DESIGN OF STEEL STRUCTURES

DESIGN OF TENSION MEMBERS

Design

It Consists of

(i) choice of materials,

(ii) determination of loads,

(iii) analysis of the structure under the most unfavourable loading combination, and

(iv) design of elements, joints, etc., of the structure.

Methods of design

All parts of the steel framework of a structure should be capable of sustaining the most adverse combination of the dead loads, superimposed roof and floor loads, wind loads, seismic forces where applicable and any other forces or loads to which the building may be reasonably subjected without exceeding the permissible stresses.

Steel structures may be proportioned based on simple design, semi-rigid design, full-rigid design and plastic design (or) plastic theory.

***(i)* Simple Design**

This method applies to structures in which the end connections between members are such that the structure will not develop restraint moments adversely affecting the members and the structure as a whole, and in consequence the structure may, for the purpose of design, be assumed to be pin-jointed.

Assumptions:

(a) The beams are simply supported,

(b) All connections of beams, girders or trusses are virtually flexible and are proportioned for the reaction shears applied with the appropriate eccentricity,

(c) The members in compression are subjected to forces applied with appropriate eccentricities combined with appropriate effective lengths,

(d) The members in tension are subjected to longitudinal forces applied over the net area of the section, and

(e) The plane sections normal to the axis remain plane after bending.

***(ii)* Semi-Rigid Design**

This method permits a reduction in the maximum bending moment in beams suitably connected to their supports, so as to provide a degree of direction fixity, in the case of triangulated frames, it permits account being taken of the rigidity of the connections and the moment of intersection of members.

***(iii)* Fully Rigid Design**

This method as compared to the methods of simple and semi-rigid designs gives the greatest rigidity and economy in the weight of steel used when applied in appropriate cases. The end connections of members of the frame should have sufficient rigidity to hold the original angles between such members and the members they connect virtually unchanged. The design is generally based on theoretical methods of elastic analysis and the calculated stress should conform to the provisions of the relevant code.

***(iv)* Design based on Plastic Theory**

Assumptions:

(a) the plastic range is entered on reaching the yield point,

(b) strain hardening can be ignored,

(c) stress-strain relation for tension is the same as that for compression, and

(d) plane sections remain plane.

Safety Concept

There will be a gap between the internal load and the internal resistance. The gap is covered in either of the two ways :

(a) In elastic design the allowable stresses are taken less than the strength of the material by an appropriate factor called '**Factor of Safety**',

(b) In ultimate strength design, the internal load is increased by a factor called the *'Load Factor'*, whereas the ultimate strength is computed on the basis of yield or buckling strength.

Let I_L be the internal load and ΔI_L be the increase in load. Let I_s be the internal strength and ΔI_S be the probable under-strength, then

$$I_S = I_L\left(1+\frac{\Delta I_L}{I_L}\right)\times\left(1+\frac{\Delta I_S}{I_S}\right)$$

This expression indicates that the computed strength should equal the internal load multiplied by a factor greater than one. This is the ultimate load analysis wherein the full strength is considered and loads are increased by a load factor.

$$\text{Also } I_L = \frac{I_S}{\left(1+\frac{\Delta I_L}{I_L}\right)\times\left(1+\frac{\Delta I_S}{I_S}\right)}$$

This is the elastic design approach, and the dividing factor is called the **factor of safety.**

Factor of Safety

In the elastic design of steel structures, the factor of safety is applied on the yield stress of the material to obtain the working stress or permissible stress in the material.

The value of factor of safety is decided considering the followings :

(*i*) The average strength of materials is determined after making tests on number of specimens. The strengths of different specimens of given structural material are not identical.

(*ii*) The values of design loads remain uncertain, but values of dead loads can be determined correctly. But live load, impact load, wind load, snow load, etc., cannot be determined with certainty since these depend upon statistics available. The probable values of these loads are only determined.

(*iii*) The values of internal forces in many structures depend upon the methods of analysis. The degree of precision of different methods varies. The methods involving detailed analysis are more precise. In case, analysis of the structure is done precisely, a small value of factor of safety may be adopted.

(*iv*) During fabrication, structural steel is subjected to different operations. The punching of a hole in a structural element distorts the surrounding material and causes high residual stresses. The warping and buckling of elements may take place during welding. The welding leaves high residual stresses. Structural elements are subjected to uncertain erection stress.

(*v*) The variations in temperatures and settlement of supports are uncertain. Many times, a well designed structure is damaged because of these effects. The strength of materials decreases because of corrosion. The extent of corrosion is more, when a structure is located in industrial areas and exposed to chemical wastes.

(*vi*) The failure of some structures or some elements of a structure is less serious and less disastrous than the failure of large structures or a main element of a structure.

Load Factor (Q)

$$Q = \frac{\text{Collapse load, } W_c}{\text{Working load, } W_w}$$

The load factor depends upon the nature of loading, the support conditions and the geometrical shape of the structural member. The bending moment at any section is directly proportional to the applied load. Therefore, bending moment M_1 is proportional to W,

or $$M_1 = kW$$

The fully plastic moment is also directly proportional to the collapse load,

$$W_c M_p = kW_c$$

If the maximum bending moment M_l corresponds to the maximum working load, then

$$M_1 = kW_w$$

$$\frac{M_0}{M_1} = \frac{W_C}{W_w}$$

$$= Q$$

$$M_1 = fZ$$

where, Z = elastic modulus, and

f = working stress or permissible stress.

Again, $$M_p = \sigma_y Z_p$$

where, Z_p = plastic modulus, and

σ_y = yield stress of steel.

$$\frac{M_p}{M_1} = \frac{Z_p}{Z} \cdot \frac{\sigma_v}{Z},$$

or load factor $Q = S \times F$

where $S = \text{shape factor} = \frac{Z_p}{Z}$, and

F = factor of safety used in the elastic design.

In general, for gravity loads, the value of load factor adopted is 1.85. Where wind loads are considered, the permissible stress is increased by $33\frac{1}{3}$ per cent. This reduces the load factor to 1.4 for wind loads.

Tension Members

A tension member is defined as a structural member subjected to tensile force in a direction parallel to its longitudinal axis. A tension member is also called a *tie member* or simply a tie.

Types of Tension Members

The types of structure and method of end connections determine the type of a tension member. Tension members used may be broadly grouped into four groups:

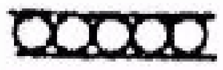
(i) wires and cables,

(ii) rods and bars,

(iii) single-structural shapes and plates,

(iv) built-up members.

(i) **Wires and cables**



The wire types are used for hoists, derricks, rigging slings, guy wires and hangers for suspension bridges.

(ii) **Rods and bars**

The square and round bars as shown in Figures are quite often used for small tension members.

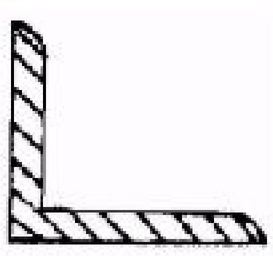
The round bars with threaded ends are used with pin-connections at the ends instead of threads.

The ends of rectangular bars or plates are enlarged by forging and bored to form eye bars. The eye bars are used with pin connections.

The rods and bars have the disadvantage of inadequate stiffiness resulting in noticeable sag under the self-weight.

(iii) **Single-structural shapes and plates**

The single structural shapes *viz.,* angles sections and tee-sections as shown in figures are used as tension members. The angle sections are considerably more rigid than the wire ropes, rods and bars. When the length of tension member is too long, then, the single angle section also becomes flexible.

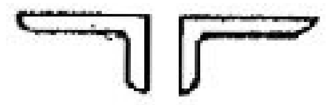


The single angle sections have the disadvantage of eccentricity in both planes in a riveted connection.

The channel section has eccentricity in one axis only. Single channel sections have high rigidity in the direction of web and low rigidity in the direction of flange. Occasionally, I-sections are also used as tension members. The I-sections have more rigidity, and single I-sections are more economical than built-up sections.

(iv) **Built-up Members**

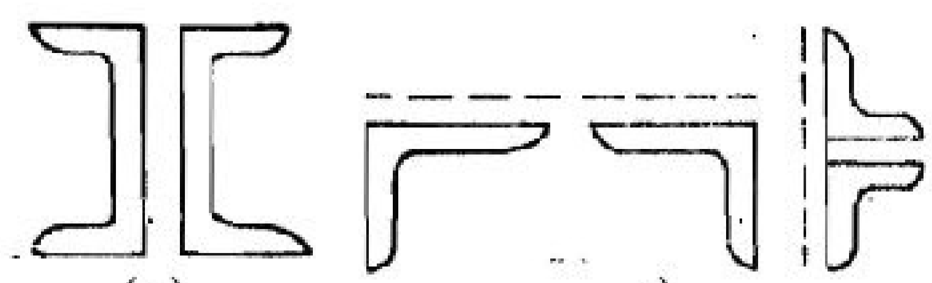
Two or more than two members are used to form built-up members. When the single rolled steel sections cannot furnish the required area, then built-up sections are used.



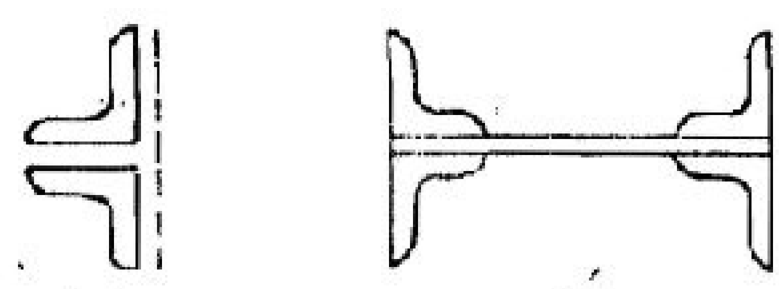
The double angle sections of unequal legs shown in the figure are extensively used as tension members in the roof trusses. The angle sections are placed back-to-back on two sides of a gusset plate. When both the angle sections are attached on the same sides of the gusset, then, built-up section has eccentricity in one plane and is subjected to tension and bending simultaneously. The two angle sections may be arranged in the star shape *(i.e.,* the angles are placed diagonally opposite to each-other with leg on outer sides). The star shape angle sections may be connected by batten plates. The batten plates are alternately placed in two perpendicular directions. The star arrangement provides a symmetrical and concentric connection.

Two angle sections as shown in the_ Figure *(a)* are used in the two-plane trusses, where two parallel gussets are used at each connection. Two-angle sections as shown in Figure *(b)* have the advantage that the distance between them could be adjusted to suit connecting members at their ends.

Four-angle sections as shown in Figure *(c)* are also used in the two-plane trusses. The angles are connected to two parallel gusset. For angle sections connected by plates as shown in Figure *(d)* are used as tension members in bridge girders.



(a) **(b)**



(c) **(d)**

A built-up section may be made of two channels placed back-to-back with a gusset in between them. Such sections are used for medium loads in a single-plane truss. In two-plane trusses, two channels are arranged at a distance with their flange turned inward. It simplifies the transverse connections, and also minimizes lacing. The flanges of two channels are kept outwards, as in the case of chord members of long-span girders, in order to have greater lateral rigidity.

The heavy built-up tension members in the bridge girder trusses are made of angles and plates. Such members can resist compression if reversal of stress takes place.

Net Area

When tension members are spliced or connected to a gusset plate by rivets or bolts, some material is removed from the cross-section due to bolt or rivet holes. The net area at any section is equal to the gross area minus the deductions for the holes at that section. The deduction for the hole is the product of the hole diameter and the thickness of the material,

$$\text{Net effective width, } b_e = b - nd + n_t\left(\frac{s^2}{4g}\right)$$

where s = the staggered pitch, *i.e.*, the distance between any two consecutive rivets, in a *zigzag* chain measured parallel to the direction of stress in the member,

g = gauge distance

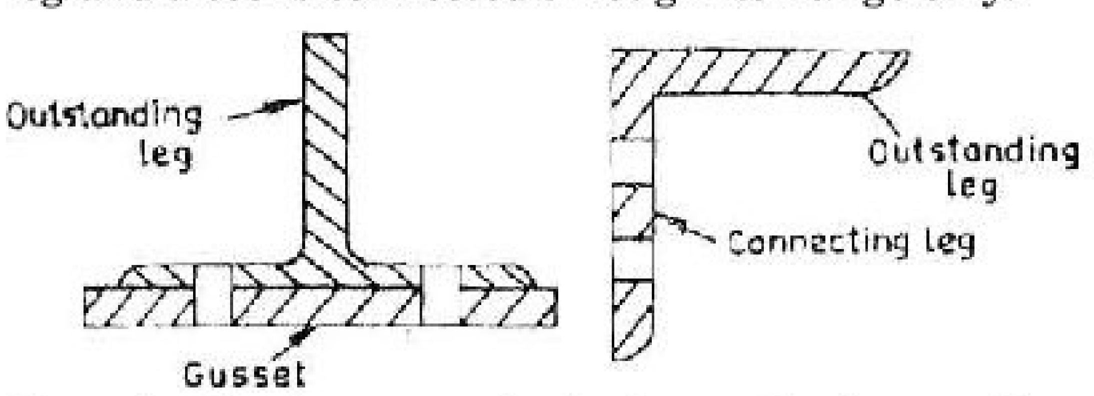
n = number of rivet holes

n_1 = number of *zigzages* or inclined lines.

This method can be applied to the angles also in which the rows of rivets in both legs are staggered with respect to each-other. For angles, the gross width shall be the sum of the width of the legs less the thickness. The gauge for holes in opposite legs shall be the sum of gauges from back of angles less the tickness.

Net Effective Section for Angles and Tees in Tension

An angle is usually connected to a gusset plate by one leg and a tee is connected through its flange only.



Case 1: In the case of single angles in tension, connected by one leg only,

Net effective area = $A_1 + K_1A_2$

where A_1 = net sectional area of the connected leg,

A_2 = area of the outstanding leg, and

$$K_1 = \frac{3A_1}{3A_1 + A_2}$$

where leg angles are used, the net sectional area of the whole angle member could be considered.

Case 2 : In the case of pair of angles back-to-back (or a single tee) in tension connected by only one leg on each angle (or by the flange of a tee) to the same side of the gusset,

Net effective area = $A_1 + K_2 A_2$

where A_1 = area of the connected legs (or flange of the tee),

A_2 = area of the outstanding leg (or web of the tee), and

$$K_2 = \frac{5A_1}{5A_1 + A_2}$$

Case 3 : In the case of double angles or tees carrying direct tension, placed back-to-back and connected to both sides of the gusset,

Net effective area = gross area of section – area of holes

Permissible Stresses in Axial Tension

It is related to the guaranteed minimum yield point of steel with an appropriate factor of safety. Most of the codes assume a factor of safety of 1.67.

The direct stress in axial tension on the effective net area should not exceed σ_{at}, given by the equation.

$$\sigma_{at} = 0.6\,\sigma_y,$$

where σ_y = minimum yield stress of steel in N/mm^2 (MPa).

Indian Standard IS : 226

It stipulates the following permissible stress in axial tension for steel

(*i*) Plates, angles, tees, I beams, channels and flats up to and

including 20 mm thickness	150 MPa,
above 20 mm to 40 mm thickness	144 MPa,
over 40 mm thickness	138 MPa,

(*ii*) Bars (round, square and hexagonal)

up to and including 20 mm diameter	150 MPa,
over 20 mm diameter	144 MPa.

Permissible Combined Stress

When tension members are subjected to both axial loading and bending moment, then the permissible stress is governed by the formula,

$$\frac{f_t}{P_t} + \frac{f_{bt}}{P_{bt}} \le 1$$

where f_t = axial tensile stress,

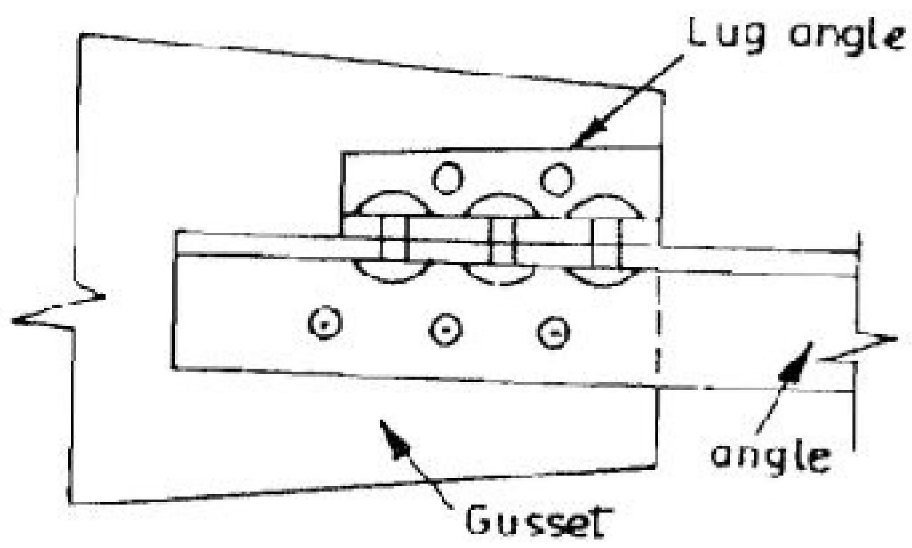
P_t = permissible axial stress in tension,

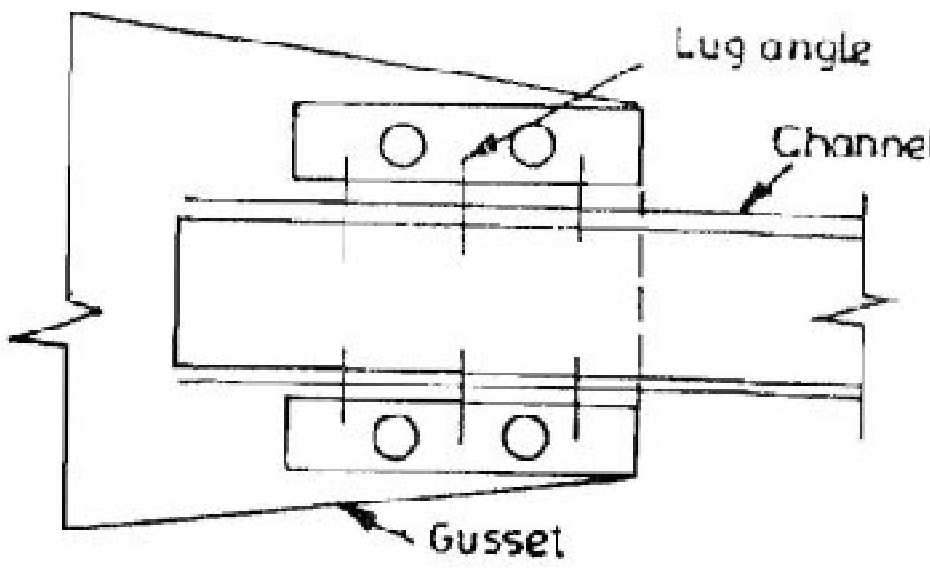
f_{bt} = calculated bending stress in tension in the extreme fibre, and

P_{bt} = permissible bending stress in tension.

Lug Angles

Lug angles are sometimes used to reduce the length of the connections. Figure below shows lug angle connection with single angle or a channel type of tension member.





Due to the possible deformation of the outstanding leg of the lug angle, the rivets connecting the gusset plate with the lug angle will share less load than the rivets connecting the main member with the gusset plate.

The Indian Standard IS : 800 specifies the followings for the design of lug angles:

(i) Lug angles connecting a channel-shaped member should, as far as possible, be disposed symmetrically with respect to the section of the member.

(ii) *In* the case of angle members, the lug angles and their connections to the gusset or any other supporting member should be capable of developing a strength not less than 20% in excess of the force in the outstanding leg of the angle and the attachment of the lug angle to the angle member should be capable of developing a strength 40% in excess of that force.

(iii) In the case of channel sections, the lug angles and their connections to the gusset or any other supporting member should be capable of developing a strength of not less than 10% in excess of the force not accounted for by the direct connection of the member, and the attachment of the lug angles to the member should be capable of developing a strength 20% in excess of that force.

(iv) In no case should fewer than two bolts or rivets be used for attaching the lug angle, to the gusset or another supporting member.

(v) The effective connection of the lug angle should, as far as possible, terminate at the end of the member connected and the fastening of the lug angle to the member should preferably start in advance of the direct connection of the member to the gusset or other supporting member

(vi) Where lug angles are used to connect an angle member, the whole area of the member should be taken as effective, z.e.,

A_{net} = *gross* area – deduction for holes.

Tension Splice

The strength of the splice plates and the rivets connecting them with the member should at least be equal to the design load of the tension member.

When tension members of different sizes have to be connected, filler plates may be used to bring the member in level.

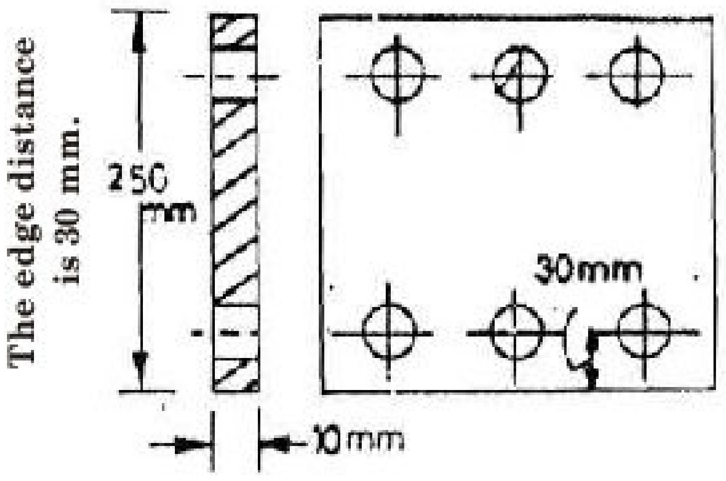
Rivets or bolts carrying a calculated shear stress through a packing more than 6 mm thick should be increased above the number required by normal calculations by 2.5% for each 2 mm thickness of packing. For double shear connections packed on both sides, the number of additional rivets or bolts required is determined from the thickness of the thicker packing. The additional rivets or bolts should preferably be placed in an extension of the packing.

Riveted and Welded Connections

In a riveted connection, the rivets are placed on the gauge lines of the angles and this results in small eccentricity of load on the joint as well as the member. In the welded connection the lengths of the welds can be adjusted so that the centre of gravity of the joint lies on the line passing through the centre of gravity line of the member.

SOLVED EXAMPLE

1. Find the net area of a plate section 250 mm x 10 mm with two rows of holes in a straight chain to accommodate 16 mm diameter rivets,



Solution: Gross area of the plate = 250×10

$= 2500 \text{ mm}^2$

Diameter of the rivet hole= $16 + 1.5 = 17.5$ mm

Area of the two holes= $2 \times 17.5 \times 10 = 350 \text{ mm}^2$

Net area of plate = $25000 \text{ mm}^2 - 350 \text{ mm}^2$

$= \mathbf{2150 \text{ mm}^2}$

2. What is the minimum net section of the 15 cm × 1.0 cm plate, with rivets, 16 mm diameter, in zigzag rows as shown in the figure

Solution:Gross Section = 150×10

$= 1500 \text{ mm}^2$

$s = 50$ mm, $g = 60$ mm

$$\therefore \quad \frac{s^2}{4g} = 10.42 \text{ mm}$$

Deduction:

(i) Chain '*abc*' area of holes = $17.5 \times 10 = 175 \text{ mm}^2$

(ii) Chain '*abde*' area of holes

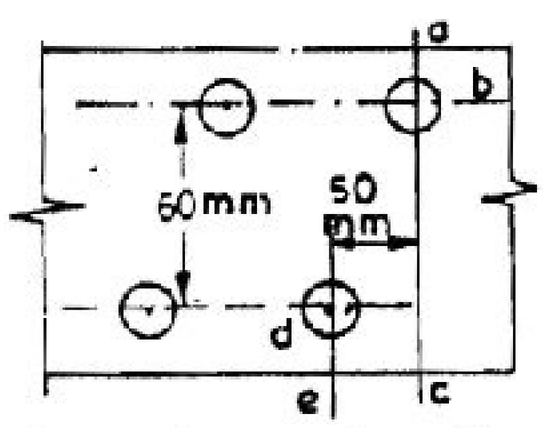
$= [2(17.5) - 10.42]\,10$

$= 245.8 \text{ mm}^2$

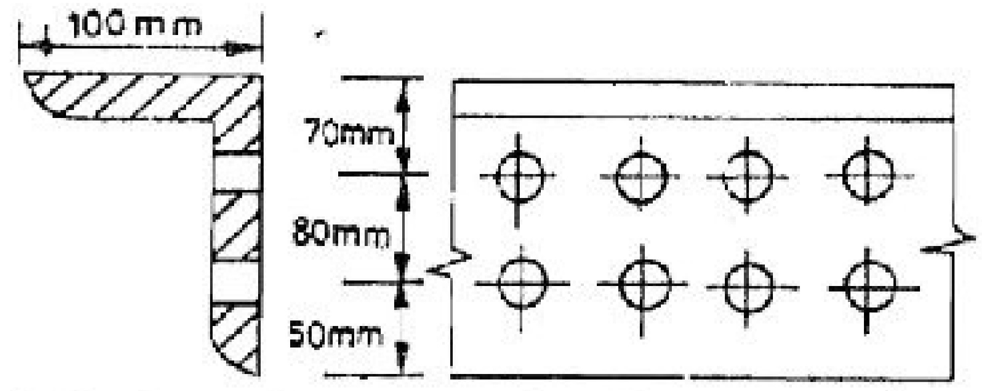
$\approx 246 \text{ mm}^2 > 175 \text{ mm}^2$

Net sectional area $= 1500 - 246$

$= \mathbf{1254 \text{ mm}^2}$



3. Find the net area of an angle section, ISA 200 × 100 × 10, where one leg is connected by two rows of rivets, 16 mm diameter, as shown in figure below,



Solution: Gross area of angle = 29.03 cm^2

$= 2903 \text{ mm}^2$

Area of the outstanding leg *i.e.,* 100 mm leg,

$A_2 = (100 - 5) \times 10$

$= 950 \text{mm}^2$

Area of the connected leg = $2903 - 950$

$= 1953 \text{ mm}^2$

Area of the holes = $2 \times 17.5 \times 10$

$= 350 \text{ mm}^2$

Net area of the connected leg, $A_1 = 1953 - 350$

$= 1603 \text{ mm}^2$

$$K_1 = \frac{3A_1}{3A_1 + A_2}$$

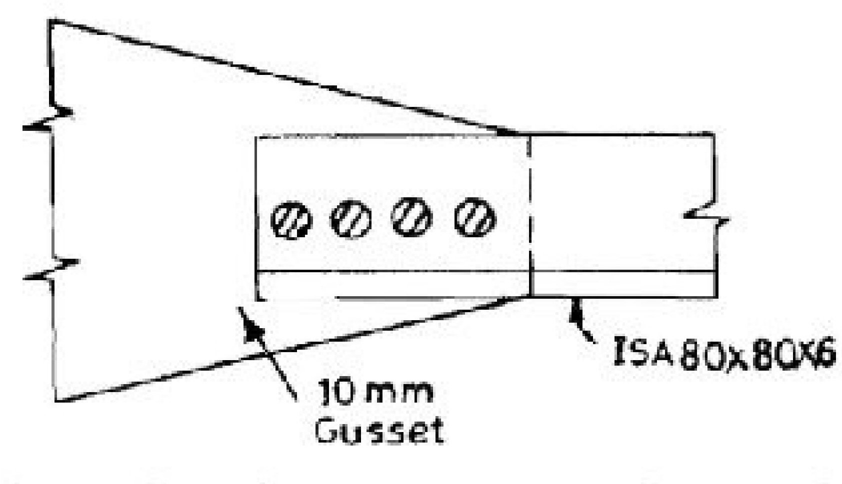
$$= \frac{3 \times 1603}{3 \times 1603 + 950}$$

$= 0.835$

Net area of the angle = $1603 + 0.835 \times 950$

$= \mathbf{2396.25 \text{ mm}^2}$

4.



A member of a truss consists of two angles, ISA 80 × 80 × 6 mm thick placed back-to-back. It carries a direct load of 150 *k*N and is connected to a gusset plate of 10 mm thick placed in between the two connected legs. The number of 18 mm diameter shop rivets required for the joint. Assume that power-driven shop rivets are used, whose strengths are given below will be

For power-driven shop rivets,

F = 102.5 N/mm² (shear),

F_b = 236 N/mm² (bearing).

The rivets are in double shear. They bear angainst the 10 mm thick gusset plate and the 6 mm thick connecting legs of two angles.

Solution: Strength of rivet in double shear

$$= 2 \times \frac{\pi}{4}(19.5)^2 \times 102.5 = 61200 \text{ N}$$

Strength of rivet bearing on 100 mm plate

$$= 19.5 \times 10 \times 236 = 46002 \text{ N}$$

Strength in bearing on two 6 mm angles

$$= 2 \times 19.5 \times 6 \times 236 = 55220 \text{ N}$$

Gross diameter of rivet is taken as 1.5 mm greater than the nominal diameter

$\therefore$ Rivet value = 46020 N

Number of rivets required for carrying the 150 kN direct load

$$= \frac{150 \times 1000}{46020} = 3.26$$

Hence Provide 4 rivets.

5. A single ISA 100 × 75 × 10 is used as a tension member with the longer leg connected to a 10 mm thick gusset plate. The connection is made with the help of a lug angle. The net area required will be [Use 20 diameter rivets σ_{at} = 150 MPa. Permissible shear and bearing stress in rivet is 100 MPa and 300 MPa respectively. Sections available for lug angles are

[ISA 60 × 60 × 8 – 896 mm², ISA 60 × 60 × 10 – 1100 mm², ISA 70 × 70 × 8 – 1200mm²]

Solution: Nominal diameter = 20 + 1.5 = 21.5 mm

Strength of rivets.

$$\text{In bearing} = \frac{300}{1000} \times 21.5 \times 10 = 64.5 \text{ kN}$$

$$\text{In single shear} = \frac{100}{1000} \times \frac{\pi}{4} \times (21.5)^2 = 36.3 \text{ kN}$$

Rivet value = 36.3 kN

Gross area of angle = 100 × 10 + 65 × 10

$$= 1650 \text{ mm}^2$$

Net area of angle = 1650 – 21.5 × 10 = 1435 mm²

$$\text{Strength of member} = \frac{150}{1000} \times 1435 = 215.25 \text{ kN}$$

Since 100 mm leg is connected to gusset plate, width of outstanding leg = 75 – 10 = 65 mm

Strength of outstanding leg

$$= \left(\frac{65}{65 + 1000}\right) \times 215.25 = 84.79 \text{ kN}$$

Strength of connected leg = 215.25 – 84.79

$$= 130.46 \text{ kN}$$

Required strength of lug angle = 1.2 × 84.79

$$= 101.748 \text{ kN}$$

$$\text{Net area required, } A_{net} = \frac{101.7481 \times 1000}{150}$$

$$= 678.32 \text{ mm}^2$$

6. A splice is used connect a 250 mm × 20 mm plate with a 250 mm × 12 mm plate. The design load is 400 kN. Find the number of rivets required

Solution : Assuming that one face of each plate is flush with each-other, a 250 mm x 8mm filler plate will be required. Use two splice plates of size 250 mm x 12 mm, one on each face.

Strength of a 20 mm diameter rivet

$$\text{in double shear} = 2 \times \frac{\pi}{4}(2.15)^2 \times 10.05$$

$$= 72.97 \text{ kN}$$

in bearing on 12 mm plate = 2.15 × 1.2 × 23.2

$$= 59.86 \text{ kN}$$

$\therefore$ Rivet value = 59.86 N

$$\text{Number of rivets} = \frac{400}{59.86}$$

$$= 6.68, \text{ say, } 7$$

7. An angle ISA 150 × 75 × 10 mm thick, steel tension member is connected by its long leg to a 10 mm gussetplate. Use 6 mm fillet weld on the toe and the back. Take the allowable unit shearing stress for weld metal as 112.5 N/mm². In the welded joint the force taken by the weld on the back will be

Solution:

Area of connected leg,

$$A_1 = (150 - 5) \times 10 \text{ as } 1450 \text{ mm}^2$$

Area of outstanding leg,

$$A_2 = (75 - 5) \times 10 = 700 \text{ mm}^2$$

$$K_1 = \frac{3A_1}{3A_1 + A_2}$$

$$= \frac{3 \times 1450}{3 \times 1450 + 700}$$

$$= 0.861$$

Effective area = $A_1 + K_1A_2$ = 1450 + 0.861 × 700

$$= 2053 \text{ mm}^2$$

Allowable tensile stress = 150 N/mm²

Allowable load = 150 × 2053 = 307950 kg

Strength of 6 mm fillet weld = 6 × 0.7 × 112.5

$$= 473 \text{ N/mm.}$$

Strength of 8 mm fillet weld = 8 × 0.7 × 112.5

$$= 630 \text{ N/mm.}$$

Distance of centroidal axis of angle from its back is 53.2.

Then force taken by the weld on the back,

$$P1 = \frac{150 - 53.2}{150} \times 307950 = 198730.4 \text{ N}$$

DESIGN OF COMPRESSION MEMBERS

A structural member loaded axially in compression is generally called a *compression member.* Vertical compression members in buildings are called *columns, posts or stanchions.* Compression members in roof trusses are called *struts* and in a crane is called a *boom.*

Columns which are short are subject to crushing and behave like members under pure compression. Columns which are long tend to buckle out of the plane of the load axis.

Theory of Columns

Euler's formula for critical load for a pin-ended column subject to axial load is,

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

where L = length of column between the hinged ends;

E = modulus of elasticity, and

I = moment of inertia of the column section.

The column will become unserviceable if the loads are larger than P_{cr}. In the Euler equation, it is assumed that stress is proportional to strain, therefore

$$\text{Critical stress} = \frac{P_{cr}}{A} = \frac{\pi^2 EI}{AL^2} = \frac{\pi^2 E}{\left(\frac{L}{r}\right)^2}$$

where A = area of cross-section, and

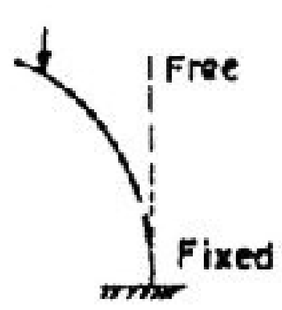
r = radius of gyration about the bending axis.

Various end conditions

Columns with length L and effective length l are shown in the figure.

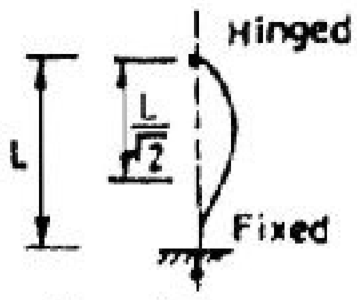
Case (1)

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$



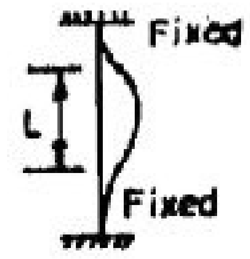
Case (2)

$$P_{cr} = \frac{\pi^2 EI}{(2L)^2}$$



Case (3)

$$P_{cr} = \frac{2\pi^2 EI}{L^2}$$



Case (4)

$$P_{cr} = \frac{4\pi^2 EI}{L^2}$$

Strength of an Axially Loaded Compression Members

Maximum axial compression load permitted on a compression member,

$$P = \sigma_{ac} \times A$$

where P = axial compressive load (N);

σ_{ac} = permissible stress in axial compression (MPa);

A = effective cross-sectional area of the member $(mm)^2$

Indian Standard IS 800:1984 (second revision)

It stipulates that the direct stress on the cross-sectional area of axially loaded compression members should not exceed 0.6 f_y nor the permissible stress calculated using the Merchant-Rankine formula

Permissible stress in axial compression (MPa);

$$\sigma_{ac} = 0.6 \times \frac{f_{cc} \times f_y}{\left[f_{cc}^n + f_y^n\right]^{1/n}}$$

where f_y = yield stress of steel (MPa);

f_{cc} = elastic critical stress in compression

$$= \frac{\pi^2 E}{\lambda^2}$$

$$\lambda = \frac{l}{r}$$

where l = effective length of the member

r = appropriate radius of gyration of the member

E = modulus of elasticity = 2×10^5 MPa; and

n = a factor assumed as 1.4

Effective Length

Table below gives the values of effective lengths recommended by the Indian Standard IS : 800. The actual length L of the compression member should be taken as the length from centre-to-centre of intersection of supporting members or the cantilevered length in the case of free standing struts.

Table : Equivalent lengths for various end conditions

	Type	Effective length of member l
1.	Effectively held in position and restrained in direction at both ends.	0.67L
2.	Effectively held in position at both ends restrained in direction at one end.	0.85L
3.	Effectively held in position at both ends but not restrained in direction.	L
4.	Effectively held in position and restrained in direction at one end and at the other end effectively restrained in direction but not held in position.	L
5.	Effectively held in position and restrained in direction at one end and at the other end partially restrained in direction but not held in position.	1.5L
6.	Effectively held in position and restrained in direction at one end but not held in position or restrained in direction at the other end.	2.0L

Note 1: L is the unsupported length of compression member.

Note 2 : For battened struts the effective length should be increased by 10 per cent,

Maximum Slenderness Ratio

According to Indian Standard IS : 800, the slenderness ratio should not exceed the values

given in the Table below.

	Type of member	Slenderess s ratio $1 = \frac{l}{r}$
1	A member carrying compressive loads resulting from dead and superimposed loads.	180
2	A member subject to compressive loads resulting from wind/earthquake forces provided the deformation of such members does not adversely affect the stress in any part of the structure.	250
3	A member normally carrying tension but subjected to reversal of stress due to wind or earthquake forces.	350

Angle Struts

Single angle discontinuous struts connected by a single rivet or bolt may be designed for axial load only provided the compressive stress does not exceed 0.80 σ_{ac}. The value of σ_{ac} can be determined on the basis that the effective length l of the strut is from centre-to-centre of intersection at each end and r is the minimum radius of gyration. In no case, the $\left(\frac{l}{r}\right)$ ratio for single angle struts should exceed 180.

If a single discontinuous strut is connected by a weld or by two or more rivets or bolts in line along the angle at each end, it may be designed for axial load only provided the compression stress does not exceed σ_{ac} arrived at on the basis that l is taken as 0.85 times the length of the strut, centre-to-centre of intersection at each end, and r is the minimum radius of gyration.

For double angle struts which are discontinuous, back-to-back connected to both sides of the gusset or section by not less than two bolts or rivets in line along the angles at each end or by the equivalent in welding, the load may be regarded as applied axially. The effective length l in the plane of end gusset could be taken between 0.7 and 0.85 times the distance between intersections depending on the restraint provided; in the plane perpendicular to that of the end gusset, the effective length should be taken as equal to the distance between centres of intersections. The calculated average compressive stress should not exceed values of σ_{ac} obtained for the appropriate slenderness ratios. The angles should be connected together with tack rivets or welds at intervals along their lengths,

Compression Members Composed of Back-to-Back Components

A compression member composed of two angles, channels or tees, back-to-back, in contact or separated by a small distance should be connected together by riveting, bolting or welding so that the slenderness ratio of each member between the connections is not greater than 40 nor greater than 0.6 times the most unfavourable slenderness ratio of the strut as a whole. In no case, the spacing of tacking rivets in a line exceed 600 mm for such members.

For other types of build-up compression members, where cover plates are used, the pitch of tacking rivets should not exceed 32 t or 300 mm, whichever is less, where t is the thickness of the thinner outside plate. Where plates are exposed to bad weather conditions, the pitch should not exceed 16t or 200 mm, whichever is less.

The rivets, welds and bolts in these connections should be sufficient to carry the shear force and bending moments, if any, specified for battened struts. Diameter of the connecting rivets should not be less than the minimum diameter given in the table below;

Thickness of member	Minimum diameter of rivets
Up to 10 mm	16 mm
Over 10 mm up to 16 mm	20 mm
Over 16 mm	22 mm

Solid packing or washers should be used for riveting, bolting or welding, where the members are separated back-to-back.

The ends of struts should be connected together with not less than two rivets or bolts or their equivalent in welding and there should be not less than two additional connections spaced equidistant in the length of the strut.

A minimum of two rivets or bolts should be used in each connection; one on line of each gauge mark, where the legs of the connected angles or tables of the connected tees are 125 mm wide or over, or where the webs of channels are 150 mm wide or over.

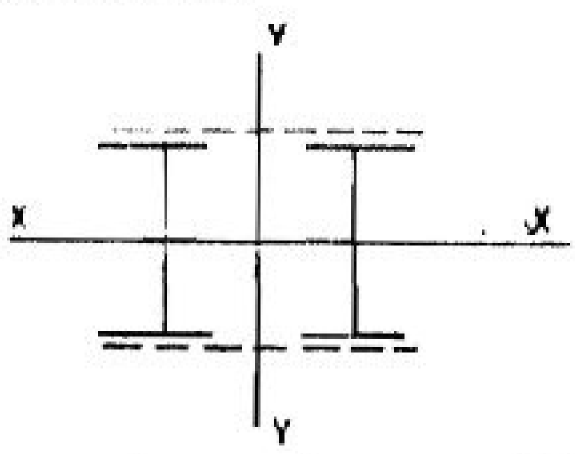
Lacings and Battens for Built-up Compression Members

As per Indian Standard IS 800-1984, the following specifications are used for design of lacing and batten plates :

In a built-up section, the different components are connected together so that they act as a single column. Lacing is generally preferred in case of eccentric loads. Battening is normally used for axially loaded columns and in sections where the components are not far apart. Flat bars are generally used for lacing. Angles, channels and tubular sections are also used for lacing of very heavy columns. Plates are used for battens.

Lacings

A lacing system should generally conform to the following requirements :



(i) The compression member comprising two main components laced and tied should, where practicable, have a radius of gyration about the axis perpendicular to the plane of lacing not less than the radius of gyration at right angles to that axis.

(ii) The lacing system should not be varied throughout the length of the strut as far as practicable.

(iii) Cross (except tie plates) should not be provided along the length of the column with lacing system, unless all forces resulting form deformation of column members are calculated and provided for in the lacing and its fastening.

(iv) The single-laced systems on opposite sides of the main components should preferably be in the same direction so that one system is the shadow of the other.

(v) Laced compression members should be provided with tie plates at the ends of the lacing system and at points where the lacing systems are interrupted. The tie plates should be designed by the same method as followed for battens.

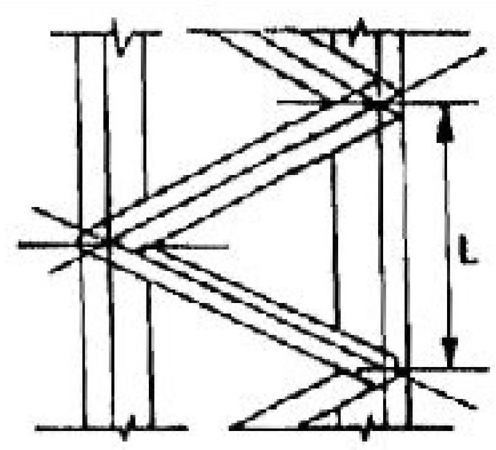
Guidelines for the design of lacing system

(i) The angle of inclination of the lacing with the longitudinal **axis** of the column should be between 40° to 70°

(ii) The slenderness ratio $\frac{l_e}{r}$ of the lacing bars should not exceed 145.

(iii) The effective length l_e of the lacing bar should be according to the Table given below

Type of lacing	Effective length, l_e
1. Single lacing, riveted at ends.	Length between inner end rivets on lacing bar.
2. Double lacing, riveted at ends and at inter-sections.	0.7 times the length between end rivets on lacing bars.
3. Welded lacing.	0.7 times the distance between inner ends of effective lengths of welds at ends.



(iv) For riveted or welded lacing system, $\left(\frac{L}{r^c_{min}}\right) > 50$ or 0.7 times maximum slenderness ratio of the compression member as a whole, whichever is less.

Here L = distance between the centres of connections of the lattice bars, and

r^c_{min} = the minimum radius of gyration of the components of the compression member.

(v) Minimum width of lacing bars in riveted connections should be according to the Table given below:

Nominal rivet diameter (mm)	22	20	18	16
Width of lacing bars (mm)	65	60	55	50

(vi) *Minimum thickness of lacing bars* :

$t < \frac{l}{40}$, for single lacing;

$< \frac{l}{40}$, for double lacing,

where l = length between inner end rivets.

(vii) The lacing of compression members should be designed to resist a transverse shear, V = 2.5 per cent of the axial force in the member. The shear is divided equally among all transverse lacing systems in parallel planes. The lacing system should also be designed to resist additional shear due to bending if the compression member carries bending due to eccentric load, applied end moments, and/or lateral loading.

(viii) The riveted connections may be made in two ways, as shown in the figure *(a)* and *(b)*.

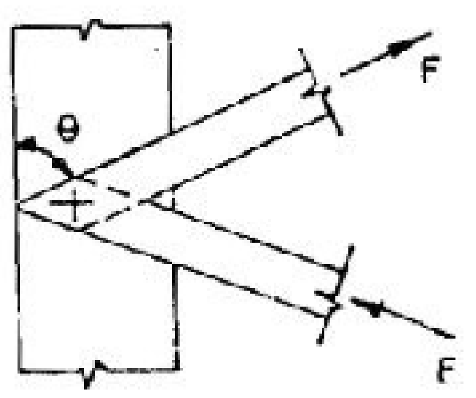


Fig- (a)

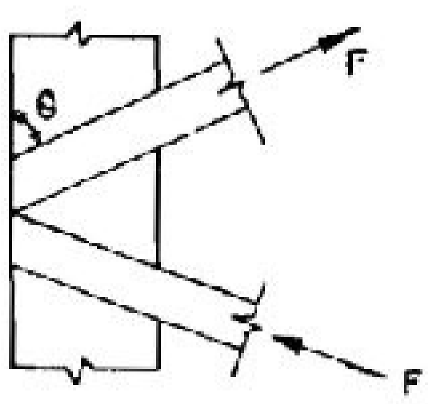


Fig. (b)

Welded Connections

Lap joint — Overlap should be not less than $\frac{1}{4}$ times thickness of bar or member, whichever is less.

Butt joint — Full penetration butt weld or fillet weld on each side; lacing bar should be placed opposits to flange or stiffening component of main member.

Battens

Compression members composed of two main components battened should preferably have these components of the samecross-section and symmetrically disposed about their X-X axis.

The battens should be placed opposite to each-other at each end of the member and at points where the member is stayed in its length, and should as far as practicable, be spaced and proportioned uniformaly throughout.

The effective length of columns should be increased by 10 per cent

Design details of battens

(i) Spacing of batten C, from centre-to-centre of end fastening should be such that the slenderness ratio of the lesser main component, $\frac{C}{r^{c}_{min}} > 50$ or 0.7 times the slenderness ratio of the com pression member as a whole about the X-X axis (parallel to battens), whichever is less.

(ii) Effective depth of battens, d shall be taken as distance between end rivets or end welds.

$d > \frac{3}{4} a$ for intermediate battens;

$d > a$ for end battens and

$d > 2b$ for any batten;

where d = effective depth of batten

a = centroid distance of members

b = width of member in the plane of battens.

(iii) Thickness of battens, $t > \left(\frac{l_b}{50}\right)$

where l_b = distance between the innermost connecting line of rivets or welds.

Design of Battens

Battens should be designed to carry bending moment and shear arising from a transverse shear,

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

where P = total axial load in the compression member

Transverse shear V is divided equally between the parallel planes of battens. Battens and their connections to main components resist simultaneously a

Longitudinal shear, $V_1 = \frac{V \times C}{N \times S}$

and moment, $M = \frac{V \times C}{2N}$

due to transverse shear V

where, C = spacing of battens

N = number of parallel planes of battens

S = minimum transverse distance between centroids of rivet group or welding.

The end connections should also be designed to resist the longitudinal shear force V_1 and the moment M.

For welded connection,