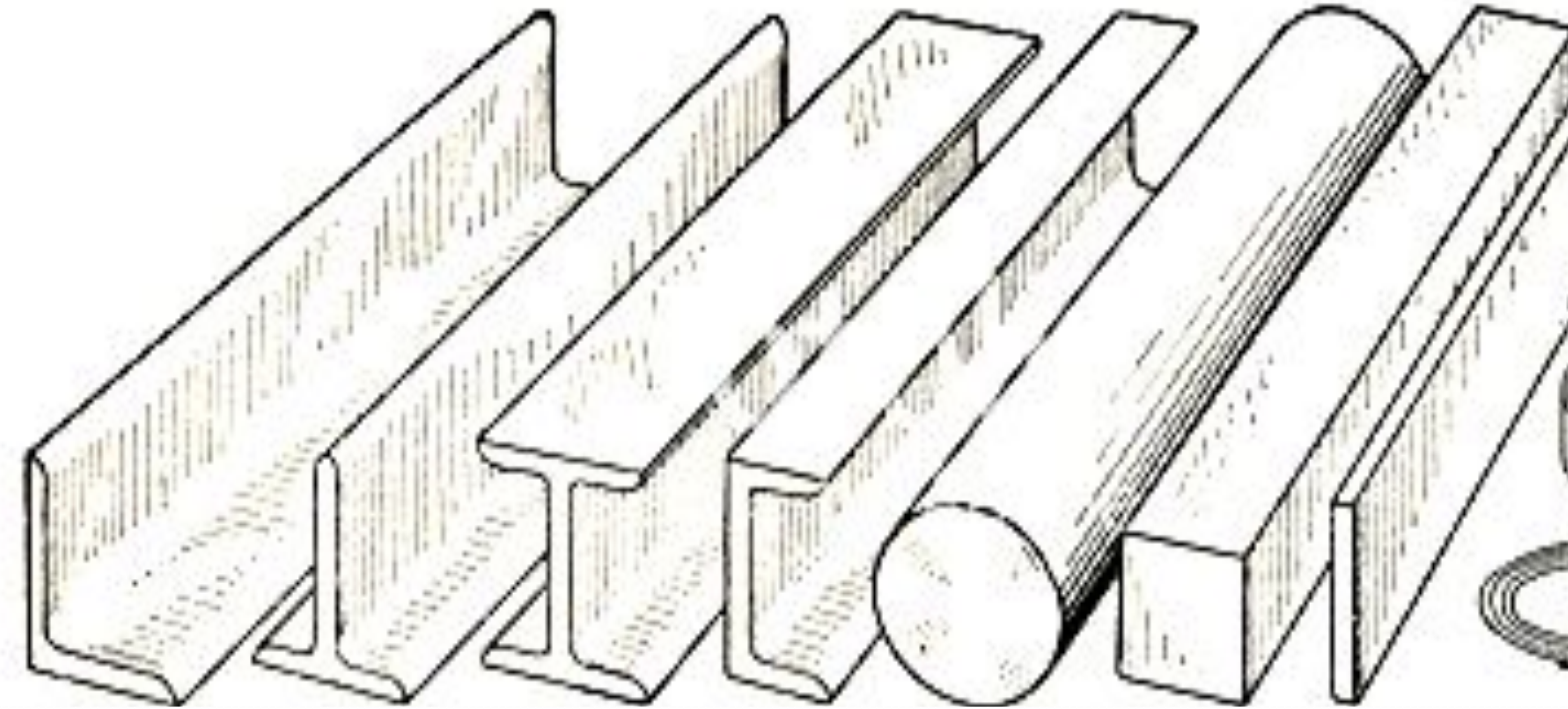
Module 2

Tension Members

Rolled Structural Steel Sections

- The steel sections manufactured in rolling mills and used as structural members are known as rolled structural steel sections.
- The steel sections are named according to their cross sectional shapes.
- The shapes of sections selected depend on the types of members which are fabricated and to some extent on the process of erection.
- Many steel sections are readily available in the market and have frequent demand.
  - Such steel sections are known as regular steel sections.
- Some steel sections are rarely used.
  - Such sections are produced on special requisition and are known as special sections. ‘
- ISI Handbook for Structural Engineers’ gives nominal dimensions, weight and geometrical properties of various rolled structural steel sections.



TYPES OF ROLLED STRUCTURAL STEEL SECTIONS

- The various types of rolled structural steel sections manufactured and used as structural members are as follows:
  - Rolled Steel I-sections (Beam sections).
  - Rolled Steel Channel Sections.
  - Rolled Steel Tee Sections.
  - Rolled Steel Angles Sections.
  - Rolled Steel Bars.
  - Rolled Steel Tubes.
  - Rolled Steel Flats.
  - Rolled Steel Sheets and Strips.
  - Rolled Steel Plates.

ROLLED STEEL BEAM SECTIONS

The rolled steel beams are classified into following four series as per BIS : (IS : 808-1989)

1. Indian Standard Joist/junior Beams	ISJB
2. Indian Standard Light Beams	ISLB
3. Indian Standard Medium Weight Beams	ISMB
4. Indian Standard Wide Flange Beams	ISWB

The rolled steel columns/heavy weight beams are classified into the following two series as per BIS (IS : 808-1989)

1. Indian Standard Column Sections	ISSC
2. Indian Standard Heavy Weight Beams	ISHB

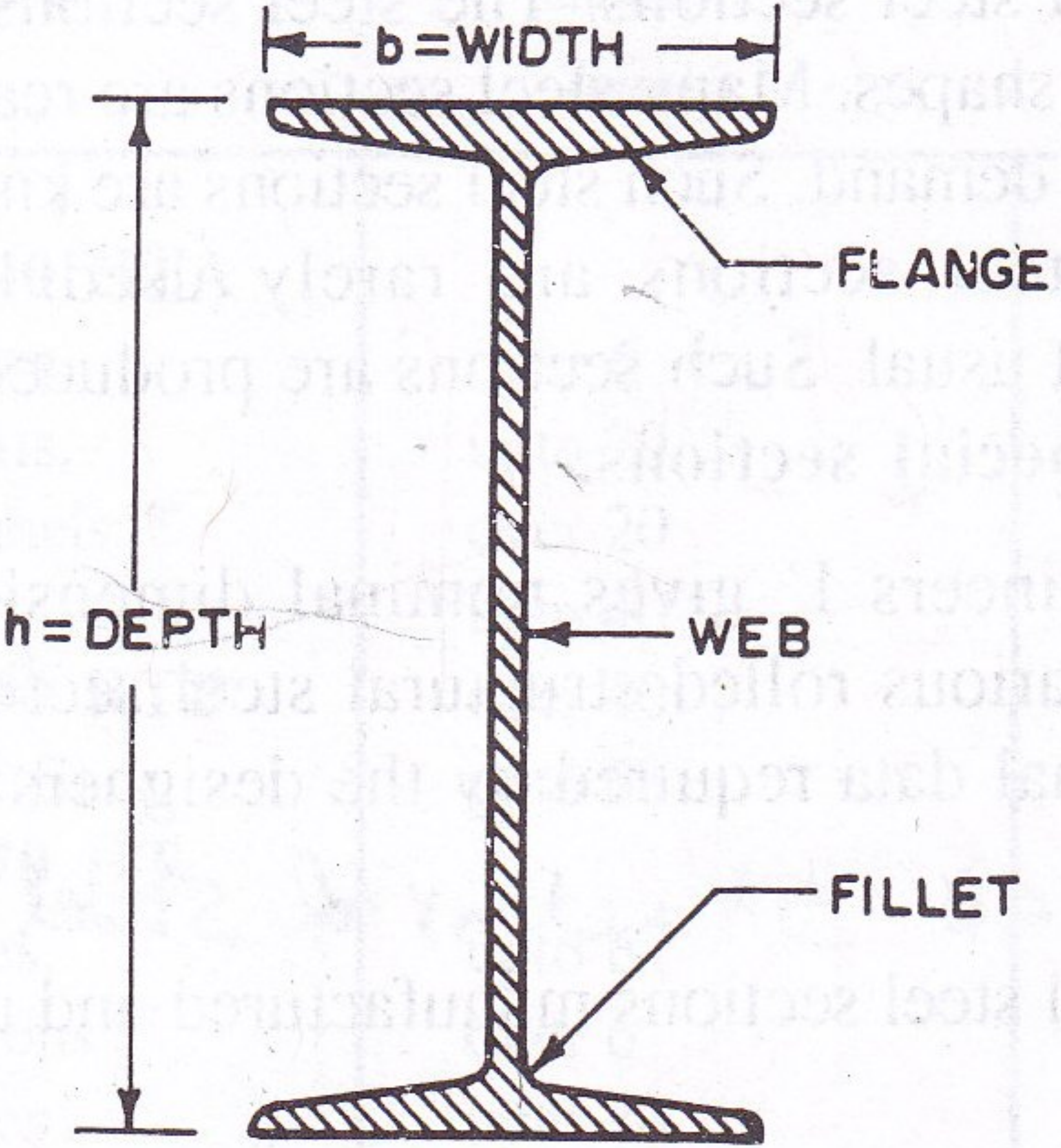
- The beam section consists of web and two flanges.
- The junction between the flange and the web is known as fillet.
- These hot rolled steel beam sections have sloping flanges.
- The outer and inner faces are inclined to each other and they intersect at an angle varying from 1½ to 8° depending on the section and rolling mill practice.
- The angle of intersection of ISMB section is 8°.
- Abbreviated reference symbols (JB, LB, MB, WB, SC and HB) have been used in designating the Indian Standard Sections as per BIS (IS 808-1989)

- The rolled steel beams are designated by the series to which beam sections belong (abbreviated reference symbols), followed by depth in mm of the section and weight in kN per metre length of the beam,
  - e.g., MB 225 @ 0.312 kN/m.
- H beam sections of equal depths have different weights per metre length and also different properties
  - e.g., WB 600 @ 1.340 kN/m,

    WB 600 @ 1.450 kN/m,

    HB 350 @0.674 kN/m,

    HB 350 @0.724 kN/m.



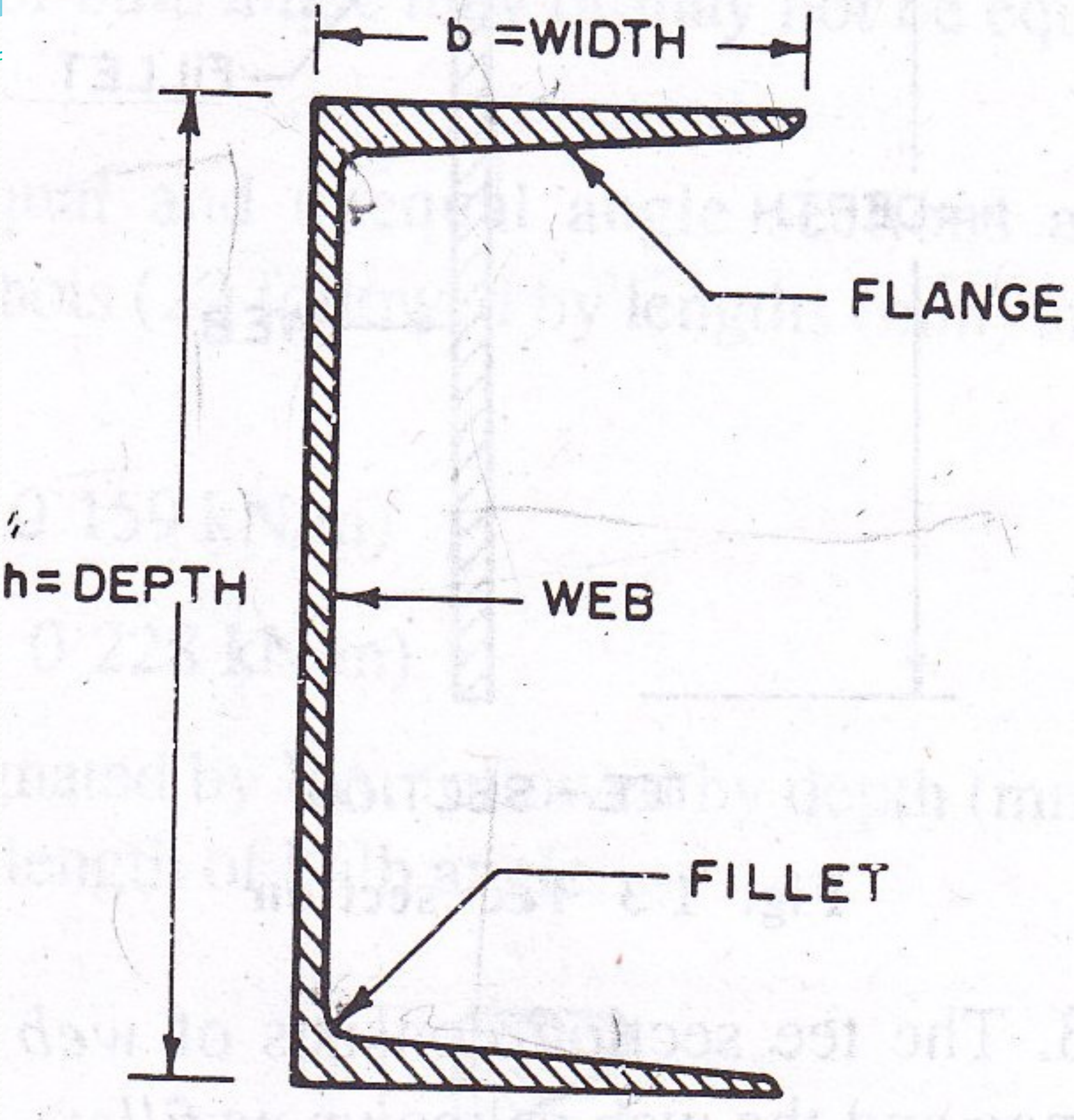
BEAM SECTION

- I-sections are used as beams and columns.
- It is best suited to resist bending moment and shearing force.
- In an I-section about 80 % of the bending moment is resisted by the flanges and the rest of the bending moment is resisted by the web.
- Similarly about 95% of the shear force is resisted by the web and the rest of the shear force is resisted by the flanges.
- Sometimes I-sections with cover plates are used to resist a large bending moment.
- Two I-sections in combination may be used as a column.

ROLLED STEEL CHANNEL SECTIONS

The rolled steel Channel sections are classified into four categories as per ISI, namely,

1. Indian Standard Joist/Junior Channels ISJC
2. Indian Standard Light Channels ISLC
3. Indian Standard Medium Weight Channels ISMC
4. Indian Standard Medium Weight Parallel Flange Channels ISMCP



CHANNEL SECTION

- The channel section consists of a web and two flanges.
- The junction between the flange and the web is known as fillet.
- The rolled steel channels are designated by the series to which channel section belong (abbreviated reference symbols), followed by depth in mm of the section and weight in kN per metre length of the channel,
  - e.g., MC 225 @ 0.261 kN/m
- Channels are used as beams and columns.
- Because of its shape a channel member affords connection of an angle to its web.
- Built up channels are very convenient for columns.
- Double channel members are often used in bridge truss.

- The channels are employed as elements to resist bending e.g., as purlins in industrial buildings.
- It is to note that they are subjected to twisting or torsion because of absence of symmetry of the section with regards to the axis parallel to the web, i.e., yy-axis.
    - Therefore, it is subjected to additional stresses.
- The channel sections are commonly used as members subjected to axial compression in the shape of built-up sections of two channels connected by lattices or batten plates or perforated cover plates.
- The built-up channel sections are also used to resist axial tension in the form of chords of truss girders.

As per IS : 808-1989, following channel sections have also been additionally adopted as Indian Standard Channel Secions

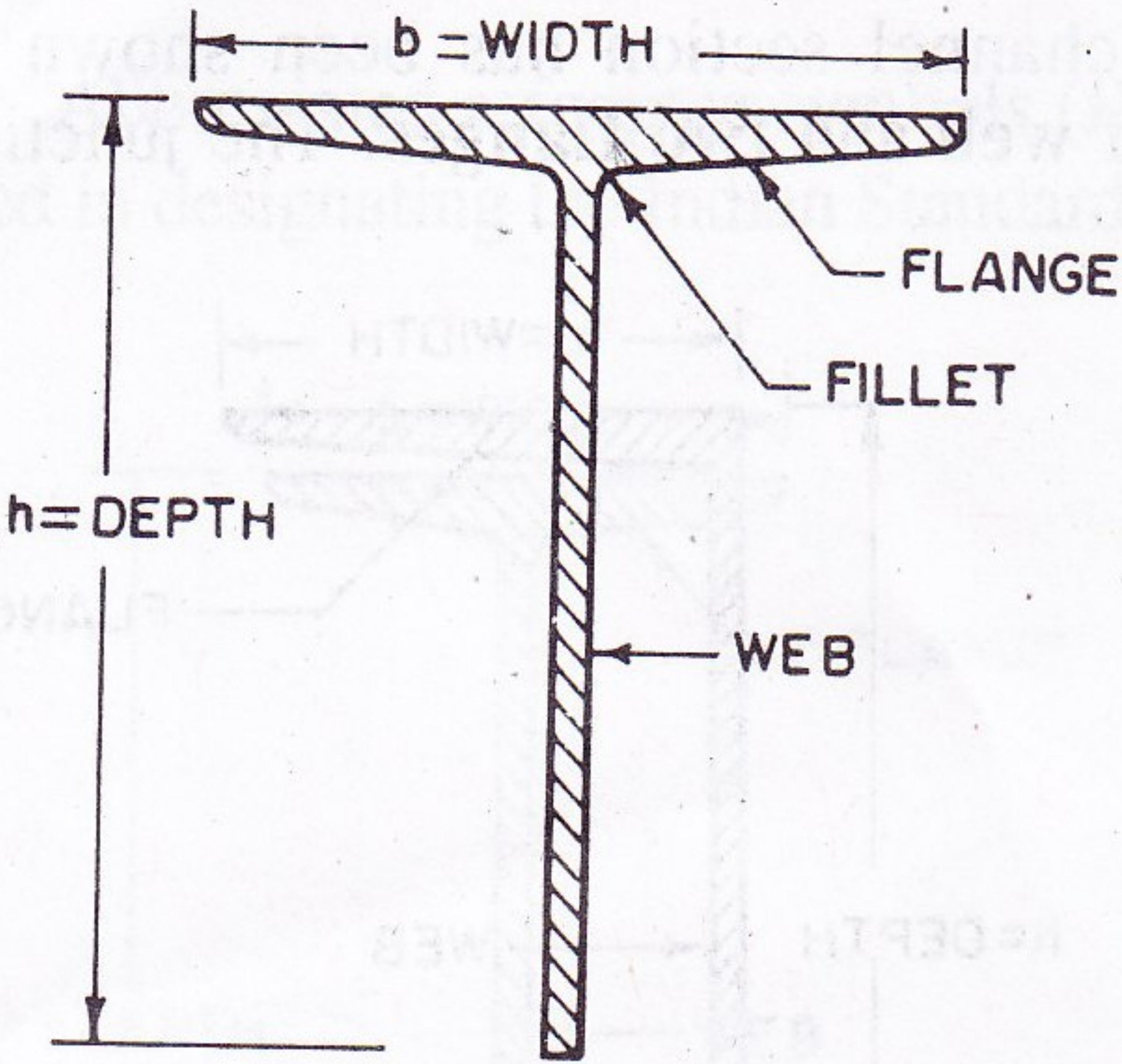
1. Indian Standard Light Channels with parallel flanges ISLC(P)
2. Medium weight channels MC
3. Medium weight channels with parallel flanges MCP
4. Indian Standard Gate Channels ISPG

In MC and MCP channel sections, some heavier sections have been developed for their intended use in wagon building industry. The method of designating MC and MCP channels is also same as that for IS channels.

ROLLED STEEL TEE SECTIONS

The rolled steel tee sections are classified into the following five series as per ISI:

1.	Indian Standard Normal Tee Bars	ISNT
2.	Indian Standard Wide flange Tee Bars	ISHT
3.	Indian Standard Long Legged Tee Bars	ISST
4.	Indian Standard Light Tee Bars	ISLT
5.	Indian Standard Junior Tee Bars	ISJT



TEE - SECTION

- The tee section consists of a web and a flange.
- The junction between the flange and the web is known as fillet.
- The rolled steel tee sections are designated by the series to which the sections belong (abbreviated reference symbols) followed by depth in mm of the section and weight in kN per metre length of the Tee,
  - e.g., HT 125 @ 0.274 kN/m.
- The tee sections are used to transmit bracket loads to the columns.
- These are also used with flat strips to connect plates in the steel rectangular tanks.

A per IS: 808-1984, following T-sections have also been additionally adopted as Indian Standard T-sections.

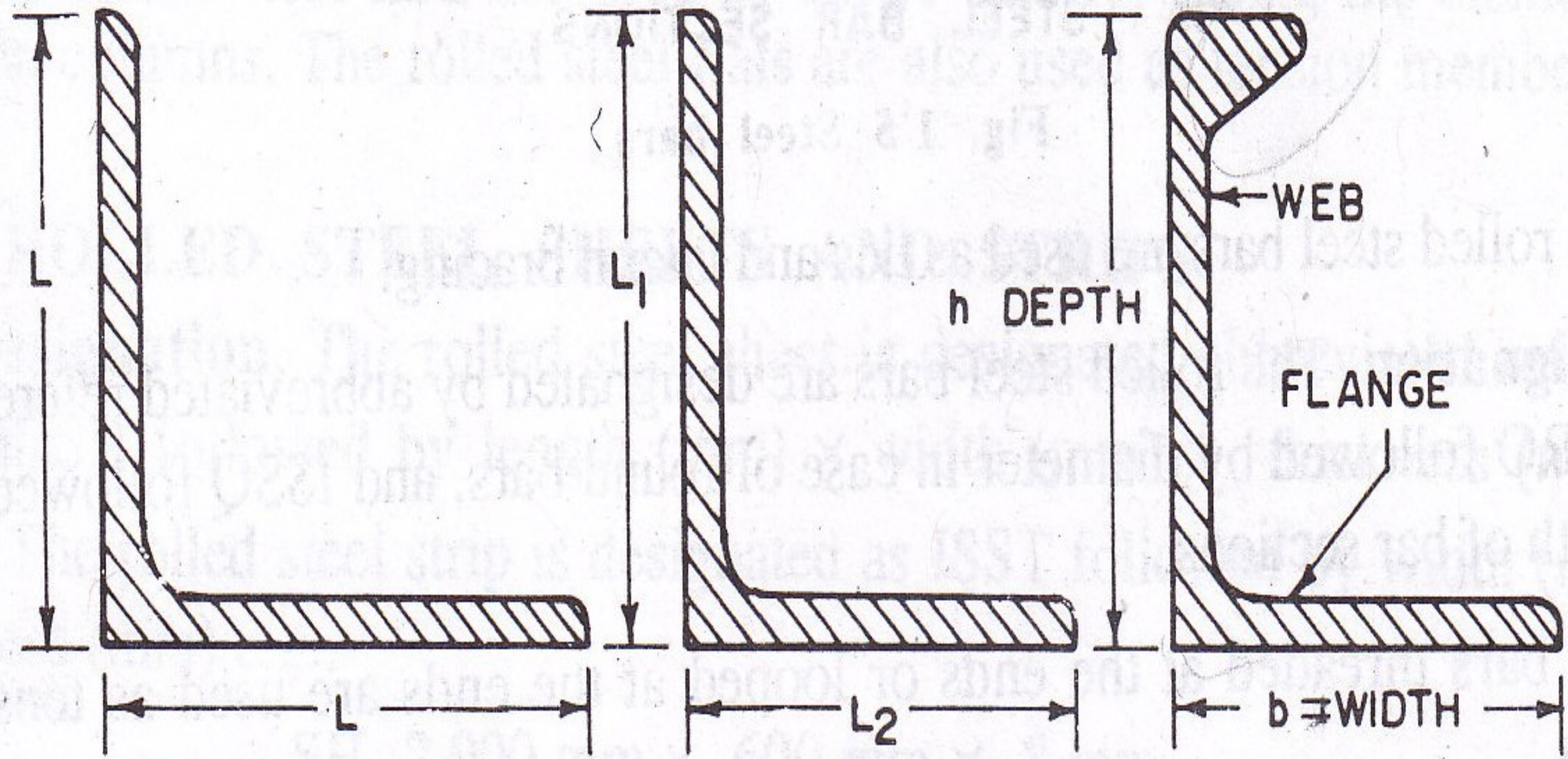
1. Indian Standard deep legged Tee bars ISDT
2. Indian Standard Slit medium weight Tee bars ISMT
3. Indian Standard Slit Tee bars from I-sections ISHT

It is to note that as per IS 808 (part II) 1978, H beam sections have been deleted.

ROLLED STEEL ANGLE SECTIONS

The rolled steel angle sections are classified in to the following three series.

1. Indian Standard Equal Angles	ISA
2. Indian Standard Unequal Angles	ISA
3. Indian Standard Bulb Angles	ISBA



L = LENGTH OF LEG   L = LENGTH OF LEG

(A) EQUAL ANGLE   (B) UNEQUAL ANGLE   (C) BULB ANGLE

ANGLE SECTIONS

- Angles are available as equal angles and unequal angles.
- The legs of equal angle sections are equal and in case of unequal angle section, length of one leg is longer than the other.
- Thickness of legs of equal and unequal angle sections are equal.
- The bulb angle consists of a web a flange and a bulb projecting from end of web.

The rolled steel equal and unequal angle sections are designated by abbreviated reference symbols ∟ followed by length of legs in mm and thickness of leg, e.g.,

∟130 x 130 x 8 mm (∟130 130 @ 0.159 kN/m)

∟200 x 100 x 10 mm (∟ 200 100 @ 0.228 kN/m)

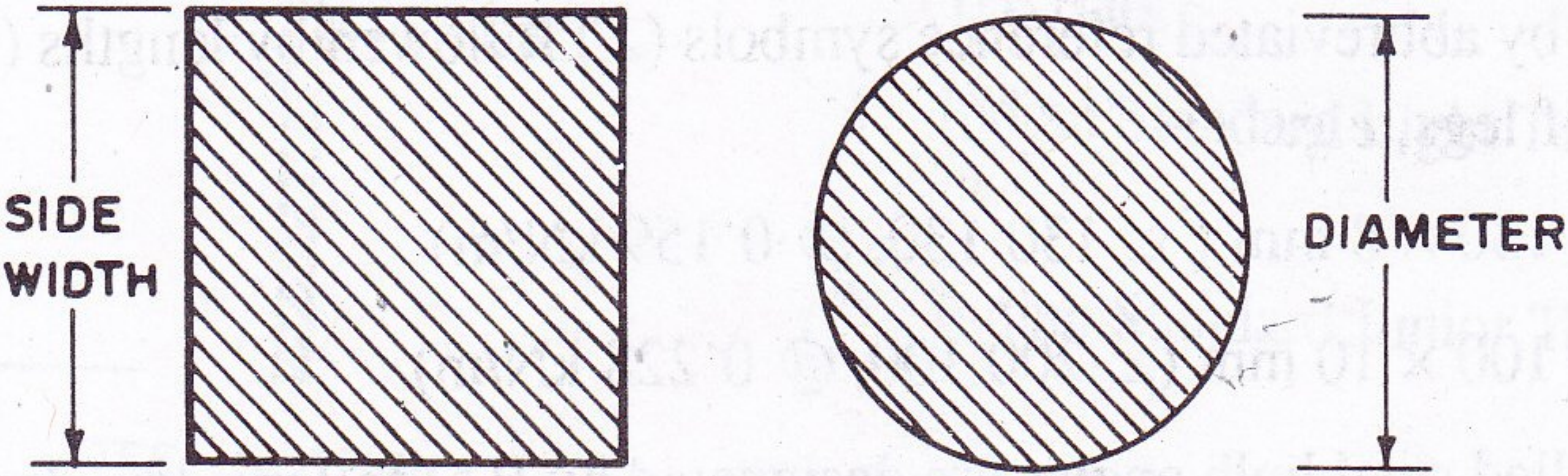
The rolled steel bulb angles are designated by BA, followed by depth in mm of the section and weight in kN per metre length of bulb angle.

- Angles have great applications in the fabrications.
- The angle sections are used as independent sections consisting of one or two or four angles designed for resisting axial forces (tension and compression) and transverse forces as purlins.
- Angles may be used as connecting elements to connect structural elements like sheets or plates or to form a built up section.
- The angle sections are also used as construction elements for connecting beams to the columns and purlins to the chords of trusses in the capacity of beam seats, stiffening ribs and cleat angles.
- The bulb angles are used in the ship buildings.
- The bulb helps to stiffen the outstanding leg when the angle is under compression.
- As per IS : 808-1984, some supplementary angle sections have also additionally adopted as Indian Standard angle sections.
- However prefix ISA has been dropped.
- These sections are designated by the size of legs followed by thickness e.g., ∟200 150 x 15.

ROLLED STEEL BARS

The rolled steel bars are classified in to the following two series:

1. Indian Standard Round Bars	ISRO
2. Indian Standard Square Bars	ISSQ



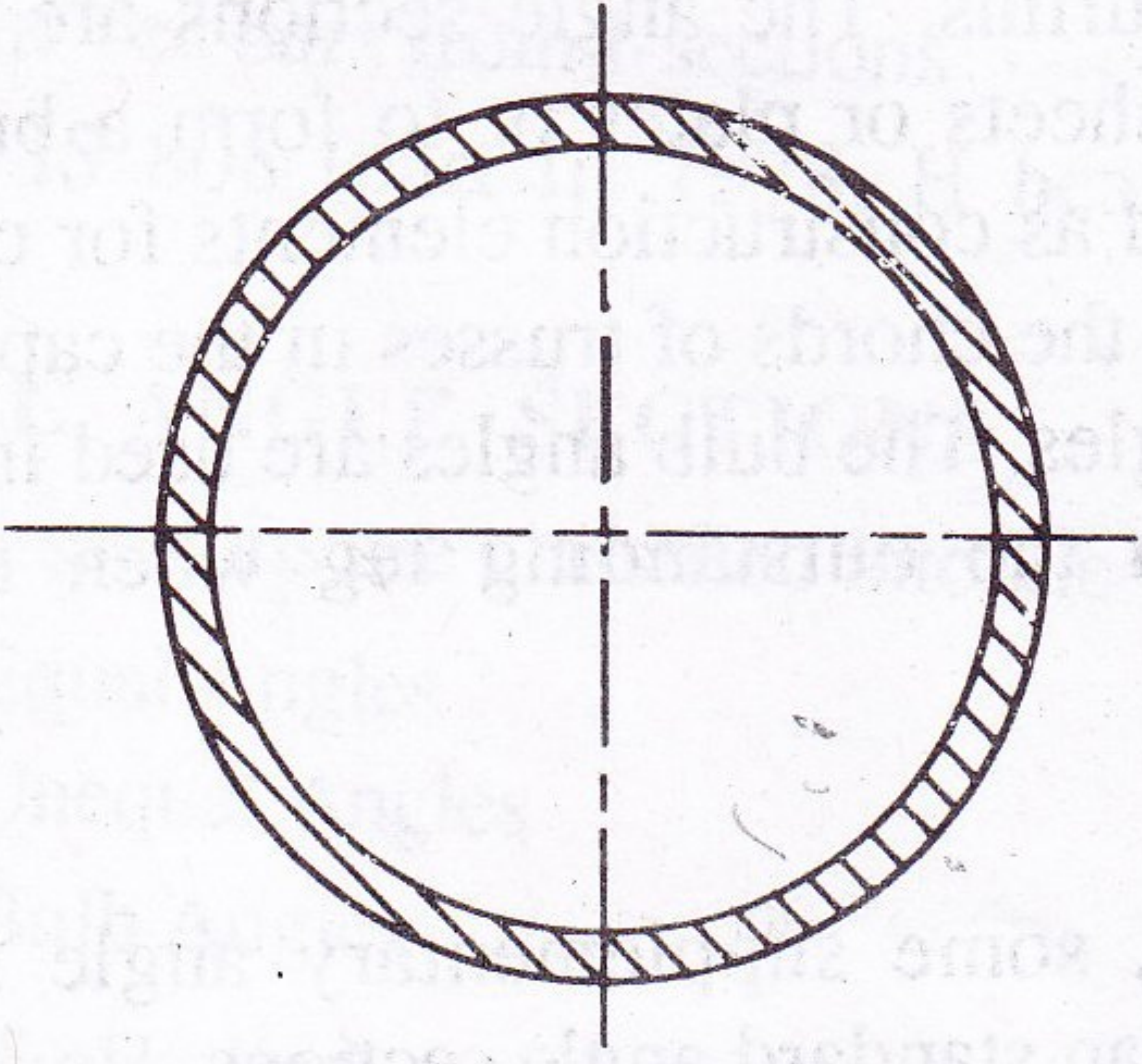
(A) SQUARE BAR (B) ROUND BAR

STEEL BAR SECTIONS

- The rolled steel bars are used as ties and lateral bracing.
- The rolled steel bars are designated by abbreviated reference symbol RO followed by diameter in case of round bars and ISSQ followed by side width of bar sections.
- The bars threaded at the ends or looped at the ends are used as tension members.

ROLLED STEEL TUBES

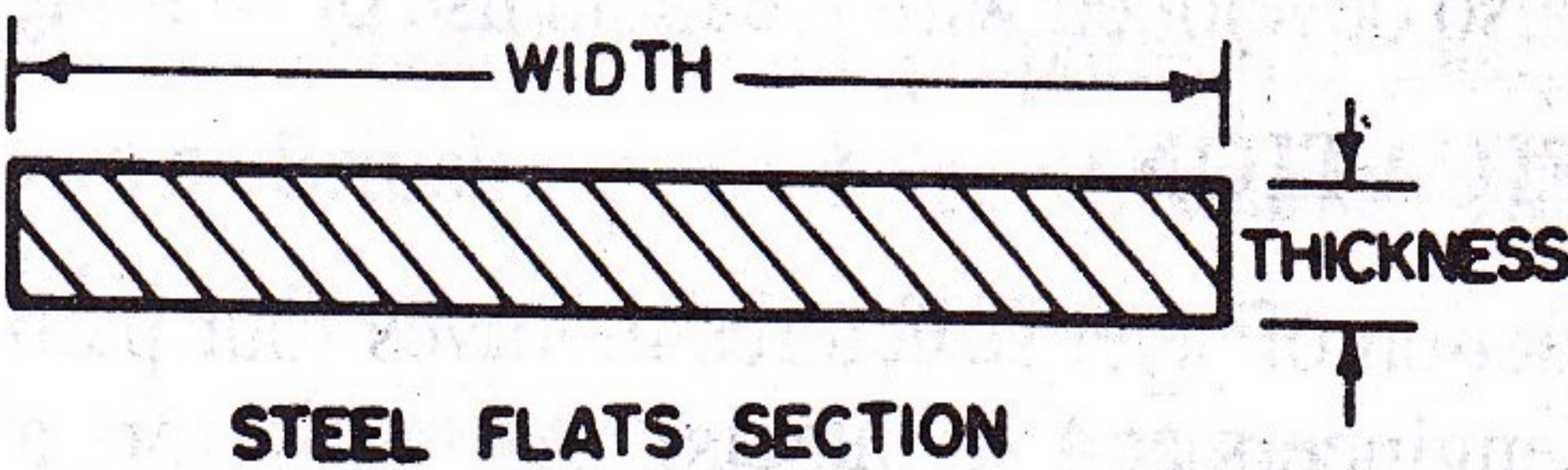
- The rolled steel tubes are used as columns and compression members and tension members in tubular trusses.
- The rolled steel tubes are efficient structural sections to be used as compression members.
- The steel tube sections have equal radius of gyration in all directions.



STEEL TUBES SECTION

ROLLED STEEL FLATS

- The rolled steel flats are used for lacing of elements in built up members, such as columns and are also used as ties.
- the rolled steel flats are designated by width in mm of the section followed by letters (abbreviated reference symbol) F and thickness in mm, e.g., 50 F 8.
  - This means a flat of width 50 mm and thickness 8 mm.
- The rolled steel flats are used as lattice bars for lacing the elements of built up columns.
- The rolled steel flats are also used as tension members and stays.


WIDTH
THICKNESS
STEEL FLATS SECTION

ROLLED STEEL SHEETS AND STRIPS

- The rolled steel sheet is designated by abbreviated reference symbol SH followed by length in mm x width in mm x thickness in mm of the sheet.
- The rolled steel strip is designated as ISST followed by width in mm x thickness in mm, e.g., SH 2000 x 600 x 8 and ISST 250 x 2.

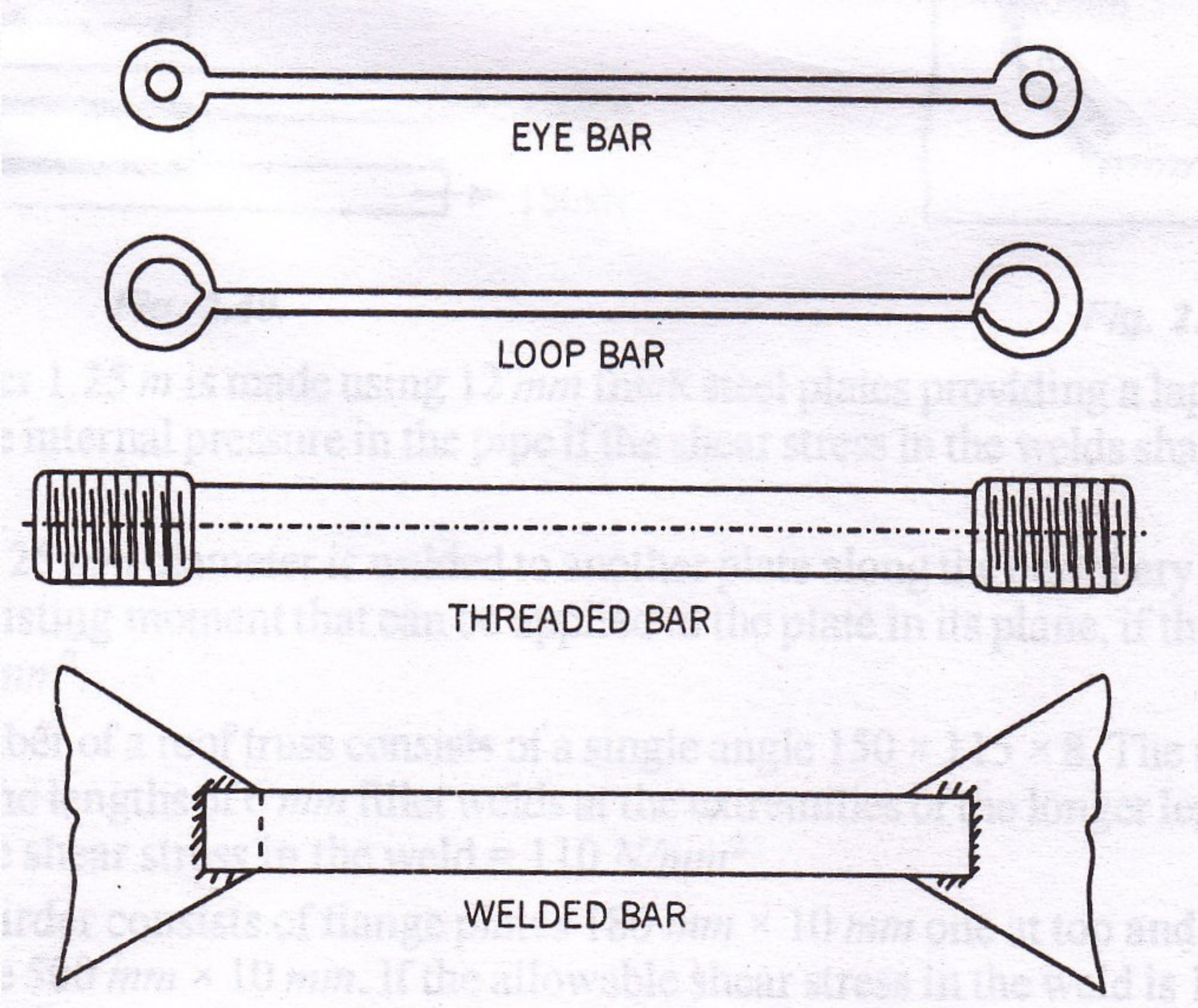
ROLLED STEEL PLATES

- The rolled steel plates are designated by abbreviated reference symbol PL followed be length in mm x width in mm x thickness in mm of the plates,
  - e.g., PL 2000 x 1000 x 6.
- The rolled steel sheets and plates are widely used in construction.
- Any sections of the required dimensions, thickness and configuration may be produced by riveting or welding the separate plates.
- The rolled plates are used in the web and flanges of plate girders, plated beams and chord members and web members of the truss bridge girders.
- The rolled steel plates are used in special plate structures,
  - e.g., shells, rectangular and circular steel tanks and steel chimneys.

Tension Member

- A tension member is a member which carries mainly a tensile force in the direction parallel to its longitudinal axis.
- A tension member is also called as a tie member or simply a tie.
- In some cases tension member also subjected to bending either due to eccentricity of the longitudinal load or due to transverse loads acting in addition to the main longitudinal load.
- A tension member is one of the most commonly occurring types of structural members.
- Tension members may occur either as minor tension members such as bars, flats, rods etc. or as major tension members of roof and bridge trusses

MINOR TYPES OF TENSION MEMBERS



Eye-bars

- These members are used where flexible end connections are desired
- They are used as the members of pin-connected truss bridges.
- Eye bars are made by first upsetting each end of a bar of rectangular section to a nearly round shape and then boring holes of the desired sizes on the enlarged ends.
- A pin is passed through the eye or the hole in the bar and also through corresponding holes in the other members meeting at the joint.
- The pin provides means of transmission of load from the eye bar to the other members at the joint.

Loop bars

- These are made by bending each end of a bar of square or round section, back upon the bar itself and then welding it so as to form a loop.
- Stress transmission is exactly similar to that in the eye-bar.

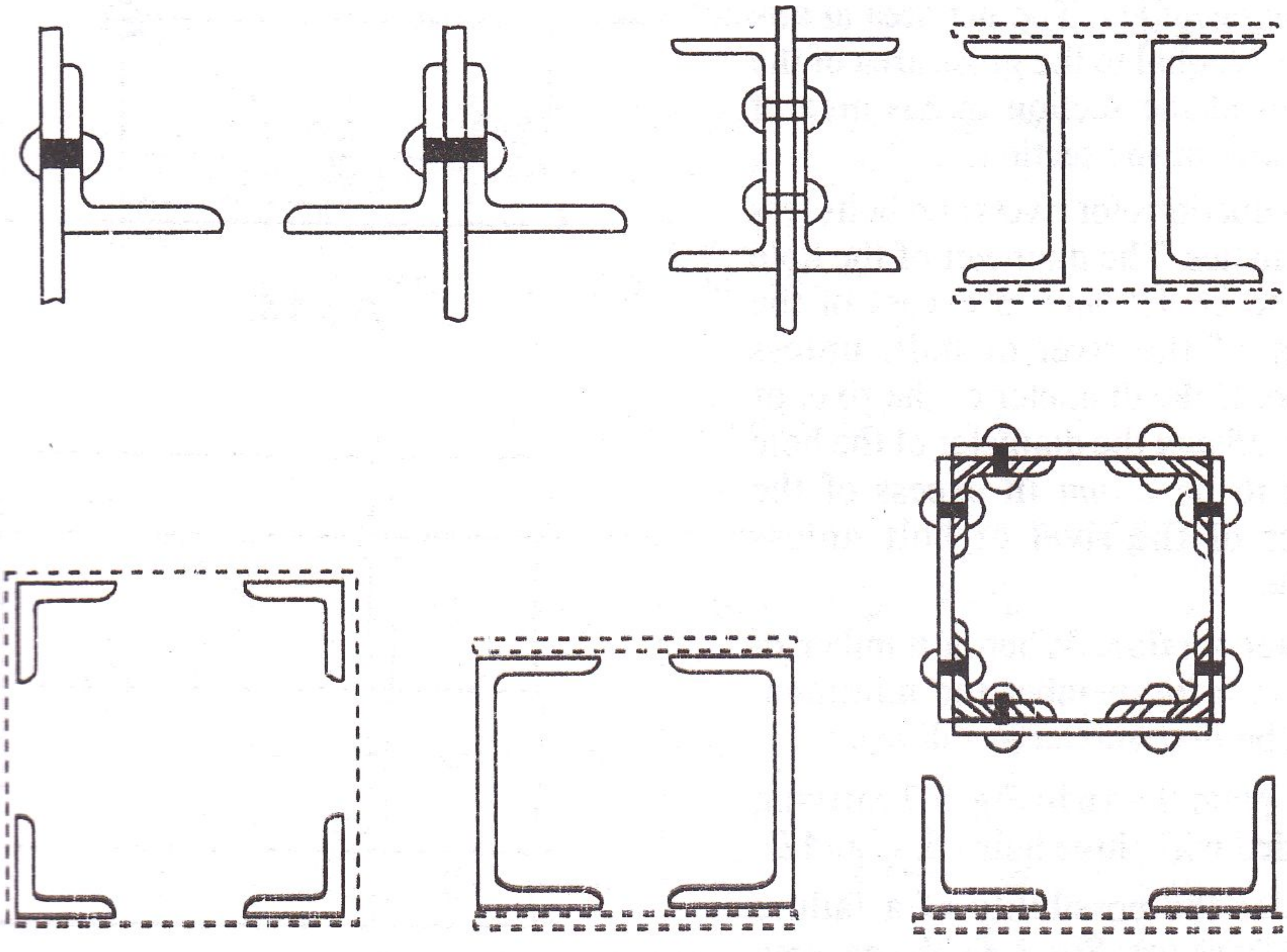
Welded bars

- These are flat bars carrying light tensile loads and welded at their ends.

Threaded bars

- These consist of round bars whose ends are threaded.
- Nuts are attached on the threaded ends after the bar has been placed in its proper position.
- The ends of the rod are first upset and then threaded so that the sectional area at the root of the threads is not less than the sectional area of the bar.
- After upsetting, usually the sectional area at the ends will be about 20 per cent greater than the sectional area of the bar.
- If a non-upset threaded bar is to be selected, the designer must select a bar in which the diameter at the root of the threads will be at least 1.5 mm greater than the normally required diameter.

MAJOR TYPES OF TENSION MEMBERS



- Single angle tension members are commonly used in roof trusses carrying light loads.
- They are also used as bracings for members of composite section.
- A single angle member transfers its load eccentrically to the gusset plate and is hence also subjected to bending moment.
- This factor should also be taken into account in the design.

- Double angle tension members are often used connected on either side of a gusset plate at the end.
- If provided in this manner eccentric load transfer to the gusset plate will be avoided and hence the member will be practically free from bending stresses.
- These are most commonly used in roof trusses and foot bridge trusses.

- Double channel tension members may also be used in a manner similar to double angle members.
- In view of considerably greater depth of web available two or even three rows of rivets can be provided.
- These members therefore require less length of gusset plate.
- Besides the above two angle members, four angle members with or without a plate; two channel members may be used as tension members in more heavily loaded bridge trusses.

Design Strength of Tension Members

The factored design tension T, in the members shall satisfy the following requirement (**Clause 6.1, IS:800-2007**) :

$$T < T_d$$

Where T_d = design strength of the member under axial tension.
T_d is the lowest of the design strength due to the

(i) yielding of gross-section, T_{dg} ,
(ii) rupture of critical section T_{dn} and
(iii) block shear failure, T_{db}.

Design Strength due to Yielding of Gross-section

The design strength of the member under axial tension, T_{dg} as governed by yielding of gross section is given by **(Clause 6.2, IS 800: 2007)**

$$T_{dg} = A_g f_y / \gamma_{m0}$$

Where,
f_y is the yield stress of material in MPa,
A_g is the gross area of cross-section
γ_{m0} is the partial safety factor of failure in tension by yielding (**Table 5, IS 800: 2007**)

Design Strength Due to Rupture of Critical Section

Plates

The design strength in tension of a plate, T_{dn} *as* governed by rupture of net cross-sectional area, A_n , at the holes is given by (**Cl. 6.3.1, IS 800: 2007**)

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

Where,

f_u is the ultimate stress of material in MPa,

A_n is the net effective area of cross-section

γ_{m1} is the partial safety factor of failure in tension at ultimate stress (**Table 5, IS 800: 2007**)

Threaded Rods

The design strength of threaded rods in tension, T_{dn} *as* governed by rupture is given by (**Cl. 6.3.2, IS 800: 2007**)

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

Where,

A_n is the net root area at the threaded section

Single Angles

The rupture strength of an angle connected through one leg is affected by *Shear Lag*. The design strength, T_{dn} as governed by rupture at net section is given by (**Cl. 6.3.3, IS 800: 2007**):

$$T_{dn} = 0.9 A_{nc} f_u / \gamma_{m1} + \beta A_{go} f_y / \gamma_{m0}$$

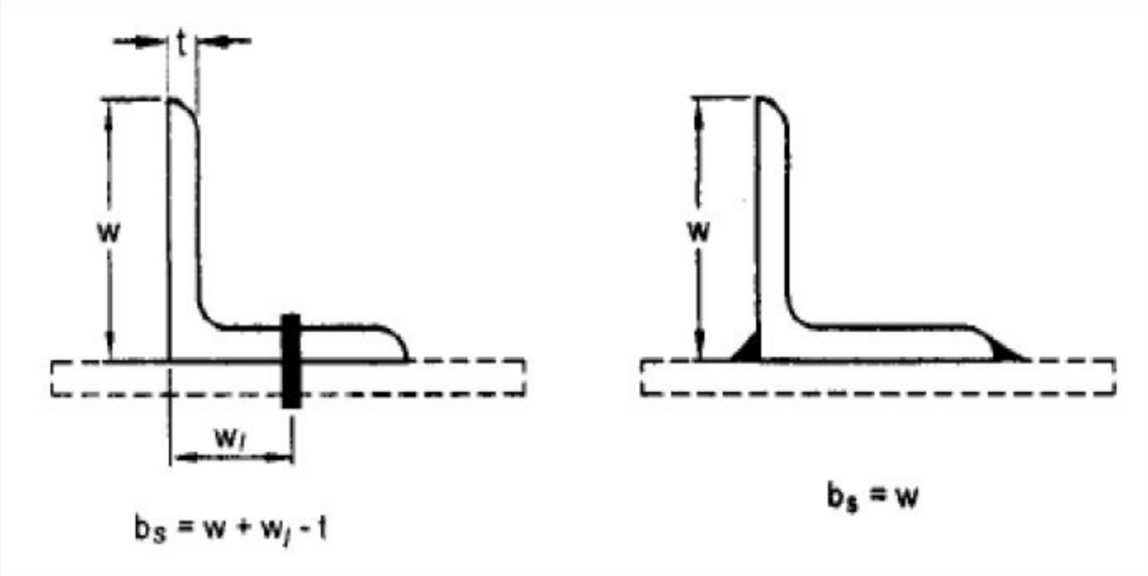
Where,

$$\beta = 1.4 - 0.076\,(w/t)\,(f_y/f_u)\,(b_s/L_c) \quad \leq f_u \gamma_{m0} / f_y \gamma_{m1}$$

$$\geq 0.7$$

Here, w = outstanding leg width,

b_s = shear lag width, as shown in figure below.



Angles with single leg connection (**Fig. 6, IS 800: 2007**)

L_C = length of the end connection, that is the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction.

For preliminary sizing, the rupture strength of net section may be approximately taken as:

$$T_{dn} = \alpha\, A_n f_u / \gamma_{m1}$$

Here, $\alpha = 0.6$ for one or two bolts, 0.7 for three bolts and 0.8 for four or more bolts along the length in the end connection or equivalent weld length;

A_n = net area of the total cross-section;
A_{nc} = net area of the connected leg;
A_{go} = gross area of the outstanding leg; and
t = thickness of the leg.

Other Section (Clause 6.3.4)

The rupture strength, T_{dn}, of the double angles, channels, I-sections and other rolled steel sections, connected by one or more elements to an end gusset is also governed by shear lag effects. The design tensile strength of such sections as governed by tearing of net section may also be calculated using equation in **Cl. 6.3.3, IS 800: 2007**, where β is calculated based on the shear lag distance b_s, taken from the furthest edge of the outstanding leg to the nearest bolt/weld line in the connected leg of the cross section.

Design Strength due to Block Shear (Cl. 6.4, IS 800: 2007)

The strength as governed by block shear at an end connection of plates and angles is calculated as follows:

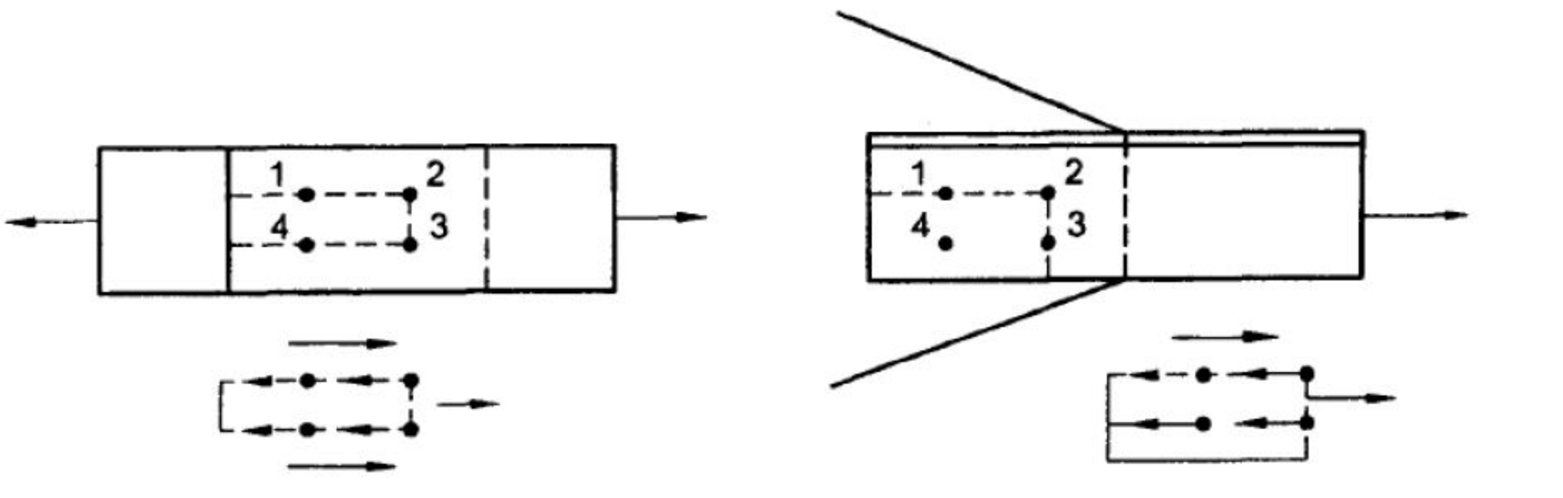
Bolted Connections

The block shear strength, T_{db} of connection shall be taken as the smaller of,

$$T_{db} = A_{vg} f_y / \sqrt{3}\gamma_{m0} + 0.9 A_{tn} f_u / \gamma_{m1}$$ *(For tension fracture and shear yield)*

or

$$T_{db} = 0.9 A_{vn} f_u / \sqrt{3}\gamma_{m1} + A_{tg} f_y / \gamma_{m0}$$ *(For tension yield and shear fracture)*



Block shear failure (**Fig. 7, IS 800: 2007**)

where

A_{vg} and A_{vn} = minimum gross and net area in shear along bolt line parallel to external force, respectively (1-2 & 3-4 as shown in Fig. 7A and 1-2 as shown in Fig. 7B)

A_{tg} and A_{tn} = minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of force, respectively (2-3 as shown in Fig. 7B), and f_u and f_y = ultimate and yield stress of the material, respectively.

Welded Connection

The block shear strength, T_{db} shall be checked for welded end connections by taking an appropriate section in the member around the end weld, which can shear off as a block.

Slenderness Ratio

The slenderness ratio is the ratio of unsupported length and least radius of gyration. Theoretically there should not be any upper limit of the slenderness ratio for a tension member as stability is of little importance. However, a tension member may be subjected to reversal force like wind, earthquake etc. Also, the limitation is necessary to prevent undesirable vibration and lateral movement. For this, **IS 800-2007 code (clause 3.8, Table 3)** has specified the maximum values of effective slenderness ratio.

Maximum effective slenderness ratio (Table 3, IS 800: 2007)

Member	Maximum effective slenderness ratio
A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
A member subjected to compressive forces resulting only from a combination of wind/earthquake actions, provided the deformation of such a member does not adversely affect the stresses in any part of the structure.	250
A member normally acting as a tie in a roof truss or a bracing member which is not considered effective when subjected to reversal of stress resulting from the action of wind or earthquake forces	350
Members always in tension (other than pre-tensioned members)	400

STEPS FOR DESIGN OF TENSION MEMBERS

Steps to design tension members

1. Find the gross area required to carry the given factored load (T_u) considering the strength in yielding from the following expression.

$$A_g = \frac{T_u \times \gamma_{m0}}{f_y}$$

2. Select a suitable shape of section depending on the type of structure and location of the member such that the gross area is more than the gross area obtained in step 1.

Note:
Usually if the minimum edge and pitch distance is maintained, strength in yielding gives least value. So, the design will be safe if gross area provided is greater than the gross area required.

3. Determine the number of bolts or the welding length required and suitably arrange the bolts.

Steps to design tension members

4. Find the strength considering

- Yielding of gross section (T_{dg})
- Rupture at critical section (T_{dn})
- Strength in block shear(T_{db})

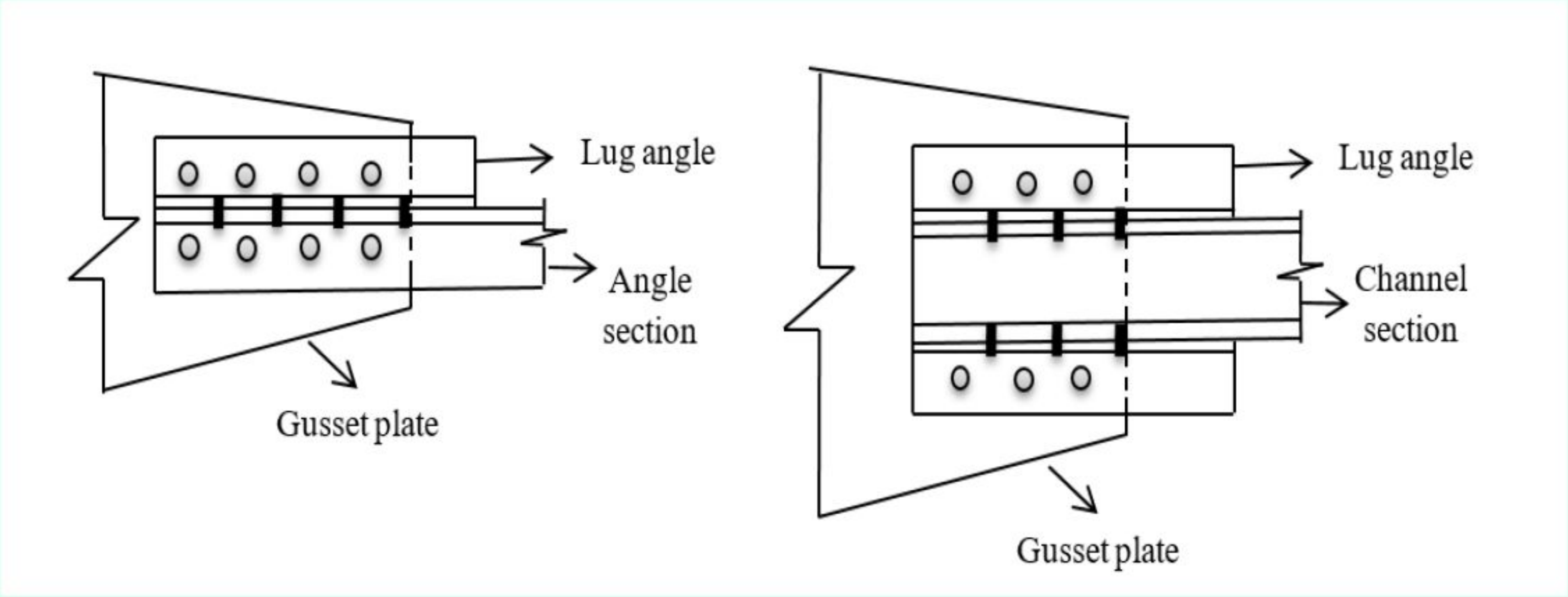
5. If any of the above strength (T_{dg}, T_{dn} and T_{db}) become less than the factored tensile force (T_u), increase the size of the section and repeat from step 3.

Steps to design tension members

6. Also, if the design strength (minimum of T_{dg}, T_{dn} and T_{db} in step 4. is too high compare to the factored load (T_u), decrease the section size suitably and repeat from step 3.

7. Check for the slenderness ratio of the member as per **Table 3, IS 800: 2007**. If the value of slenderness ratio exceeds the value given in code, then increase the size of the section and redesign.

LUG ANGLES


Lug angle
Angle
section
Gusset plate
Lug angle
Channel
section
Gusset plate

Lug Angles

- For a tension member subjected to a very large loading, the number of bolts or the length of weld required to make its connection with other members may often become large. Therefore, the size of gusset plates becomes very large which will be uneconomical.
- The lug angle is a short length of an angle section used at a joint to connect the outstanding leg of the member, thereby reducing the length of the joint.
- For effective sharing of loads, the lug angle is provided at the beginning of the joint.
- Lug angle is connected to outstanding leg of the main angle.

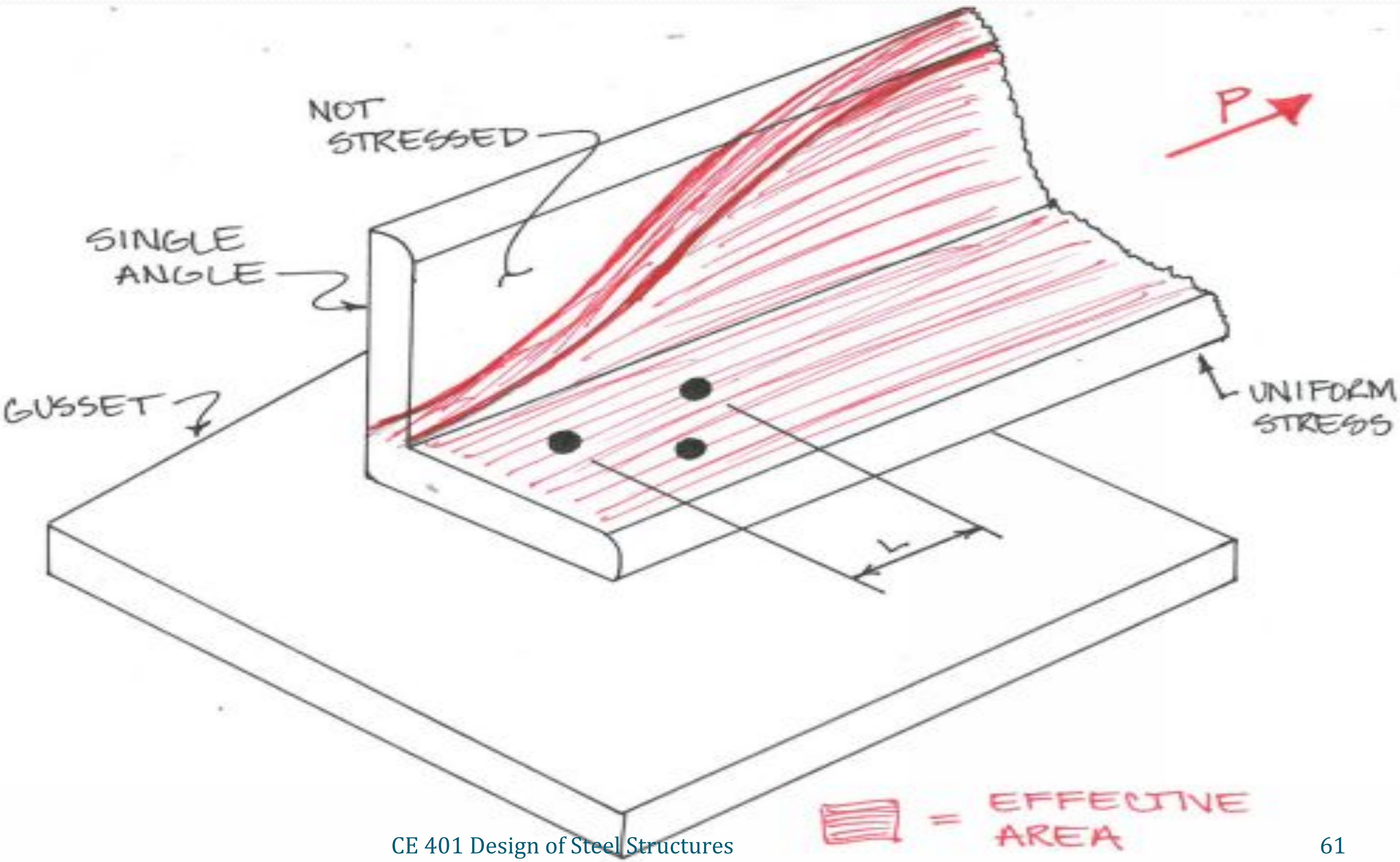
Lug Angles

- Thus, the gusset plate material can be saved by the use of lug angles. However, extra material is necessary for the use of lug angles and their connections. Also, lug angles are not very efficient in transmitting the load.
- Moreover, an eccentricity develops between the load and the c.g. of the bolt group; thereby the use of lug angles is generally avoided.
- Lug angles may be avoided by the use of unequal angle section with the larger leg as the connected leg and using two rows of staggered bolts.

Splices

Splices are introduced if the available length is less than the required length of a tension member. If a single piece of requisite length is not available, tension members are spliced to transmit the necessary tension from one member to another. Various types of splices are shown below.

Shear Lag Effect



Shear Lag Effect

- The force is transferred to a tension member by a gusset or the adjacent member connected to one of the legs either by bolting or welding
- The force thus transferred to one leg by the end connection locally gets transferred as tensile stress over the entire cross section by shear
- The non-uniform stress distribution that occurs in a tension member adjacent to a connection, in which all elements of the cross section are not directly connected, is commonly referred to as the shear lag effect.
- This effect reduces the design strength of the member because the entire cross section is not fully effective at the critical section location.