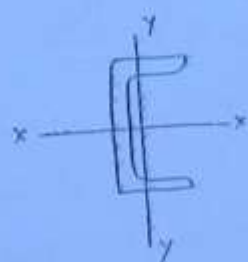
1-3 staggered.

Design

1) Angle of inclination of lacing with the longitudinal axis of column should be between 40 - 70 degrees. θ



2) Slenderness ratio of individual member of column b/w intermediate connections should not be more than 50 neither more than 0.7 time slenderness ratio of whole section.



$$\left(\frac{c}{r_{min}}\right)_{one}$$

$$\neq 50$$

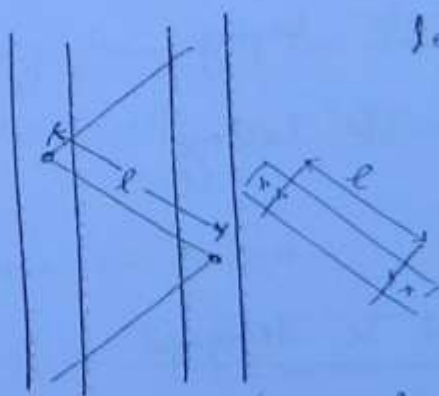
$$\neq 0.7 A_{whole}$$

} criteria for local buckling

Note To start with θ angle will be chosen. As spacing has already been chosen for component members, c becomes fixed this c check for local buckling criteria.

- If it is not met θ can be increased.

Effective length of lacing bar



$$l_{eff} = l \text{ for single lacing (rivetted)}$$

$$= 0.7 l \text{ for double lacing}$$

(when there is connection at the overlap)

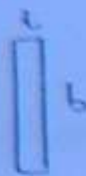
$$= 0.7 l \text{ for welded lacing}$$

$l \rightarrow$ Distance b/w inner ends of rivet or weld

Slenderness ratio of lacing bar should not be more than 145

$$\frac{l_{eff}}{r_{min}} \neq 145$$

L



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

$$\frac{l_{eff}}{t/\sqrt{12}} \neq 145$$

Min width of lacing bar.

(108)

Nominal dia of rivet (mm)

22

20

18

16

Min width { 3 times the nominal dia of rivet
(mm)

65

60

55

50

Min thickness of lacing bar.

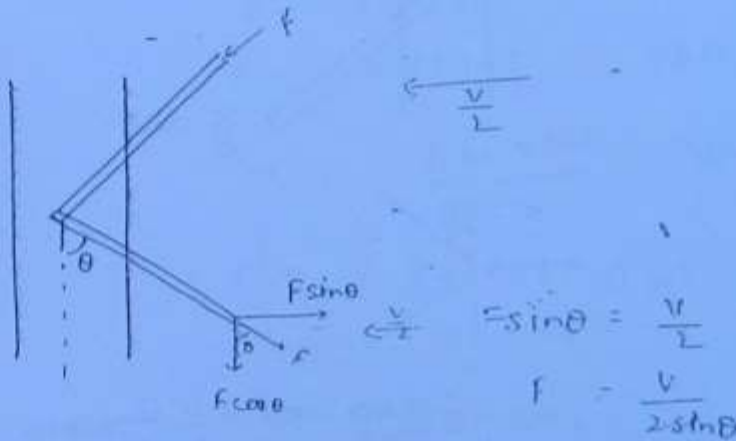
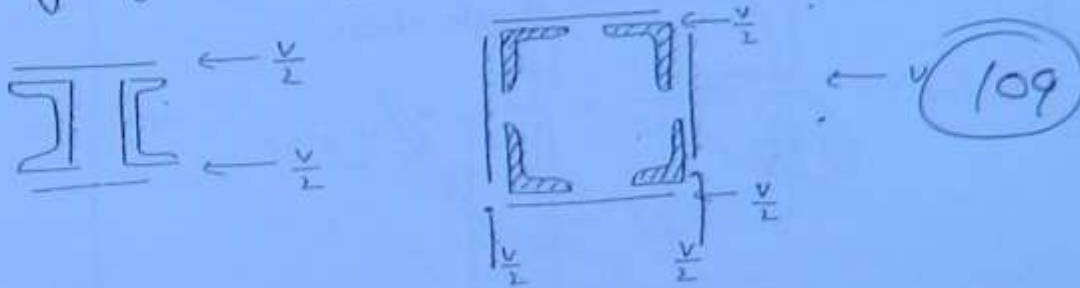
Min thickness $\neq \frac{l}{40}$ for single lacing
 $\frac{l}{60}$ for double lacing

Force for which lacing should be designed.

The lacing should be designed for shear force in column arising due to

- B.M.
- Lateral loading
- Incidental $\hookrightarrow$ Eccentricity
 $\hookrightarrow$ Unavoidable

For incidental eccentricity transverse shear = 2.5% of axial load in the member is taken into account. This shear is divided equally between all transverse lacing system in parallel planes.



Lacing bar will be designed for tension and compression the force will be taken equal to $\left(\frac{V}{2 \sin \theta} \right)$

Check for tension



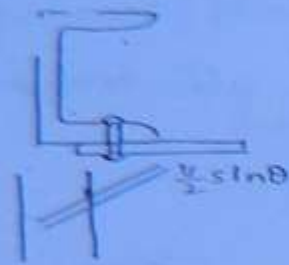
$$(b - d') t \sigma_{at} \geq \frac{V}{2 \sin \theta}$$

Check for compression



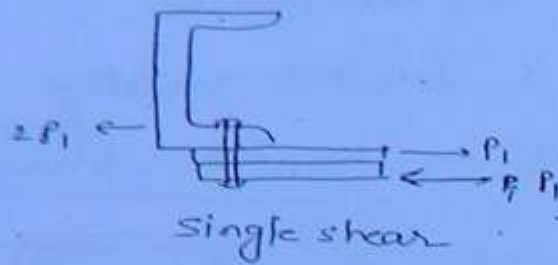
$$\frac{\frac{V}{2 \sin \theta}}{b \times t} < \sigma_{ac} \quad \left(\text{corresponding to } \text{effl} \sin \theta = \frac{t}{\sqrt{12}} \right)$$

Design for connection of lacing bar

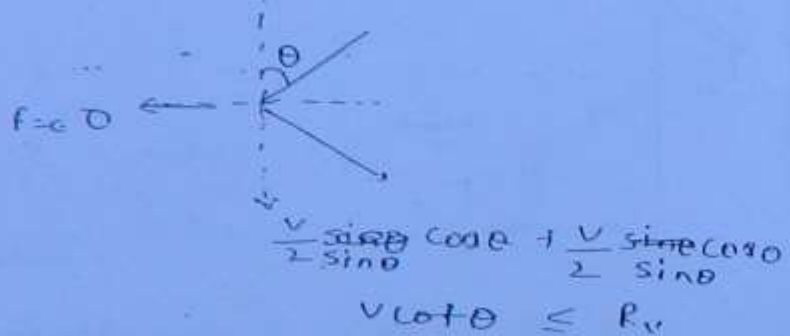
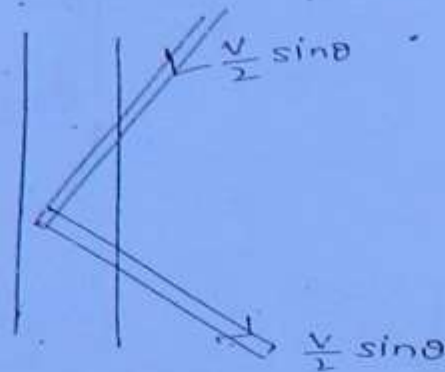


$$\frac{V}{2 \sin \theta} \leq R_v$$

(1/10)

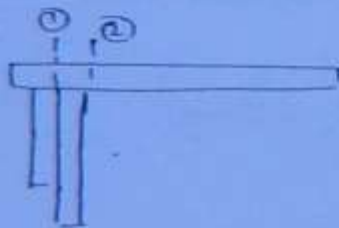


single shear



- sec

Note



Shear at secⁿ 1 will correspond to $\frac{V}{2 \sin \theta}$

Shear at secⁿ 2 " " " $V \cot \theta$

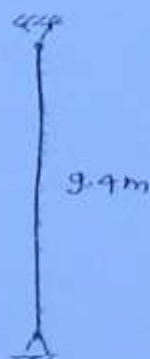
Normally check is done for $V \cot \theta$ However if $\frac{V}{2 \sin \theta}$ becomes more than $V \cot \theta$ means

$$\frac{V}{2 \sin \theta} > V \cot \theta \Rightarrow \theta > 60^\circ$$

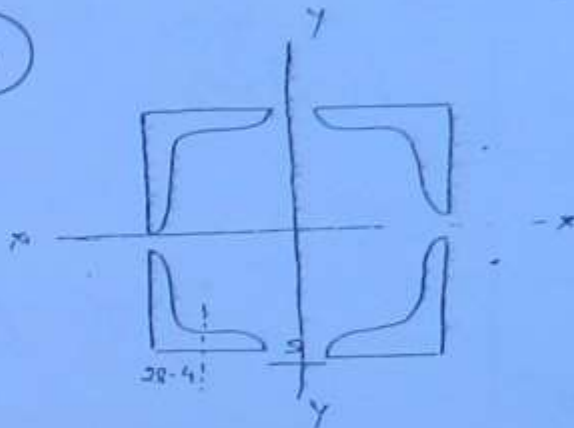
Secⁿ ① will become critical hence

check should be done for $\frac{V}{2\sin\theta}$ force but normally θ is around 45° so $(V\cot\theta)$ governs.

9-8



(7/11)



$$P = 750 \text{ kN}$$

$$A = 4 \times 1903 = 7612 \text{ mm}^2$$

$$\sigma_{ax} = \frac{750 \times 10^3}{7612} = 98.13 \text{ N/mm}^2$$

$$\sigma_{\text{avg}} = 82.247$$

$$\sigma_{\text{avg}} \leq 82.247 \text{ MPa}$$

$$\frac{\sigma_{\text{avg}}}{\gamma_{\text{min}}} < 82.247$$

$$\gamma_{\text{min}} \geq 114.29 \text{ mm}$$

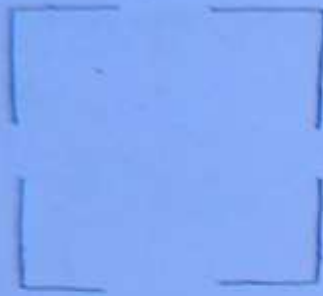
$$I = A r^2$$

$$= (4 \times 1903) 114.29^2 = 99.43 \times 10^6 \text{ mm}^4$$

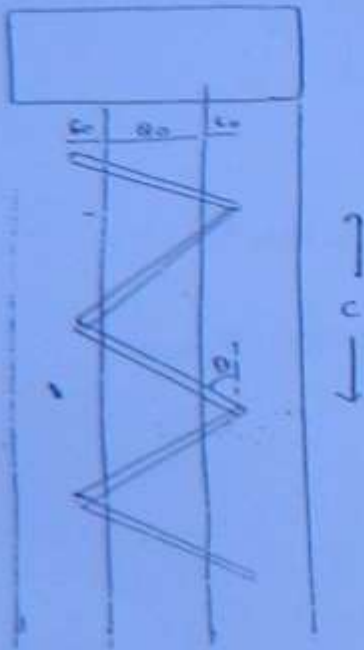
$$I_{\text{min}} = 4 \times \left[177 \times 10^4 + \left\{ (100 - 28.4) + \frac{S}{2} \right\}^2 \times 1903 \right] = 99.43 \times 10^6$$

$$S = 77.09 \text{ mm}$$

$$\text{Adopt } S = 80 \text{ mm}$$



(112)



taking $g = 40 \text{ mm}$ ($> \frac{c \cdot s}{c_{yy}}$)

$$\tan \theta = \frac{200}{c/2}$$

$$c = \frac{400}{\tan \theta}$$

assuming $\theta = 45^\circ$

$$c = 400 \text{ mm}$$

check for local buckling

$$\frac{c}{r_{min}} \neq 50$$

$$\neq 0.7 \lambda_{\text{whole}}$$

$$\frac{400}{r_{yy}} \neq 50$$

$$\frac{400}{19.4} = 20.62 \neq 50 \quad \text{ok}$$

Note: for slenderness ratio 82.247 spacing is 77.09
If spacing is increased δ_{min} will increase hence λ will fall thus for spacing equal to λ would be less than 82.247 if local buckling criteria is satisfied for larger slenderness ratio

(113)

Design of lacing

Local buckling criteria is satisfied for $\theta = 45^\circ$ in single lacing hence single lacing is sufficient.

$$l = 200\sqrt{2} = 282.843 \text{ mm}$$

$$\text{Area of rivet} = 6.05 \text{ cm}^2 = 6.05 \sqrt{10} = 19.13 \text{ cm}^2$$

$$\text{Min width of lacing} = 60 \text{ mm}$$

$$\text{min thickness} = \frac{l}{40} = \frac{282.843}{40} = 7.07$$

adopt 8 mm

check for slenderness ratio of lacing

$$\text{S.R. lacing} \neq 145$$

$$\frac{l_{eff}}{t/\sqrt{12}} \neq 145$$

$$\frac{282.843\sqrt{12}}{8} \neq 145$$

$$122.47 \neq 145$$

OK

check for tension

$$V = 2.5\% \text{ of } P$$

(16)

$$= \frac{2.5}{100} \times 750 = 18.75$$

Tensile force in lacing $F = \frac{V}{2 \sin \theta} = 13.25 \text{ kN}$

Tearing strength > 13.25

$$(60 - 21.5) \times 8 \times 0.6 f_y > 13.25$$

$$46.2 \text{ kN} > 13.25 \text{ kN}$$

OK.

check for compression

$$d = 122.5$$

d	σ_{ac}
120	67.1
130	59.7

$$\sigma_{ac} = 65.27 \text{ N/mm}^2$$

$$P' = \sigma_{ac} b t$$

$$= 65.27 \times 60 \times 8 = 31.33 \text{ kN} > 13.25 \text{ kN}$$

Safe in compression

Design for connection.



$$\downarrow V \cot \theta = 18.75 \text{ kN}$$

$$\therefore \text{Rivet value} = 8 \text{ Min (shearing, bearing)}$$

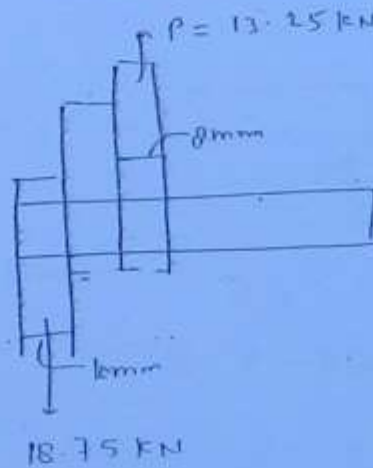
$$\text{Adopting power driven shop rivet} = \min \left\{ \frac{A \sigma_L}{f} \times 100, 300 \times 21.5 \times 18 \right\} = \min \left\{ 36.3 \text{ kN}, 64.5 \text{ kN} \right\}$$

$$\text{shearing strength of rivet} = 36.3 \text{ kN}$$

$$\text{No. of rivet} = \frac{18.75}{36.3}$$

Adopt 1 rivet

check for bearing

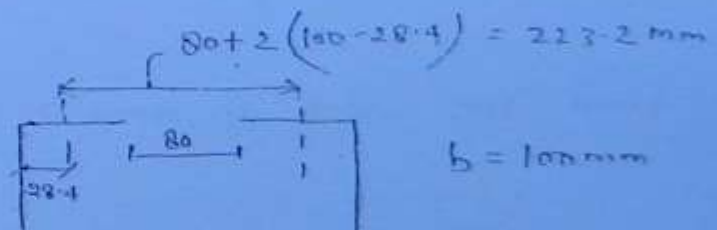


$$64.5 > 18.75 \quad \text{OK}$$

$$51.6 > 13.25 \quad \text{OK}$$

safe in bearing

Design of End batten



d $\rightarrow$ Eff. depth of end batten

$$\left. \begin{array}{l} d \neq \alpha \neq 223.2 \\ d \neq 2b \neq 200 \end{array} \right\} \Rightarrow \text{Adopt } d = 225 \text{ mm}$$

$$D \neq d + 2 \text{ edge distance} = 225 + (2 \times 20) \times 2 = 305 \text{ mm}$$

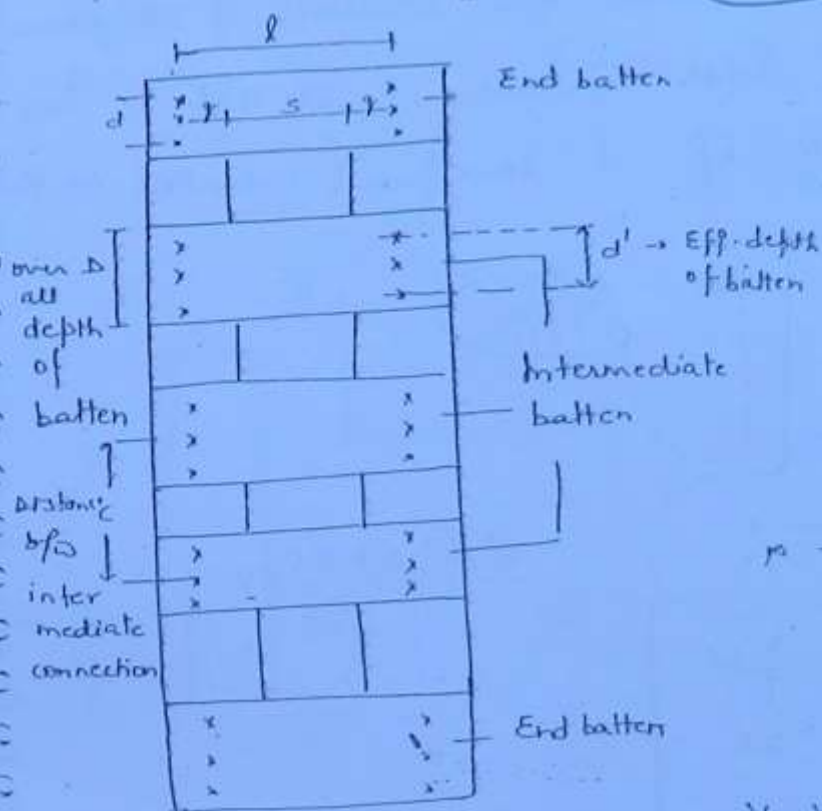
$$\text{Thickner} = \frac{l}{50} = \frac{200}{50} = 4$$

Adapt 8 mm

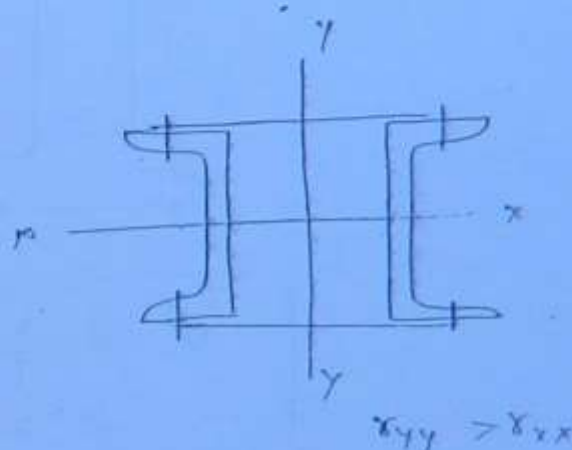
116

Design of End batten.

(1/1)



The effective length of batten column is taken 10% more than that of laced column.



the plane of batten

Batten on opposite faces should be mirror image. No. of batten should be such that it divides the column longitudinally in not less than 3 parts.

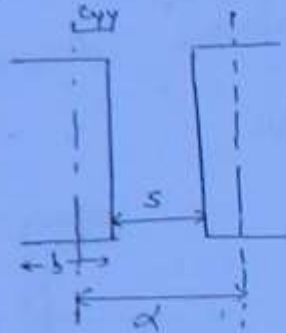
Effective length of battened column is taken 10% more.

Design specification.

$$\frac{c}{(r_{min})_{batt}} \neq 50$$

$$\neq 0.7 d \text{ where}$$

3
Effective depth of intermediate batten should not be less than $\frac{3}{4}$ times the distance b/w centroid of component member, the eff. depth however should not be less than twice the width of 1 component member in the plane of batten



(118)

$$d = s + 2C_{yy}$$

$$\begin{aligned} d &\neq \frac{3}{4}s \\ &\neq 2b \end{aligned}$$

- For End batten

Effective depth of end batten $d \neq s$
 $\neq 2b$

- The thickness of batten should not be less than $\frac{l}{50}$ where l is the distance b/w innermost connecting line of rivet or weld

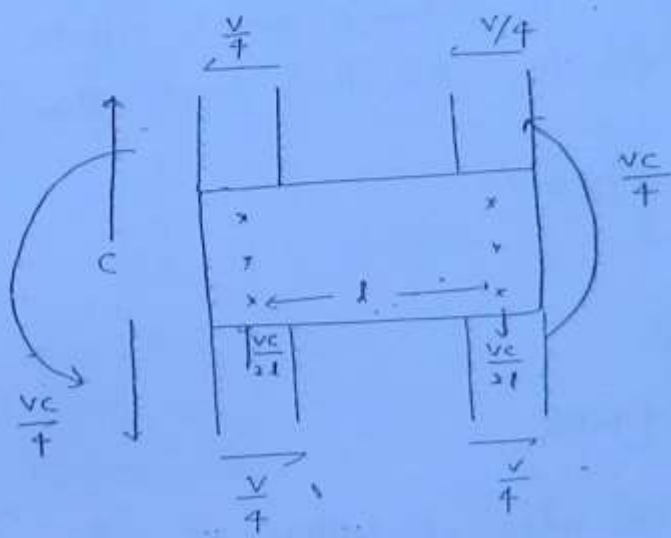
$$l = (s + 2g)$$

check for safety

Batten should be designed to carry B.M. and shear arising due to transverse shear. Transverse shear for incidental

$$\text{Eccentricity} = v = \frac{2.5}{100} \text{ Panel}$$

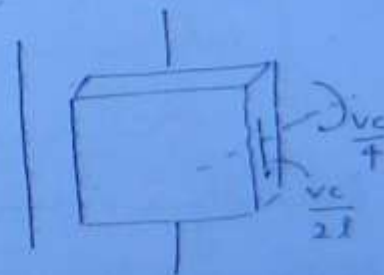
(1/9)



Hence batten plate will be designed for

$$\text{Shear} = \frac{V_c}{2l}$$

$$\text{Moment} = \frac{V_c}{4}$$



check for shear

Permissible average shear stress = $0.4 f_y$

$$\left(\frac{V_c}{2l} \right) \leq 0.4 f_y$$

check for bending

Permissible av. bending stress = 185 N/mm^2

$$\left(\frac{V_c}{4} \times \frac{D}{2} \right) \leq 185 \text{ N/mm}^2$$

$$\left(\frac{t D^3}{12} \right) \leq 165 \text{ N/mm}^2$$

Design of connection will be done as eccentric connection in which rivet group is subjected to transverse shear of $\left(\frac{V_e}{2l}\right)$ and torsional moment $\left(\frac{V_e}{t}\right)$

From this torsional moment ($\Rightarrow$ torsional shear) and transverse shear, shear force in extreme rivet will be found out and this should be less than rivet value for safety of connection.

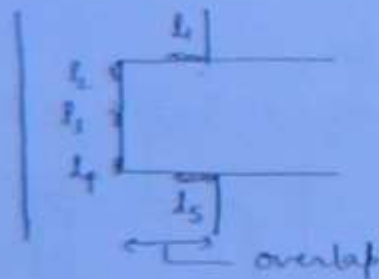
(120)

Welded Connection

Overlap $\neq 4t$

$t \rightarrow$ thickness of plate

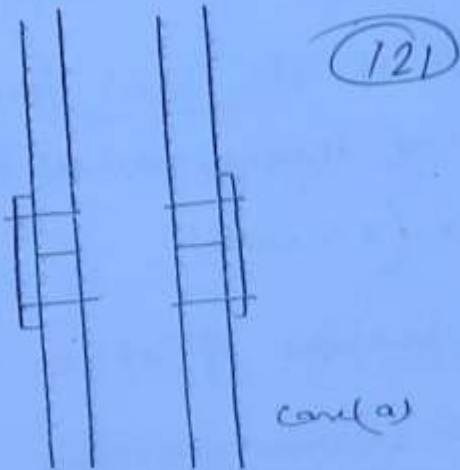
Total length of weld at the edge of batten $\neq \frac{D}{2}$



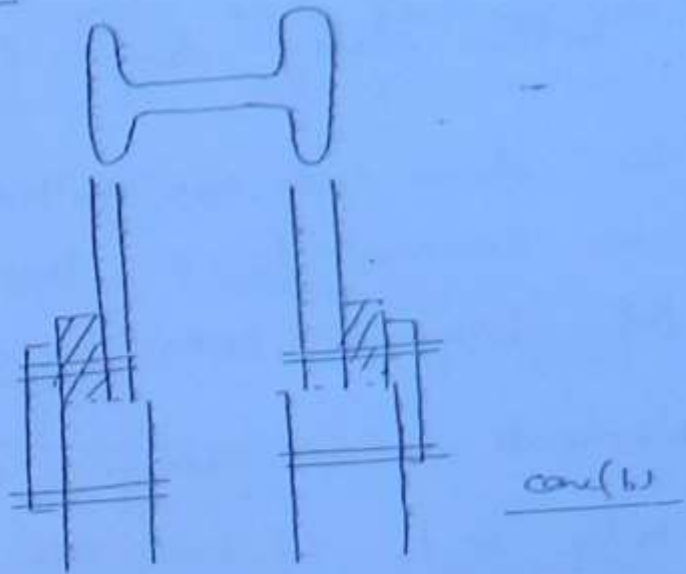
$$(l_1 + l_3 + l_4) \neq \frac{D}{2}$$

Practically we provide continuous connection hence these recommendation will not be required to be checked.

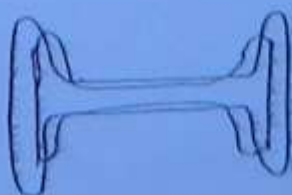
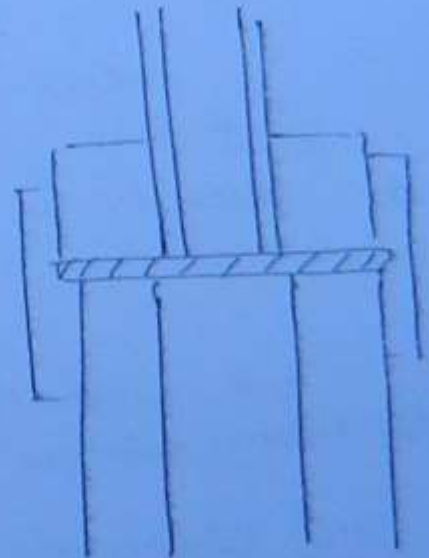
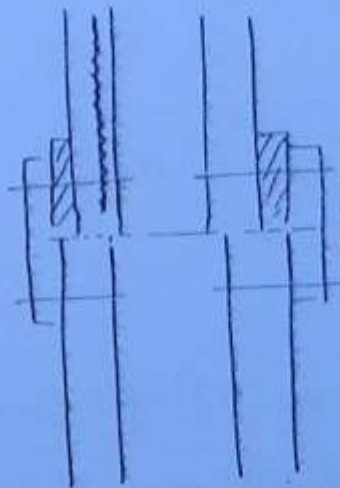
Column splices



Top storey column & bottom storey column are of same size



top & bottom storey column are of different size but top storey column flange resting completely on bottom storey flange



In case of complete bearing of top storey column flange on bottom storey column flange the design is as follows

If the column ends are milled all of the direct force will be assumed to be transferred through direct bearing of top storey to bottom storey. (IS code)

If moments are not acting, the purpose of splice plate will only be to hold the two column together.

However to find out the sectⁿ of splice plate it will be assumed that 50% of the direct load is transferred through splice plates

Hence force on one splice plate = $\frac{P}{4}$

$$\text{Area of splice plate} = \frac{P/4}{(\sigma_{ac})}$$

As there is no buckling i.e. $\sigma_{ac} = 0.6 f_y$

$$b \times t = \frac{(P/4)}{0.6 f_y}$$

$b \rightarrow$ width of column flange
- If the column ends are not milled design force = $\frac{P}{2}$ for one splice

If the column is subjected to direct load as well as moment

Cases

When column ends are milled

All direct force will be assumed to transferred through direct bearing. Splice plate however will be designed for forces generated due to moment. Hence
design force = $\left(\frac{M}{l}\right)$

$l \rightarrow$ spacing b/w splice plate.

(123)

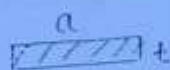
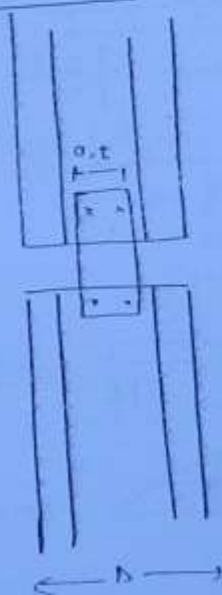
(Case. b)

When column ends are not milled

Design force = $\left(\frac{P}{2} + \frac{M}{l}\right)$ in compression.

= $\left(\frac{P}{2} - \frac{M}{l}\right)$ in tension. (When value becomes (-)ve)

Web splice



$$\frac{V}{2(a)t} \leq 0.4 f_y$$

Web splice are provided to resist shear in the column

Max space available for providing splice plate is

$$(D - 2t_w)$$

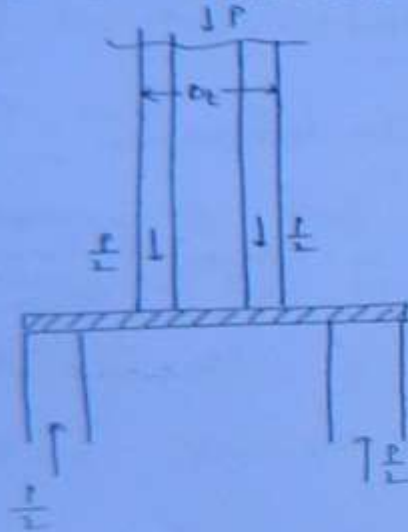
a should be chosen smaller than this

Rivets here will be designed to be in double shear.

03/10/11

ii When top storey column flange is not resting on the bottom storey column flange:

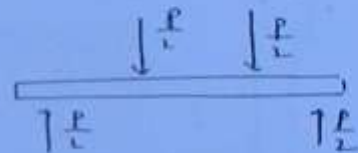
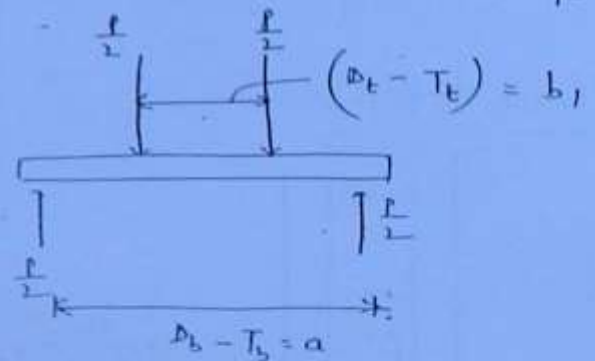
In this case the total top load is assumed to have been transferred through the column flanges to the base plate and then through the base plate to the bottom storey column flanges. The connection will be designed by usual methods. However the base plate needs to be designed.



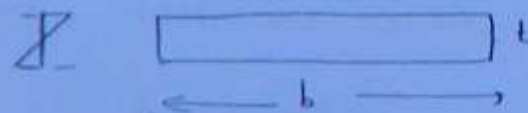
(124)



$D_t \rightarrow$ Depth of top storey column
 $T_t \rightarrow$ Thickness of top storey column flange



$$M_{max} = \frac{P(a-b)}{4}$$



Per Bending stress $= \sigma_{per} \times Z = \frac{P(a-b)}{4}$

165 for forged
185 for solid steel

M.O.R.

$$\sigma_{per} \cdot \frac{bt^2}{6} = \frac{P(a-b_1)}{t} \quad \text{from here calc. } t$$

125

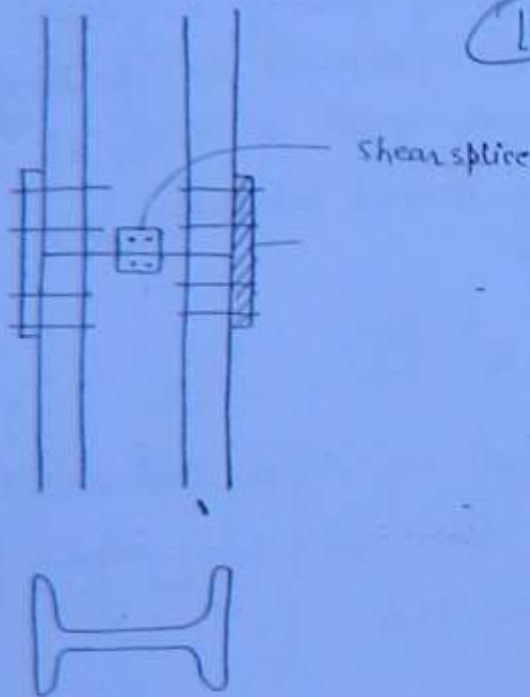
Note

- i) If packing is required, thickness of packing will be equal to the gap to be filled
- ii) In this case if thickness of packing is greater than 6mm additional rivets will be provided on packing extension and no. of such rivets is equal to 2.5% of the no. of rivets obtained from normal calculation per 2 mm thick new of packing.

- In case of partial bearing all the direct load will be assumed to have been transferred from top storey column to bottom storey column through splice plate.

Question

Q. 2 ISHB 300 sections are spliced using compression splice the applied load is 300 kN. S.F. is 75 kN and applied moment is 20 kNm assume column ends to be not milled Design column splice



126

As the column ends are not milled all of the direct force will be transferred through the splice plate.

Hence force in splice plate = $\frac{P}{2} \pm \frac{M}{l}$

Adopt $l = 300 \text{ mm}$

to be on safer side

The forces in splice are

$$\frac{P}{2} + \frac{M}{l}$$

$$\frac{300}{2} + \frac{20}{0.3}$$

216.67 kN

comp

$$\frac{P}{2} - \frac{M}{l}$$

$$\frac{300}{2} - \frac{20}{0.3}$$

83.33 kN

comp. L

Design force for column splice = 216.67 kN

Permissible stress in compression in splice = $0.6 f_y$
= $b/t \cos$ column

(127) splice will not buckle individually

$$\text{area required} = \frac{216.67 \times 10^3}{0.6 \times 250} \quad \text{Assuming } f_y = 250$$

$$= 1444.47 \text{ mm}^2$$

width of splice plate is taken as the width of column flange

$$b \times t = 1444.47$$

$$b = 250$$

$$\therefore t = \frac{1444.47}{250} = 5.7$$

$$\text{adopt } t = 8 \text{ mm}$$

Length of column splice will depend on no. of rivets

Design of connection.

Rivets will be designed for force of 216.67 kN

Adopting the dia of rivet as 18 mm and choosing
power driven field driven

Per stress in rivet in shear = 90 MPa

bearing = 270 MPa

Rivet value in { shear, Bearing }

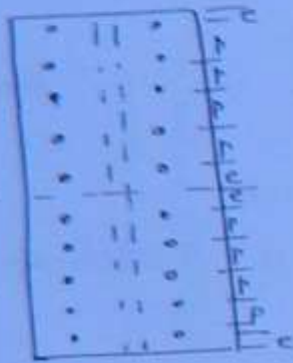
$$= \frac{1}{7} \times 19.5 \times 90 \quad 19.5 \times 8 \times 270$$

$$\text{min } \{ 26.87 \text{ kN}, 42.12 \text{ kN} \}$$

$$R_u = 26.87 \text{ kN}$$

$$\text{No of rivet} = \frac{216.67}{26.87} = 8.06$$

Adopt 10 No. (even no. due to symmetry)



(128)

$$\begin{aligned} l &= 8P + 4C \\ &= 8 \times 2.5d + 4 \times 2d' \\ &= 28d + 28 \times 18 \\ &= 504 \text{ mm} \\ &= 20 \times d + 8d' \\ &= 520 \text{ mm} \end{aligned}$$

splice plate on the other side will also be of same xsect & connection detailing will also be same.

Design for shear splice.

Area required to resist shear

$$= \frac{75}{0.4f_y}$$

$$= \frac{75 \times 10^3}{100} = 750 \text{ mm}^2$$

$$2at \geq 750$$

adopt width of splice 125 mm

$$\begin{aligned} t_{req} &= \frac{750}{125} \\ &\geq 3 \text{ mm} \end{aligned}$$

Adopt thickness of plate = 6 mm

Rivets are in double shear hence

$$\begin{aligned}
 R_v &= \min \left\{ \frac{2 \times \pi \times 12}{4} \times 90, \frac{6 \times 270}{7.6} \right\} \\
 (129) \quad &= \min \{ 53.75, 40.014 \text{ kN} \} \\
 R_v &= 40.014 \text{ kN}
 \end{aligned}$$

$$\text{No. of rivet} = \frac{75}{40.014} \approx 1.8$$

Adopt 2 rivet.

Note:

ISSC $\rightarrow$ Is a I section

Q. An ISHB 300 in lower story and ISHB 200 in the upper story has been used

ISHB 300

$$D = 300$$

$$B = 250$$

$$T = 10.6$$

$$t_w = 7.6$$

ISHB 200

$$200$$

$$200$$

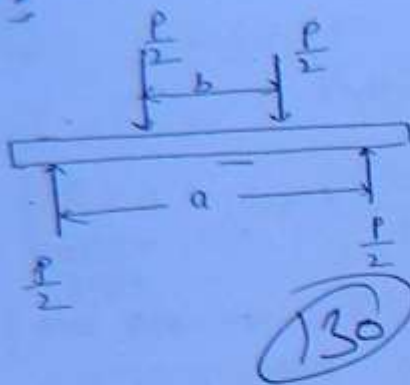
$$9$$

$$6.1$$

Column load is 650 kN design the base plate placed between top & bottom story column.

Sol. The top story column flange is not resting at all on the bottom story column flange hence we require the base plate.

Size of the base plate will be $= 300 \times 250 \times t$



$$a = 300 - 10.6 = 289.4 \text{ mm}$$

$$b = 200 - 9 = 191 \text{ mm}$$

$$P = 650 \text{ kN}$$

$$\frac{P(a-b)}{4} \leq \text{M.O.R.} \quad \text{Adopting } \sigma_{\text{per}} = 185 \frac{\text{N}}{\text{mm}^2} \text{ for solid plate}$$

$$10^3 \times \frac{650}{4} (289.4 - 191) \leq \sigma_{\text{per}} \cdot Z$$

$$\leq \frac{0.66 \times 150}{185} \times \frac{250 \times t^2}{6}$$

$$t \geq 45.54 \text{ mm}$$

$$\text{Adopting } t = 50 \text{ mm}$$

Column Bases

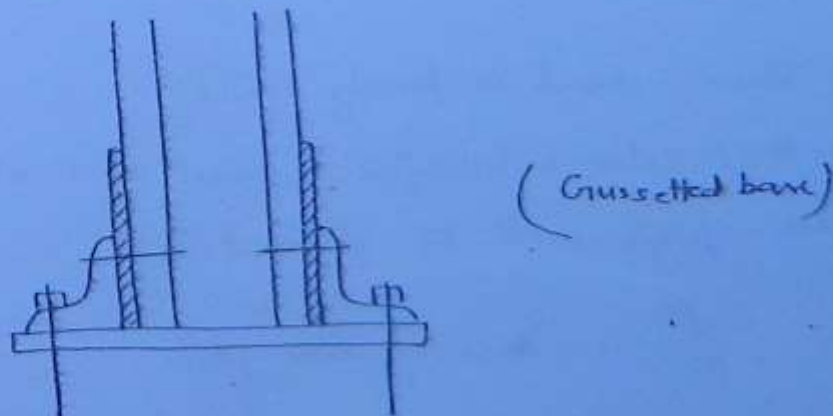
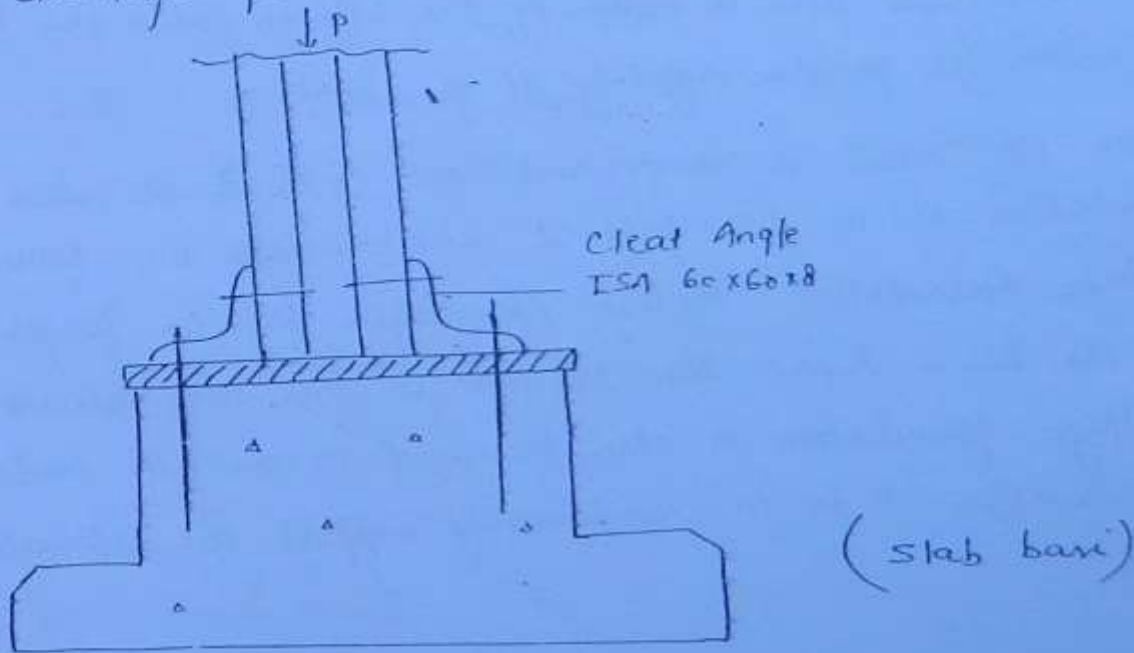
Column Bases

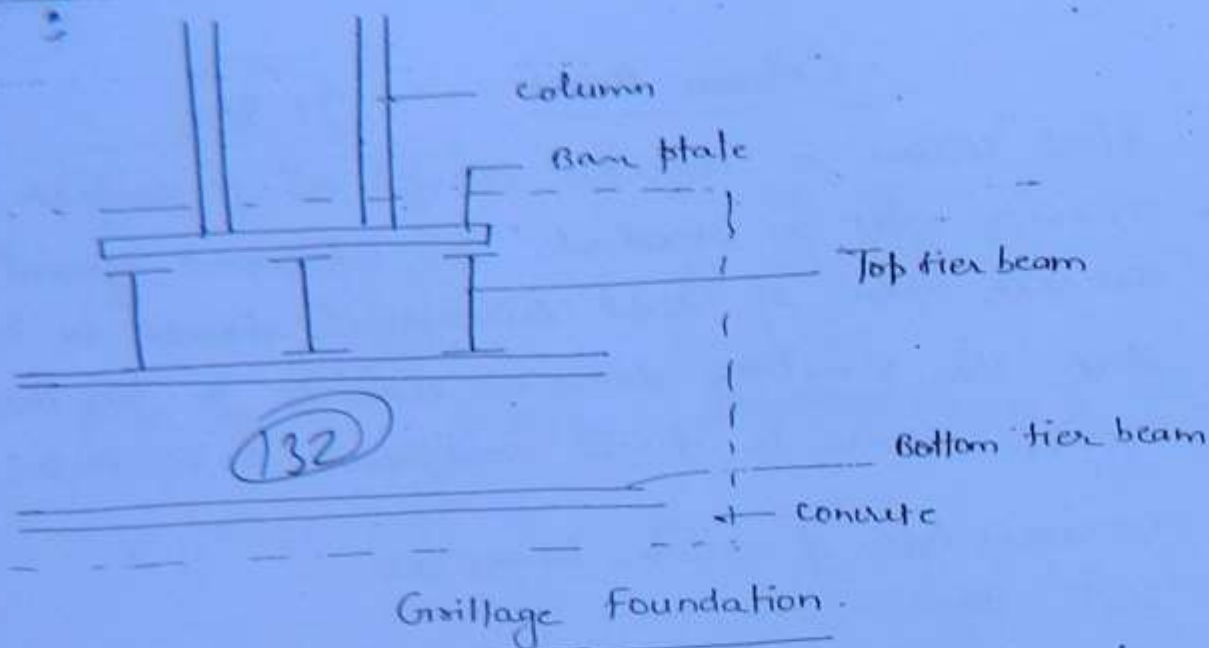
(13)

If steel column is directly placed on a concrete pedestal the concrete will get crushed. To safeguard against crushing of concrete, area of load transferred should be increased so that the resulting stress on concrete is less than the permissible stress in direct compression in concrete.

The various types of column bases are -

- Slab Base
- Gusseted base
- Grillage foundation





Note (as compare to slab base)
Grouted base is better if the column loads are heavy
It provides greater rigidity at the joint.

- When the load is heavy and soil is weak or when the foundation is to be laid at shallow depth we provide grillage foundation. Grillage foundation provides larger area at the base hence the pressure on the soil reduces.
Grillage foundation is also provided in case of temporary construction & or to temporarily support the structure.

When the column load is purely axial

Assuming that column transfers a load of P at the base plate
Size of base plate will be decided as

$$\frac{P}{\sigma_c} = \text{Area of base plate}$$

σ_c Per stress in concrete in compression

(133)

Note - If applied load is given we should take into account the dead wt. also hence the design force for base plate will be $1.1 \times P$ where P = Applied load on column and 1.1 takes into account the dead wt. which is taken as 10% of applied load.

For purely axially loaded column

$$t = \sqrt{\frac{3W}{\sigma_b} \left(\frac{a^2 - b^2}{4} \right)}$$

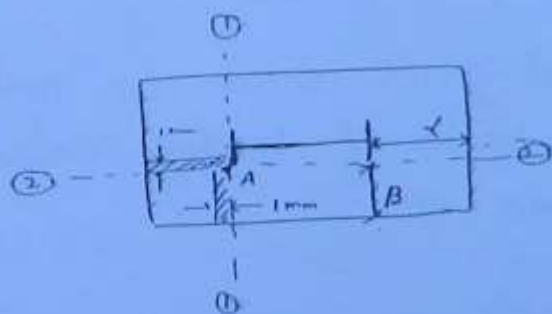
a. Larger overhang

b. Smaller overhang

t → Thickness of base plate

σ_b - Per. bending stress in base plate (185 N/mm²)

bf a & b are smaller and larger overhangs



Larger ($\alpha_c A$) = a
Smaller ($\alpha_c B$) = b

$$W = \frac{\text{load on base plate}}{\text{Area of base plate}}$$

$$M_{11} = \frac{W a^2}{2}$$

$$M_{22} = \frac{W b^2}{2}$$

$$\sigma_{11} = \frac{M_{11} \times \frac{t}{2}}{\frac{1}{12} \frac{t^3}{12}}$$

$$\sigma_{22} = \frac{M_{22} \times \frac{t}{2}}{\frac{1}{12} \frac{t^3}{12}}$$

$$\frac{\sigma_A}{E} = \frac{\sigma_{A,0}}{E} - \frac{\mu \sigma_{22,A}}{E}$$

$$\sigma_A = \frac{(M_{11} - \mu M_{22}) \times 6}{t^2} = \frac{\left(\frac{W a^2}{2} - \frac{\mu W b^2}{2}\right) 6}{t^2}$$

$$= \frac{3W(a^2 - \mu b^2)}{t^2} \quad (134)$$

$$\sigma_A \leq \sigma_{bs} \Rightarrow t \geq \sqrt{\frac{3W}{\sigma_{bs}} (a^2 - \mu b^2)}$$

Assuming $\mu = 0.25$ for steel

$$t_{min} = \sqrt{\frac{3W}{\sigma_{bs}} \left(a^2 - \frac{b^2}{4}\right)}$$

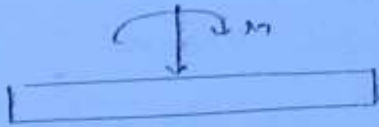
Note

The plate is critical in bending at section 1-1 hence thickness is decided on the basis of bending however check for shear can be done as

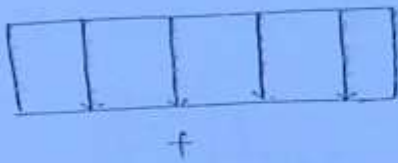
$$\frac{W \times 1 \times a}{1 \times t} \leq 0.4 f_y$$

If the column is subjected to load as well as moment. Net base pr. is to be calculated and bending stress at critical section is evaluated. This bending stress is shown to be less than the permissible bending stress. This analysis helps us in finding out thickness of base plate.

Slab base subjected to moment and axial loading -



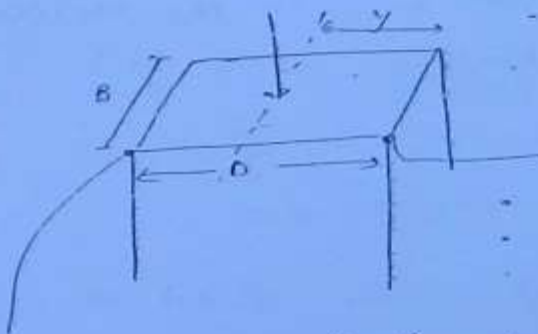
(135)



$\frac{P}{A}$ effect of axial loading = $\frac{P}{BD}$



$\frac{My}{I}$ effect of bending



Net stress = $\frac{P}{BD} + \frac{6Pe}{BD^2}$
comp

$$\frac{P}{BD} \left(1 + \frac{6e}{D} \right)$$

$$\text{Net stress} = \frac{P}{BD} \left(1 - \frac{6e}{D} \right)$$

$$\text{If } e < \frac{D}{6}$$

$$\frac{6e}{D} < 1$$



$$\frac{P}{BD} \left(1 + \frac{6e}{D} \right)$$

For design

$$\frac{P}{BD} \left(1 + \frac{6e}{D} \right) \leq \sigma_c$$

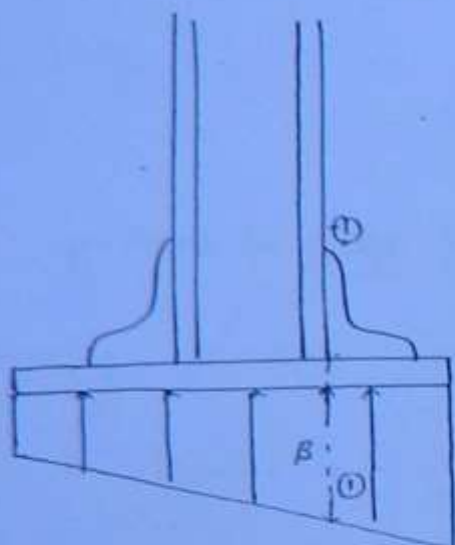
↳ per stress in concrete

using this formula we can choose L & find out other
(choose either of B & D & calc. other)

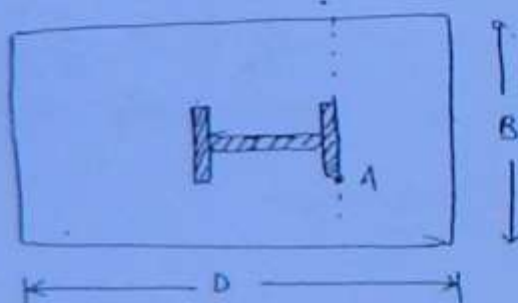
thus size of base plate will be known -

Thickness of base plate

(136)



section 1-1 is the critical secⁿ
for bending



$$\sigma_A = \sigma_{11} - \mu \sigma_{22}$$

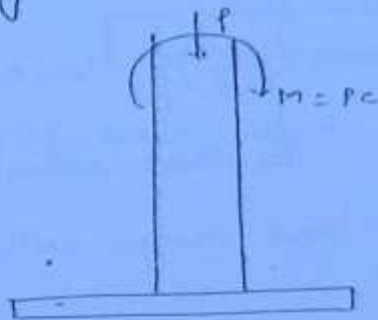
$$= \frac{M_{11} \frac{t}{2}}{t^3/12} - \frac{\mu M_{22} \frac{t}{2}}{1 \times t^3/12}$$

$$\sigma_A = \frac{6}{t^2} (M_{11} - \mu M_{22}) \leq \sigma_{bs}$$

$$t \geq \sqrt{\frac{6 (m_1 - \mu m_2)}{\sigma_{bs}}}$$

(139)

If value of μ is not given we can neglect it by doing so we will be on safer side.



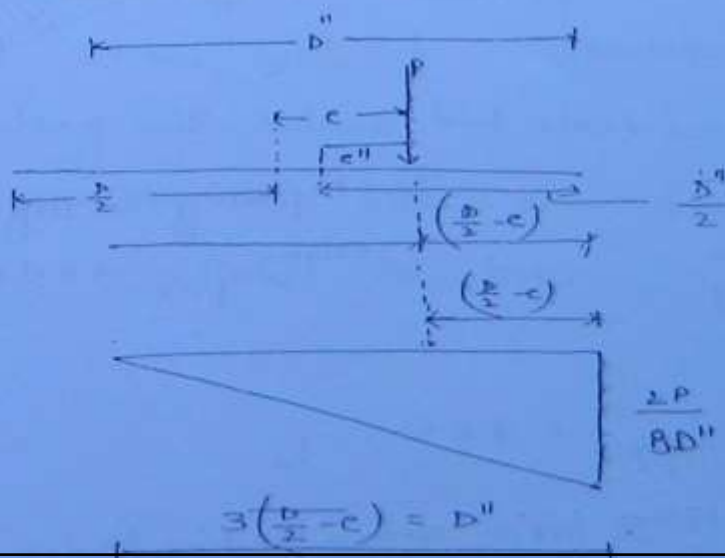
04/10/11

$$\text{max stress} = \frac{P}{BD} \left(1 + \frac{6e}{D} \right)$$

$$\text{min stress} = \frac{P}{BD} \left(1 - \frac{6e}{D} \right)$$

If $e > \frac{D}{6}$
min stress = $\frac{P}{BD} \left(1 - \frac{6e}{D} \right)$ becomes $\ominus$ i.e. Tensile

Due to tensile stress there will be loss of contact between plate and concrete. In the final length of contact situation minimum stress will be zero. For this



Hence final length of contact = $3\left(\frac{D}{2} - e\right)$

$$e = \frac{M}{P}$$

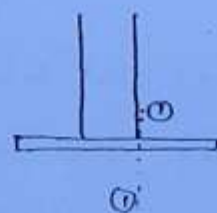
and Max. comp. stress = $\frac{2P}{3B\left(\frac{D}{2} - e\right)} = \frac{2P}{B \cdot 3\left(\frac{D}{2} - e\right)}$

$$e > \frac{D}{6}$$

138

In the starting e will be known $\left\{\left(\frac{M}{P}\right)\right\}$ Hence D will be chosen such that $e < \frac{D}{6}$. In that situation stress will be compressive through out and design will be done as discussed in previous case.

However if D is given, then if $e > \frac{D}{6}$, there would be loss of contact. Hence final length of contact and max^m compressive stress will be calculated. From this stress distribution max^m bending stress at critical sect 1-1 will be calculated and should be $\leq$ per Bending stress



P. 49

Q. 11

SC 200

$$P = 700 \text{ kN}$$

$$M = 55 \text{ kNm}$$

$$\sigma_c = 3.75 \text{ MPa}$$

$$f_y = 250 \text{ MPa}$$

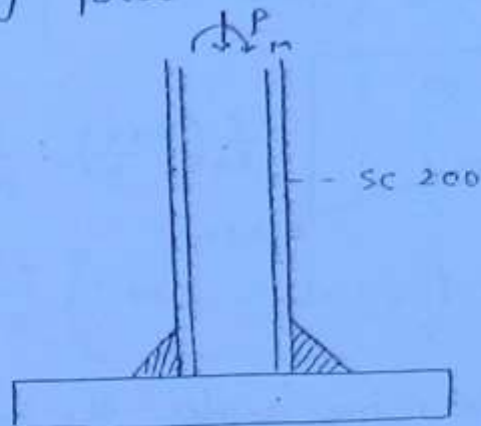
$$T = 15 \text{ mm}$$

$$\text{Stress} = 1 \text{ mm weld / mm} = 76 \text{ N}$$

$$f_{bt} = 0.7 f_y = 175 \text{ N/mm}^2 \text{ perm. stress in bending tension}$$

Sol. Neglecting the self wt column

Shearing force that can be resisted by weld = 512×76



(139)

Design of base plate

$$e = \frac{M}{P} = \frac{55}{700} = 78.57 \text{ mm}$$

$$\text{Choose } D > 6e \\ > 471.43 \text{ mm}$$

$$\text{Choose } D = 500 \text{ mm}$$

Max. stress

$$\frac{P}{B \cdot D} \left(1 + \frac{6e}{D} \right) \leq \sigma_c$$

$$\frac{700}{B \times 500} \left(1 + \frac{6 \times 78.57}{500} \right) \leq 3.75$$

$$B \geq 725.37 \text{ mm}$$

$$\text{Adopt } B = 730 \text{ mm}$$

Note

by increasing the value of D overhang portion will ($\uparrow$) but stress will $\downarrow$. However by choosing smaller D overhang will reduce but stress will $\uparrow$. Final selection is generally done based on economy i.e. vol. of steel $B \times D \times L$ should be less.

stress dist

$$\frac{P}{8D} \left(1 - \frac{6e}{D} \right)$$

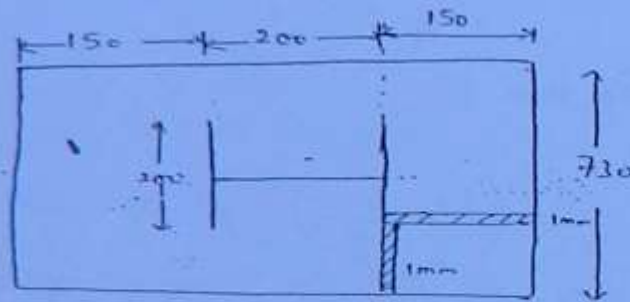
$$= 109 \frac{\text{N}}{\text{mm}^2}$$



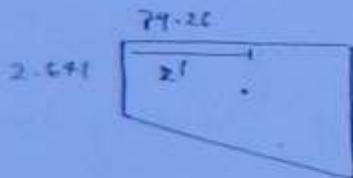
$$\frac{P}{8D} \left(1 + \frac{6e}{D} \right) = \frac{700}{500 \times 730} \left(1 + \frac{78.57 \times 6}{500} \right) = 3.726 \frac{\text{N}}{\text{mm}^2}$$

(140)

Note
if connection has been made using angles the length of plate should be chosen such that the connecting angle could be accommodated in the chosen length



$$\sigma_A = \frac{M_{11} \frac{t}{2}}{\frac{t^3}{12}} - \frac{M_{22} \frac{t}{2}}{\frac{t^3}{12}} \leq \sigma_b$$



$$\bar{x} = 79.26 \text{ mm}$$

$$\text{force on 1 mm width} = \frac{1}{2} (2.641 + 3.726) \times 150 \times 1$$

$$= 477.45 \text{ N}$$

$$M_{11}$$

$$= 477.45 \times 79.26 = 37848.275 \text{ Nmm}$$

$$M_{22}$$

$$= \frac{2.641 \times 265^2}{2} = 92728.6 \text{ Nmm}$$

$$\frac{6}{t^2} (M_{11} - 4M_{21}) \leq 0.7 \times 250$$

$$t \geq 34.135 \text{ mm}$$

Similarly

(141)

$$\frac{6}{t^2} (M_{22} - 4M_{12}) \leq 0.7 \times 250$$

$$t \geq 53.43 \text{ mm}$$

Let us adopt max. thickness

$$t = 55 \text{ mm}$$

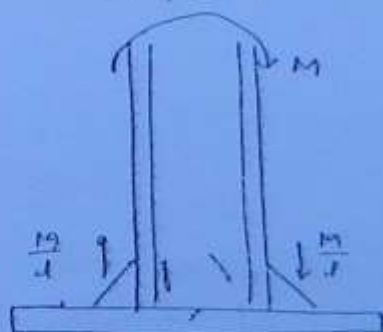
$$B = 730 \text{ mm}$$

$$D = 500 \text{ mm}$$

$$t = 55 \text{ mm}$$

Design of weld.

As the column ends are milled all the direct load will be assumed to have been transferred through direct bearing on the base plate hence weld should be designed only to resist the moment.



$$\frac{M}{L} = \frac{55 \times 10^6}{200} = 275 \text{ kN}$$

$$8 \times 5 \times 76 \geq 275 \times 10^3$$

min size - 10 mm

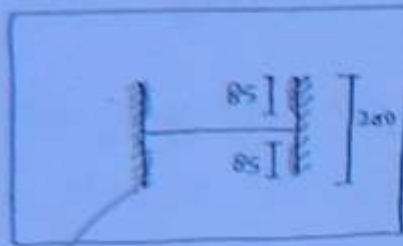
max size - $15 - 1.5 = 13.5 \text{ mm max.}$

Act. size - 13.5 mm

$$I_{S \times 7.6} \approx 275 \times 10^3$$

$$I \geq 361.84 \text{ mm}^4$$

$$\text{Adopt } I = 370 \text{ mm}^4$$



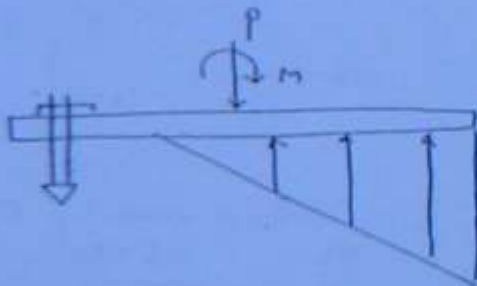
10 mm fillet weld

142

there is

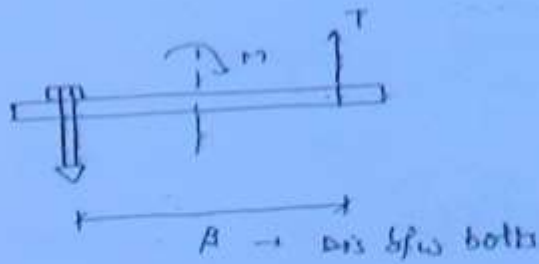
Note

If there is tension at the base the bolt will come under tension and we need to design the bolt as well. Bolt can be designed if the tension in the bolt can be estimated. A actual determination of T will be based on following fig.



1)

However a conservative estimate of tension in the bolt is as follows

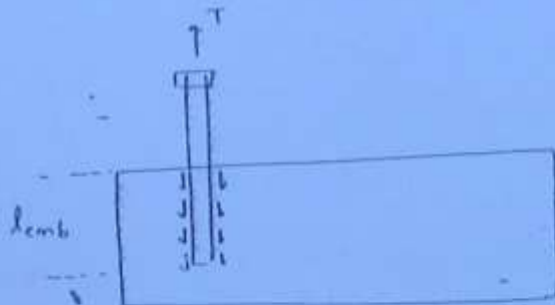


$$T/B = M$$

$$T = \frac{M}{B}$$

(143)

Once tension is known the dia of bolt and length of embedment can be calculated.



$$\pi \phi \times l_{emb} \times \sigma_a \geq T \quad \text{--- (i)}$$

↓
Per. adhesive stress b/w bolt & conc.
depends on grade of steel

$$\frac{\pi \phi^2}{4} \cdot \sigma_t \geq T \quad \text{--- (ii)}$$

$\phi \rightarrow$ A dia at the root of thread

from (i) & ii dia of bolt & length of embedment can be calculated

- 1] a solid round steel column is supported over a square base plate



then for purely axial load thickness is given by

$$\sqrt{\frac{90W}{16\sigma_{bs}} \left(\frac{B}{B-d_o} \right)}$$

$$B \neq 1.5 (d_o + 75) \text{ mm}$$

$$W \rightarrow \text{KN}$$

$$t \rightarrow \text{mm}$$

$$\sigma_b \rightarrow \text{MPa}$$

144

Design of Beam

(145)

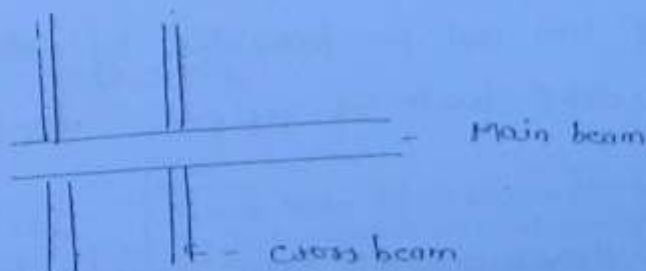
For a beam to be safe

- | | |
|---|----------------------|
| a) It should be safe in bending | } Primary criteria |
| b) safe in shear | |
| c) deflection | |
| d) safe in local buckling of flange plate | } Secondary criteria |
| e) safe in web crippling | |
| f) safe in web buckling | |

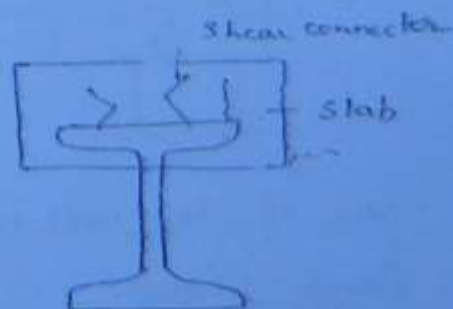
* Laterally restrained and unrestrained Beams

Beam can buckle laterally if the compression flange is weak hence to safeguard against lateral buckling

- a) Beam can be laterally restrained by using cross beams



- b) By inserting the compression flange inside the floor slab



c) By making compression flange heavy.



146

For laterally restrained beam

$$\sigma_{bc} = \sigma_{bt} \quad \text{per stress in bending tension} = 0.67 f_y = 165 \text{ N/mm}^2$$

per stress in bending comp

For laterally unrestrained beam $\sigma_{bc} < \sigma_{bt}$

Design of beam (laterally restrained beams)

1.) Beam is designed for bending and checked for other criteria.

$$\frac{M_{max}}{\sigma_{bc} \text{ or } \sigma_{bt}} = Z_{req.}$$

Choose section that provides $Z > Z_{req.}$

When $Z_{req.}$ can not be provided by using single rolled section we will adopt built up section.

Note



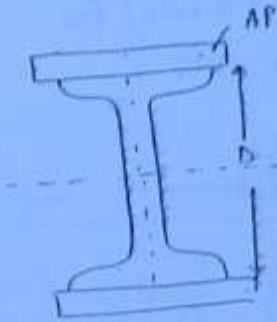
Most suitable arrangement for deflection criteria.



As per

one of the most common built up section is I section with flange plates

In I section and flange plate combination the largest I_{sec} available is used and deficiency in Z is met by using plates



$$I_{\text{req}} = I_{\text{rolled}} + I_{\text{plates}}$$

$$\frac{I_{\text{req}}}{D/2} = \frac{I_{\text{rolled}}}{D/2} + \frac{I_{\text{plates}}}{D/2}$$

$$Z_{\text{req}} = Z_{\text{rolled}} + \frac{A_p \times (D/2)^2 \times 2}{D/2}$$

$$\frac{Z_{\text{req}} - Z_{\text{rolled}}}{D} = A_p$$

The above approach gives the approximate value of A_p the Area of plate chosen is more than A_p .

Note: The increase in A_p should cater for the area of hole on the tension flange because in tension net area is effective.

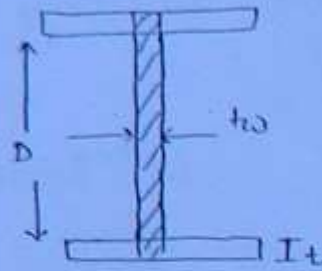
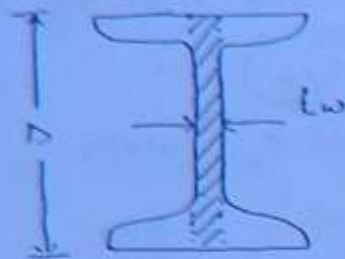
built up
The beam should be checked for safety in bending as follows

$$\frac{M Y_{\text{comb}}}{I_{\text{gross}}} \leq \sigma_{bc}$$

$$\frac{M Y_{\text{ten}}}{I_{\text{gross}}} \times \left(\frac{\text{Gross area of tension flange}}{\text{Net area of tension flange}} \right) \leq \sigma_{bt}$$

I_{gross} corresponds to NA of section neglecting holes

Check for shear



$$\frac{V_{max}}{(D+2t) t_w} \leq 0.4 f_y$$

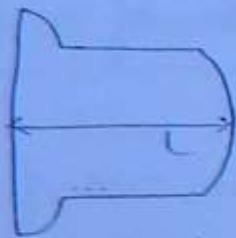
$V_{max} \rightarrow$ Max. s.f. in Beam

$$\frac{V_{max}}{D t_w} = \text{Av. shear stress} \leq 0.4 f_y$$

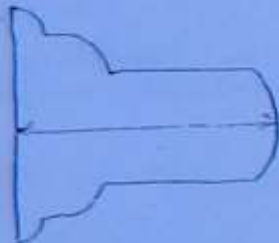
per av. shear stress

(148)

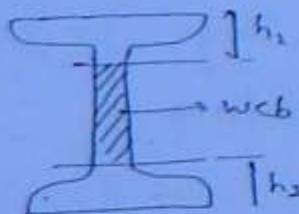
Note



$$\text{Max. shear stress} \leq 0.45 f_y$$



$$\text{Max. shear stress} \leq 0.45 f_y$$



$$\frac{V_{max}}{(D-2h_2) t_w} = \text{Max. shear stress} \leq 0.4 f_y$$

Check for Deflection.

$$\text{Max. permissible deflection} = \frac{\text{span}}{325}$$



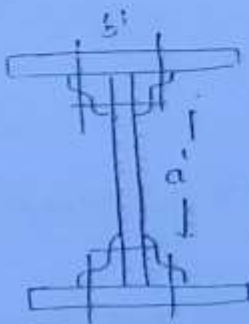
$$\Delta_{\text{max}} = \frac{5}{384} \frac{w l^4}{E I} \leq \frac{1}{325}$$

Check for secondary criteria.

(149)

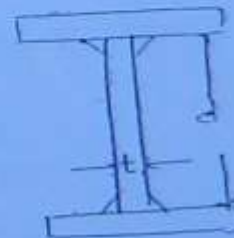
Local buckling of flange plate -

Note Secondary criteria need not to be checked for rolled section because sections are designed in such a way that overall failure of the section takes place before the local failure has had the chance to take place.

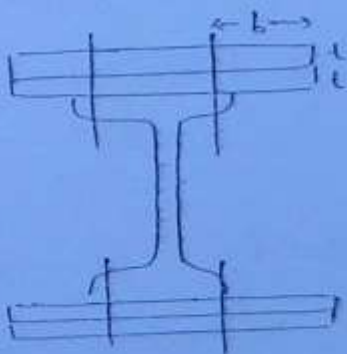


$$\frac{a'}{t} \neq 50$$

$$\frac{b'}{t_f} \neq 50$$



$$\frac{d}{t} \neq 50$$



$$\frac{b}{t} \neq 16$$

plates are simply supported
placed one over the other

if however two plates are welded
so that they behave as 1 unit

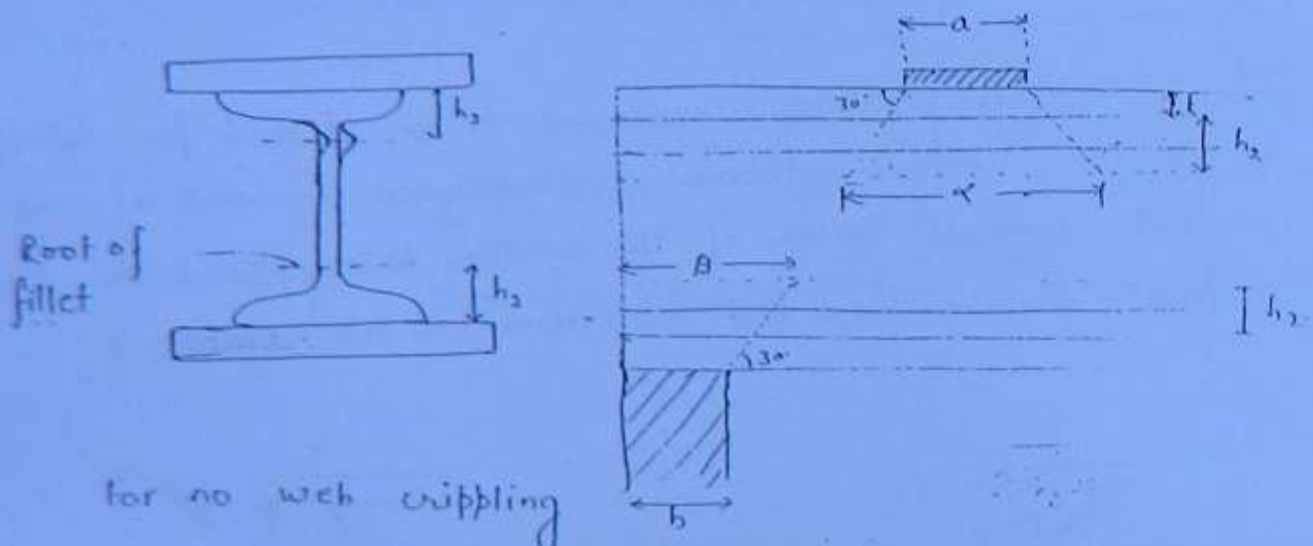
$$\frac{b}{2t} \neq 16$$

This criteria should be checked at the time of selection of plate only

check for web crippling

150

Web crippling takes place at the location of heavy point load. The heavy point load can come in the span and at the support. The point load are dispersed as shown below.



$$\frac{P}{a t_w} \leq \sigma_{br} \quad (\text{per bearing stress})$$

Web crippling takes place at location where section provides least area of resistance such location is first encountered at the root of fillet. Hence web crippling takes place at the root of fillet.

For safety against web crippling bearing stress at the root of fillet should be less than permissible bearing stress ($0.75 f_y$)

L

$$\frac{P}{\{a + 2.5t(h_s + t)\} tw} \leq \sigma_{br}$$

At support .

(15)

$$\frac{R}{\{a + 5t(h_s + t)\} tw} \leq \sigma_{br}$$

Note

If the beam is carrying UDL web crippling needs to be checked at the support

The support width is decided based on the bearing failure of supporting structure as well as web crippling of steel section

Web Buckling

Web buckling occurs due to heavy cone load, diagonal compression due to shear. To check for safety in web buckling

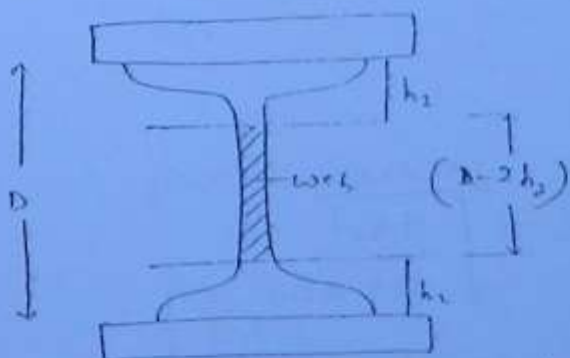


Fig (i)

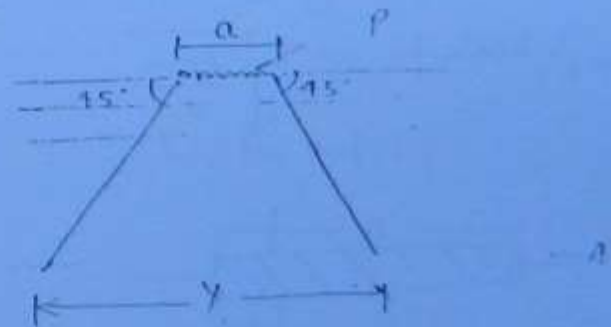


Fig (ii)

web buckling

$$\text{Area at N.A.} = \gamma tw = a$$

To check for web buckling web is treated as a column
of slenderness ratio = $\frac{dw\sqrt{3}}{tw}$ where

(152)

$$dw = D - 2b_f$$

tw - thickness of web

The area resisting compression is calculated as follows (fig ii)

for safety against web crippling

$$\text{carrying capacity} = \sigma_{ac} \times A > P$$

σ_{ac} $\rightarrow$ Per stress in axial compression obtained from
slenderness ratio = $\frac{dw\sqrt{3}}{tw}$

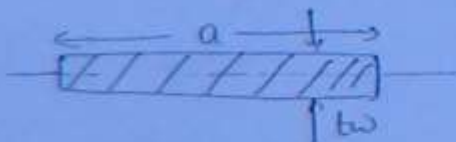
$P \rightarrow$ Applied load

Note

Case The web can be treated as a column which is fixed at the two flange ends hence

$$l_{eff} = \frac{dw}{2}$$

$$\sigma_{min} = \sqrt{\frac{I_{min}}{A}}$$



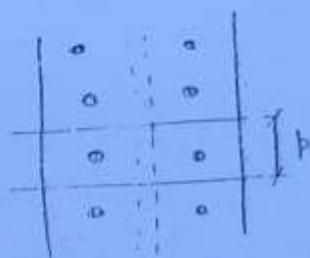
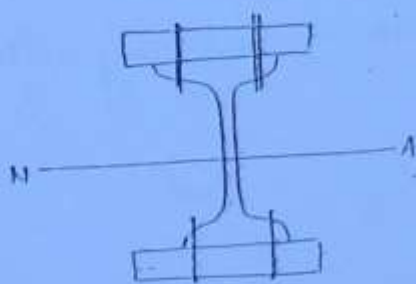
$$\begin{aligned} \sigma_{min} &= \sqrt{\frac{\frac{a tw^3}{12 \times a tw}}{}} \\ &= \frac{tw}{\sqrt{12}} \end{aligned}$$

$$\frac{l_{eff}}{\sigma_{min}} = \frac{(dw/2)}{\frac{tw}{\sqrt{12}}} = \frac{dw\sqrt{3}}{tw}$$

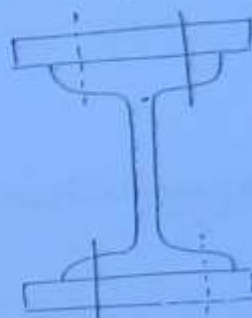
Generally if beam is safe in web crippling it will be safe in web buckling

(153)

Design of rivets



No of rivet per pitch length = 2



No of rivet per pitch length = 1

$$\frac{V A \bar{y}}{I_{xx}} \times p = \text{shear force per pitch length} \leq n R_v$$

n = no. of rivet / pitch length

For safety



Rivet diameter will be assumed and pitch will be calculated for max. shear.

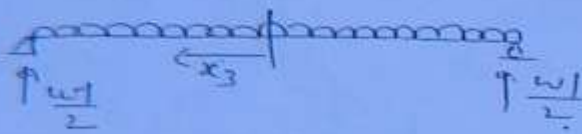
same pitch can be adopted throughout the span

In reality, as shear force decreases towards the mid span, the pitch should increase towards the mid span.

Curtalement of Plates

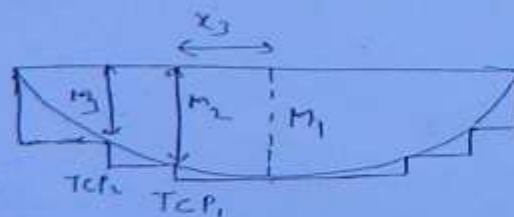
(154)

Theoretical cutoff point is the location at which B.M. is equal to MOR of continuing section.



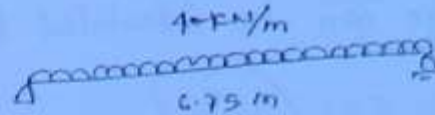
B.M. at x_3 location

$$\begin{aligned}
 &= \frac{wl}{2} \left(\frac{l}{2} - x_3 \right) - w \left(\frac{l}{2} - x_3 \right)^2 \\
 &= \frac{w}{2} \left[\frac{l^2}{2} - l x_3 - \frac{l^2}{4} - x_3^2 + l x_3 \right] \\
 &= \frac{w}{2} \left(\frac{l^2}{4} - x_3^2 \right) \\
 \frac{w}{2} \left(\frac{l^2}{4} - x_3^2 \right) &= \sigma_b Z_2 \\
 &\text{find } x_3
 \end{aligned}$$



At least one plate must continue through out the span.

Q.3 Page 52



(155)

ISMB 300

$$I_{xx} = 89.9 \times 10^6 \text{ mm}^4$$

$$Z_x = 59.9 \times 10^3$$

$$B = 140 \text{ mm}$$

$$t = 7.7 \text{ mm}$$

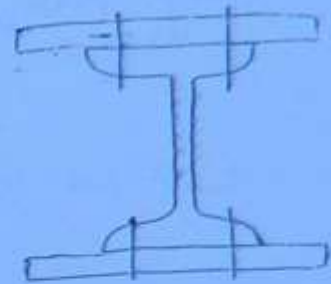
ISMB 400

$$205 \times 10^6$$

$$102 \times 10^3$$

$$140$$

$$8.9$$



$$M_{\max} = \frac{wl^2}{8} = \frac{40 \times 6.75^2}{8} \text{ kNm} = 227.813 \text{ kNm}$$

$$Z_{\text{req.}} = \frac{M_{\max}}{\sigma_b \times \delta_{b1}} = \frac{227.813 \times 10^6}{165} = 138 \times 10^3 \text{ mm}^3$$

No rolled secⁿ can provide $Z = Z_{\text{req.}}$

Hence plates will be used to increase the Z value

Hence let us use ISMB 400 and cover plate as the secⁿ

$$\begin{aligned} \text{Approx area of plate req.} &= \frac{Z_{\text{req.}} - Z_{\text{rolled}}}{D} \\ &= \frac{(138 \times 10^3 - 102 \times 10^3)}{400} \\ &= \frac{36 \times 10^3}{400} = 900 \text{ mm}^2 \end{aligned}$$

$$\text{let us choose } A_p = 1200 \text{ mm}^2$$

$$\text{Adopting } t = 8 \text{ mm}$$

$$\text{width req.} = \frac{1200}{8} = 150 \text{ mm}$$

Check for bending.

Area of tension flange = Area of flange plate + Area of flange of rolled secⁿ

As the thickness of flange of rolled steel is not given the gross and Net area of flange can be calculated from the area of flange plate only

$$\frac{\text{Gross area}}{\text{Net area}} = \frac{150 \times 8}{150 \times 8 - 21.5 \times 8 \times 2}$$

$$= 1.4$$

$$I_{gross} = 205 \times 10^6 + 2 \left[\frac{150 \times 8^3}{12} + 150 \times 8 \times 204^2 \right]$$

$$= 304.89 \times 10^6 \text{ mm}^4$$

$$Y_{max} = 208 \text{ mm}$$

$$\frac{\text{Max. } Y_T}{I_{gross}} \times \frac{GA}{NA} = \frac{227.813 \times 10^6 \times 208}{304.89 \times 10^6} \times 1.4$$

$$= 217.58 > 165$$

Let us adopt area of plate 1800 mm^2 and staggering of rivets hence

$$B \times t = 1800 \text{ mm}^2$$

$$\text{adopt } t = 10 \text{ mm}$$

$$B = 180 \text{ mm}$$

$$\frac{GA}{NA} = \frac{1800}{1800 - 21.5 \times 10} = 1.136$$

$$I_{gross} = 205 \times 10^6 + 2 \left[\frac{180 \times 10^3}{12} + 1800 \times 205^2 \right]$$

$$= 356.32 \times 10^6 \text{ mm}^4$$

check for bending

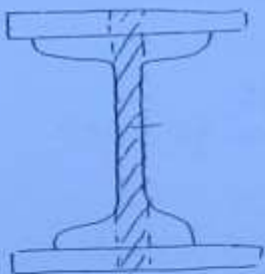
$$\frac{mY}{I} \times \frac{SA}{NA}$$

(157)

$$= \frac{227.813 \times 10^6 \times 210}{356.32 \times 10^6} \times 1136$$

$$= 152.52 \text{ N/mm}^2 < 165 \text{ N/mm}^2$$

check for shear



$$\text{Area} = 420 \times 8.9 = 3738 \text{ mm}^2$$

$$\text{Av. shear stress} = \frac{V_{\max}}{3738} \text{ N/mm}^2$$

$$= \frac{135 \times 10^6}{3720} = 36.12 \text{ N/mm}^2 < 100 \text{ N/mm}^2$$

O.K.

Check for Deflection:

$$\Delta_{\max} = \frac{5}{384} \frac{wL^4}{EI_{\text{gross}}} = \frac{5}{384} \times \frac{40 \times 6750^4}{2 \times 10^5 \times 356.32 \times 10^6}$$

$$= 15.17 \text{ mm}$$

$$\frac{\text{Span}}{325} = \frac{6750}{325} = 20.77$$

$$15.77 < 20.77$$

O.K.

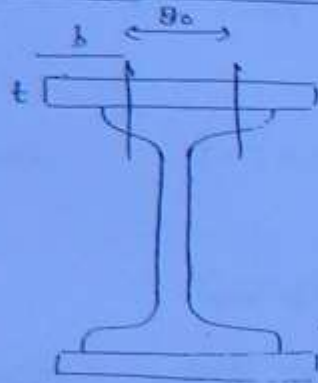
Note → over from the column point of view.

Check for secondary criteria.

Assuming $g = 80\text{mm}$

$$h_2 = 32.8\text{mm}$$

check for local buckling of flange plate.



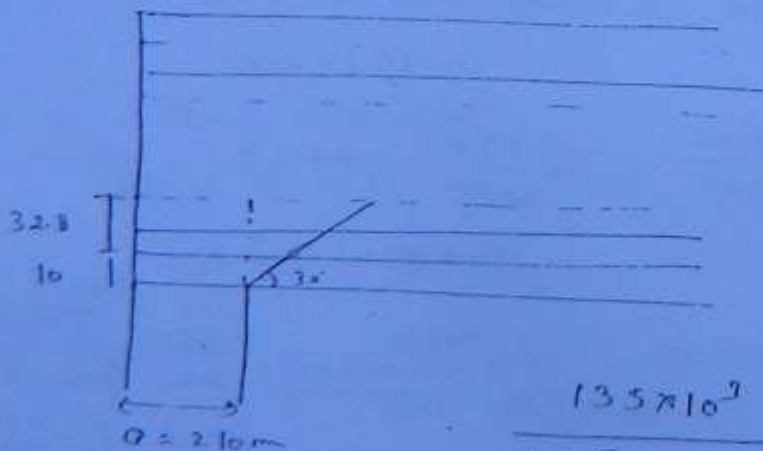
158

$$b = \frac{180 - 80}{2} = 50\text{mm}$$

$$\frac{b}{t} = \frac{50}{10} = 5 < 16$$

Check for web crippling.

The beam is carrying vdl hence point loading will only be at support thus web crippling will be checked at support.



$$\frac{135 \times 10^3}{8.9 \{ 210 + \sqrt{3} (32.8 + 10) \}} \leq 0.75 f_y$$

$$53.39 \leq 107.5$$

Safe from web crippling

check for web buckling

$$\lambda = \frac{dw \sqrt{3}}{tw} = \frac{(D - 2h_o) \sqrt{3}}{tw}$$

$$= \frac{(400 - 2 \times 32.8) \sqrt{3}}{8.9} = 65.071$$

(159)

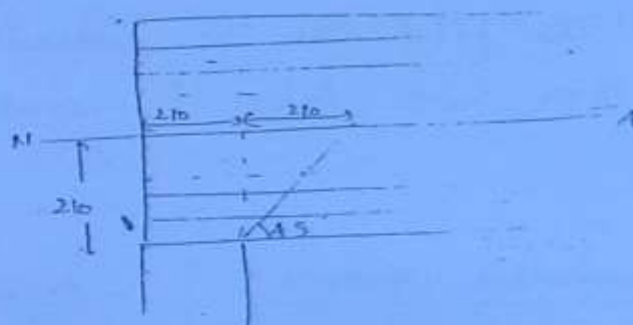
$$\sigma_{ac} = 110.207 \text{ N/mm}^2$$

λ	σ_{ac}
60	113
70	107.5

Area of resisting section

$$= (210 + 210) \times 8.9$$

$$= 3738 \text{ mm}^2$$



Carrying capacity

$$= 3738 \times 110.207 = 411.95 \text{ kN}$$

> 135 kN
safe

Rivet Design

$$\frac{V A \bar{y}}{I} \cdot b \leq R_v$$

because no. of rivet per pitch length = 1

$$180 \times 10 = 1800 \text{ mm}^2$$

$$\bar{y} = 201 \text{ mm}$$

$$I_{x_{cm}} = 356.32 \times 10^6$$

$$V = 135 \times 10^3 \text{ N}$$

$$\text{Rivet dia} = 20 \text{ mm}$$

$$R_v = 36.3 \text{ kN}$$

$$p \leq 259.68 \text{ mm}$$

Note

16t or 12t, 200 mm is a recommendation for direct loading. In this case limit would be 32t or 300 mm. hence max. pitch will be

$$\text{min } \{ 320, 300 \}$$

Max pitch = 300 mm

Adopt $p = 250 \text{ mm}$

The pitch can be increased towards the mid span however we take it constant through out.

Permissible stresses

$$\sigma_{bc} = \sigma_{bt} = 0.67 f_y$$

$$\sigma_{\text{shear}} = 0.4 f_y$$

$$\sigma_{br} = 0.75 f_y$$

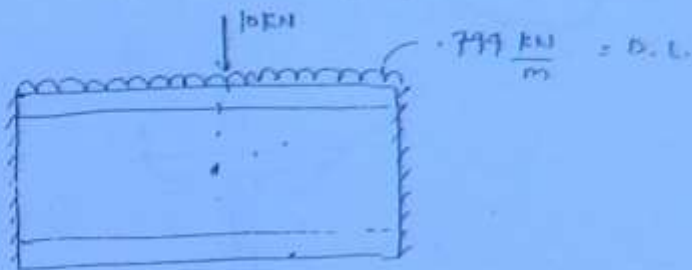
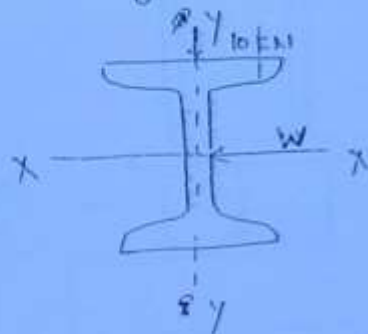
All these permissible values are increased by $33 \frac{1}{3} \%$ if effect of wind or ED or is taken into account.

Sol. 6 ISWB 450 @ 79.4 kgf/m

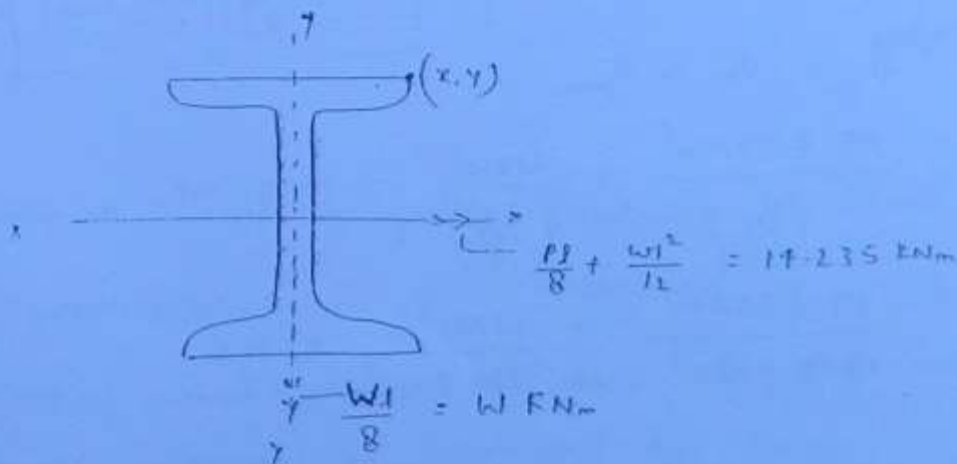
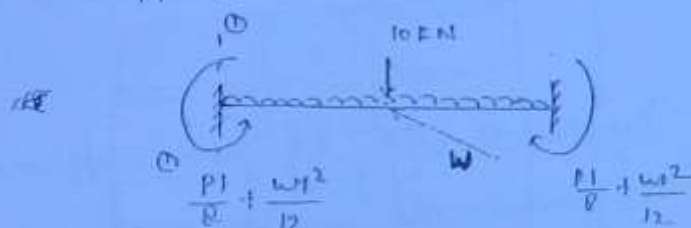
(16)

$$1000 \text{ kgf} = 10 \text{ kN}$$

$$g = 10$$



for the restrained beam like this max. B.M. will occur at the support



Tension (+ve)

$$\sigma = \frac{14.235 \times 10^6 y}{I_{xx}} + \frac{W y}{I_{yy}}$$

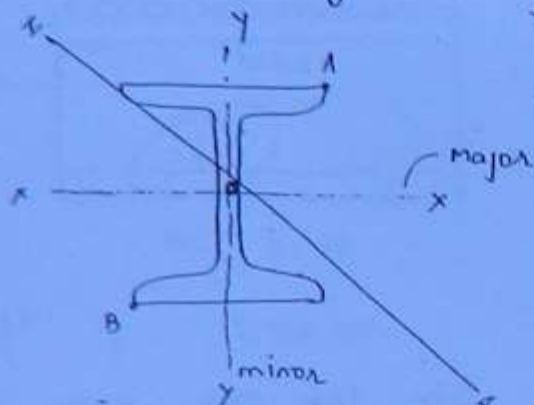
at N.A. Bending stress is zero

$$\frac{M \cdot 235 \times 10^6}{I_{yy}} y + \frac{W \times 10^6}{I_{yy}} x = 0$$

162

$$ax + by = 0$$

$$y = -\frac{a}{b} x$$



location of N.A. shows B. stress will be max_m either at A or B

Note Instead of finding out location of N.A. by above approach we could have located it under the concept that N.A. lies b/w minor axis and the direction of resultant moment for safety

$$\sigma_A \leq \sigma_{perm}$$

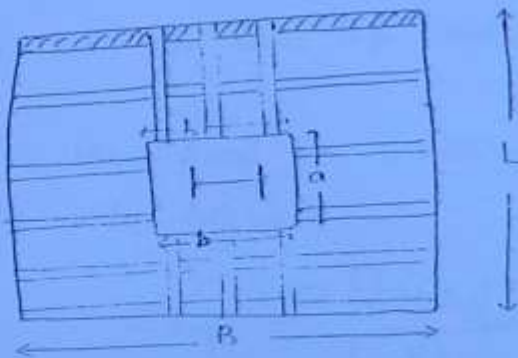
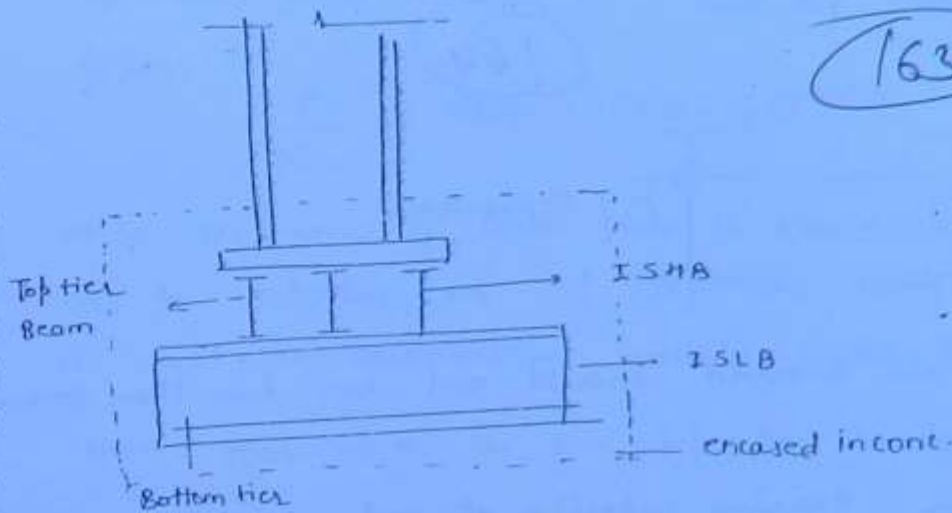
$$\frac{14 \cdot 235 \times 10^6}{\left(\frac{I_{yy}}{y}\right)} + \frac{W \times 10^6}{\left(\frac{I_{yy}}{x}\right)} \leq 165 \text{ MPa}$$

$$\frac{14 \cdot 235 \times 10^6}{1558.1 \times 10^3} + \frac{W \times 10^6}{170.7 \times 10^3} \leq 165$$

$$W \leq 26.6 \text{ kN}$$

Grillage Foundation

(163)



Permissible stress If the grillage foundation is encased in concrete the permissible stresses are increased by $33\frac{1}{3}\%$.

If effect of wind and EO is also taken into account permissible stresses are increased by 50%.

Note

Per. Bending stress normally is $0.67 f_y$

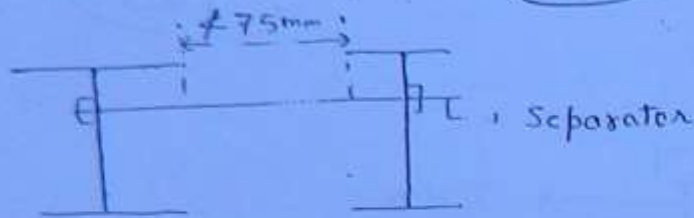
Per. All the stresses are increased by 33 percent

Per. in grillage foundation = $1.33 \times 0.67 f_y$

Per. Bending stress in grillage foundation when effect of wind or EO is also taken in account = $1.5 \times 0.67 f_y$

Separation must keep the beam properly spaced such that the distance between edges of adjacent beam is not less than 75 mm

(164)

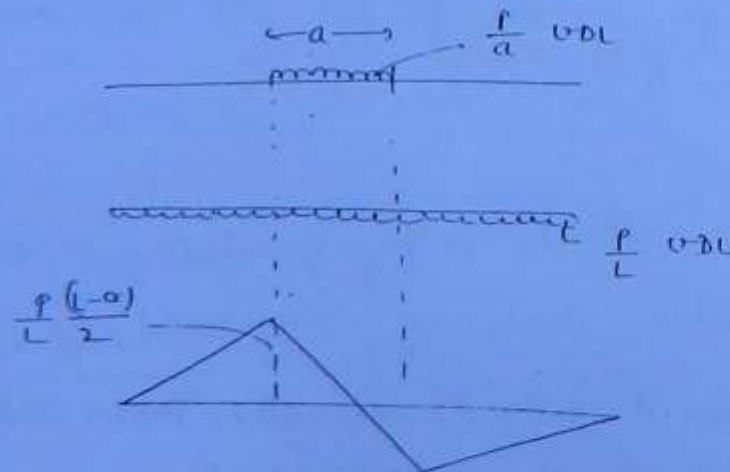


Clear cover all around should not be less than 100mm

$$\frac{P}{L \cdot B} \leq \text{Bearing capacity of soil}$$

Choose L & B on this criteria

Top tier Beams



$$M_{max} = \frac{1}{2} \times \frac{P}{L} \times \frac{(L-a)}{2} \times \frac{1}{2}$$

$$M_{max} = \frac{1}{8} \frac{P(L-a)}{L}$$

The above max SF & Bm are for all top tier beam taken together. Hence to design top tier beam no. of

beams needs to be selected.

To start with area of base plate can be calculated as follows

$$\frac{P}{\sigma_{tens}} = A_{req.} = a \times b$$

(163)

once the size of base plate is known no. of top tier beam can be selected, no. of top tier beam should be such that it could be accommodated within width b

$$\text{Hence Max. B.M. in one top tier beam} = \frac{P(l-a)}{8n}$$

Where $n \rightarrow$ no. of top tier beam

$$\text{Max. s.f. in one top tier beam} = \frac{P(l-a)}{2L \times n}$$

P is the load in which effect of dead wt. ^{is} already been taken into account.

$$Z_{req.} = \left\{ \frac{P(l-a)}{8 \times n} \right\}$$

$$165 \times 1.33$$

Choose secⁿ and check for shear.

Bottom Tier beam.

$$\int b \quad (P/b)$$

$$\text{val} = \left(\frac{P}{B} \right)$$

$$\text{Mint. for all bottom tier beam taken together} = \frac{P(B-b)}{8}$$

V_{max} for all bottom tier beam taken together

$$= \frac{P(B-b)}{2B}$$

(166)

Note

If there is a chance of web crippling it will be there in top tier beam only hence top tier beam can be checked for web crippling also.

Q

Load on a column is 2500 kN the safe bearing capacity of soil is $250 \frac{\text{kN}}{\text{m}^2}$ & permissible bearing stress in conc. is $4000 \frac{\text{kN}}{\text{m}^2}$. Design grillage foundation.

Sol. Load on base plate = $1.1 \times 2500 = 2750 \text{ kN}$
Choosing square base plate

$$a \times a = \frac{1.1P}{\sigma_c} = \frac{2750}{4000}$$

$$a = 0.829$$

$$= 850 \text{ mm}$$

$$\frac{1.1P}{250} = L^2$$

$$L = \frac{1.1 \times 2500}{250} = 3.316 \text{ m}$$

$$a_{dept} = 3.4 \text{ m}$$

$$M_{max} = \frac{1.1P(L-a)}{8} = \frac{1.1 \times 2500(3.4 - 0.85)}{8} = 876.56 \text{ kNm}$$

$$V_{max} = \frac{1.1P(L-a)}{2L} = 1031.25 \text{ kN}$$

Z_{req} for all beams taken together

$$= \frac{876.56 \times 10^6}{165 \times 1.32} = 4000 \text{ cm}^3$$

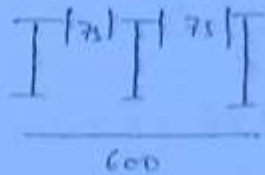
let us choose 3 no. of top tier beams

$$2 \text{ no. for } 1 = \frac{4000}{3} = 1333.33$$

(167)

3 let us choose ISMB 450

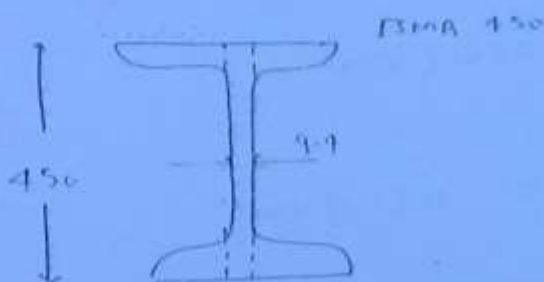
$$Z_{max} = 1350.7 \text{ cm}^3$$



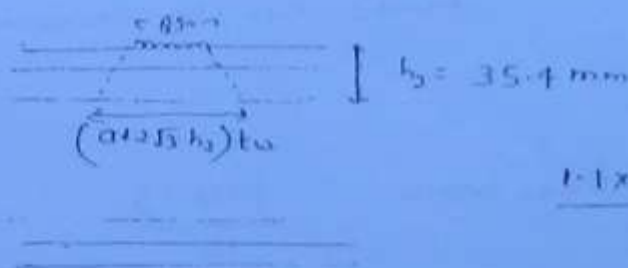
$$b = 150$$

So 3 no. of ISMB 450 can be accommodated within the base plate

$$V_{max \text{ one}} = \frac{1.1 P(L-a)}{2L \times 3} = 343.75 \text{ KN}$$



$$\begin{aligned} \text{Av shear stress} &= \frac{343.75 \times 10^3}{450 \times 1.4} \\ &= 81.264 < 133 \times 100 \\ &\text{Safe} \end{aligned}$$



$$\frac{1.1 \times 2500}{3} = 916.7 \text{ KN}$$

$$\frac{916.7 \times 10^3}{(a + 2\sqrt{3}b_2) t_w} \leq 1.33 \times 0.75 f_y$$

$$100.26 \leq 247.17 \text{ MPa}$$

max. spacing b/w bottom tier beam is generally 200 to 250 mm.

No. of bottom tier beam

168

Max bottom tier for all beams taken together

$$= \frac{P(B \cdot b)}{8}$$

$$= 876.56 \text{ kNm}$$

$$Z_{\text{req.}} = \frac{876.56 \times 1.33}{1.33 \times 165} = 4000 \text{ cm}^3$$

Space available = 3.9 m

No. of bottom tier beams are generally 10 - 20

Let us choose 15 no.

$$Z_{\text{req. one}} = \frac{4000}{15} = 266.7 \text{ cm}^3$$

choose ISMB 225

$$Z_{\text{provided}} = 305.9 \text{ cm}^3$$

$$14 \times 75 + 15 \times 110 < 3400$$

$$270 < 3400$$

hence can be accommodated

check for shear.

Shear in one bottom shear beam

$$= \frac{1031.25}{15}$$

$$= 68.75 \text{ kN}$$

Av. shear stress

$$= \frac{68.75}{6.5 \times (225 - 400)} = 47 \text{ N/mm}^2$$

$$< 1.33 \times 100$$

OK.

Note:

If the size of column is given to us thickness can be calculated

(169)

PLASTIC ANALYSIS

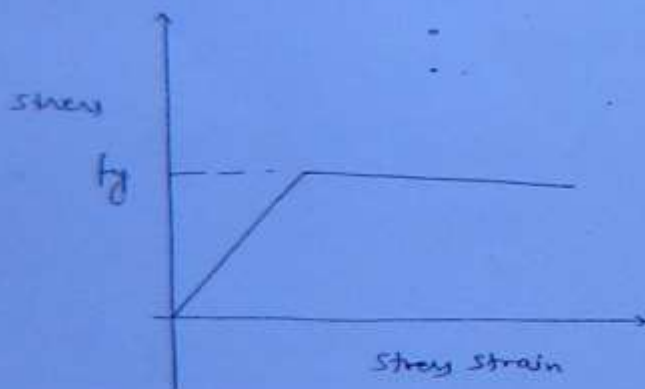
(170)

In conventional design method structure is designed for strength of steel till it yields at a point in the secⁿ.

However if yielding occurs at one point in section it does not mean collapse of the member. Due to plastic deformation and strain hardening of material, the particles which were less stressed will be brought into action so that structure is actually able to resist greater load.

In the modern design strength of steel beyond the point of first yield is utilized and this method of design is called plastic method of design.

Simply Stress-strain curve



- strain hardening range has been omitted in this case which in fact will add to the margin of safety.
- Plastic design can be applied only to redundant structures.
- In the case of simple members load causing first yield is most critical because at that load only large unacceptable deformation occurs.

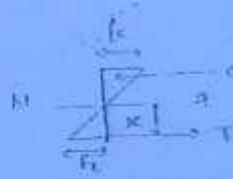
str. deformation even at the time of collapse is not much
hence plastic ^{analysis} can be applied only to redundant str.

(17)

Assumptions in plastic analysis

1. Material should possess ductility so that it can be deformed in the plastic stage.
2. Strain distribution is linear.
3. Relation b/w tensile stress and tensile strain & comp. stress & comp. strain should be same.
4. Joints should be sufficiently strong to transfer the moment.
All joints should be rigid joint.

Plastic Bending of Beams.



T = C gives N.A.

$$C = \frac{1}{2} f_c (D-x) b$$

$$T = \frac{1}{2} f_t x b$$

$$\frac{f_c}{(D-x)} = \frac{f_t}{x}$$

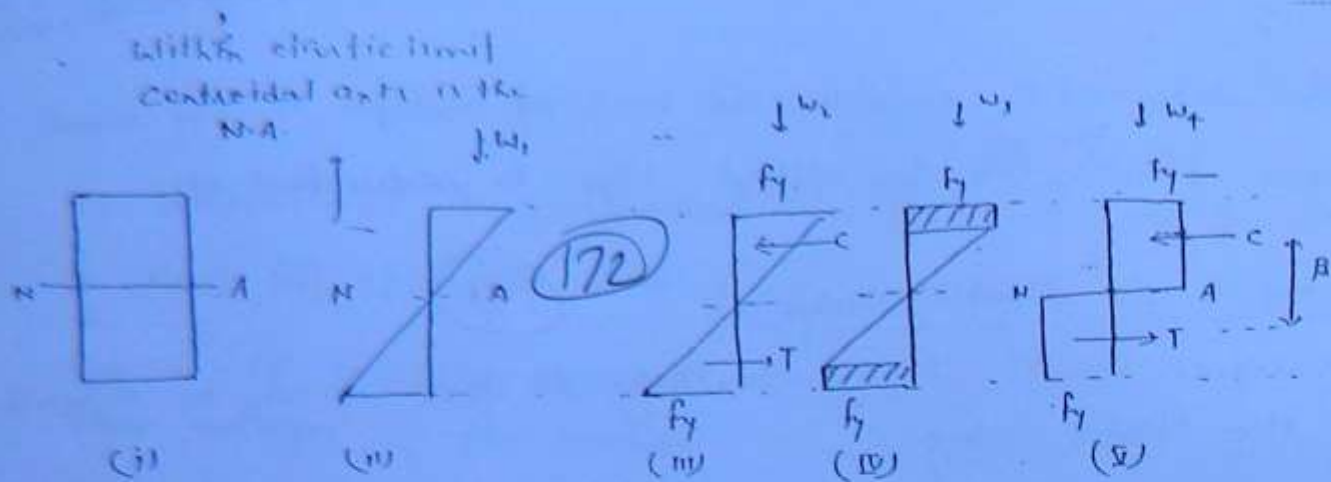
$$f_c (D-x) \cancel{b} = f_t x \cancel{b}$$

$$(D-x)^2 = x^2$$

$$b(D-x) \cdot \frac{(D-x)}{2} = \frac{b}{2} x \cdot x$$

Moment of comp area about N.A. = Moment of tension area about N.A.

This is the location of C.G.



N.A. will remain at centroidal axis if section is symmetrical about the axis of bending. (in figs (v) & (v))

In fig (v)

$$C = T$$

$$f_y A_c = f_y A_T$$

$$A_c = A_T = \frac{A}{2}$$

N.A. is equal area axis

$$CA = T \cdot B = M_p$$

M_p is full plastic moment capacity of section

In fig (iii)

N.A. is centroidal axis

$$T \alpha = C \alpha = M_y$$

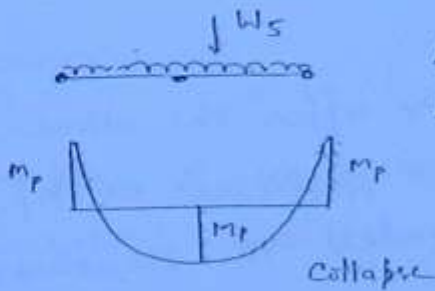
$M_y \rightarrow$ M.O.R. at the time of first yield

= Yield moment

- M_p is plastic moment capacity which depends on section only.
- A fully plastic section can not resist any further moment and if loading is applied beyond W_4 . Unrestrained rotation will take place at the fully yielded section thus we assume as if a plastic hinge has formed. Plastic hinge can be understood as rusted hinge in which rotation does not take place upto certain load and beyond that load a large deformation in the form of rotation will take place.

Formation of plastic hinge at one location does not mean the collapse of the structure. For collapse sufficient no. of plastic hinge must develop to make the structure unstable.

(173)

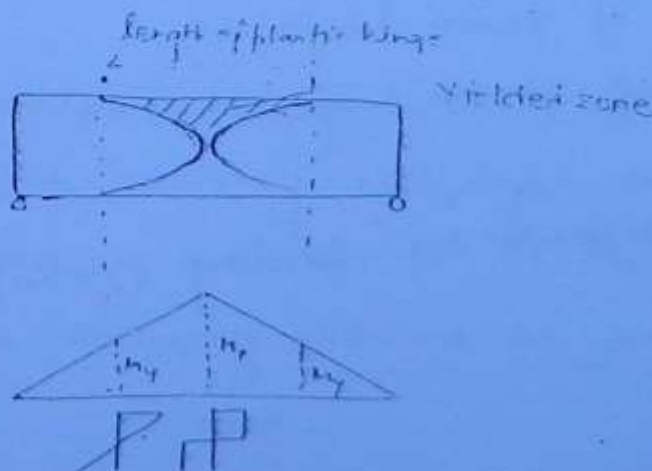


Due to plastic hinge formation fixed end start behaving as hinge.

For complete collapse of structure the margin available is $(W_5 - W_2)$ beyond the point of first yield. $(W_5 - W_2)$

For complete yielding of the secⁿ margin available beyond the point of first yield is $(W_4 - W_2)$

Definition of Plastic hinge - A plastic hinge can be defined as a yielded zone due to flexure in a structure in which infinite rotation can take place at a constant resisting moment (M_p) of the secⁿ



Some important point about plastic hinge.

1. A secⁿ is said to develop a plastic hinge when due to flexure, stress at every point of the secⁿ is equal to yield stress.
2. Plastic hinge develops first at secⁿ subjected to greatest curvature.
3. Due to formation of plastic hinge one after the other, re distribution of moments take place. Sufficient no. of plastic hinges have to be developed to render the structure to unstable or collapse state.
4. No. of plastic hinge required for complete collapse of the structure is $(r+1)$.
Where r is the degree of redundancy.



for vertical loading
 $r_s = 1$

No. of plastic hinge required for complete collapse of str = $r+1 = 2$



$r_s = 2$

partial collapse of str.

No. of plastic hinge = 2

for complete collapse no. of plastic hinge = $2+1 = 3$

1. Length of plastic hinge depends on loading & shape of section.



l_p : length of 'P.H.',



l_{p2}



l_{p3}

(175)

6) For purpose of analysis plastic hinge will be assumed as a point about which plastic rotation takes place.

7) M.O.R. of normal hinge is zero & M.O.R. of P.H. is M_p

8) Plastic hinge is expected to form at

a) Fixed ends

b) At the location of point load.

c) At the point of sudden change in geometry.

d) At points of zero shear in a span subjected to U.D.L. or U.V.L.

9) When two sections join at a point plastic hinge forms in a section of smaller M_p

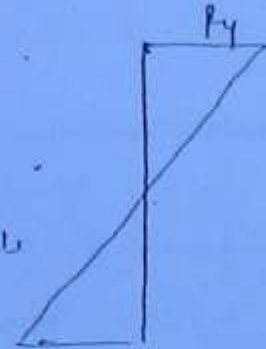
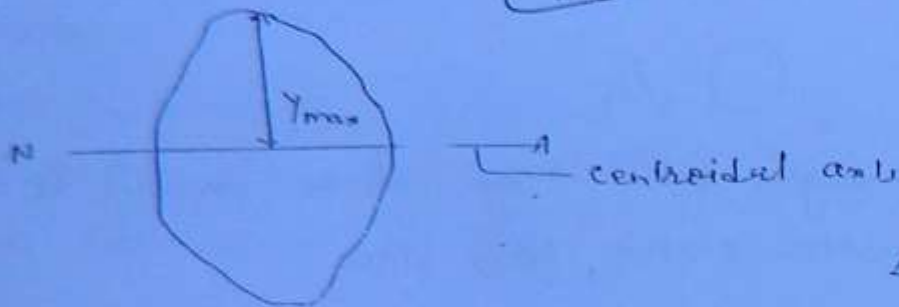
If section is loaded upto a moment of M_y and then unloaded complete recovery will take place. However if moment applied on the sect is $> M_y$ & then unloading takes place recovery will not be complete.

Shape factor

$$\text{Shape factor} = \frac{M_p}{M_y}$$

It shows the reserve of strength of a section beyond the point of first yield.

(178)



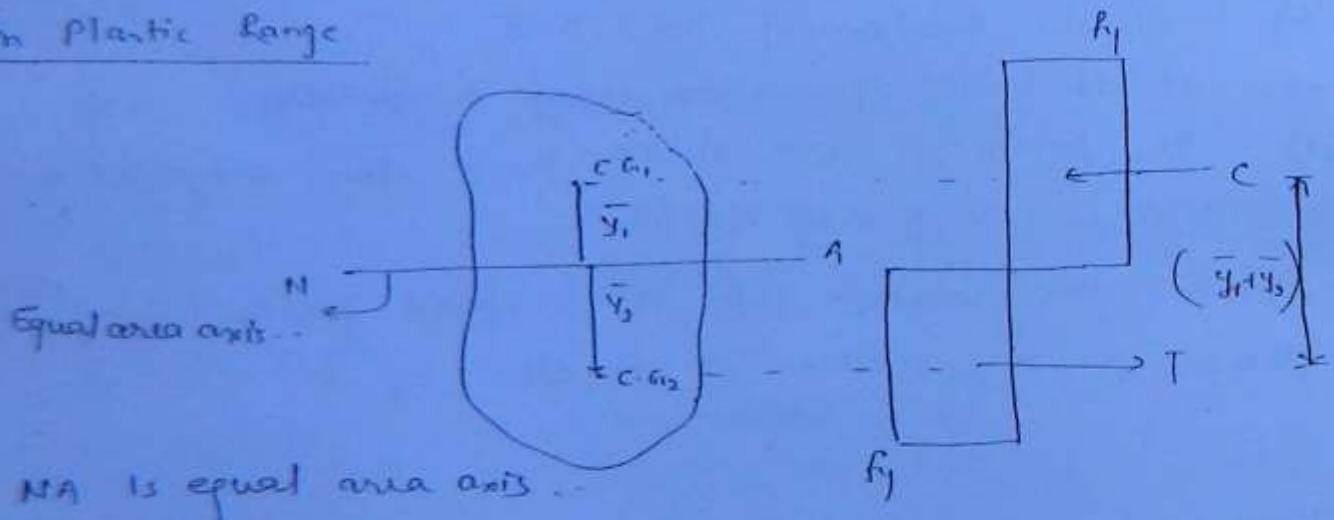
In elastic range

$$M_y = f_y \cdot Z$$

$Z \rightarrow$ section modulus

$$Z = \frac{I_{NA}}{y_{max}} = \frac{\text{M.O.I about } C-G_1}{y_{max}}$$

In Plastic Range



NA is equal area axis.

$$M_p = C(\bar{y}_1 + \bar{y}_2) = T(\bar{y}_1 + \bar{y}_2)$$

$$= f_y \cdot \frac{A}{2} (\bar{y}_1 + \bar{y}_2)$$

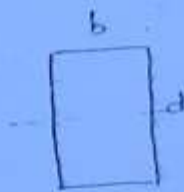
$$M_p = f_y S \quad \text{where } S \rightarrow \text{Plastic Modulus}$$

$$= \frac{A}{2} (\bar{y}_1 + \bar{y}_2)$$

$$\text{Shape factor} = \frac{M_p}{M_y} = \frac{f_y \cdot S}{f_y \cdot Z} = \frac{S}{Z} = \frac{\text{Plastic modulus}}{\text{Section modulus}}$$

$$= \frac{\frac{A}{2} (\bar{y}_1 + \bar{y}_2)}{Z} \quad (178)$$

shape factor of Rectangular secⁿ -



equal area axis & centroidal axis is same

$$SF = \frac{\frac{A}{2} (\bar{y}_1 + \bar{y}_2)}{Z} = \frac{\left(\frac{bd}{2}\right) \left(\frac{d}{2}\right)}{\frac{bd^2}{6}}$$

$$= \frac{6}{4} = \frac{3}{2} = 1.5$$

circular secⁿ



$$S.F. = \frac{\frac{A}{2} (\bar{y}_1 + \bar{y}_2)}{Z}$$

$$= \frac{\frac{\pi d^2}{8} \left(\frac{4 \cdot (d/2) \times 2}{3\pi} \right)}{\frac{\pi d^4}{64} \cdot \frac{2}{d}}$$

$$= \frac{\frac{1}{8} \times \frac{4}{3\pi}}{\frac{1}{32}}$$

$$= \frac{1}{6\pi} \cdot 32 = 1.678$$

Plastic modulus for
circular secⁿ = $\frac{d^3}{6}$



(178)

$$S = \frac{a^3}{3\sqrt{2}}$$

$$\begin{aligned} S.F. &= \frac{\frac{A}{2} (\bar{y}_1 + \bar{y}_2)}{Z} \\ &= \frac{\frac{A}{2} \left(\frac{a}{\sqrt{2}} + \frac{1}{3} \times 2 \right)}{\frac{\frac{a^4}{12} \sqrt{2}}{a}} \\ &= \frac{a^3}{3\sqrt{2}} \\ &= \frac{a^3 \sqrt{2}}{12} \\ &= 3 \frac{12^3}{\sqrt{2}} \times \frac{1}{12\sqrt{2}} = 2 \end{aligned}$$



$$\frac{t}{d} \ll 1$$

$$S.F. = \frac{\frac{A}{2} (\bar{y}_1 + \bar{y}_2)}{Z} = \frac{S}{Z}$$

$$\begin{aligned} S = \text{Plastic Modulus} &= \frac{d^3}{6} - \frac{(d-2t)^3}{6} \\ &= \frac{d^3}{6} \left[1 - \left(1 - \frac{2t}{d} \right)^3 \right] \end{aligned}$$

$$\begin{aligned} &= \frac{d^3}{6} \left[1 - \left\{ 1 - \frac{8t^3}{d^3} + 3 \frac{4t^2}{d^2} - \frac{3 \times 2t}{d} \right\} \right] \\ &= \frac{d^3}{6} \left[\frac{6 \cdot 1}{d} \right] = d^2 t \end{aligned}$$

$$Z = \frac{I}{y_{max}} = \frac{\pi d^4}{64} - \frac{\pi (d-2t)^4}{64}$$

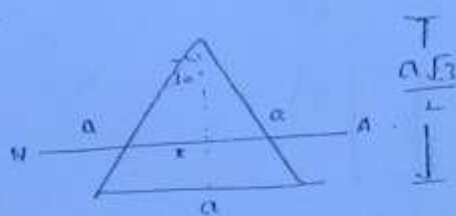
$$\frac{\pi d^3}{32} \left[1 - \left(1 - \frac{2t}{d} \right)^4 \right]$$

$$\frac{\pi d^3}{32} \left[1 - \left(1 - \frac{8t}{d} + \dots \right) \right]$$

(178)

$$= \frac{\pi d^3}{32} \times \frac{8t}{d} = \frac{\pi d^2 t}{4}$$

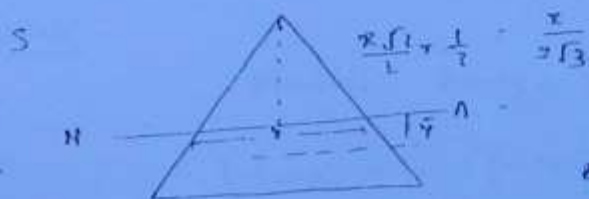
$$S.F. = \frac{d^2 t}{\pi d^2 t} \times 4 = 1.272$$



$$S.F. = \frac{S}{2}$$

$$Z = \frac{I}{Y} = \frac{a \cdot \left(\frac{a\sqrt{3}}{2} \right)^3}{36 \left(\frac{a\sqrt{3}}{2} \right)^2}$$

$$= \frac{a \left(\frac{a\sqrt{3}}{2} \right)^2}{\frac{24}{1}} = \frac{a^3 \cdot 3}{4 \times 24} = \frac{a^3}{32}$$



H.A is equal area axis

$$A \frac{Area}{2} = \frac{1}{2} \left\{ a \cdot \frac{a\sqrt{3}}{2} \times \frac{1}{2} \right\} = \frac{a^2 \sqrt{3}}{8}$$

$$Area \text{ of equilateral triangle} = \frac{a^2 \sqrt{3}}{4}$$

$$\frac{x^2 \sqrt{3}}{4} = \frac{a^2 \sqrt{3}}{4} \times \frac{1}{2}$$

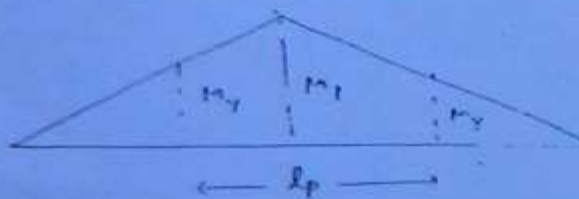
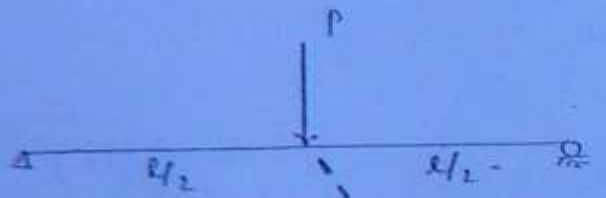
$$\bar{y} = \frac{1}{3} \left(\frac{2a + x}{a + x} \right) \times \left(\frac{\sqrt{3}a}{2} - \frac{x\sqrt{3}}{2} \right) \quad x = \frac{a}{\sqrt{2}}$$

$$= \frac{1}{3} \left(\frac{2\sqrt{2} + 1}{\sqrt{2} + 1} \right) \frac{\sqrt{3}}{2} (\sqrt{2} - 1) = .19x = .189x$$

$$= .268a$$

(189)

Length of Plastic hinge.



$$\frac{m_p}{m_y} = \frac{\frac{l}{2}}{\frac{(l - l_p)}{2}} = 1.5$$

$$l_p = \frac{l}{3}$$

3)



$$\frac{M_p}{M_y} = \frac{\frac{wl^2}{8}}{\frac{wl^2}{8} - \frac{wl_p^2}{2 \times 4}} = \frac{l^2}{l^2 - 4l_p^2}$$

only when s.f. is zero at mid point

$$l^2 = 1.5l^2 - 6l_p^2$$

$$6l_p^2 = 0.5l^2$$

$$l_p^2 = \frac{l^2}{12}$$

$$l_p = \frac{l}{\sqrt{12}}$$

(18)

$$\frac{l^2}{l^2 - l_p^2} = 1.5$$

$$l^2 = 1.5l^2 - 1.5l_p^2$$

$$0.5l^2 = 1.5l_p^2$$

$$l_p^2 = \frac{l^2}{3}$$

$$l_p = \frac{l}{\sqrt{3}}$$

Load factor and factor of safety

$$\text{load factor} = \frac{\text{collapse load}}{\text{working load}}$$

Note

Plastic Design

$$(S \times Y_m \times \text{load factor})$$

$$\frac{(S \times L \cdot F) l^2}{8} \leq M_p$$

Elastic Design

$$\frac{wl^2}{8} \leq \frac{F_y}{F.O.S.}$$

$$\frac{wl^2}{8} \leq \frac{F_y}{F.O.S.}$$

No.

$$\begin{aligned} \text{load factor} &= \frac{\text{collapse load}}{\text{working load}} = \frac{W_c}{W_w} \\ &= \frac{M_p}{\sigma_{per} \cdot Z} = \frac{F_y \cdot S}{\left(\frac{F_y}{F.O.S}\right) \cdot Z} = F.O.S \times \left(\frac{S}{Z}\right) \end{aligned}$$

$$\text{load factor} = (\text{factor of safety}) \times \text{shape factor}$$

182

Moment curvature Relationship (Rectangular Secⁿ)

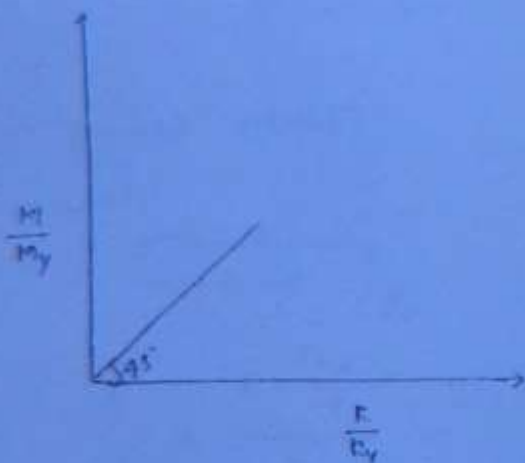
So long as moment is less than M_y

Elastic condition prevails

$$\frac{M}{I} = \frac{f}{y} = \frac{E}{R}$$

$$M = \frac{EI}{R} = EI \cdot \kappa \quad \kappa = \text{curvature}$$

$$\frac{M}{M_y} = \frac{\kappa}{\kappa_y}$$



As the secⁿ start yielding moment curvature relationship becomes non linear

Even in the yielded zone the strain variation is assumed

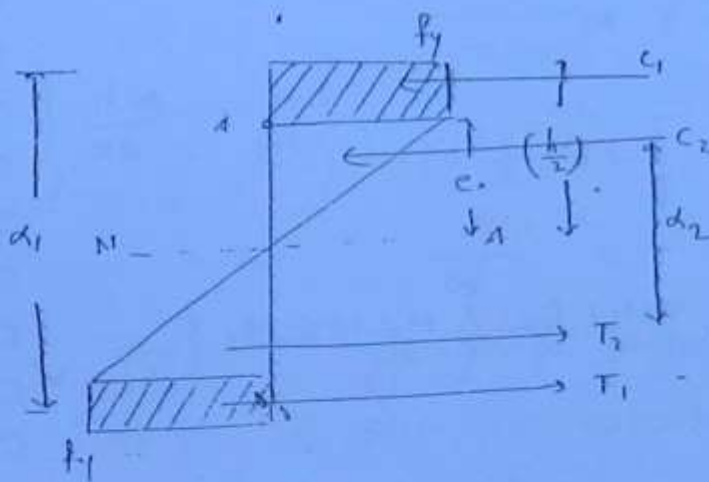
to be linear.



strain $\epsilon = \frac{y}{x} = yk$

$$k = \frac{\epsilon}{y}$$

183



stress variation

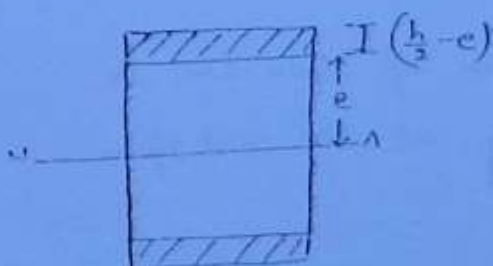
Strain at $d_1 = \frac{fy}{E} = ke$

curvature $(k) = \left\{ \frac{fy}{Ee} \right\}$

$$fy = \frac{fy}{E \cdot \frac{h}{2}}$$

$$\frac{k}{ky} = \frac{h}{2e}$$

$$M = C_1 \alpha_1 + C_2 \alpha_2 = T_1 \alpha_1 + T_2 \alpha_2$$



$$C_1 = fy \cdot \left(\frac{h}{2} - e \right) b$$

$$d_1 = h - \left(\frac{h}{2} - e \right) = \left(\frac{h}{2} + e \right)$$

$$C_2 = \frac{1}{2} fy \cdot e \cdot b$$

$$\alpha_2 = \frac{fy}{E}$$

$$M = C_1 \alpha_1 + C_2 \alpha_2$$

$$= f_y b \left(\frac{h^2}{4} - e^2 \right) + \frac{2 f_y e^2 b}{3}$$

$$= f_y \cdot \frac{b h^2}{6} \left[\frac{6}{4} - \frac{6 e^2}{h^2} + \frac{2}{3} \frac{e^2}{h^2} \times 6 \right]$$

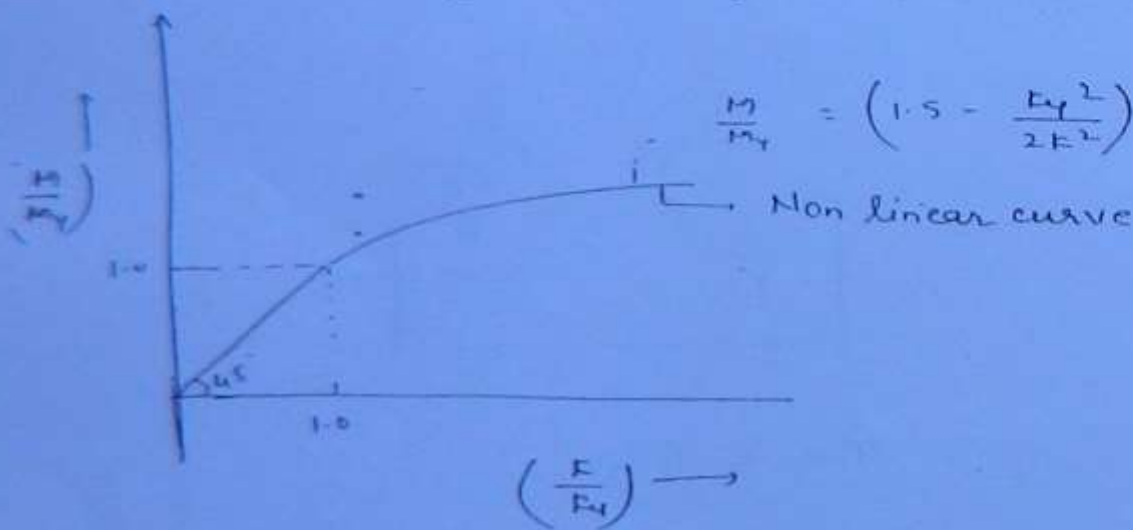
$$(184) = f_y \cdot \frac{b h^2}{6} \left[1.5 - 2 \frac{e^2}{h^2} \right]$$

$$= M_y \left[1.5 - \frac{2 e^2}{h^2} \right] = M$$

$$\frac{3}{4} = \left[1.5 - 2 \left(\frac{e}{h} \right)^2 \cdot \frac{1}{4} \right]$$

$$\left\{ \frac{t}{k_y} = \frac{e}{2e} \right\}$$

$$\left(\frac{3}{4} \right) = \left[1.5 - \frac{k_y^2}{2 k^2} \right] \text{ valid for } \left\{ M_y \leq M \leq M_p \right\}$$

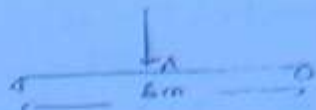


Question.

Design a simply supported beam of span 6m to support a point load of 100 kN acting at its mid span.

$f_y = 250 \text{ MPa}$ & load factor = 1.75

$$\text{collapse load} = 100 \times 1.75 = 175 \text{ kN}$$



Beam will collapse when plastic hinge forms at midspan below the point load.

$$\text{B.M. at A} = M_p = \frac{175 \times 6}{4} = 262.5 \text{ kNm}$$

$$M_p = f_y \cdot S$$

(185)

$$S = \frac{262.5 \times 10^6}{250} = 10.5 \times 10^5 \text{ mm}^3$$

$$\frac{S}{Z} = \text{shape factor}$$

$$Z = \frac{S}{SF} =$$

By choosing shape factor, i.e. by choosing the secⁿ shape Z can be calculated

Note

shape factor for I secⁿ = 1.15

$$Z_{req.} = \frac{10.5 \times 10^5}{1.15} = 913.04 \text{ cm}^3$$

Choose

ISM B - 400

$$Z = 1022.9 \text{ cm}^3$$

Important theorems in plastic analysis

In the plastic analysis following conditions must be satisfied.

1. Equilibrium condition

$$\sum F = 0$$

$$\sum M = 0$$

186

In all types of analysis equilibrium eq. is always satisfied

2. Mechanism condition

At collapse sufficient no. of plastic hinge must be developed so as to transform a part or whole of the structure into a mechanism leading to collapse.

For complete collapse of the structure no. of plastic hinge required to be formed = $(r+1)$

$r \rightarrow$ Degree of redundancy of structure.

3. Yield condition

At collapse B.M. at any section must not exceed the fully plastic moment capacity of the section

If all the above 3 condⁿ are satisfied, a unique lowest value of collapse load will be achieved.

Based on the above 3 condⁿ we get the following theorems based on which plastic analysis is performed/done.

- Upper Bound theorem or kinematic theorem
- Lower bound theorem or static theorem.

Upper Bound Theorem.

This theorem satisfies equilibrium and mechanism condition.

- (187) -

Load determined by assuming a mechanism will always be greater than equal to the collapse load ($P \geq P_u$).
 $P_u \rightarrow$ collapse load.

This theorem can also be stated as

Of the various possible mechanism, the correct mechanism is the one for which the collapse load is min.

Lower Bound Theorem.

Load determined on the basis of any collapsed B.M.D., in which B.M. at any section is less than plastic moment, will be less than or equal to actual collapse load i.e. $P \leq P_u$

This theorem satisfies equilibrium and yield condⁿ

Methods of Analysis.

- Static Method.
- Kinematic Method.

Static Method.

Steps

- Select the redundant force
Moment will be taken as redundant.



2) Draw free BMD and redundant BMD.



Free BMD

(188)



Redundant BMD

3) A combining BMD is drawn in such a way that a mechanism is formed.

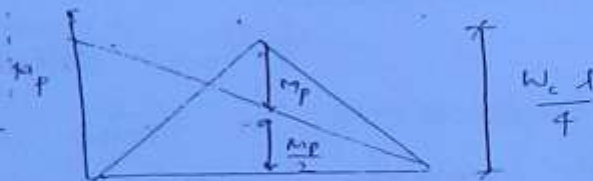
Degree of redundancy = 1

hence no. of plastic hinge req.

for complete collapse = 2

They will form at support + below point load.

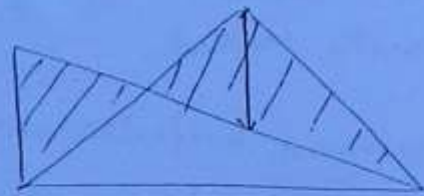
4) collapse load is found out by working out the equilibrium equation



5) It is checked that B.M. at every section is less than M_p

$$M_p + \frac{M_p}{2} = \frac{W_c l}{4}$$

$$W_c = \left(\frac{6M_p}{l} \right)$$



Kinematic Method.

Locate the possible places of plastic hinges and ascertain the various possible mechanisms.

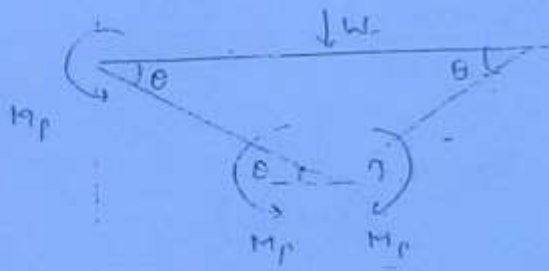
collapse load is found out by applying the principle of virtual work.

BMD of collapse mechanism is drawn and it is checked that BM at any section is not more than M_p .

(189)



No. of plastic hinge required = 2



$$-M_p\theta - M_p\theta - M_p\theta + W_c \frac{l}{2}\theta = 0$$

$$-3M_p\theta = \frac{W_c \theta l}{2}$$

$$W_c = \frac{6M_p}{l}$$

Kinematic Method.

Locate the possible places of plastic hinges and ascertain the various possible mechanisms.

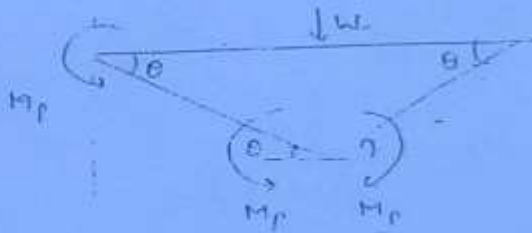
collapse load is found out by applying the principle of virtual work.

BMD of collapse mechanism is drawn and it is checked that BM at any section is not more than M_p .

(189)



No. of plastic hinge required = 2



$$-M_p\theta - M_p\theta - M_p\theta + W_c \frac{l}{2}\theta = 0$$

$$= 3M_p\theta = \frac{W_c \theta l}{2}$$

$$W_c = \frac{6M_p}{l}$$

Q i) Find M_p if c is the collapse load

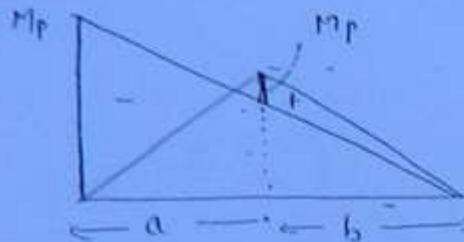
ii) Find the position of load for collapse load to be min.



$R = 1$ (for vertical loading)

No of hinge required for complete collapse $\therefore R + 1 = 2$

(190)

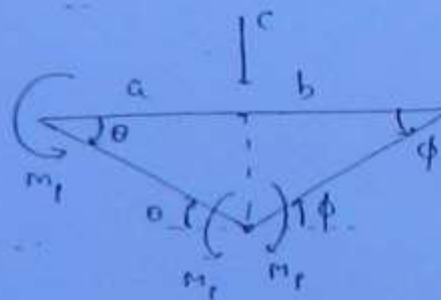


$$\left[\frac{cab}{(a+b)} \right]$$

$$M_p + \frac{M_p \cdot b}{(a+b)} = \frac{cab}{(a+b)}$$

$$M_p = \frac{cab}{(a+2b)}$$

Kinematic method



$$-M_p \theta - M_p \theta - M_p \phi + c \cdot b \phi = 0$$

$$a\theta = b\phi$$

$$-2M_p \theta - M_p \frac{a\theta}{b} + ca\theta = 0$$

$$M_p = \frac{cab}{a+2b}$$

$$(ii) \quad \frac{C a b}{a + 2b} = M_p$$

$$C = \frac{M_p (a + 2b)}{a b}$$

$$= \frac{M_p (l + b)}{(l - b) b}$$

for C to be min

$$\frac{dC}{db} = 0$$

$$\frac{M_p (l - b) b - M_p (l + b) (l - 2b)}{\{(l - b) b\}^2} = 0$$

$$(l - b) b - (l + b) (l - 2b) = 0$$

$$lb - b^2 - (l^2 - 2bl + bl - 2b^2) = 0$$

$$lb - b^2 - l^2 + bl + 2b^2 = 0$$

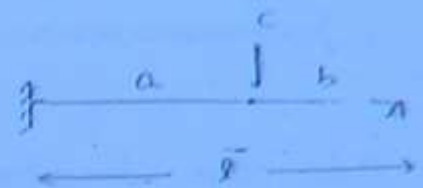
$$b^2 + 2bl - l^2 = 0$$

$$b = \frac{-2l \pm \sqrt{4l^2 + l^2}}{2}$$

$$= -l + \sqrt{2} l$$

$$= l (\sqrt{2} - 1)$$

$$b = 0.414 l$$



(191)

That in case of propped cantilever with point load collapse load will be min when load is at $0.414 l$ from the hinged end.

Q.  c - collapse load

Find M_p

In this case location of plastic hinge needs to be decided first.

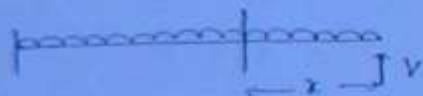
(192)

Method 1

The plastic hinge will form at support and second plastic hinge will form somewhere in span, the location of plastic hinge will be at the point of zero shear because the beam is loaded with u.d.l.



SF = 0 at x distance from hinged end



$$V - cx = 0$$

$$Vx - \frac{cx^2}{2} = M_p$$

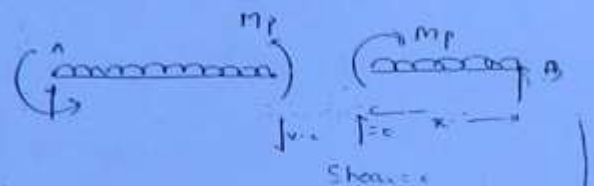
$$cx^2 - \frac{cx^2}{2} = M_p$$

$$\frac{cx^2}{2} = M_p$$

At support A

$$Vl - \frac{cl^2}{2} = -M_p$$

$$clx - \frac{cl^2}{2} = -\frac{cx^2}{2}$$



$$\sum M_B = 0$$

$$M_p - \frac{c(l-x)^2}{2} = 0$$

$$M_p = \frac{cx^2}{2}$$

$$\sum M_A = 0$$

$$2M_p - \frac{c(l-x)^2}{2} = 0$$

$$cx^2 - \frac{c(l-x)^2}{2} = 0$$

$$2x^2 - l^2 + x^2 + 2lx = 0$$

$$x^2 + 2lx - l^2 = 0$$

$$x = 0.414 l$$

$$x^3 + 2lx - l^2 = 0$$

$$x = 0.414l$$

⇒

By Kinematic Method

(193)



$$-M_p \theta - M_p \theta - M_p \phi + \omega \Delta l \text{ (area under the deflected curve)} = 0$$

$$-2M_p \theta - M_p \phi + C \frac{1}{2} l (l-x) \theta = 0 \quad \text{--- (i)}$$

$$x \phi = (l-x) \theta$$

$$\phi = \frac{(l-x)}{x} \theta \quad \text{--- (ii)}$$

$$-2M_p \theta - M_p \frac{(l-x)}{x} \theta + C \frac{l (l-x)}{2} \theta = 0$$

$$-M_p \left(2 + \frac{l-x}{x} \right) + \frac{Cl (l-x)}{2} = 0$$

$$-M_p \frac{(l+x)}{x} + \frac{Cl (l-x)}{2} = 0$$

$$M_p = \frac{Cl(l-x)x}{2(l+x)}$$

For M_p to be max. $\frac{dM_p}{dx} = 0$

$$\frac{Cl \{l-2x\}}{2(l+x)^2} - \frac{Cl(l-x)x(2)}{2(l+x)^3} = 0$$

$$(l+x)(l-2x) - (l-x)x = 0$$

$$l^2 - 2xl + lx - 2x^2 - lx + x^2 = 0$$

$$-x^2 - 2xl + l^2 = 0 \Rightarrow x = 0.414l$$

Note $M = f(x)$
We Calc the max value of M
If maximum value of M is M_p
So we use cond $\frac{dM_p}{dx} = 0$

$$\begin{aligned} M_p &= \frac{cx^2}{2} \\ &= \frac{c(0.414l)^2}{2} = (0.085)cl^2 = \frac{(3-2\sqrt{2})}{2} cl^2 \\ &= 0.6863 \left(\frac{cl^2}{8} \right) \end{aligned}$$

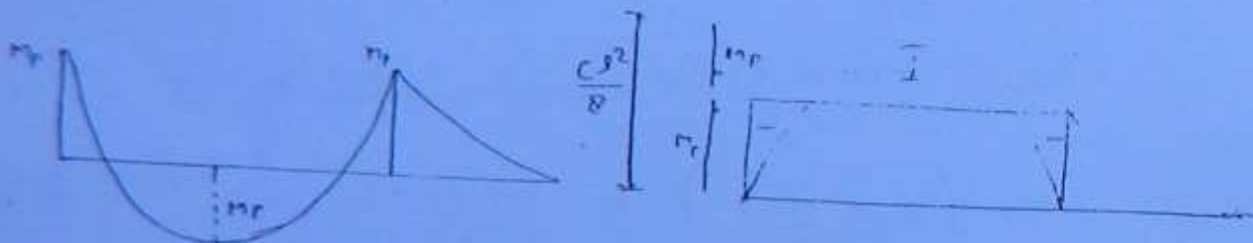
(194)



Find value of a for simultaneous collapse of AB & BD

collapse BMD

For simultaneous collapse of AB & BD plastic hinge should form at B, at A & in b/w A & B



BD will collapse

Note

Plastic hinge forms at $0.414l$ when moment at the hinged end $= 0$. But if there is moment at the hinged end plastic hinge will not form at $0.414l$



$$\frac{Ca^2}{2} = M_P$$

$$\frac{Cl^2}{8} = 2M_P$$

$$\frac{Cl^2}{8} = 2 \frac{Ca^2}{2}$$

(195)

$$a^2 = \frac{l^2}{8}$$

$$a = \frac{l}{2\sqrt{2}} = 0.353l$$

Note:If $a < 0.353l$,

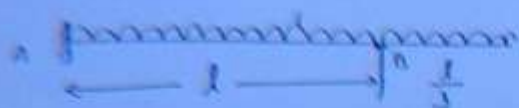
AB will collapse

If $a = 0.353l$,

AC + BD will collapse

if $a > 0.353l$

BD will collapse



Plastic moment = M_p

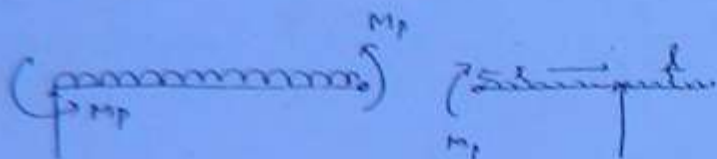
find collapse load = w

196

$$R = 1$$

No of P.H. for complete collapse = $1+1=2$

one will form at support and other at x dis from B



$$2M_p - \frac{w(l-x)^2}{2} = 0$$

$$\sum M_B = 0$$

$$M_p - \frac{wx^2}{2} + \frac{w(l/2)^2}{2} = 0$$

from ① & ②

$$\frac{w(l-x)^2}{2 \times 2} = \frac{wx^2}{2} - \frac{wl^2}{18}$$

$$(l-x)^2 = 2x^2 - \frac{2l^2}{9}$$

$$9(l-x)^2 = 18x^2 - 2l^2$$

$$9(l^2 + x^2 - 2lx) = 18x^2 - 2l^2$$

$$11l^2 - 9x^2 + 18lx = 0$$

$$9x^2 + 18lx - 11l^2 = 0$$

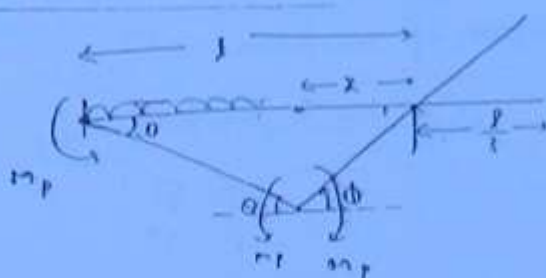
$$x = 0.4907 l$$

by putting

$$M_p = \frac{w(l-x)^2}{4}$$

$$\text{collapse load } w = \frac{4M_p}{(l-x)^2} = \frac{15.421 M_p}{l^2}$$

Kinematic Method



$$(l-x)\theta = x\phi$$

$$\phi = \frac{(l-x)\theta}{x}$$

(197)

$$-M_P\theta - M_P\theta - M_P\phi + \frac{1}{2}\omega l x\phi - \frac{1}{2}\omega \frac{l}{3} \times \frac{l}{3}\phi = 0$$

$$-2M_P\theta - M_P \frac{(l-x)\theta}{x} + \frac{\omega l}{2} \frac{(l-x)\theta}{x} - \frac{\omega l^2}{18} \frac{(l-x)\theta}{x} = 0$$

$$-M_P\theta \left[\frac{l+x}{x} \right] + \frac{\omega l\theta}{2} \frac{(l-x)}{x} - \frac{\omega l^2}{18x} \frac{(l-x)\theta}{x} = 0$$

$$M_P = \frac{\omega (l-x) l \left[1 - \frac{l}{9x} \right]}{\frac{(l+x)}{x}}$$

$$= \frac{\omega l (l-x) (9x-l)}{18 (l+x)}$$

$$= \frac{k}{l+x} \frac{(l-x)(9x-l)}{(l+x)}$$

$$= \frac{k}{l+x} (9xl - l^2 - 9x^2 + xl)$$

$$= \frac{k}{l+x} (-9x^2 + 10lx - l^2)$$

$$\frac{dM_P}{dx} = 0$$

$$(l+x) (-18x + 10l) - (-9x^2 + 10lx - l^2) = 0$$

$$-18lx + 10l^2 - 18x^2 + 10lx + 9x^2 - 10lx + l^2 = 0$$

$$-9x^2 - 18lx + 11l^2 = 0$$



Beam of uniform x sec
 M_p is constant

$$R = 2$$

No. of P.H. = 3

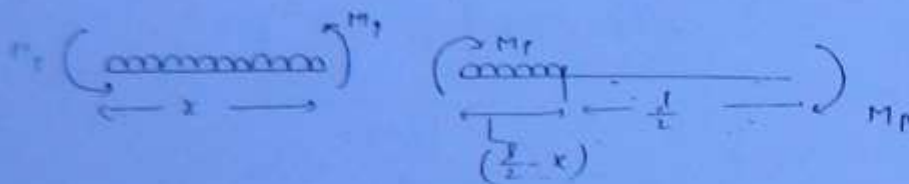
198

find collapse load w

3 hinges will form 2 at the support A

1 will form b/w A B b/w $S.F.$ will

be zero only in AB



$\sum M_A = 0$ of left FBD

$\sum M_D = 0$

$$2M_p - \frac{wx^2}{2} = 0$$

$$M_p = \frac{wx^2}{4}$$

$$2M_p = w\left(\frac{l}{2} - x\right)\left[\frac{l}{2} + \frac{l}{4} - \frac{x}{2}\right]$$

$$= w\left(\frac{l}{2} - x\right)\left[\frac{3l - x}{4}\right]$$

$$2M_p = w \frac{(l - 2x)}{2} \frac{(3l - 2x)}{4}$$

$$4 \frac{wx^2}{4} = \frac{w}{4} \left[3l^2 - 2lx - 6lx + 4x^2 \right]$$

$$4x^2 = 4x^2 - 8lx + 3l^2$$

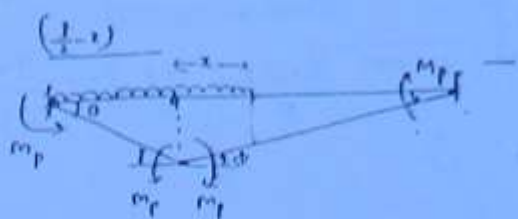
$$8lx = 3l^2$$

$$x = \left(\frac{3l}{8}\right)$$

$$\text{collapse load } w = \frac{4M_p}{x^2} = \frac{4M_p \times 64}{9l^2} = \frac{256}{9} \frac{M_p}{l^2}$$

$$= 28.44 M_p$$

By kinematic method.



$$\left(\frac{l}{2} - x\right) \theta = \left(\frac{l}{2} + x\right) \phi$$

(199)

$$-m_p \theta - m_p \theta - m_p \phi - m_p \phi + \frac{1}{2} \omega \left(\frac{l}{2} - x\right) \left(\frac{l}{2} + x\right) \phi + \left(\frac{l}{2} + x\right) \phi + \frac{l}{2} \phi \left] \frac{1}{2} x x \omega$$

$$- 2 m_p \left(\frac{\frac{l}{2} + x}{\left(\frac{l}{2} - x\right)}\right) \phi - 2 m_p \phi + \frac{1}{2} \omega \phi \left(\frac{l^2}{4} - x^2\right) + \frac{\omega x \phi}{2} (l + x) = 0$$

$$- 2 m_p \left(\frac{l + 2x}{l - 2x}\right) - 2 m_p + \frac{\omega}{2} \left[\frac{l^2}{4} - x^2 + lx + x^2 \right] = 0$$

$$+ 2 m_p \left[\frac{l + 2x + l - 2x}{(l - 2x)} \right] = + \frac{\omega}{2} \left(\frac{l^2}{4} + 2lx \right)$$

$$4 m_p \left(\frac{l}{l - 2x} \right) = \frac{\omega}{8} (l^2 + 4lx)$$

$$\omega = \frac{(32 m_p) l}{(l - 2x) (l^2 + 4lx)}$$

$$\frac{d\omega}{dx} = 0 = \frac{k l}{(l^3 + 4l^2 x - 2x l^2 - 8lx^2)}$$

$$= - l (4l^2 - 2l^2 - 16lx) = 0$$

$$2l^2 - 16lx = 0$$

$$m_p (l + 2x) (l - 2x)$$

$$2x = \frac{1}{8} l$$

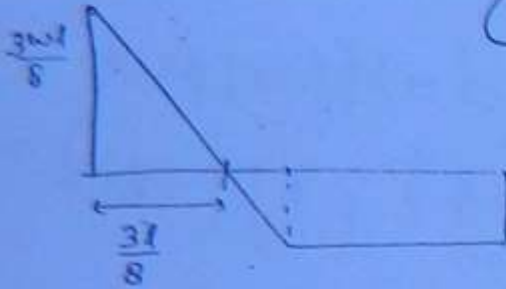
$$\left(\frac{l}{2} - x\right) = \frac{l}{2} - \frac{l}{8} = \frac{4l - l}{8} = \left(\frac{3l}{8}\right) \phi$$

Static method

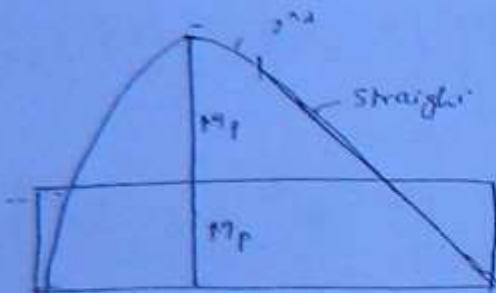


Free BMD

$$M_{max} = \frac{1}{2} w \times \frac{3wl}{8} \times \frac{3l}{8} = \frac{9wl^2}{128}$$



SFD



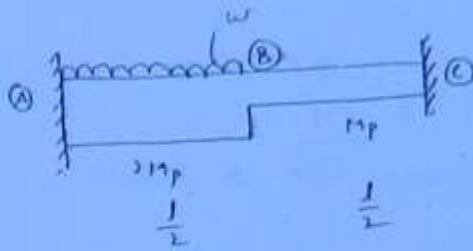
$$2M_p = \frac{9wl^2}{128}$$

$$wl = \frac{256 M_p}{9l^2}$$

Note

In case of fixed beam with constant x_{scn} location of plastic hinge in the span will be at the location of max. moment in free BMD

Q.



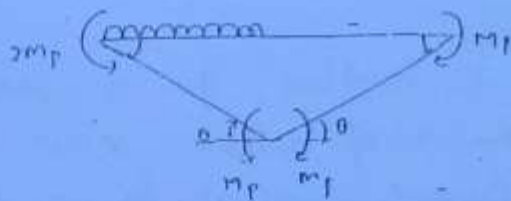
Find collapse load w

Degree of redundancy = 2

(20)

No. of P.H. req. = 3

Case I mode of failure

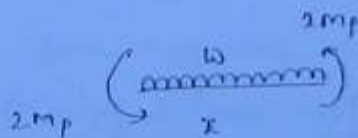


When two member join at a point Plastic hinge form in the member of smaller M_p

$$- 5 M_p \theta + \frac{1}{2} \cdot \frac{l}{2} \theta \times \frac{l}{2} w = 0$$

$$w = \frac{40 M_p}{l^2}$$

Case II



$$4 M_p = \frac{w x^2}{2}$$

$$M_p = \frac{w x^2}{8}$$

$$3 M_p = w \left(\frac{l}{2} - x \right) \left[\frac{l}{2} + \frac{l}{4} - \frac{x}{2} \right]$$

$$\frac{3 w x^2}{8} = w \left(\frac{l}{2} - x \right) \left(\frac{3l}{4} - \frac{x}{2} \right)$$

$$\frac{3 x^2}{8} = \frac{(1-2x)(3l-2x)}{8}$$

$$x^2 - 0.2x l + 0.1l^2 = 0$$

$$x = 0.3944 l$$

$$3x^2 = 3l^2 - 8xl + 4x^2$$

$$W = \frac{8 M_p}{r^2}$$

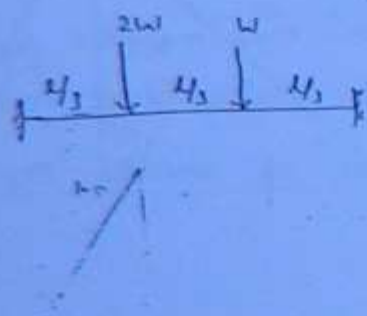
$$= \frac{8 M_p}{(0.3944 l)^2} = 51.43 \frac{M_p}{l^2}$$

(202)

Out of various possible mechanism correct mechanism is the one for which loading is min hence mechanism 1 is the correct mechanism & correct collapse load will be

$$\left(\frac{40 M_p}{l^2} \right)$$

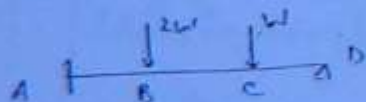
Q.



Beam is of uniform x secⁿ
find w collapse load

$$\frac{12}{51}$$

Note



Two mechanism needs to be checked

Mechanism 1 - P.H. at A & B
Mechanism 2 - " " A & C



For location of Plastic hinge in

the span, S.F. Needs to be checked. for 3rd hinge

(293)

Continuous Beam.



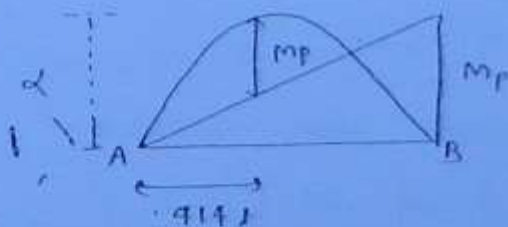
Beam is of uniform x secⁿ find the collapse load.

In case of continuous beam failure of individual span is considered and the correct mechanism will be the mechanism corresponding to which loading will be minimum.

In this case failure of AB & BC is considered as two mechanism.

Mechanism 1. Failure of AB

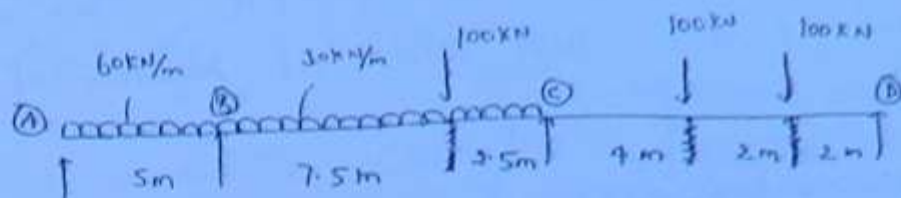
Beam segment AB will fail if plastic hinges are developed one at B and other somewhere b/w A & B



$$\alpha = \frac{wl}{2} \cdot 4l + l - \frac{w(4l+l)^2}{2}$$

$$\alpha = -12.13 \, wl^2$$

If Plastic moment at B and in the span are same, Plastic hinge will form at $0.414 \, l$ from the hinged end A

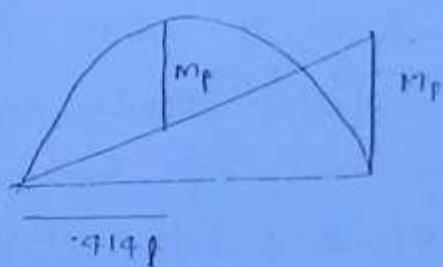


(205)

continuous beam shown above has uniform x secⁿ find the value of M_p . The given loads are collapse load.

For the continuous beam each of the span will be considered separately for its failure and M_p required for each of the span will be calculated. If a uniform secⁿ is to be provided, we will adopt secⁿ corresponding to largest M_p .

For failure of AB two hinges are required. 1 will form at B and other at 0.414 l from hinged end (end A).



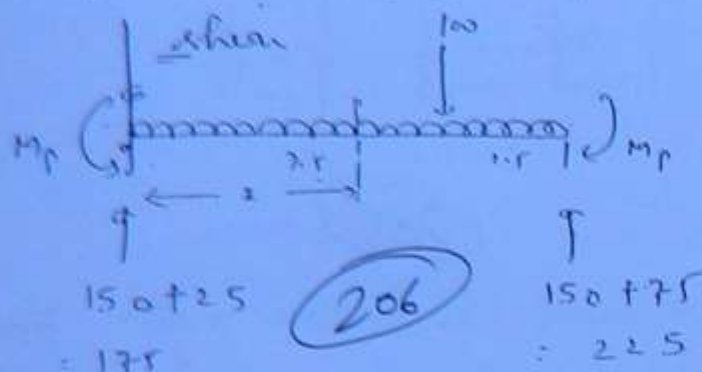
$$M_p = -6869 \frac{w_u l^2}{8}$$

$$= 128.7 \text{ kNm}$$

If instead of collapse load working load is given and M_p required is to be found out. we will have to load the structure with collapse load.

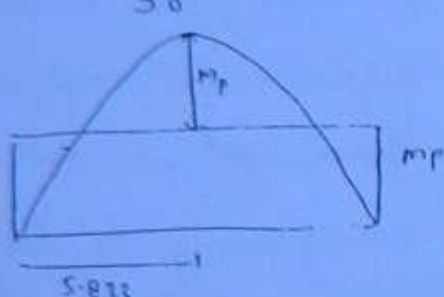
$$\text{Collapse load} = \text{load factor} \times \text{working load}$$

Span BC $\rightarrow$ BC will fail with 3' D.U. Two will form at B & C and one at location of zero



location of zero shear

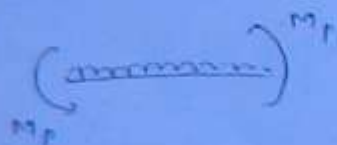
$$x = \frac{175}{30} = 5.833 \text{ m}$$



$$\text{Free BMD ordinate} = 175 \times 5.833 - \frac{30 \times 5.833^2}{2} = 510.47 \text{ kNm}$$

$$2 M_p = 510.47$$

$$M_p = 255.237 \text{ kNm}$$

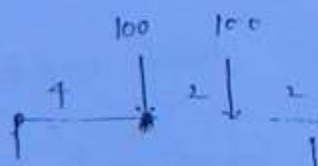


$$2 M_p = \frac{30 \times 5.833^2}{2}$$

$$M_p = 255.17 \text{ kNm}$$

For failure of CD hinge will form at C & below either of point loading

CD Mechanism 1



free B.M.D ordinate

$$M_p + \frac{M_p}{2} = 300$$

$$\frac{3}{2} M_p = 300$$

$$M_p = 200$$

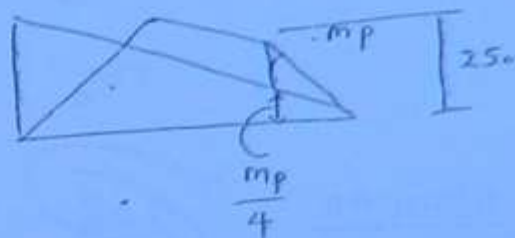
(207)

Mech. (2)

$$M_p + \frac{M_p}{4} = 250$$

$$\frac{5M_p}{4} = 250$$

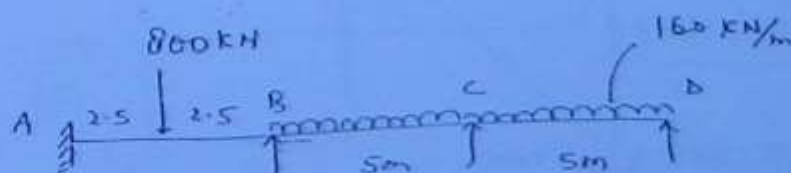
$$M_p = 200$$



Hence largest M_p will be selected thus M_p required is 255.178 kNm

B. A continuous beam as shown below is subjected to a collapse load system each span has a uniform sec. If under the action of collapse load system all the spans should collapse, determine the plastic moment required for each span. Assume middle span to be lightest

$$M_p BC < M_p AB$$



When two sections meet at a point plastic hinge forms corresponding to smaller M_p

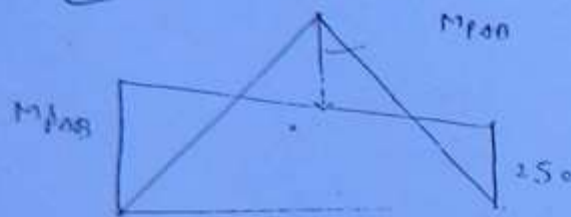
Span BC

$$2M_{pe} = \frac{wl^2}{8}$$

$$M_{pe} = \frac{wl^2}{16} = \frac{10 \times 160 \times 25}{16} = 250 \text{ kNm}$$

Span AB

(208)



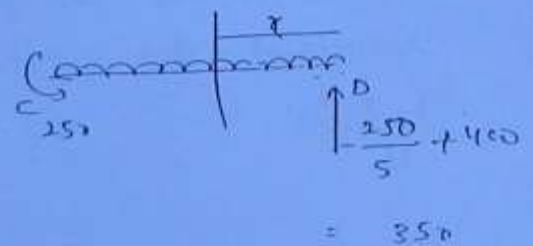
$$M_{pAB} + \frac{M_{pAB} + 250}{2} = 1000$$

$$M_{pAB} = 583.33 \text{ kNm}$$

Span CD



Zero shear location



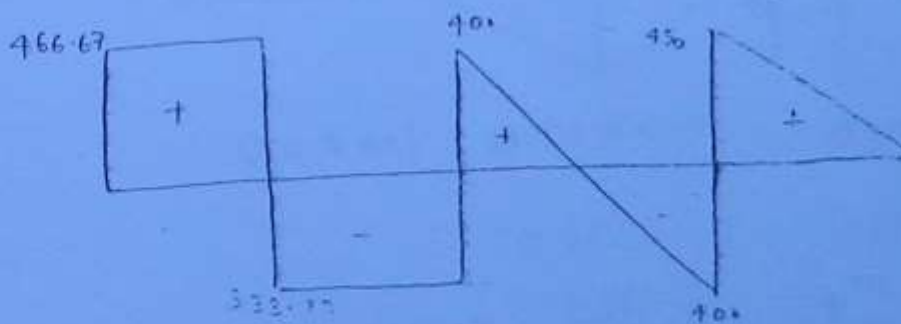
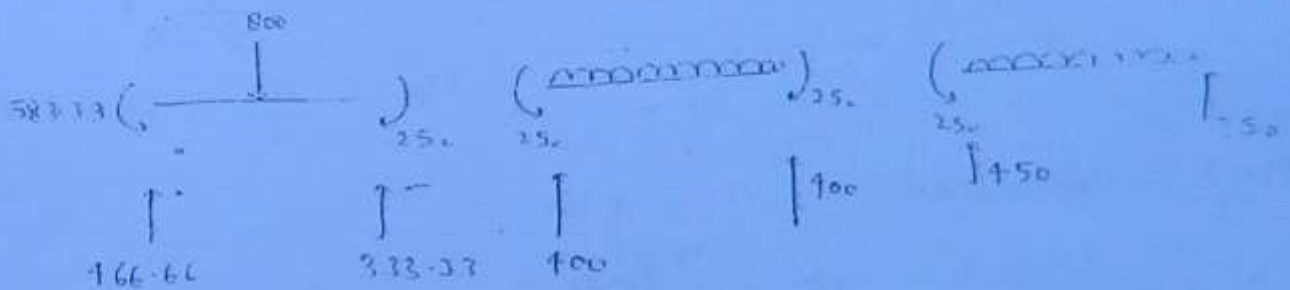
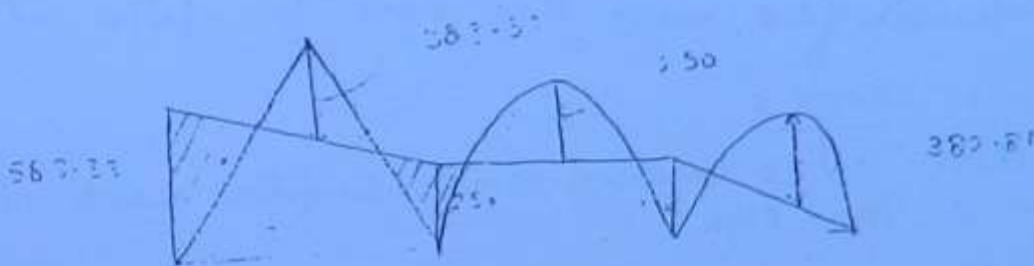
$$M_{fcd} = \frac{160 \times 2.1875^2}{2} = 382.8125 \text{ kNm}$$

$$x = \frac{350}{160} = 2.1875 \text{ m}$$

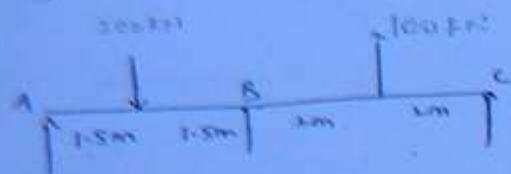
Collapsed BMD



(209)



Collapsed SFD



Secⁿ is uniform find M_p req. to be provided. Given loadings are collapsed loading.

Station Mechanism are 210

Mech 1



$$M_p + \frac{M_p}{2} = \frac{200 \times 3}{4}$$

$$M_p = 100 \text{ kNm}$$

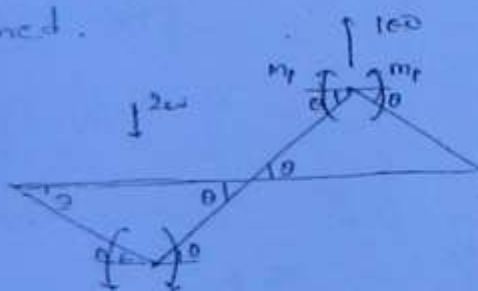
Mech 2



$$\frac{3M_p}{2} = \frac{100 \times 1}{4}$$

$$M_p = \frac{200}{3} = 66.67 \text{ kNm}$$

Mech 3 combined.



$$2M_p\theta + 2M_p\theta = 200 \times 1.5\theta + 100 \times 2\theta$$

$$4M_p\theta = 500\theta$$

$$M_p = 125 \text{ kNm}$$

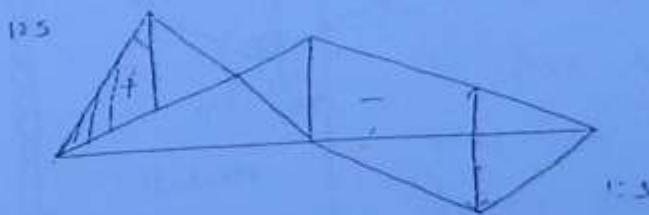
Section will be provided corresponding to $M_p = 125 \text{ kNm}$

collapsed BMD



The collapse of beam will occur only corresponding to Mech-3

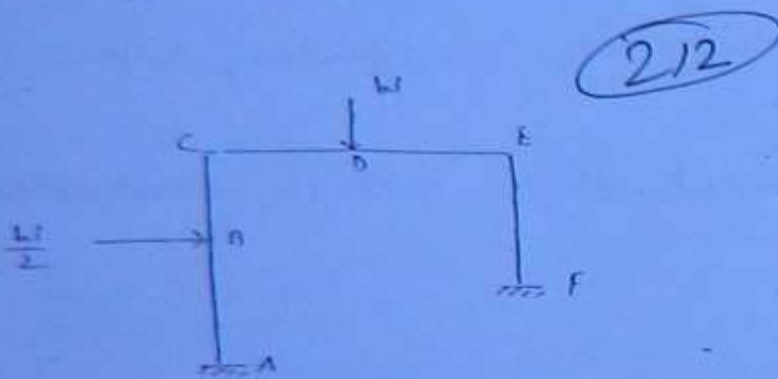
To draw collapsed BMD moment at B needs to be calculated



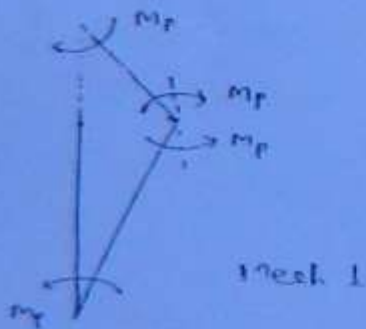
Plastic Analysis for Portal Frames.

In the portal frames various mechanism considered are

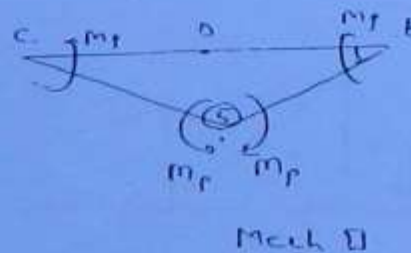
- I) Beam Mechanism
 - II) Sway Mechanism
 - III) Gable Mechanism
 - IV) Combined Mechanism
 - V) Joint Mechanism
- Independent Mechanism



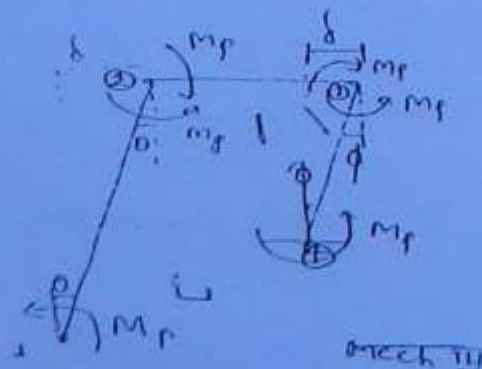
Beam mechanism in AC

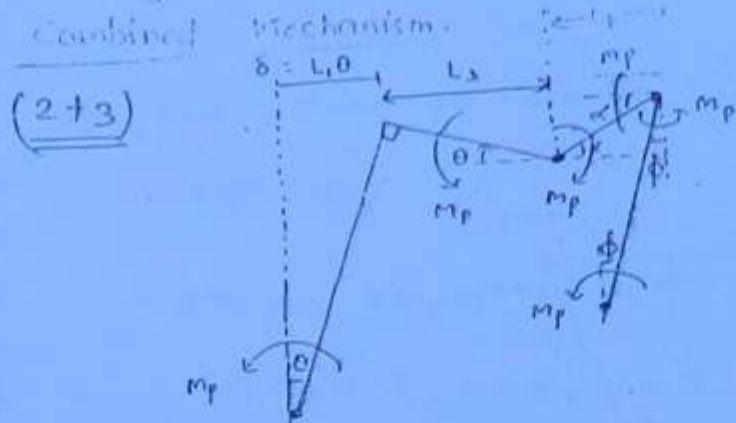


Beam mechanism in CE



Sway mechanism.

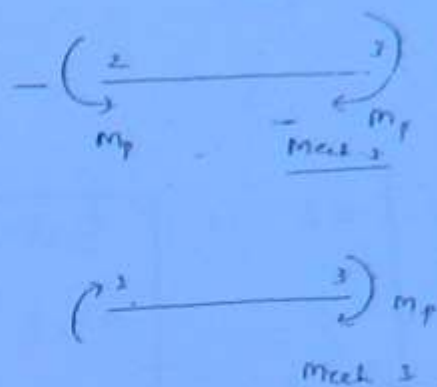




$$L_1 \theta = L_2 \phi$$

$$L_3 \theta = L_4 \alpha$$

(23)



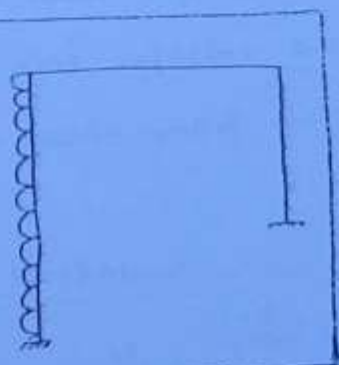
Eliminate (2) due to opposite moments at 2

Mech 1 + Mech 3

Eliminate (2)



Q.

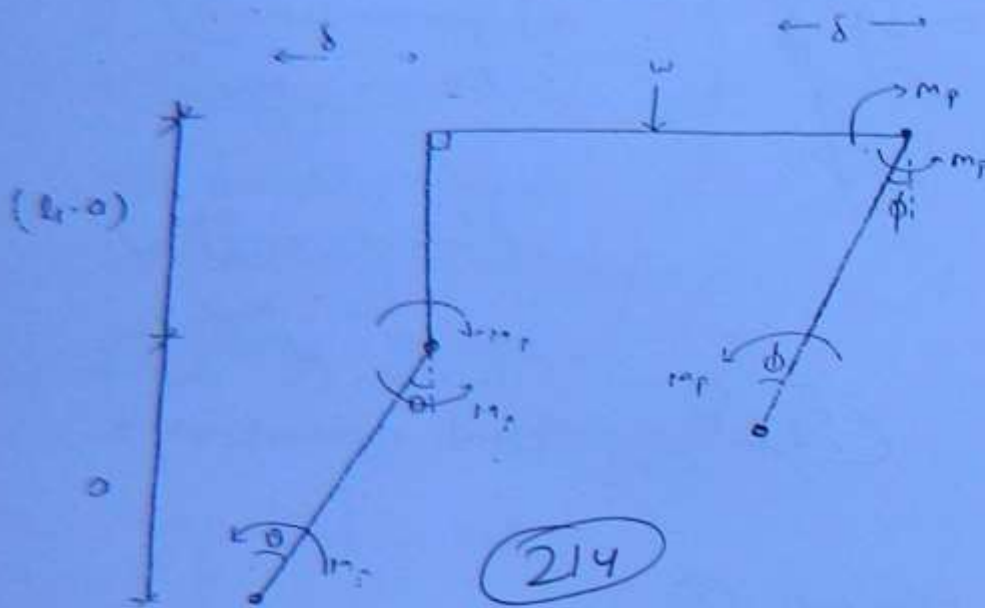


When beam & sway mechanisms are considered combinedly as in this case if we consider mech 2 & 3, No. of hinges will be five but max. no. of hinge that can be formed is 4 only hence one of the hinge needs to be eliminated. The common

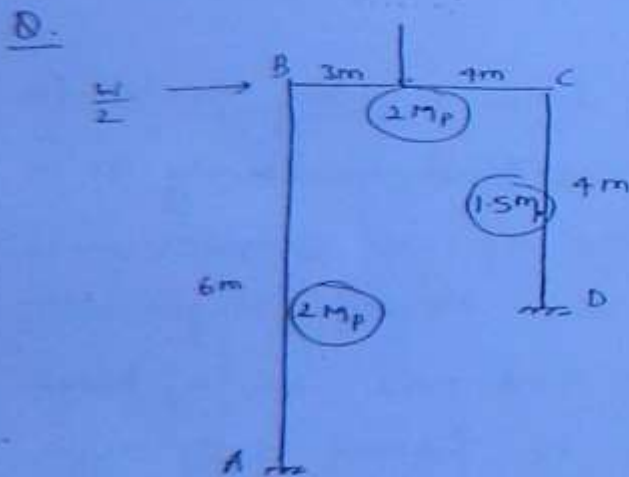
hinge b/w beam & sway mechanism are (2) & (3)

At (2) the moment from beam and sway mechanism are opposite in nature but they are of same nature at 3 hence in combined mechanism hinge at 2 will be eliminated.

Combined Mechanism 2
(1+3)



$$\Delta D = L_2 \phi$$

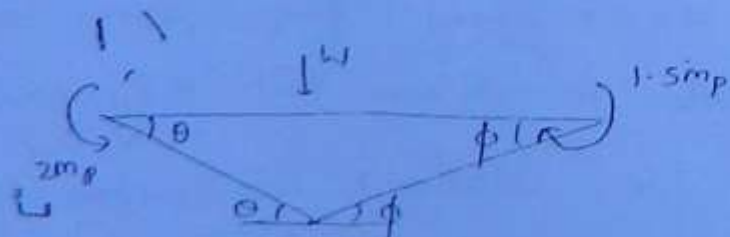


Find collapse load w and draw collapse BMD for the portal frame shown above.

$$R = 3$$

Max. no. of plastic hinge = 4

Beam mechanism BC



At C, the form due to $1.5 m_p$ is less than the form at joint due to smaller m_p .

$$3\theta = 4\phi$$

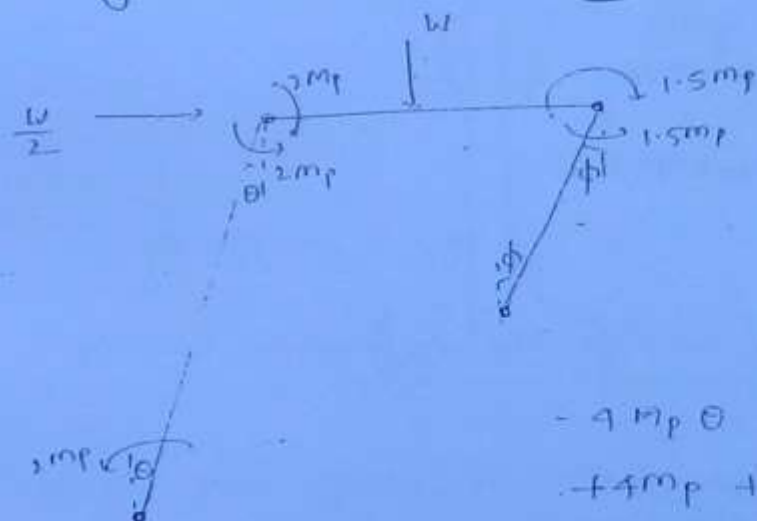
$$-2m_p\theta - 2m_p\theta - 2m_p\phi - 1.5m_p\phi + W \cdot 3\theta = 0$$

$$+4m_p\theta + 3.5m_p \cdot \frac{3\theta}{4} = 3W\theta$$

$$\theta = \frac{5.3}{2.4} m_p = 2.208 m_p$$

Sway mechanism.

(215)



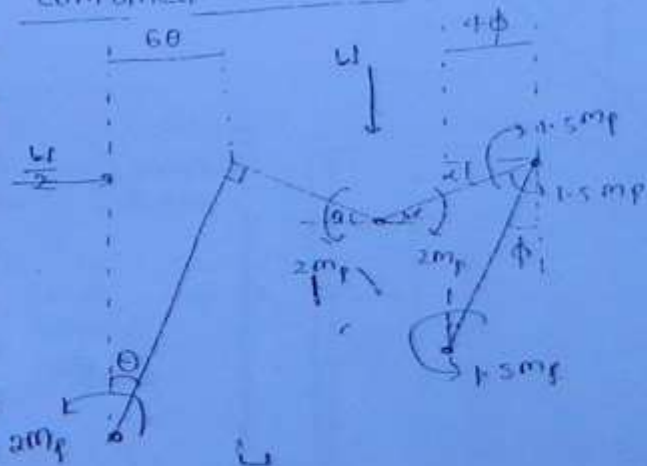
$$6\theta = 4\phi$$

$$-4m_p\theta - 3m_p\phi = -\frac{W}{2} \cdot 6\theta$$

$$+4m_p + 4.5\theta m_p = 3W$$

$$W = \frac{8.5}{3} m_p = 2.833 m_p$$

Combined Mechanism



$$6\theta = 4\phi \quad \text{--- (i)}$$

$$3\theta = 4\alpha \quad \text{--- (ii)}$$

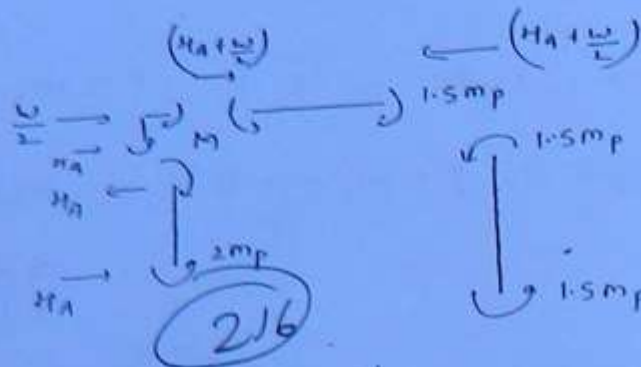
$$-2m_p\theta - 2m_p\theta - 2m_p\alpha - 1.5m_p\alpha - 3m_p\phi = -W \cdot 3\theta - \frac{W}{2} \cdot 6\theta$$

$$-4m_p\theta - 3.5 \times \frac{3}{4} m_p\theta - 3 \times 1.5m_p\alpha = 6W\theta$$

$$W = 1.854 m_p$$

Out of various possible mechanism correct mech. is
one for which collapse loading is min.
hence collapse load is $1.854 M_p$.

Collapsed B.M.D.



$$H_A + H_B + \frac{W}{2} = 0 \quad (1)$$

$\Sigma M_o = 0$ for CD portion

$$1.5 M_p + 1.5 M_p + H_B \times 4 = 0$$

$$H_B = -\frac{3}{4} M_p = -0.75 M_p$$

$$H_A = -H_B - \frac{W}{2} = -0.147 M_p$$

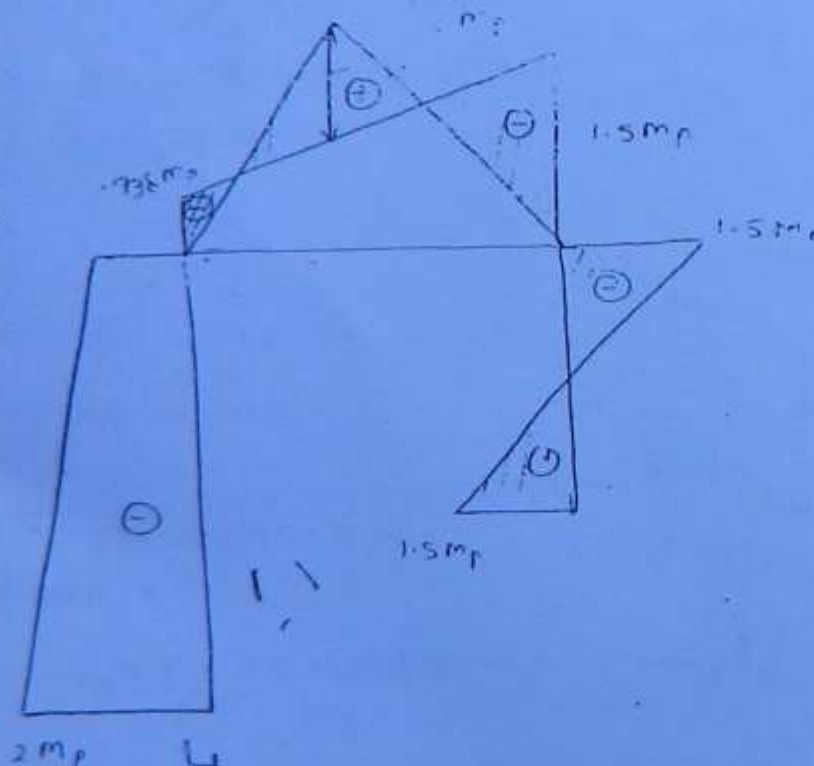
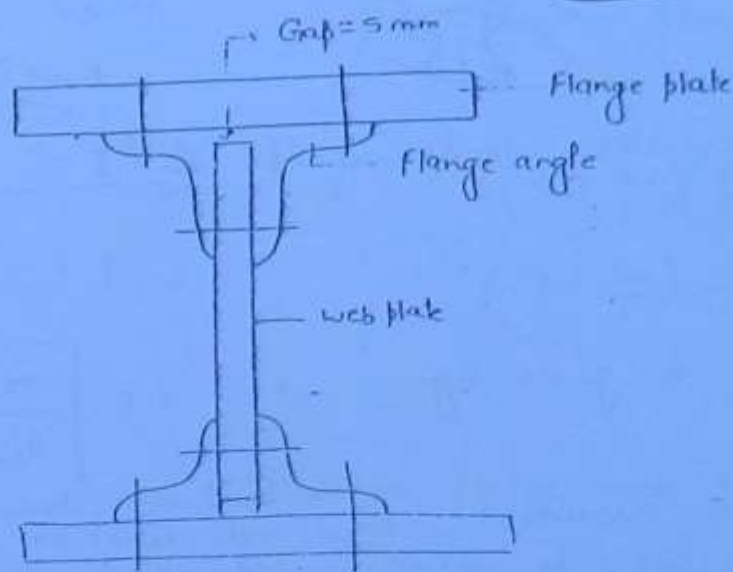


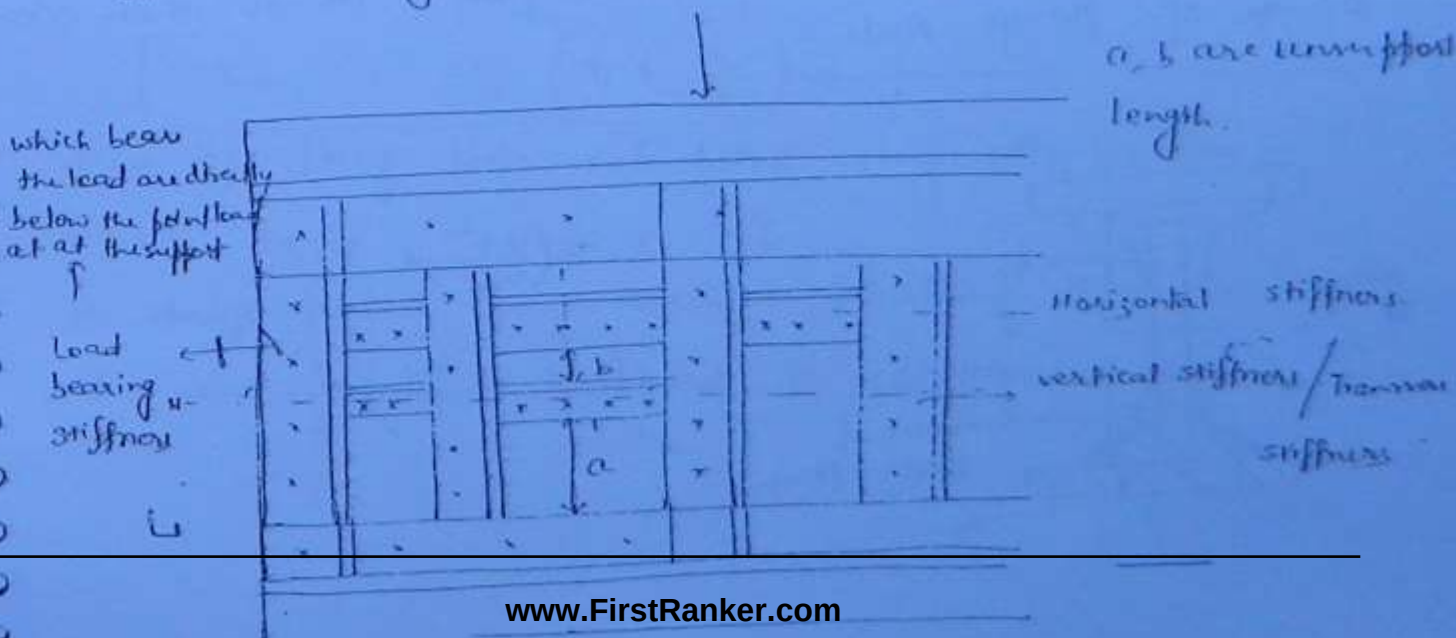
PLATE GIRDERS

Plate girders (beams made using plates) adopted when span and loading becomes large. For span upto 10 m I section + plates may be used but for larger span 15 to 30 m plate girders are used.

21.7



As the plate girder are deeper chances of web buckling is more hence web has to be supported by using stiffeners. Stiffeners actually increase the moment of inertia.






$$I = 2 A_f \left(\frac{d}{2} \right)^2 + \frac{b d^3}{12}$$

$$= \left(A_f + \frac{A_w}{6} \right) \frac{d^2}{2}$$

Flange plate is designed to resist bending moment

$$MOR = \sigma_{bt} \times Z$$

$$M_{max} = \sigma_{bt} \times \frac{I}{d/2}$$

$$= \sigma_{bt} \left[\left(A_f + \frac{A_w}{6} \right) d \right]$$

(219)

Effective flange area on compression side



$$I = 2 \left(A_f + \frac{A_w}{6} \right) \left(\frac{d}{2} \right)^2$$

$$= \left(A_f + \frac{A_w}{6} \right) \frac{d^2}{2}$$

On tension side reduction in flange area will occur due to formation of holes henceth area of flange plate has to increase. The effective flange area for tension side is taken as $\left(A_f + \frac{A_w}{8} \right)$

$$\left[M_{max} = \sigma_{bt} \left(A_f + \frac{A_w}{8} \right) d \right]$$

Area of flange plate calculated using this formula will be more.

For design purpose flange area is calculated than on tension side and same is adopted for compression side.

Check for bending

$$\frac{M_{max} \cdot Y_{max}}{I_{gross}} \leq \sigma_{bc}$$

$$\frac{M_{max} \cdot Y_{max}}{I_{gross}} \times \frac{(\text{G.A. of tension flange})}{(\text{Net area of tension flange})} \leq \sigma_{bc}$$

(520)

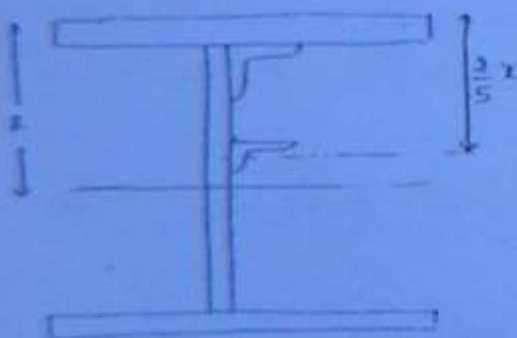
Tension flange will comprise of flange plate, flange angles and area of web plate included b/w flange angle

Design of Stiffener

i) $\frac{d}{t_w} < 85$ No stiffener required (No hor. or vert stiffener)

ii) $85 < \frac{d}{t_w} \leq 200$ Only vertical stiffener is required

iii) $200 < \frac{d}{t_w} \leq 250$ Apart from vertical stiffener one horizontal stiffener is provided at a distance from compression flange equal to $\frac{2}{5}$ th of the distance of compression flange from N.A.



iv) If $\frac{d}{t_w} \in [250 - 400]$ One more hor. stiffener is provided at N.A.

$$250 < \frac{d}{t_w} \leq 400$$

$$\frac{d}{t_w} \leq 120$$

$$t_w \geq \frac{d}{120}$$

for stiffened web min thickness of web = $\left(\frac{d}{120}\right)$

for unstiffened web $t_{w_{min}} = \left(\frac{d}{85}\right)$

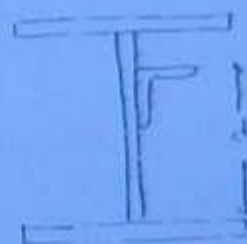
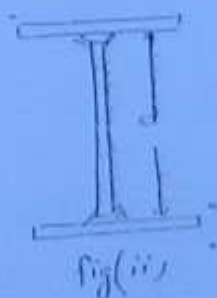
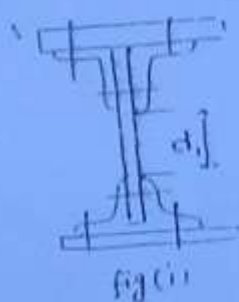
(22)

Design of vertical stiffener

spacing is selected such that permissible shear stress is greater than $\frac{V}{dt_w}$.

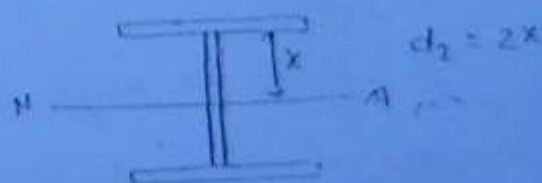
The max. & min spacing of vertical stiffener are $1.5d$ or $0.33d$ respectively.

Note



To decide about the type of stiffener to be provided we work on actual length of web however to design the vertical stiffener i.e. to decide on the cross section of stiffener required we work on d_1 (actual unsupported length)

d_2 = twice the clear distance from N.A. of the beam to the compression flange



Larger & smaller clear dimension should be maintained below

270 t_w & 180 t_w

In case of flat plate overhang $\gamma \leq 10t$

$t \rightarrow$ thickness of plate.

vertical stiffener is primarily supposed to resist shear buckling.

Horizontal stiffener

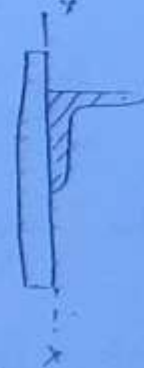
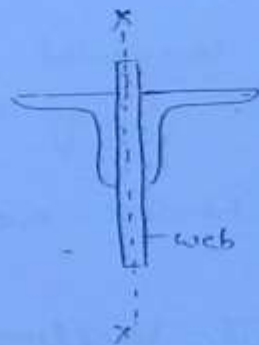
(223)

i) $200 < \frac{d_2}{t_w} \leq 250$

$I \neq \frac{1}{12} t_w^3$

ii) $250 < \frac{d_2}{t_w} \leq 400$

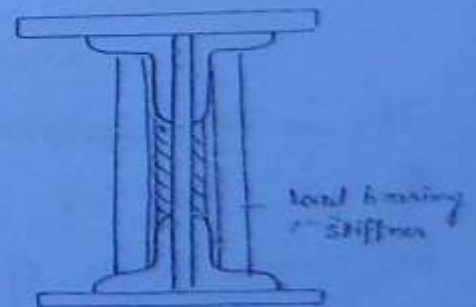
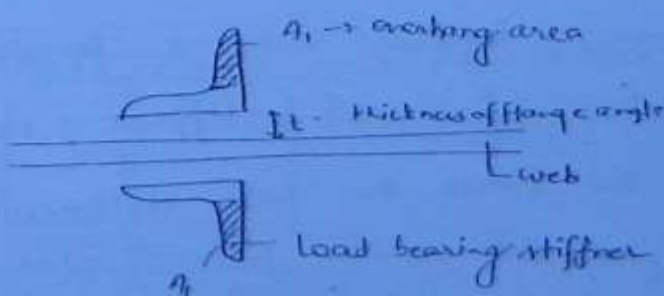
$I_{xx} \neq \frac{1}{12} d_2 t_w^3$



connection of hor. stiffener will be done in same way as vert stiffener.

Horizontal stiffener primarily safeguards against buckling due to bending compression.

Design of load bearing stiffener



1. outstanding leg of the stiffener is assumed to provide the necessary bearing area hence bearing area required is found out

$$\frac{P}{\sigma_{br}} = \text{bearing area req.}$$

$$\sigma_{br} \rightarrow \text{perm. bearing stress} = 0.75 f_y$$

2. Unequal angle is chosen in such a way that the overhang portion provides the necessary bearing area. smaller leg will be connected to the web larger leg will be overhang.
3. Once the angle is chosen overall buckling is to be checked.
4. To check for overall buckling the stiffener is assumed to be a column. The permissible load capacity of that column should be greater than applied load.

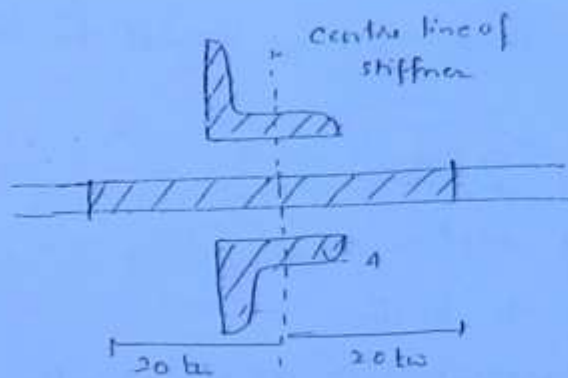
To find out σ_{cr} λ is required and

$$\lambda = \frac{l_{eff}}{\sigma_{min}}$$

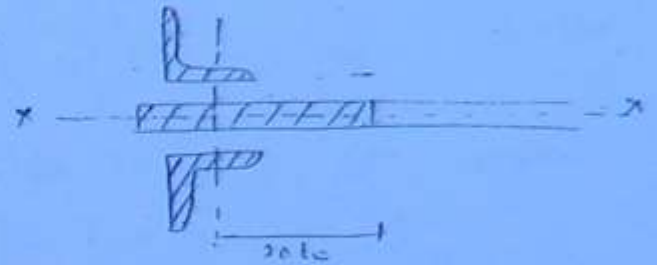
Where l_{eff} is taken as $0.7 l$

$l \rightarrow$ overall depth/length of stiffener

The section resisting compression is assumed to be consisting of a pair of stiffeners together with a length of web on either side of centre line of stiffener, where available, equal to 20 times the web thickness.



225



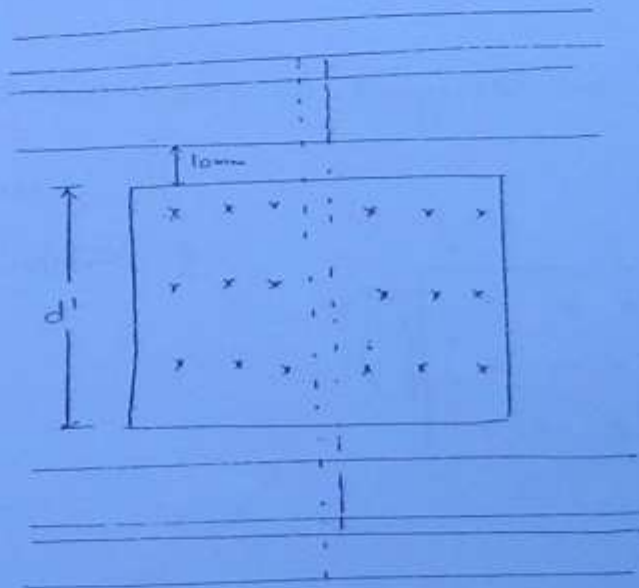
if support

A : shaded area

$$= 40tw \times tw + 2A$$

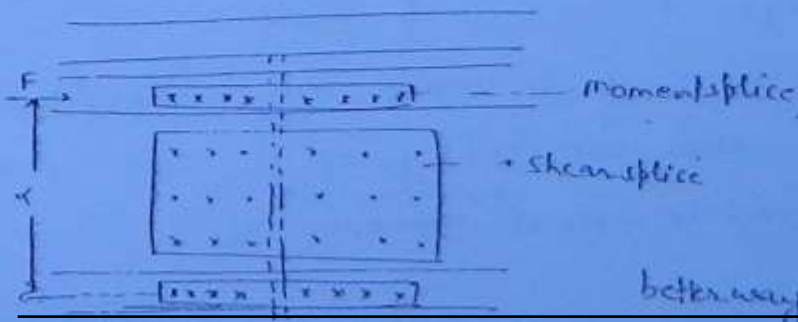
Load carrying capacity $\therefore \sigma_{all} \times A > P$

Web splices



For exam

In fig (i)



In fig (i) web splice plate will be assumed to carry 100% shear at the splice location and moment equal to M_w where

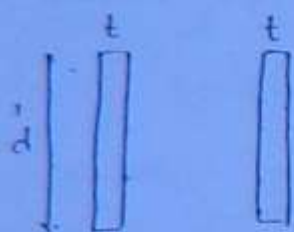
$$M_w = \frac{M I_w}{I}$$

226

where M_w B.M. at splicing section

$I_w \rightarrow$ m.o.i. of web plate

$I \rightarrow$ gross m.o.i. of original section about bending axis.



$$\frac{V}{2dt} \leq 0.4 f_y$$

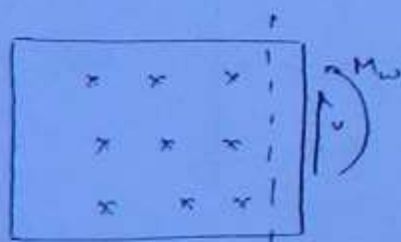
$$MOR = \sigma_{bt} \times Z$$

$$= \sigma_{bt} \cdot \frac{2t \times d^2}{6} \geq M_w$$

connection will be designed as eccentric connection

for direct s.f. = V

& Torsional moment = M_w



In fig (ii) we provide two sets of plate

- i- shear splice $\rightarrow$ Assumed to resist only shear (100%)
- ii- moment splice $\rightarrow$ Assumed to resist moment M_w

Moment splice

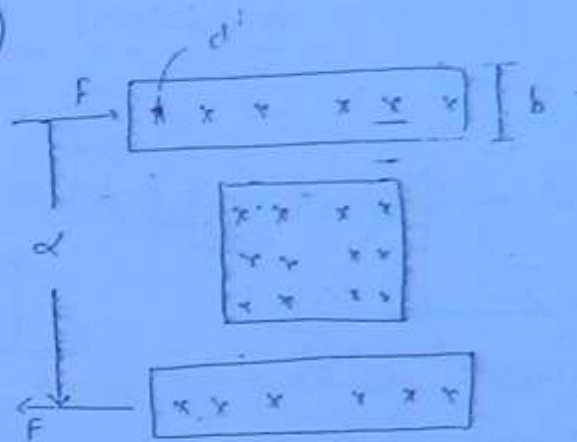
(227)

$$F d = M_u$$

$$F = \frac{M_u}{d}$$

$$2 (b - d') \times t_f \times \sigma_{at} \geq F$$

$$n = \frac{F}{R_v}$$



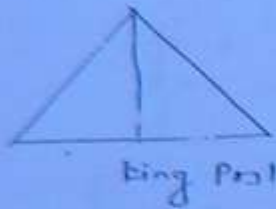
This design is for tension and same area is provided for compression

Shear Splice

$$\frac{V}{2 d_w \times t} \leq 0.4 f_y$$

$$n = \frac{V}{R_v}$$

Industrial Building.



King Post
Span < 6m

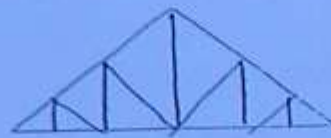
(228)



Queen post truss
9m



Fink truss



Howe truss
12 - 18 m



Howe truss (flat)
Up to 24 m

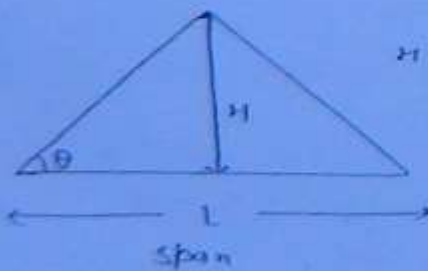


Compound fink
12 - 18 m



Saw tooth

glaz
for sun
light



H → Height of truss

$$\text{Slope of truss} = \frac{H}{L/2} = 2 \left(\frac{H}{L} \right)$$

$$\text{pitch of truss} = \frac{H}{L}$$

$$\boxed{\text{Slope} = 2 \times \text{Pitch}}$$

Deeper trusses have smaller deflection as compared to shallow truss.

(229)

Member forces are larger in shallow truss as compared to deep truss.

For smaller span height of truss is normally taken as $\frac{1}{6}$ th of the span.

$$\frac{H}{L} = \frac{1}{6}$$

$$\text{Slope} = \frac{1}{3}$$

For larger span depth may be taken as $\frac{1}{10}$ th of the span

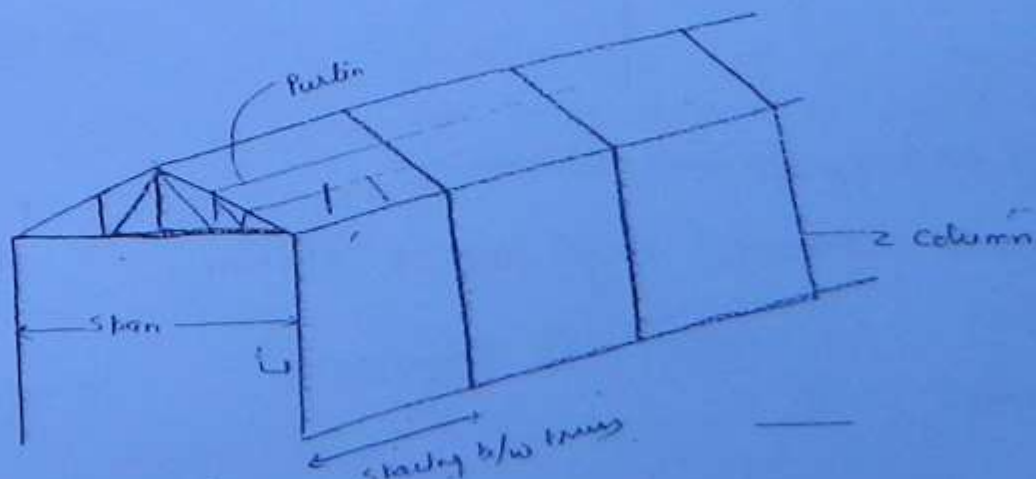
Galvanised iron

* If G.I. sheet is used as roof covering pitch of truss taken as 1 in 6

for AC (asbestos cement) sheet roof covering pitch may be taken as 1 in 12

Lower pitch is advantageous for wind pressure

Spacing of truss



Usually spacing is taken $\frac{1}{4}$ to $\frac{1}{5}$ span. Span upto 15m
 $\frac{1}{5}$ th of span, for span $> 15m$

for economy in roof

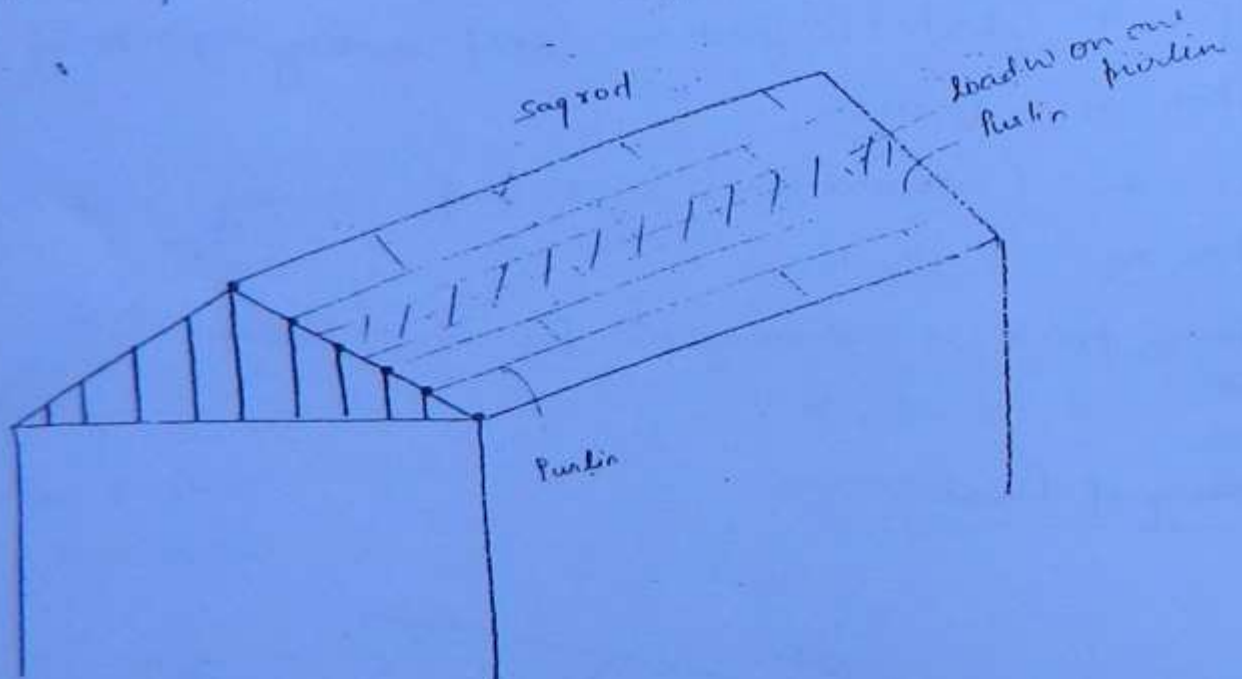
(230)

$$\frac{\text{cost of truss}}{\text{Area}} = \frac{\text{cost of purlin}}{\text{Area}} \times 2 + \text{cost of roof covering}$$

Area $\Rightarrow$ Area of floor or plan area of building.

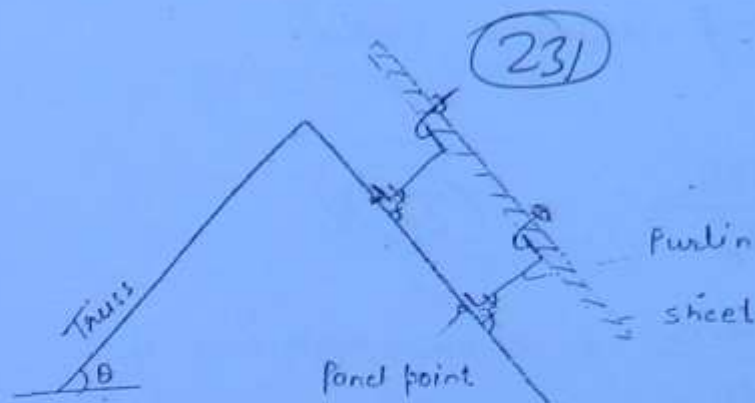
Purlins

Purpose of purlin is to support the roof sheet.



sag rod - Tension member.

Purlin are channel, angle or I section.



max spacing b/w purlin is 1.4 m



Purlins are subjected to
bixial loading

Hence design of it should be
done as bixial bending.

However if slope of roof truss
is $< 30^\circ$

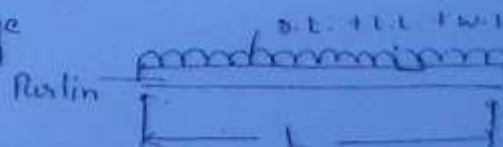
We may avoid design purlin by
bixial bending.

Hence desi

In this case ($\theta < 30^\circ$) angle purlins
can be used and it will be designa
as uniaxial bending condition.

In this case

D.L., L.L. & W.L. are assumed to be acting $\perp$ to
the roof coverage



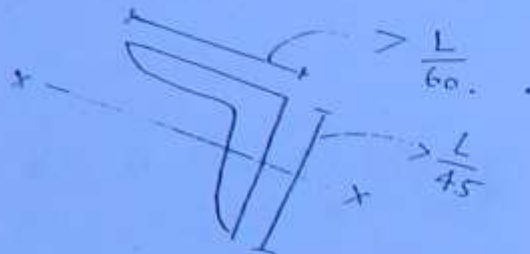
$$M_{max} = \frac{wL^2}{10}$$

$l \rightarrow$ span of purlin
 $=$ spacing b/w truss
 $w \rightarrow$ Total load resisted by purlin

$$Z_{req} = \frac{wl/l_0}{\sigma_{bc}}$$

(239)

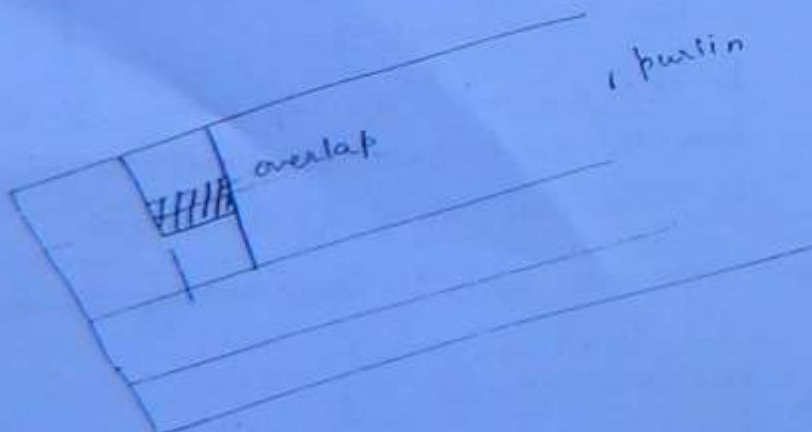
$$Z_{xx} \geq \frac{wl/l_0}{\sigma_{bc}} \quad \leftarrow \text{choose angle such that}$$



Angle chosen should be such that

width of angle	I to roof covering	$> \frac{L}{45}$	} Recommended only for angle purlins
"	" II to "	$> \frac{L}{60}$	

- Sag rod resist tangential component of D.L due to sheet (roof covering) & purlin itself.



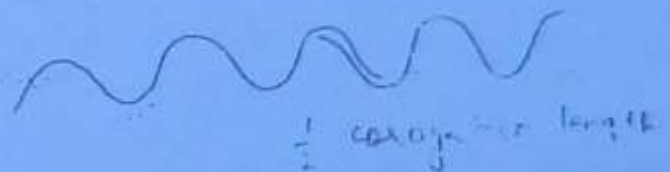
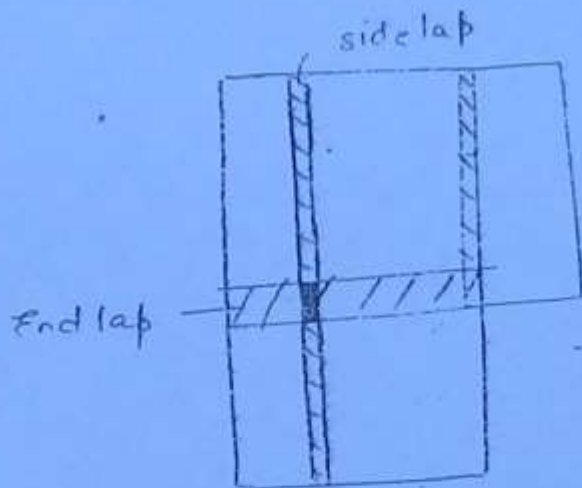
Try to make overlap connection at the location of purlin

overlap length

for slope upto 1:3

(233)

→ For flatter slope overlap length can be $\uparrow$ ed



Side lap for A.C. sheet $\frac{1}{2}$ corrugation length lap
for G.I. sheet it is full corrugation length lap

Note when 4 sheets overlap at location two sheets are cut at corners this process is called mitring

Northers Lightning

234

Most of the time in a yr. sun moves from east to west through south hence direct sunlight will come in the building from south which will cause shadow formation. To avoid it windows should be provided on north side so that diffused light come inside the building which does not cause any shadow formation.

DSS 190