Design Of Steel Structures

Design of Steel Structures
Types of section.
Grades of steel
Strength characteristics
IS Code, Connections
Design of tension and compression members
Steel roof truss, beams, column bases.

Iron

1. Pure iron (non alloy)

- It is natural metal available directly in the Earth Ores.
- Silvery white in colour.
- It is very soft solid (such that it can be cut by knife) having high ductility.
- It is not used in any structural element since it directly reacts with oxygen and to form rust and reacts with moist air.
- It is available in Fe2+ anf Fe3+ forms.

2. Pig Iron :

- Basic raw iron is called Pig iron 9transported in the form of bricks).
- It is also not used in any structural element since it is composed of highest carbon content 5%).
- The pig iron can be converted into structural iron by removing excess carbon content and by adding oxygen or chemicals in molten stage.

3. Cast Iron :

- It is the structural element (in specific shape from molten pig iron having almost same properties of pig iron.

4. Wrought Iron

- Lowest carbon content (0.0 - 0.1%) of structural iron.
- It has high ductility, easily converted in specific shape.
- Largely used to make thin wires.

5. Steel

- Steel is an alloy of (iron + carbon + chromium + copper + magnesium + nickel + silica).
- The structural element used to resist any type of load.

Carbon Content

Pig iron (4 - 5%)
> Cast Iron (2 - 4.5%)
> Cast steel (>2%)
> Carbon steel (less than 2%)
> High carbon steel (0.6 - 1.4%)
> Medium carbon (0.25 - 0.6%)

ENTRI

> Low carbon steel (less than 0.25%)
> Wrought Iron (less than 0.1%)
> Pure iron (0%)

Properties	Low carbon	Medium carbon	High carbon
Carbon	Lower than 0.25 weight percent	In between 0.25 and 0.6 weight percent	In between 0.6 and 1.4 weight percent
Some properties	Excellent ductility and toughness. Weldable and machinable Not amenable to Martensite transformation	Low hardenability. These steel grades can be heat treated	Hardest, strongest and least ductile
Some applications	Common products like nuts, bolts, sheets etc.	For higher stength such as in machinery,Auto-mobiles and agricultural parts (gears, axels, connecting rods) etc.	Used where strength, hardness and wear resistance is required. Cutting tools, cable, Musical wires etc.

Introduction

- Steel is an alloy of Fe+ Carbon
  - * MILD STEEL (carbon content - 0.23%)
    - When carbon content is increased in steel then strength, hardness and brittleness will increase but ductility will decrease.
  - * STAINLESS STEEL
    - Alloy of iron and chromium
    - Chromium is 18% and nickel is 8%
    - Young's modulus of steel 'E' is equal to 2×10^5 MPa or 200 GPa
  - * $E_{Aluminium} \approx 1/3\ E_{steel}$
  - * $E_{Aluminium} \approx 0.7 \times 10^5$ MPa or 70 GPa
  - * Density of steel

$$\rho = \begin{cases} \rho_{steel} = 7850\ kg/m^3 \\ \rho_{Aluminium} = \rho_{steel}/3 = 2700\ kg/m^3 \end{cases}$$

  - * Modulus of Rigidity (G)
    - $G = 0.769 \times 10^5$ MPa
  - * Poisson's ratio (μ)
    - $\mu = \dfrac{\text{Lateral strain}}{\text{Longitudinal strain}}$
    - μ for mild steel = 0.286
    - In elastic range : 0.3
    - In plastic range : 0.5
  - * Deflection/ Increase in length
    - $\Delta L = \dfrac{PL}{AE}$

- $(\delta L)_{\text{mild steel}} = \frac{1}{3}(\delta L)_{Al}$

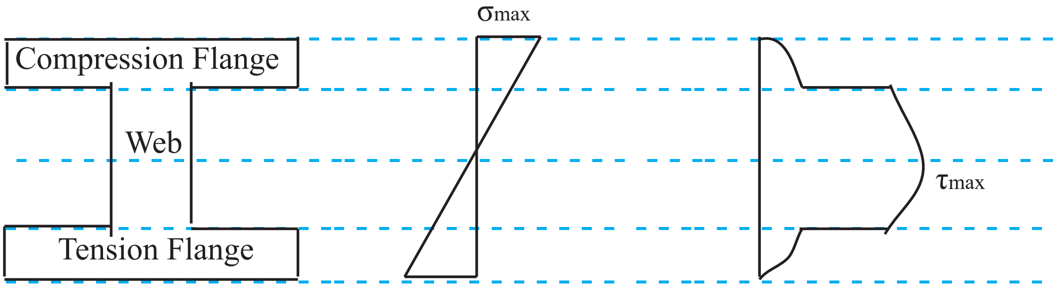
* Thermal coefficient
  - $\alpha_{steel} = \alpha_{concrete} = 12 \times 10^{-6}\ ^{o}C^{-1}$
  - $\alpha_{Al} = 23 \times 10^{-6}\ ^{o}C^{-1}$
  - Steel is ductile while concrete or rubber are brittle

* Note : Rubber is a very brittle material, there is very little plastic deformation beyond elastic range.

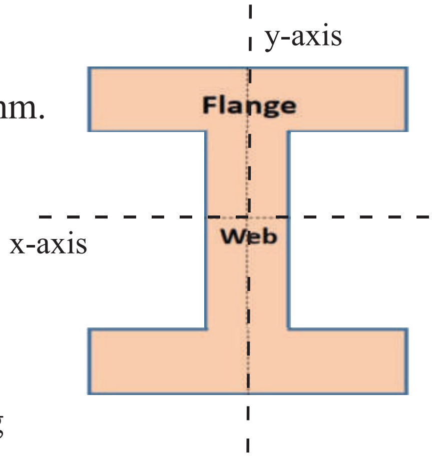
Some Important Codes

- IS 456 : 2000 RCC
- IS 800 : 2007 Steel (2007-LSM, 1984-WSM)
- IS 1343 Pre Stress Concrete
- IS 10262 Design Mix
- IS 383 Fine and coarse Aggregate
- IS 875 Design load for buildings and structures

Standard Structural Steel Section



In I-section, the web resists shear forces, while the flanges resist most of the bending moment experienced by the beam.



(i) ISLB 300
  - Indian standard light beam where overall depth is 300 mm.
  - Maximum bending stress is resisted by flange and maximum shear stress by web.
  - Generally used in roof beam.

(ii) ISMB
  - Indian Standard Medium flange beam generally used in floor beams.
  - High moment of inertia about x-axis, so lateral buckling occurs about y-axis

(iii) ISWB
  - Indian Standard wide flange beam generally used in column.
  - High moment of inertia about y-axis, so they have buckling strength about y axis.

(iv) ISJB
  - Indian Standard junior beam.

(v) ISHB

- Indian Standard heavy beam

2. Angle Section

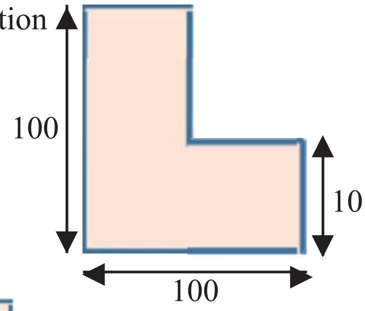
(i) Equal angle section

- ISA - 100 × 100 × 10

  Where 10mm is the thickness of angle section

  100 × 100 both legs are same

Equal Angle section

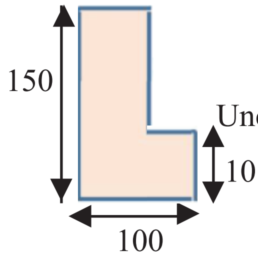


(ii) Unequal angle section

- ISA - 150 × 100 × 10

  Where 10mm is the thickness of angle section

  150 × 100 both legs are different.

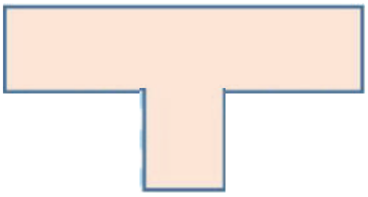


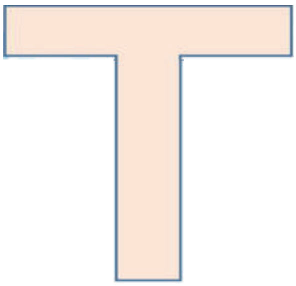
Unequal Angle section

3. T section

(i) ISHT - Indian Standard wide flange T section

(ii) ISST - Indian Standard long legged T section


ISHT


ISST

4. Channel Section

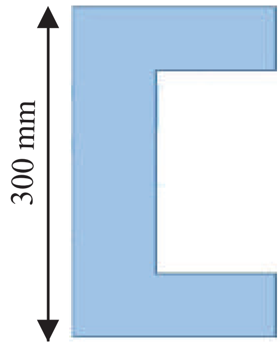
- They are used as Purlins or columns (Purlin is a beam in a roof truss which supports the roof covering material).

(i) ISJC - Indian Standard Junior Channel Section

(ii) ISLC - Indian Standard Light Channel Section

(iii) ISMC 300 - Indian Standard Medium Channel Section where 300 is the overall depth of channel section.

(iv) ISSC - Indian Standard Special Channel Section



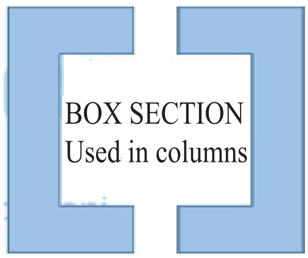
5. Box Section - Used in column

6. Flat Section -

- ISF - Indian Standard Flat Section
- Generally used in the design of lacing and batten
- Eg. 50 ISF 8

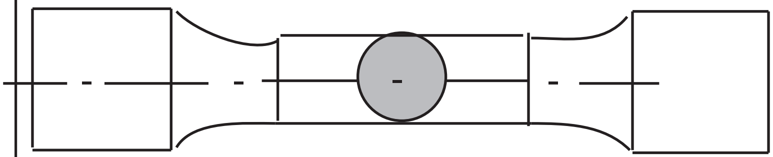
  Here 50 is width of plate

  And 8 is thickness of plate

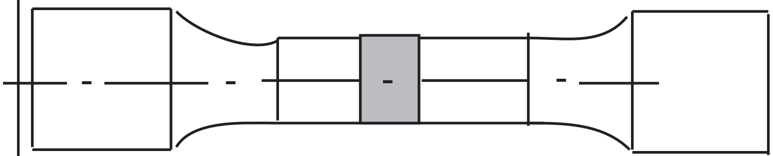


Uniaxial Tension Test

- This test is of static type i.e. the load is increased comparatively slowly from zero to a certain value.
- UTM or Tensile Testing Machine is used.



Specimen with Circular Cross-Section



Specimen with Rectangular Cross-Section

(i) The ends of specimen's are secured in the grips of the testing machine.
(ii) There is a unit for applying a load to the specimen with a hydraulic or mechanical drive.
(iii) There must be a some recording device by which you should be able tomeasure the final output in the form of Load or stress.

True Stress & Nominal Stress

1. Nominal Stress - Strain Or Conventional Stress - Strain Diagrams:

Stresses are usually computed on the basis of the **original area** of the specimen; such stresses are often reffered to as **conventional or nominal Stress.**

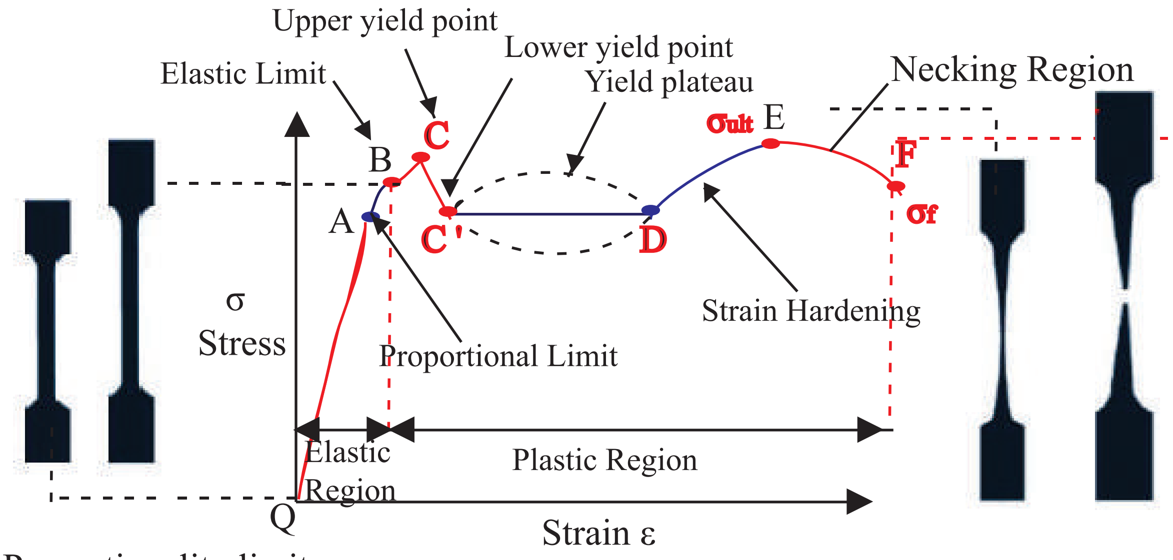
2. True Stress - Strain Diagram :

Since when a material is subjected to a uniaxial load, some contraction or expansion always takes place. Thus, dividing the applied force by the corresponding **actual area** of the specimen at the same instant gives the so called **true stress.**

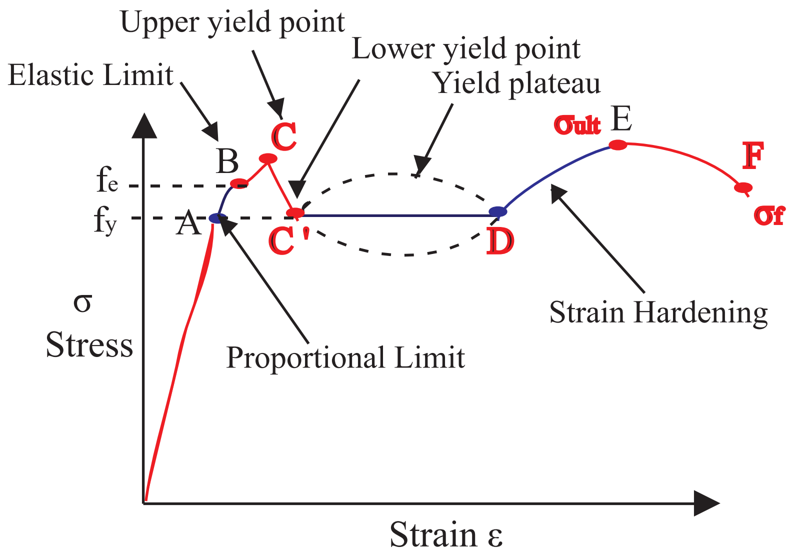
Original Area

Actual Area

Stress - Strain Curve for Mild Steel



- **OA** is Proportionality limit.
- **OB** is Elastic limit bu **OB** is Non linear
- The slippage of the carbon atom within a molecular mass leads to dropdown of stress marginally from C to C'.
- **C** is upper yield point.
- **C'** is lower yield point (also known as Yield Stress f_y).
  - For exp Fe-250 => $f_y = 250N/mm^2$
- **C'D** is constant stress region called ield Plateau.
- **DE** is Strain Hardening region, material starts offering resistance against deformation.
- EF is Neckling region where drop down of stresses occur upto Failure point.
- Necking region exists only in ductile material.
- In mild steel, ABC are closer to each other, therefore it is known as Linear elastic Metal, and Yield stress and elastic stress is taken as $250N/mm^2$.
- The Fracture or Failure in mild steel depends upon Percentage of carbon present in the steel.



Permissible Stress in Steel Structures

$$\text{Permissible stress} = \frac{\text{Yield stress } f_y}{\text{Factor of safety}}$$

- It is the maximum load carried by the member without deformation.
- In working stress method, it is assumed that members can carry load up to elastic limit, hence members will be designed such that they can resist less loads as compared to the resistance of maximum capacity by proper factor of safety to whole Permissible Stress.
- FOS = 1.67 for members subjected to Axial tension or compression.
- FOS = 1.50 for members subjected to bending
- Since in axial loading all fibers reach maximum stresses, but in bending only extreme fibers will reach maximum stresses. Hence FOS will be less for bending.

Working Stress Method

- In the field there are always worst combination of loads (DL, LL, EL, WL, etc) hence members will be designed such that they can resist more and more loads of actually we needed.
- Ultimately size and cross section area of the member increases and hence working/ failure stress decreases.
- $\text{Working stress} = \frac{\text{Load supplied to the members}}{\text{Cross sectional area}}$

  Or
- $\text{Working stress} = \frac{\text{Yield stress } f_y}{\text{FOS}}$
- Merits of WSM :
  - The members cannot be failed in future having large life span.
  - The design is very simple.
- Demerits :
  - Weight of the structure increases, hence it is uneconomical.

Plastic State or Llimit State Method

- The design of the members may touch the plastic range i.i FOS will be desired for each loads by considering load combinations and strength and servicibility requirements.
- Hence it is called as Partial Factor of Safety
- $\text{Design load} = \frac{\text{Corresponding characteristic load}}{\text{Partial safety factor}}$

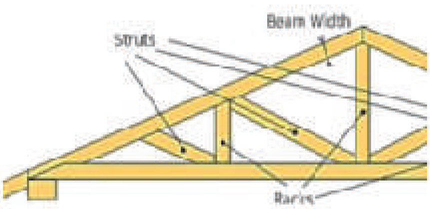
Permissible Stresws in Steel Structures

1. As per WSM

(i) Maximum permissible AXIAL stress in compression is given by

$\sigma_{ac} = 0.60$ fy

- Used in the design of columns and struts.



- Column is a compression member where bending moment exist while in case of struts, also being a compression member, bending moment is zero. Because strut is a component of roof trusses and roof trusses ar pin jointed connection having bending moment equal to zero.

(ii) Maximum permissible Axial stress in tension is given by

$\sigma_{at} = 0.60$ fy

It is used in design of tension members

- FOS = 1.67 for members subjected to AXIAL tension or compression
- FOS = 1.50 for members subjected to bending

(iii) Maximum permissible bending stress in compression is given

- Used in design of flexural (bending) member that is beam, built up beam, plate girder etc.

$\sigma_{bc} = 0.66$ fy

(iv) Maximum permissible bending stress in tension is given

- Used in the design of beams

$\sigma_{bt} = 0.66$ fy

(v) Maximum permissible average shear stress is given by

$\tau_{v\,avg} = 0.40$ fy

(vi) Maximum permissible maximum shear stress is given by

$\sigma_{v\,max} = 0.45$ fy

- FOS = 2.5 for average shear stress
- FOS = 2.2 for maximum shear stress

(vii) Maximum permissible bending stress is given by

$\sigma = 0.75$ fy

Increase of permissible stress

- When wind and earthquake load are considered, the permissible stresses in steel structure are increased by 33.33%
- When wind and earthquake load are considered, the permissible stresses in connections (rivet and weld) are increased by 25%.

Permissible Deflection In Steel Structures

- Maximum permissible horizontal and vertical deflection is given by

$$\delta = \frac{\text{span}}{325} \quad \text{as per WSM}$$

- Maximum permissible horizontal and vertical deflection is given by

(a) If supported elements are not susceptible to cracking

$$\delta = \frac{\text{span}}{300}$$

(b) If supported elements are susceptible to crackingh

$$\delta = \frac{\text{span}}{360}$$

Permissible Stress in Gantry Girder

Gantry girders are laterally supported beams to carry heavy loads from place to place at the construction sites.

1. For manually operator crane, the maximum permissible deflection is

$$\delta = \frac{\text{span}}{500}$$

2. For electrically operator crane, the maximum permissible deflection for capacity upto 50T or 500kN

$$\delta = \frac{\text{span}}{750}$$

3. For electrically operator crane, the maximum permissible deflection for a capacity more than 50T or 500kN

$$\delta = \frac{\text{span}}{1000}$$

Factor of Safety for Different Stresses

$$\text{Factor of safety} = \frac{\text{yield stress}}{\text{working stress}} = \frac{f_y}{f}$$

1. For axial stress, $\text{F.O.S} = \frac{f_y}{0.60 f_y} = 1.67$

2. For bending stress, $\text{F.O.S} = \frac{f_y}{0.66 f_y} = 1.50$

3.
- FOS = 1.67 for members subjected to AXIAL tension or compression
- FOS = 1.50 for members subjected to bending

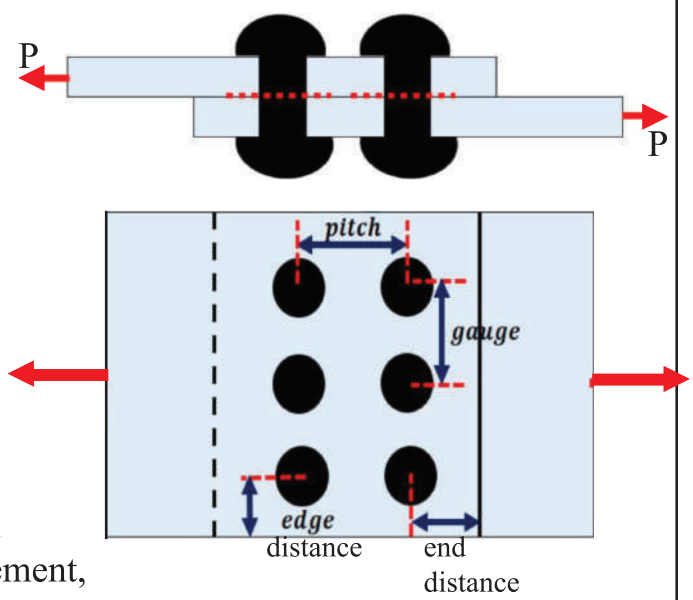
Important Terms

1. Pitch - It is the distance between two consecutive/continuous rivets measured parallel to the direction of force. It is denoted by ‘p’.

2. End Distance - It is the distance between centre of rivet and edge/end of the plate element, measured parallel to the direction of force.

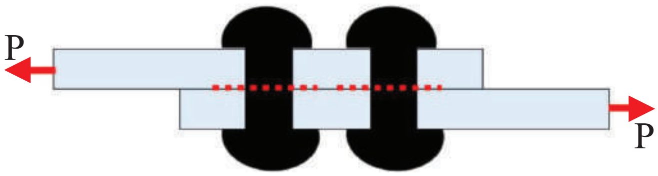
3. Gauge Distance - It is the distance between two continuous rivets measured perpendicular to the force of direction.

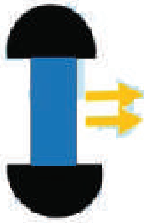
4. Edge Distance - It is the distance between centre of rivet and edge/end of the plate element, measured perpendicular to the force of direction.

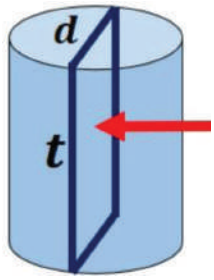


Bearing stresses : The bearing stress is nothing but compressive stresses developed at the surfaces of two different materials.

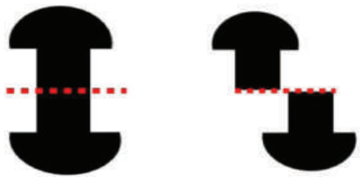
Or "Compressive force divided by characteristic area perpendicular to it".







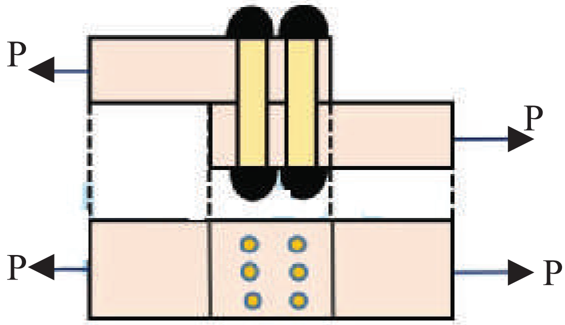
Shearing Stresses :
Two forces, equal and opposite in nature, when act tangential to the resisting section, as a result of which the body shear off across the section is known as Shear Stress.



Types of Joints

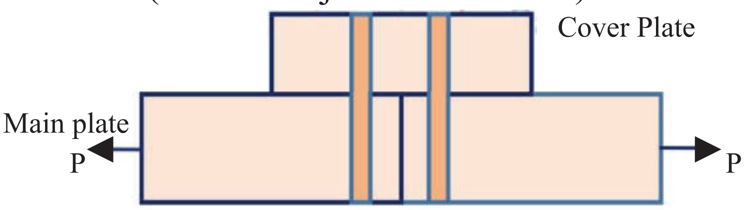
1. Lap Joint :

- It is the least efficient joint as the lines of action of two forces are not same.
- In lap joints, the rivets are subjected to single shear and bearing.
- These forces form couple and additional bending stresses are developed in the rivets.

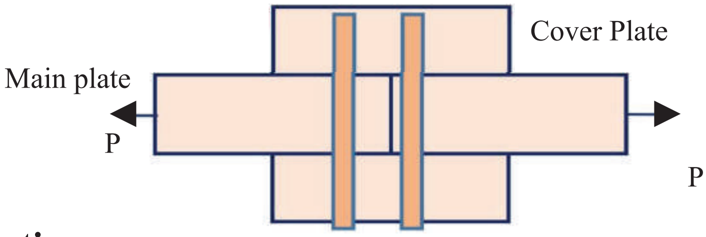


2. Butt Joint

- Single Cover Butt Joint :
  * The line of action of two forces is same therefore eccentricity is eliminated completely which existed in lap joint hence this joint is more efficient in carrying the forces as compared to lap joint.
  * But the connection is not symmetrical.
  * The rivets are subjected to single shear and bearing.
  * $t_{cover} \geq t_{main}$ (so that the joint doesnot fail)

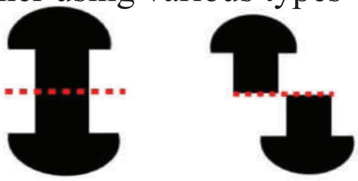


- Double cover Butt Joint :
  * It is the most efficient joint because the line of action of two forces is same and connection is symmetrical w.r.t applied load.
  * The rivets are subjected to double shear and bearing.
  * Sum of thickness of cover plate $\geq t_{main}$



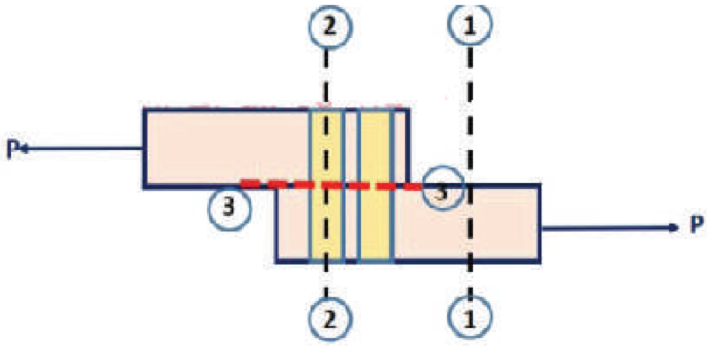
Connections

- In steel structure, various types of elements are connected together using various types of connections like :
  1. Riveted connections
  2. Bolted connections
  3. Welded connections



Strength of Plate

Section 1 - 1 → Tearing strength of plate
Section 2 - 2 → Bearing strength of plate
Section 3 - 3 → Shear strength of plate



Failure of Rivetted Joint

Failure of Rivets

1. Shearing Failure of Rivets

- In a shearing failure, Rivet gets cut into two or more pieces.

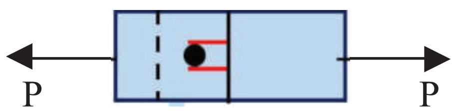
2. Bearing failure of Rivet

- In a bearing failure, rivet cross section changes from circular to elliptical.

Failure of Plates

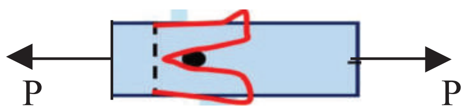
1. Shearing Failure of Plate

- In this failure, cracks are developed parallel to the applied forces direction.



2. Splitting failure of Plate

- Splitting failure occurs due to diagonal tension in the plate at the rivet level.

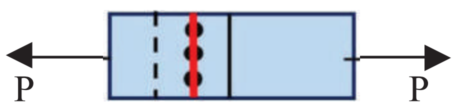


3. Bearing Failuree of Plate

- This plate is pushed forward by the rivet. This type of failure occurs generally due to insufficient end distance.

4. Tearing/Tension Failure of the plate

- The cracks are developed perpendicular to the direction of applied force.



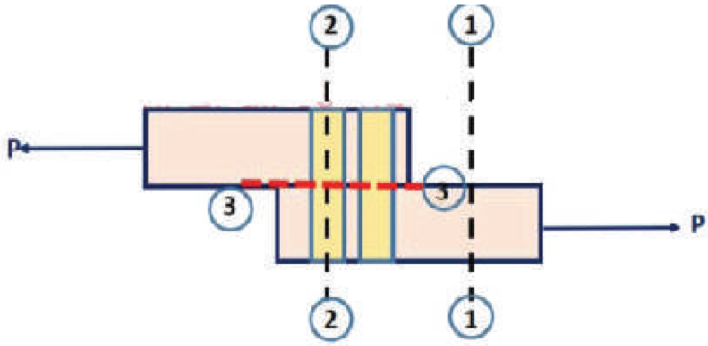
Note :

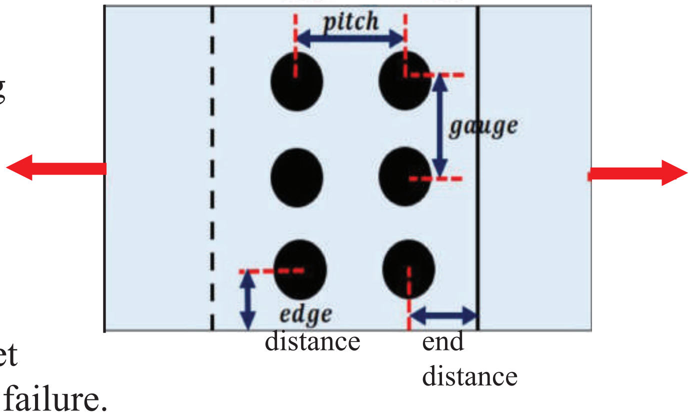
(i) Shear, bearing and splitting failure of plate are due to insufficient end distance.

(ii) By providing the proper end distance, these three failures can be prevented.

(iii) In the design of riveted joint which should consider the remaining three failure only, i.e. Shear and Bearing failure of rivets and Tearing failure of plate.

(iv) In the design of riveted joint, we have to ensure that, shear strength and bearing strength of rivets is more than the tearing strength of plate because rivet failure is more dangerous than the plate failure.





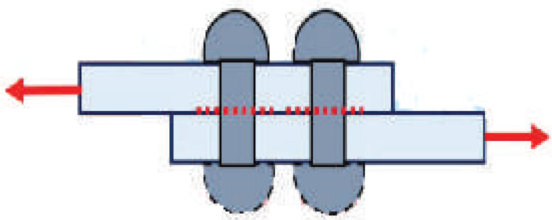
Strength of Riveted Joint

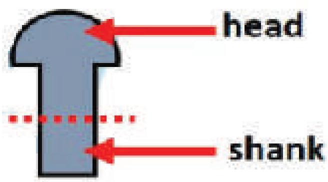
- **Plate**
  - Shearing
  - Bearing
  - Splitting
  - Tearing
- **Rivet**
  - Shearing
  - Bearing

Connections

1. Riveted Connections :

- In the riveted connection, rivets are inserted in the hole made to join the two members together and hammering is done to make head on other side.



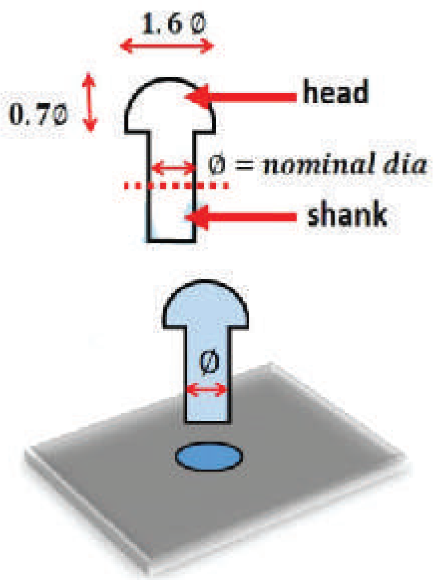


- Rivets are made of mild steel. The riveting can be hot riveting (or) cold riveting.
- Cold riveting is not adopted for dia > 10 mm.
- In cold riveting there is no gripping action but strength is better due to cold working.
- When hot rivet is used, it becomes plastic, it expands and fill the rivet hole completely in the process of forming a head at the other end. On cooling, the rivet shrinks in the

length and diameter due to shortening of rivet shank length.

- The connected part becomes lighter consequently resulting in tension of unpredictable amount in a shank length and some compression in plates that are connected.
- Due to reduction of diameter of shank on cooling, this small amount of space available on cooling is provided for temperature variation of unpredictable amount.
- In hot riveting, rivets are heated to 550-1000ºC and hammering is done on other side to make head. According to the type of hammering we have
  (i) Power driven rivets
  (ii) hand driven rivets
- Power driven rivets have better quality control and hence have a higher permissible stress.
- Riveting can be done in the factory (or) in the field and according in these hop riveting & field riveting thus we have,
  (i) Power shop rivets
  (ii) Power driven field rivets
  (iii) Hand driven field rivets

N/mm^2	Axial Tension	Shearing	Bearing
PDS	100	100	300
PDF	90	90	270
HDF	80	80	250

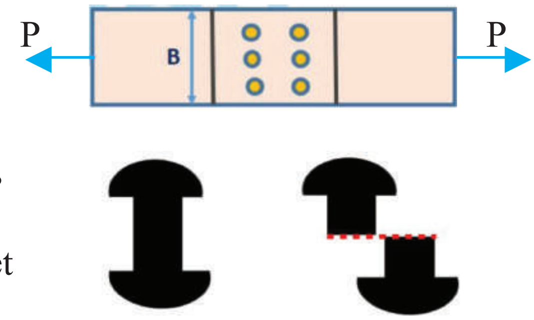


- The nominal dia of rivet is said to be shank dia under cold condition, and gross dia of rivet is taken as dia of hole.
- The strength of rivet is based on its gross diameter under the assumption that rivet fills the hole completely.
- For ease in connection dia of hole is taken larger than nominal dia of rivet thus as per IS : code :
  - For nominal dia ≤ 25mm
    - Gross dia = nominal dia + 1.5mm, dia of hole = ø + 1.5
  - For nominal dis > 25 mm
    - Gross dis = nominal dis + 2mm, dia of hole = ø + 2
- Due to many demerits, riveted connections is not in practice in modern steel instruction.
- Design of Riveted connection is same as that of bolted connection but with the following differences :
  - The diameter of rivet to be used in the calculation is dia of hole, whereas for Bolted connection it is the nominal dia.
  - The design stresses are different (IS : 800 : 1984) the permissible stress are reduced for bolts.

- **Strength of riveted joint**
  - It is taken as minimum of shear strength, bearing strength and tearing strength.
- **For Lap Joint :**

1. For Entire Plate

(a) Shear Strength of Rivets



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

Where n → Total number of rivets at joint

F_s → permissible shear stress in rivets

F_s = 1000 MPa (WSM)

F_u = Ultimate shear stress in rivet

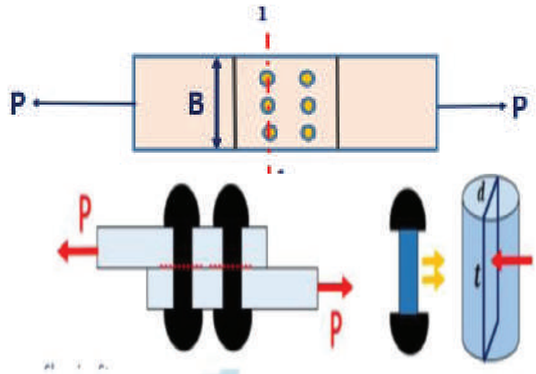
So in LSM = $\dfrac{F_u}{\sqrt{3} \times 1.25}$

d → gross diameter of rivet (hole diameter)

Gross dis = nominal dis + 1.5 mm, for nominal dia ≤ 25mm

Gross dia = nominal dis + 2 mm, for nominal dia > 25 mm

(b) Bearing strength of All Rivets



$$P_B = n \times (t \times d) \times F_b$$

Where n → total number of rivets at joint

t → thickness of thinner main plate

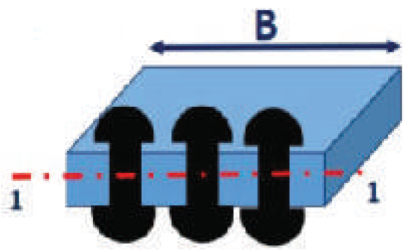
F_b → permissible shear stress in rivets (300MPa in WSM)

d → gross diamter of rivet (hole diameter)

gross dis = nominal dia + 1.5 mm, for nominal dia ≤ 25 mm

gross dia = nominal dis + 2 mm, for nominal dia > 25 mm

(c) Tearing Strength of Plate



$$P_t = (B - n_1 d)t \times F_t$$

Where n_1 → total number of rivets at critical section 1 - 1

t → thickness of thinner main plate

B → width of plate

F_t → permissible tensile stress in rivets

(Axial = 0.6fy = 0.6×250 = 150 MPa)

d → gross diameter of rivet (hole diameter)

gross dia = nominal dia + 1.5 mm, for nominal dia ≤ 25 mm

gross dia = nominal dia + 2 mm, for nominal dia > 25

2. For Gauge Length/ Pitch length

(a) Shear Strength of Rivets

$$P_{s1} = n \times \frac{\pi}{4} \times d^2 \times F_s$$

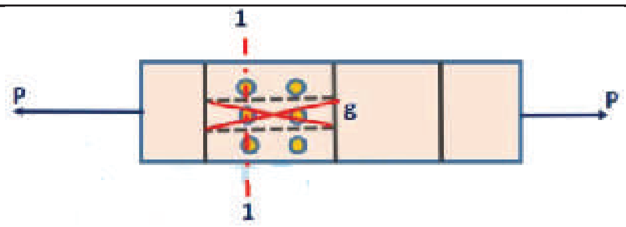
Where n → total number of rivets at joint in crossed gauge length

$F_s \rightarrow$ permissible shear stress in rivets

$F_s = 100MPa$ (WSM)

F_u = ultimate shear stress in rivet

So in LSM = $\frac{F_u}{\sqrt{3} \times 1.25}$



$d \rightarrow$ gross diameter of rivet (hole diameter)

Gross dis = nominal dia + 1.5 mm, for nominal dia $\leq$ 25 mm

Gross dia = nominal dia + 2mm, for nominal dia > 25 mm

(b) Bearing strength of Rivets

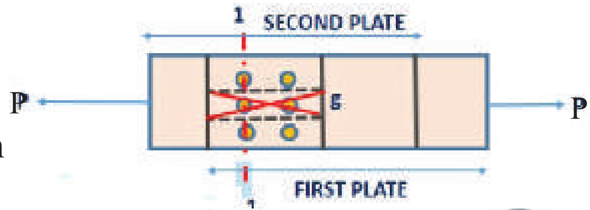
$P_{B1} = n_1 \times (t \times d) \times F_b$

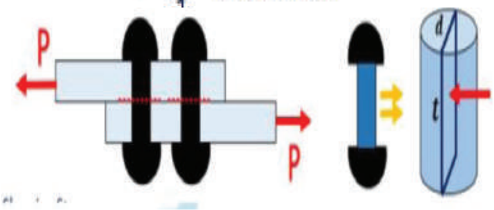
Where $n \rightarrow$ total number of rivets at joint in crossed gauge length

$t \rightarrow$ thickness of thinner main plate

$F_b \rightarrow$ permissible shear stress in rivets (300MPa in WSM)

$d \rightarrow$ gross diamter of rivet (hole diameter)





(c) Tearing Strength of Plate

$P_{t1} = (g - d)t \times F_t$

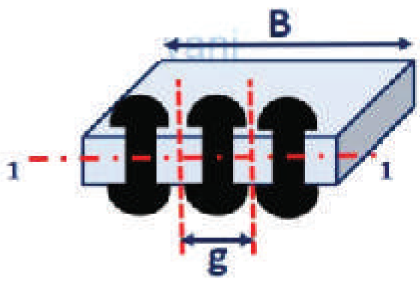
Where $g \rightarrow$ gauge length

$t \rightarrow$ thickness of thinner main plate

$F_t \rightarrow$ permissible tensile stress in rivets (Axial = 0.6fy = 0.6×250 = 150 MPa)

When pitch distance is given then

$P_t = (P - d)t \times F_t$



- **Double Cover Butt Joint :**

1. For entire width of plate

- **Shear Strength of Rivets**

$P_{s1} = 2 \times n_1 \times \frac{\pi}{4} \times d^2 \times Fs$

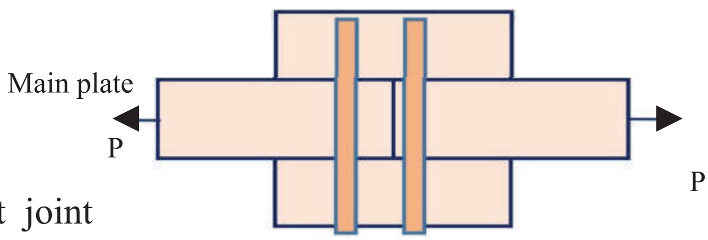
Where $n \rightarrow$ total number of rivets at joint

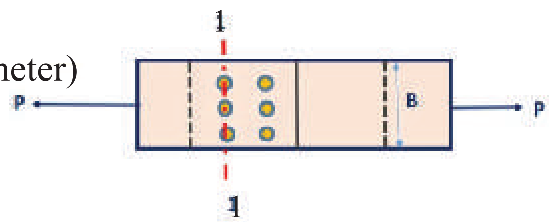
$F_s \rightarrow$ permissible shear stress in rivets

$F_s \rightarrow 100MPa$ (WSM)

$d \rightarrow$ gross diameter of rivet (hole diameter)

$2 \rightarrow$ Double shear





- **Bearing strength of Rivets**

$P_B = n \times (t \times d) \times F_b$

Where $n \rightarrow$ total number of rivets at joint

$t \rightarrow$ min of (thickness of thinner main plate, sum of cover plate thickness)

$F_b \rightarrow$ permissible bearing stress in rivets d → gross diameter of rivet (hole diameter)

- **Tearing Strength of Plate**

  $P_t = (B - n_1 d)t \times F_t$

  Where n_1 → total number of rivets at critical section 1 - 1

  t → min of (thickness of thinner main plate, sum of cover plate thickness)

  B → width of plate

  F_t → permissible tensile stress in rivets

  d → gross diameter of rivet (hole diameter)

2. For gauge length

- **Shear Strength of Rivets**

  $P_{s1} = 2 \times n \times \frac{\pi}{4} \times d^2 \times Fs$

  Where n → total number of rivets at joint in crossed gauge length (here 2)

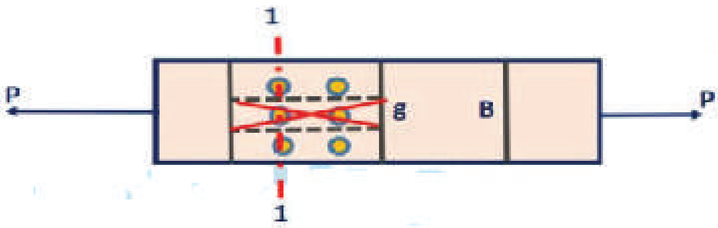
  F_s → permissible shear stress in rivets

  F_s → 100MPa (WSM)

  F_u = ultimate shear stress in rivet

  So in LSM = $\frac{F_u}{\sqrt{3} \times 1.25}$

  d → gross diameter of rivet (hole diameter)



- **Bearing strength of Rivets**

  $P_{B1} = n_1 \times (t \times d) \times F_b$

  Where n → total number of rivets at joint in crossed gauge length

  t → min (thickness of thinner main plate, sum of cover plate thickness)

  F_b → permissible bearing stress in rivets (300MPa in WSM)

  d → gross diameter of rivet (hole diameter)

- **Tearing Strength of Plate**

  $P_{t1} = (g - n_1 d)t \times F_t$

  Where g → gauge length

  t → thickness of thinner main plate

  F_t → permissible tensile stress in rivets (Axial = 0.6fy = 0.6 × 250 = 150MPa)

  n → total number of rivets at in critical section 1 - 1 in crossed gauge length (here 1)

- Number of Rivets required at a joint = $\frac{\text{Total force at a joint}}{\text{Rivet value}}$

$$n = \frac{F}{R_v}$$

- Effeciency of joint

$$\eta = \frac{\text{least value of } P_s, P_b, P_t}{\text{Strength of solid plate}} \times 100$$

P_s = Shearing strength of joint
P_b = Bearing strength of joint
P_t = Tearing strength of joint

- Effeciency for entire plate
  - We have to ensure that P_t is less because rivet failure is more dangerous
  - **For entire plate :**

$$\eta = \frac{\text{least value of } P_s, P_b, P_t}{\text{Strength of solid main plate}} \times 100$$

$$\eta = \frac{(B - n_1 d) \times t \times F_t}{B \times t \times F_t} \times 100$$

$$\eta = \frac{(B - n_1 d)}{B} \times 100$$

  - **For Gauge Length :**

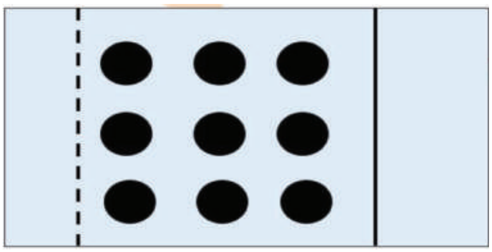
$$\eta = \frac{(g - d) \times t \times F_t}{g \times t \times F_t} \times 100$$

$$\eta = \frac{(g - d)}{g} \times 100$$

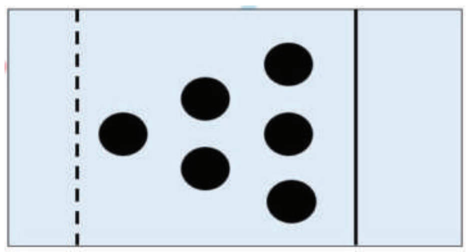
Arrangement of Rivets

Rivets in a riveted joint are arranged in two forms, namely,

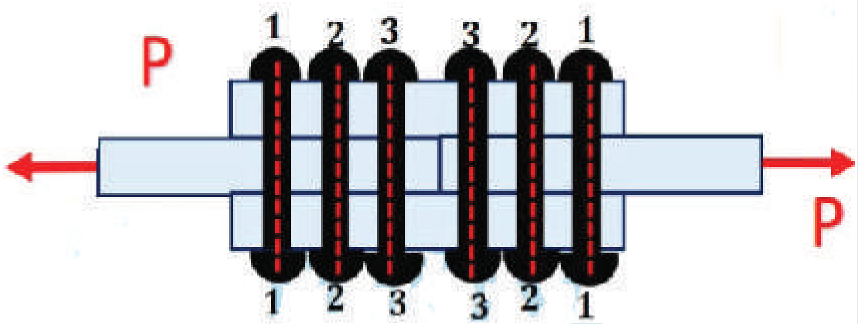
1. Chain riveting,

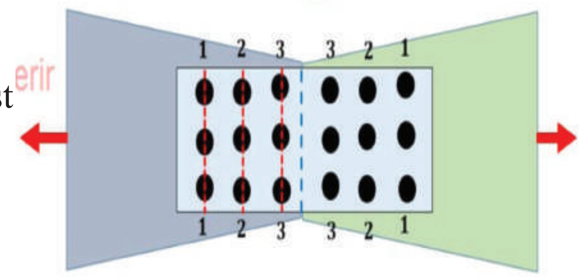


2. Diamond riveting



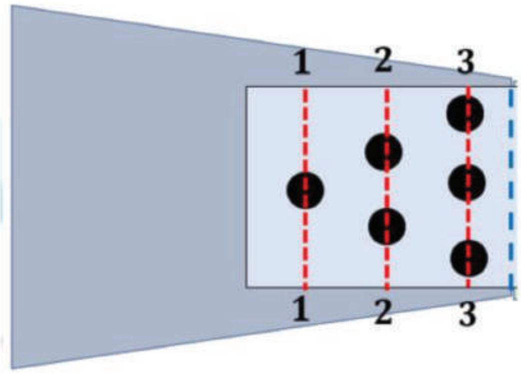
- In chain riveting the rivet are arranged as shown
- 1 - 1, 2 - 2 and 3 - 3 shows sections on either side of the joint.
- Section 1 - 1 is the critical section for Main plate.
- Section 3 - 3 is the critical section for Cover plate
- Critical section for main plate will be outer most section.
- Critical section for cover plate will be inner most



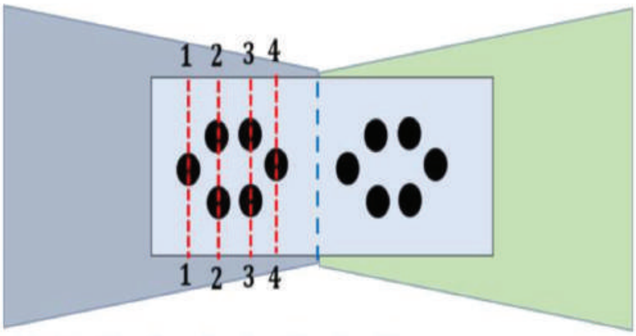


- Strength for main plate
  - $P_{1-1} = (B - 3d) \times t \times F_t$
  - $P_{2-2} = (B - 3d) \times t \times F_t + 3R_v$
  - $P_{3-3} = (B - 3d) \times t \times F_t + 6R_v$

• In Diamond pattern of riveting, section 1-1, section 2-2 and so on has to be checked for main plate in carrying a required load, but for cover plate the last section is checked for carrying a required load.



- Strength for main plate
  - $P_{1-1} = (B - d) \times t \times F_t$
  - $P_{2-2} = (B - 2d) \times t \times F_t + R_v$
  - $P_{3-3} = (B - 3d) \times t \times F_t + 3R_v$
- Strength for cover plate
  - $P_{3-3} = (B - 3d) \times t \times F_t$
  - $P_{2-2} = (B - 2d) \times t \times F_t + 3R_v$



- In triangular Square Pattern of Riveting, section 1-1 and the section 2-2 is chaecked for main plate in carrying a required load.
- And for cover plate, 4-4 (main plate) or first section for cover plate is supposed to be checked for cover plate, also section 3-3 and 2-2 is also checked for safety.
- Strength for main plate
  - $P_{1-1} = (B - d) \times t \times F_t$
  - $P_{2-2} = (B - 2d) \times t \times F_t + R_v$
  - $P_{3-3} = (B - 2d) \times t \times F_t + 3R_v$
  - $P_{4-4} = (B - d) \times t \times F_t + 5R_v$

Specifications As Per IS 800 - 1984

- **Minimum End and Edge Distance**
  - This recommendation is provided to prevent three types of failure in plates :
    i. Splitting failure of plates
    ii. Shearing failure of plates
    iii. bearing failure of plates
  - Edge distance and end distance (minimum)
    - = 1.5 × gross dia of rivet (machine cut element)
  - The above provision is valid for the end distance and edge distance is done by machine cut element.
  - Edge distance and end distance (minimum)
    - = 1.7 × gross dia of rivet (hand driven element)
  - The above provision is valid for the end distance and edge distance is done by hand driven element.
  - But for analysis and design purpose, we adopt edge distance and end distance (minimum)
    - 2.0 × gross dia of rivet

- **Pitch**
  - Minimum pitch of rivet is 2.5 × nominal dia of rivet
  - Maximum pitch of rivet or weld
    - IN COMPRESSION
      - The maximum pitch provision is provided to ensure the prevention of buckling between the connections.
      - Maximum pitch = min(12t or 200mm) where t is thickness for thinner plate
    - IN TENSION
      - The maximum pitch provision is provided to ensure the prevention of seperation of plates between the connections.
      - Maximum pitch = min(16t or 200mm) where t is thickness for thinner plate

Note :

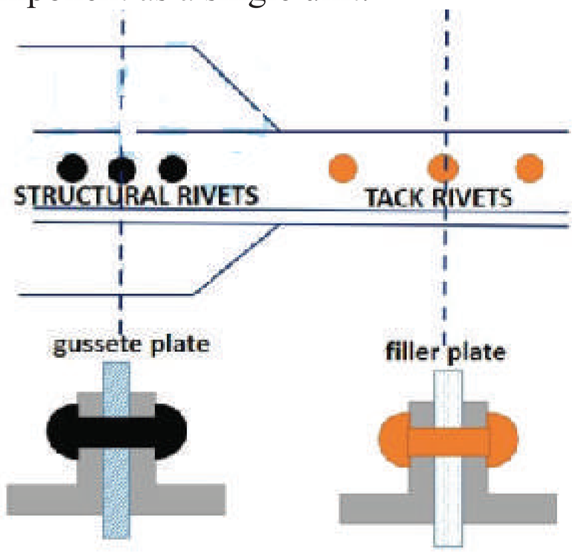
- If the rivets are staggered (not in the same line) and of the gauge distance smaller than 75mm, the above recommended values in compression and tension zone for maximum pitch are increased by 50%, i.e.
- FOR COMPRESSION
  - Maximum pitch = 18t or 300 mm (minimum of the two)
- FOR TENSION
  - Maximum pitch = 24t or 300mm (minimum of the two)

- Gauge length (g) should not be more than 100 + 4t or 200mm.
- Maximum edge distance should not exceed 12 τε

  Where $\varepsilon = \sqrt{\frac{250}{f_y}}$
- When the member are exposed to corrosion, then maximum edge distance should not be greater than 40 + 4t.

Track Rivets

- They are the rivets used to make the structural component as a single unit.
- They don't carry any load because we consider tack rivets not as a structural unit i.e, provided at a location of gussete plate.
- The maximum pitch provided in the case of track rivet when two angle sections are placed back to back to gussete plate as
  - 1000mm in case of tension
  - Less than 600mm in case of compression.
- The above recommendations are valid for both angles and channel section.
- When two plates are attached to gussete plate back to back, then the maximum pitch is taken as



- 32t or 300mm (whichever is minimum)

Unwin's Formula

- It is used when diameter of rivet is not known.

$$\phi = 6.04\sqrt{t}$$

Where t is thickness of thinner plate

Note :

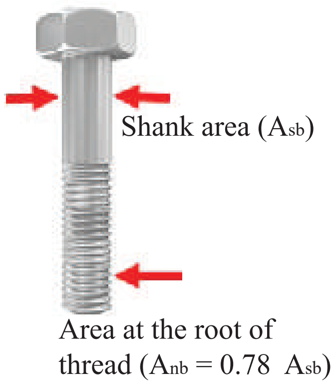
1. For field rivet, the permissible stress is reduced by 10%
2. The permissible stress in rivet under wind load condition as per IS800 can be increased by 25%.
3. The permissible stress in rivet under wind and earthquake load condition as per IS800 can be increased by 25%.
4. When thickness of cover plate is not given, then the thickness of cover plate should not be $\nless \frac{5}{8} t_{main(thinner)}$

Assumptions in Design of Riveted Joint

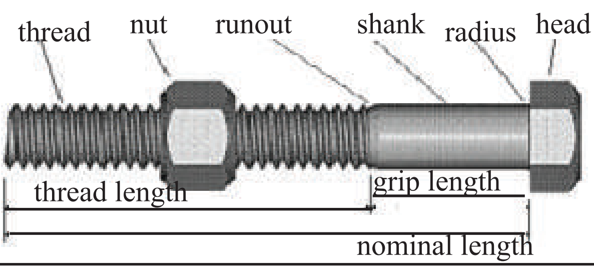
1. The applied axial load is assumed to be shared by all the rivets equally.
2. The tensile stress($0.6f_y$), shear stress ($0.4f_y$) and bearing stress at their respective centres are assumed to be uniform.
3. The effect of bending stress is neglected.
4. Grip length is the sum of thickness of two plates
    1. Grip length $l_g \ngtr 5\phi$ (LSM)
    2. Grip length $l_g \ngtr 8\phi$ (WSM)
5. The friction b/w the plates is neglected.
6. $(g - d)\ t\ F_t \leq nR_v$ (MOST IMPORTANT CONSIDERATION)

Connections

2. Bolted Connections :



- A bolt is a metal pin with a head at one end and a shank threaded at the other end to receive a nut.
- Various type of Bolts are :
    - *Black bolt/ Ordinary bolt/ Unfinished bolts*
        - It is the least expensive bolts, used for light structures subjected to static loads and for secondary members such as purlins, bracings etc.
        - They are not recommended for connections subjected to impact load, vibration and fatigue.
        - The bolts are available from 5mm to 36mm, in diameter and are designed as M5 to M36.



- Bolt of property class 4.6 means :
  i) Ultimate strength of bolt (f_{ub}) = 400 MPa
  ii) Yield strength of bolt (f_{yb}) = 0.6 × 400 = 240 MPa
- *Turned Bolts / Close tolerance bolts*
  - It has small tolerances and are used in no slip connection. They are mainly used machines and under dynamic loading conditions.
- *High Strength Bolt*
  - They are available from 16 mm to 36mm in diameter.
  - The most commonly used bolts are of 8.8s (or) 10.9s property class, where ‘s’ stands for high strength.
  - This bolts may be tightened until they have many high tensile stresses so that the connected parts are tightly clamped together between the bolt head and nut and friction develops between the plate surfaces subjected to clamping force.
  - The high strength bolts with specified initial tensile are known as High Strength friction Grip (HSFG) Bolt.

Types of Bolted joints

1. Lap Joint

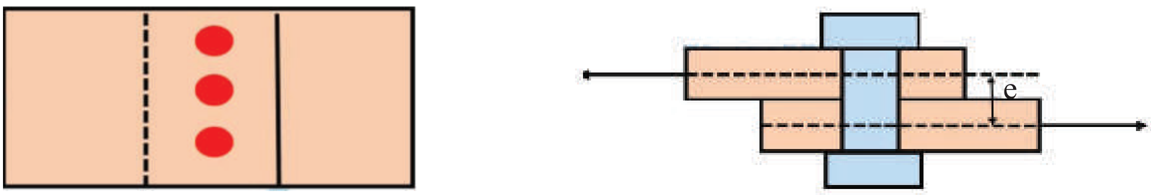
1. Single bolted lap joint
2. Double bolted lap joint

2. Butt Joint

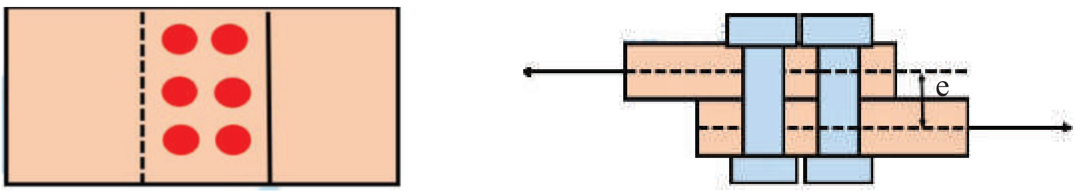
1. Double cover single bolted butt joint
2. Double cover double bolted butt joint
3. Single cover single bolted butt joint

1. Lap Joint

1. Single bolted lap joint

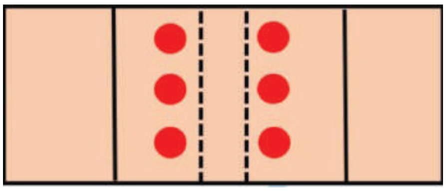
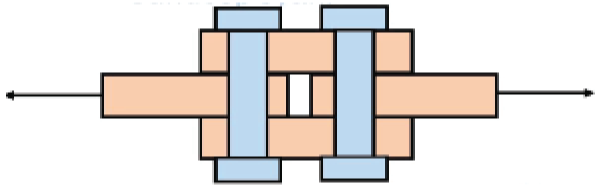


2. Double bolted lap joint

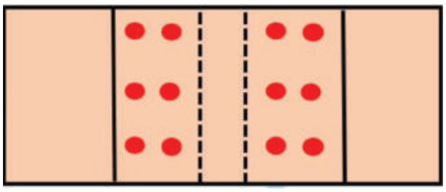
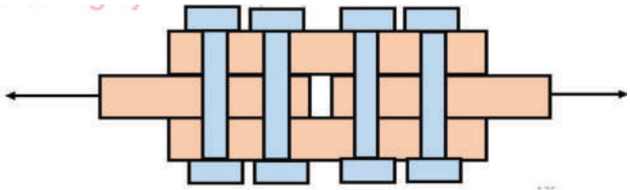


2. Butt Joint

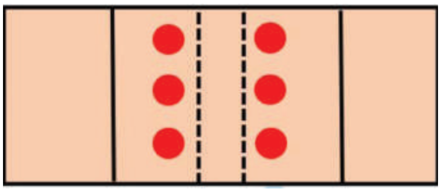
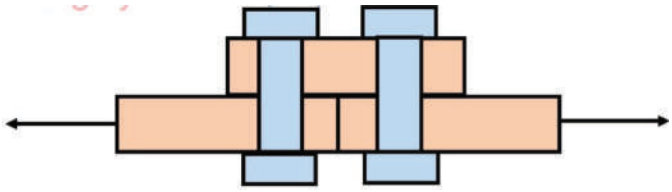
1. Double cover single bolted butt joint

2. Double cover double bolted butt joint

3. Single cover single bolted butt joint

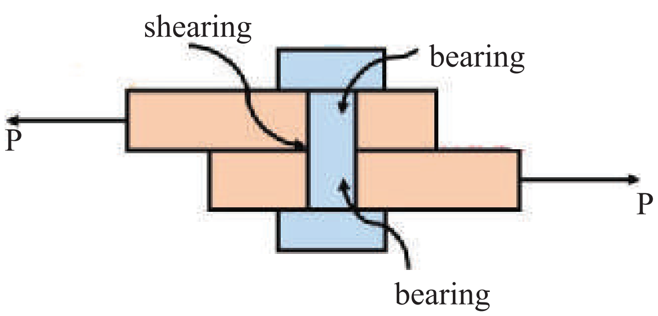
Types of Bolted Joints

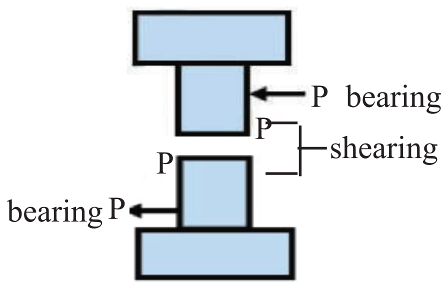
- Double cover butt joint eliminated the eccentricity hence bending is eliminated.
- The load in the lap joint has eccentricity hence a couple is formed which causes undesirable bending in the connection and bolts may fail in tension.
- To minimize the effect of bending in lap joints atleast two bolts in a line must be provided.

Load Transfer Mechanism

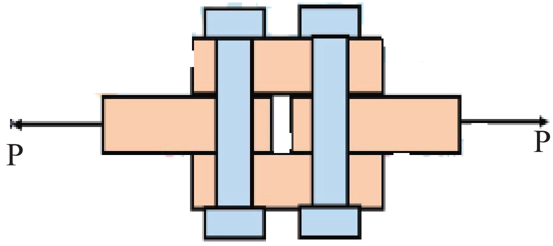
- Load transfer from one connected part to anopther depends on the type of connection.
- In bearing type connection, using ordinary bolts, the load transfer is by shearing and bearing.
- In slip critical/ slip resistant connection, using HSFG bolts, the load transfer is by friction.
- **Transfer of forces in lap joint and butt joint**

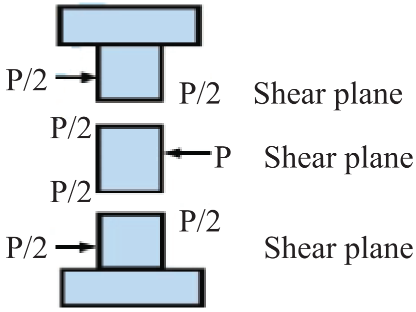
  1. Lap joint, bolts are in single shear





2. Butt joint, bolts are in double shear

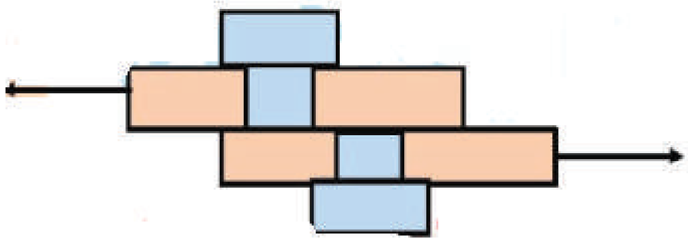




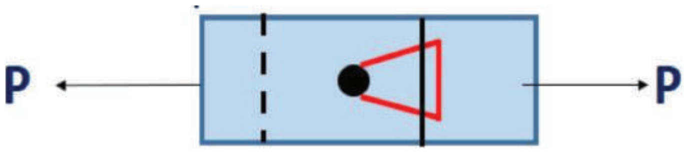
- **Transfer of forces in lap joint and butt joint**
  - Bolts with single shear plane and double shear plane are called 'single shear bolt and double shear bolt' respectively.
  - Shear capacity of a bolt in a double cover butt joint is double that of a bolt in a lap joint because of two shear planes.

Failure of Bolted Connection

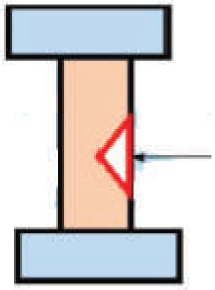
1. Shear failure of bolts



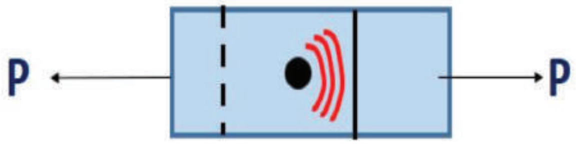
2. Shear Failure of Plate



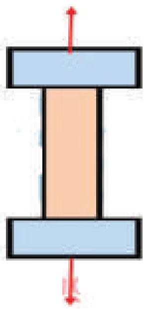
3. Bearing failure of bolts

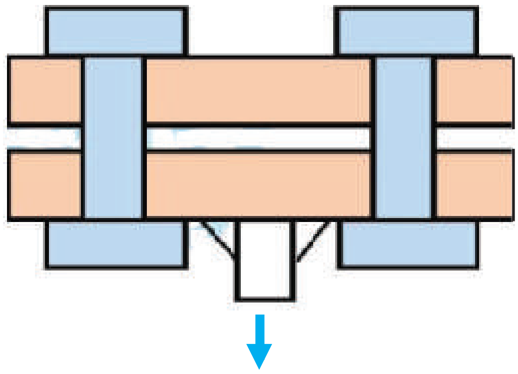


4. Bearing failure of plate

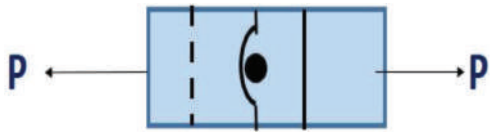


5. Tension failure of bolts



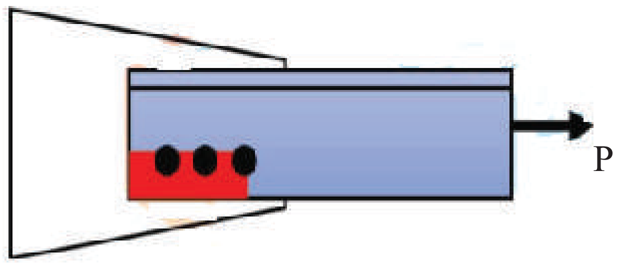


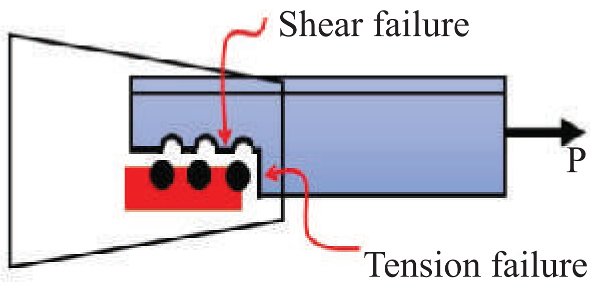
6. Tension failure of plate



7. Block shear failure

- It is a limit state that combines tension failure on one plane and shear failure on another plane.
- Block shear failure may occur when material bearing strength and bolt shear strength is high.





Specifications of Bolted Connections

1. Diameter of bolt holes

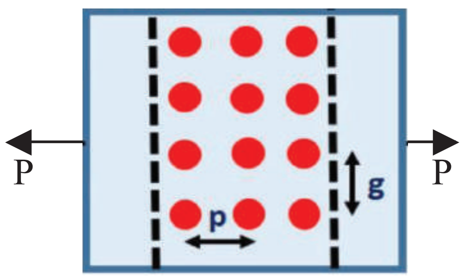
- Under normal situation, dia of bolt hole is made larger than the shank area to facilate erection.

Nominal dia of Bolt	12mm	14mm	16mm	20mm	24mm	30mm	36mm
Dia of hole	13mm	15mm	18mm	22mm	26mm	33mm	39mm

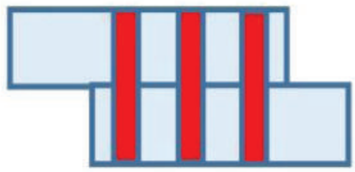
+1mm   +2mm   +3mm

2. Pitch (p) and gauge (g)

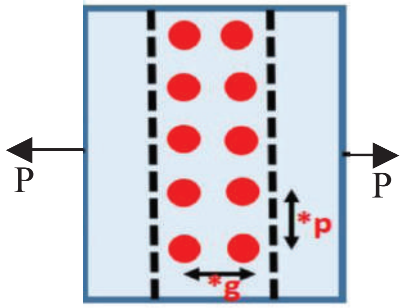
- Minimum pitch and gauge = 2.5d
  - Where d is the nominal dia of bolt.
- Pitch is the distance between two consecutive bolts in the direction of force.
- Gauge is the distance between two consecutive bolts perpendicular to the direction of force.

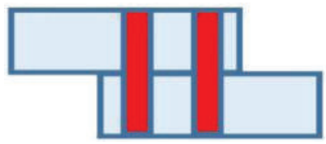


- Bolts are kept apart at a sufficient distance and a minimum pitch is ensured due to :
  - To prevent bearing failure of members between the two bolts.
  - To permit effective installation of bolts.



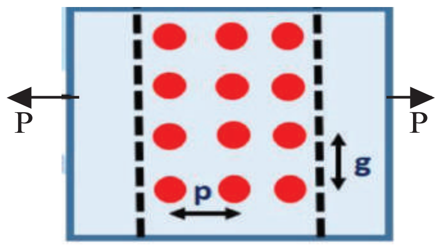
- Minimum pitch :
  - It is desirable to place the bolts sufficiently close together for the following reasons :
  - To reduce the length of connection & gusset plate i.e. to have a compact joint.
  - To have uniform stress in the bolts.
- Note :
  - For wide plates, pitch is defined as centre to centre distance of bolts measured along the length of the connection.

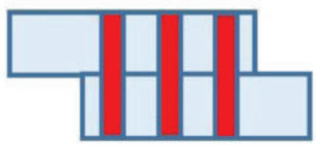




1. For tension member
   - $p \ngtr 16t$ or 200mm
2. For compression member
   - $p \ngtr 12t$ or 200mm
3. For rows near the edge
   - $p \ngtr 4t + 100$mm or 200mm
4. Staggered pitch
   - When the gauge doesnot exceed 75mm, the pitches in 1,2 and 3 may be increased by 50% when bolts are regularly staggered.
5. Maximum gauge
   - $g \ngtr 32t$ or 300mm

- *Maximum pitch :*
  - It is assumed that the load on the joint is shared equally among all the bolts, in short length joints the force in the bolts will be redistributed by plastic action and hence the bolt will share load equally.
  - However in long joints (>15 times dia of both) the shear deformation is not uniform.
  - The bolts at the ends of the joints are heavily stressed resulting in a progressive failure called "unbuttoning." Thus a compact joint is desirable.





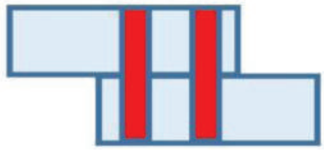
3. Edge and end distance

- Distance from the centre of bolt hole to the adjacent edge of the member at right angles to the direction of stress is called edge distance.

P

e_2 = edge distance

e_1 = end distance



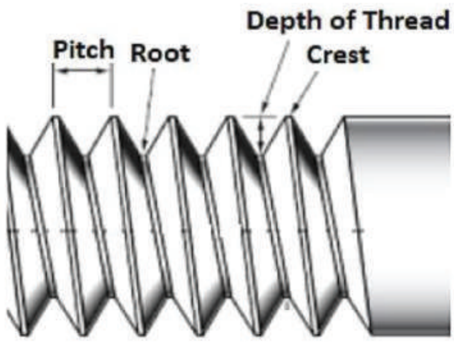
- Distance form the centre of bolt hole to the adjacent edge of the member in the direction of stress is called end distance.
- Bolt holes should no be placed too near the edges due to :
  - The failure of plate in tension may take place.
  - The steel of the plate opposite to the hole may bulge and crack.

- *Minimum end or edge distance = 1.7*d_0
  (for sheared or hand flame cut edge)
- *Minimum end or edge distance = 1.5*d_0
  (for machine cut and plained edges)
  Here d_0 is dia of bolt hole
- *Maximum end or edge distance =* $12t\varepsilon$
  Where t is the thickness of thinner plate
  And ε is equal to $\sqrt{\frac{250}{f_y}}$
- When the members are exposed to corrosive environment, maximum edge distance
  - Maximum edge distance $\ngtr$ 40mm + 4t

Tacking Bolts

- Maximum pitch = 32t or 300mm
  (When plates are not exposed to weather)
- Maximum pitch = 16t or 200mm
  (When plates are exposed to weather)
- For two members placed back to back, the maximum pitch of tacking bolts $\ngtr$ 1000mm

Assumptions in the Analysis of simple Bolted joints



1. Friction between the plates is neglected and load is resisted by bolts, in bearing and shearing.
2. In case of bolts if threads occurs in the plane of shear, the effective area resisting shear is taken as the area at the root of thread. However if threads do not occur in plane of shear, effective area is the coss-section area of the shank.
3. The applied load is equally resisted by all the bolts.
4. Distribution of stress on the portion of plate between the bolt holes is uniform , i.e. stress concentration around the holes is neglected.
5. This assumption is made for ease in calculation, However at the time of collapse this assumption would be actually valid:
   - The bending stress in the bolt is neglected.
   - Bearing stress is assumed to be uniform over the nominal contact area between the plate and the bolts.

Strength of Bolt in Bearing type Connection

Design strength of bolt = min $\begin{cases} \text{Design shear strength of bolt} \\ \text{Design bearing strength of bolt} \end{cases}$

$$V_{db} = \min \begin{cases} V_{dsb} \\ V_{dpb} \end{cases}$$

Nominal shear strength of bolt	V_{nsb}
Nominal bearing strength of bolt	V_{npb}
Partial safety factor for material	$V_{mb} = 1.25$
Factor shear load in one bolt	V_{sb}

$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}}$$

$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}}$$

For safety, $V_{sb} \leq V_{db}$ (also called bolt value)

A. Shear strength of bolt

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} \left(n_n A_{nb} + n_s A_{sb} \right) B_{lj}\, B_{lg}\, B_{pk}$$

Where

A_{nb} is Net tensile area of bolt (or) Area at the root of thread

$A_{nb} = 0.78 A_{sb}$

A_{sb} is nominal shank area of the bolt

n_n is no. of shear planes with threads intercepting the shear plane

n_s is no. of shear planes without threads interceting the shear plane

f_{ub} is ultimate strength of bolt

$\gamma_{mb} = 1.25$

B_{lj} B_{lg} B_{pk} are reduction factors taking into the effect of long joints, large grip length & packing plates.

1. For single Shear case :

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} \left(1 \times A_{nb} \right)$$

Unless specified V_{dsb} would be calculated corresponding to shear plane intercepting the thread.

2. For double Shear case :

$$V_{dsb} = \frac{f_{ub}}{\sqrt{3}\,\gamma_{mb}} \left(1 \times A_{nb} + 1 \times A_{nb} \right)$$

Under the assumption that one of the shear plane is intercepting the roof of thread and other is intercepting the shank.

B. Bearing strength of bolt

$$V_{dpb} = \frac{V_{npb}}{\gamma_{mb}}$$

$$V_{dpb} = \frac{2.5 \times k_b \times d \times t \times f_u}{1.25}$$

Where d is the nominal dia of bolt

t is summation of thickness of plate elements expressing bearing in same direction.

2.5 is constant whose value corresponds to hole elongation about 6 mm.

k_b is minimum of $\frac{e}{3d_0}$, $\frac{p}{3d_0} - 0.25$, $\frac{f_{ub}}{f_u}$ and 1

Where e is the end distance
p is pitch
d_0 is dia of bolt hole
f_{ub} is ultimate strength of bolt
f_u is ultimate strength of plate

Nominal bearing strength of bolt	V_{npb}
factor shear load in one bolt	V_{sb}

- Bearing failure in the bolts is possible only if the bolts used are of very low grade and plate joint are high grade which is not possible.
- Therefore the bearing strength of bolted connection is afunction of strength of connected plate and the arrangement of bolts rather than grade of bolts.
- The bearing strength is also a function of bolt hole. The bearing strength calculated above is for standard bolt holes, for oversized and short slotted holes it is 0.7 times the bearing strength and for slotted holes it is 0.5 times the bearing strength.

C. Tensile strength of bolt

$$T_{db} = \frac{T_{nb}}{\gamma_{nb}} = \frac{0.9\, f_{ub} A_{nb}}{1.25}$$

Where $A_{nb} \rightarrow$ net tensile area of bolt = $0.78\, A_{sb}$

$$T_{db} < \frac{f_{yb}\, A_{sb}}{\gamma_{mo}}$$

$\gamma_{mo} = 1.1$

Design Strength of Plate

The plate may fail by :

1. Shearing of plate

- It can be avoided by keeping sufficient edge distance.

2. Yielding of plate

- For gross section yielding
- $T_{dg} = \dfrac{f_y A_g}{\gamma_{mo}}$

Where $\gamma_{mo} = 1.1$
T_{dg} = design tensile strength in gross section yielding
A_g = gross area of solid plate

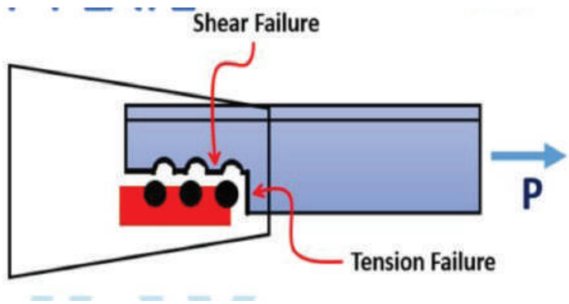
3. Rupture of plate

- For net section rupture

$$T_{dn} = \frac{0.9\, f_u A_n}{\gamma_{m1}}$$

T_{dn} = design tensile strength in rupture
A_n = effective net area of section
Factor 0.9 is introduced as there is no reserve strength beyond ultimate strength

4. Block ahear failure



- When a block of material within the bolted area breaks away from the remainder portion of the section, the failure is termed as BLOCK SHEAR FAILURE.
- This occurs along a path involving tension in one plane and shear on a perpendicular plane.
- For the block shear failure to occur, one of the surface (stronger one) fractures while the other yields.
- Yielding occurs on gross area while fracture on net area.

$$T_{db} = \min \begin{cases} \text{Shear yielding and tension rupture} \\ \text{Shear rupture and tension yielding} \end{cases}$$

$$\text{Shear yielding and tension rupture} = \frac{f_y A_{vg}}{\sqrt{3}\gamma_{mo}} + \frac{0.9\, f_u A_{tn}}{\gamma_{m1}}$$

$$\text{Shear rupture and tension yielding} = \frac{0.9\, f_u A_{vn}}{\sqrt{3}\gamma_{m1}} + \frac{f_y A_{tg}}{\gamma_{mo}}$$

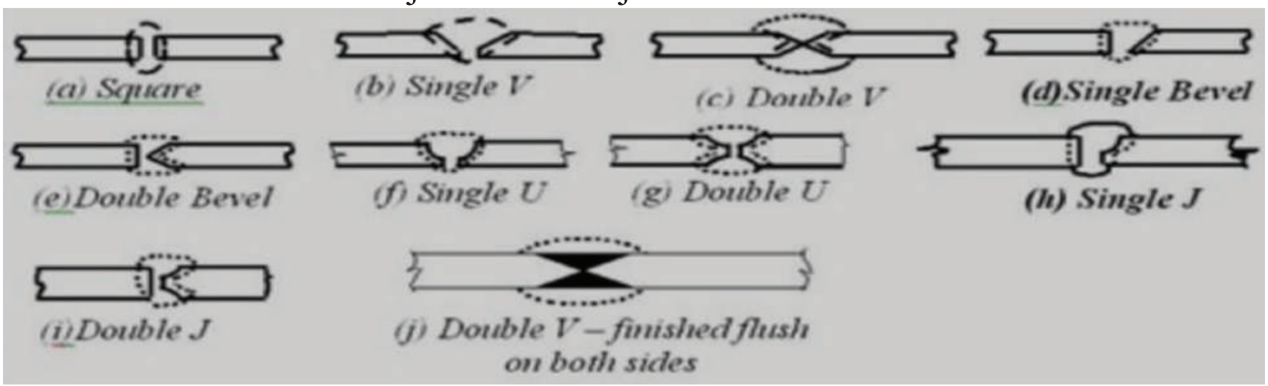
- Block shear failure occurs in joints made with high strength bolts, where few bolts are required for making the connection.
- When sufficient end distance is not provided, plates may shear out.

Connections

3. Welded Connections :

1. Butt weld

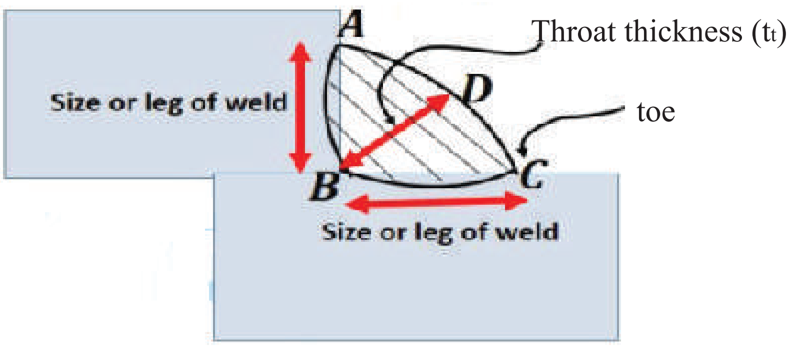
- This type of weld is used when the members are in same plane.
- Butt weld is also termed as groove weld.
- The butt weld is used to join structural members carrying direct compression or tension.
- It is used to make tee-joint and butt-joint.

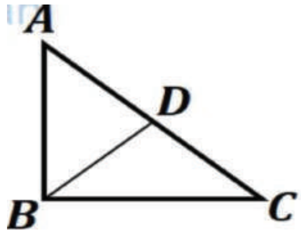


2. Fillet weld

- This type of weld is used when the members to be connected overlap each other.
- A fillet weld is a weld of approximately triangular cross section joining two surfaces approximately as right angles to each other in lap joint or tee joint.
- The part of weld which is assumed to be effective in transferring the stress is called throat.

- It is assumed that fillet weld always offers resistance in the form of the shear.
- The design of only is done for shear in fillet weld.





AB or BC = size of weld
BD = throat thickness (t_t)

Throat thickness (t_t) = minimum dimension in fillet weld

- The effective length of fillet weld should not be less than 4 × thickness of weld (S) i.e.
  - l_{eff} = 4 × thickness of weld (S)
- The size of normal fillets shall be taken as the minimum weld leg size.
- Fillet weld should not be used if the angle between fusion faces is less than 60º and greater than 120º or we can say
- In weld, angle should be between 60º to 120º
- Throat thickness (t_t) = K × S(size of weld)
- (t_t) = K × S

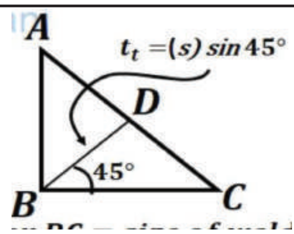
Table 22 Values of K for Different Angles Between Fusion Faces (Clause 10.5.3.2)

Angle between fusion faces	60º-90º	91º-100º	101º-106º	107º-113º	114º-120º
Constant K	0.70	0.65	0.60	0.55	0.50

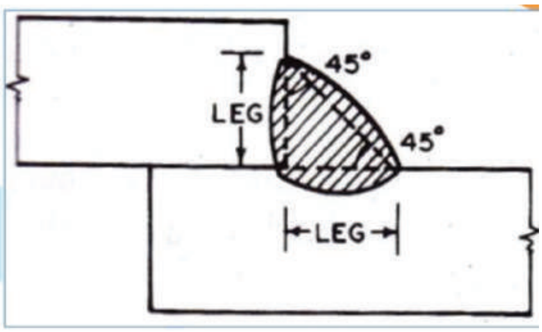
- If only size of weld is given,
- Example :

t_t = (S) sin 45º

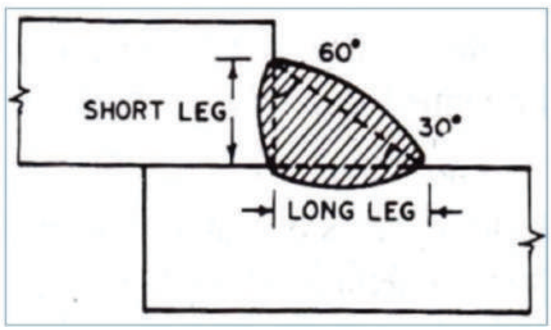
=> t_t = 0.7S



- When the cross section of fillet weld is 45º, isoceles triangle, it is known as a standard fillet weld.
- When the cross section of the fillet weld is 30º and 60º triangle, it is known as special fillet weld.
- The standard 45º fillet weld is generally used.

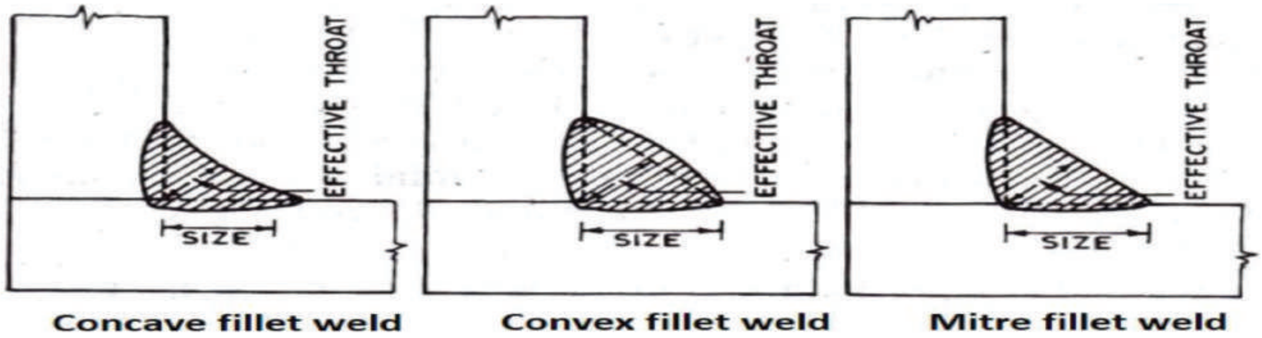


Standard fillet weld



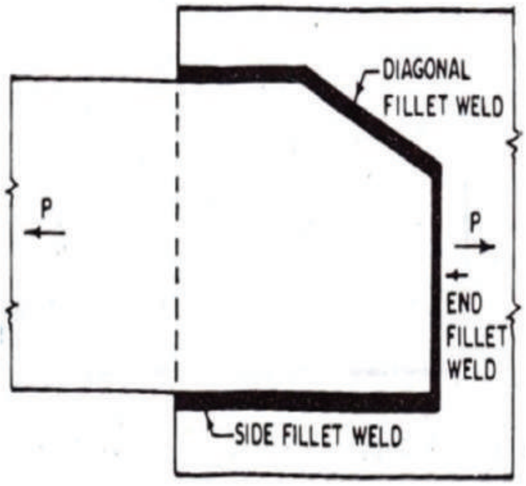
Special fillet weld

- A fillet weld is termed as concave fillet weld or convex fillet weld or mitre fillet weld depending on the weld face in concave or convex or approximately flat.
- A fillet weld is termed as normal fillet weld or deep penetration fillet weld depending upon the depth of penetration beyond the root is less than 2.4mm or more respectively.



1. Side fillet weld

- It is the fillet weld stressed in longitudinal shear, i.e. a fillet weld, the axis of which is parallel to the direction of these applied loads. It is also termed as longitudinal fillet weld.



2. End fillet weld

- It is the fillet weld stressed in transverse shear, i.e. a fillet weld, the axis of which is at right angles to the direction of the applied loas. It is also termed as transverse fillet weld.

3. Diagonal fillet weld

- It is the fillet weld the axis of which is inclined to the direction of the applied load.
- A fillet weld is placed on the sides or end of the base metal and it is subjected to shear along with tension or compression and usually bending.

IS Recommendations

1. Minimum size of weld

- It depends upon the thickness of thicker plate.
- If thickness is not given, then we assume s = 3mm

Thickness of thicker plate (mm)	Minimum size of weld(mm)
0 - 10	3
11 - 20	5
21 - 32	6
> 32	8 (if > 50, then 10mm)

2. Size of fillet

- Minimum size of the weld :
  - If the thickness of thicker part is up to 10mm, the minimum size of the welding is 3mm.

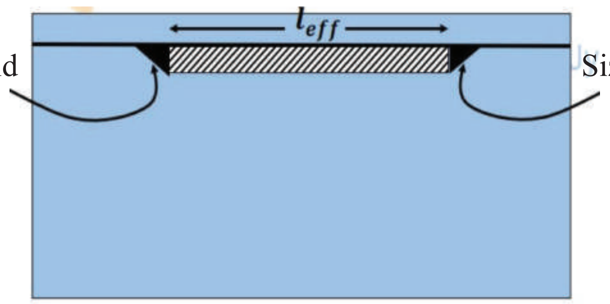
- If the thickness of thicker part is between 11mm to 20mm, the minimum size of the welding is 5mm.
- If the thickness of thicker part is in between 21mm to 32mm, the minimum size of the welding is 6mm.
- If the thickness of the thicker part is above 32mm, the minimum size of the welding is 10mm.
- When the minimum size of the fillet weld is greater than the thickness of the thinner part, the minimum size of the weld should be equal to the thickness of the thinner part.
- Where the thickness part is more than 50mm, special precaution like preheating will have to be taken.

3. Maximum size of weld

- It depends upon the thickness of thinner plate.
- CASE 1 : In square edge -
  Max size of weld = thickness of thinner plate - 1.5mm
- CASE 2 : A rounded edge -
  Max size of weld = 3/4 t(75% of the thickness of thinner plate)

4. Effective length of weld

- It depends upon the size of weld.
- Effective length of weld = Actual length of weld - 2 × size of weld
- Effective length of weld should not be less than 4 times the size of weld.



5. Effective cross section area of weld (Throat area)

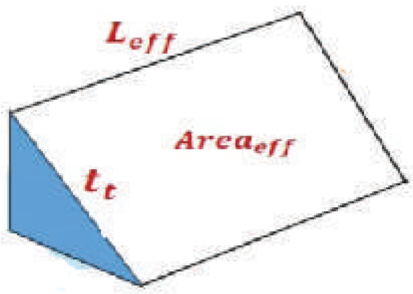
- Effective cross section area of weld = effective length of weld × throat thickness
  $Area_{eff} = L_{eff} \times t_t$

6. Load Carrying Capacity of weld/ Shear strength of weld

- P = Perimissible shear stress × effective area of weld
- $P = F_s \times L_{eff} \times t_t$
  - $F_s \rightarrow$ permissible shear stress
  - F_s = 100MPa(WSM)

  F_u = ultimate tensile stress in weld metal

  So in LSM = $\frac{F_u}{\sqrt{3} \times 1.25}$ (1.25 for shop weld and 1.5 for field weld)

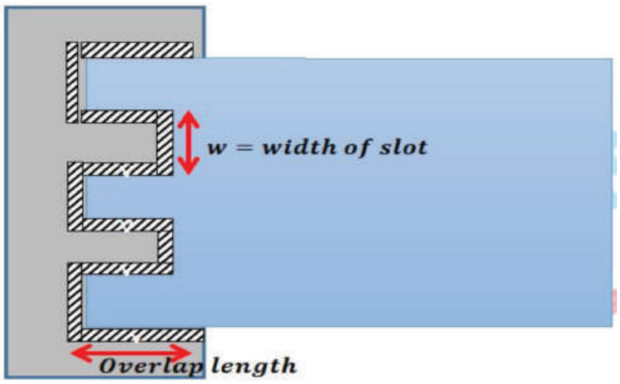


7. Pitch of weld

- For weld in compression zone, max pitch p = 12t or 200mm
  In tension zone, max pitch p = 16t or 200mm

Slot Welding

- If overlap length is limited, then the slot welding is done by making slots in the connecting plate as shown



P

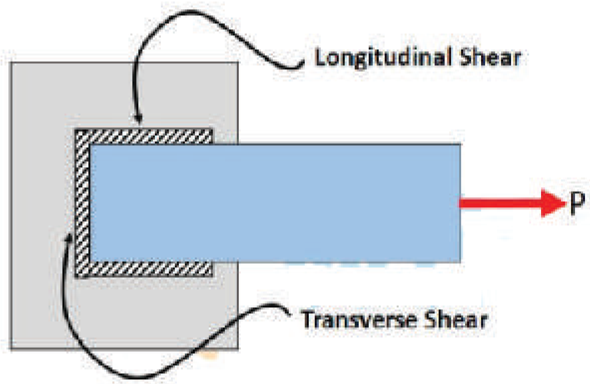
w = width of slot

w should be maximum of (25mm and 3t)

Longitudinal and Transverse Shear

- A longitudinal Shear in fillet weld, load and length of weld are in same direction.
- In Transverse Shear, load and length of weld are perpendicular to each other.

Note : Strength of Transverse Fillet weld is about 30% more than longitudinal Fillet weld.

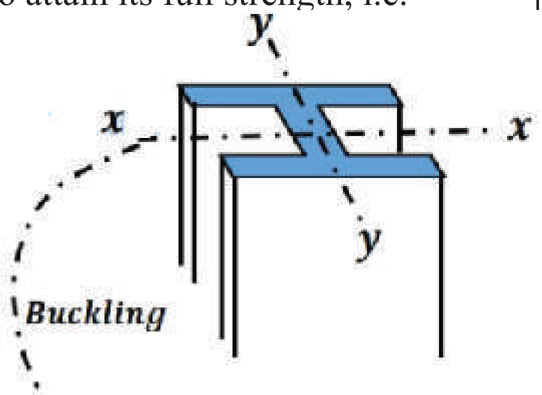


Compression member

- Structural members subjected to axial compression or compression forces.
- Their design is governed by strength and buckling.
- Most commonly used compression member is column.
- Other compression members are strut, truss, frame etc.
- **Column**
  - It is a structural member mainly subjected to compression.
  - Bending moment can also exist in this member.
  - Column is used for compression of frame, i.e RCC frame and steel frame.
- **Strut**
  - It is a compression member whose B.M. is zero because it is used in roof truss as a compression member.
- **Truss**
  - It is a structure in which all the members are either subjected to tension or compression.
  - B.M. is zero everywhere.
- **Frame**
  - It is a structure which is subjected to B.M. also in addition to tension and compression.
- **Stanchion**
  - The vertical compression member in RCC building is called column while for a steel building it is called stanchion.
- **Boom**
  - The principal compression member in a crane is called boom.

Modes of failure of Column

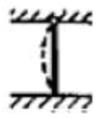
- Squashing
- Local buckling
- Flexural buckling
- Tensional buckling
- Flexural torsion buckling
- **Squashing**
  - When the length is relatively small and the component plate elements are prevented from local buckling, then the column will be able to attain its full strength, i.e. squash load.
  - Squash load = Yield stress × Area of cross section
- **Local Buckling**
  - Failure occurs by buckling of one or more individual plate elements.
  - Exp: flange or web locally prior to overall buckling of column.



- **Flexural Buckling**
  - In this mode, failure of the member occurs by excessive deflection in the plane of weaker principal axis.
  - In the figure, x-x and y-y axis are shown. Ixx > Iyy, so the resistance about y-y axis is less as compared to x-x axis. hence buckling will occur about y-y axis.
- **Torsional Buckling**
  - This type of failure is caused by twisting about longitudinal axis of member. It can occur only in doubly symmetrical cross section with very slender cross sectional elements.
- **Flexural Torsional Buckling**
  - It is caused by combination of flexural and torsional buckling. The member bends and twists simultaneously. This type of failure can occur only in unsymmetrical cross sections and singly symmetrical cross section.

Effective Length

- In SOM, we use Theoretical value, and in Design we use IS recommended values.
- For laced Columns, above values are increased by 5%.
- For battened column above values are increased by 10%
- Effective length in IS code is slightly larger than the theoretical value to account for the lack of 100% fixity at support.

Sl. no	Degree of end Restraint of compression members	Figure	Theo. value of Eff. length	Reco. value of Eff. length
1.	Effectively held in position & restrained against rotation in both ends		0.50 l	0.65 l
2.	Effectively held in position at both ends, restrained against rotation at one end		0.70 l	0.80 l
3.	Effectively held in position at both ends, but not restrained against rotation		1.00 l	1.00 l
4.	Effectively held in position and restrained against rotation at one end, and at the other restrained against rotation but not held in position		1.00 l	1.20 l
5.	Effectively held in position and restrained against rotation in one end, and at the other partially restrained against rotation but not held in position.		-	1.50 l
6.	Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position.		2.00 l	2.00 l
7.	Effectively held in position and restrained against rotation at one end but not held in position nor restrained against rotation at the other end.		2.00 l	2.00 l

Note :

- Load capacity of column depends upon the end condition and strongest column in both end fixed.
- The most efficient cross section in resisting compression is " Thin hollow circular section" or "4 angle box section" because for a given cross section area MOI is maximum so load carrying capacity is maximum.
- The most effecient cross section in resisting bending moment is I-sectionbecause for a given cross section area, section modulus and plastic modulus are maximum for l section.

- As per IS 800, the permissible axial compressive stress is given by Rankine's merchant formula
- σ_{ac} = minimum of $\begin{cases} 0.6\, f_y \\ \text{or} \\ \dfrac{0.6\, f_y}{[(F_{cc})^n + (f_y)^n\,]^{1/n}} \end{cases}$
- Where $F_{cc} = \dfrac{\pi^2 E}{\lambda^2}$
- n = imperfection factor = 1.4

- **Unsupported length of column**
  - It is maximum clear distance between bottom of the floor level and top of beam.
- **Effective length of column**
  - It is length of column between points of zero moment or distance between points of contraflexure.

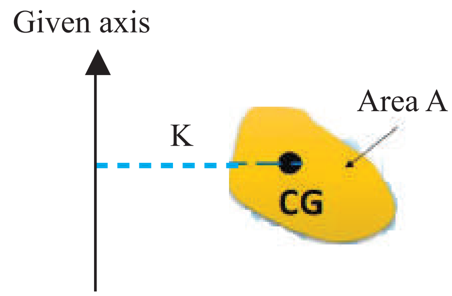
Slenderness ratio

Radius of gyration

- It is the distance such that its square multiplied by area gives Moment of inertia about the given axis.

$$\gamma^2_{min} \times A = I$$

$$\gamma^2_{min} = \sqrt{\frac{I}{A}}$$



$$\text{Slenderness ratio } \lambda = \frac{\text{Effective length}}{\text{Radius of gyration}}$$

$$\lambda = \frac{L_{effective}}{\gamma_{min}}$$

Table 3 Maximum Values of Effective Slenderness ratios

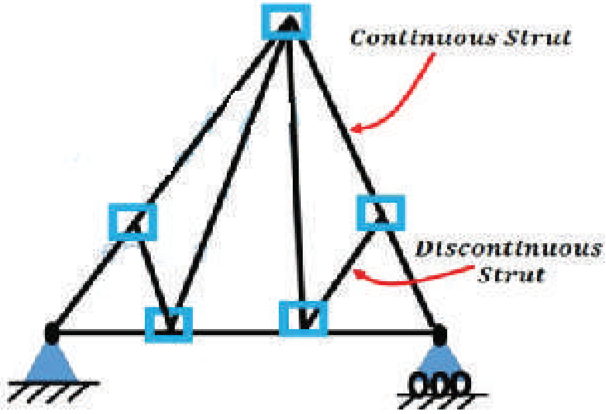
S.No (1)	Member (2)	Maximum effective Slenderness ratio (KL/r) (3)
i)	A member carrying compressive loads resulting from dead loads and imposed loads	180
ii)	A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
iii)	A member subjected to compression forces resulting only from combination with wind/ earthquake actios, provided the deformation of such member does not adversely affect the stress in any part of the structure.	250
iv)	Compression flange of beam against lateral torsional buckling	300

v) A member normally acting as a tie in a roof truss or a bracing system not considered effective when subject to possible reversal of stress into compression resulting from the action of wind or earthquake forces. 350

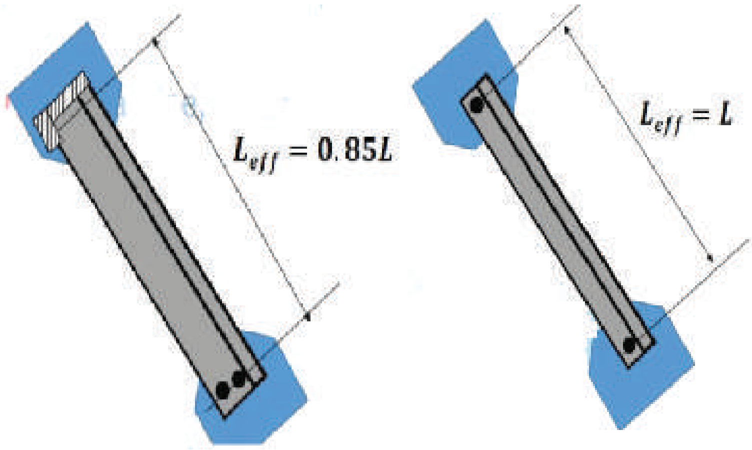
vi) Members always under tension (other than pre-tensioned members) 400

"Tension members, such as bracing's pre-tensioned to avoid sag, need not satisfy the maximum slenderness ratio limits."

Effective length of Strut

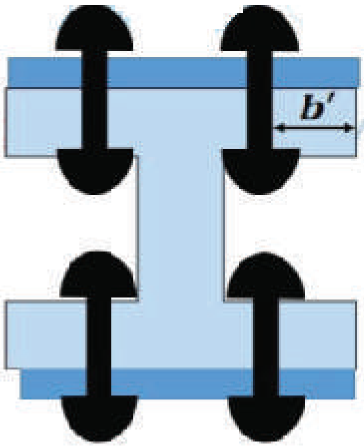


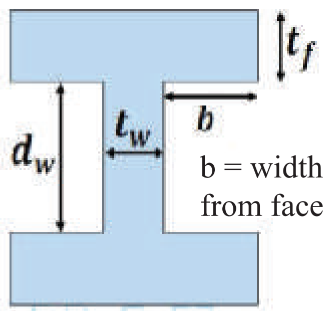
- If a strut span between two joint only, it is called as Discontinuous Strut.
- If a strut span over more than two joints then it is called as continuous Strut.
- If a single angle discontinuous strut is connected by only one rivet at each end, then effective length ($L_{eff} = L$) and axial compressive stress $\sigma'_{ac} = 0.8$. σ_{ac} i.e Permissible stress is reduced by 20%.
- If a single angle discontinuous strut is connected by two or more rivets or weld, then effective length $L_{eff} = 0.8L$ and $\sigma'_{ac} = \sigma_{ac}$



Local Buckling of Flange and Web plate of I section

- Width of outstand is measured from outer line of rivet to extreme edge for built up section.





b = width of flange from face to web

- To prevent local buckling due to compression as per IS 800 : Specify the following condition.

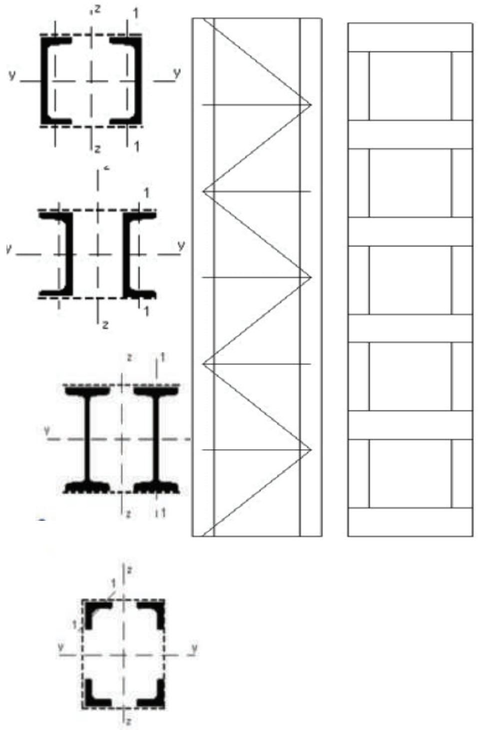
$$\frac{b}{t_f} \not> 16 \text{ (WSM)} \qquad \frac{b}{t_f} \not> 8.4 \text{ (LSM) for plastic section}$$

$$\frac{d_w}{t_w} \not> 50 \text{ (WSM)}$$

- If the flange and web plate dimensions exceed the above limits, the excess width should be neglected (Not considering in area calculation).
- Load carrying capacity in compression member
  - $P = \sigma_{ac} \times Ag \quad (\sigma_{ac} = 0.6\, f_y)$

Built Up Column

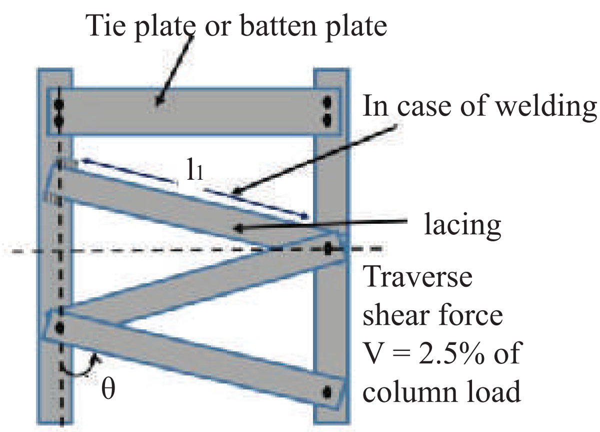
- The size and shapes of rolled section are limited because of limitations of rolling mills, so when rolled sections do not furnish the required sectional area or when a special shape or large radius of gyration is required in two differet directions, built up columns are used.
- Built-up columns are widly used in steel construction especially when the effective lengths are great and the compression forces light.
- They are composed of two or more parallel main components interconnected by lacing or batten plates.
- The greater the distance between the chord axes, the greater is the moment of inertia of the built up cross section; the increase in stiffness, however, is counterbalanced by the increased weight and cost of the connection of members.



- It should be noted that built-up columns(espicially battened built-up columns) are more flexible than solid columns with the same moment of inertia.

Lacings

- Lacing is the system of connecting elements in built up column.
- Lacing make the component of column act as a single unit.
- If the components of column are each very close to each other, then tack rivets are used to make then act as a single unit.
- If the spacing of component is more then the rivets are useless and so we use lacing or batten.



Inclined member - Lacing
Horizontal member - Batten

- Lacing member are idealised as truss element, i.e., they are subjected either to tension or compression.
- B.M. in lacing member is zero, to ensure that bending moment is zero, provide only one rivet at each end as far as possible.
- Maximum slenderness ratio λ for lacing member is limited to 145.
- The angle of lacing w.r.t. vertical is 40º to 70º (welding 60º to 90º).
- If θ decreases, length of lacing will increase.
- Effective length
  - For single lacing $L_{eff} = L_1$
  - For double lacing $L_{eff} = 0.7\ L_1$
  - For welded lacing $L_{eff} = 0.7\ L_1$
- Minimum thickness of lacing member

$t_{min} = \frac{l_1}{40}$ (for single lacing)

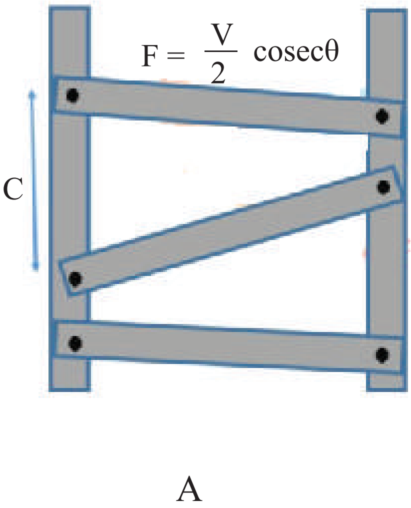
$t_{min} = \frac{l_1}{60}$ (for double lacing)

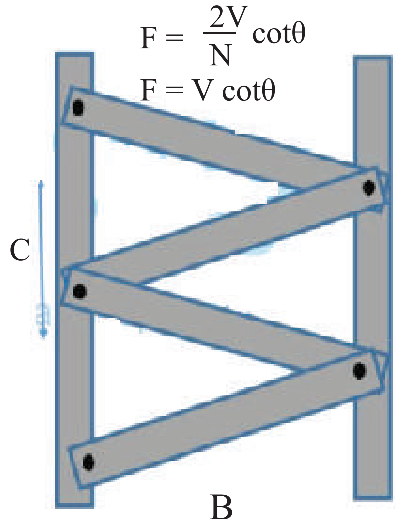
- Minimum width of lacing member
  - It depends upon the nominal dia of rivet.
  - In case of welding, width of lacing bar is 50mm.

Nominal dia of rivet	Minimum width of lacing member
16 mm	50 mm
18 mm	55 mm
20 mm	60 mm
22 mm	65 mm

- To prevent buckling of column component b/w lacing connection -
  - $\lambda_{(component)} \ngtr 50$
  - $\lambda_{(component)} \ngtr 0.7\ \lambda_{column}$
    - For tack rivets
      - $\lambda_{(component)} \ngtr 40$
      - $\lambda_{(component)} \ngtr 0.6\ \lambda_{column}$
- At the end of lacing system, at top and bottom, tie plates are provided (tie plate is called batten plate)
  - These batten plate prevent distortion of built up columns.

Arrangement in A is better than B, because if one rivet fails, spacing of lacing member does not change in A while in B, spacing will be doubled. Hence there will be possibility of buckling of connection in B.





Forces in Lacing Member

- Lacing system is designed to resist a transverse shear force of V = 2.5% of column load.
- The transverse shear force V is shared by lacing system both side equally, so the transverse shear force on each lacing bar is V/2
  - 2 denotes number of parallel paltes
  - For single lacing system of two parallel force system, the force in each lacing bar

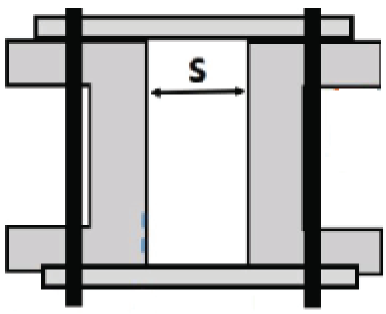
$$F = \frac{V}{2\sin\theta}$$

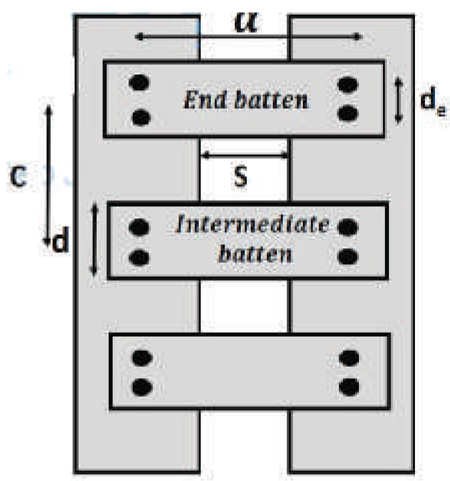
  - For double lacing system

$$F = \frac{V}{4\sin\theta}$$

Battens

- It behave like very small beam member and subjected to bending moment.
- The effective length of battened column should be increased by 10%.
- Minimum number of battens provided = 4.
- Provide batten on opposite faces such that one should be the mirror image of other.

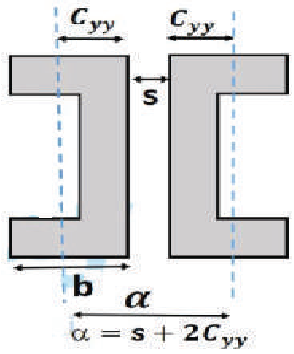


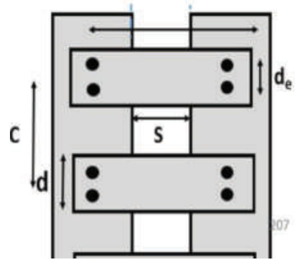


- Effective slenderness ratio
  - $\lambda = 1.10\lambda_0$ (increase by 10% in battens)
  - λ_0 is maximum actual slenderness ratio
- Effective depth
  - Effective depth should not be less than the distance between centroid component members.

    $d_e \nless \alpha$
  - Effective depth should not be less than twice the width of one component in plane of batten(b).

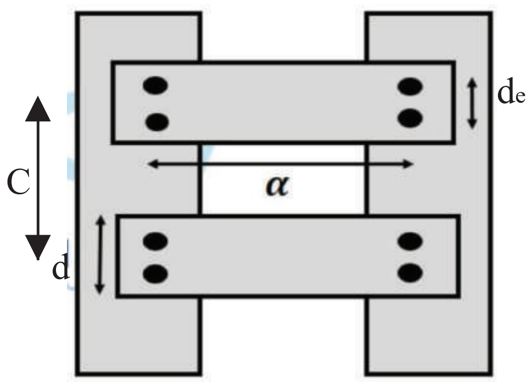
    $d_e \nless 2b$





- Thickness of batten (t)

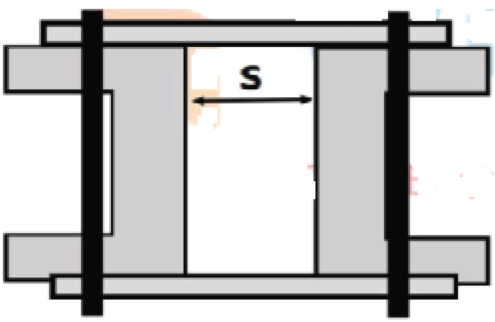
  $t \geq \frac{\alpha}{50}$
- To prevent local buckling of individual component between the battens, following conditions are satisfied
  - $\frac{c}{\gamma_{yy}} < 50$
  - $\frac{c}{\gamma_{yy}} < 0.7\gamma_{column}$
- For intermediate batten,
  - $d_e \geq \frac{3}{4}\alpha$
  - $d_e \geq 2b$
- For end batten,
  - $d_e > \alpha$
  - $d_e > 2b$



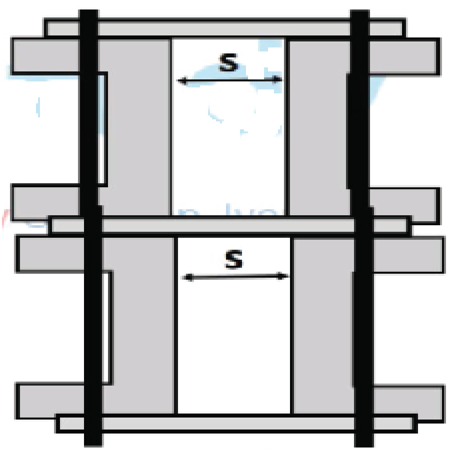
Force in battens

- Transverse shear force V is shared by parallel planes (N) equally i.e. Transverse shear force on each batter = V/N

  Where N = no. of parallel planes

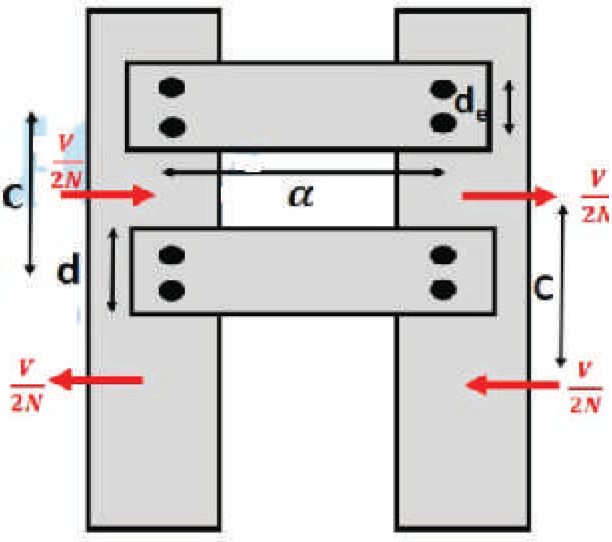


N = 2



N = 3

1. Batten should be designed to carry bending moment and shear force arising from the transverse shear force, V, which is 2.5% of total axial load on compression member.
2. The transverse shear force is equally divided in all the parallel planes Nin which there are shear resisting elements such as battens or continuous plates battens.
3. Battens should be able to resist the longitudinal shear and moment arising from Transverse shear V

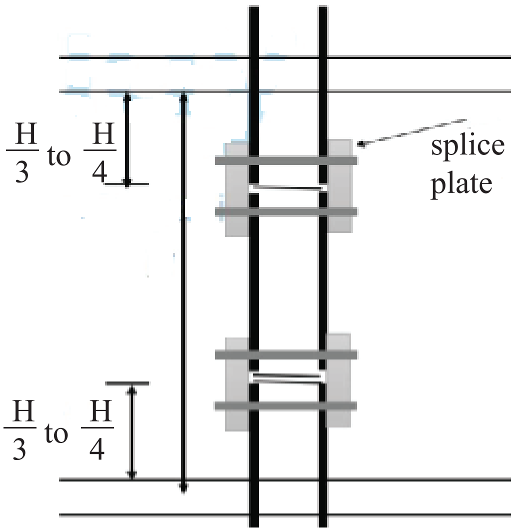


- Longitudinal shear (V_1)
    - $V_1 = \frac{VC}{N\alpha}$
        - Where V is transverse shear force (2.5% of P)
        - N is number of parallel plates of battens
- Longitudinal moment (M)
    - $M = \frac{VC}{2N}$

Column Splicing

- Splicing of column is done to increase the length of column.
- The most suitable location splicing is at a suitable location of H/3 to H/4 from the top and bottom level floor.
- When the column end are machined then it is assumed that 50% of load is transferred by direct bearing action and remaining 50% of the load is transferred through splice and its connection.

$$P \rightarrow \frac{P}{2} \rightarrow \text{Bearing Action}$$
$$P \rightarrow \frac{P}{2} \rightarrow \text{Splice end connection}$$

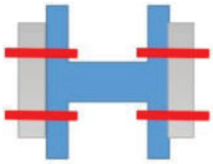


- If a column is subjected to a compression load P, then P/2 is transferred by bearing action and remaining P/2 is taken by splicing plate, P/4 by each splicing plate (since 2 splicing plates are used)
- If a column is subjected to moment M also, the splice plate must also resist additional force of M/H, so maximum force in splice plate is

Max load for each splice plate $= \frac{P}{4} + \frac{M}{H}$

$\frac{P}{4} \rightarrow$ each splice per plate

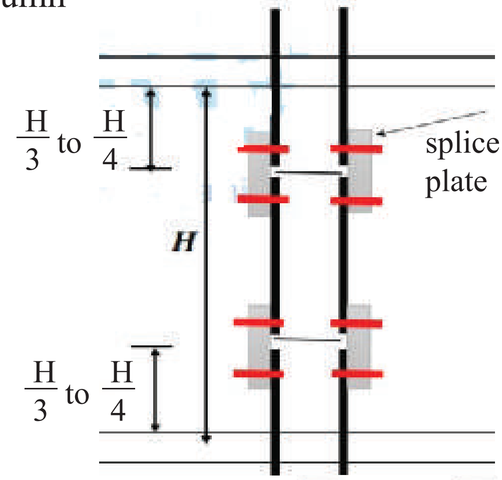
• Note : If the column ends are not smooth, for complete bearing, entire load is assumed to be transferred to the bottom column through splice plate and connection only.



• Hence maximum force in each splice plate when column ends are not smooth

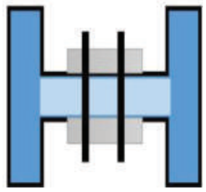
$\frac{P}{2} \rightarrow$ Each splice per plate

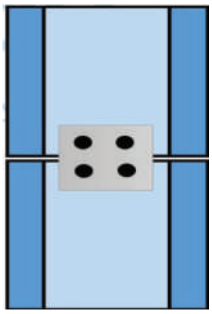
Max load for each splice plate $= \frac{P}{4} + \frac{M}{H}$



• If shear force is also acting at a column splice, a web splice must be done, both side of the web as shown.

• The rivet in web splice are subjected to double shear and bearing but rivet in flange splice are subjected to single shear and bearing





Column Bases

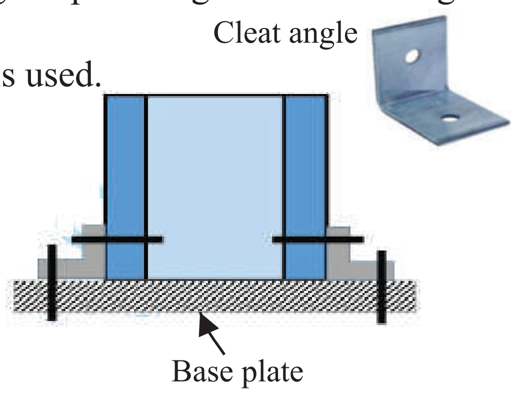
• Column base is a base plate used to reduce the bearing pressure on the concrete footing.

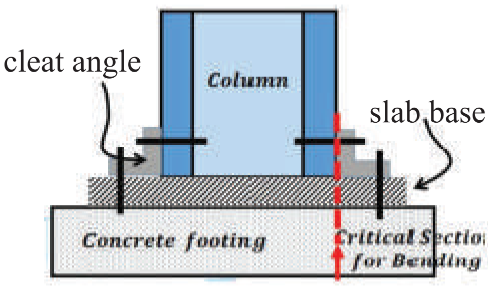
• It transfers the load to the concrete footing, preventing the punching shear of footing.

• If the column load is less, slab base is used.

• If the column load is more/heavy, then gusseted base is used.

• If the soil is weak, grillage foundation is used.





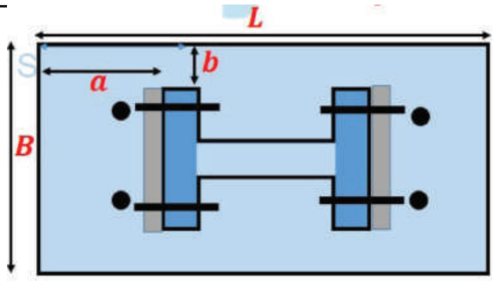
Slab Base

• Permissible tensile stress of bolt used in column base is 120 MPa.

• In slab base, base plate and cleat angle are used.

• If column load is axial, then thickness of base plate is given by -

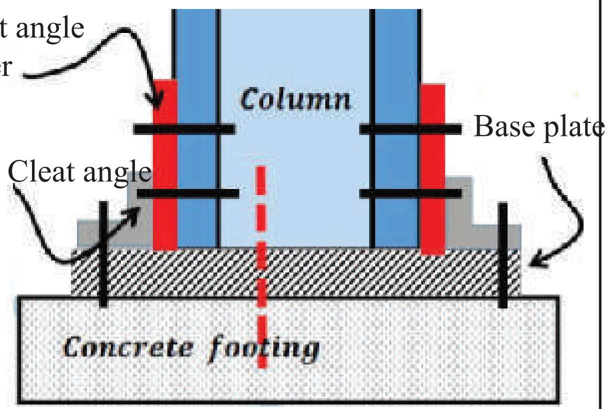
- $t = \sqrt{\frac{3w}{\sigma_{bs}}\left(a^2 - \frac{b^2}{4}\right)}$ (WSM)
- $t = \sqrt{\frac{2.5w}{\sigma_{bs}}(a^2 - 0.3b^2)}$ (LSM)



  - Where w is upward pressure on base plate in N/mm²
  - a, b are greater and smaller projection of base plate beyond column edge.
  - σ_{bs} is permissible bearing compressive stress in base plate.

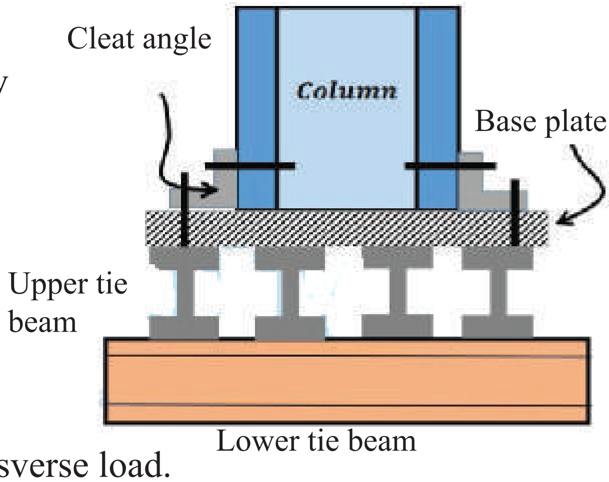
Gusset Base

- Adopted when the load is large.
- Axial load accompanied by bending moments.
- Having eccentric loadings.
- Area can be increased by adding gusset plates.
- Loads are transferred 50% by fastners.
- Critical section for bending moment is at toe of Gusset plate.
- Core and kernel : It is the small portion at cross section within which load is applied, tension will not be developed.



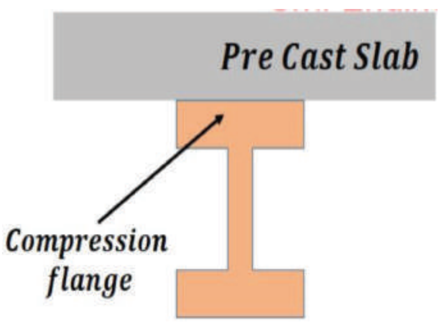
Grillage Foundation

- Adopted when loads on columns are extremely heavy.
- The bearing capacity of soil for the area of gusset/slab is not enough.
- Distribution area is very large.

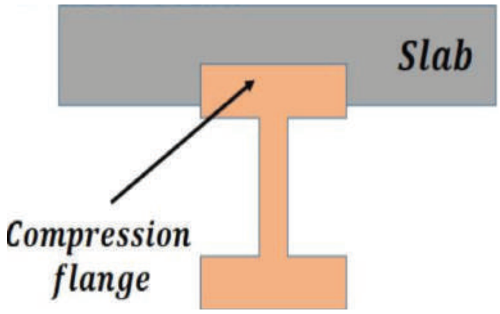


Beams

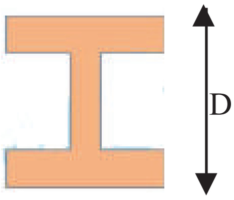
- Beam is a structural member subjected to transverse load.
- Flexural Formula : $\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$
  - Where R = radius of curvature
  - 1/R = curvature
  - i.e. Moment is directly proportional to curvature $M \propto$ Curvature 1/R
- **Laterally Unsupported beam :**
  - If the compression flange of beam is not restrained against lateral moment, then it is called as Laterally Unsupported beam or laterally Unrestrained beam.



- **Laterally Supported beam :**
  - If the compression flange of beam is restrained against lateral moment, then it is called as Laterally Supported beam or laterally Restrained beam.



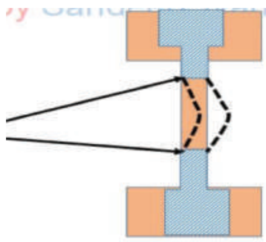
- In the design of beam, we assume that the depth of Web is resisting shear is taken as overall depth of the beam, so



- $\tau_{va\ calculate} = \dfrac{V}{Dt_w}$

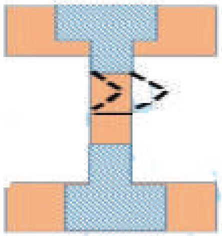
Web Buckling :

- It occurs due to diagonal compression in web/concentrated load which is produced due to shear force in web.
- Web buckling occurs between toe of fillet weld.



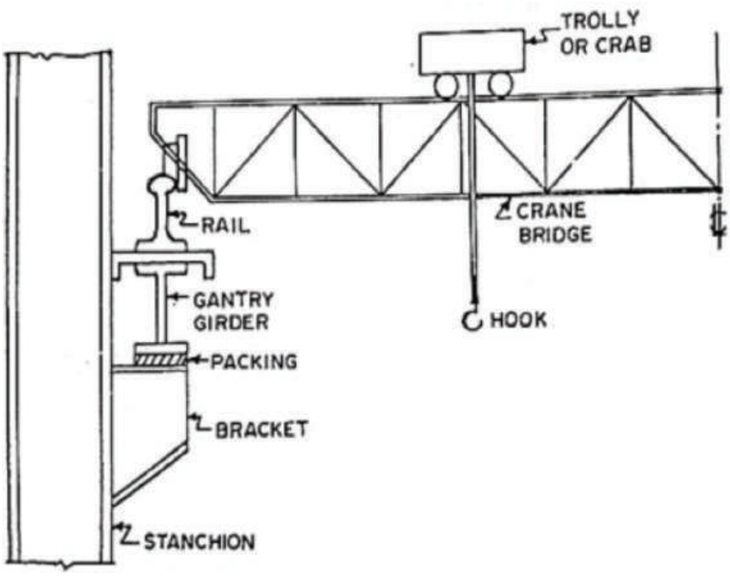
Local buckling of Web/ Web crippling :

- Web near the portion of the stress concentration tends to fold over the flange is called as Web crippling.
- Developed due to large amount of bearing stresses.
- Stress concentration occurs at the junction of web and the flange.



Gantry Girder

- Gantry Girder are subjected to
  1. Gravity loads, (i.e. dead load + live load + weight if crane truss + weight of trolley, etc)
  2. Lateral load (due to starting or stopping of crab)
  3. Longitudinal load (due to starting or stopping of crane)
- These three loads are mutually perpendicular to each other.
- Horizontal and vertical loads are applied simultaneously, allowable stress in gantry girder are increased by 10%



Additional Load due to Impact

Additional impact load Type of loading	Impact Allowance
Vertical loading	
1. E.O.C	25% of maximum static wheel load
2. M.O.C.	10% of maximum static wheel load
Horizontal force transverse to rail	
1. For E.O.C	10% of weight of trolley and weight lifted.
2. For M.O.C	5% of weight of trolley and weight lifted
Horizontal force along the rail	5% of static wheel load

Permissible Stress in Gantry Girder

Gantry girders are laterally unsupported beams to carry heavy loads from place to place at the construction sites.

1. For manually operator crane, the maximum permissible deflection is

$$\delta = \frac{\text{span}}{500}$$

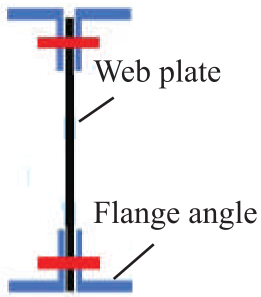
2. For electrically operator crane, the maximum permissible deflection for a capacity upto 50T or 500kN

$$\delta = \frac{\text{span}}{750}$$

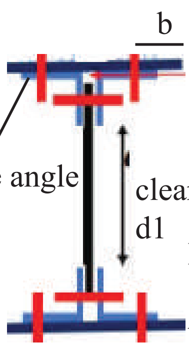
3. For electrically operator crane, the maximum permissible deflection for a capacity more than 50T or 500kN

$$\delta = \frac{\text{span}}{1000}$$

Plate Girder



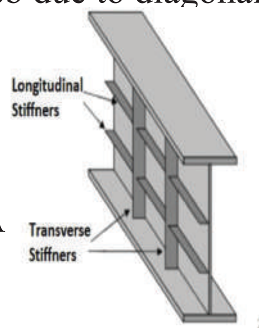
- A plate girder as usually thought as flexural member whose cross section is composed of plate elements, flange plate, angle and web equivalent.
- If built up beam can not withstand applied load then plate girder are used.
- Plate girder consists of flange plate, flange angle and web plate.
- *Compression flange :*
  - It consists of flange plate, flange angle and web equivalent.
  - Web equivalent is the web area embedded between two flange angle.
  - In compression zone flange, web equivalent is taken as $\frac{\text{area of web}}{6}$ or $\frac{a_w}{6}$
- *Tension flange :*
  - It consists of flange plate, angle and web equivalent.
  - In tension zone, web equivalent is taken as $\frac{a_w}{8}$



- It is assumed that entire shear force is taken by web plate and bending moment is taken by flange (to ensure that web takes only shear force, gap of 5mm will be maintained between flange plate and web plate so that direct bearing action between flange plate and web plate is avoided).
- The load is transferred from flange plate to web plate through flange angles only.
- Width of outstand in compression flanges
    - $b \ngtr 16\,t_f$
    - $b \ngtr \frac{256\,t_f}{\sqrt{f_y}}$
- The width of outstand in tension zone
    - $b \ngtr 20t_f$
- Economical depth of web plate (which is corresponding to minimum weight but not minimum cost)
    - $d = 1.1\sqrt{\frac{M}{\sigma_{bc} \times t_w}}$
- Self weight of Plate girder is assumed as
    - $w = \frac{W}{300}$ kN/m $\rightarrow$ WSM
    - $w = \frac{1.5W}{300}$ kN/m $\rightarrow$ LSM $= \frac{W}{200}$ kN/m

Important Points

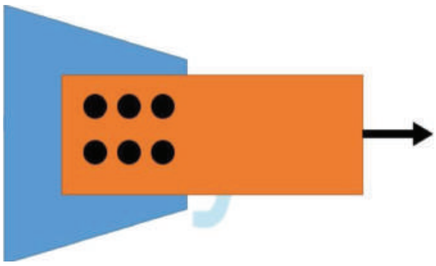
- If $\frac{d_1}{t_w} < 85$, web buckling due to shear will not happen, so stiffener are not provided. The web will be unstiffened.
- If $\frac{d_1}{t_w} > 85$, vertical stiffeners are provided to prevent buckling of web due to diagonal compression which is developed due to shear force.
- If $\frac{d_1}{t_w} > 200$, horizontal stiffeners are provided above NA as they prevent buckling web due to bending compressive stress.
- If $\frac{d_1}{t_w} > 250$, then additional horizontal stiffeners are provided at NA
- If $\frac{d_1}{t_w} > 400$, the section must be redesigned.



- After providing all the stiffners, lesser clear dimension of web should not exceed $180t_w$
- Greater clear dimension of web panel $\ngtr 270t_w$

Tension Members

- A structural member subjected to axial tension is called “Tension member” (or) “Tie”.
- The members & connections are so arranged that eccentricity in the connection & bending stress are not developed.



Types of failure

- A tension member may fall in any of the following modes :
  1. Gross section yielding
     - Considerable deformation of the member in longitudinal direction may take place before it fractures, making the structure unserviceable. Hence we must also consider yielding on gross-section.
  2. Net section rupture
     - The fracture of the member occurs when the net cross section of the member reaches ultimate stress.
  3. Block shear failure
     - A segment of block of material at the end of member shears out due to the possible use of high bearing strength of steel and high bolts resulting in smaller connection length.

Design strength of tension member

- *For gross section yielding*
  - Design strength $T_{dg} = \frac{f_y}{\gamma_{mo}} . A_g$
  - $A_g \rightarrow$ gross sectional area
  - $\gamma_{mo} \rightarrow 1.1$ partial safety factor
- Note : When a tension member is subjected to tensile force although the net cross section yields first, the deformation within the length of connection will be smaller than the deformation in the remainder of tension member.
- It is because the net action exist within the small length of member, most of the length of member will have an unreduced cross section, so attainment of yield stress on gross area will result in larger total elongation.
- *Net section rupture (fracture)*
  - Design strength in fracture $T_{dn} = \frac{0.9 f_u}{\gamma_{m1}} . A_n$
  - Where f_u = ultimate strength of material
  - $\gamma_{m1} \rightarrow 1.25$
  - A_n = effective net area of cross section
- *Block shear*
  - For plates :
  - For shear yield and tension fracture :
    - $T_{db1} = \frac{f_y A_{vg}}{\sqrt{3}\gamma_{m0}} + \frac{0.9 f_u A_{tn}}{\gamma_{m1}}$
  - For tension yield and shear fracture
    - $T_{db1} = \frac{f_y A_{tg}}{\gamma_{m0}} + \frac{0.9 f_u A_{vn}}{\sqrt{3}\gamma_{m1}}$
      - Where A_{vg} is minimum gross area in shear along the line of force
      - A_{vn} is minimum net area in shear along the line of force
      - A_{tg} is minimum gross area in tension

- A_{tn} is minimum net area in tension

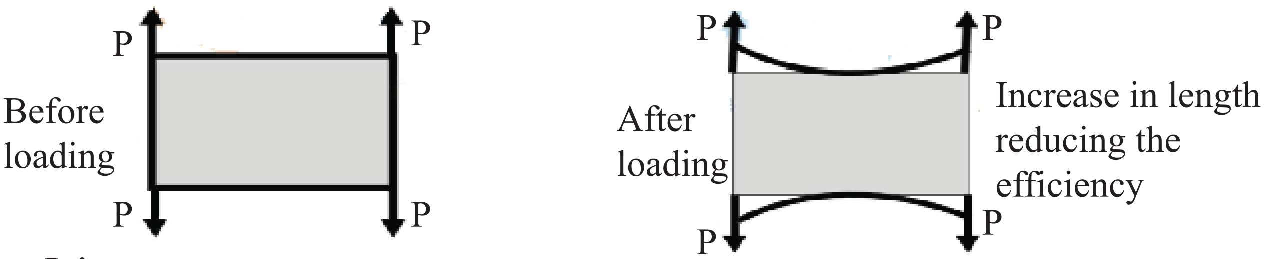
Slenderness Ratio

- The slenderness ratio of a tension member is the ratio of its unsupported length 'L' to its least radius of gyration.
- Maximum slenderness ratio for tension members is given as :

A tension member in which reversal of direct stress due to loads other than wind or seismic forces occur.	180
A member normally acting as a tie in roof truss or a bracing system but subjecetd to possible reversal of stresses resulting from the action of wind and earthquake forces.	350
Members always under tension (other than 400 pretensioned members)	400

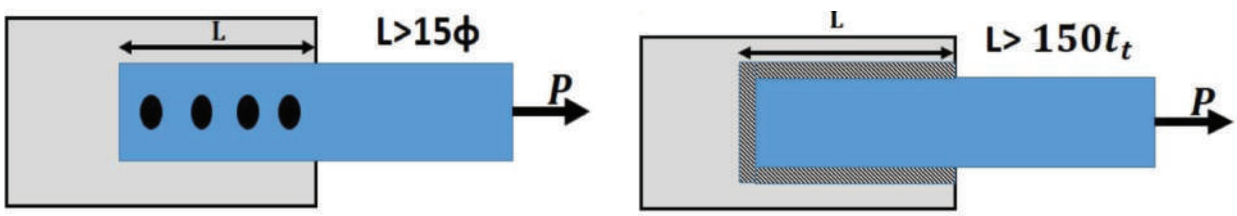
Shear Leg

- Non uniform straining of member due to tension is called shear leg.
- Shear leg reduce the efficiency of tension member that are not connected to the gusset plate.
- For reducing shear leg, lengthening of connection and reduction in efficiency are done.



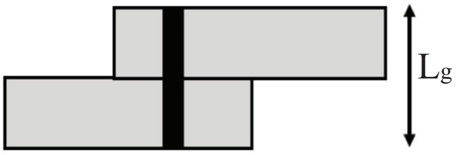
Long Joint

- If the length of the joint is greater than 15ϕ or 150t_t, then it is called long joint.
- It is assumed that applied load is shared by all the rivets, but in long joint, outer rivet takes more load than the inner rivets so failure of rivets in long joints is sequential, beginning with those at the ends and progressing towards centre, this type of failure is termed as 'unbuttoning.'



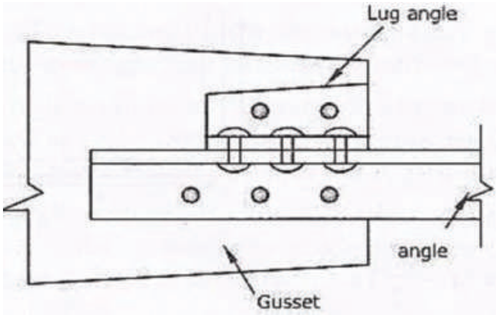
L = Overlapping length

- If the length of joints is more, efficiency of the tension member would be less.
- Grip length = 5ϕ (LSM)
- Grip length = 8ϕ (WSM)
- If the grip length increases then the efficiency of joints decreases due to additional bending stress developing in rivets.

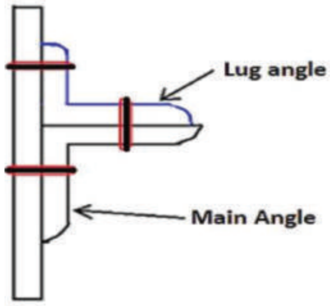


L_g = Grip length

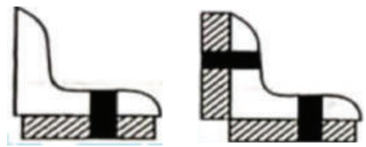
Lug Angle



- It is a small piece of angle used to connect the outstand leg of the structural member to the gusset plate.
- The purpose of lug angle is to reduce the length of connection to gusset plate and reduce the shear leg effect.
  - Shear leg effect is reduced by increasing the length of connection and by providing lug angles.
- If lug angle are used, the efficiency of tension members increases.
- If length is increased, then shear leg effect is decreased but efficiency is also decreased, if lug angle is used then efficiency is increased and shear leg is reduced.



Splices



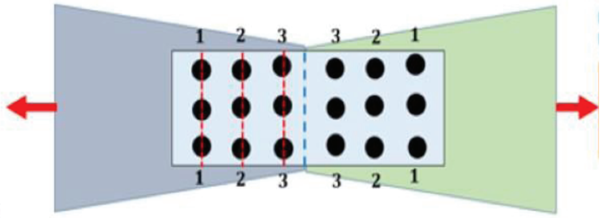
- They are used to join two sections when a joint is to be provided, i.e these replace the members at the joint where it is cut.
- When a splice occurs in an angle, channel, tee or joint section, the force is received from the member through the connection on one side of joint and is transferred to the splice cover plate.

- The force is then carried through these covers across the joint and is transferred to other portion of member through the connections.

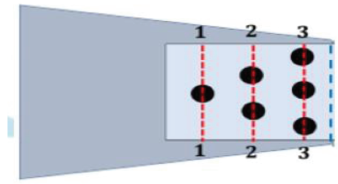
Load carrying Capacity

- Load carrying capacity of tension member :
  - Safe load carrying capacity :
  - $P_t = \sigma_{at} A_{net}$ (WSM)
    - Where σ_{at} is permissibleaxial tensile stress ($0.6f_y$)
    - And A_{net} is net effective cross section area.
  - $P_t = \min \left(A_g \frac{f_y}{1.10} \;|\; A_{net} \frac{0.9 f_u}{1.25} \right)$
  - To prevent fracture
    - $A_{eff} = 0.9\, A_{net}$
    - Hence $P_t = A_{eff} \frac{f_u}{1.25}$

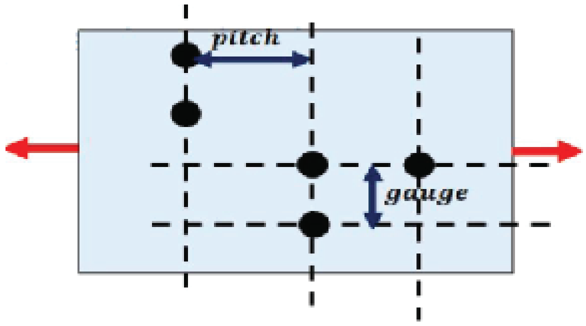
Load Carrying Capacity For Plate



- Load Carrying Capacity of tension member :
  - Safe load carrying capacity :
  - Calculation of A_{net}
    - Chain riveting
      - $A_{net} = (B - 3d)t$
    - Diamond riveting
      - $A_{net} = (B - d)t$

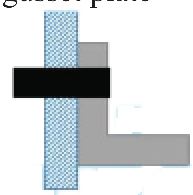


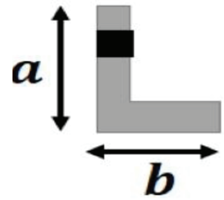
    - Staggered riveting
      - $A_{net} = (B - n_1 d + \frac{r_1^2}{4g_1} + \frac{r_2^2}{4g_2})t$
        - n_1 is no. of rivets along critical section
        - d is gross dia or hole dia
        - r_1 and r_2 are staggered pitch
        - g_1 and g_2 are staggered gauge



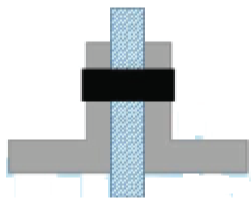
Load carrying capacity for angle

- Load carrying capacity of tension member :
  - Safe load carrying capacity:
  - Calculation of A_{net}
  - For angle
  - $A_{net} = (A_1 + kA_2)$
    - $k = \frac{3A_1}{3A_1 + A_2}$
    - K = shear leg effect
    - Where A_1 is net area connected leg
    - A_1 = [gross area of connected leg - area of rivet hole]
    - A_1 is gross area of unconnected leg/outstand leg
    - $A_1 = (a - d - \frac{t}{2})t$
    - $A_2 = (b - \frac{t}{2})t$





  - If two angles are placed back to back and connected to both sides of gusset plate



  - $A_{net} = (A_1 + kA_2)$ where K = 1
  - $A_{net} = (A_1 + A_2)$
  - It is the most efficient way of connecting, then load carrying capacity is maximum.
  - If the two angles donot have rivet, then each angle behaves independently hence

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

- Design of Tension member
  1. To find A_{net} required

ENTRI

- $A_{net\ required} = \frac{P}{\sigma_{at}}$

2. Increase A_{net} by 40 to 50% to get A_g required when riveting is done.
3. Increase A_{net} by 20% to get $A_{g\ required}$ when welding is done
4. Select a suitable section and find the number of rivets required.
5. If $A_{g\ provided} > A_{g\ required}$, so design is safe.

As per IS 800

- In case of single angles in tension connected by one leg only, the net effective area = $a + \frac{b}{1 + (0.2)(b/a)}$
- Effective area of plate girder
  - In tension = $A_f + \frac{A_w}{8}$
  - In compression $A_f + A_w$

As per IS 800, for mild steel

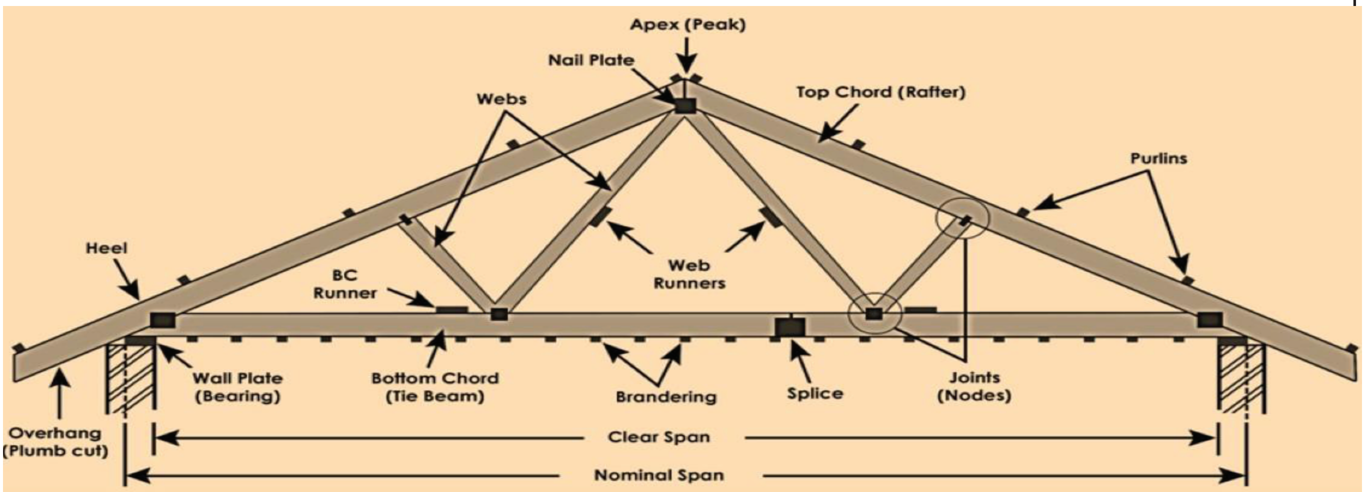
Proportional Limit	190-220 N/mm²
Yield strength	230-250 N/mm²
Ultimate strength	410-530 N/mm²
Fracture strength	250-300 N/mm²
Elongation of fracture	23-35%
Bearing stress	$0.75f_y$

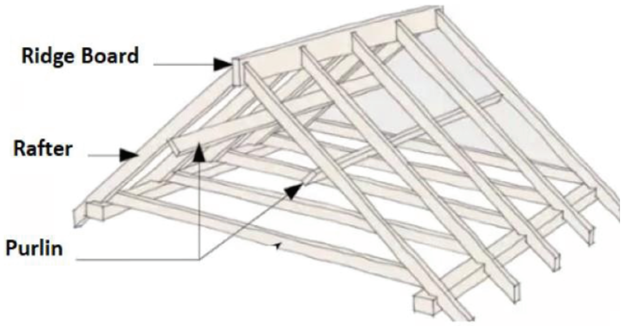
- NOTE :
  - Vertical Stiffeners are provided to prevent shear buckling of web.
  - Horizontal Stiffeners are provided to avoid compression buckling
- Vertical Stiffeners :
  - These stiffner are not designed as column are not designed.
  - Minimum spacing of vertical stiffeners is $\frac{d_1}{3} = 0.33d_1$
  - Maximum spacing of stiffeners = $1.5\ d_1$
- End Bearing Stiffeners
  - They are designed as imaginary column with both end are fixed whose effective length = $0.7l_1$

Roof Truss

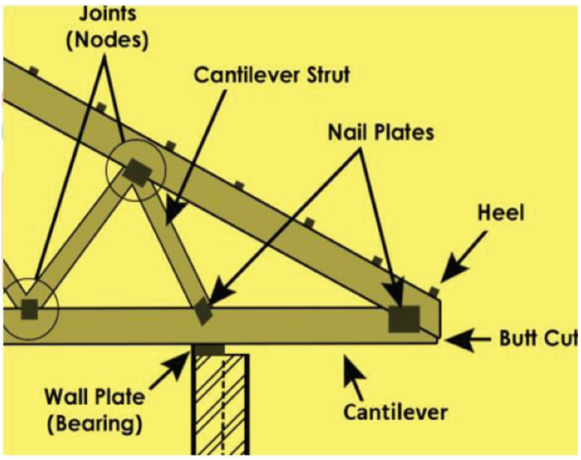
- Trusses are triangular frame works, consisting of essentially axially loaded members which are more efficient in resisting external loads since the cross section is nearly uniformly stressed.
- They are extensively used to span large gaps.
- Trusses are used in roots of single storey industrial buildings, long span floors and roots of multistory buildings, to resist gravity loads.
- Trusses are also used in walls and horizontal planes of industrial buildings to resist lateral loads and give lateral stability.

Components of Roof Truss



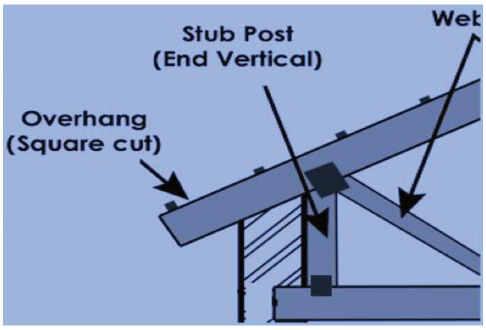


- Purlin - Horizontal beam spanning between the two adjacent trusses.
- Apex - Highest point where the sloping top chords meet.
- Bearing - Structural support of trusses (usually walls) normally with a timber wall plate.
- Bottom Chords (BC) - The lowest longitudinal member of a truss.



- Cantilever - Part of structural member that extends beyond its support.
- Cantilever Strut - Web that joins the bottom chord above the bearing point to the top chord of cantilevered truss.
- Overhang - Extension of the top chord of a truss beyond the bearing support.
- Panel - truss segment defined by two adjacent joints or nodes.

• Plumb Cut - Vertical cut to the end of the top chord to provide for vertical (plumb) installation of the fascia or gutter.



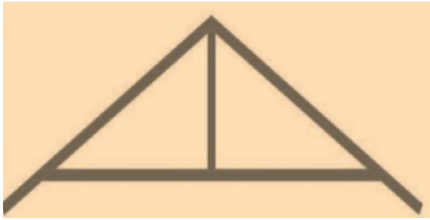
• Splice Point - Top and bottom chord splice.
• Square cut - Perpendicular to the edge of the chord.
• Top chord or rafter - a horizontal member that establishes the upper edge of a truss.
• Stub End - a truss type formed by the truncation of a normal triangular truss.
• Web - Members that join the top and bottom chords to form a triangular pattern.

Types of Roof Trusses

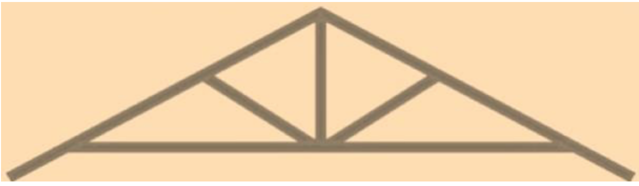
Different types of Wooden and steel Roff trusses :

• King Post Truss
• Queen Post Truss
• Howe Truss
• Pratt Truss
• Fan Truss
• North Light Roof Truss
• Quadrangular Roof Truss

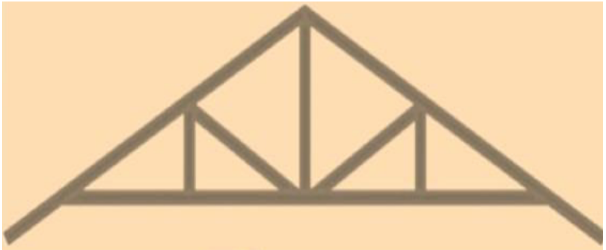
• **King Post Truss**
  • King post truss is a wooden truss.
  • It can also be built of combinations of wood and steel.
  • It can be used for spans upto 8m.



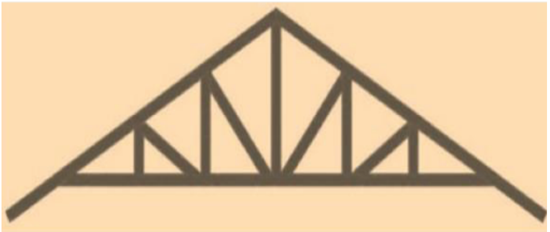
• **Queen Post truss**
  • Queen Post Truss is also a wooden truss.
  • It can be used fgor spans upto 10m.



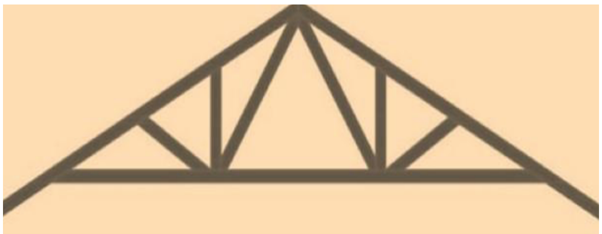
- **Howe Truss**
  - It is made of combination of wood and steel.
  - The vertical members or tension members are made of steel.
  - It can be used for spans from 6-30m.



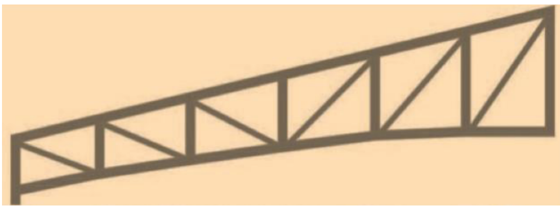
- **Pratt Truss**
  - Pratt truss is made of steel.
  - These are less economical than the Fink Trusses.
  - Vertical members are tension and diagonal members are compression.
  - Fink Trusses are very economical form of roof trusses.
  - It can be used for spans from 6-10m



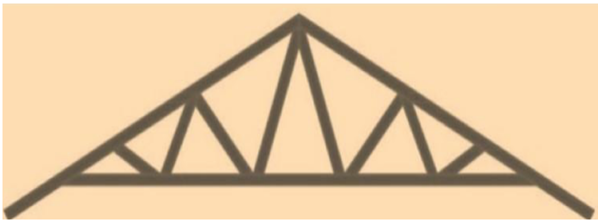
- **Fan Truss**
  - It is made of steel.
  - Fan trusses are form of fink roof truss.
  - In fan Trusses, top chords are divided into small lengths in order to provide supports for purlins which would not come at joints in Flink trusses.
  - It can be used for spans from 10-15 m.



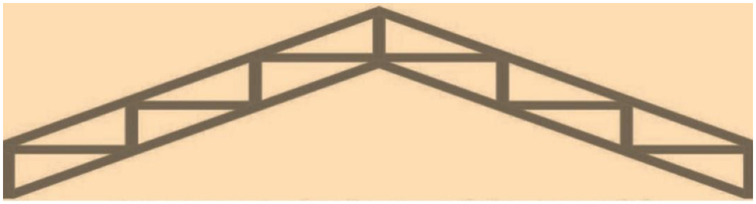
- **Quadrangular roof Truss**
  - These trusses are used for large spans such as railway sheds and Auditoriums.



- **North Light Roof Truss**
  - When the floor span exceeds 15m, it is generally more economical to change from a simple truss arrangement to one employing wide span lattice girders which support trusses at right angle.
  - In order to light up the space satisfactorily, roof lightining has to replace or suppliment, side lightining provision must also be made for ventilation form the roof.
  - This roof consists of a series of trusses fixed to girders. It can be spans from 20-30 m.
  - Used for industrial buildings, drawing rooms etc.



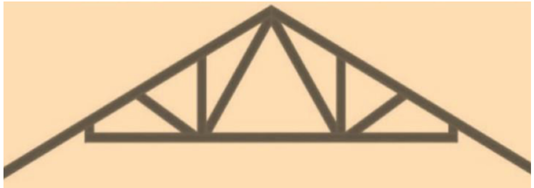
- **Parallel chord Roof Truss**
  - They are constructed with two chords running parallel to each other and supported by reinforcing



trusses in between the top and bottom chords.

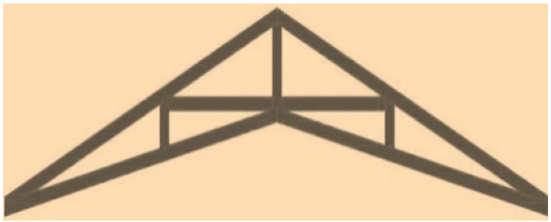
- This roof truss reduces the condensation problems and mold conditions since they create a vapor barrier.

- **Raised Heel Roof Truss**



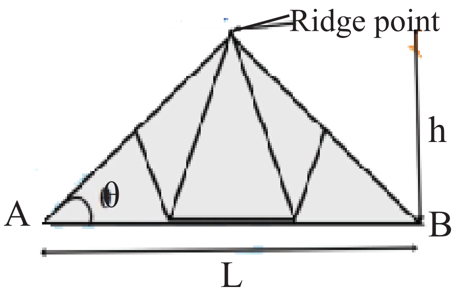
  - They provide a cost-effective way to meet more energy efficiency codes and improve the energy efficiency of your building envelope.
  - Raising the truss higher greatly simplifies attic ventilation and it leaves ample room for insulation above exterior wall top plates.

- **Scissor Roof Truss**

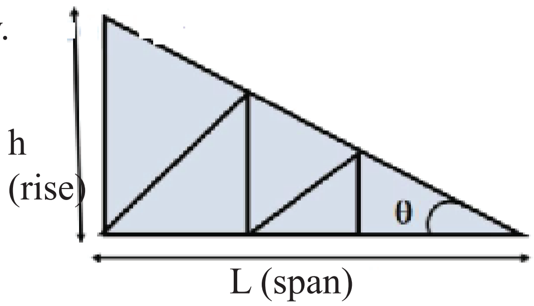


  - A scissor roof truss can particularly be found in cacthedrals. It doesnt require beams or bearing walls, however it doesn't leave that much space for insulation which makes its energy efficiency very poor.
  - On the other hand, the upside here is that the ceiling gets vaulted and you receive more space in the attic.

Design of Root Tursses



- Slope of truss $\theta = \tan\theta = \frac{h}{L/2} = \frac{\text{Rise}}{\text{Half of span}}$
- Pitch of truss $(p) = \frac{h}{L}$
- The angle, or pitch, of a roof is calculated by the number of inches it rises vertically w.r.t horizontally.



- Slope of truss $\theta = \tan\theta = \frac{h}{L} = \frac{\text{Rise}}{\text{Span}}$
- Pitch of truss $(p) = \frac{h}{L}$

- CANTILEVER TRUSS are idealized as cantilever beam so all top member are subjected to tension and bottom member are subjected to compression.
- ROOF TRUSS - Tension member in roof truss called 'tie' and compression member is called 'strut'.
- In cantilever beam, main reinforcement (tension reinforcement) are provided above the N.A.

Specifications of Load on Truss

1. Live Load :

- If slope of truss is less than 10°, then

  Live load = $0.75\ kN/m^2$

- If slope of truss is more than 10°, then

  Live load = 0.75 - 0.02(θ - 10°) kN/m²

  Live load ≮ 0.4 kN/m²

2. Snow Load :

- Snow load = 2.5 N/m² for 1mm depth of snow.
- If the slope of truss is more than 50°, then snow load need not to be considered because snow will slip from the roof surface itself.

3. Dead Load :

- If the spacing of truss is 4m, and pitch of truss is 1:4, then self weight of truss may be taken as -

  $w = (\frac{1}{3} + 6)$ kg/m² of plan area

  where plan area = spacing × span

Specifications of Truss

- Economical spacing of trusses is the spacing that make overall cost of truss, purlin and roof covering to a minimum value.

  t = 2p + r

  Where t is cost of truss

  p is cost of purlin

  r is cost of roof covering
- Purlin - Horizontal beam spanning between the two adjacent trusses. They may be designed as cantilever, simply supported or continuous beam but IS 800 recommends that the purlin are to be designed as continuous beam.
- For SSB or purlin

  Max B.M = $\frac{wl^2}{8}$ or $\frac{WL}{8}$
- But purlins are designed as continuous beam
  - Hence minimum width of purlin = $\frac{L}{60} = \frac{\text{span of purlin}}{60}$

Plastic Analysis

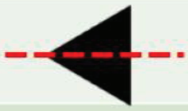
- In plastic analysis and design of structure, the ultimate load of the structure as a whole is regarded as the design criterion.
- This method is rapid and provides a rational approach for the analysis of the structure.
- Plastic analysis and design has its main application in the analysis and design of statically indeterminate framed structures.
- The ratio of the plastic moment to the yield moment is known as the shape factor.
- The ratio of the collapse load to the working load is known as the load factor.
- Due to the increase in BM, a stage will be reached when all fibres will be yielded.
- The beam at this stage reaches its maximum resisting capacity.
- The plastic section modulus depends on the location of the plastic neutral axis.
- The plastic section modulus is the sum of the area of the cross section on each side of the plastic neutral axis (which may or may not be equal) multiplied by the distance

from the local centroids of the two areas to the plastic neutral axis.

- Elastic hinge is the location where structural member is free to rotate, i.e, member cannot resist B.M. at elastic hinge location.
- Plastic hinge is a yielding zone in a structural elements which generally develops at the point of maximum bending moment, support etc.

  For instance - For a simply supported beam subjected to a point load, the plastic hinge will occur at the position of point load.
- Plastic Hinges are generally formed at following position of a beam -
  - Points under concentrated loads.
  - At supports
  - At point of maximum bending moment.

Shape Factor

SHAPE	SHAPE FACTOR
Triangle 	2.343
Triangle 	2.0
Rhombus 	2.0
Rectangle and Square	1.50
Circle	1.698
Hollow circle	1.273