UNIT 8 ROOF TRUSSES

Structure

8.1 INTRODUCTION

For covering large industrial or residential areas, to protect them against rain, sun, dust or other natural vagaries, we require roofing. The material used for roofing are called roof covering, which may range from tiles, corrugated steel and asbestos sheets to light FRP covers and tarpaulins. However, these materials are not structurally strong enough to support themselves and need to be supported by steel or concrete structures. Beams are some of the more common structural elements to support roofs. But when the area and the span also to be covered become too large, beams also become too heavy and uneconomical as structural members. The next most common type of roof supporting structures are truss elements, called *roof trusses*. Roof trusses are composed of tension and compression members joined together by welding or riveting. Purlins are the members which carry the roof cladding directly and are subjected to bending as in (Figure 8.1). The shape of the roof trusses are determined largely by the area and space to be covered, the use under which the covered premises is put and the type of roof cover used. The truss can be visualised as beam with inclined flanges and open web.

There are a large varieties of roof trusses in use. Figure 8.2 shows some of the most common types of steel roof trusses.

The *king-post* (Figure 8.2(a)) and *queen-post* (Figure 8.2(b)) trusses are some of the oldest forms of roof trusses and were largely used for small span timber roof trusses construction. Fink (Figures 8.2(c) and (d)), and Howe (Figures 8.2(e) and (f)) trusses are quite suitable for steel construction, both for large and smaller spans.

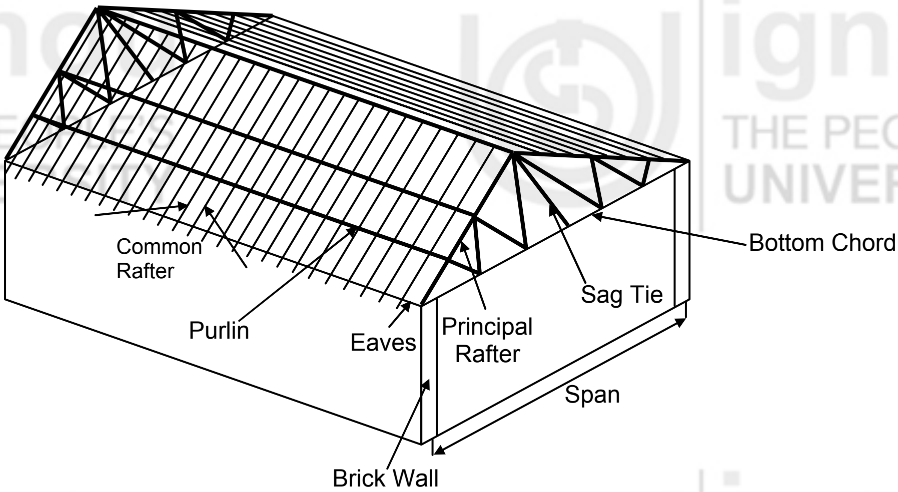
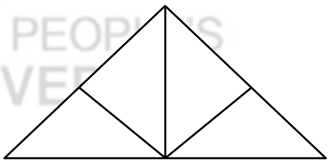
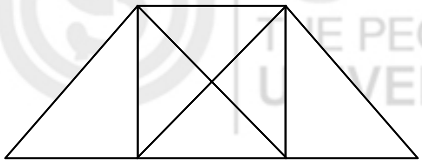


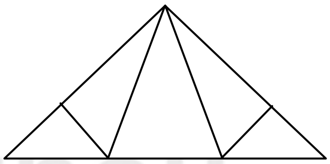
Figure 8.1



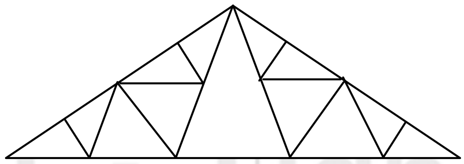
(a) King Post Roof Truss



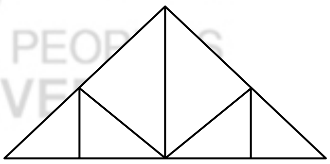
(b) Queen Post Roof Truss



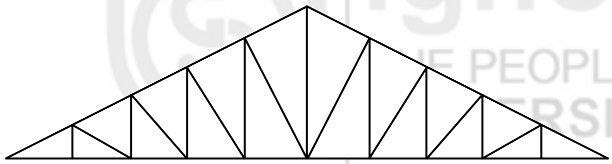
(c) Fink Roof Truss (Short Span)



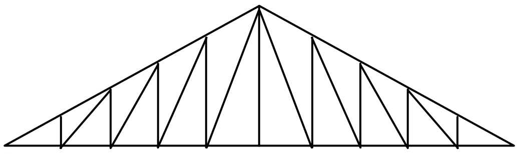
(d) Fink Roof Truss (Long Span)



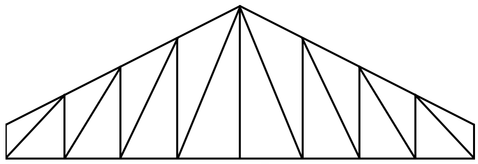
(e) Howe Truss (Short Span)



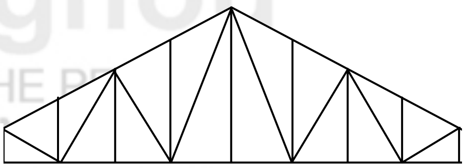
(f) Howe Truss (Long Span)



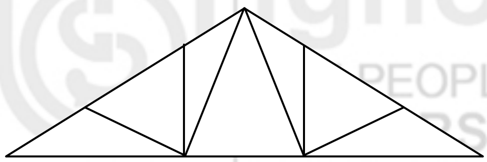
(g) Pratt Truss



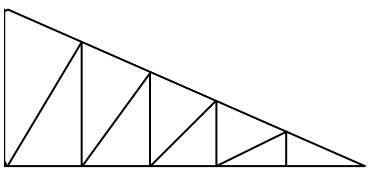
(h) Modified Pratt Truss



(i) Warren Truss



(j) Fan Truss



(k) North Light Roof Truss

Figure 8.2 : Types of Roof Truss

The Pratt truss (Figures 8.2(g) and (h)), Warren truss (Figure 8.2(i)) and Fan truss (Figure 8.2(j)), are also quite common types of roof trusses. Figure 8.2(k) shows a *north light roof truss* (unsymmetrical), which is normally used for factories and workshops.

Normally the purlins are fixed at the node points or joints of the top sloping member of the truss. The nodes in roof trusses are assumed to be pinned joints for purposes of analysis. Hence, the roof truss members are not subjected to any bending as the loads (through the purlins) are transmitted at the pinned joints. They are subjected only to axial loads, compressive or tensile. The roof trusses are normally supported at their ends on columns (steel or reinforced concrete) or masonry walls. Steel base plates are used for transferring the loads from the truss to the support. One of the base plates is fixed and the other is of sliding type, representing a fixed hinged support and a roller support respectively for statical calculations. The truss is analysed by using the principles of statics as laid out in *Section 2.5 of Unit 2 of "Applied Mechanics" course*. You are required to go through it once again before proceeding in this unit.

After determining the forces in the truss members they are designed as tension or compression members as the case may be. The purlins are designed as flexural members.

Objectives

After studying this unit, you should be able to

- select from the various types of roof trusses, the one most suitable for your job,
- estimate the loads acting on the roof truss selected,
- analyse and calculate the forces in the various truss members, under these loads,
- design the members of the truss for the worst combination of loads,
- design the purlins under various load condition, and
- design the wind bracings, joints, bearing plates, etc.

8.2 ROOF TRUSS : COMPONENTS AND DEFINITIONS

There are various terms, as given below, having special meaning when used in context of roof trusses. These terms are explained here.

Span

It is the horizontal distance between supports of the truss. When supported on wall bearings, the distance centre to centre of bearings is the *span.* In case of trusses framed into supporting steel columns, the clear distance between the column faces is the actual *span* (Figure 8.3).

Rise

The vertical distance between the apex and the line joining the support is the *rise* of the truss.

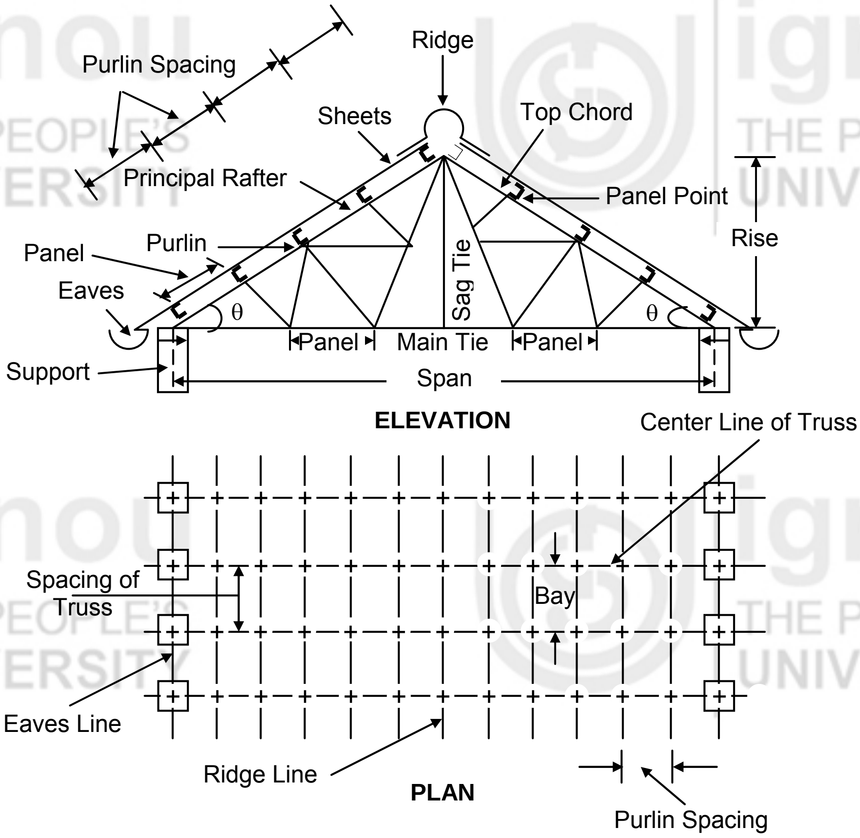


Figure 8.3 : Steel Roof Truss

Pitch

It is the ratio of the rise to the span of the truss, thus

$$\text{Pitch} = \frac{\text{Rise}}{\text{Span}}$$

The roof pitch depends upon the rain or snow which falls on the roof and has to be drained off. The pitches are steeper in areas of greater rainfall or where snowfall takes place. It also depends upon the nature of roof cladding used (Table 8.1).

Slope

Slope of the roof is the angle which the inclined roof surface makes with the horizontal and may be expressed in terms of degrees or as 1 vertical to x horizontal (1 V : x H). Thus, value of slope is numerically twice that of pitch.

$$\text{Slope} = \frac{2\ (\text{Rise})}{\text{Span}}$$

Table 8.1 : Pitch of Roof

Roof Covering	Pitch of Roof
Corrugated Iron Sheet	$\frac{1}{3}$ to $\frac{1}{6}$
Corrugated Asbestos Cement Sheets	$\frac{1}{5}$ to $\frac{1}{6}$
Tar and Gravel	0 to $\frac{1}{124}$
Slate and Tile	$\frac{1}{3}$ to $\frac{1}{4}$

Truss Spacing

The spacing of trusses is the distance (centre to centre) between adjacent trusses. This may vary between 4 m to 10 m depending upon their size. Normally they vary between $\frac{1}{5}$ to $\frac{1}{3}$ of the span.

Ridge Line

It is the line joining the vertices of the trusses.

Eaves Line

It is the line joining the lowest point of the roof trusses, on either side, where the drained water is collected and lead to rainwater pipes.

Top Chord

The uppermost line of members extending from the eaves to the ridge is the top chord. It is also called the *principal rafter*.

Bottom Chord

The lowermost line of members extending from support to support is known as the bottom chord. It is also known as *main tie*.

Ties

Members of the truss which are mainly under tension.

Struts

Those members of the truss which are principally under compression.

Joints

The point where more than one member meet; they are usually connected to a gusset plate by means of welds or rivets; and are known as *welded* or *riveted* joints.

Panel

It is the distance between two adjacent joints in the same line in a member.

Purlin

The purlins are horizontal members spanning across top chord of trusses and support the roof cladding.

In case of tiles and slates these are supported on secondary members called rafters which are laid over purlins.

The purlins are normally placed at the adjacent panel points of the top chord (or principal rafter), hence the distance between these points is also the '*spacing of the purlins'*.

Sag Tie

A sag tie is a vertical member joining the apex of the truss to the mid-point of the bottom chord. It is provided to reduce the deflection of the bottom chord member.

Sag Rods

These are round bar threaded at their ends (parallel to the roof slope) and secured to the purlin webs with nuts (often at their mid-points or one-third points of their span). This is used to reduce the stresses caused by biaxial bending of the purlins.

Wind Bracing

In case of roof trusses supported on steel columns, lateral bracing has to be provided against horizontal forces due to wind or earthquake. These are known as wind bracings.

Bearing Plates

When a roof truss is supported on masonry (stone or brick) walls, the load is transferred to a suitable concrete base through steel plates which are connected to it by suitable anchor bolts. The size of the plate depends upon the support reaction and the allowable bearing pressure on the wall.

8.3 LOADS ACTING ON ROOF TRUSSES

The loads acting on the roof truss may be classified as :

(a) Dead loads,

(b) Live loads, and

(c) Wind loads.

The IS : 875 (Indian Standard Code of Practice for Structural Safety of Buildings: Loading Standards) has been generally followed in the following discussion of these loads.

8.3.1 Dead Loads

The dead load on a roof truss includes the weight of roof coverings, purlins, bracings, self weight of roof truss etc. As some of these weights can only be exactly known after their final design/selection, a rough estimate is made for preliminary design as follows :

Weight of Roof Covering

Weight of roof covering are given for some of the common material in Table 8.2 as the weight per sq. metre of plan area.

Table 8.2 : Weight of Roof Covering

Material	Weight per m^2 of Plan Area
Slates	350 to 400 N /m^2
Glazing (6 mm glass)	250 to 300 N /m^2
Corrugated ACC sheets	160 N /m^2
Galvanised Corrugated Iron sheets (GCI)	150 N / m^2

Weight of Purlins

This can be assumed as given in Table 8.3, which are given for each sq. metre of roof plan area.

Table 8.3 : Weight of Purlins

Purlins	Weight per m^2 of Plan Area
For slate roof	100 to 150 N /m^2
For glazed roof	75 to 125 N /m^2
For corrugated sheet roofs	60 to 90 N/m^2

Weight of Bracings

The dead load of bracings may be estimated as 15 N /m^2 of plan area.

Weight of Roof Trusses

The self weight of the truss depends upon the type of roof covering material and its weight, the span and rise of the truss and the truss spacing. It may vary from 90 to 150 kN/m^2 of plan area. However, the following empirical formula is sometimes suggested to approximately estimate the truss weight.

$$W = 10\left(\frac{l}{3} + 5\right) \text{ N/m}^2 \qquad \text{. . . (8.1)}$$

where l is the span of the truss in metres.

Table 8.4 may also be used to estimate the approximate weight of the truss when the design load q in N/m^2 is known.

Table 8.4 : Self Weight of Roof Truss

Span (m)	Weight of Roof Truss (w) (N/m^2)
18	$w = 10\left(2.2 + \frac{q}{12.5}\right)$
24	$w = 10\left(2.78 + \frac{q}{5.42}\right)$
30	$w = 10\left(4.44 + \frac{q}{3.47}\right)$
36	$w = 10\left(5.27 + \frac{q}{2.1}\right)$

If the plan area A (= Span of truss × Spacing of truss) in sq. metre is taken as the variables, the following expressions give the estimated weight of roof truss per sq. metre of plan area.

Table 8.5 : Weight of Roof Truss

Connection Type	Roof Covering	Weight of Roof Truss in N/m^2 of Plan Area
Riveted	Sheeted	W = 10 (5.88 + 0.075 A)
	Partly glazed	W = 10 (4.88 + 0.088 A)
Welded	Sheeted	W = 10 (5.37 + 0.053 A)
	Partly glazed	W = 10 (5.37 + 0.064 A)

However, after finally designing the members of the roof truss, the total weight of the roof truss must be compared with the estimated W, assumed in design calculations, and adjustments may be made if a wide discrepancy is observed.

8.3.2 Live Loads

The live loads on roof has been recommended in the IS : 875 as shown in Table 8.6.

Table 8.6 : Live Load on Roofs

Sl. No.	Type of Roof	Live Load Measured on Plan	Minimum Live Load Measured on Plan
1.	Flat, sloping or curved roof with slopes up to 10^o		3.75 kN uniformly distributed over any span of 1 m width of the roof slab and a uniformly distributed over the span in the case of all beams.
	(a) Access Provided	1.50 kN/m^2	
	(b) Access not Provided	0.75 kN/m^2	1.90 kN uniformly distributed over any span of 1 m width of the roof slab and 4.5 kN unit distribution over the span in the case of beams.
2.	Sloping roof with slope greater than 10^o	(a) For roof membrane, sheets or purlins 0.75 kN/m^2; less 0.02 kN/m^2 for every degree increase in slope over 10^o (b) For members supporting the roof membrane and roof purlins, e.g. trusses, beams girders, etc. : 2/3 of load in (a) (c) Loads in (a) and (b) do not include loads due to snow, rain, dust collection etc. and such loads shall be appropriately considered.	Subject to a minimum of 0.4 kN/m^2
3.	Curved roof with slope at springing greater than 10^o	$(0.75 - 3.45\,\gamma^2)$ kN/m^2 where $\gamma = \frac{h}{l}$ h = height of the highest point measured from its springing l = chord width of the roof if single curved; and shortest of the two sides, if doubly curved	Subject to a minimum of 0.40 kN/m^2

8.3.3 Snow Loads

Design snow load may be 'actual snow load' or the live load in Table 8.6 whichever is more severe. The actual snow load will depend upon the shape of roof and its capacity to retain the snow. This may be assumed to be 25 N/m^2 per cm depth of snow. Snow loads may be disregarded in the case of roofs with slopes greater than 50^o.

8.3.4 Loads Due to Rain

This load to be considered separately if due to certain reasons accumulation of rain water becomes possible on roofs; otherwise provisions of Table 8.6 are sufficient.

Every member which is directly supporting the roof covering shall be designed to carry the more severe of the loads caused by live load and wind load (given in the next section) or an incidental concentrated load of 0.9 kN placed at the most unfavourable position of the member. The roof coverings also should be capable of carrying this load concentrated on an area of 12.5 cm square. (This load may be reduced up to 0.5 kN with the approval of the Engg-in-charge where it is ensured that the roof covering would not be traversed without suitable aids).

8.3.5 Wind Loads

Wind velocities and the pressures caused by them vary from place to place and season to season. They vary from gentle gales to strong cyclonic storms and can cause extensive damage to roofs, buildings or other structures, and therefore have to be taken into account in the design of these structures. Wind velocities, etc. are assessed in meteorological observatories all over the country.

Basic wind Pressure

Wind pressures are expressed in terms of a basic pressure, p, which is an equivalent static pressure in direction of wind. The IS : 875 gives maps of India showing basic maximum wind pressure.

The basic wind speed, V_b, is the wind speed measured in a 50 year return period, based on a gust velocity averaged over a short interval of time (3 seconds). As per IS : 875 (Part-III wind loads) – 1987 six winds have been identified which correspond to the basic wind speed of 55, 50, 47, 44, 39 and 33 m/sec respectively.

Design Wind Speed

It is the wind speed for which the structure is to be designed. The basic wind speed, V_b, for any site is modified to include the effect of risk level, terrain roughness, height and size of the structure and local topography. It may be mathematically expressed as :

$$V_Z = (k_1\ k_2\ k_3)\ V_b$$

where, V_Z = design wind speed at any height z (in m /sec),

k_1 = risk coefficient,

k_2 = terrain, height and structure size factor, and

k_3 = topography factor.

Design Wind Pressures (P_Z)

It depends upon the basic wind velocity (V_b), the height of the structure (z) above ground level, the terrain category, the local topography, the aspect ratio (i.e. ratio of the length and breadth of the building or structure), the slope of the structure and the solidity ratio or openings in the structures. This is obtained by the following formula

$$P_z = 0.6\ (V_z)^2\ \text{N/m}^2$$

where V_z is the design wind speed in m/sec at height z. For determination of V_z and, therefore, P_z, you are referred to consult IS : 875 (Part III : Wind Loads). Normally, you will be provided with the values of P_z.

The effect of wind on steel roof structures is also to create either *suction* (negative pressure) or *pressure* (positive) depending on the angle of inclination or slope of the roof, and the direction of prevailing winds. In case of GCI or AC sheets the suction pressures may be quite high which require the anchorage of the sheets and their supporting elements against the possibilities of their flying off (Figure 8.3).

The maximum wind speed as given in IS : 875 (III) is 55 m/sec corresponding to which the basic wind pressure at a height of 10 m from ground level is about 1.8 kN/m^2. For the smallest indicated wind speed of 33 m/sec the corresponding value of wind pressure is 0.65 kN/m^2. For a particular region a suitable value is selected and prescribed for design purposes.

8.3.6 Earthquake Loads

The details of calculation of earthquake loads on structure is available in IS : 1893-1985. In case of steel structures and roof trusses, where the weight of the roof cladding in negligible and for low rise buildings, the effect of earthquake loads may be ignored.

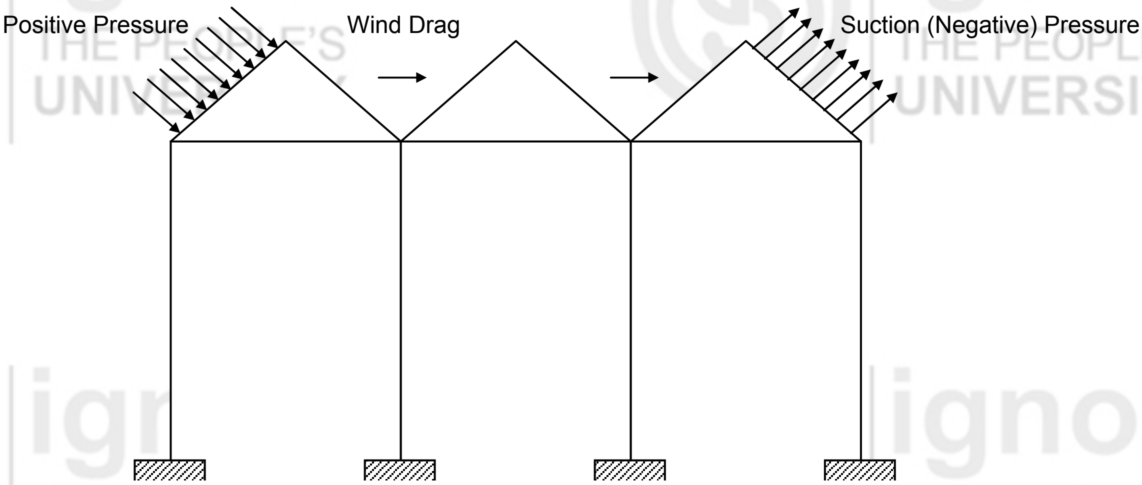


Figure 8.4 : Negative and Positive Pressures on Roof Trusses

SAQ 1

(a) Sketch a steel roof truss that you will adopt for a workshop building 12 m × 50 m in plan.

(b) What are the loads acting on the truss. Give an estimate for each of them. The building is situated in South Andhra Pradesh Coast.

8.4 DESIGN OF PURLINS

Purlins are members which directly carry the loads of the roof covering and are supported at the nodes (joints) of the adjacent roof trusses. Hence, they act like a beam with a span equal to the roof truss spacing. As the top members of the roof truss is sloping the purlins which are generally angles or channel sections (rarely light weight beam sections) are also inclined to the vertical. Hence, any vertical (live or dead load) causes biaxial bending in them, this has been discussed in detail in Section 7.3 in Unit 7, which may be referred to. However, wind loads acting normal to the roof truss rafter causes uniaxial bending of the purlins in the plane containing the *y*-axis.

8.4.1 Design of Angle Iron Purlins

For normal inclined roof trusses (slopes not greater than 30^o) and minimum basic imposed load of 0.75 kN/m^2 the following guidelines are recommended for angle iron purlins (conforming to steel grade Fe 415)

(a) The depth of the purlins should not be less than $\frac{1}{45}$ of its span.

(b) The width of the purlin should not be less than $\frac{1}{60}$ of its span.

(c) The maximum bending moment in the purlin may be taken as

$$M_{max} = \frac{WL}{10}$$

where, W = Total uniformly distributed load (including wind load) on the purlin, and

L = Span of the purlin (distance centre to centre between roof trusses).

Here the bending of the purlin about their minor axis is neglected.

(d) The maximum bending stresses in compression or tension may be increased by 33% (1.33 times) as the effect of wind loads are also included.

(e) The purlins may sometimes be designed as continuous beams supported over the roof trusses.

Example 8.1

Design an angle iron purlin for a steel roof truss given the following :

Span of roof truss = 15 m

Slope = 26^o

Spacing of roof truss = 5 m

Number of purlins along the roof truss = 7

Wind load on roof truss = 1.12 kN/m^2

Dead load from roof covering = 0.50 kN/m^2

Solution

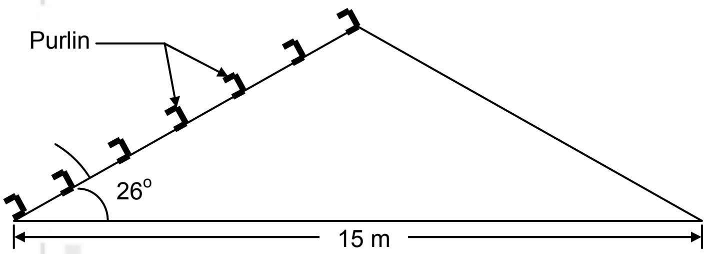


Figure 8.5(a)

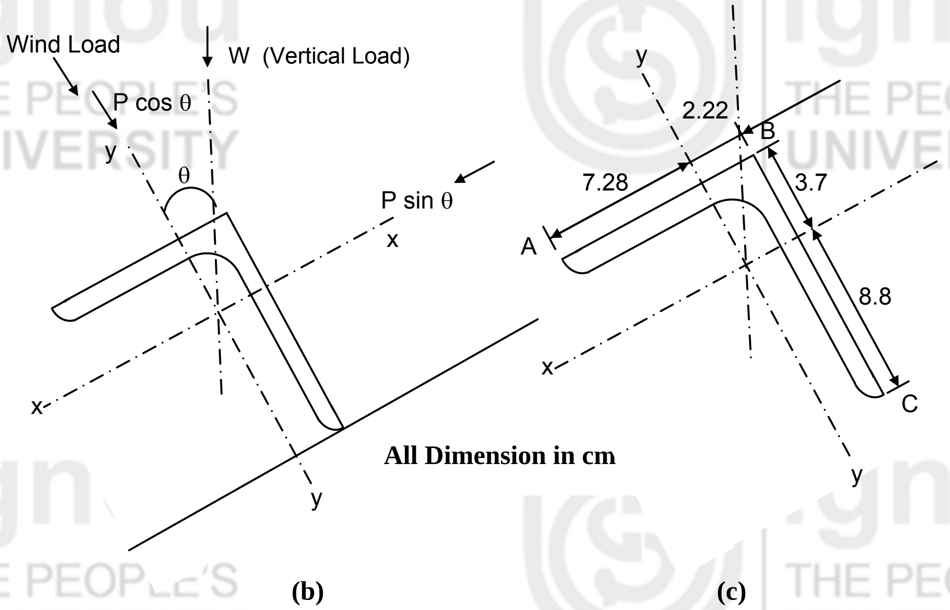


Figure 8.5

Loads

Assume self weight of purlin = 70 N/m^2

Weight of roof covering (AC sheets) = 160 N/m^2

Live load = (0.75 – 0.02) × (26^o – 10^o) = 0.43 kN/m^2 = 430 N/m^2

Total vertical load per m^2 of plan area = 660 N/m^2

Horizontal plan area for each purlin $= \frac{\left(\frac{15}{2}\right)}{6} \times 5 = 6.25 \text{ m}^2$

$\therefore$ Total load on each purlin, W = 660 × 6.25 = 4125 N

Component of load parallel to y-axis of purlin

$= W \cos 26^o = 4125 \cos 26^o = 3708$ N

Component of load parallel to x-axis of purlin

$= W \sin 26^o = 4125 \sin 26^o = 1808$ N

Wind load on roof truss = 1.12 kN/m^2 = 1120 N/m^2 parallel to y-axis of purlin.

Sloping area for each purlin $= \frac{7.5}{6} \sec 26^o \times 5 = 6.95 \text{ m}^2$

$\therefore$ Total wind load on each purlin = 1120 × 6.95 = 7784 N

$\therefore$ Total load parallel to y-y axis, W_y = 3708 + 7784 = 11492 N

Total load parallel to x-x axis, W_x = 1808 N

Bending moment parallel to y-y axis, $M_y = \frac{W_y \cdot L}{10}$

$$= \frac{11492 \times 5}{10} = 5746 \text{ Nm} = 5746 \times 10^3 \text{ Nmm}$$

Bending moment parallel to x-x axis, $M_x = \frac{W_x \cdot L}{10}$

$$= \frac{1808 \times 5}{10} = 904 \text{ Nm} = 904 \times 10^3 \text{ N mm}.$$

Selection of Purlin

$$\text{Approximate depth} = \frac{L}{45} = \frac{5000}{45} = 110 \text{ mm}$$

$$\text{Approximate width} = \frac{L}{60} = \frac{5000}{60} = 85 \text{ mm}$$

Adopt 125 × 95 × 6 mm angle having the following properties

Area = 12.86 cm^2; I_{xx} = 203.2 cm^4; I_{yy} = 102.1 cm^4

The angle is placed as shown in Figure 8.5(b) such that the smaller leg is at the top and the longer leg is placed such that the corner *B* is placed upwards. The major axis *y-y* is perpendicular to the principal rafter. It is important to note that such an orientation of the angle leads to smaller compressive stresses. As permissible stresses in compression is always less than that in tension such a placement of the angle is the best suitable one. Any other orientation will lead to larger bending stresses at the corner *A*, *B*, and *C*.

Calculation of Stresses

The distances of the CG of the angle from the corners (obtained from the IS : Handbook) are shown in Figure 8.5(c).

The stresses at the extreme corner points *A*, *B* and *C* are calculated below as in the case of biaxial bending (Example 7.3).

$$f_A = -\frac{(5746 \times 10^3) \times 37}{203.2 \times 10^4} + \frac{(904 \times 10^3) \times 72.8}{102.1 \times 10^4}$$

$$= -107.5 + 64.5 = -43.0 \text{ N/mm}^2 \text{ (Compressive)}$$

$$f_B = -\frac{(5746 \times 10)^3 \times 37}{203.2 \times 10^4} - \frac{(904 \times 10^3) \times 22.2}{102.1 \times 10^4}$$

$$= -107.5 - 19.7 = -127.2 \text{ N/mm}^2 \text{ (Compressive)}$$

$$f_C = +\frac{(5746 \times 10)^3 \times 88}{203.2 \times 10^4} - \frac{(904 \times 10^3) \times 22.2}{102.1 \times 10^4}$$

$$= 248.8 - 19.7 = +229.1 \text{ N/mm}^2 \text{ (Tensile)}$$

The maximum permissible tensile stress (including wind effects)

$$= 1.33 \times 165 = 219.5 \text{ N/mm}^2$$

The maximum stress, f_c, is only slightly in excess to this value (< 5%). Hence, the angle may be adopted. Otherwise the next higher section may be chosen.

The compressive stresses being much smaller are within the permissible value (you are expected to check this also).

8.5 DESIGN OF ROOF TRUSSES

8.5.1 Selection of the Truss Type

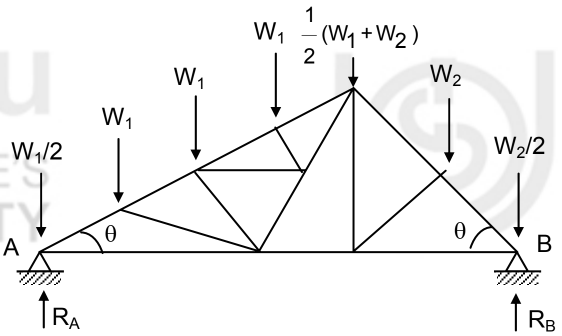
It is important to select the type of roof truss suited best to the type of use the building is to be put, the clear span which has to be covered and the area and spacing of the roof trusses and the loads to which the truss may be subjected. In the introductory section, various types of roof trusses have been shown which are most common and prevalent. After choosing the truss and deciding upon the loads to which it will be subjected, the truss is analysed and the force in the various truss members is calculated.

8.5.2 Analysis of Trusses

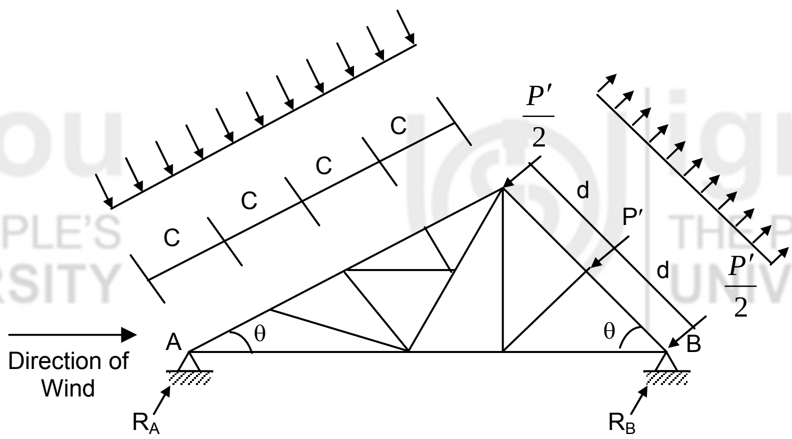
The member forces is analysed for the following two conditions :

Dead and Live Loads

These are calculated per square metre of (horizontal) plan area, and acts in a vertical direction at the joints. This is shown in Figure 8.6(a).



(a) Live Load and Dead Loads



(b) Wind Loads (Wind Blowing From Right)

Figure 8.6

Wind Loads

In this case, the wind is blowing normally to the roof truss. It is calculated per square metre of sloping roof area and is supposed to act at the joints normal to the principal rafter. If the truss is unsymmetrical, the member forces will be different for wind blowing from left, and when it blows from the right (Figure 8.6(b)).

8.5.3 Design of Truss Members

As the truss is supposed to be loaded at their joints, and the joints are assumed to be pin-jointed, there will be no bending in the members and they shall be subjected to either tensile or compressive forces only. Their design should be carried out as indicated in Unit 5 (Tension Members) and Unit 6 (Compression Members). Usually, the forces in the members may be so small as to indicate very small angle sections. However, from the point of view of truss-stiffness and also to resist transport and erection stresses, the following minimum sections are recommended.

Rafters and main ties	75 × 50 × 6 angles
Internal ties and struts	65 × 45 × 6 angles
Minor struts and ties	50 × 50 × 6 angles
Vertical sag tie	50 × 50 × 6 angles

Sometimes when the main rafters carry an intermediate purlin (placed in between two node points) it may be subjected to bending moments in addition to compressive forces, hence a double-angle section may be required. This happens when the spacing between the nodes is too large (greater than 1.6 m say).

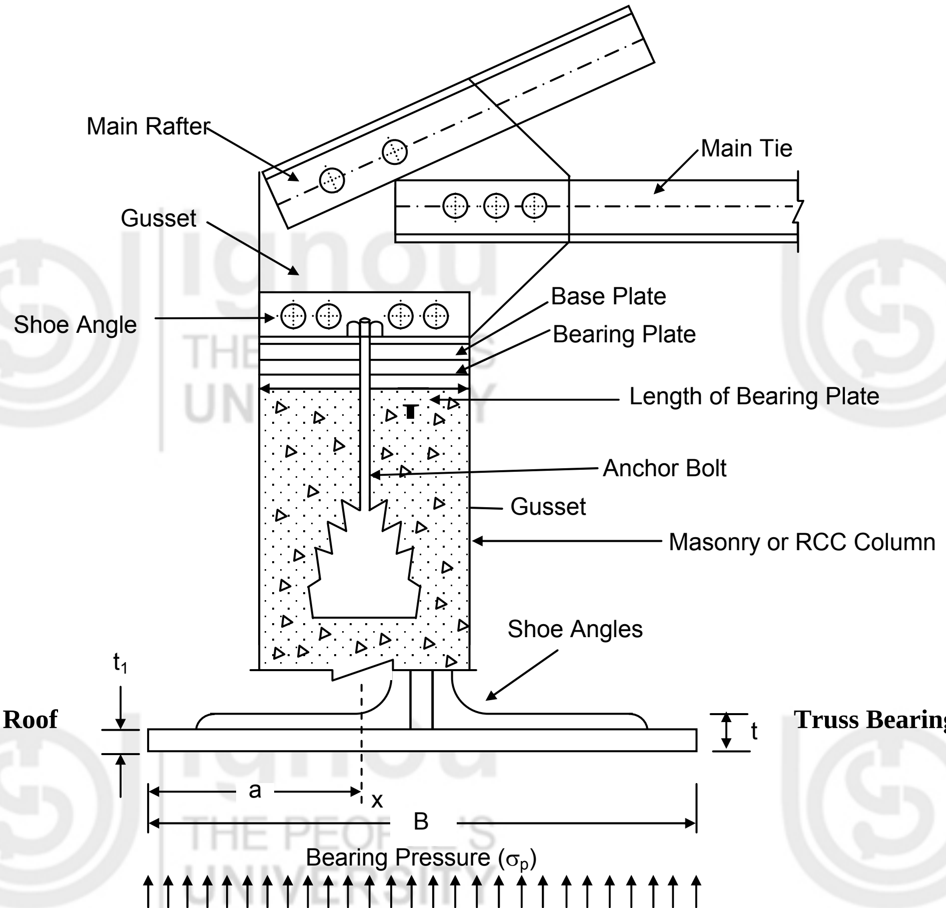
8.5.4 Design of Joints

At joins where more than one member meet, the members are connected either by rivets or welds, through a common gusset plate whose thickness is more than the thickness of any connected member.

The joints are made such that the centroidal axes of the members meet at one point, to avoid eccentricity of connection. The joints are designed to resist the forces acting on the members and are designed according to the principles laid down in Unit 4 (Riveted and Welded Joints). The minimum nominal diameter of rivets should be 16 mm and the gusset plates should not be less than 6 mm thick.

8.5.5 Design of Roof Truss Bearings

If the steel roof truss is supported on steel columns, they are joined to the latter by the usual beam column type of connections, which have been already discussed in earlier sections. If they are supported on masonry columns a suitable *bearing plate* is used which is anchored to the masonry by suitable *anchor bolts*. The roof truss is connected to the bearing plate through shoe angles (Figure 8.7(a)).



(a) A Roof Truss Bearing

(b) Shoe Angles and Base Plate

Figure 8.7

The area of the bearing plate A is given by

$$A = \frac{R}{\sigma_p}$$

where, R = Vertical reaction at the truss bearing,

σ_p = Allowable bearing stress in concrete or masonry (may be taken as 4 N/mm^2), and

$A = B \times L$ = Width × Length of bearing plate.

To determine the thickness of the bearing plate t_1, we have to equate the moment of resistance of the plate (M_R) to the bending moment (M) due to actual bearing pressure along the section x-x (Figure 8.8(b)).

Here $$M_R = \sigma_{bs} \cdot Z = \sigma_{bs} \frac{L t_1^2}{6} \qquad \text{. . . (8.2)}$$

where σ_{bs} = allowable bearing stress in steel plates = 185 N /mm^2

But $$M = \sigma_p \cdot L \cdot \frac{a^2}{2} \qquad \text{. . . (8.3)}$$

as $M_R = M$

we have $$\sigma_{bs} \frac{L t_1^2}{6} = \sigma_p \, L \, \frac{a^2}{2}$$

This gives $$t_1 = \sqrt{3 \frac{\sigma_p}{\sigma_{bs}}} \cdot a$$

Substituting σ_p = 4 MPa and σ_{bs} = 185 MPa

we get $t_1 \approx 0.25\, a$

The *shoe angles* are designed to accommodate the number of rivets required to transmit the maximum support reaction. Normally double angle 75 × 75 × 6 mm are used as shoe angle.

Anchor Bolts

These are designed to resist the net uplift pressure acting on the roof truss. One end of the roof truss is fixed and is the *fixed bearing*. The other end which is the *sliding bearing* is provided with elliptical slots so as to allow some horizontal movement of the base plate, over the bearing surface.

Example 8.2

Design a four-panel Howe roof truss, as shown in Figure 8.8(a), of 10 m span and 2.5 m central rise. The roof carries ACC sheet covering. The wind pressure may be taken as 1.25 kN/m^2 of surface area normal to the roof. The spacing of trusses are 4 m center to center. The trusses are supported on 25 cm wide RCC columns

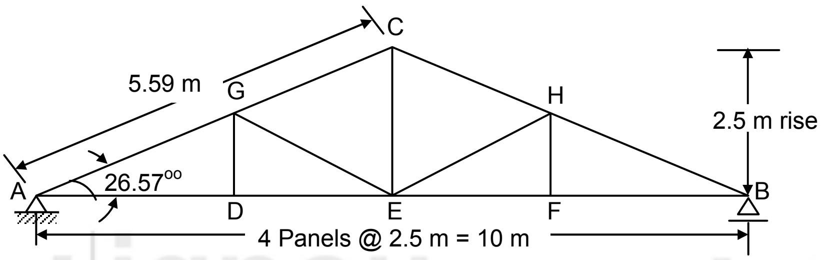


Figure 8.8(a)

Solution

The slope of the roof truss is $\tan^{-1} \frac{1}{2} = 26.57^{o}$

The sloping side of the truss is $= \sqrt{5^2 + (2.5)^2} = 5.59 \text{ m}$

Assumed dead loads

(i)	Weight of roof covering	160 N/m^2 of plan area
(ii)	Weight of purlin (assumed)	80 N/m^2
(iii)	Weight of bracings (assumed)	15 N/m^2
(iv)	Weight of roof truss (assumed)	85 N/m^2
From the formula $w = 10\left(\frac{l}{3} + 5\right)$		
Total dead Load		340 N/m^2
Live Load on roof from the formula $w_L = [0.75 - (\theta - 10) \times 0.02]$ kN/m^2		430 N/m^2
Total vertical load		770 N/m^2

Analysis of Roof Trusses for Vertical Dead and Live Loads

The total plan area for each roof truss = Span × Spacing

= 10 × 4 = 40 m^2

Total load on a roof truss = 770 × 40 = 30800 N

As there are five panel points *A*, *G*, *C*, *H*, *B* and the load at eaves points *A* and *B* is half that of the other points we have load at each intermediate joints

$$W = \frac{30800}{4} = 7700 \text{ N}$$

The load at the eaves points is half of this = 3850 N

This is shown in Figure 8.8(b).

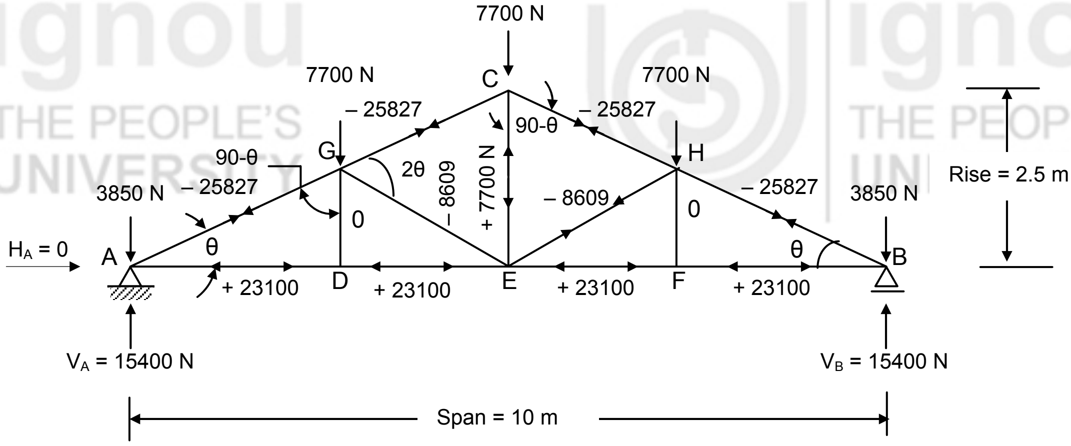


Figure 8.8(b) : Vertical Load Analysis

$$\tan\,\theta = \frac{1}{2},\ \cos\,\theta = \frac{2}{\sqrt{5}},\ \sin\,\theta = \frac{1}{\sqrt{5}}$$

Determination of the Support Reactions

At the fixed support A there are vertical and horizontal reaction V_A and H_A, at the sliding support B there can only be a vertical reaction V_B.

As there are no horizontal components of loads

we have $\quad H_A = 0$

Taking moments of all forces about A, we see that

$$V_B \times 10 = 7700 \times 2.5 + 7700 \times 5 + 7700 \times 7.5 + 3850 \times 10$$

$$\Rightarrow \quad V_B = 15400 \text{ N}$$

As $\Sigma\, V = 0$,

$$V_A + V_B = 7700 \times 4 = 30800 \text{ N}$$

$$\therefore \quad V_A = 15400 \text{ N}$$

Knowing the external loads and the support reactions, now you can find the force in the members of the roof truss, either by 'method of joints' or 'method of sections'. The forces as calculated are shown along with the members with their directions (signs, + ve tension or – ve compression) in Figure 8.8(b). You are required to verify these calculations.

Analysis of Roof Truss for Wind Loads

Next, we have to analyse the truss for the wind forces. As the wind pressure is 1.25 kN/m^2 of sloping roof area, the total wind load

$$W = \text{Wind pressure} \times \text{Sloping roof length} \times \text{Spacing of truss}$$

$$= 1250 \times 5.59 \times 4 = 27950 \text{ N}$$

(a) Assume the wind blowing from left side. As the wind load acting at joints A and C is half that at joint G; we have the loads at joints A and C as 6987.5 N and at G as 13975 N. This is shown in Figure 8.8(c).

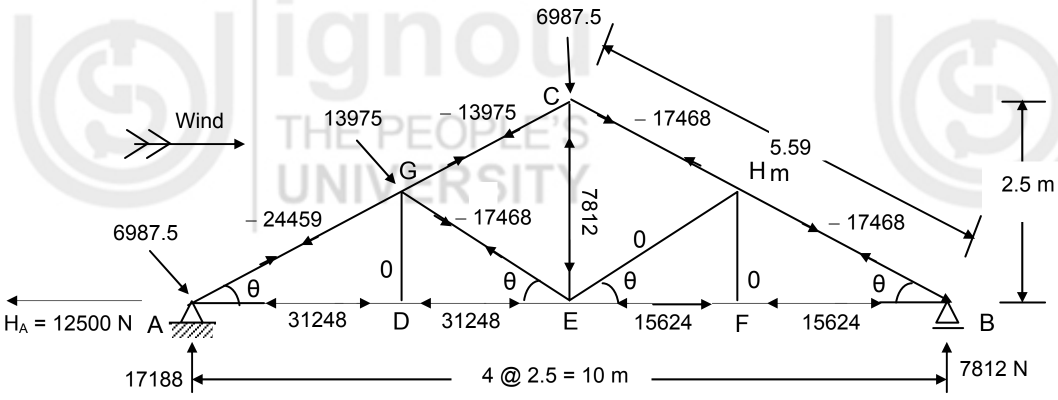


Figure 8.8(c) : Wind Load Analysis (Wind Blowing from Left)

The reactions at the supports are calculated as follows :

Taking moment of all forces about the point A

$$V_B \times 10 = 13975 \times \frac{5.59}{2} + 6987.5 \times 5.59$$

$$V_B = 7812 \text{ N}$$

Now vertical component of wind loads is

$$W_T \cdot \cos \theta = 27950 \times \frac{2}{\sqrt{5}} = 25000 \text{ N}$$

$\therefore$ $V_A + V_B = 25000 \text{ N} \Rightarrow V_A = 17188 \text{ N}$

Also, H_A is equal and opposite to the horizontal components of the wind loads

$\therefore$ $H_A = W_T \sin \theta = 27950 \times \frac{1}{\sqrt{5}} = 12500 \text{ N}$

and is acting towards the left as shown in Figure 8.8(c).

Knowing the loads and the reactions, the truss is analysed as before for member forces and these are indicated along with them in Figure 8.8(c) with their signs and direction arrows. (You have to check the calculations yourself.)

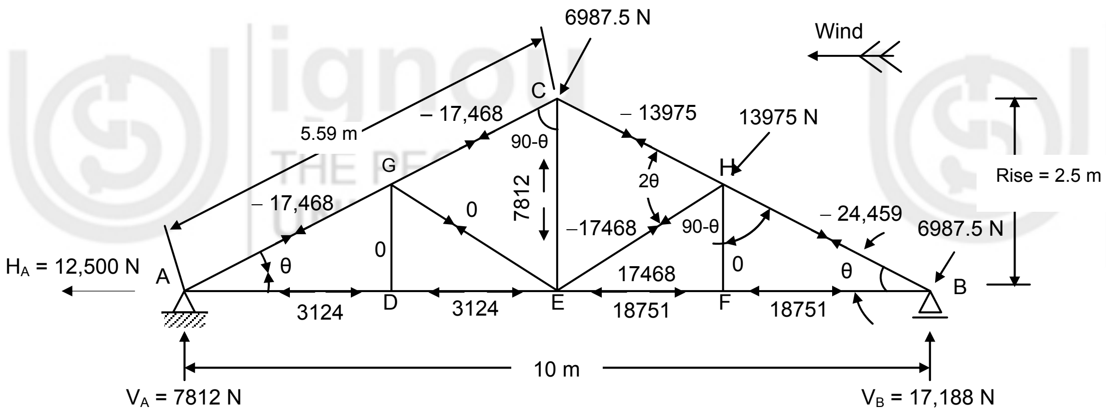


Figure 8.8(d) : Wind Load Analysis (Wind Blowing From Right)

(b) Next, the roof truss is analysed for wind forces, with the wind blowing from the right. This is shown in Figure 8.8(d). The reaction and member forces are calculated as indicated above which may be verified.

The above results are tabulated in Table 8.7.

Table 8.7 : (All Values in Newtons)

Sl. No.	Members	Force Due to Vertical Loads	Force Due to Wind Load (Wind from Left)	Force Due to Wind Load (Wind from Right)	Maxm. Compressive Force in Member	Maxm. Tension in Members
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	AG	– 25, 827	– 24, 459	– 17, 468	– 50, 286	–
2.	GC	– 25, 827	– 13, 975	– 17, 468	– 43, 295	–
3.	CH	– 25, 827	– 17, 468	– 13, 975	– 43, 295	–
4.	HB	– 25, 827	– 17, 468	– 24, 459	– 50, 286	–
5.	AD	+ 23, 100	+ 31, 248	+ 3, 124	–	+ 54, 348
6.	DE	+ 23,100	+ 31, 248	+ 3, 124	–	+ 54, 348
7.	EF	+ 23,100	+ 15, 624	+ 18751	–	+ 57,475
8.	FB	+ 23, 100	+15,624	+ 18751	–	+ 57,475
9.	GD	0	0	0	0	0
10.	GE	— 8609	– 17, 468	0	– 26, 077	–
11.	CE	+ 7700	+ 7,812	+ 7,812	–	+ 15,512
12.	HE	–8609	0	–17,468	–26,077	–
13	HF	0	0	0	0	0

Design

Looking at Table 8.7, columns (6) and (7), it is at once obvious that which member is to be designed for what magnitude (and type) of force.

The rafter members *AG* and *GC* have different maximum compressive forces in them (50,286 N and 43,295 N). But as it will not be economical to have two separate sizes of members for each panel, as the cost of cutting and joining them will be more than having a single continuous piece (with a difference of perhaps a few kg of metal) the entire principal rafter *AC* (and *CB*) will be designed for the greater of the two loads, i.e. 50,286 N (Compression).

Similarly, the principal tie *ADEFB* will be designed as one member for the bigger tensile force of 57,475 N (Tension).

The sloping members *GE* and *HE* will be identical, designed for a compressive force of 26,077 N and the vertical tie *CE* will be designed for a maximum tension of 15,512 N. As the vertical ties *GD* and *HF* do not carry any load only a nominal member of smallest size may be used.

Design of Truss Members

Principal Rafter

The principal rafter *AC* or *BC* is designed for a maximum compression of 50,286 N.

The effective length of one panel between joints

$$= 0.85 \times L = 0.85 \times \frac{5.59}{2} = 2.376 \text{ m}$$

Select an IS angle 80 × 80 × 6 @ 7.3 kg/m

From the handbook : Area = 9.29 cm^2

Radii of gyration, $(r_{xx}) = r_{yy} = 2.46$, $r_{uu} = 3.11$, $r_{vv} = 1.56$ cm

$\therefore$ Minimum, $r_{\min} = 1.56$ cm

$\therefore$ Slenderness ratio, $\lambda = \frac{2376}{15.6} = 152$

corresponding to this the permissible stress in axial compression (for steel, $f_y = 250$) is $\sigma_{ac} = 44$ MPa.

This is increased by 33% to include wind effects

$\therefore$ σ_{ac} allowed $= 1.33 \times 44 = 58.5$ MPa

$\therefore$ Allowed axial compression $P = 58.5 \times 929 = 54{,}365$ N

$> 50{,}286$ N $\therefore$ OK.

Principal Tie

The bottom tie member *ADEFB* is designed for a maximum tension of 54,348 N.

Permissible stress in axial tension

$\sigma_{at} = 0.6\, f_y = 0.6 \times 250 = 150$ MPa

This is increased by 33% to include wind effects

$\therefore$ σ_{at} allowed $= 1.33 \times 150 = 200$ MPa

$\therefore$ Net area required $= \frac{57475}{200} = 284 \text{ mm}^2$

Select IS angle 45 × 45 × 6 (Area = 5.07 cm^2 @ 4 kg/m)

Assuming 16 mm dia rivet holes

Area of rivet hole $17.5 \times 6 = 105$ mm^2

Area of each leg $= \frac{507}{2} = 253 \text{ mm}^2$

A_1 = Effective area of connected leg $= 253 - 105 = 148$ mm^2

A_2 = Gross area of outstanding leg = 253 mm^2

Then, $k = \frac{3A_1}{3A_1 + A_2} = \frac{3 \times 148}{3 \times 148 + 253} = 0.637$

Effective sectional area $= A_1 + k\,A_2$

$= 148 + 0.637 \times 253 = 309 \text{ mm}^2 > 284 \text{ mm}^2$ $\therefore$ OK.

Inclined Struts (*GE and HE*)

The inclined struts *GE* and *HE* are designed for a compressive force of 26,077 N.

The actual length of the member $= \frac{2.5}{\sec 26.56} = 2.8\,\text{m}$

Effective length = 0.85 × 2.8 =2.38 m

Select IS angle 65 × 65 × 6 mm @ 5.8 kg

Area = 7.44 cm^2, $r_{\min} = 1.26$ cm

$\therefore$ Slenderness ratio, $\lambda = \frac{2380}{12.6} = 189$

Corresponding, $\sigma_{ac} = 30$ MPa

Allowing 33% increase for wind effects $\sigma_{ac\ (perm)}$ = 40 MPa

$\therefore$ Allowable axial compression = 40 × 744 = 29,760 N

> 26,077 N $\therefore$ OK.

Vertical Tie (*CE*)

The vertical tie or sag tie, *CE*, will be designed for a tensile force of 15,512 N.

The actual length being 2.5 m

As determined earlier σ_{at} allowed = 200 MPa

$$\therefore \text{ Net area required } = \frac{15512}{200} = 78\,\text{mm}^2$$

Selecting a 40 × 40 × 5 IS angle,

Area = 3.78 cm^2

Assuming 16 mm dia rivets,

Area of rivet hole = (16 +1.5) × 6 = 105 mm^2

$$\text{Area of attached leg } = A_1 = \frac{378}{2} - 105 = 84 \text{ mm}^2$$

$$\text{Area of outstanding leg } A_2 = \frac{378}{2} = 189 \text{ mm}^2$$

$$K = \frac{3A_1}{3A_1 + A_2} = \frac{3 \times 84}{3 \times 84 + 189} = 0.57$$

$\therefore$ Net effective area = $A_1 + k\,A_2$

$= 84 + 0.57 \times 189 = 192 \text{ mm}^2 > 78 \text{ mm}^2$ OK.

The Minor Ties

GD and *HF* which do not carry any load at all may be provided by nominal IS : angle 30 × 30 × 5 mm.

Design of Bearing Plate

The maximum support reactions are

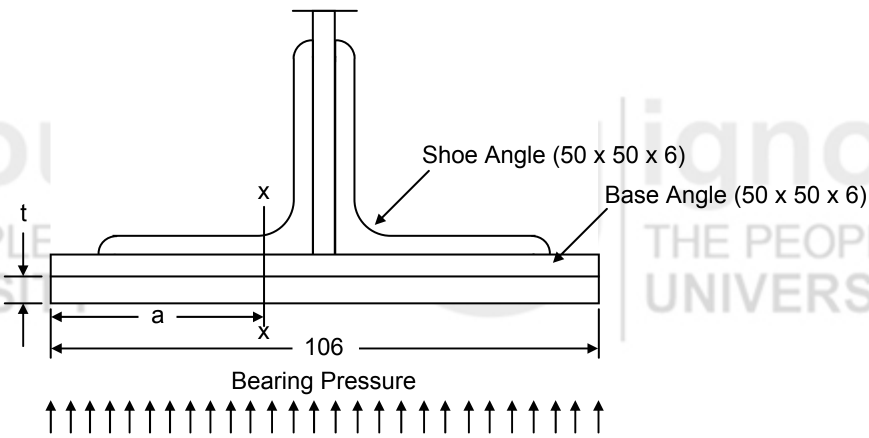


Figure 8.9

Due to Vertical Loads	= 15,400 N
Due to Wind Loads	= 17,188 N
Total R	= 32,588 N

Assuming allowable bearing stress in concrete σ_p = 4 MPa

The area of the bearing plate $= \frac{32,588}{4} = 8150 \text{ mm}^2$

Width of column = 250 mm (Adopt bearing plate of 200 mm)

$\therefore$ Width of bearing plate $= \frac{8,150}{200} = 42$ mm

Adopting 2 No. 50 × 50 × 6 mm shoe angles

The width of the base plate = 50 + 50 + 6 = 106 mm > 42 mm $\therefore$ OK.

Bearing pressure on concrete

$$p = \frac{32,588}{200 \times 106} = 1.54 \text{ N/mm}^2$$

Moment at the section *x*-*x*,

$$M = \frac{1.54 \times 200 \times 50^2}{2} = 3,85,000 \text{ N mm}$$

Let allowable bearing stress in steel σ_{bs} = 185 MPa.

Then section modulus $z = \frac{3,85,000}{185} = 2081 \text{ mm}^3$

If *t* is the thickness of the plate

$$z = \frac{bt^2}{6} = \frac{200 \times t^2}{6} = 2081$$

giving $t = 7.90 \approx 8$ mm

Hence, 8 mm thick base plate may be adopted.

SAQ 3

(a) Design a fink truss shown in Figure 8.10 for the following data :

Span of truss = 15 m

Slope of roof with horizontal = 30°

Roof covering : Tiles

Wind pressure in the locality = 1.15 kN/m^2 of inclined roof area

Spacing of roof trusses = 4.5 m

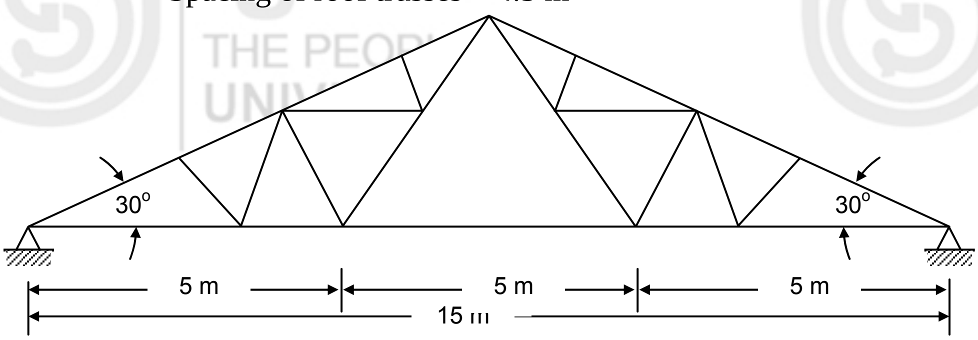


Figure 8.10

Give detailed structural drawing of the steel truss, along with the details of joints.

(b) Write short notes on the following :

(i) Pratt Truss

(ii) North Light Roof Truss

(iii) Details of an Eaves Joint

(iv) Basic Wind Pressure

(v) Base Plate and Shoe Angles.

8.6 SUMMARY

Let us conclude this unit by summarizing what we have covered in it. In this unit, we have

- introduced the concept of roof trusses,
- described various terms used in roof trusses,
- explained various types of roof trusses,
- evaluated the forces in truss members under dead, and wind load combinations,
- studied the design of purlins and guidelines for selecting a particular section for purlins,
- studied the design of wind bracing, truss members and joints, and
- understood the design concept of bearing plates.

8.7 ANSWERS TO SAQs

Refer the relevant preceding text in the unit or other useful books on the topic listed in the section 'Further Reading' given at the end to get the answers of the SAQs.