DESIGN OF
STEEL STRUCTURES

Introduction

Objectives:

- To learn the behavior and design of structural steel components.
- To gain an educational and comprehensive experience in the design of steel structures.

Advantage of steel design :

- Better quality control, Lighter, Faster to erect.
- Less material handling at site, Less % of floor area occupied by structural element
- Has better ductility and hence better earthquake resistance

Disadvantage of steel design :

- Skilled labor is required, Higher cost of construction, Maintenance cost is high.
- Poor fire resistance, as at 538^0C (1000^0F) 65% and at 871^0C (1600^0F)15% of strength remains.

Rolled Steel Section :

Rolling is the most common method used for shaping and is particularly suitable for large scale production of simple constant cross sections, such as bars, universal beams and columns, plate and sheet.

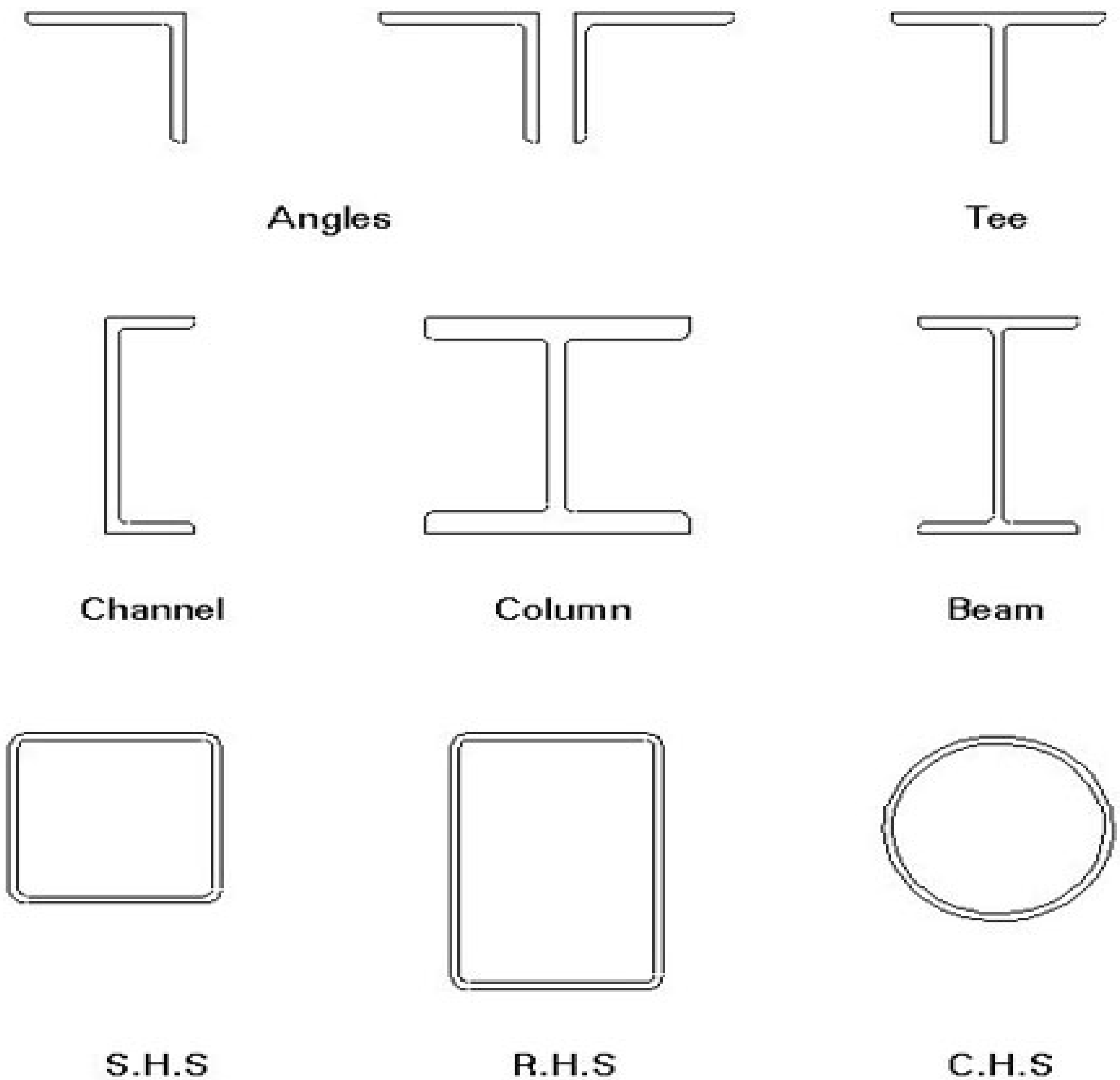
Types of Structural Steel

Carbon steel (IS:2062)

- Specified yield strengths - 230-300 MPa
- Ultimate tensile strengths - 410-440 MPa
- Only adopted in IS:800-1984/2007

High-strength carbon steel

- *Specified yield strengths - 350-400 MPa*
- *Ultimate tensile strengths - 480-550 MPa*
- *Used transmission lines & microwave towers*
- *Low ductility, toughness & weldability*


Angles
Tee
Channel
Column
Beam
S.H.S
R.H.S
C.H.S

Permissible value of stresses in WSM

Axial Tensile stress(σ_{at}) = 0.6 f_y

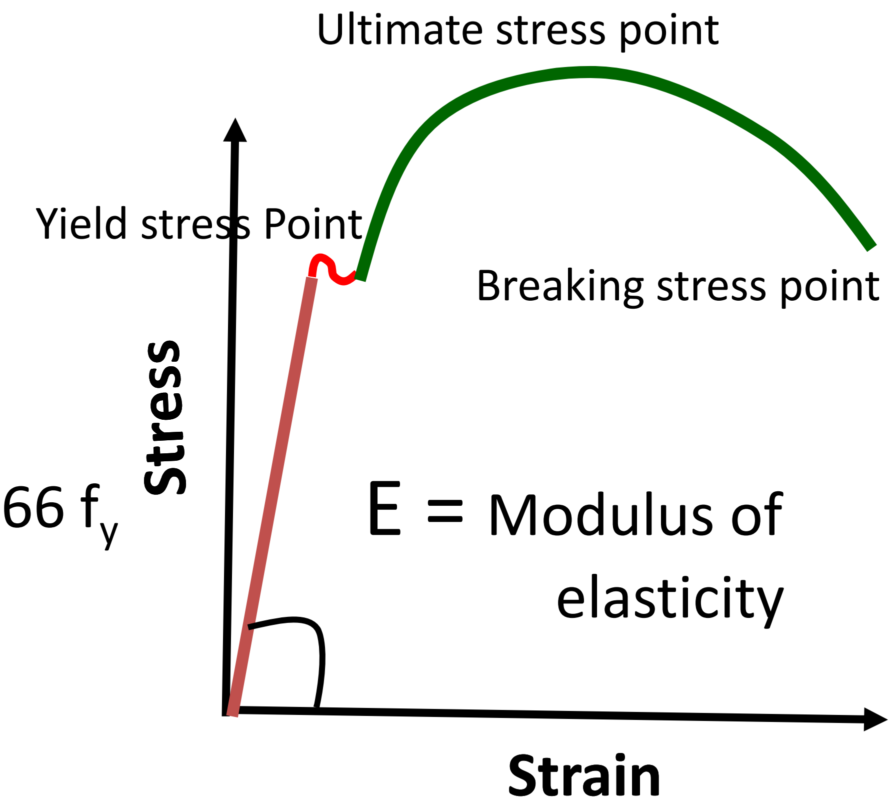
Bending tensile stress (σ_{bt}) = 0.66 f_y

Bending compressive stress (σ_{bc}) = 0.66 f_y

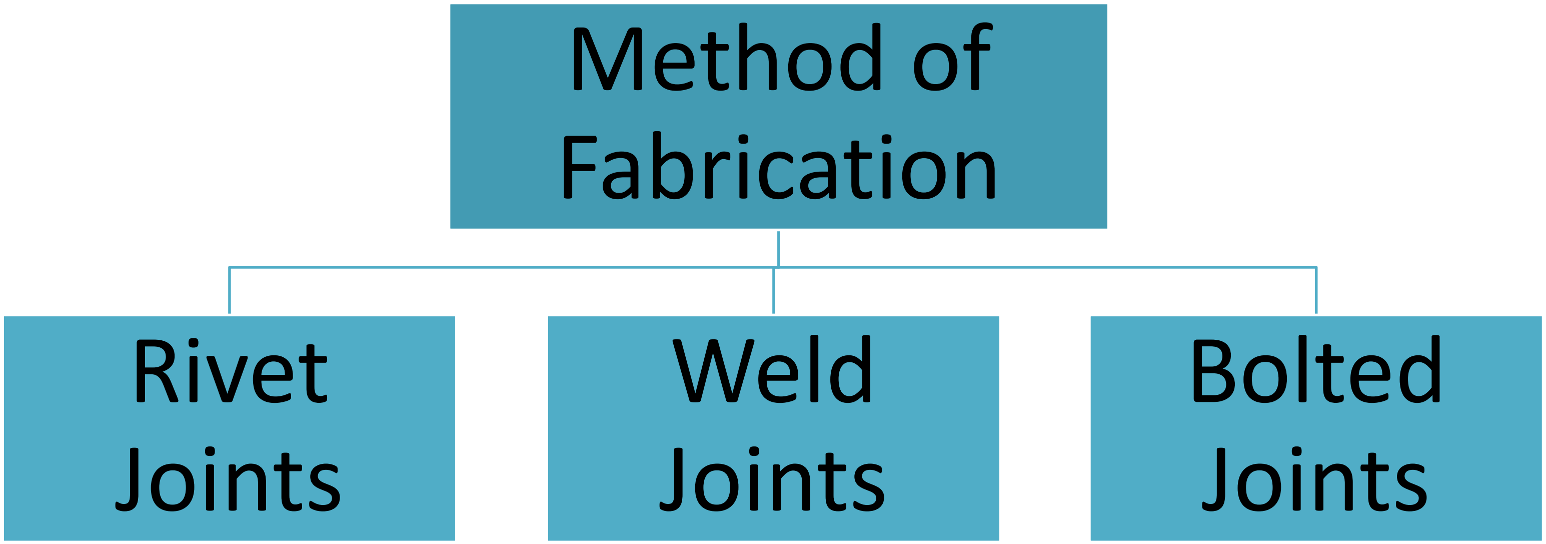
Bearing stress (σ_{pf}) = 0.75 f_y

Maximum shear stress (τ) = 0.45 f_y

Average shear stress (τ_{av}) = 0.4 f_y

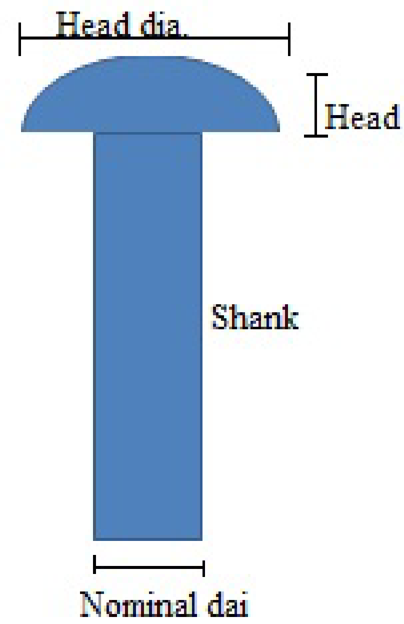


Fabrication of Structure:



The Combination of the above joints

Rivet Joints:



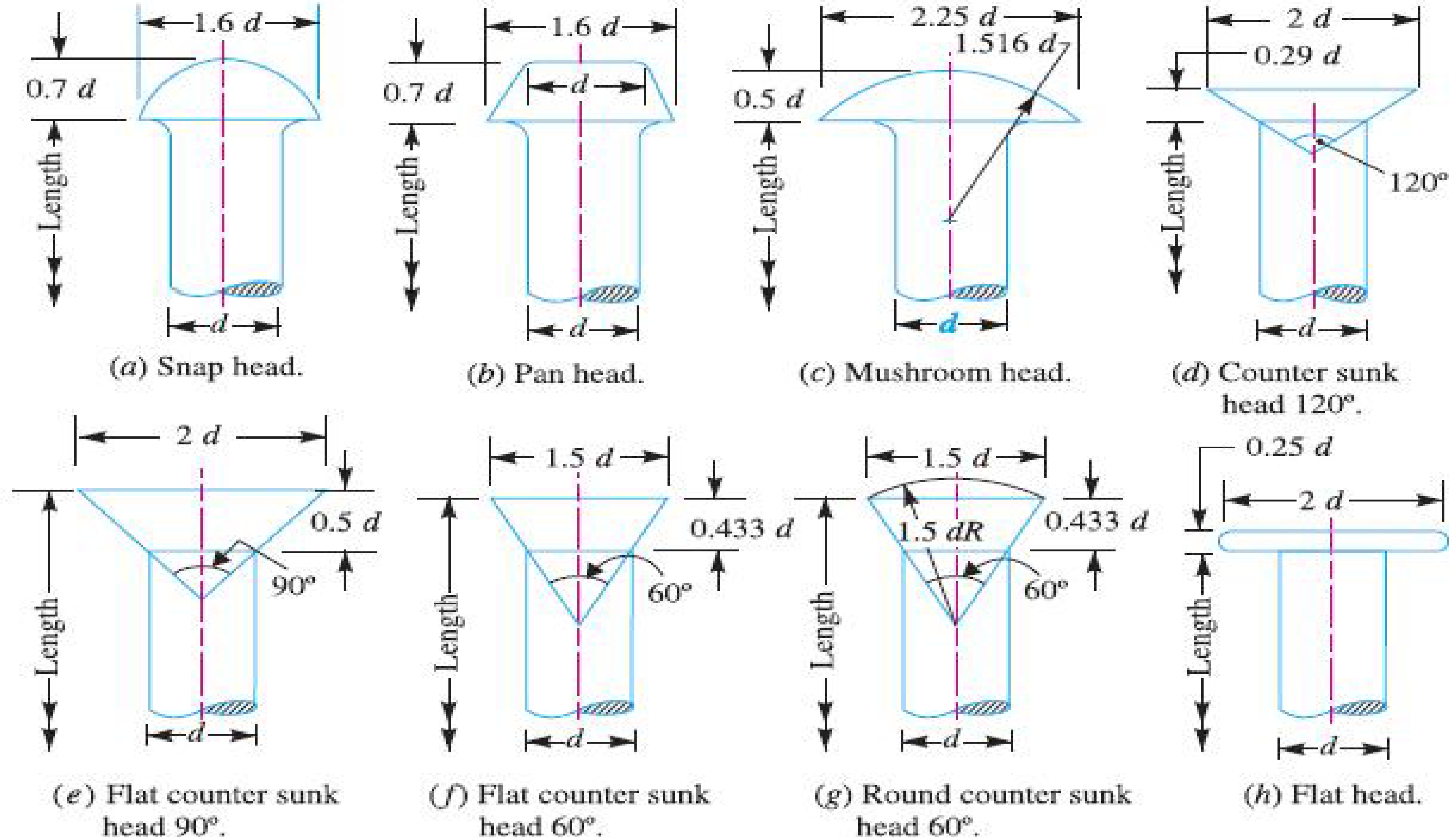
Gross diameter(ϕ) = Nominal diameter(d) + Clearns(s)

$$S = 1.5mm, \forall d \leq 25mm$$

$$= 2mm, \forall d > 25mm$$

Assumptions :

- Friction between plates is neglected
- The shear stress is uniform on the cross section of the rivet
- The distribution of direct stress on portion of the plates between the rivet hole is uniform.
- Rivet in group subjected to direct load share the load equally.
- Bending stress in the rivet is neglected.
- Rivets fill completely the hole in which they are driven.
- Bearing stress distribution is uniform and contact area is d x t

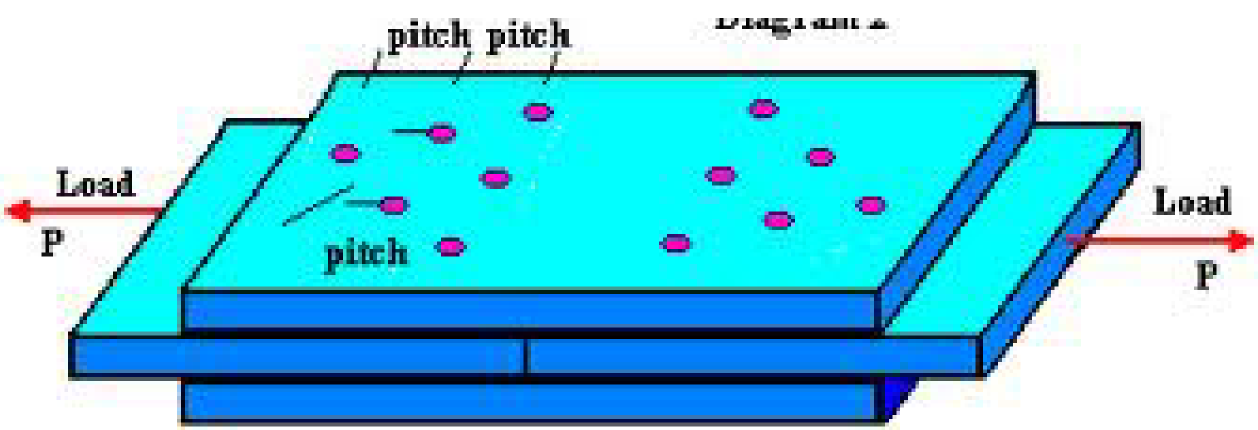


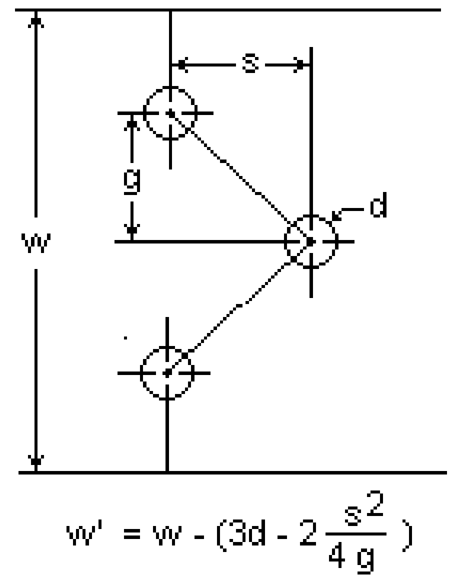
(*a*) Snap head. (*b*) Pan head. (*c*) Mushroom head. (*d*) Counter sunk head 120°.

(*e*) Flat counter sunk head 90°. (*f*) Flat counter sunk head 60°. (*g*) Round counter sunk head 60°. (*h*) Flat head.

Types of Rivets (IS 800, Table-8.1, Pg-95)

1) Power-driven shop/field rivets (PDS/F), or Hot rivet.
2) Hand-driven shop/field rivets (HDS/F), or Cold rivet.





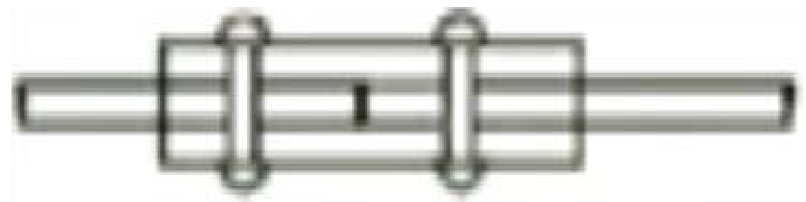
Types of Rivet joint :

1) Depending upon arrangement of rivets and plates :

- Lap Joint

  - Single riveting
  - Chain riveting
  - Staggered or, Zig-Zag riveting

➢Butt Joint



- Single riveting
- Chain riveting
- Staggered or, Zig-Zag riveting

2) Depending upon the mode of load transmission:

1) Single shear, 2) Double shear, 3) Multiple shear
4) Bearing

3) Depending upon nature and location of load:

1) Direct shear connection
2) Eccentric connection
3) Pure moment connection
4) Moment shear connection

Pitch of the Rivet (IS:800, Clause 8.10.1)

Minimum Pitch

$$P_{\min} \geq 2.5d$$

Maximum Pitch

(a) Including tacking rivets

$$\left.\begin{aligned} P_{\max} &= 32t \\ &= 300mm \end{aligned}\right\} \text{Minimum of this}$$

Where, d- Nominal diameter of rivet,

t – Minimum thickness of connected member

(b) Distance between center of two adjacent rivets in a line in direction of stress.

1) For Tension member

$$\left.\begin{aligned} P_{\max} &\leq 16t \\ &= 200mm \end{aligned}\right\} \text{Minimum of this}$$

2) For Compression member

$$\left.\begin{aligned} P_{\max} &\le 12t \\ &= 200mm \end{aligned}\right\}\text{Minimum of this}$$

Note:-

If forces transferred through butting face, then P_{max} = 4.5 x d for the distance = 1.5 x Width of the member (W)

(c) The distance between centers of any two consecutive rivets in a line adjacent and parallel to an edge of an outside plate shall not exceed (100 mm + 4t) or 200 mm, whichever is less.

(d) When rivet is staggered at equal intervals and the gauge does not exceed 75 mm, the distance specified in (b) & (c) may be increased by 50 %.

Failure of Rivet joint

1) Tearing of Plate between rivet holes.
2) Edge cracking.
3) Shearing of Rivet.
4) Bearing of plate or rivet.

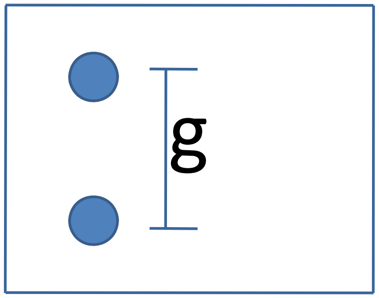
Items 1–2: **Plate failure**; Items 3–4: **Rivet failure**

Plate failure

- Strength of the section in Tearing failure case :

$$F = \sigma_{at}(g - \phi)t$$

t- Thickness of the plate



- Edge cracking

The minimum from center of hole to the edge of a plate shall be not less than that in IS 800,Table – 8.2, Pg – 97.

Rivet failure

- Shearing of Rivet

$$V = \tau_{vf} \times \frac{\pi}{4}\phi^2$$

IS 800 :1984, Table – 8.1, Pg - 95

- Bearing of plate or rivet

$$P = \sigma_{pf} \times \phi \times t$$

$$or, = \sigma_p \times \phi \times t$$

For efficient joint Nominal diameter(d) of rivet is taken as :

$$d = 6.05\sqrt{t} \text{ mm}$$

Rivet Value (R) = Mini (V, P).

➢ Efficiency of a joint (η):

$$\eta = \frac{Strength\ of\ joint}{Strength\ of\ the\ Member}$$

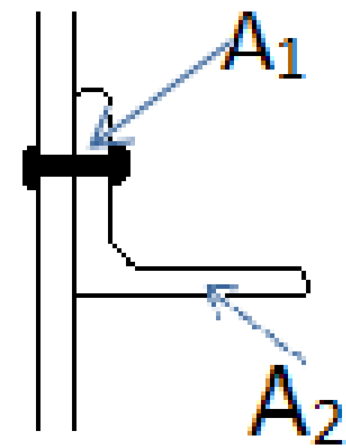
- Equivalent area of angle section in rivet joint :-

From IS 800 :1984, clause 4.2.1, Pg – 37.

If, A_1 – Area of the connecting leg.

A_2 – Area of the other leg.

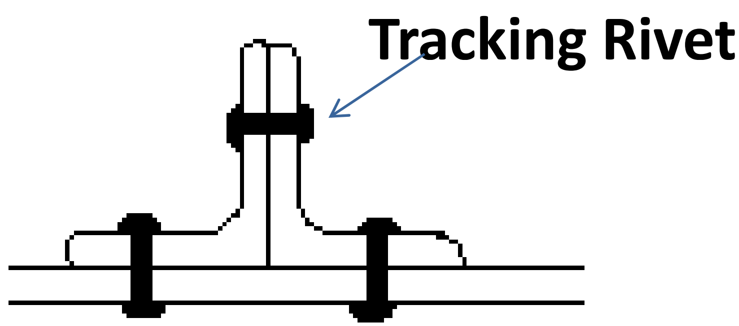
$$A_{eq} = A_1 + KA_2$$



Case – 1:- Only one leg is connected.

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

Case – 2:- Back-to-Back connected only One leg of each angle section.

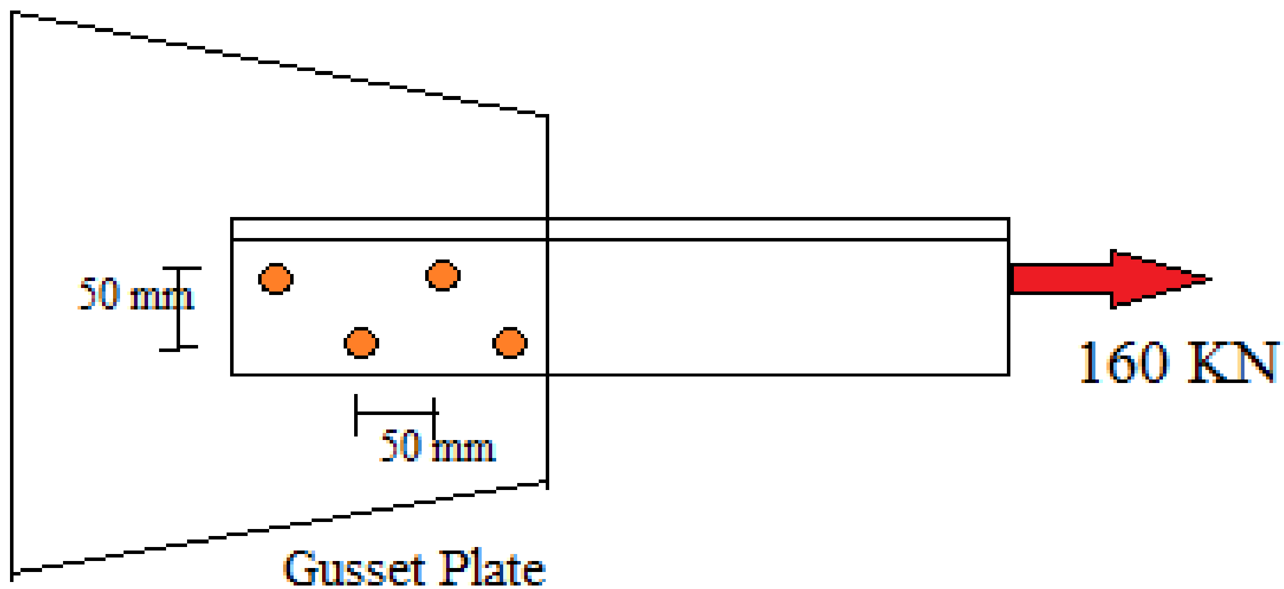


$$K = \frac{5A_1}{5A_1 + A_2}$$

Case – 3:- If angle section connected by using gusset plate both side.

$$K = 1$$

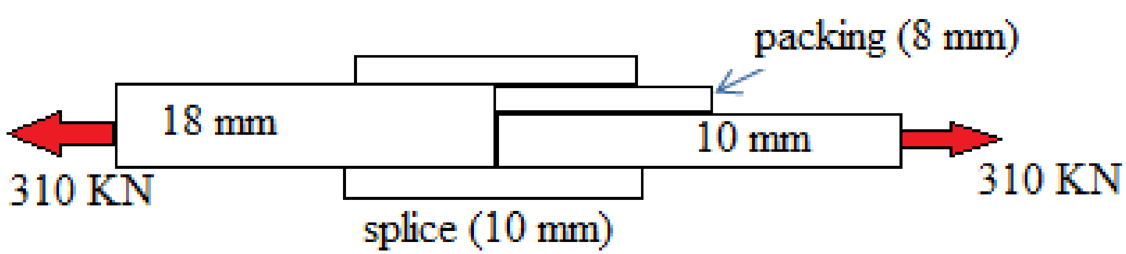
An unequal angle section ISA 125x75 mm is required to carry a tensile load of 160 KN. The angle section is connected to the gusset plate through the longer leg by 18 mm diameter rivet by zig-zag riveting, Gauge length= 50 mm and Pitch length = 50 mm select the suitable thickness for the angle.



➢ Packings (IS 800 :1984, clause 8.6, Pg - 93)

- Rivets or Bolts Through Packings- Number of rivets or bolts carrying calculated shear through a packing shall be increased above the number required by normal calculations by 2.5 percent for each 2.0 mm thickness of packing except that, for packings having a thickness of 6 mm or less, no increase need be made.

Design a tension splice to connect two plates of size 300x18 mm and 300x10 mm if the design load is 310 KN thickness of splice plate is 10 mm on both side and rivet diameter is 22 mm.



Weld joint :

- Welding is the process of connecting metal pieces by application heat (i.e. fusion) with or without pressure

Types of Welding

- Forge Welding

Thermit Welding

- Gas Welding

Resistance Welding

Electric-arc Welding

- **Forge welding :-** The edge to be joined by applying an extremely high external mechanical pressure.
- **Thermit welding :-** A mixture of iron oxide and aluminum Called thermit is ignited.
- **Gas welding :-** The edge are to joined are melted on Oxy-acetylene gas flame.
- **Resistance welding :-** The parts are to be joined are pressed together and current is passed from one end to another when welding temperature is attained, mechanical pressure is applied to forge the weld.
- **Electric-arc welding :-** Heat is applied by means of an electric arc struck between the parts to be welded and an electrode melts and fills the gap at the joint.

➢ Advantages of welding joints :

- As no hole is required for welding, hence no reduction of area so, structural member are more effective in taking he load.
- In welding filler plates, gusset plates, connection angle etc. are not used, which leads to reduction in overall weight and cost of construction.
- The efficiency of welded joint is more than that of the riveted joint.

➢ Disadvantages of welding joints :

- Welding joints are more brittle and therefore their fatigue strength is less than the member jointed.

- Due to uneven heating and cooling of the members during the welding. The member may distort resulting in additional stress.
- No provision for expansion and contraction is kept in welded connection and therefore, there is possibility of cracks.
- Defects like internal air pocket, slag inclusion and incomplete penetration are difficult to detect.

Types of welds:-

- Fillet weld
- Butt weld
- Plug weld

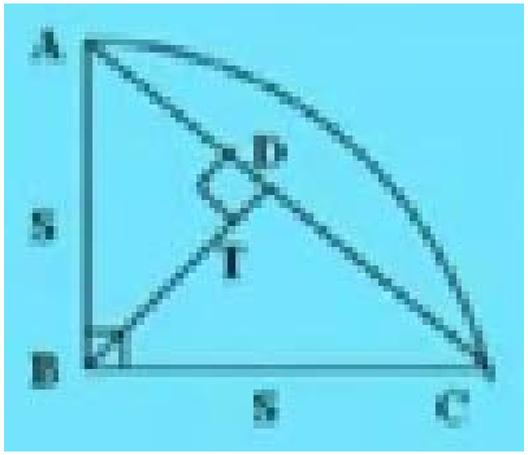
➢ Welds and there symbol :

Figure 3-9. Arrow side fillet welding symbol.

Figure 3-10. Other side fillet welding symbol.

Size of fillet weld (S) :

- The sides containing the right angle of the fillet weld are called legs. The size of the weld is specified by the minimum leg length. **S – is the size of the weld**



From, Annex A.2.1.8 of IS 9595 :1996

Thickness of Thicker plate	Minimum size of fillet weld
Up to 6 mm	3 mm
6 to 12 mm	4 mm
12 to 18 mm	6 mm
18 to 36 mm	8 mm
36 to 56 mm	10 mm
56 to 150 mm	12 mm
Above 150mm	16 mm

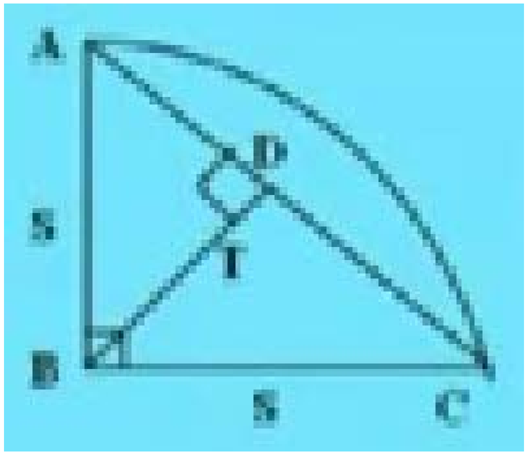
- **Maximum size of weld**
  - For square edge :-
    $S = (t - 1.5)mm$
  - For rounded edge :-

$$S = \frac{3}{4}t$$

t – thickness of thinner plate

Effective throat thickness(r) :-

- The effective throat thickness of a fillet weld is the perpendicular distance from the root to the hypotenuse joining the two end of the legs.



$$r = \frac{S}{\sqrt{2}} = 0.707S = KS$$

For the angle other than Right-angle, the value of "K"

From, IS 816 :1969, Table - 2

Angle between fusion face	Constant, K
60°-90°	0.7
91°-100°	0.65
101°-106°	0.6
107°-113°	0.55
114°-120°	0.5

➢ Effective length of fillet :-

- It is the length of the weld for which the specified size and the effective throat thickness of the weld exist.

$$Effective Length(l) = Overall Length(L) - 2S$$

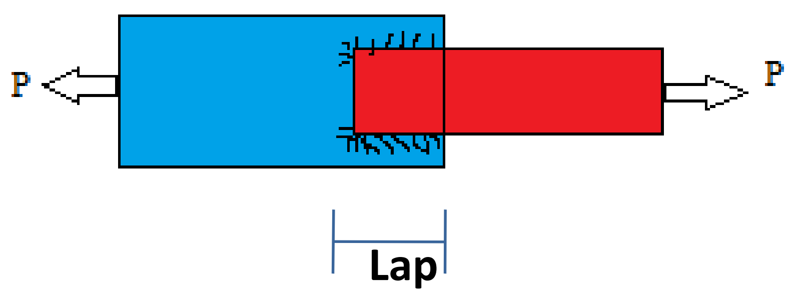
$$l_{min} > 4S$$

From, IS 816 :1969

Permissible stress in weld (p_t) = 108 MPa

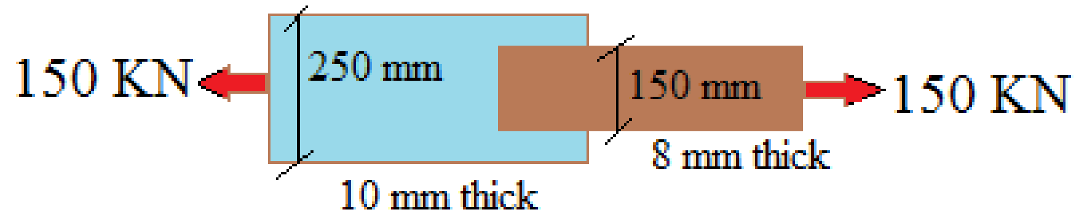
End Return $\geq$ 2S

Lap $\geq$ 5t



t – thickness of thinner plate.

Design a suitable fillet weld to connect the two plates as shown in figure.



Minimum size of fillet weld = 4 mm

Maximum size of weld = (8 – 1.5) mm

= 6.5 mm

Let's size of weld = 6 mm

Throat thickness = 0.7x6 = 4.2 mm

Strength of the 6 mm weld / mm length = p_tx4.2x1 = 108x4.2x1

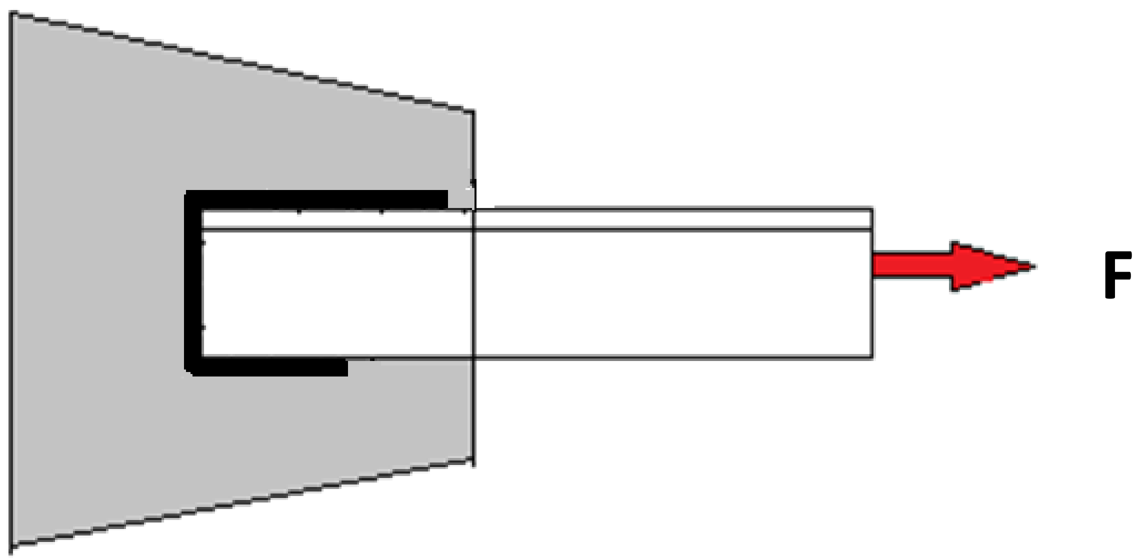
= 453.6 N/ mm length.

Required length of weld $= \frac{P}{weld\ .strength} = \frac{150 \times 1000}{453\ .6} = 330\ .68\, mm$

Let’s provide weld length = 345 mm

Length of side weld = (345 – 150)/2 = 97.5 mm

A tie in a truss consist of a pair of angle ISA 90x90x10 mm Welded on either side of a gusset plate 12 mm thick through the longer legs. Design the welded joint if the permissible Stress in the angle section and fillet weld are 150 MPa and 108 MPa respectively.



Butt welding

➢ Size of the weld :-

Size of the weld is specified by the effective throat thickness as follow :

- The size of the butt weld is the thickness of the thinner plate.
- The effective throat thickness in case of complete penetration is taken as the thickness of the thinner plate e.g. Double-V, Double – U, Double – J and Double Bevel butt joint are the examples of completely penetration butt weld.
- In case of incomplete penetration of butt weld the effective throat thickness is taken as the 7/8th of the thickness of the thinner part. But for stress calculation the effective throat should not exceeding 5/8th of the thickness of the thinner part

- The difference in thickness between the two plates should not be more than 25% of the thickness or, 3 mm whichever is more.

$$\frac{t_2 - t_1}{t_1} \leq 25\% of, t_1$$

- If difference is more than 25%, tapering less than 1:5 is to be done.

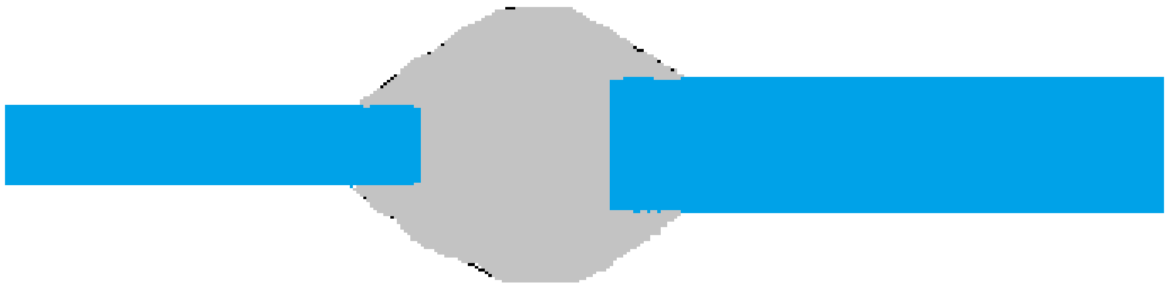
Effective length of the butt weld

- It is the length of the weld for which the specified size and the effective throat thickness of the weld exist.

$$l_{\min} > 4S$$

➢ Reinforcement :-

The extra deposit of metals above the thinner plate between 1 mm to 3 mm is not considered for stress Calculation or design.



➢ Stress in butt weld :-

The stresses of the butt weld should be taken equal to the stresses of the parent metal in the case of shop weld. These value are reduced to 80% if field welding is done.

The plate of dimension 180x10 mm and 180x12 mm are Joined by butt-welding. Calculate the maximum tension the Joint can transmit, if

a) Single – V butt weld.

b) Double – V butt weld is provided.

The permissible tensile stress of plate is 150 MPa.

Sol:- Thickness of thinner plate (t_1) = 10 mm

a) The strength of single –V butt joint $= \sigma_{at} \times \frac{5}{8} \times t_1 \times w$

$$= \frac{150}{1000} \times \frac{5}{8} \times 10 \times 180 KN$$

$$= 168.75 KN$$

b) The strength of Double – V butt joint $= \sigma_{at} \times t_1 \times w$

$$= \frac{150}{1000} \times 10 \times 180 KN$$

$$= 270 KN$$

Design a butt weld to join two strip of 180x12 mm and 180x8 mm to carry an axial tension of 110 KN.

Sol :-

Difference between plate thickness = (12 – 8) mm

= 4 mm, > 3mm, or 25% of t_1

So, We have to provide slope of 1:5 in thicker plate.

Let's provide Double – V butt weld joint having weld size "S".

The strength of weld/mm length $= \frac{108}{1000} \times S \times 1KN/mm$

$= 0.108 SKN/mm$

Required weld length (l_{eff}) $= \frac{F}{0.108S} = \frac{110}{0.108S} mm$

Maximum length we can provide is equal to width of plate (180 mm)

Thus,

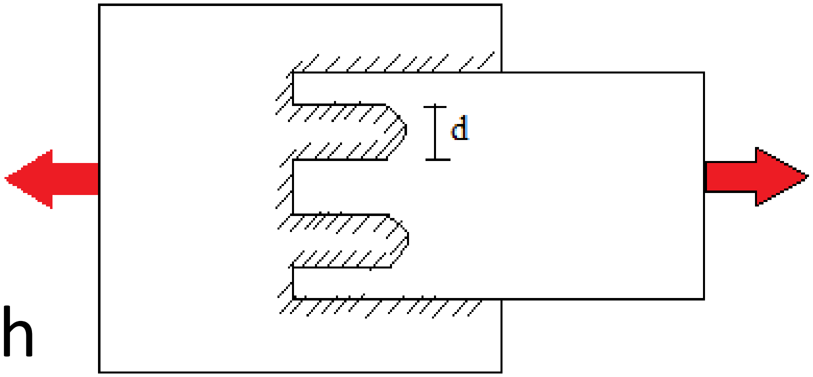
$$180 = \frac{110}{0.108\ S}$$

$S = 5.658\ mm$ < thickness of thinner plate (8 mm

So, OK

➢ Plug and Slot weld:-

❑ A slot is cut in one of the overlapping member and the welding metal is filled in the slot.



- If the slot is small and completely filled with weld metal, it is called plug weld.
- If periphery of the slot is filled with weld metal, it is called a slot weld.

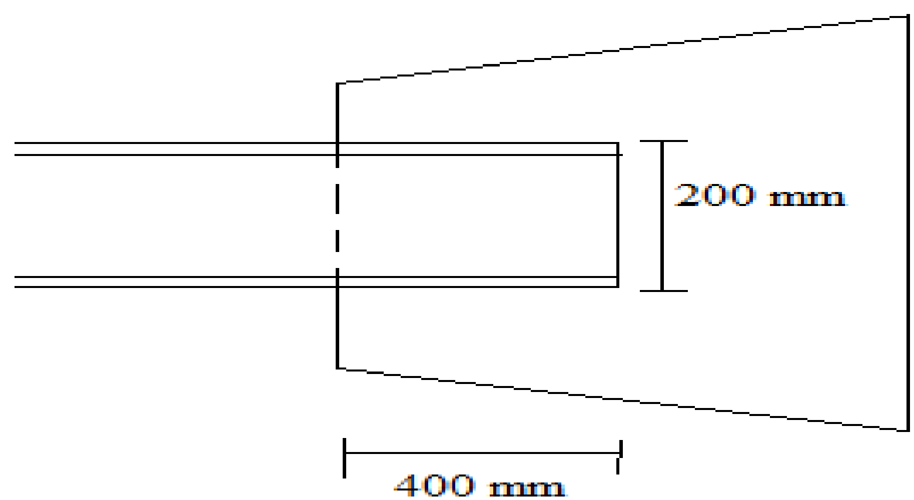
From, IS 816 :1969

- The width or diameter (d)of the slot should not be less than three time the thickness (t_1) of the part in which the slot is formed or, 25 mm whichever is greater.

$$\frac{d}{t_1} \geq 3, or\ .d = 25\ mm$$

- The distance between the edge of the plate and the slot or, between edge of adjacent slots should not be less than twice the thickness of the upper plate.

A tie member consisting of 2 channels ISMC 200, back-to-back, is required to connect to gusset plate of 10 mm thick . Design the fillet weld joint to develop full strength of the member. The overlap is limited to 400 mm. Assume permissible stress in weld is 108 MPa and permissible stress in section is 150 MPa.



Sol:-

Properties of ISMC 200:-

Thickness of web (t_w) = 6.1 mm

Thickness of flange (t_f) = 11.41 mm

Cross-section area of the section(A_{st}) = 2821 mm^2

Tensile strength of each channel section $= \sigma_{at} A_{st}$

$$= 150 \times 2821 N$$

$$= 423.15 KN$$

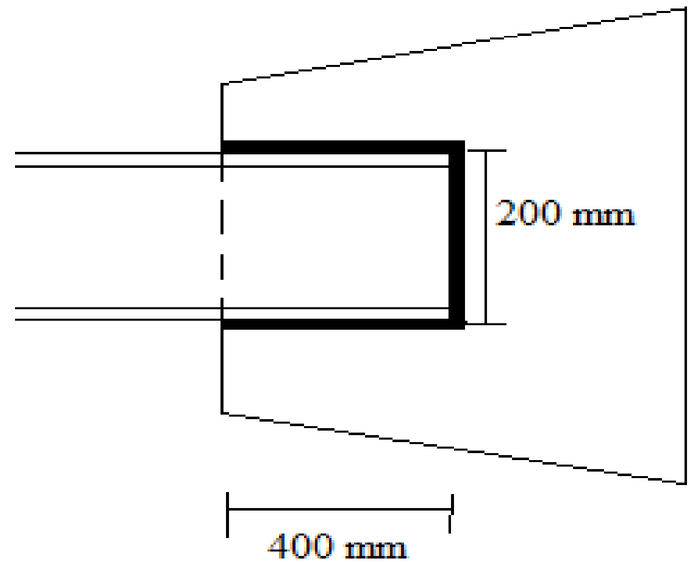
Minimum weld size = 4 mm

Maximum weld size = 6.1- 1.5 = 4.6 mm

Let's provide weld size (S) = 4 mm

Strength of weld / mm length = 108 x 0.7 x 4 N = 0.3024 KN.

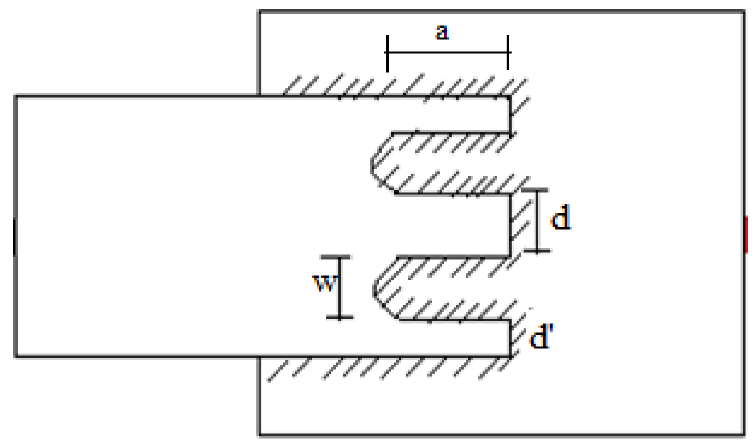
$$\text{Required weld length} = \frac{F}{0.3024} = \frac{423.15}{0.3024}$$
$$= 1399 mm$$



Available length = 400 x 2 + 200 mm
= 1000 mm

So, we have to provide slot.

Let’s provide two slot as shown in fig.



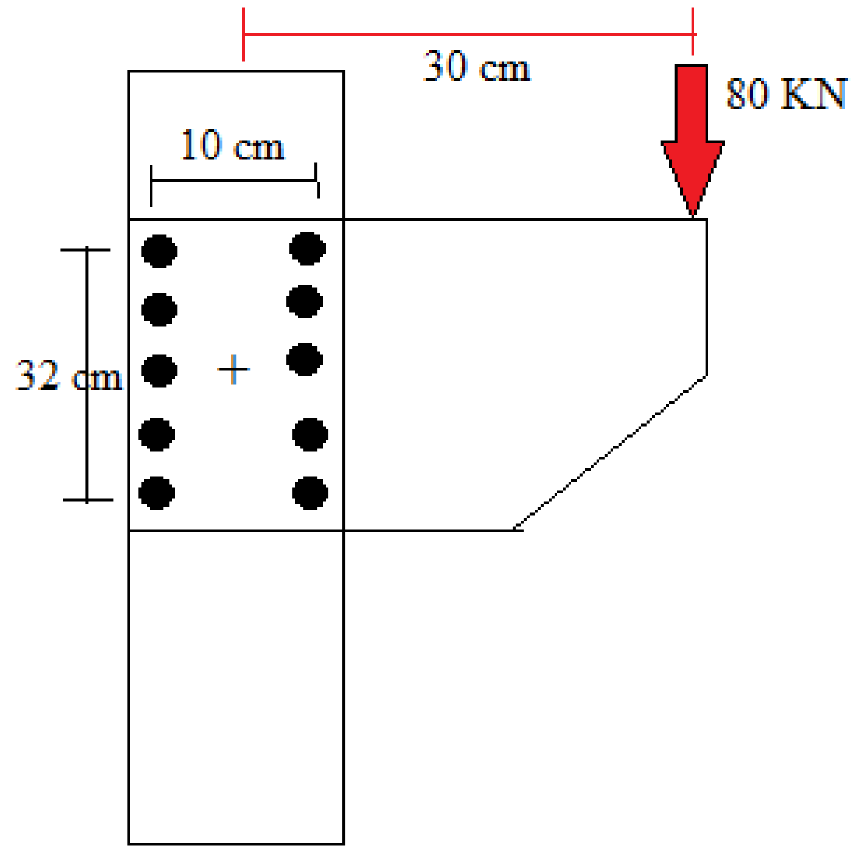
$$W = 25 mm > 3t (= 3 \times 6.1 = 18.3 mm)$$

$$d = 50 mm > 2t$$

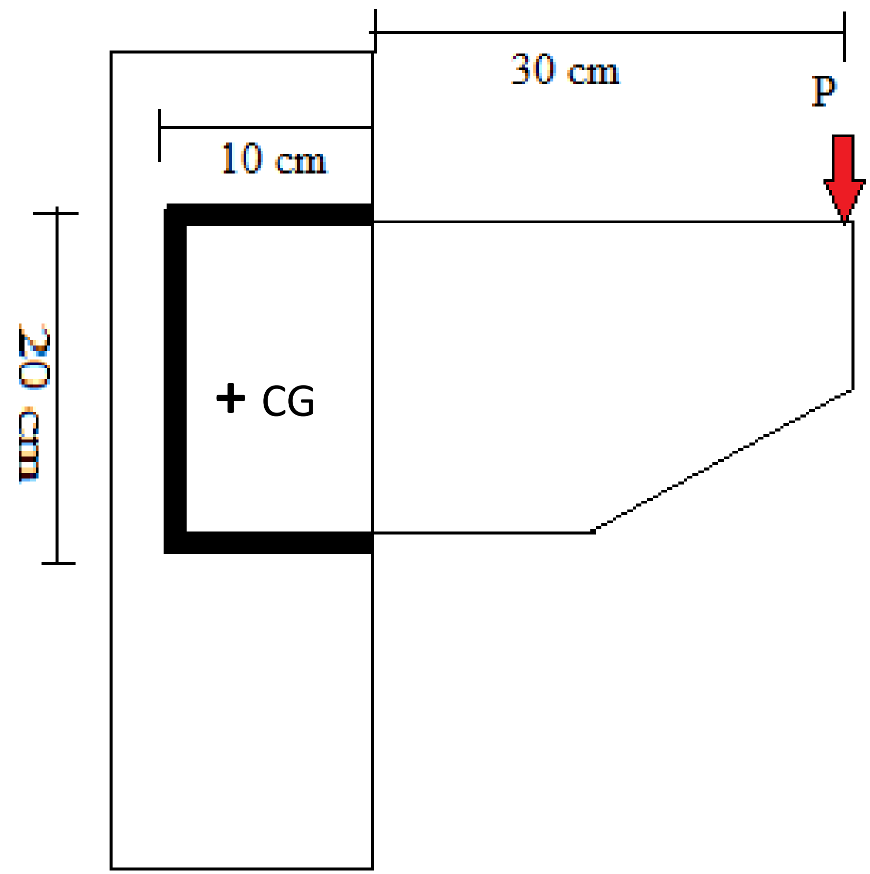
$$d' = 50 mm > 2t$$

$$So.ok, and, a = 100 mm$$

A bracket transmits a load of 80 KN at eccentricity of 30 cm to a column through 10 rivet of 22 mm diameter arrange in two vertical row 10 cm apart, the pitch is 8 cm and load lies in the plane of the rivet. Calculate the maximum stress in the rivets.



As shown an eccentric weld connection with 7 mm fillet weld size. Determine the maximum value of load “P”. If permissible shear stress in the weld is 108 Mpa.



Throat thickness (t) = 0.7x7 = 4.9 mm

C.G. of the weld -

$$\bar{x} = \frac{\sum A_i x_i}{\sum A_i}$$

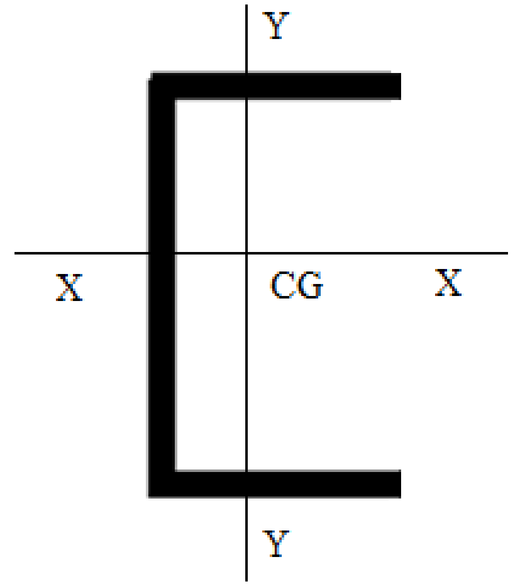
$$= \frac{20 \times t \times 0 + 10 \times t \times 5 + 10 \times t \times 5}{20 \times t + 10 \times t + 10 \times t}$$

$$= 2.5\,cm = 25\,mm$$

Direct stress (σ_1) $= \dfrac{P}{l_{eff}t} = \dfrac{P\times 1000}{400\times 4.9} = 0.5102PN/mm^2$

Torsion stress at extreme point $= \dfrac{Mr}{I}$

$$M = P\times(30+7.5)KN-cm = P\times 37.5\times 10^4\,N-mm$$



$$r = \sqrt{10^2+7.5^2} = 12.5cm = 125mm$$

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

$$I_{xx} = \frac{1}{12}\times 4.9\times 200^3 + 2\left\{\frac{1}{12}\times 100\times 4.9^3 + 100\times 4.9\times 102.5^2\right\}$$

$$= 13564752.48mm^4 \approx 13.56\times 10^6\,mm^4$$

$$I_{yy} = \frac{1}{12}\times 200\times 4.9^3 + 200\times 4.9\times 27.5^2 + 2\left\{\frac{1}{12}\times 4.9\times 100^3 + 100\times 4.9\times 25^2\right\}$$

$$= 2172252.483\,mm^4 \approx 2.17\times 10^6\,mm^4$$

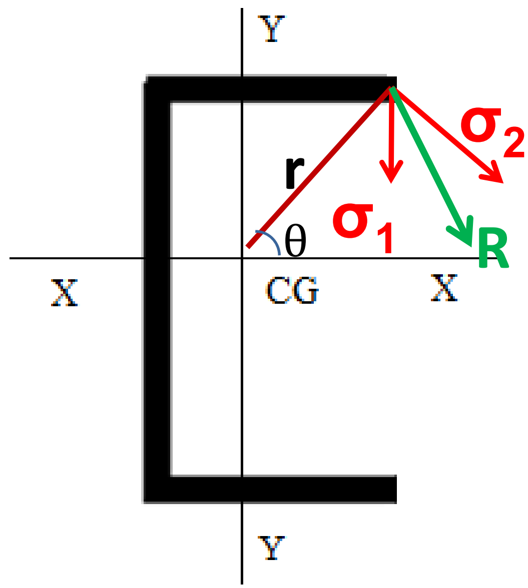
Thus,

$$I = 13.56\times10^6 + 2.17\times10^6 = 15.73\times10^6\, mm^4$$

Torsion stress(σ_2) = $\frac{Mr}{I} = \frac{P\times 37.5\times10^4\times125}{15.73\times10^6}$

$$= 2.9799\ P,\ N/mm^2$$

$$\theta = \tan^{-1}\left(\frac{102.5}{75}\right) = 53.806^0$$



Resultant stress (R)

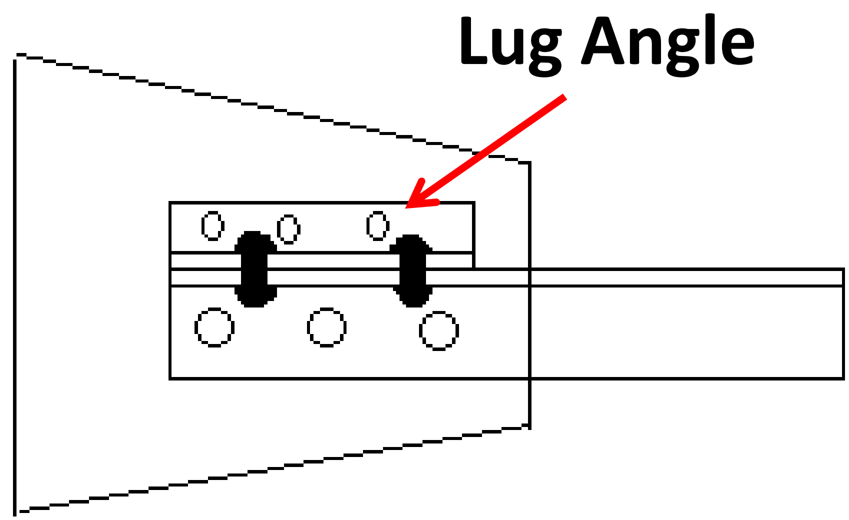
$$R = \sqrt{\sigma_1^2 + \sigma_2^2 + 2\sigma_1\sigma_2 Cos\theta} = 3.168P$$

Thus, Permissible load (P)

$$P = \frac{weld\cdot strength}{3.168} = \frac{108}{3.168} \approx 34KN$$

➢Lug angle :-

From IS 800 1984, clause 8.8



➢ For angle section :

- Strength of Lug angle and there connection with gusset plate = 1.2 x Strength of outstanding leg.
- Connection strength between Lug angle and outstanding Leg = 1.4 x Strength of outstanding leg.

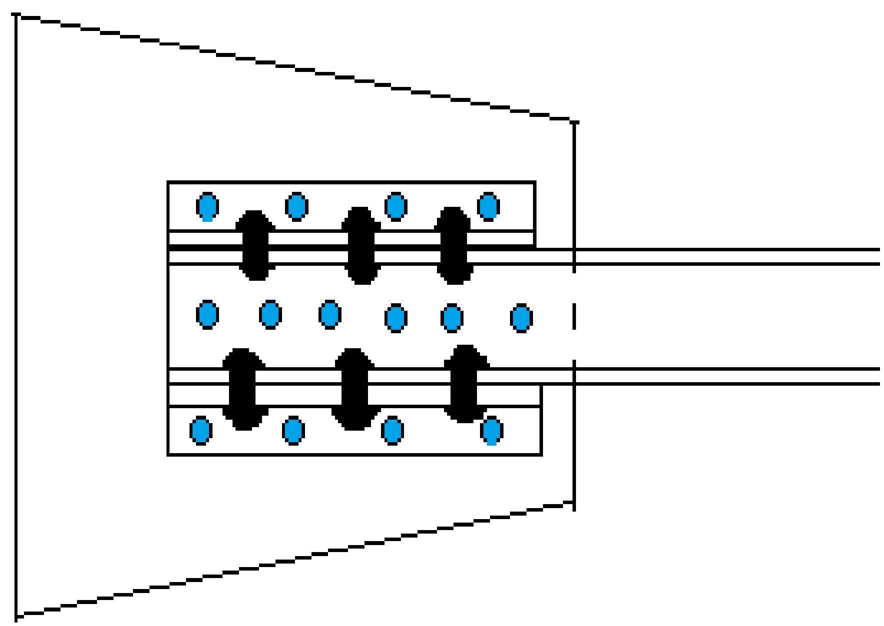
➢ For channel section:

- Strength of Lug angle and there connection with gusset plate = 1.1 x Strength of outstanding leg.
- Connection strength between Lug angle and outstanding Leg = 1.2 x Strength of outstanding leg.

- Minimum number of rivet should be two.
- Where Lug angles are used to connect an angle member, the whole area of the member should be taken as effective area.

Design an end connection for a tension member ISMC 300 @35.8 Kg/m with 12 mm thick gusset plate using Lug angle and 20 mm dia. Pds rivets. The design load on channel is 560 KN.

Sol :-



Gross area of the section(A_g) = 4564 mm^2

Net area is,

$$A_{net} = A_g - \phi \times t_w = 4564 - 21.5 \times 7.6 = 4400.6 mm^2$$

Stress due to applied load

$$\sigma_{at,cal} = \frac{P}{A_{net}} = \frac{560 \times 1000}{4400.6} = 127.26 MPa < \sigma_{at} (150 MPa)$$

Area of connected leg = (300 – 7.6)x7.6 = 2222.24 mm^2

Area of outstanding leg = (4564 – 2222.24)/2 = 1170.88 mm^2

Force taken by outstand leg $= 560 \times \frac{1170.88}{4546} = 143.67 KN$

Force taken by connected leg = 560 – 2x143.67 = 272.66 KN

Design of lug angle :

Strength of lug angle = 1.1 x Force of outstanding leg

= 1.1 x143.67 = 158.03 KN

Required net sectional area :

$$A_{net} = \frac{158.03 \times 1000}{150} = 1053.53\ mm^2$$

Let's provide ISA 90X90X8,

Area of the section = 1379 mm^2

$$A_{net} = 1379 - 21.5 \times 8 = 1207\ mm^2$$

Strength of rivets :

- In bearing in web of channel -

$$P_1 = \frac{300}{1000} \times 7.6 \times 21.5$$
$$= 49.02 KN$$

- In bearing in outstand leg of channel -

$$P_2 = \frac{300}{1000} \times 8 \times 21.5 = 51.6 MPa$$

- In shearing -

$$V = \tau_{av} \times \frac{\pi}{4}\phi^2 = \frac{100}{1000} \times \frac{\pi}{4} \times 21.5^2 = 36.3 MPa$$

Thus, Rivet value (R) = 36.3 MPa

- Number of rivet required to connect :

Channel web with gusset plate $= \dfrac{272.66}{36.3} = 7.51 \approx 8$

Lug angle with outstanding leg $= \dfrac{1.2 \times 143.67}{36.3} = 4.74 \approx 5$

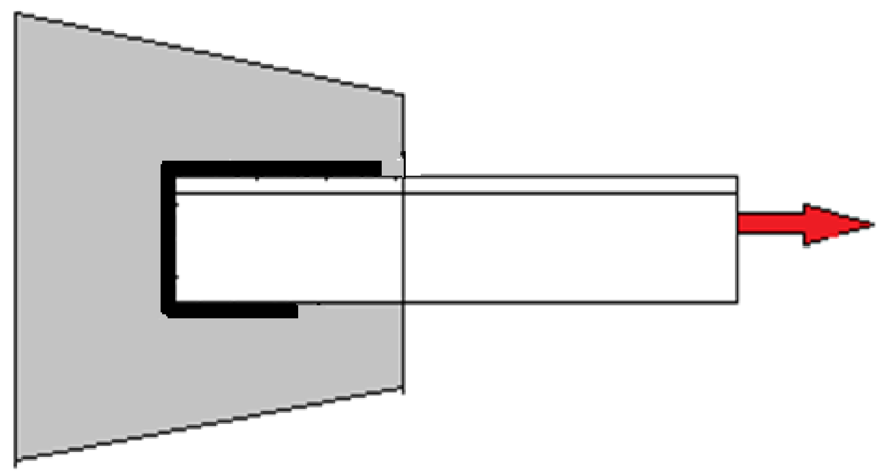
Lug angle with gusset plate $= \dfrac{1.1 \times 143.67}{36.3} = 4.35 \approx 5$

Spacing of rivet = 3x21.5 = 64.5 mm (say 65 mm)

Design a fillet-weld end connection for a tension member ISA 80x50x10 mm connected by longer Leg to 8 mm thick gusset plate. Assume weld Strength is 108 Mpa and $\sigma_{at} = 150$ Mpa.

Sol :-

Equivalent area of the section



$$A_{eq} = A_1 + KA_2$$

$$A_1 = \left(80 - \frac{10}{2}\right) \times 10 = 750\, mm^2$$

$$A_2 = \left(50 - \frac{10}{2}\right) \times 10 = 450\, mm^2$$

$$K = \frac{3A_1}{3A_1 + A_2} = 0.833$$

$$A_{eq} = 1125 mm^2$$

Maximum tensile force taken by the angle section :

$$T = \sigma_{at} \times A_{eq} = \frac{150}{1000} \times 1125 = 168.75\,KN$$

Minimum weld size = 4 mm

Maximum weld size = (t -1.5)=(8-1.5)= 6.5 mm

Let’s provide weld size (S) = 6 mm