Chapter 2

Introduction

Structures are required to support loads, and to transfer these loads to the foundations of the structures. Structural engineer's responsibility is to frame a structural system which will transfer the loads acting on it safely, meeting the requirements of serviceability. The structural engineer should consult the owner, the architect, the construction team, mechanical and process engineers before finalising the arrangement of structural components.

The arrangement of structure for a building is based on many factors. Some such factors are listed below.

(1) Functional requirement including lighting and ventilation.
(2) Process requirement
(3) Environmental factors
(4) Elevations of platforms based on equipment disposition.
(5) Maintenance requirement
(6) Accessibility
(7) Soil condition
(8) Utility services like gas ducts, pipes, etc. The structural component should not interfere with these service lines.
(9) Head room requirement for erecting and maintaining equipment.
(10) Crane capacity and span.

Apart from other requirements specific to the process, keeping all the above in mind, the structural engineer should bring out a suitable arrangement. Such arrangement should meet the functional and process requirements. It should also result in economy, safety and durability.

Advantages of Using Steel Structure

(1) It is possible to have a smaller section since steel is capable of carrying higher load compared to other materials. Steel shapes and plates of different grades with different yield/ultimate stresses are available.
(2) It is homogeneous and has long life if protected from corrosion.
(3) Pre-rolled sections are available for use. If the designer requires, he can arrange for built-up section of his choice by adding members (or) plates to rolled shapes.

If a structural member no longer meets the service requirements, that is, its limiting stage, this means the member cannot withstand the load coming over (or) the member may undergo local damage (or) excessive deformation. The first limiting state is determined by its strength (or) load carrying capacity. The second is development of excessive deformation.

Design force in a member due to the worst combination should be less than the strength of the member (or) load carrying capacity of the member. This state is the first limiting state. The design load used in the limit state method is not the actual load (working or service load). The design load is arrived at by multiplying the actual (working or service) load by a factor called partial safety factor for loads while designing a structure using the limit state method. The actual load multiplied by partial safety factor for loads is called the factored load. The partial safety factors for loads used for arriving at design load from actual or working or service load is more than unity and the same is given in Table 4 of IS:800:2007.

The design strength of the member shall be more than (or) equal to the design force (factored load) to meet the strength requirement. The design strength is calculated based on geometry, length, section modulus, radius of gyration, yield stress and ultimate stress. While considering the yield stress (or) ultimate stress, a factor called partial safety factor for materials is used. This is presented in Table 5 of IS:800:2007.

The second limiting state is determined by the deflection of the member which depends on service load, span of the member, Young's modulus and moment of inertia. To meet this limiting state, the member should have sufficient stiffness. Many times the designer may not have the options to reduce the load, span or change the material with higher Young's modulus. But the designer can increase the moment of inertia by increasing the width/thickness/depth of the member. The best option is to increase the depth since the moment of inertia depends on depth to the power of three. The deflection limit for members used as various structural elemets are given in Table 6 of IS:800:2007.

In the allowable (or) working stress method of design, the actual load acting on the structure is considered. The actual load is not multiplied by a factor as in the case of limit state method. The stress induced in the structural members by the external actual load should not exceed the allowable stress as in the codes and standards. The allowable stress is a fraction of yield stress of the material. This fraction is to account for variation in loads, variation in the geometrical property and mechanical property of the material. This fraction varies with respect to type of load and mode of failure.

For example, let us consider a tension member. The member is subjected to a tensile force of T. The permissible (or) allowable stress in the steel member under direct tension = $0.6\,f_y$

$$\text{Stress} = \frac{\text{Load}}{\text{Area}} = \frac{T}{\text{Area}} = 0.6\,f_y$$

$$\therefore \qquad \text{Area} = \frac{T}{0.6\,f_y} = 1.67 \times \left(\frac{T}{f_y}\right)$$

This 1.67 is the factor of safety.

In the limit state method, the same tensile force will be multiplied by the partial safety factor Therefore, factored tensile load or forssce = 1.5 T

$$\text{Area} = \frac{\text{Load}}{\text{Stress}} = \frac{1.5T}{f_y/(\gamma_{mo})} = 1.5 \times 1.1\left(\frac{T}{f_y}\right) \text{ where } \gamma_{mo} = 1.1$$

$$= 1.65\left(\frac{T}{f_y}\right)$$

In the limit state method, the load is given a separate factor called partial safety factor for loads as presented in Table 4 of IS:800:2007 and the stress is given a separate factor called partial safety factor for materials as presented in Table 5 of IS:800:2007.

Finally, it can be noticed that the factor is 1.67 in the case of allowable (or) working stress design and 1.65 in the case of limit state design.

But this is not same for compression member. Let us consider a compression member for which the slenderness ratio (= KL/r) = 100 and f_y = 250 MPa. The permissible compressive stress as in working stress method (IS:800/1984 Table 5.1) = 80 MPa.

Let us refer to IS: 800/ 2007 Table 9(a), 9(b), 9(c) and 9(d) for limit state method. For the same value of the slenderness ratio (= KL/r) = 100 and f_y = 250 MPa, we get

As per Table 9(a), f_{cd} = 132 MPa

As per Table 9(b), f_{cd} = 118 MPa

As per Table 9(c), f_{cd} = 107 MPa

As per Table 9(d), f_{cd} = 92.6 MPa

In Working Stress Method

Load = Area × 80 MPa

∴ Area = (Load/80) mm^2

In Limit State

(a) Buckling class a

$$1.5 \times \text{Load} = \text{Area} \times 132$$

$$\therefore \quad \text{Area} = \left(\frac{1.5 \times \text{load}}{132}\right) = \left(\frac{\text{load}}{88}\right) \text{mm}^2$$

(b) Buckling class b

$$1.5 \times \text{Load} = \text{Area} \times 118$$

$$\therefore \quad \text{Area} = \left(\frac{1.5 \times \text{load}}{118}\right) = \left(\frac{\text{load}}{78.7}\right) \text{mm}^2$$

(c) Buckling class c

$$1.5 \times \text{Load} = \text{Area} \times 107$$

$$\therefore \quad \text{Area} = \left(\frac{1.5 \times \text{load}}{107}\right) = \left(\frac{\text{load}}{71.3}\right) \text{mm}^2$$

(d) Buckling class d

$$1.5 \times \text{Load} = \text{Area} \times 92.6$$

$$\therefore \quad \text{Area} = \left(\frac{1.5 \times \text{load}}{92.6}\right) = \left(\frac{\text{load}}{61.7}\right) \text{mm}^2$$

Now it can be noticed that the area required (or) load carrying capacity of the member in compression is different for different buckling classes under the limit state method of design. The required area calculated using the working stress method does not take into account the buckling class. The buckling class for various cross sections are given in Table 10 of IS:800:2007. This depends on the height to width ratio and thickness of the flange. From the above working, we can understand that a member with buckling class will be economical under the limit state method when compared to the working stress method. For other buckling classes, it is different.

In the design of members using allowable (or) working stress method, the structural member is considered in working state. In the case of the limit state method, the member is considered in limit state. Hence, it is necessary to find the limiting states based on failure mode of the structural member. This has resulted in various safety factors as against a single factor of safety in the case of working stress method. In working the stress method, the factor of safety varies based on type of load. The partial safety factor for load, partial safety factor for material, buckling class, effective length for simply supported beams taking into account torsional restraint and working restraint imperfection factor and other factors are more scientifically chosen for the design of structural members using limit state method.

Many engineers have started asking whether the limit state method will bring economy compared to working stress method. To put it in simple terms "will the weight of the structural members will come down as compared to working stress method"?

Limit state method takes care of all the factors scientifically as explained above and the same will be safe. Achieving economy rests with the design engineer who applies the optimum load and optimises the design.

Structural Steel

Eight grade designations are available as per IS: 2062: 2006. There are four sub-qualities for grade designations E250 to E450 and two sub-qualities are available for grade designations E 550 to E650. The grade designations are based on yield stress. For grade designation E250, the yield stress is 250 N/mm^2.

The sub-qualities *A*, *BR*, *BO* and *C* are generally used for welding process.

Sub-quality *A* stands for "Impact test not required, semi-killed/killed. Sub-quality *BR* stands for "impact test optional, at room temperature (25 ± 2°C) if required, killed.

Sub-quality *BO* stands for “Impact test mandatory at 0°C, killed".

Sub-quality *C* stands for “Impact test mandatory at – 20°C, killed".

Normally the Indian rolled shapes *I*, channel and angle are of grade designation E250 sub-quality *A*.

Poor hardening, high plasticity and weldability are the properties of low carbon steel. The carbon content should be less than or equal to 0.23% for low carbon steel.

2.1 STRUCTURAL COMPONENTS OF AN INDUSTRIAL SHED

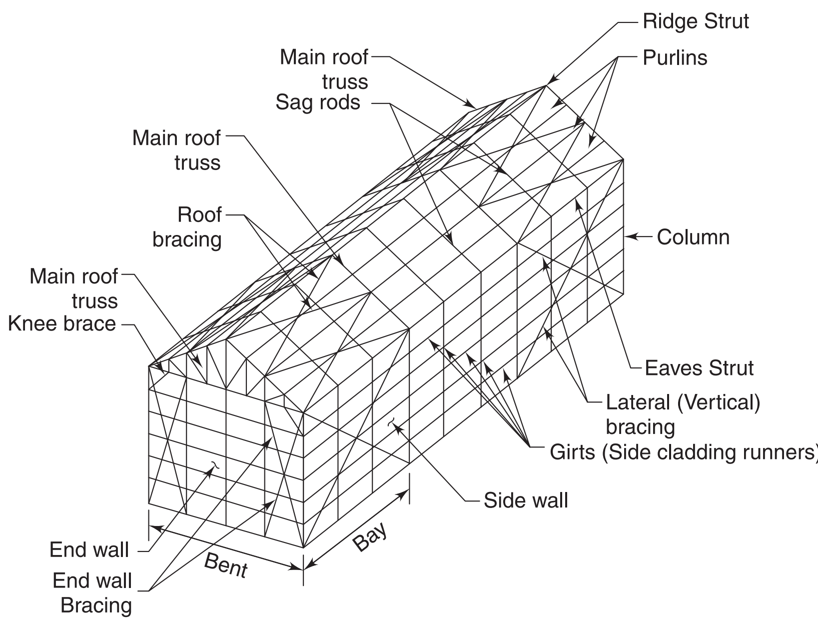


Fig. 2.1

2.2 ROLLED SECTIONS USED FOR STRUCTURES

(i) Angle section
(ii) Channel section
(iii) *I*-section
(iv) *Z*-section (thin gauge)
(v) Solid circular section (rods)
(vi) Hollow circular section (tubes and pipes)
(vii) Plate section
(viii) Solid square section
(ix) Hollow square and rectangular section

Some Compound and Built-up Sections

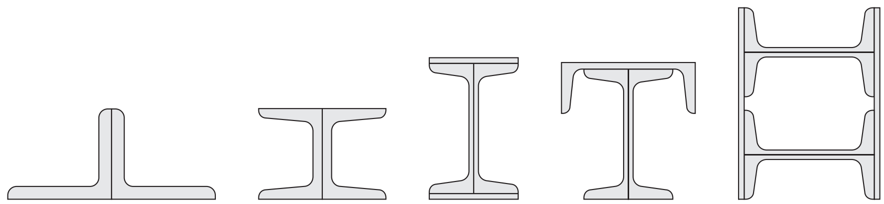
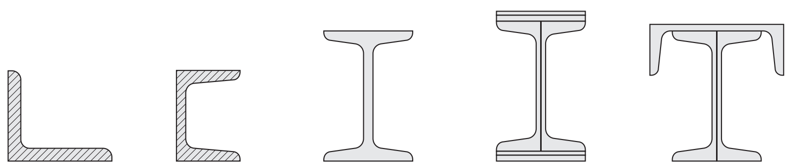


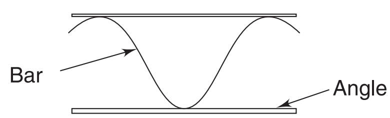
Fig. 2.2 Compound and built-up sections

2.3 BEAM SECTIONS

Sections used for flexural members (beams) are shown below.

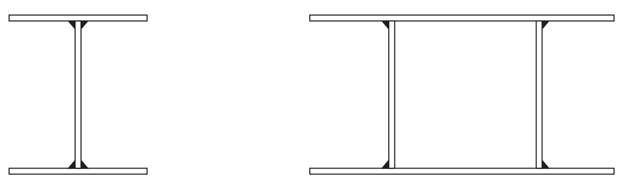


(a) Angle (b) Channel (c) I-section (d) Built-up sections



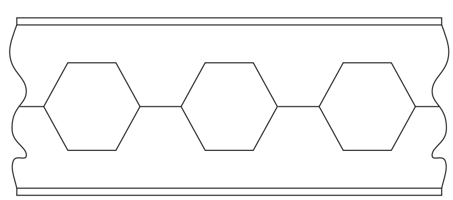
(e) Bar joist

Fig. 2.3(a)



(f) Plate girder (g) Double web box girder

Fig. 2.3(b)



(h) Castellated beam

Fig. 2.3(c)

2.4 TYPICAL TENSION MEMBERS

Sections used for tension members are shown below.

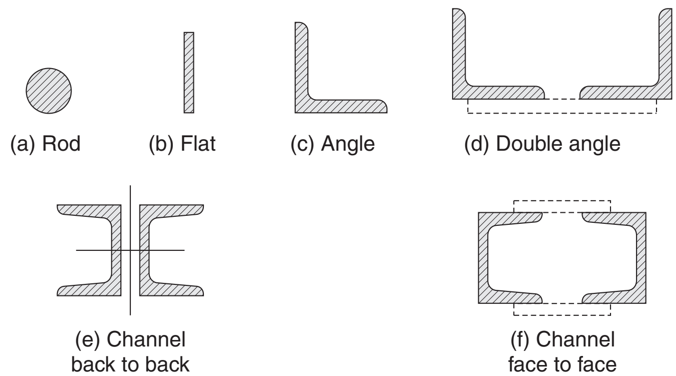


Fig. 2.4(a)

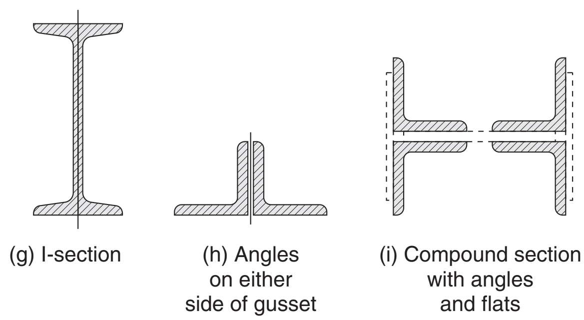
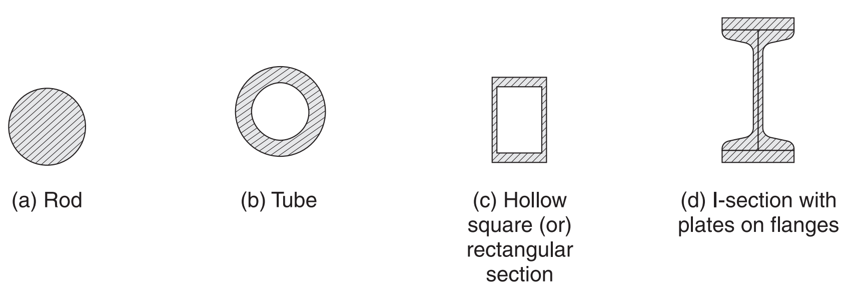
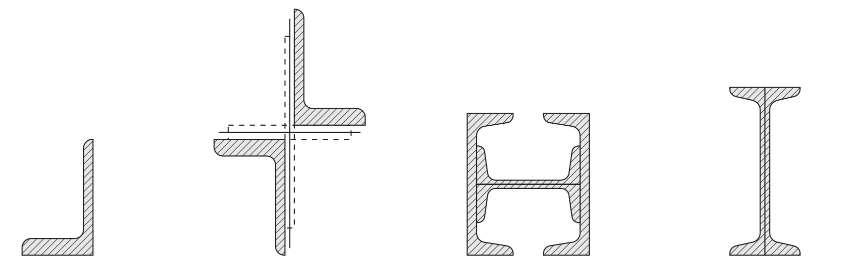


Fig. 2.4(b)

2.5 TYPICAL COMPRESSION MEMBERS

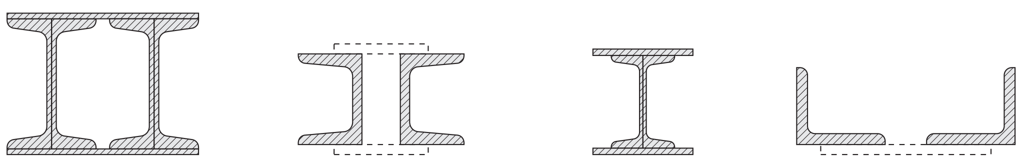
Sections used for compression members, columns and beam-columns are shown below:





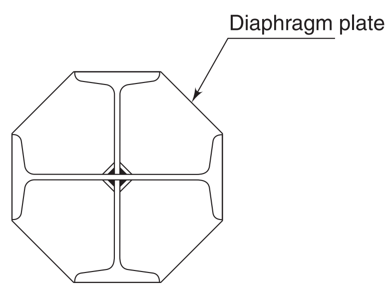
(e) Angle (f) Star angle (g) Built-up member i-section & channels (h) I-section with plates on flanges

Fig. 2.5(a)

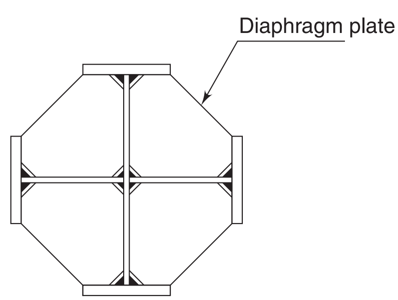


(i) Double I-section with cover plate (j) Channel back to back with batten (k) I-section with wide plates and flanges (l) Double angle with flat lacing

Fig. 2.5(b)



(m) Plus-i-using rolled i-section



(n) Plate formed plus-i

Fig. 2.5(c)

2.6 DESIGNATION FOR PHYSICAL PROPERTY OF SECTION

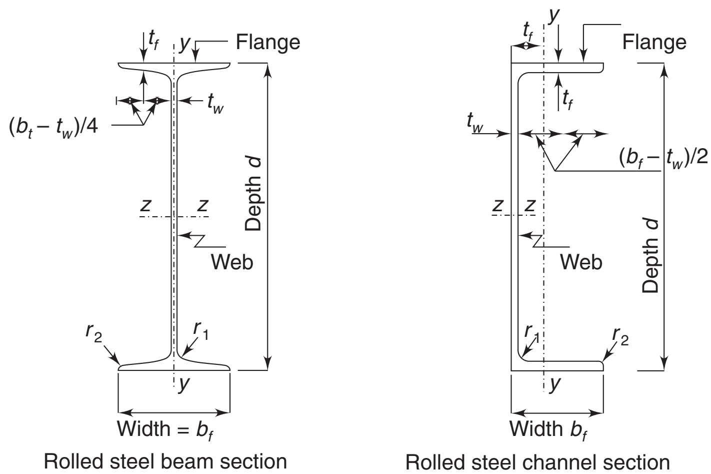


Fig. 2.6(a)

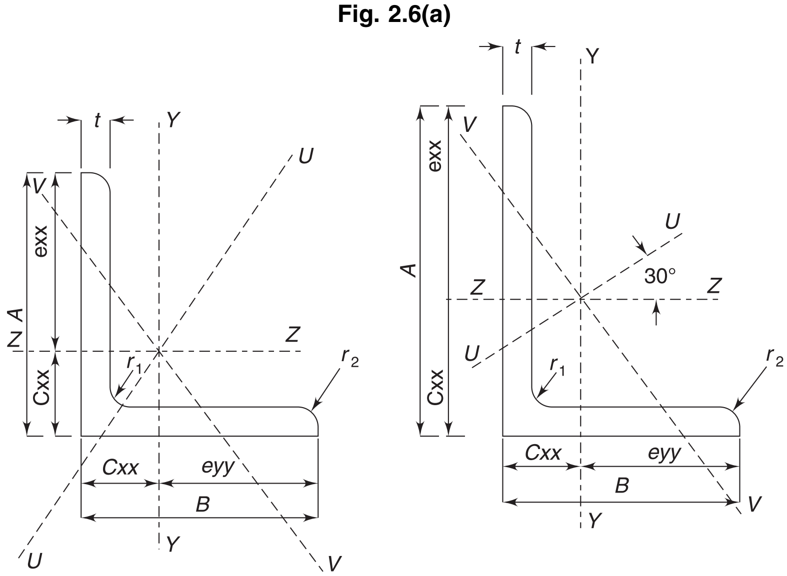


Fig. 2.6(b)

2.7 TYPES OF CONNECTION AND BEHAVIOUR

(a) Shear connection (or) simple connection: This will transfer only shear. Cleat angles or fin plate connected to web of beam is an example (Fig. 2.7(a)).

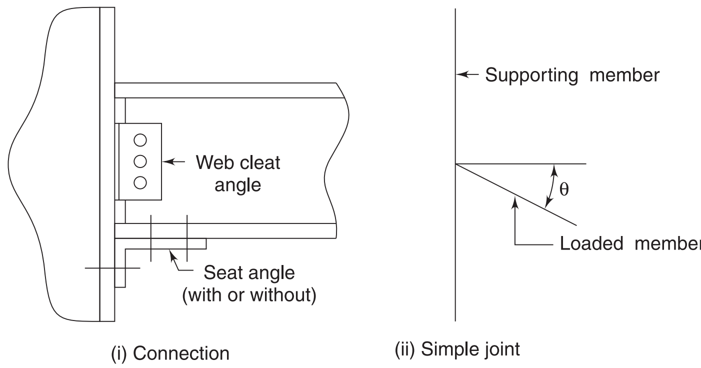
(b) Semi-rigid connection: This will transfer shear and partial moment (Fig. 2.7(b)).

(c) Rigid connection: This will transfer shear and moment. End plate connection is an example (Fig. 2.7(c)).

Figures showing typical arrangement of these connections using bolts are provided below and in chapter relevant to connection design. These connections can also be made by welding in place of bolts.

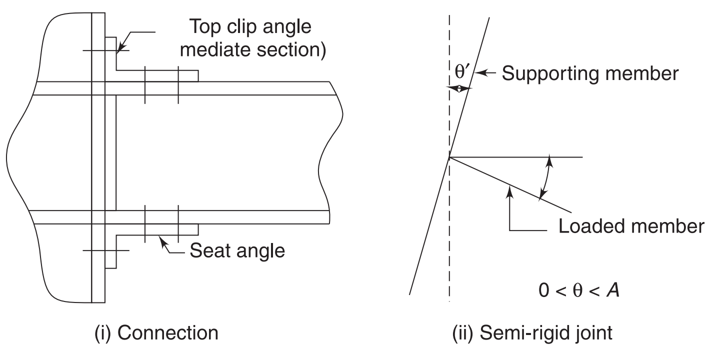
Rotation of the members is also shown against relevant figures to give an idea. It can be noticed that the supporting member is not rotating with respect to simple connection.

Figures 2.8 *a* to 2.8 *j* give various types of bolted connections.



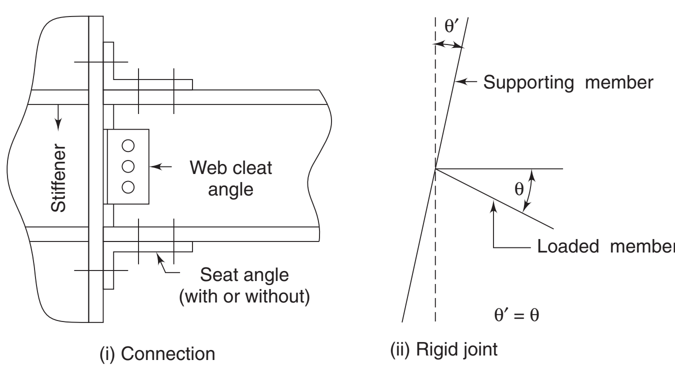
(a) Shear connection

Fig. 2.7(a)



(b) Semi-rigid connection

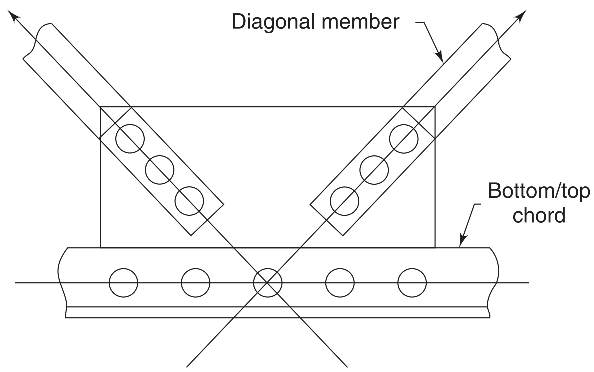
Fig. 2.7(b)



(c) Rigid connection

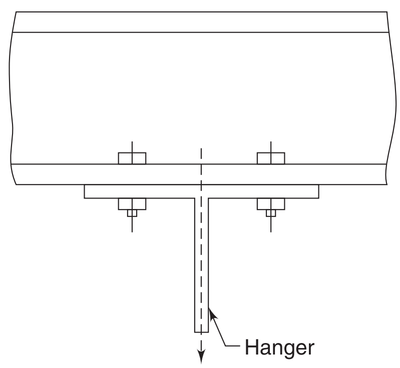
Fig. 2.7(c)

2.8 TYPES OF BOLTED CONNECTIONS



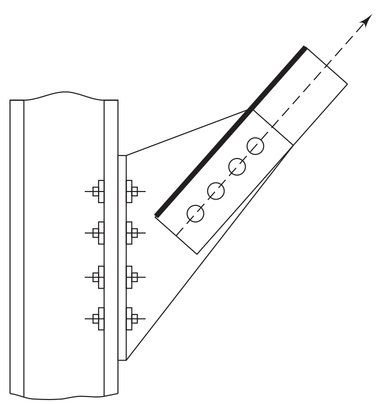
(a) Connection at a truss joint

Fig. 2.8(a)



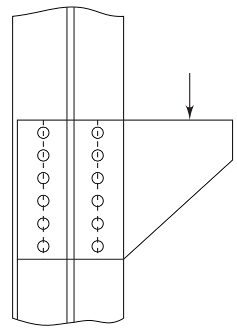
(b) Hanger connection

Fig. 2.8(b)



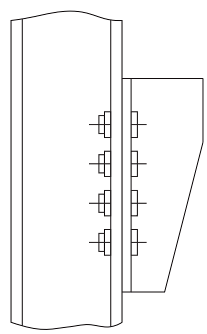
(c) Bracing connection

Fig. 2.8(c)



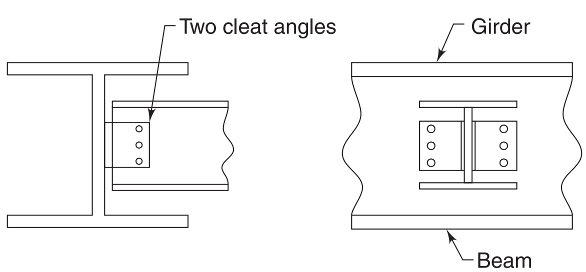
(d) Eccentrically loaded bracket connection
(moment parallel top lane)

Fig. 2.8(d)



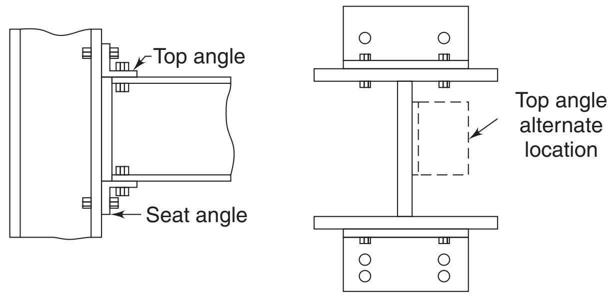
(e) Eccentrically loaded connection
(moment perpendicular top lane)

Fig. 2.8(e)



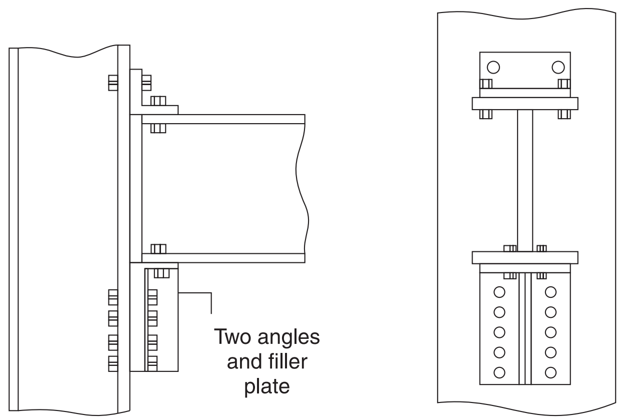
(f) Simple beam connections–beam to girder

Fig. 2.8(f)



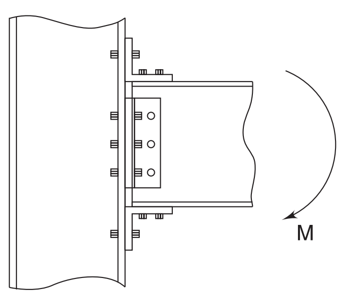
(g) Unstiffened seated beam connection

Fig. 2.8(g)



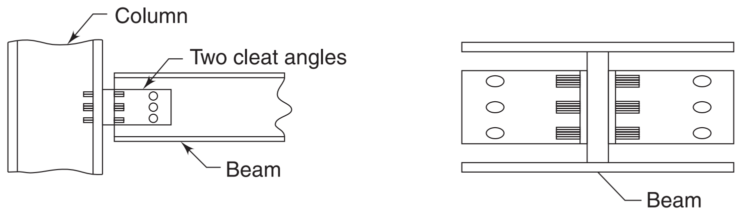
(h) Stiffened seated beam connection

Fig. 2.8(h)



(i) Moment connection

Fig. 2.8(i)



(j) Simple beam connections–beam to column

Fig. 2.8(j)

2.9 DEFINITIONS OF CERTAIN TERMS

Allowable Stress Design (Working Stress Method)

A method of sizing the structural members such that elastically computed stress produced in the members by actual loads do not exceed allowable stresses.

$$\text{Allowable stress} = \text{Yield stress/Factor of safety}$$

P-Delta Effect

The second order effect on shear and moments of vertical members of the frame induced by axial loads on a laterally displaced building frame.

Forces

Self weight of the structural components, weight of materials with which the building is constructed (example: walls, wall cladding), weight of the occupants, weight of stored materials, wind pressure are called forces (or) loads on the structure. The force due to earthquake is also to be considered.

Unit of Measurement of Force

Forces are measured in newtons (N) or kN in SI system.

External Forces

To fully describe a load (or) force, we need to specify the following characteristics of load:

The magnitude
The direction
The location

Resultants and Components

A single force replacing two or more forces which has the same effect, i.e., which is equivalent to the sum of the effects of other forces can be calculated. This single force is called the resultant (Fig. 2.9).

The moment due to the force P_1 about 'o' is $P_1 \times d_1$ where d_1 is the lever arm. The rotation is anticlockwise and hence the moment is –ve. The moment due to the force P_2 about 'o' is $P_2 \times d_2$, where d_2 is the lever arm. The rotation is clockwise. Hence, it is +ve. Net moment at $o = P_2 d_2 - P_1 d_1$.

Couple of Forces

Two equal, parallel, non-collinear forces of opposite sense are called couple of forces. Moment at any point in its plane is constant, and is obtained by the multiplication of one of the forces and the perpendicular distance between the forces, (Fig. 2.12). Moment = $Q \times a$.

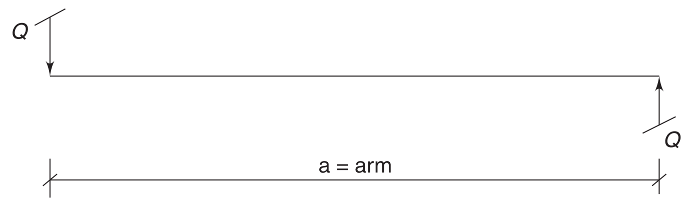


Fig. 2.12

Equilibrium Conditions

For a body to remain in equilibrium, the following conditions are to be satisfied:

(a) The sum of force components in the x direction is zero, $\Sigma F_x = 0$

(b) The sum of force components in the y direction is zero, $\Sigma F_y = 0$

(c) The sum of force components in the z direction is zero, $\Sigma F_z = 0$

(d) The resultant moment about any point is zero, $\Sigma M = 0$

The x, y, z axes are mutually perpendicular.

Reactions at Supports

For the structural component to remain in equilibrium, the supports should be capable of carrying the forces. These forces at the support are called reactions, and they must be calculated before the structure is analysed.

In single-plane structures, we are concerned with three types of supports:

(*a*) A support which permits rotation of a structural component about its axis, capable of providing reaction components in two directions and can prevent motion in two perpendicular directions is called a hinged (or) pinned support (Fig. 2.13(a)).

P_r is the resultant.

P_1 is the shear.

P_2 is the vertical reaction.

(*b*) A roller is provided along with the hinge to avoid the force P_1 (Fig. 2.13(b)).

$$\text{Stress} = \frac{\text{Total internal force}}{\text{Internal area over which the force acts}}$$

Types of Stresses

The force acting perpendicular to a surface is called normal force, and the force acting parallel to the surface is called shear. There will be two types of stresses, one is normal stress and the other is shear stress. When certain parts slide over other parts, shear stresses are developed by shear force.

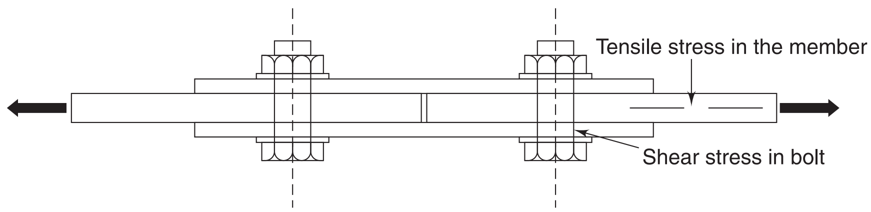


Fig. 2.14

Strain and Young's Modulus

The change in dimension, expressed as a fraction of the original dimension, is called the strain. Example, the change in length of a bar and its original length.

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}}$$

The ratio between stress and strain is called Young's modulus of elasticity (E).

$$\text{Stress} = E \times \text{Strain}$$

Young's modulus is a measure of the stiffness of a material. Materials having a large value of E can be used to form stiff structures.

Permissible Stress (or) Allowable Stress

Safety is the first and foremost requirement of a structure. Every structure is designed to have a reserve strength above that required to take up the externally applied loads.

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

For example, the yield stress of a particular type of steel may be 250 MPa. With a safety factor of safety of 1.67, the permissible stress in tension will be (250/1.67) = 150 MPa.

Ties and Struts

A structural member carrying an axial tensile force is called a tie. A structural member carrying an axial compressive force is called a strut or a column.

Portal Frame

A rigid frame in a single plane fixed at base is called a portal frame or rigid frame.

2.10 LOADS ON STRUCTURES

The loads acting on steel structures are dead load, imposed load including both gradually applied and dynamic load, wind load, seismic load, earth or groundwater load and those due to temperature changes and foundation settlement.

Dead Load

Dead loads are those loads which will be applied permanently during the life of the buildings. They are the gravity forces. They are from the mass of the structure, finishes, cladding and all other permanent parts of the building. They can be accurately estimated of all loads, since they are calculated from the known densities of the materials (IS:875:Part-1) used in construction.

Imposed Load

Imposed loads are the loads applied to the floor of a building as a result of the activities carried on within the building based on functional requirement. Consequently, they result from the type of occupancy of a particular part of a building, and are usually expressed in kN per square metre of floor area. (IS: 875: Part-2). Imposed load on a roof are those produced as follows:

(a) During maintenance and (b) During the life of the structure by movable objects.

Wind Loads

Air in motion is called wind. When the flow of wind is obstructed by an object; the wind exerts a pressure on the object. This pressure depends on velocity of wind and shape and orientation of the object. The design wind velocity depends on many factors. They are basic wind speed in the region and the type of terrain and topography. From design wind speed (or) velocity; design wind pressure can be calculated (IS: 875-Part-3). External pressure coefficients and internal pressure coefficients depend on the height, width, length, shape and opening of the object (structure). By utilising the design wind pressure, pressure coefficients; and area resisting, wind force on the structure can be calculated.

Earth or Groundwater Load

The loads due to earth or groundwater act as pressure normal to the contact surface of the structure. These loads are considered static.

Seismic Loads

Ground in motion creates force on the structure and this is called seismic force (or) load on the structure. Earthquake load is horizontal, it can act in any direction at a time. One direction only is to be considered at a time while analysing. The following factors are considered in calculating the seismic force on a structure.

should be capable of carrying load due to combinations excluding wind or seismic loads without increase in stresses.

Errors and Uncertainties

Deliberate errors

Assumptions made (i) to simplify the analysis, (ii) in the assessment of loading and (iii) in the structural behaviour

Accidental errors

Lack of precision in calculating the load, behaviour of the structure and in the method of analysis.

Uncertainties

- Material property (Example: yield strength)
- Variation in dimensions (Physical property) of the sections (Tolerances are specified)
- Manufacturing (Tolerances are specified)
- Erection (Tolerances are specified)
- Density of material
- Imposed loads
- Wind and seismic loads (By probability theory)

Material

The value of Young's modulus of elasticity, $E = 2 \times 10^5$ N/mm$^{2.}$ (Clause 2.2.4.1 of IS: 800).

$$\text{Strain at yield} = f_Y/E$$

The yield stress also varies with the heat treatment used and with the amount of working which occurs during the rolling process. For design purpose, minimum yield stress is identified.

$$\text{Shear yield stress} = f_y/\sqrt{3}$$

Analysis of Structures

The term analysis of structure is used to denote the analytical process by which the information of the response of the structure for various loads and load combinations can be obtained. The basis for this process is the knowledge of the behaviour of the material, and this is used to analyse the behaviour of the individual components and joints of the structure. Response of the structure depends on material specification, shape, physical property, span, end/support condition and location, direction and magnitude of the load.

Area (1) I_g

$$b_1 d_1^3/12 = 10 \times 0.5^3/12 = 0.104 \text{ cm}^4$$

Area (2) I_g

$$b_2 d_2^3/12 = 0.5 \times 6^3/12 = 11.44 \text{ cm}^4$$

Example 2.2 *Find the centre of gravity of the cross section as shown in Fig. 2.16.*

Area ID	*a*	*y*	$a \times y$	*h*	h^2	$a \times h^2$	$bd^3/12$
1	7.5	0.25	1.875	2	4	30	0.15625
2	6	3.5	21	1.25	1.56	9.36	18
3	6	3.5	21	1.25	1.56	9.36	18
Total	$\Sigma a = 19.5$	–	$\Sigma ay = 43.875$	–	–	$\Sigma ah^2 = 48.72$	$\Sigma I_g = 36.16$

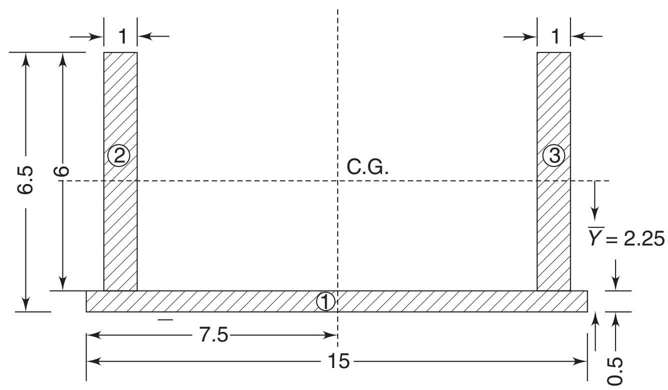


Fig. 2.16

$C = \Sigma ay/\Sigma a = 43.875/19.5 = 2.25$

$I = ah^2 + I_g = 48.72 + 36.16 = 84.88 \text{ cm}^4$ = Moment of inertia about xx axis

Area = $a_1 = 15 \times 0.5 = 7.5 \text{ cm}^2$

$$a_2 = a_3 = 6 \times 1 = 6 \text{ cm}^2$$

$$I_g = b_1 d_1^3/12 = 15 \times 0.5^3/12 = 0.15625 \text{ cm}^4$$

$$I_{g2} = I_{g3} = 2 \times b_2 d_2^3/12 = 1.0 \times 6^3/12 = 18 \text{ cm}^4$$

Example 2.3 *Find the centre of gravity of the cross section as shown in Fig. 2.17.*

Area ID	*a*	*y*	*a × y*	*h*	h^2	$a \times h^2$	$bd^3/12$
1	20	1	20	2.59	6.7	134	6.67
2	6	5	30	1.41	1.99	11.94	18
3	8	9	72	5.41	29.27	234.16	2.67
Total	$\Sigma a = 34$		$\Sigma ay = 122$			$\Sigma ah^2 = 380.1$	$\Sigma I_g = 27.34$

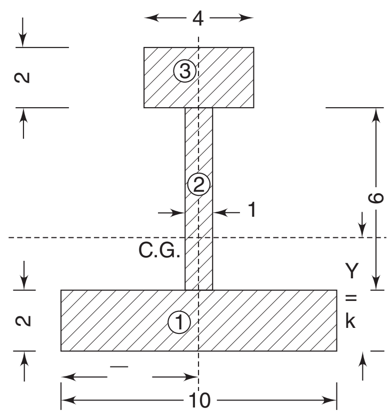


Fig. 2.17

$$C = \Sigma ay/\Sigma a = 122/34 = 3.59$$

$$I = ah^2 + l_g = 380.1 + 27.34 = 407.44 \text{ cm}^4$$

ea (1) I_g

$$b_1 d_1^3/12 = 10 \times 2^3/12 = 6.67 \text{ cm}^4$$

Area (2) I_g

$$b_2\, d_2^3/12 = 1 \times 6^3/12 = 18 \text{ cm}^4$$

Area (3) I_g

$$b_3 d_3^3/12 = 4 \times 2^3/12 = 2.67 \text{ cm}^4$$

Example 2.4 *Find the centre of gravity of the cross section as shown in Fig. 2.18.*

Area ID	*a*	*y*	*a × y*	*h*	h^2	$a \times h^2$	$bd^3/12$
1	3.2	0.1	0.32	3.1	9.61	30.75	0.01
2	0.76	4	3.04	0.5	0.25	0.19	3.65
3	0.76	4	3.04	0.5	0.25	0.19	3.65
4	2.4	7.9	18.96	4.4	19.36	46.46	0.0
Total	$\Sigma a = 7.12$	–	$\Sigma ay = 25.36$	–	–	$\Sigma ah^2 = 77.59$	$\Sigma I_g = 7.4$

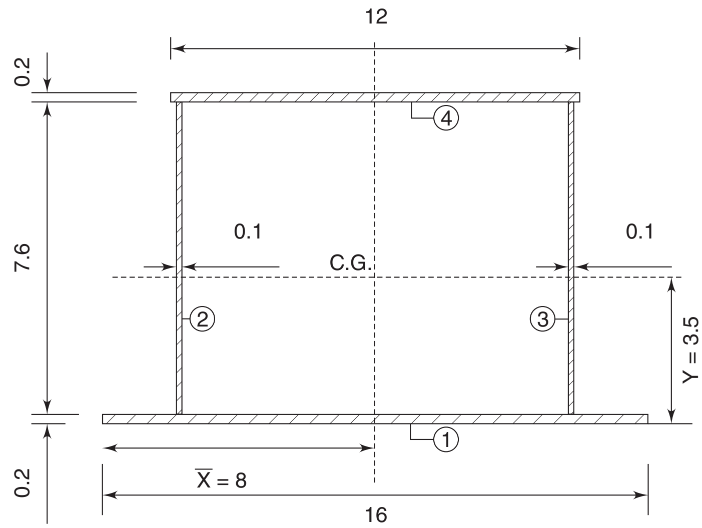


Fig. 2.18

$$C = \Sigma ay/\Sigma a = 25.36/7.12 = 3.56$$

$$I = ah^2 + I_g = 77.59 + 7.4 = 84.99 \text{ cm}^4$$

$$a_1 = 16 \times 0.2 = 3.2 \text{ cm}^2 \; a_2 = 0.1 \times 7.6 = 0.76 \text{ cm}^2$$

$$a_3 = 0.1 \times 7.6 = 0.76 \text{ cm}^2 \; a_4 = 12 \times 0.2 = 2.4 \text{ cm}^2$$

Area (1) I_g; $b_1d_1^3/12 = 16 \times 0.2^3/12 = 0.01 \text{ cm}^4$

Area (2) I_g; $b_2d_2^3/12 = 0.1 \times 7.6^3/12 = 3.65 \text{ cm}^4$

Area (3) I_g; $b_2d_2^3/12 = 0.1 \times 7.6^3/12 = 3.65 \text{ cm}^4$

Area (4) I_g; $b_3d_3^3/12 = 12 \times 0.2^3/12 = 0.00 \text{ cm}^4$

2.14 EQUIVALENT UNIFORMLY DISTRIBUTED LOAD FOR TRIANGULAR LOAD AND TRAPEZOIDAL LOADS

Equivalent uniformly distributed load for

(1) Short span = $wS/3$ w = load in kN/sqm

S and L are in metre

$m = S/L$

(2) Long span = $(wS/3) \times [(3 - m^2)/2]$

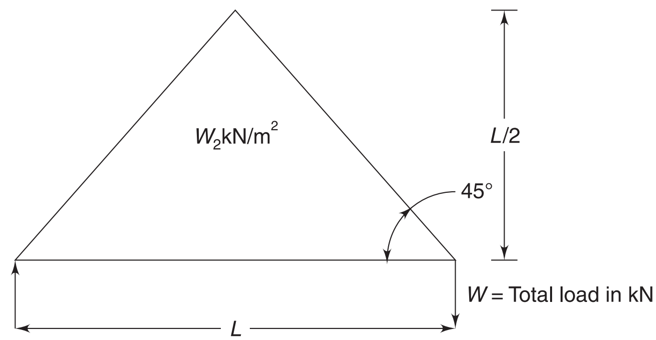


Fig. 2.21

- **For Triangular Load**

$$\delta_2 = WL^3/60EI$$

$$W = 1/2 \times L \times L/2 \times = (w_2L^2/4)$$

$$\delta_2 = (w_2L^2/4) \times (L^3/60EI) = w_2L^5/240EI$$

$$M_2 = WL/6 = (w_2L^2/4) \times L/6 = w_2L^3/24$$

Equating Deflection

Deflection due to uniformly distributed load = $5w_1L^4/384EI$

Deflection due to triangular load = $w_2L^5/240EI$

Deflection due to triangular load = $w_2L^5/240EI$

Equating the two $5w_1L^4/384EI = w_2\mathrm{L}^5/240EI$

$$w_1 = (w_2 \times L/240) \times (384/5) = w_2L \times 384/240 \times 5 = \frac{w_2L}{3.125}$$

Equating BM

Bending moment due to uniformly distributed load = $w_1L^2/8$

Bending moment due to triangular load = $w_2L/24$

Equating these two, $w_1L^2/8 = w_2L^3/24$

$$w_1 = w_2L/3$$

Shear Force

Total load on short span = $2 \times (w_2L/3) \times L = 2 \times (w_2L^2/3)$ (1)

Say $L_1 = 2L_2$

$$m = S/L = L/2L = 0.5$$

Equivalent uniformly distributed load on long span

$$(w_2L/3) \times ((3 - m^2)/2) = (w_2L/3) \times ((3 - 0.5^2/2) = (w_2L)/(2.75/6) = (w_2L) \times (11/24)$$

In some structures, the frames may not be in orthogonal directions. The frames may meet at less or more than 90°.

(i) **Braced Structure** *A* simple braced frame is shown in Figs. 2.24 and 2.28. The structure system (frame) consists of columns and beams to transfer loads to the foundation. These frames are provided with diagonal members which are called bracing or diagonal bracing. The joints will be having a thin flexible plate called gusset plate to create pin joints at ends. These bracing members are expected to take only axial forces. These bracing members give stability to the frames against the action of horizontal or lateral loads. Bracing members are provided in frames to reduce or prevent sway of the frame. A frame with bracing members is very efficient in taking lateral load due to wind/seismic/other loads. These bracing members are subjected to tension or compression depending on the direction of horizontal loads/forces. But these members may interfere with pipes, ducts and other openings which has to be considered at the initial planning stage.

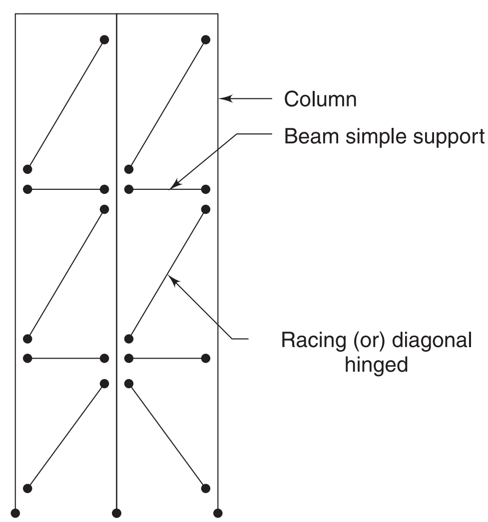


Fig. 2.24

(ii) **Rigid Frames** If the frames are not provided with bracing members and the beams are pin jointed; columns will be heavy to take up horizontal loads and to prevent or reduce the sway. In such cases, the joints between beam and columns will be made rigid or fixed. Such frame is called a rigid frame. Bending moments will be more because of fixity and to resist horizontal loads. This system is not advisable for tall structures and structures subjected to high lateral (or) horizontal loads. Also refer to Figs. 2.25 and 2.28.

(iii) **Shear** If the structure consists of walls, these walls will resist lateral loads. When the applied lateral load lies in the same plane as that of the wall, the wall is subjected to shear and is called a shear wall. This system is the most economic of all.

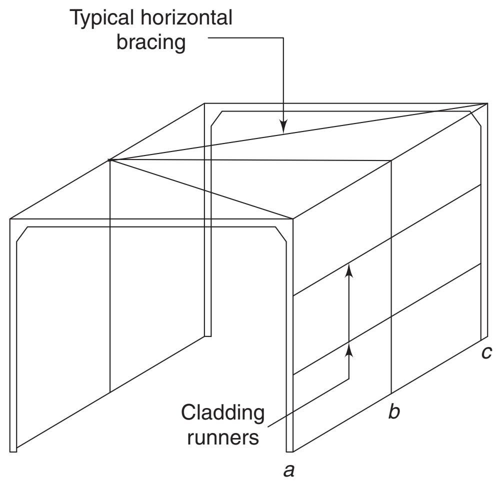


Fig. 2.27

We can form a horizontal truss in the plane of the roof as shown in Fig. 2.27 connecting top of columns to share the horizontal load.

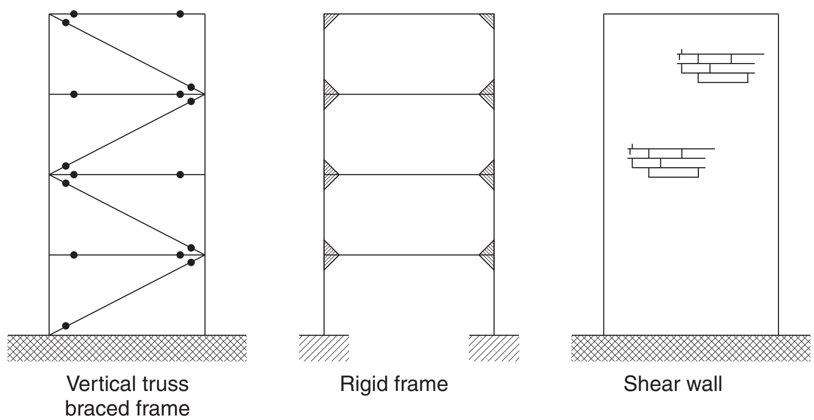


Fig. 2.28

2.16 SHEAR FORCE, BENDING MOMENT AND POINT OF CONTRAFLEXURE

Shear Force

The shear force at any cross section *AA* in a beam loaded as in Fig. 2.29 is the algebraic sum of all forces acting perpendicular to the axis of the beam either to left (or) right side of section *AA*.

Plastic Section Modulus

Z_{pz} = 2 × [Area of flange × Distance between centre of gravity of flange and *ZZ* axis] + 2 × [Area of web above the *ZZ* axis × Distance between centre of gravity of this area and *ZZ* axis].

$$Z_{pz} = b_f \times t_f \times [(d/2) + (t_f/2)] \times 2 + (d/2) \times t_w \times (d/4) \times 2$$
$$= (b_f \times t_f \times d) + (b_f \times t_f^2) + (d^2 \times t_w/4)$$
$$= (b_f \times t_f \times (d + tf)) + (d^2 t_w/4)$$

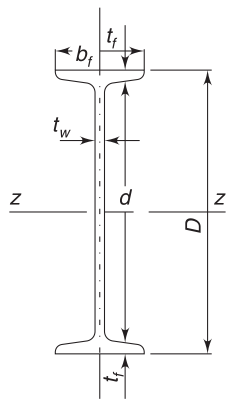


Fig 2.33

Z_{py} = 4 × [Area of flange on one side of *YY* axis × Distance between centre of gravity of this area and *YY* axis] + 2 × [Area of web on one side of *YY* axis × Distance between centre of gravity of this area and *YY* axis].

$$Zpy = [4 \times (b_f \times t_f/2) \times (b_f/4)] + [2 \times (d \times t_w/2) \times (t_w/4)]$$
$$= (b_f^{\,2} \times t_f/2) + (dt_w^{\,2}/4)$$

2.17 REACTION ON COLUMNS DUE TO CONCENTRATED LOAD "W" ON FLOOR

This will help to find the reaction on column due to concentrated load anywhere on the platform irrespective of the arrangement of beams.

2.18 BUILT-UP MEMBERS

Many options are available to a design engineer to choose built-up members. Different built-up sections are shown in Figs. 2.2, 2.3, 2.4 and 2.5.

The longitudinal spacing of fasteners connecting components of built-up compression members, for example, battens or lacings must be such that the effective slenderness ratio of the individual shape does not exceed 70% of the slenderness ratio of the whole member about the axis parallel to the batten or lacings or 50 whichever is less. Minimum two such intermediate

Bending Stresses & Stength

A French engineer by name Navier, based his theory upon three principal assumptions as follows:

(1) Strain is proportional to stress for the material of the beam.

(2) Cross sections which are plane and normal to the beam axis before bending remain plane and normal after bending.

(3) The beam is assumed to bend in a plane containing the vertical centroid axis and the beam axis.

From the theory of simple bending $(M/I) = (f/y/) = (E/R)$ Equation 1.0

where f = bending stress (tension or compression in a particular fibre), N/mm^2

Y = distance of extreme fibre from centroid of cross-sectional area, mm

M = applied B.M. at the cross section being considered, Nmm

I = second moment of area of the cross section, mm^4

E = Young's modulus of the material, N/mm^2

R = radius of curvature of the beam.

By rearrangement of Equation 1.0, we have

$f = (M \times y)/I = M/z$ Equation 2.0

i.e., the stress in any fibre is proportional to the bending moment and inversely proportional to the second moment of area of the cross section of the beam. The above three assumptions are important for understanding the behaviour of beams.

For beams of constant cross section, the most highly stressed points are the extreme fibres at the location of maximum bending moment, because at these points both M and Y are maximum.

$$f_{max} = M_{max}/Z_{min}$$

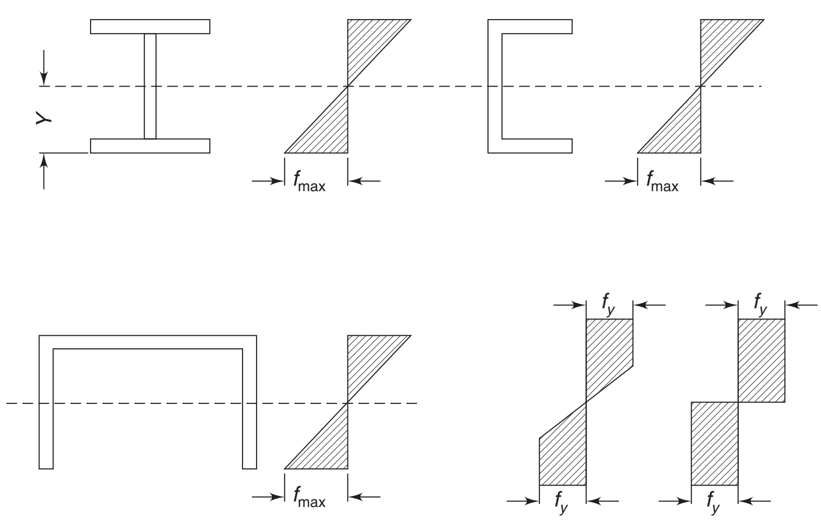


Fig. 2.35

where b' is the thickness of web or flange of the member. Maximum shear will occur at centre of one of the long sides of the rectangular part that has the greater thickness.

2.20 PROPERTIES OF STRUCTURAL STEEL

(a) $E = 2 \times 10^5$ MPa (N/mm^2)

(b) G = Shear modulus (modulus of rigidity) = 0.769×10^5 MPa

(c) Poisson's ratio = 0.3

(d) Coefficient of thermal expansion 0.000012 mm/mm/°C

(e) From 50° to + 150°F, density of carbon steel 7850 kg/cum

2.21 GRAPHICAL STATICS

Vectors

A force is represented by a vector in graphical statics (Fig. 2.36). A vector is shown graphically as an arrow, for which:

(1) the length is proportional to the magnitude of the force to a scale; and

(2) the direction is same as the direction of the force with respect to reference.

Graphical solutions require two diagrams:

Free body diagram or space diagram showing all forces acting on a body in their correct location.

A vector diagram or force diagram shows the vectors by which the forces are represented. These two diagrams must be drawn accurately and to scale.

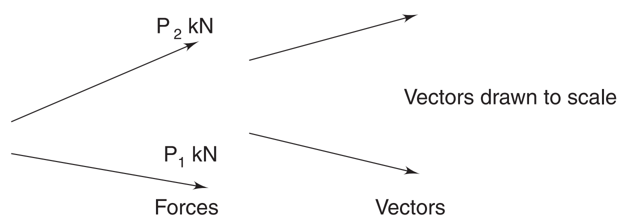


Fig. 2.36

Bow's Notation

The space between the forces is named using alphabets (capital letters) in a free body diagram. This naming is done by reading the spaces in clockwise direction. The forces are named using the names of spaces on either side of the force.

The vectors are named by lower case alphabet letters, with the earlier letter of the alphabet being attached to the tail of the vector, and the latter to the head of the vector in the vector diagram.

find the magnitude of force in all members. Let us consider the joint (*T*). The members are *E*-1, 1-2, 2-3 and 3-*E* from vector diagram *e*-1 is towards left. At joint (*T*) mark an arrow towards left for member *E*-1. From vector diagram, 1-2 is upward. At *T*, mark the arrow for member 1-2. Thus, the directions of forces can be obtained. The arrows away from the joint denotes tension. The arrows towards the joint indicates compression.

In the above diagram *T* denotes tension and *C* denotes compression.

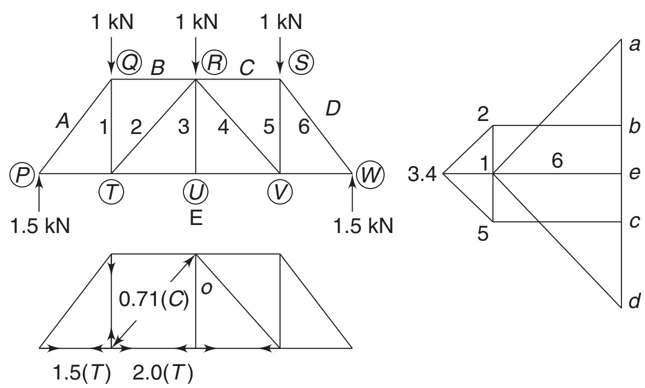


Fig. 2.38 Vector diagram and force diagram

In this method of joints, the following points are important:

(a) Reactions must be obtained before drawing the Maxwell diagram.

(b) Forces at a joint are always read in clockwise order.

(c) The order in which the joints are to be analysed is dictated by unknown forces, only two unknown forces per joint can be analysed.

(d) All forces are applied to the joint and not to the member.

(e) If two points in the Maxwell diagram coincide (e.g., 3 and 4 in Fig. 2.38), the force in that member is zero.

(f) The results of the analysis should be shown on the diagram of the truss. *A* member appearing thus ◄──► is in compression. Similarly ──►◄── indicates tensile force in the member.

Maxwell's diagram is used to analyse the pin-jointed frame and is called method of joints. Two equations of equilibrium $\Sigma H = 0$ and $\Sigma V = 0$ are established for forces in two mutually perpendicular directions. Those equations are solved to get the forces in the members. Thus, only two unknown forces can be solved at each joint.

Method of Section

Equilibrium of the section to the left of *XX* or to the right of *XX* is considered for finding the forces in members. To determine the force in the member *GH* in Fig. 2.39; let us cut the truss through section *XX*. The members *BC*, *BH* and *GH* are cut by section *XX*. To keep the portion

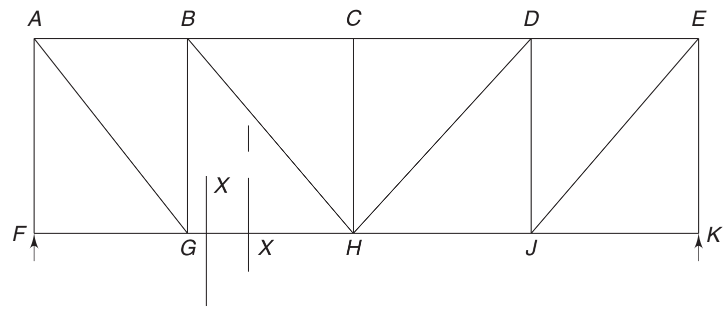


Fig. 2.39

of the truss on the left of section *XX* in equilibrium; let us assume that forces F_{BC}, F_{BH} and F_{GH} are applied.

The method of sections is explained below.

Cut three members for which forces are to be determined and apply forces that are applied at the ends of cut members.

Take the moment about a point of intersection so that the force in the other member can be found out by using the equilibrium equations.

Method of joints gives speedy solution for parallel chord trusses. The method of sections is more useful for pitched roof and north light roofs (saw-tooth roofs).

EXERCISE

1. Draw a neat sketch of an industrial shed with steel members and show the main components.
2. List the rolled shapes used as structural members.
3. Draw the sketches showing channels face to face and back to back and show the two mutually perpendicular axes.
4. List the types of connections used to connect a beam to column.
5. Draw a sketch showing moment connection between a beam and column flange.
6. What is the unit of measurement of force in SI unit?
7. What are all the requirements to fully specify a force?
8. What is meant by resultant of forces?
9. Explain with a sketch, the law of parallelogram of forces.
10. Explain couple of forces with a sketch.
11. What are all the conditions to be satisfied to keep a body in equilibrium?
12. Explain the difference between pressure and stress.
13. Define strain, permissible stress and yield stress.