Structural System in Architecture

Prof. Shankha Pratim Bhattacharya
Department of Architecture and regional Planning
Indian Institute of Technology Kharagpur

Lecture – 24
Application of Truss in Architecture

Welcome students, to our NPTEL online certification course on Structural Systems in Architecture. We are in module 5 and today is the 24th lecture of this series and this is the 4th lecture in the module 5. The topic of this lecture is "Application of Truss in Architecture".

The basic concepts to be covered are:

- Load Calculation Procedure for Truss
- Advantages of Steel Roof Trusses
- Application of Truss in Architecture
- Basic Construction of Roof Trusses

In the last 3 lecture we have discussed about all the all Truss systems and how they will be provided, their different types, load calculations based on the point load method etc. But we will see, in real time how the load calculations will occur. Today, we will start with load calculation procedure of Truss, then we will discuss about the advantages of steel roof Truss and the application of the Truss An architecture. Finally, we will just have some a glimpse, with some of the photograph from a site, and we will try to understand the basic concept or the construction concept of the roof Truss.

The intended learning objectives are to:

- Outline various steps of load calculation of Truss.
- Application of Truss in Architecture.
- Illustrate the construction process of Truss.

The learning objective of this particular lecture will include 3 bullets above. The first one is that, we will outline the steps of load calculations, what we will see in a very brief format. The detailed calculations are not in the scope of this particular course. Then we will go to the applications Truss in Architecture. There are lot of applications and examples of modern buildings; but we will see very few selective examples. and few applications are the applications. Then very briefly we will see the construction process of Truss.

into account. Finally, we have to take care of the third type of load, that is wind load; because due to typical triangular pattern or the pitch roof pattern of the Truss it will experience sudden change of the air pressure in the opposite sides of the slopes, and a heavy amount of load will be contributed on the Truss.

So, to understand all these, we have considered a very simple Truss. The span of the Truss is 12 meters and divided into six panels of 2 meters each; and considering rise of the Truss is 3 meters. So, we can say that first we have generated the 3m by 12m triangle; and then the 6 panels will divide the hypotenuse or the inclined members of the triangle into the three equal segments on each side. The divided segments will be of equal dimensions, which will be equal to 2.236 meters each. It is shown in Figure-1.

This is one Truss that we have discussed. But this Truss will be placed one after another to serve the purpose, may be the area you want to cover with roof for some activities. While placing the Truss one after another, I have taken the spacing of the Truss as 3 meters, that means the distance between one Truss to the next (may be Truss1 to Truss2) or the interval between the two successive Truss is 3 meters. Refer Figure-1.

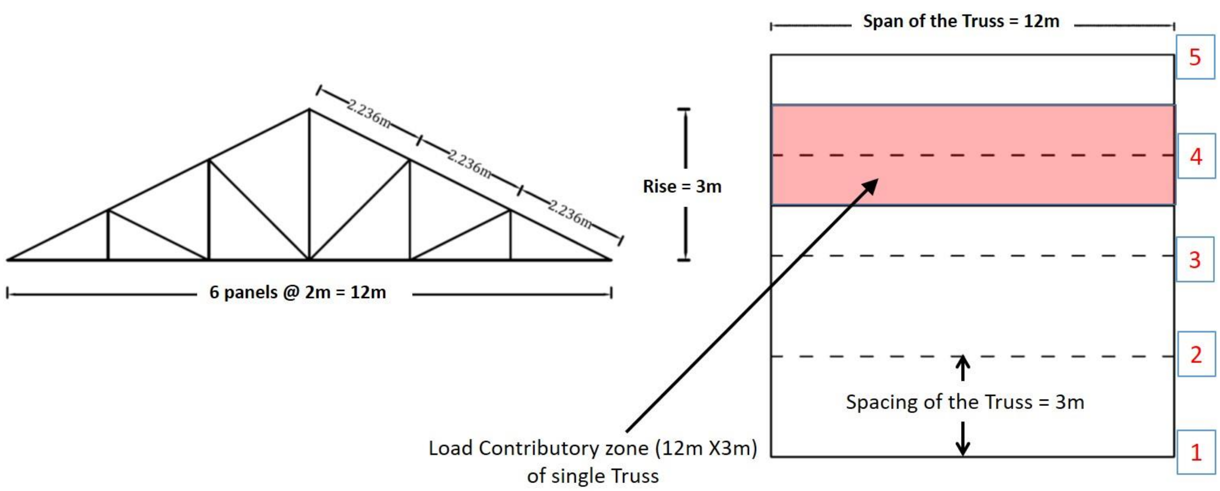


Figure 1 : considered Truss to understand its load calculation procedure

Next, again we will see one single Truss to understand about the influence area of the Truss. So, what is influence area? Influence area is nothing but the extent of area up to which one single Truss can tackle all kinds of loads whatever comes on it.

Here, in Figure-1, if I take the fourth Truss then influence area of this Truss will cover half of the spacing of Truss on both sides. So, this will be 1.5 meters on each side and that gives me 3 meters which is also equal to the spacing of the Truss. Hence, the load contributory zone of one single Truss (the fourth Truss) will be $3 \times 12 = 36\ m^2$, the red shaded area which is shown in Figure-1. Because span of the Truss is 12 meters and distance of influence zone is 3 meters. So, whatever may be the dead load, or live load, or wind load will be imposed here this area will be responsible to tackle all those. Or we can say that all forms of loads, the dead load, live load, wind load etc. are responsible to create deformations or the tension, compression etc. in this Truss. So, like that we have found $36\ m^2$ is a contributory zone of a particular Truss**.**

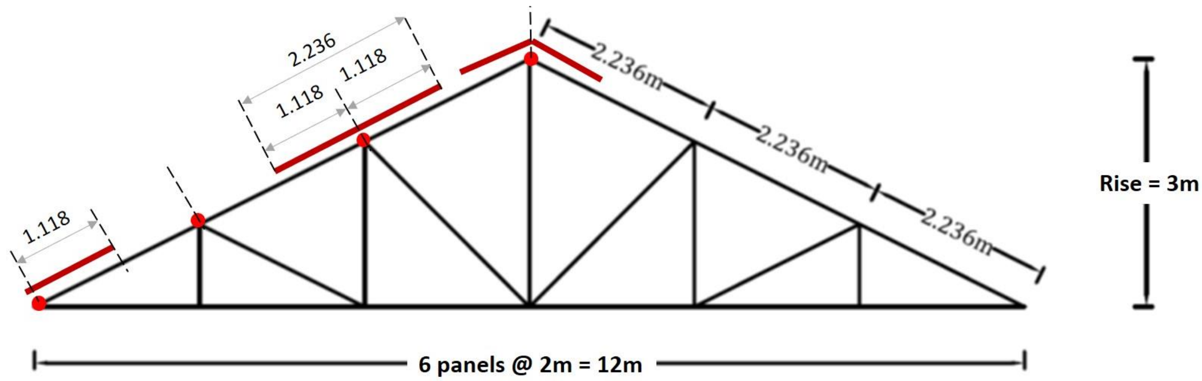


Figure 2 : force contribution of Purlins with respect to influence area

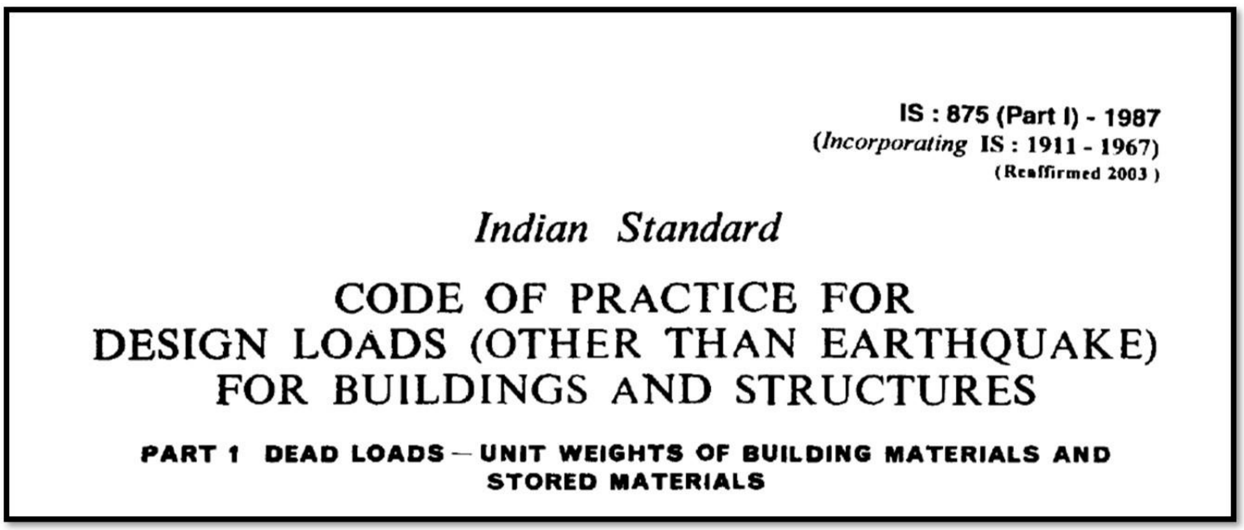
Now, next we will see the force contribution of purlins of the Truss. In Figure-2, the red dots represent the positions of the purlins. So, when we put a load on one of it then this will be influenced by the contribution area of half the distance of two successive purlins, as shown in Figure-2. Earlier we have calculated that the intermediate distance between two purlins or two nodes is 2.236 meters. So, the contribution area of the purlin will half of 2.236 on both sides of the purlin. So, altogether this length will be again 2.236 meters. We know that the distance of influence area of the Truss is 3 meters. So, the contributory area of any intermediate purlin will be $2.236 \times 3 = 6.708\ m^2$. But if we see the contributory area of the Eave purlin then we notice that it is not extended further the red dot or towards downward or to the left side. So, the contributing length is only half of 2.236 meters. half of 2.236 meter. So, the contributory area for the Eave purlin becomes $\frac{1}{2} \times 2.236 \times 3 = 3.354\ m^2$. After this if we see the ridge purlin, then similar to the middle purlin, it will also cover length in both side and total will be 2.236. Therefore, the contributory area of ridge purlin will be $2.236 \times 3 = 6.708\ m^2$, because the length of influence area of the Truss remains same, that is 3 meters.

Now, if we see, the nodal force contribution from one intermediate purlin and ridge purlin is of same amount, that is $2.236 \times 3 = 6.708\, m^2$; and of eave purlin is half of it, that mean $\frac{1}{2} \times 2.236 \times 3 = 3.354\, m^2$

Next, we need to know some of the unit weights of the material that we will use. So, if you want to put GI sheet, asbestos sheet, poly carbonate sheet or any material of the materials, the you have to find out from the Indian Standard code or IS code. So, the IS code which is used for the dead load unit weight of the building materials is IS : 875 (Part 1) – 1987, and Part-1 is for dead loads. Refer Figure-3.

So, you can go through this particular IS code and find out the unit load of building materials.

Hence, if you know the contributory area, if you know the thickness of the material, then multiplying by the density of the material you can find out how much is the load.


IS : 875 (Part I) - 1987
(*Incorporating* IS : 1911 - 1967)
(Reaffirmed 2003)

Indian Standard

CODE OF PRACTICE FOR
DESIGN LOADS (OTHER THAN EARTHQUAKE)
FOR BUILDINGS AND STRUCTURES

PART 1 DEAD LOADS — UNIT WEIGHTS OF BUILDING MATERIALS AND STORED MATERIALS

Figure 3 : IS code 857 Part-1 for dead loads

Similarly, to the dead load, the units of materials for the imposed load will be given by IS : 875 (Part-2) – 1987. Refer Figure-2. So, depending upon the activities the loads will vary. In case of our roof, which is an inclined roof, this particular imposed load will depend upon the angle θ. Because, if the angle θ increases that means the roof is very stiff, then the imposed load intensity will be reduced. And if it is very flat the intensity of the imposed load will increase. Logically, if the roof is very steep then nobody or no human being will generally climb into that, but if it is very flat, the angle θ is very small the inclination is very small then there is a possibility that people will go and on the top of the roof. So, these all depends upon the angle θ. Hence, this IS : 857 (Part 2) will give you the impose load.

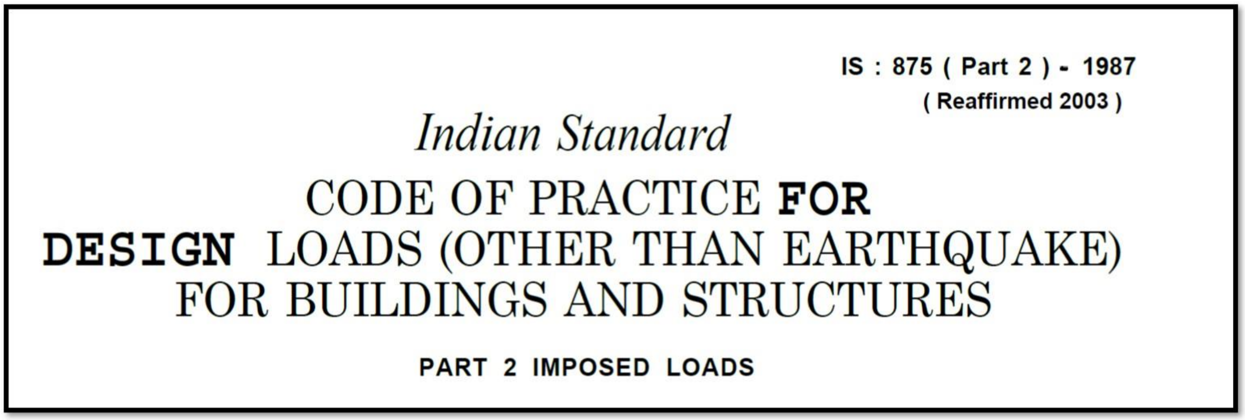

IS : 875 (Part 2) - 1987
(Reaffirmed 2003)
Indian Standard
CODE OF PRACTICE FOR
DESIGN LOADS (OTHER THAN EARTHQUAKE)
FOR BUILDINGS AND STRUCTURES
PART 2 IMPOSED LOADS

Figure 4 : IS code 857 Part-2 for imposed loads

Now, without considering these two codes, I have simply considered the intensity of the dead load as 500 N/m^2 (which is equal to 0.5KN) and intensity of the impulse load I have just for the time being is taken 0 for the Truss what we have lately discusses, that is the Truss shown in Figure-2. Here, instead of 0, even if you take some value, you can do it in the same way. So now as I have discussed the influence area of the intermediate purlin is $6.708\ m^2$. Then the load contribution for different purlins will be:

Nodal Force contribution from one intermediate purlin of influence area of $6.708\ m^2 = 0.5 \times 6.708 = 3.354$ KN

Nodal Force contribution from one Eave purlin of influence area of $3.354\ m^2 = 0.5 \times 3.354 = 1.677$ KN

Nodal Force contribution from one Ridge purlin of influence area of $6.708\ m^2 = 0.5 \times 6.708 = 3.354$ KN

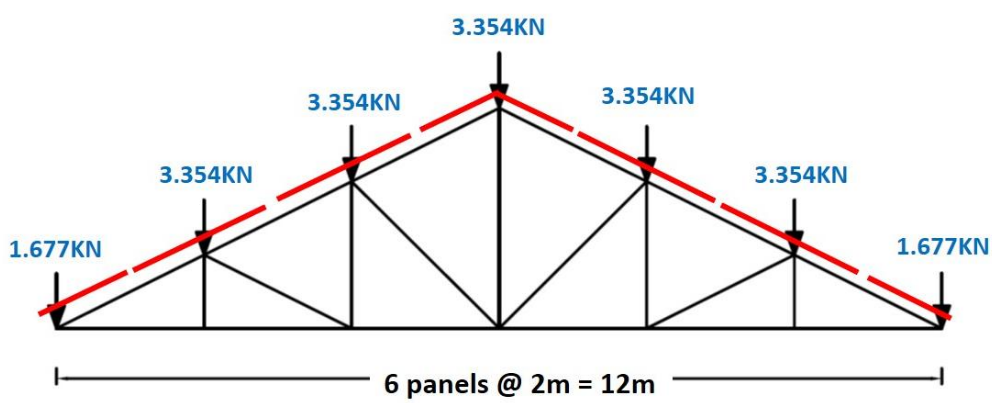


Figure 5 : nodal force contribution of different purlins

So, the forces on intermediate purlins and Ridge purlins remains same, because their influence zone is spreading toward both side of the purlin, resulting to 2.236 meters (Refer Figure-2); and nodal force contribution is 3.354 KN. Similar to the earlier case, the Eave purlin has the are only on one side, it does not go beyond the purlin. So, influence zone is only half as 1.118 meters. So, the nodal force is also half, that is 1.677 KN.

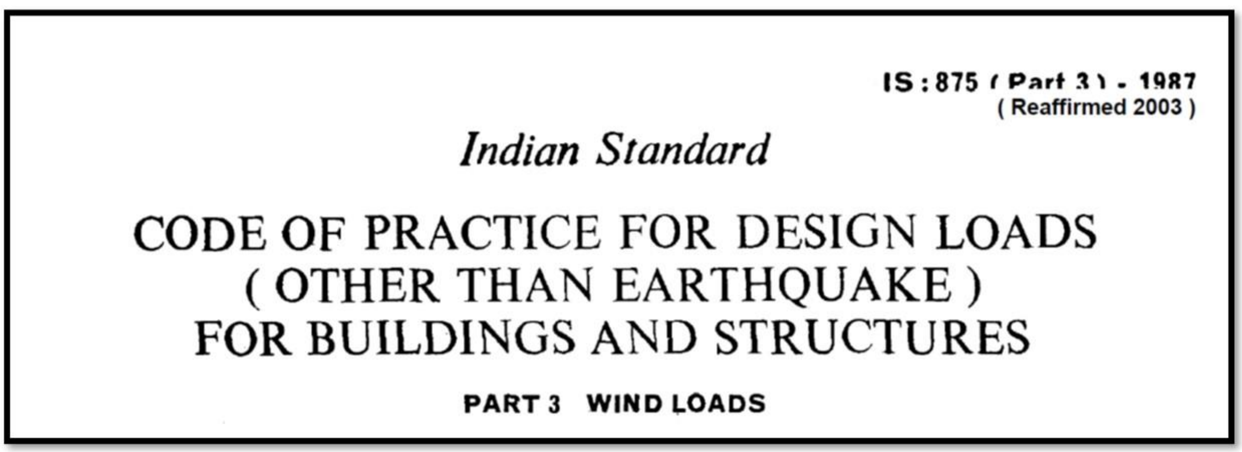
The details of the nodal force contribution are shown in Figure-5.

These computations can be done by hand, or can be analysed through some basic or advanced software. Some people have their own programming ways to calculate the forces in all the Truss member.

Now, next is the Wind pressure. Like the other loads, the wind load also has to be calculated. For the wind load also we follow the IS Code; that is IS : 857 Part-3. IS : 857 Part-1 and Part-2 was for dead and imposed loads.

If you go through this Part-3, you can find lot of parameters considered for wind load. I have listed down some of the parameters, which are responsible for wind pressure on building roof. They are:

- Basic Wind Speed.
- Type of Building and Class of Structure (Risk Coefficient).
- Terrain Category, Height and Size of Structure.
- Local Topography.


IS : 875 (Part 3) - 1987
(Reaffirmed 2003)

Indian Standard

CODE OF PRACTICE FOR DESIGN LOADS
(OTHER THAN EARTHQUAKE)
FOR BUILDINGS AND STRUCTURES

PART 3 WIND LOADS

Figure 6 : IS code 857 Part-3 for wind loads

If you see the Part-3 of the code, then you will find taha, India’s map is shown with intensities or basic wind speed in different regions. The red colored zones experiences high speed or high intensity wind speed. There are factors also like terrain factor, risk coefficient factor etc. that you can go through. The PDF version of the code will be sent to you. These are basic ways to deal with this. For detailed and further understanding of load criteria, you can go through other NPTEL programmes. You can have a look on programmes run by our civil engineering professors to know the mathematical computations for all these.

However, for an architect, if you are not going to design in that much details, then please understand that the basic wind speed is one of the criteria which is very important and it is different in different parts of the country. There of the building class is also there, where the risk coefficient factor also came. So, building class is like type A class, type B class etc. So, depending upon the class you can have the risk coefficient. There is the terrain category, the height and size of the building. Terrain category, if the building is situated in a very dense area, then definitely the wind pressure is less. If it is placed in an area where very less number of buildings are there in the neighbourhood; in that case the wind pressure will be higher, because obstruction will be less. Another factor is local topography; that means, if there is an elevated area or hilly area where the slope exists. If you are building in the hill slope or maybe in the top of the hill then it is going to have some other calculation method. So, based on that also we can calculate the wind pressure.

However, for the time being let us consider an example. suppose the wind flowing from one direction to other direction and it has wind pressure in the windward side is plus, suppose $+1.5KN/m^2$, and in the leeward side that is the other side of the wind flow, it is $-0.9KN/m^2$, as shown in Figure-7. Then, what is this plus and minus? Plus is the compressed pressure and the minus is the suction pressure. Based on these values you can also calculate what will be the wind load.

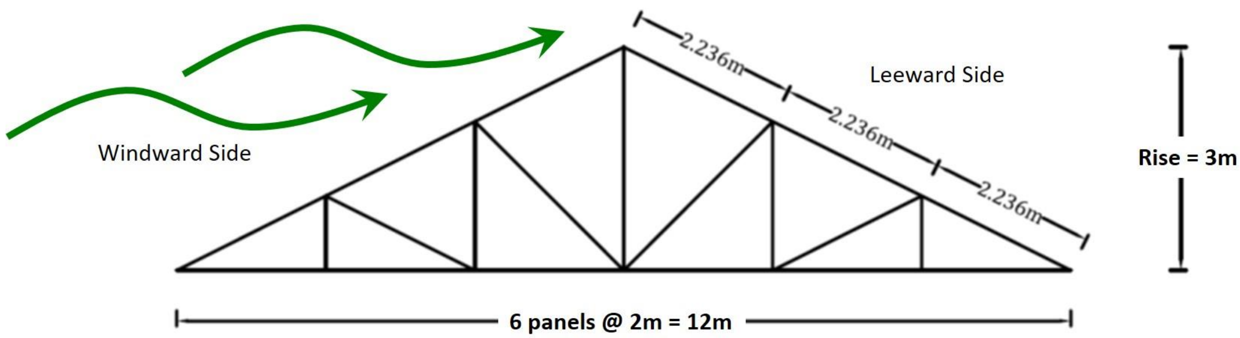


Figure 7 : wind pressure on a given truss

If it is +1.5 then it is compression and the forces are coming towards the roof and if it is minus then it is going to going outward; that is the difference between this plus and minus, the suction and compressed pressure. Now, it is very simple because if I know the intensity of the loading, then I can calculate the force, which is same as before, intensity will be multiplied with the area.

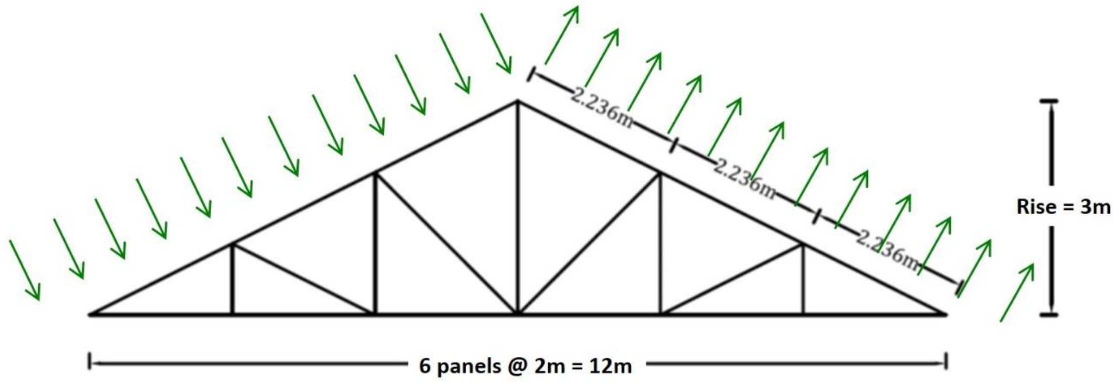


Figure 8 : wind pressure directions on a Truss

Therefore, the calculations will be

Wind pressure at windward side= +1.5 KN/m^2

Intermediate purlin = $1.5 \times 6.708 = 10\ KN$

Eave and Ridge purlin = $1.5 \times 3.354 = 5\ KN$

Wind pressure at leeward side= -0.9 KN/m^2

Intermediate purlin = $0.9 \times 6.708 = 6\ KN$

Eave and Ridge purlin = $0.9 \times 3.354 = 3\ KN$

Now ridge purlin will also be the half; why I will just tell you a little later. So, in case of the leeward side is 0.9, minus of course, so minus gives me the direction outward.

So, finally, the forces will look like in Figure-9.

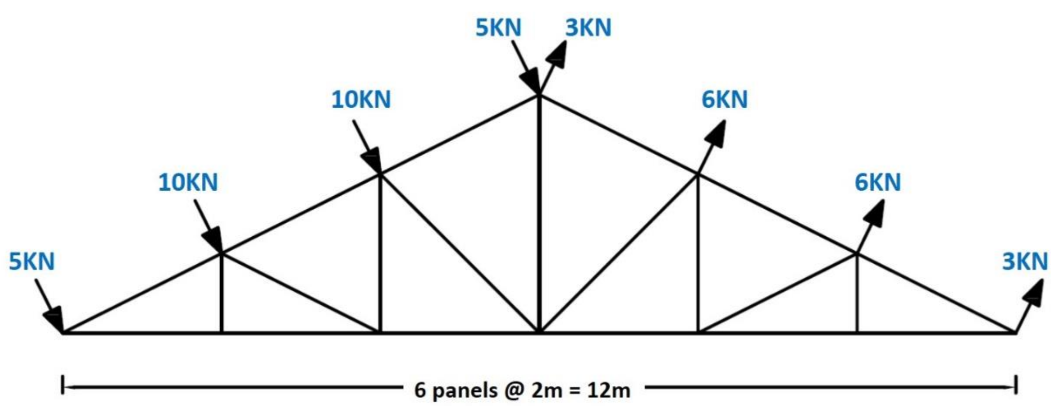


Figure 9 : wind pressure forces on a Truss

Now, on windward side the ridge and eave both are 5KN. Because, here the load is not downward imposed load. Both the sides of the Truss experiences different nature of pressure. So, the influence of the ridge will be half on both side with respect to positive and negative pressures. The windward side will face the positive pressure and the leeward side will face negative pressure. Therefore, on windward side it is 5KN on eave and ridge where as 10 KN on intermediate purlins. Because intermediate purlins have influence area half on both sides of the purlin. Similarly, for leeward side, the eave and the ridge have 3 KN and the intermediate purlins are with 6 KN.

With this you can put the values and you can again go and do the calculations. Then you can combine these, the first calculation and the second calculation, superimpose and see what the resultant force in each member. So, these are the typical procedure of the wind load calculation on a Truss.

Now, let us go to the advantage of the Truss. As you know the advantages are many and few of them are:

- Steel trusses have good strength and may be economical to beams for large spans.
- Steel trusses are most suitable for long spans and can be made in various geometric shapes.
- Steel trusses can be fabricated easily.
- It is a clean and dry method of construction.
- Materials like angles, channels etc. can be easily available and transported from place to place.
- Steel members are free from attack by white ants and dry rot. But have issues of corrosion, which can be taken care by means of suitable paints.
- Steel members are fire resistive, and
- Steel trusses can be erected fast and easily.

Now, let us go for some of the application of the Truss. The Figure-10 shows a very ancient building which was a grain store in UK, the Coggeshall Grange Barn (built around 1240AD). This barn uses King Trusses to support the roof, and wooden Truss. One of Europe's oldest timber-framed buildings, it has a cathedral-like interior. So, I have put this example for you, because it is of very early time, built during the late Roman times, but here you need to see the how geometrically they erected this Trusses. They are in different directions and different ways creating the different elevations, creating some extra members to provide those arrays. So, this indicates that Truss is one of the structural systems that have enormous potential since ages and this kind of a building, this kind of activity areas require a large column free space for movements of the grains and other for other functions as well.

Figure 10 : the Coggeshall Grange Barn, UK

This is one of Europe's oldest timber-framed buildings, and it has a cathedral-like interior.

Next is one in one of the very important examples, an important building of modern history of Architecture, the Crystal Palace London (1853). Again, you can see it is a historical building. Yes, this building was built with glasses and Truss. You can see the ribs are created, this is simple arch kind of it, and these ribs are supported by the flank Trusses. We can see that there are typical Truss on the side of the arch ribs.

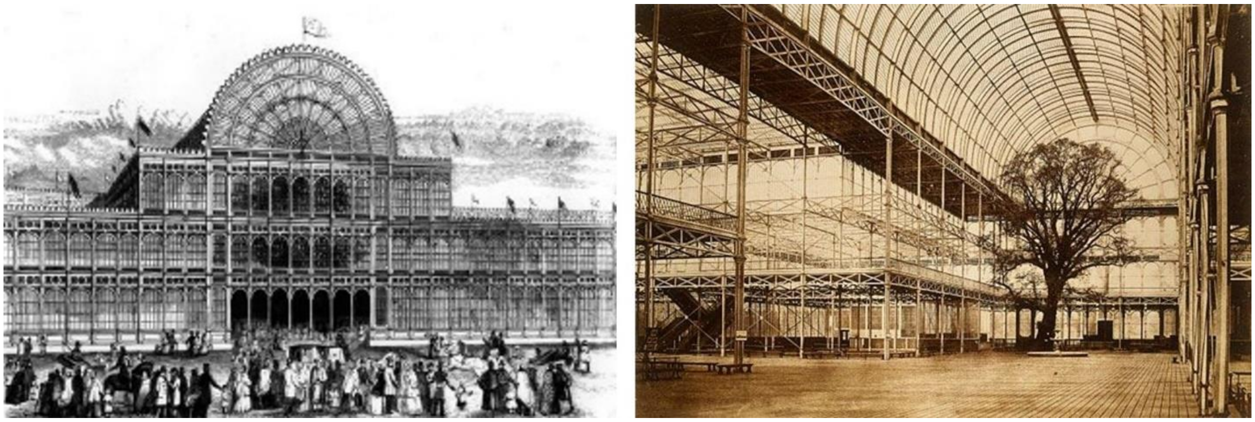


Figure 11 : Crystal Palace London (1853)

There are also Truss with orthogonal direction, and cross bracings as well, and some of the posts are also introduced to take care of various floors in both the sides of the arch. But nowadays it is not the type of Truss which we look for.

The next example is a Truss bridge. You can see that; this is the Truss where the vertical members are placed near to the support. Refer Figure-12. It is a tree track walkway at Kew Garden, London. So, the vertical members are provided like web members. But in the intermediate portions, there are lot of diagonal members, because the intermediate portions have to take the moments.

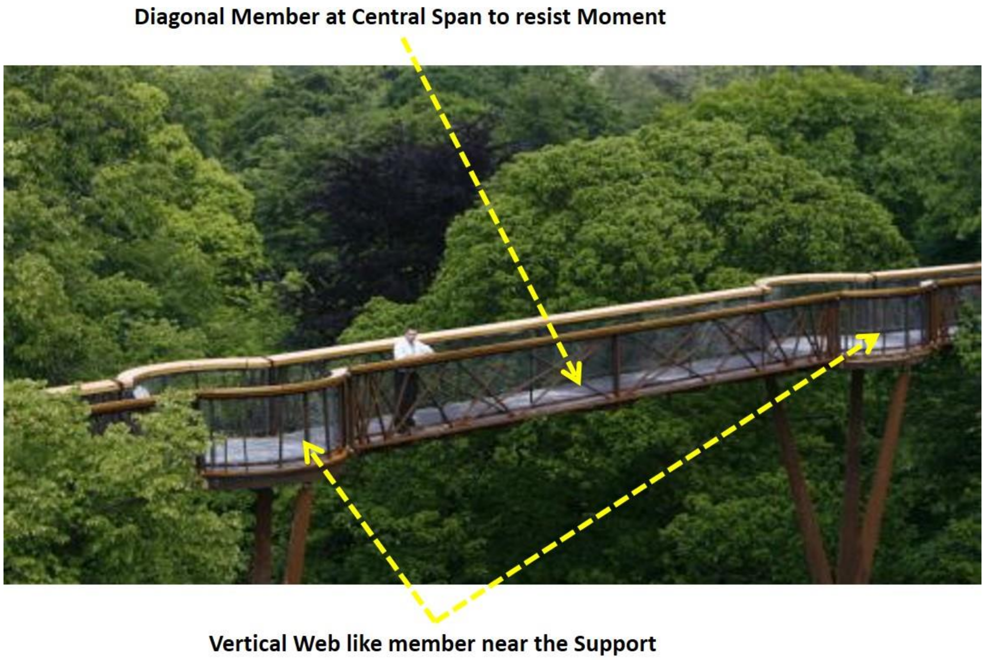


Figure 12 : Tree top Walkway at Kew Garden, London

Whereas in the vertical members in the flanks are introduced mainly near to the support because this area has to take care of shear force; and in the central portion it is bending moment. So, that is where it is vertical webs are there near to the supports and bracings at the central portion to take care of the bending moment.

This not a very special example; but I have given this to you because this picture gives you a very clear idea that even a Truss member can act as a beam. As well as in the design of this Truss, the philosophy of designing a beam is also taken care of.

The last example is Padmanabhapuram Palace in Kerala. It is located in South Kerala. It is a wonderful ancient building made up of timber. As you know, the Kerala Architecture follows steep sloping roofs to respond the extensive torrential rainfall, prolong monsoon and other climate conditions.

This Palace made up of timber Trusses, and this is a wonderful timber structure, made by the Kerala Kings. This building reflects the potential of timbers as a structural material, because the timbers of those days are still in good condition. This is a wonderful building, and everybody must visit this building to know about the potential and strength of timbers. In the Figure-13, the exterior view of the building is shown. It is actually a small portion of the building, near the entry. From the Figure it is not very much clear that how the Truss systems are there. I have some photographs but they are very dull because of the very low light inside Palace.

Figure 13 : Padmanabhapuram Palace, Kerala

It has lot of folds, there are the eaves, valleys etc. with folds and a lot of connections; and each and every connection are thoroughly taken care of by different Trusses.

Here, some of the Trusses are half Truss, some are quarter Truss, some are very thin and elongated portion of the Truss, some of the Trusses are definitely very extensive and wide, some are typical common Truss, some are very flat and some of the Trusses are very, very steep. So, there are enormous examples of the wooden Trusses in this building.

The palace is very huge and every nook and corner of the palace is made up by the timber Truss. Finally, let us go to some of the basic construction methods of roof Truss. As you know, if there is a Truss then it has to be provided with masonry structure. Beforehand you need to put some anchor bolt and grout hole. Refer Figure-14. These pictures have been taken from when in a site in Birla Institute of Technology, Mesra, Ranchi, where they have constructed their open-air auditorium to cover it with sloping roof.

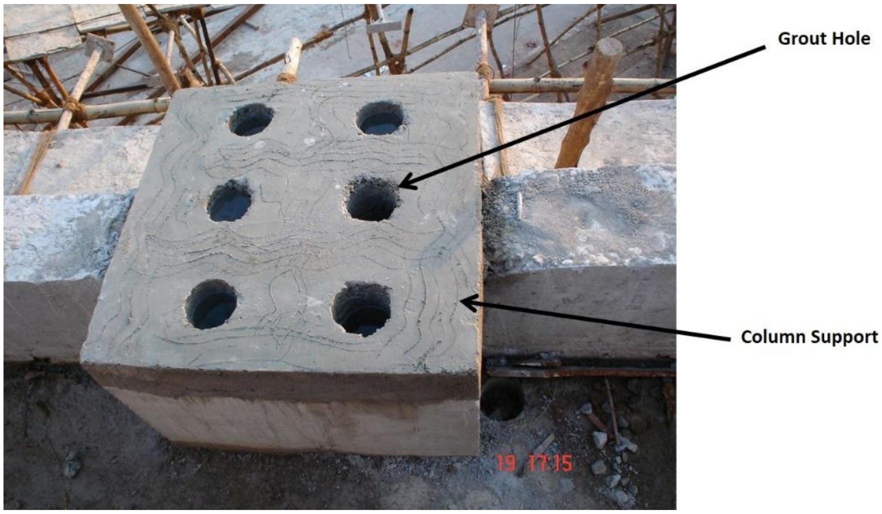


Figure 14 : masonry structure for Truss

So, those are the grout hole and column support you have to provide.

Then you have to put a base plate, and the grout holes can take care of your anchor bolts which holds the base plate. Refer Figure-15.

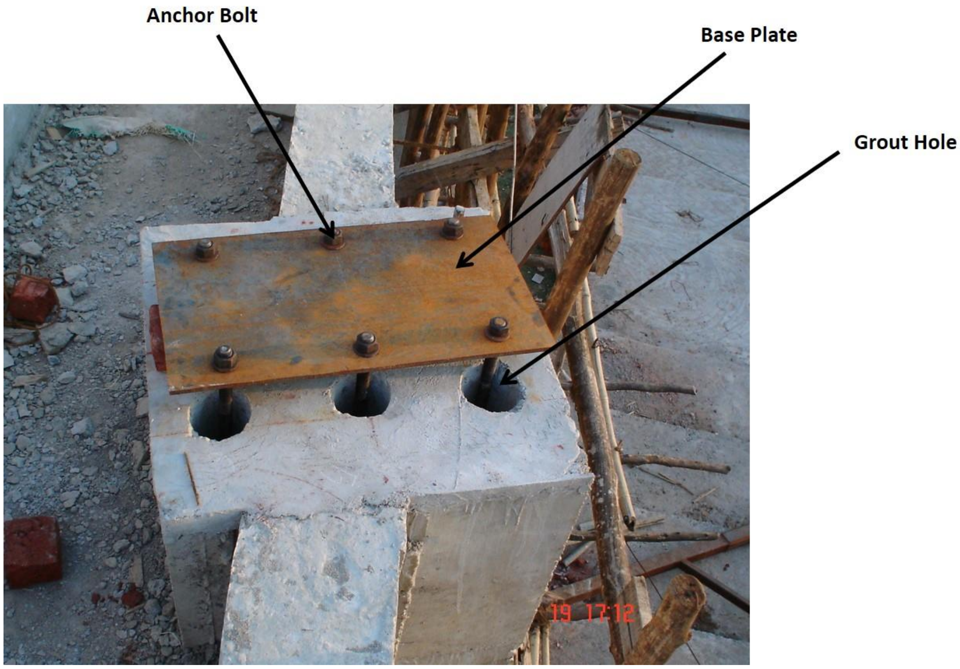


Figure 15 : anchor bolt, base plate and grout hole

So, these pictures, if I go one after another it will be very easy foy you to understand how the things are to be placed one after another.

In the next picture, the Figure-16, you can see how cement slurry has been provided to hold the anchor bots in the grout hole.

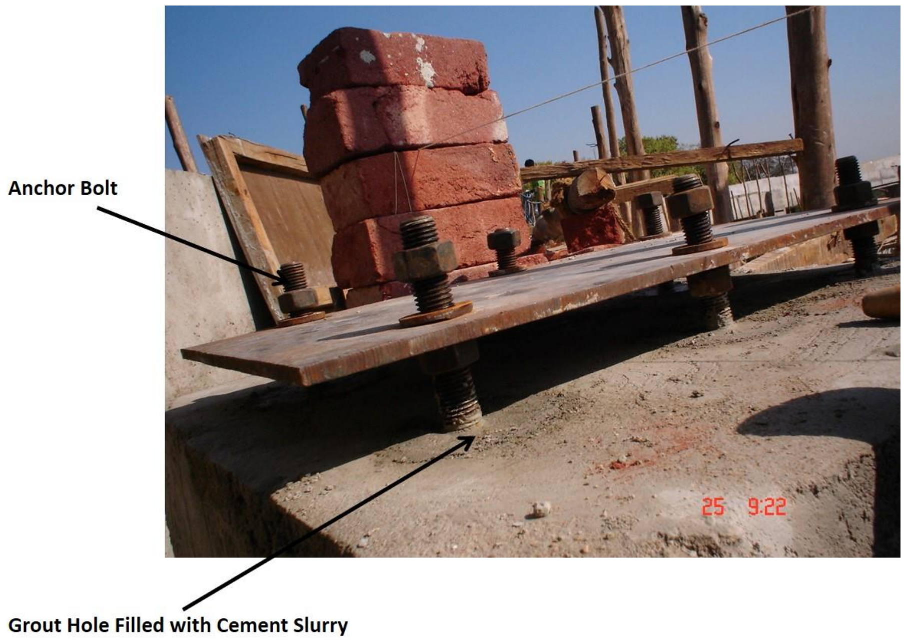


Figure 16 : anchor bolt, grout hole and the base plate

Then finally additional gusset plate has been created and attached with the Tie beam.

Figure 17 : gusset plate, base plate and rafter

By now, the base plate is very much settled without any gap. In the earlier image, Figure-16, there were some gaps. Then gradually some loads will be kept on it and it will settle down after the grouting, and then it is fixed.

Finally, the Truss is erected and it is a very huge Truss. The span of the Truss is almost about 30 to 40 meters; or at central span it is much more, maybe around 50 meters. Refer Figure-18. So, those are the typical details of the Truss.

Figure 18 : the erected Truss

The Figure-18 shows the erected Truss for the auditorium. In this Truss the top members are inclined and the bottom part of the Truss is flat that is the Tie beam.

I have taken some reference for this lecture and they are:

- **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

In conclusion I must say that; It is important to understand and analysis of load in a truss. Due to the inclined shape, truss is analyzed for the wind load. The Truss is having a wide application in Architecture. It is used for cost effective long span structures.

Thank you very much.