Structural System in Architecture

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Lecture - 21
Introduction to Truss

Welcome to the NPTEL online certification course on Structural Systems in Architecture. We are now in module number 5, the week 5; and from this week onwards we will start the various types of structural systems one by one. In this week we will start with one of the very important structural system called the Truss and the Space Frames. The two main topics Truss and the Space Frames are further subdivided into five lectures of half an hour each. This is lecture number 21; and topic of the lecture “Introduction to Truss”.

We will try to cover the following concepts:

- Definition of Truss
- Structural Concept of Truss
- Types of Truss
- Truss Geometry
- Parts of Truss
- Structural Advantages

The intended learning objectives of this lecture is:

- To Outline the Structural Concept of Truss.
- To know about Classification of Truss.
- To Illustrate Truss Geometry and Parts of Truss.

Truss is one of the very important and very popular structural systems, that you might have noticed in various buildings or built environments. This is used as a one of the major and common structural systems. Truss is composed of or made up by triangular units or the triangular component. These triangular units are constructed with straight members and their ends are joint in some typical points known as nodes. Sometimes it is also referred as open web girder. About the girder, we have discussed in the earlier lectures that, it is a kind of a deep beam, where the webs are open. We will discuss the details it further.

Truss is a vector active system because it has a direction and also a magnitude of the forces acting on it. The connections in a Truss System is normally pinned. In the Truss System the external forces and reactions to those forces are considered to act only at the nodes; and result in forces in the members which are either Tensile or Compressive forces. When all the members and applied forces are in a same plane, the system is a plane or two-dimensional Truss. Whereas, a space truss has members and nodes extending into three-dimensions, here the members are not confined in one plane, it is in the three-dimensional plane.

We will discuss about Space Frames in the last lecture of this module. The first four lectures will be based on two-dimensional Truss. In the first four lectures gradually, we will see about analysis and then comparative analysis of two-three type of Trusses.

Now, let us first discuss about structural components or the concept of a Truss. Here, I have started with a beam and this beam is having two pointed loads dividing the beam into three equal parts. So, the bending moment diagram is trapezoidal diagram; and I have deliberately drawn the bending moment diagram in the negative side, to look into some basic principles and to understand that how that will be governed out (Refer Figure-1).

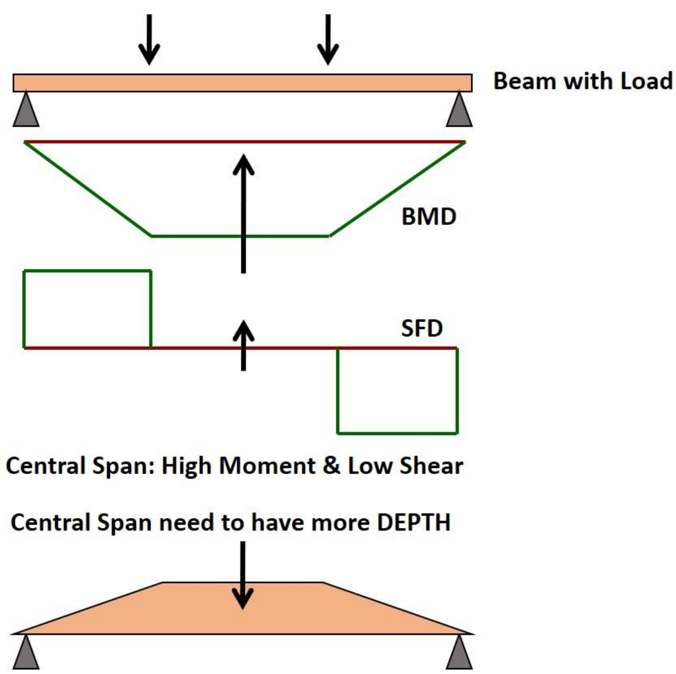


Figure 1: bending and shear in beam

It is also very important to have the shear force diagram (SFD) as shown in Figure-1, and we have already discussed this thing many times in the earlier lectures. Here in the SFD, in the middle one third portion there is high bending moment, that is under pure bending and the side portions are under the shear. But if we see the bending moment diagram, what we understand from it is that the central span is having the high moment and almost low shear, in the sense almost 0 shear. Therefore, the central span needs to have more depth; because, it will have to encounter a high moment. Hence, we have to increase the distance between the top and bottom fiber, that is the sectional depth as it has to encounter the high moment, as well as to reduce the bending stress in the top and bottom fiber.

So, we can say that a girder can be designed as shown in Figure-2.

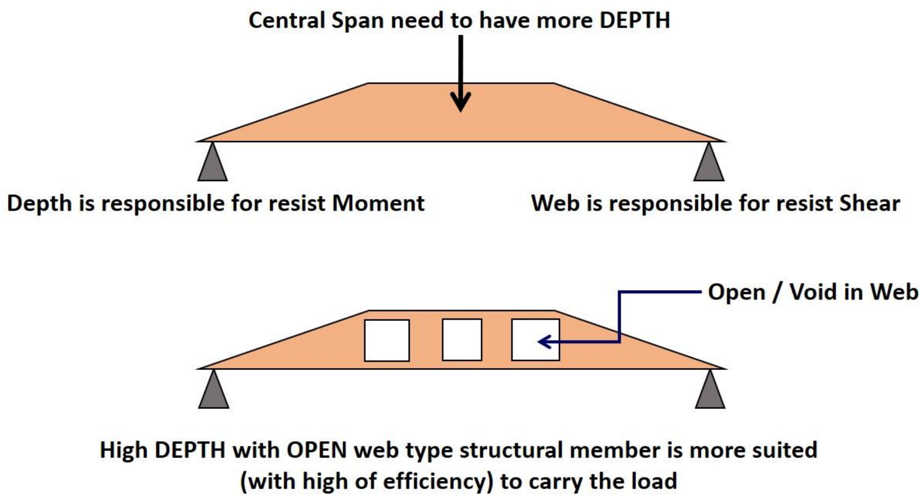


Figure 2 : the bending moment and shear stress details in a beam section

A beam will always have an equal cross section, but the cross section in the end part is not that much efficient, because it does not encounter that much amount of bending moment. Therefore, the central portion need a high amount of depth, and this depth is actually responsible for resisting moment and web is responsible for the resisting shear. The central wide portion shown in Figure-2 is called the web and that is responsible for the shear. But if you remember, in the earlier Figure-1 we have seen that, in this central portion of the beam there is no shear. So, in this portion we can make it open or we can save some amount of materials by making voids. We can put some material at the top and bottom of it, because we require a high amount of material to resist the moment; and as the shear is 0, we can open out few portions of the web.

So, a high depth with open web typic of structural member is more economical, suitable, and efficient to carry the load.

Next, if I take this particular proposition, for a pointed load with a huge span, where there will be very heavy or huge amount of bending moment at the central portion, the I will be in need of higher central depth; which means we need material at the top and bottom. Because as per bending moment diagram, we know that we need higher stress value at top and bottom; and therefore, we need more materials at top and bottom. whereas the central portion may be with void, as shown in Figure-3

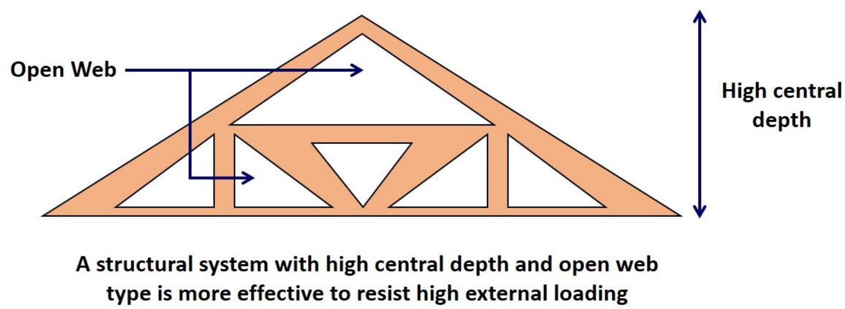


Figure 3 : pointed load with wide span and high central depth

So, what we can think of; we can think of a structural system which shown in Figure-3. It is a very theoretical structural system, and what I did is, I followed the bending moment pattern of uniform distributed load, or may be a pointed load which is parabolic, or may be a triangular system for a simply supported beam of length high length L. Then I took out some materials from central portion of it and make it like an open web. Because, the central portion web will experience less amount of shear force but high amount of bending moment. Therefore, I require the depth, but not high denseness of material. So, high central depth with the open web type design is more efficient; which I have discussed earlier for 2 point loads. But this is for 3 point loads.

So, this proposition or this type of the structure conclude to be a Truss kind of structure; where we can see triangular elements in the central portion of the span; the depth of the portion is high and it is having number of triangular voids which is the open web kind of portion. Therefore, Truss is called as an open web kind of structure or open web girder.

Now, when we see a Truss, we notice that it is a composition of lot of smaller triangles. So, why we need triangulation? Why it is triangle? Why not square or pentagon or any other shape? Why it is triangle? Let us discuss that why the triangle suits best in case of the load resisting phenomena.

See, in Figure-4, I have considered a square consisting of four bars or may be four ice-cream sticks of equal size. These four bars are joined pinned; and the resultant structure out of it may be very flexible in nature. The bottom member is pasted to a table or to a particular platform.

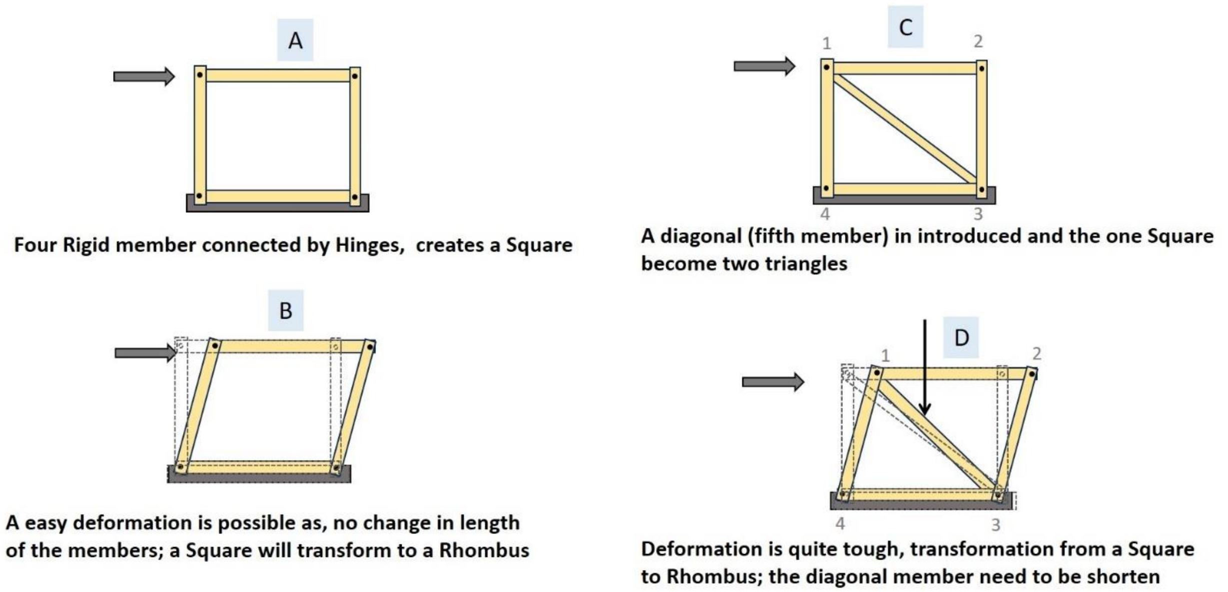


Figure 4 : deformation of shapes and stability of a triangle

Now, if you apply a lateral load as shown in case-A, in Figure-4, then what will happen? The structure will change its shape, and the square will change to Rhombus, as shown in case-B. So, it is very easy to deform with application of a small amount of load. But there is no change in length of the member.

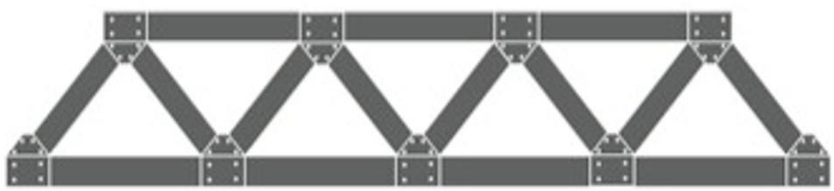
But the if I put a fifth member, that is a diagonal member as shown in case-C of Figure-4. The diagonal member may in any direction; it may connect point 1 and 3, or point 2 and 4. Here, I am showing the diagonal member from point 1 to 3. After introducing the fifth member, if apply the same amount of force in same direction as it was in case-A, then, deformation of the shape will not be easy. Why it is so? Because, if we want to make a deformation the diagonal member has to be shortened (when connected from point 1 and 3). Whereas, if we put it on the other way, connecting point 2 and 4, this it has to elongate. Therefore, we can say that it is quite tough to deform or transform from square to Rhombus.

So, what happened here is that because of introduction of the fifth member, the whole system divided into two triangles; and deformation of the triangle is not easy. To deform the triangle, at least one of the sides of the triangle either has to compress or elongate, and that is going to be tough; and therefore, triangulation is very stable.

Therefore, in case of a square or any other polygon, it will be much easier to change its shape without deforming or any member of it.

There are lot of examples of truss in the nature, and one is wing bone of Vulture. Vulture is the one of the strongest birds we have ever seen in our nature, and its wing bone seems like a true truss structure, which is shown Figure-5.

Wing bone structure of Vulture



A Truss: conceptually similar to vulture wing bone

Figure 5 : wing bone of Vulture and a conceptual truss similar to it

Hence, conceptually it seems like a Truss, which we commonly notice in the railway bridges.

Now, let us see mechanism of the Truss with respect to Figure-6.

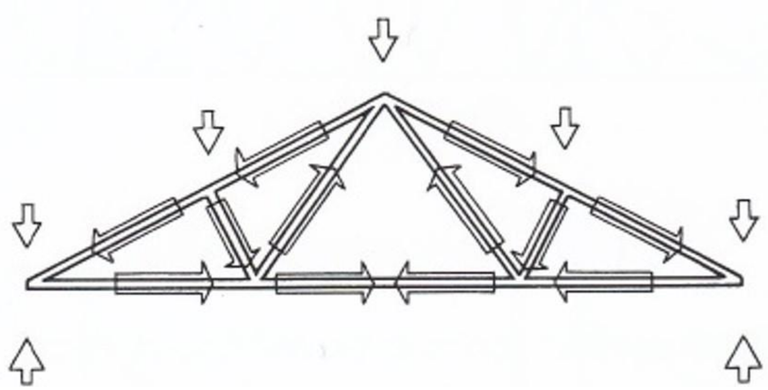


Figure 6 : Truss Mechanism: reduction of external forces through suitable patterns of individual members

So, in this case, if you have the loads and these loads are placed in typical nodes. These loads will now act on the members placed. Therefore, it is very important that we have to choose the right inclination of the members to distribute the force evenly through the members, by virtue of nodal forces or the external forces applied at the nodal points.

Hence, the geometrical pattern of the Truss will definitely provide an impact on total system design and total assessment of the load; as well as in final design of each individual members.

Now, let see the classification of Truss. Truss is broadly classified into two types, as given in Fogure-7.

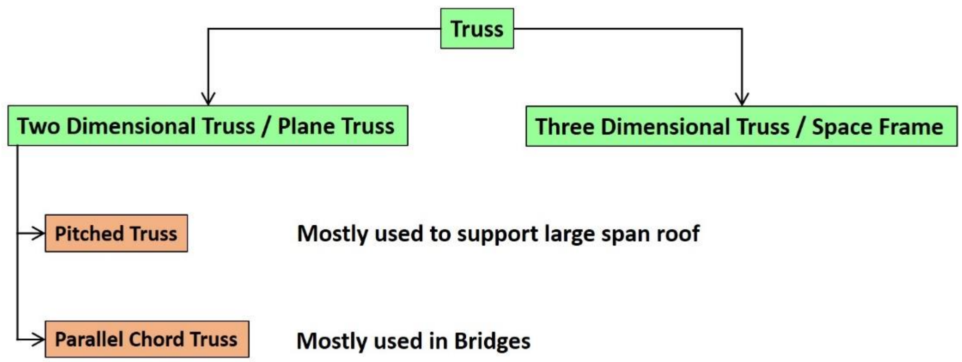


Figure 7 : classification of Truss

the Plane Truss are again subdivided into two further categories, one is called Pitched Truss another is called Parallel Chord Truss. Parallel Chord Truss are mostly used in the bridge and Pitch Truss is mostly used for the large span roofs.

The pitch Truss is something like which pitch that means it is inclined. It is triangular in shape and often used as for roof construction. There are plenty of its types. When we see it from geometrical form, there are various types of Pitched Truss, which are applied in various types of buildings and to cater various needs. For example: Pratt Truss, Howe Truss, Fan Truss, Fink Truss, Fan Fink Truss, Mansard Truss, North-light Truss, Attic Truss, Scissors Truss

The two most common Pitched Truss are Fink and Fan. They are almost similar, but the Fan has two additional vertical members than Fink. Refer Figure-8.

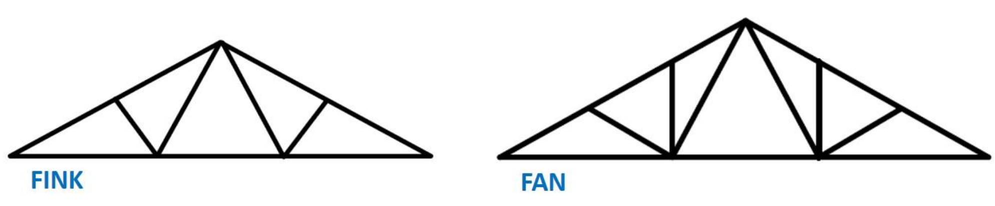


Figure 8 : Fink Truss and Fan Truss

The next, with vertical members are Pratt Truss and Howe Truss, as shown in Figure-9. Here, the difference between them is mainly the direction or orientation of the internal vertical members.

They are opposite in direction.

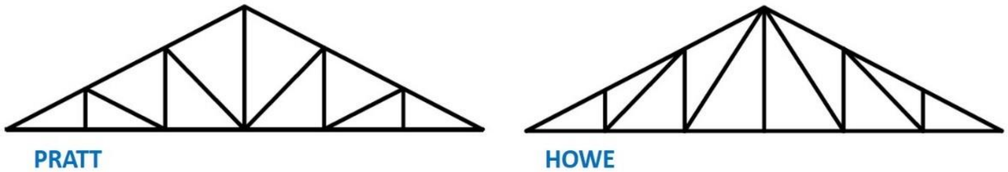


Figure 9 : Pratt Truss and Howe Truss

The Fink, Fan, Pratt and Howe are for smaller spans, may be 10 meters to 12 meters.
Now, if we go for a larger span, then we have to increase the number of triangular units. Mansard and the Fan-Fink Trusses are examples of such.

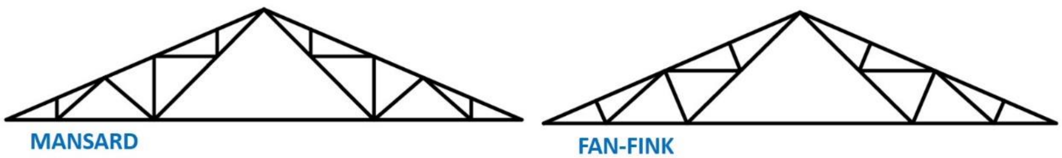


Figure 10 : Mansard and Fan-Fink Truss

So, when we have to go beyond 10- 12 meters, say 15 meters or more than that, we go for Mansard Truss and Fan-Fink Truss. Here in the Fan- Fink the members are mostly inclined, whereas in Mansard Truss it is vertical and horizontal.

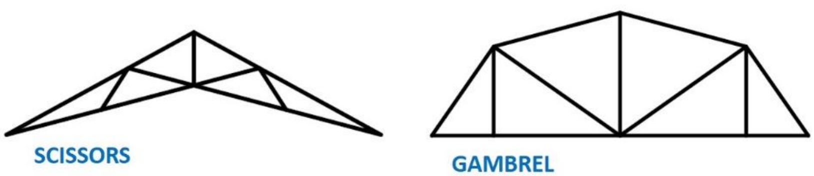


Figure 11 : Scissor and Gambrel Truss

In Scissors Truss or the Gambrel Truss, due to different geometrical orientations of the unit elements, its roof profile or the outer profile and the bottom profile changes or differs. So due to the change in the geometrical pattern the name also changes.

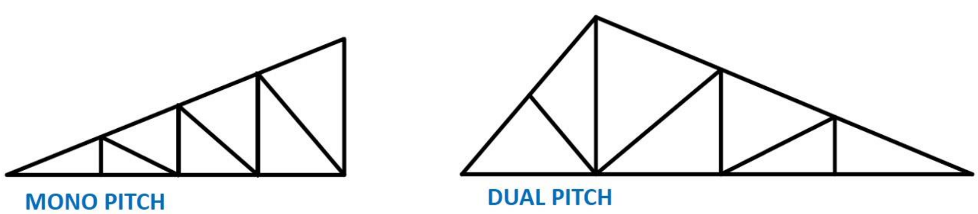


Figure 12 : Mono Pitch and Dual Pitch Truss

When we intend to get diffused North Light, then we go for Mono and Dual Pitch Truss. As the name suggests, Mono Pitch is unidirectional sloped pitch and Dual Pitch is with two directional sloped Truss. These Trusses are widely used in libraries and industrial buildings to get diffused natural light. They are also called as North-Light Truss.

When we need to cater a large span like railway station, then we go for Truss with very wide spans. One such is Bowstring Truss. It looks like a bow which is circular in the top and flat in bottom, as shown in Figure-13. The internal members are in zigzag pattern resulting into composition of triangular units. This type of Truss we can see in Howrah Railway Station, Kolkata.

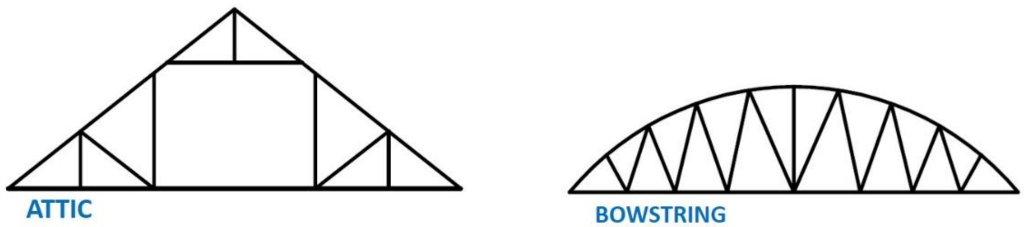


Figure 13 : Attic and Bowstring Truss

Attic Truss is also useful. Most commonly it is used in houses or we can say for smaller spans. In this Truss the central portion is created with a larger void, as shown in Figure-13, and this space is used as a storage space. This void or the storage space also acts as a thermal barrier helping to create a better and comfortable indoor environment.

Another type is Double Inverted Truss. As shown in Figure-14 (the top image), it seems like to be consists of two inverted Fan-Fink type of Truss, but central member is missing in this Truss.

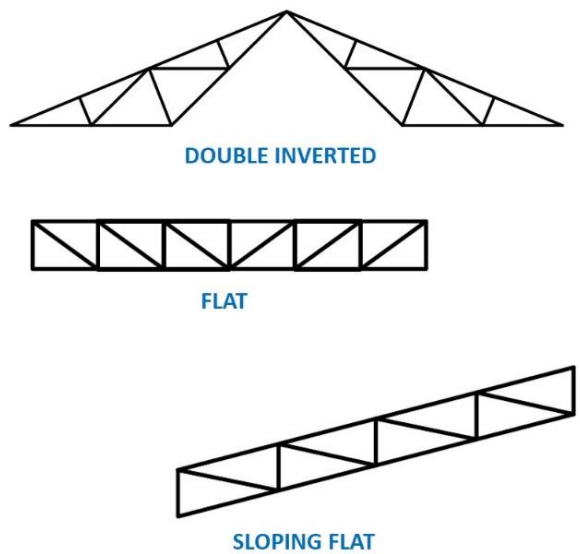


Figure 14 : Double Inverted, Flat and Slopping Flat Truss

Another two types are Flat Truss and Sloping Flat Truss. They are commonly used for long span designs such as auditoriums, stadiums, warehouses etc.

Next is the Parallel Chord Truss. In this, the top and bottom Chords are parallel to each other, and within that the triangular units are composed. They are mostly used for bridges, floor joists, framing in multistoried buildings, and auditoriums. There are many types of Parallel Chord Truss. Some are: Lattice Girder, Warren Truss, Floor Girder, K-Type Web, Diamond-Type Web etc. Refer Figure-15.

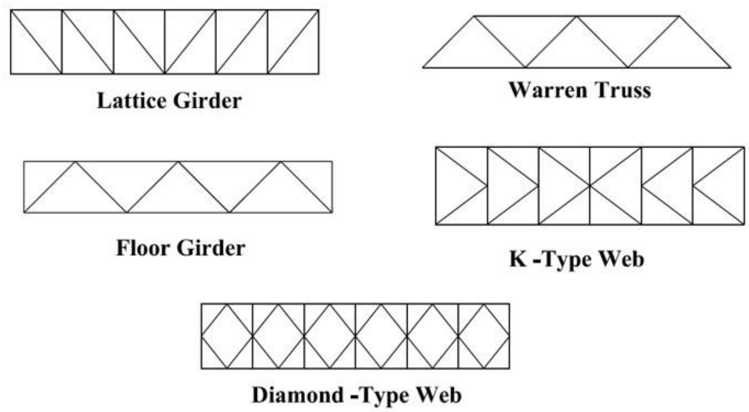


Figure 15 : examples of Parallel Chord Truss

Sometimes to increase the strength and rigidity, we can introduce or add some additional members, increasing the number of triangular units. This addition is done when we expect some additional load on it.

Now, let us discuss about geometry of Truss.

We know that Truss is inclined or pitch in nature, therefore, span of the Truss is measured from support to support. We do not want to have any intermediate support, because we wish to go for long span applications with less hinders. For example, a railway station or an auditorium or a stadium etc. where we need free and open spaces.

The span has to be catered with the rise of the Truss. Rise is the central vertical most point or the depth of the Truss. Refer Figure-16.

So, these two are the elementary geometrical dimensions for a Truss. Therefore, first we have to decide how much is the span and what should be the rise for that span? What should be the ratio between this R (rise) and L (Span)?

This ratio is very much important, and we generally keep it around 1:3 or 1:4; where 1 is the rise and the 3 or 4 those are span. So, by virtue of that, we can also find out the slope of the Truss, that is the angle θ, in Figure-16. Because we know the R and L/2. We can also find the gradient of the Truss given 1 in 'n'; and 'n' is some number.

Let us suppose a Truss with span (L) of 12 meters and rise (R) of 3 meters. Then we can compute it as:

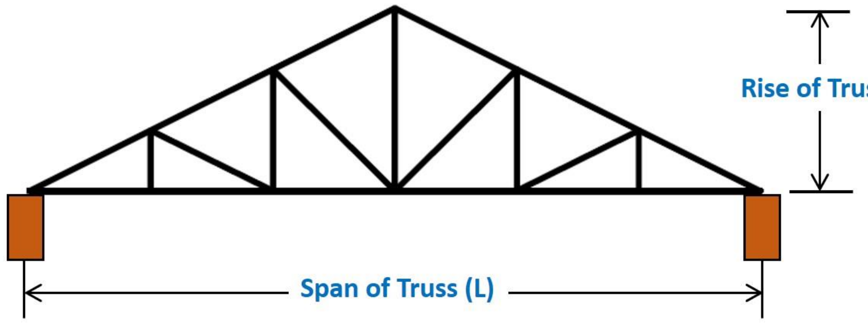


Figure 16 : geometry of a Truss

Slope of the Truss: Angle θ

Pitch of the Truss is the gradient of roof slope given 1 in 'n'

Now, considering L=12m; and R=3m

Then;

$$\theta = \tan^{-1}\left\{\frac{R}{\frac{L}{2}}\right\} = \tan^{-1}\left(\frac{3}{6}\right) = \tan^{-1}(0.5) = 26.56^0$$

$$Pitch = 3\ in\ 6 = 1\ in\ 2$$

So, if we go 6 horizontally, then 3 will be the rise, or we can say that 1 is the rise when we go 2 in horizontal.

A Truss is the skeleton of the structure and it always has to be covered with a roof. So, to put the roof coverings we need some supports or we can say some connecting members between the roof covering and the Truss; and they are known as Purlins. The purlins are placed on the Truss, but not on any intermediate places. So, whatever the load comes from the roof is transferred to the purlins, then to the nodes and then to the Truss.

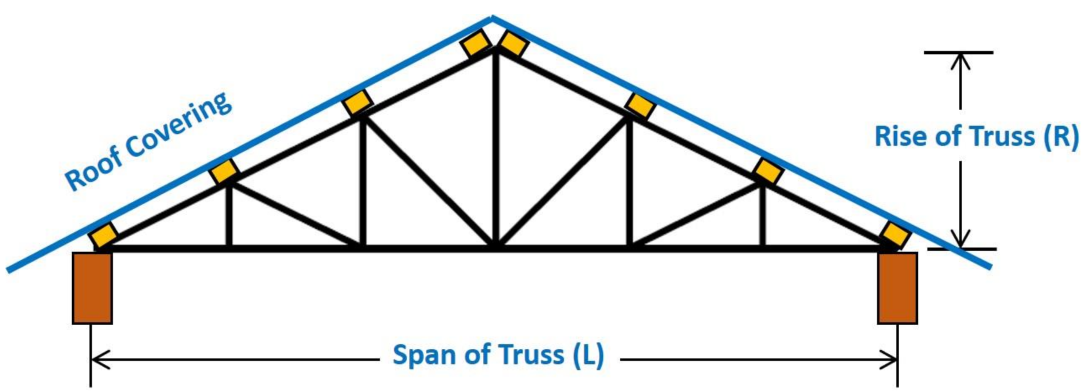


Figure 17 : roof covering, purlins and the Truss

The various components of the Truss are having further detailed nomenclatures, as shown in Figure-18 and Figure 19.

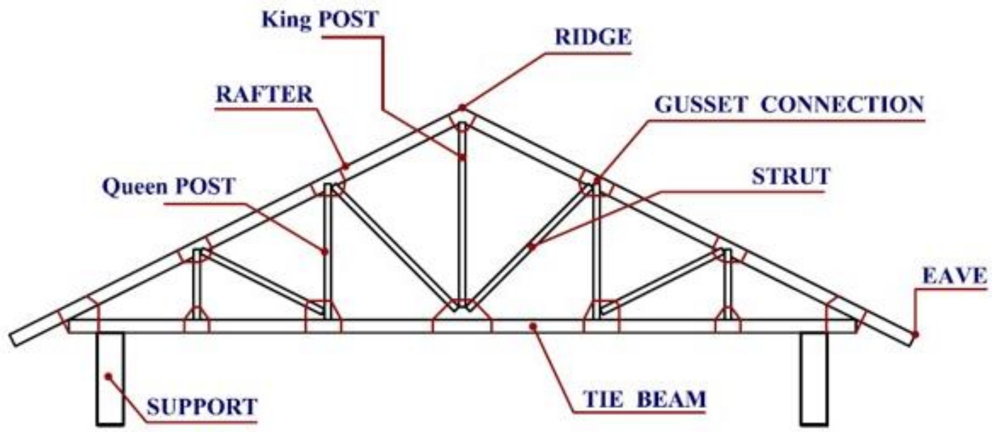


Figure 18 : components of a Pitch Truss

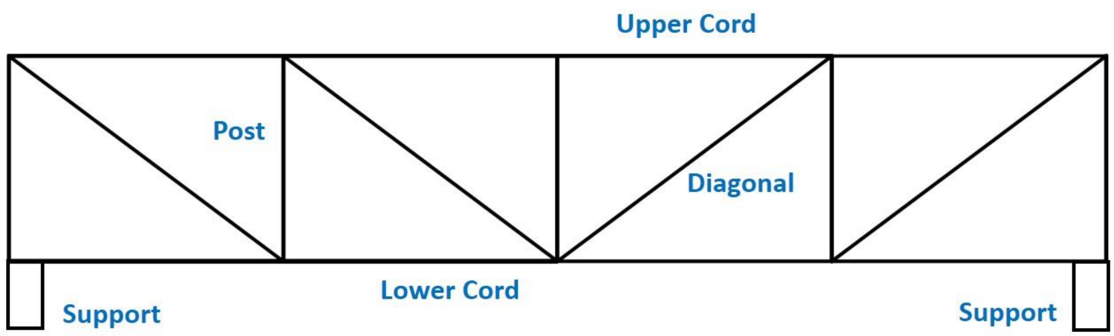


Figure 19 : components of a Parallel Chord Truss

There are various advantages of Truss system.

Truss can be assembled by individual members, so it results quicker and faster installation. It can provide higher span requirements like stadium, industry and auditorium. It is a light weight construction method and it saves time and cost.

The references taken for this lecture are as follows:

- Structure as Architecture by Andrew W. Charleson, Elsevier Publication
- Basic Structures for Engineers and Architects by Philip Garrison, Blackwell Publisher
- Structure and Architecture by Meta Angus J. Macdonald, Elsevier Publication
- Examples of Structural Analysis by William M.C. McKenzie
- Engineering Mechanics by Timishenko and Young McGraw-Hill Publication

- Strength of Materials By B.C. Punmia, Ashok K.Jain & Arun K.Jain Laxmi Publication
- Understanding Structures: *An Introduction to Structural Analysis* By Meta A. Sozen & T. Ichinose, CRC Press

At last we can conclude that, Truss is considered as a vector active structural system and it is widely used structural forms, providing long span solutions in buildings. It is used for supporting the roofs.

So, in the next lecture, we will discuss the analysis of Truss part-1.

Thank you very much.