Engineering Mechanics
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Module - 01
Statics
Lecture - 07
Trusses - I

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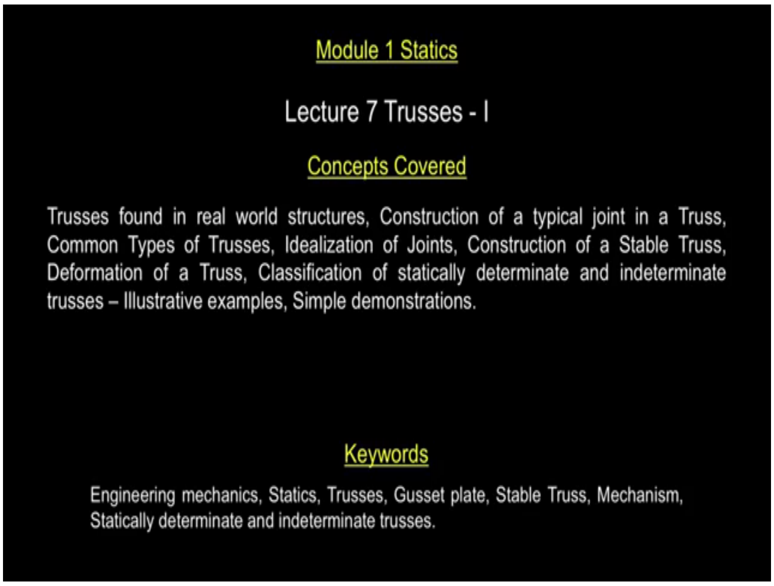

Let us move on to the next chapter on trusses. It is desirable to know first what is the origin of the word truss?

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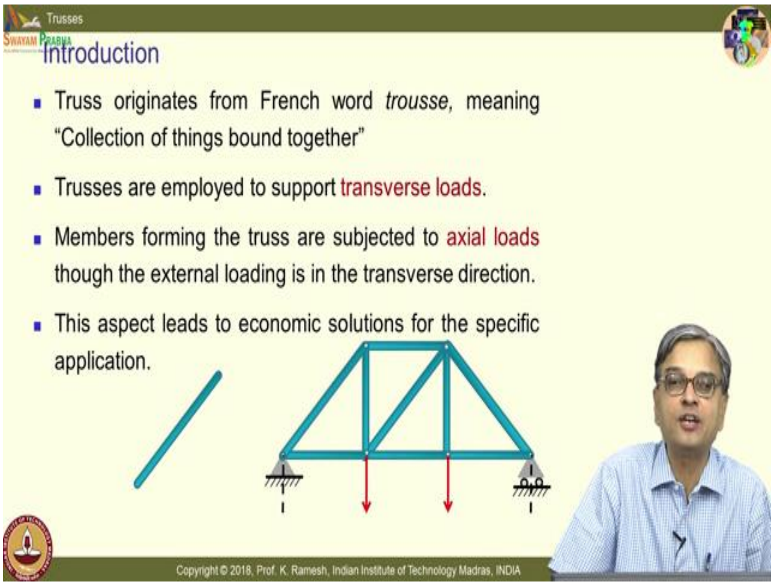
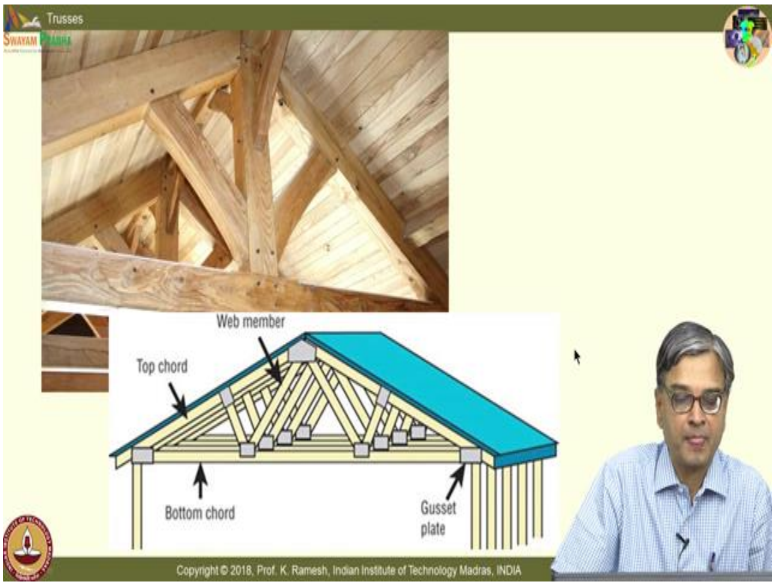
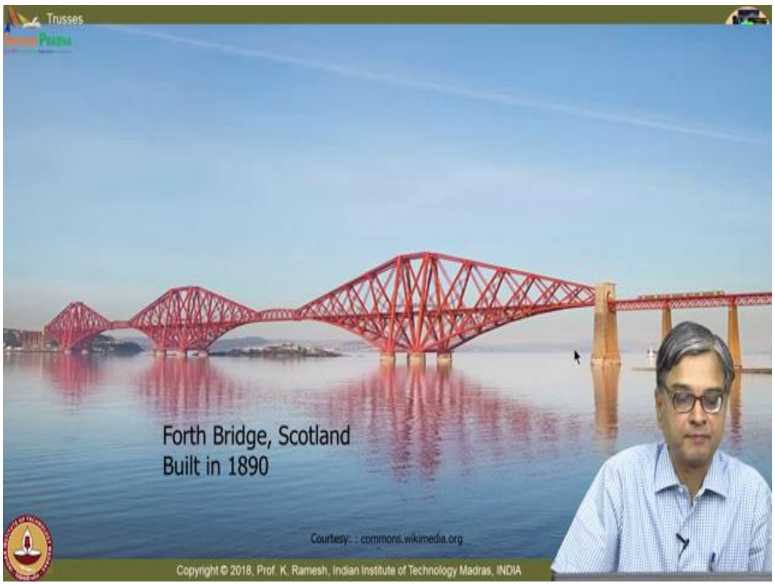


Truss originates from French word trousse, meaning "Collection of things bound together". When you look at the chapter, you would really understand the meaning better. Trusses are basically employed to support transverse loads and this is what you call it as a truss, this has many members.



The members forming the truss are subjected to axial loads; that is very important to notice, though the external loading is in the transverse direction. I have the truss; I have the loads which are transverse to the truss. But if you look at the members; the members may be in tension, it maybe in compression or it may not even transfer any load, they are called zero force members. They are very important part and parcel of a functional truss just because the member is not transmitting any force you cannot take out that member and keep it away.

So, if you look at a truss it is nothing but collection of essentially two force members subjected to axial loads; what is the advantage? This aspect leads to economic solutions for the specific application that is a greatest advantage. You save enormous amount of material and you utilize the material to its fullest extent.



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You had trusses made by carpenters and the truss looks like this, they also call the joining of these members using a gusset plate.

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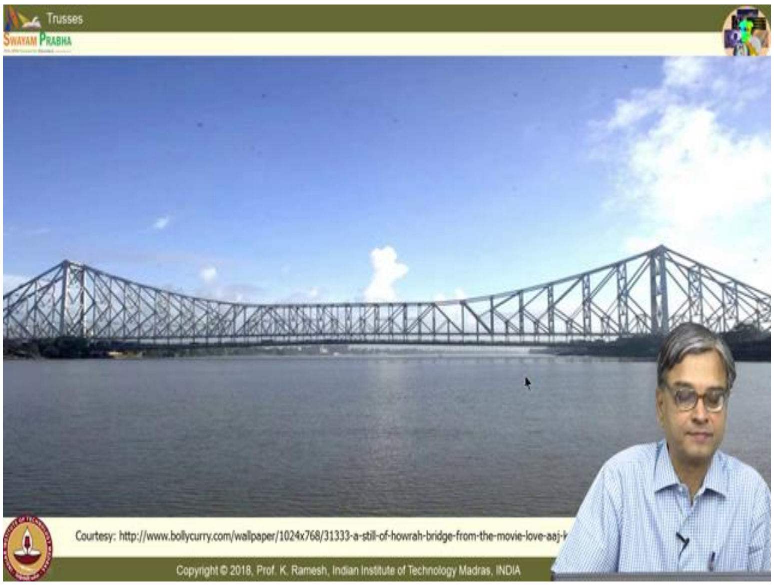

And this is one of the oldest truss bridges that I could access to this was built in 1890. You know we had seen Eiffel tower it was built in 1889, it is before that and what I want you to notice is what is the span, and what is the amount of material that is being used. Because it was designed in 1890 people were very conservative, they wanted to have redundancy in the design.

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We also have a nice bridge in Kolkata this is the Howrah Bridge and you can; you could look at here a very long span. It is over the Ganges the span may be of the order of may be close to 2 kilometres.

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And if you walk into the bridge you have a maze of steel structures heavy very heavy.

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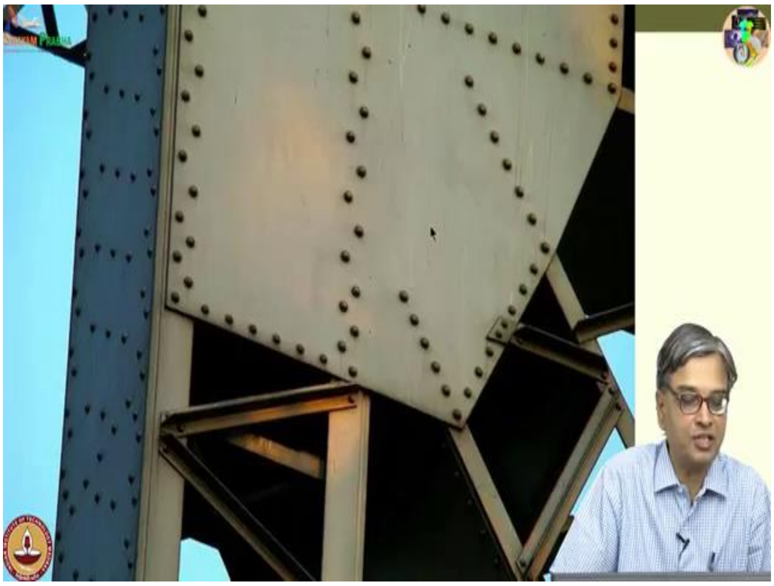
And you look at one of the joints you find the joint is having lot of bumps which I told you that these are rivets that is how the joints are made.



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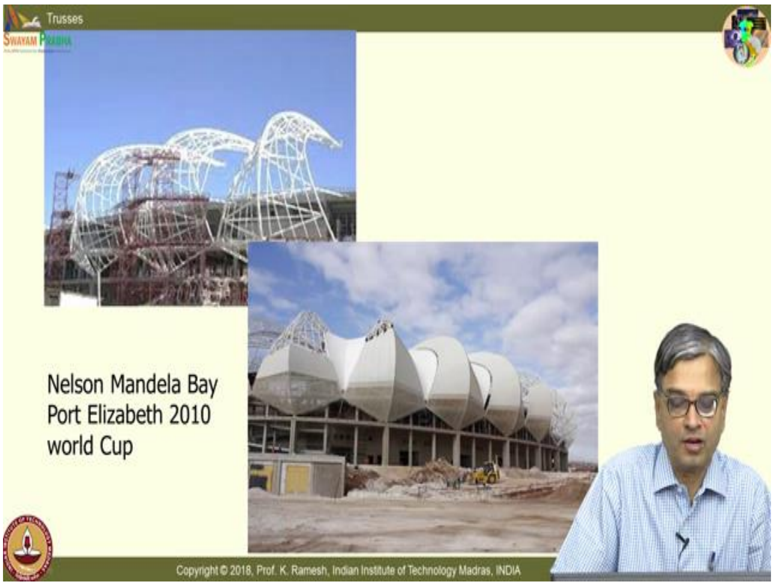
And you go across the world and see many structures including sports stadium they are all made of trusses. You have a truss like this which is covered nicely, I think this was for the football world cup they had this stadium built. This is another picture of a truss which is a space truss you have this occupying in three dimensions.



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And if you look at many of the practical structures from an analysis point of view, you could consider them as planar trusses. See engineers would always want to reduce a three-dimensional problem to two dimensions or if possible, even one dimension. It makes our life lot simpler, even though I have a stadium which is three-dimensional unit structure.

We would find ways to simplify our analysis by looking at whether I could make it as a planar truss for the analysis and then carry on with it that is what is shown here, each truss may be treated as a two dimensional structure and can be considered as a plane truss for purpose of analysis.

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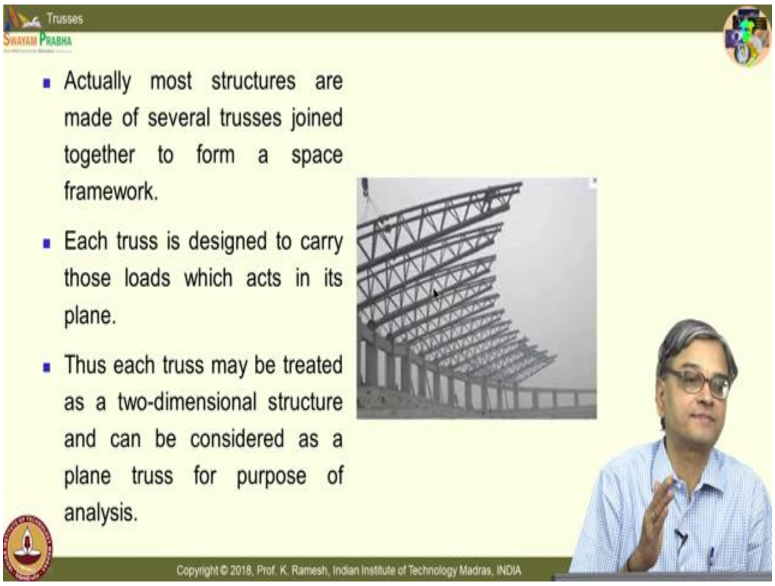
This is another interesting truss the structure is very interesting I have this below the bridge and then in this segment this is above the bridge to allow vehicles, I mean the boats to pass through. And we would look at a typical joint in this truss.



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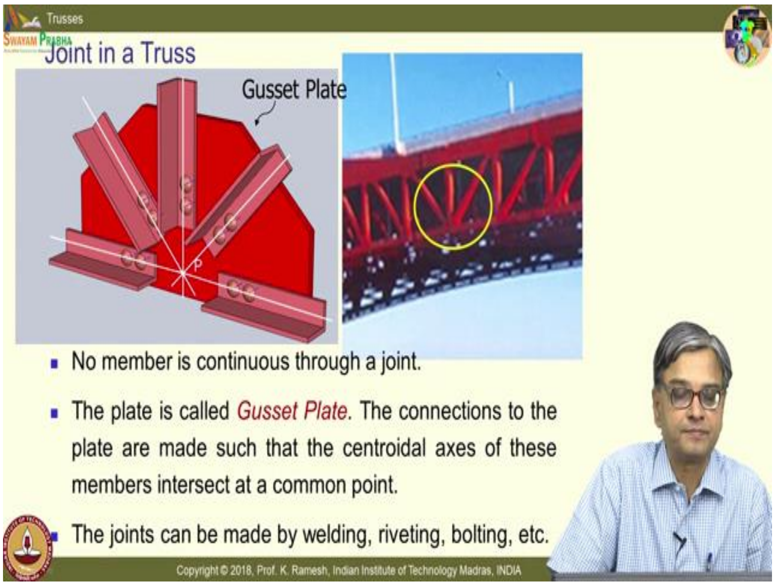
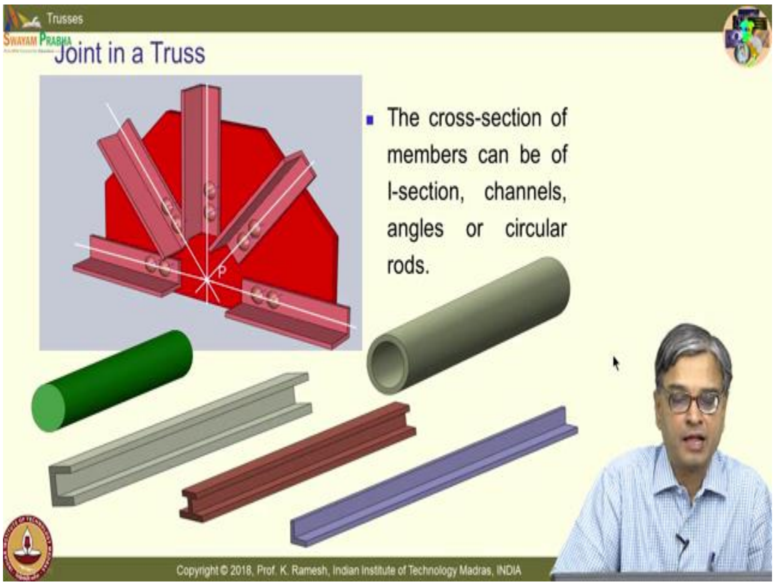
So, this is a joint that we are going to look at, and if you look at the details it is made by riveting. And what you see here is you have the riveted pins that are inserted, they are hammered from the other side to have this head. And you must be getting used to what is workshop practice in your first semester.

You might have heard that these holes are normally drilled, but drilling is not sufficient in a riveting operation you need to have a very fine dimensional tolerance on the holes. So, they also have to do what is known as a reigning operation. There is no clearance between the hole and the riveting pin it has to be very closely done.

So, it is a very costly manufacturing process, and what you should notice here is that they are aligned in a particular way and the base plate you call that as a gusset plate. So, what I have here is if you look at the centroidal axis, they all meet at a point this is very important it is intentionally done.



If you do not know the mechanics of a truss you would not make it like this, because I have seen people have made trusses using welding a welder may not know the mechanics of it, he just takes the members and welds it. I have seen some of the trusses which are used for less critical applications where they do not meet at a point which is not correct.



If you go and supervise any of those structures you must ensure if you want to make a truss the members should be aligned properly and another aspect you should notice no member is continuous through a joint. If a member is continuous; then it behaves like a beam, we do not want the members to behave like a beam. I have already told you that this is a gusset plate, and the joints can be made by welding, riveting, bolting etcetera there are many operations.

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You have seen that these are l angles in engineering terminology. The cross section could be different for different applications it can be an I-section, it can be channels, angles or circular rods. That is what you see here I could have a circular road, I could have a channel, I could have an I-section. And I could have a l angle like what we have seen here or it could also be a hollow tube. Depending on the application you will have to decide the cross-sectional dimensions.

So, in your engineering mechanics you find out the forces in the members in your next course on strength of materials. Once you determine the forces what should be the minimum cross section to withstand. So, engineering mechanics is only a feeder for the next level course. You do not solve everything completely in this course, you get first level of information.

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And if you look at a practical bridge this is the Pamban Bridge in Rameshwaram. The individual members forming the truss could be so huge and complicated. It is not like a single cross section and you know very well that this bridge opens up to pass a boat.

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And you have this as a space truss, this was there in Chandigarh airport.

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And if you look at very closely here again you find the members are carefully connected no member is continuous through a joint. And you can recognise that this is more like a ball and socket joint; that is the equivalence of a pin joint in three dimensions.

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This is another view of it; you can see very clearly that this is joined by pin joints here very clearly.

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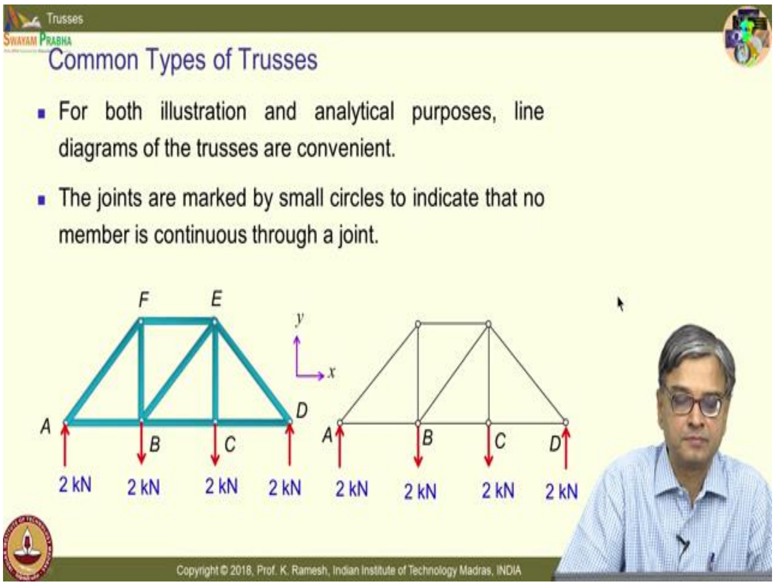
For both illustration and analytical purposes line diagrams of the trusses are convenient. I have the luxury to show the trusses like this, but I would recommend you just draw it as a line sketch with one important modification. I would like you to put circles on all these joints to indicate no member is continuous through the joint. It is a very important constructional aspect of the truss which you can over look if you do not put these circles.

For the horizontal member at the bottom particularly you may imagine that it is a continuous member, it is not built that way. And it is also desirable that you label the each joint separately in an ordered fashion. If it is not given in the problem statement you should label it yourself and you should also put the coordinate axis. And all our discussion we would first do it for a planar truss get the mathematics then we will think about space truss.



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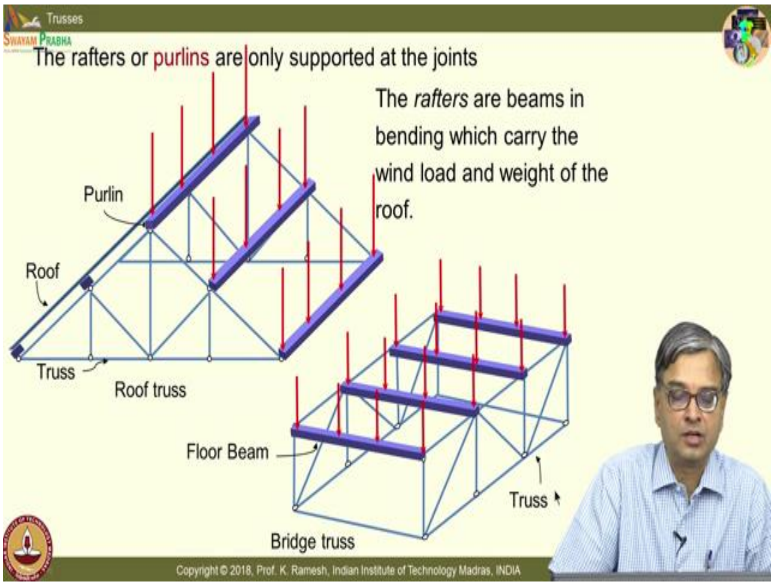

And this shows how a roof is constructed, I have basically a truss. And I have these rafters in the carpenter terminology they also call this as purlin, where essentially beams which support the wind loads and also the weight in foreign countries, they have a problem of snow falling on the roofs.

So, whatever the snow weight all of this weight is taken by the rafters and transmitted to the truss below. And this shows the typical bridge truss, here again I have a truss and a combination of beams they are called floor beams. They go together and we would again revisit this from a different perspective later. You have loads acting on this floor beams that is transmitted to the truss below.

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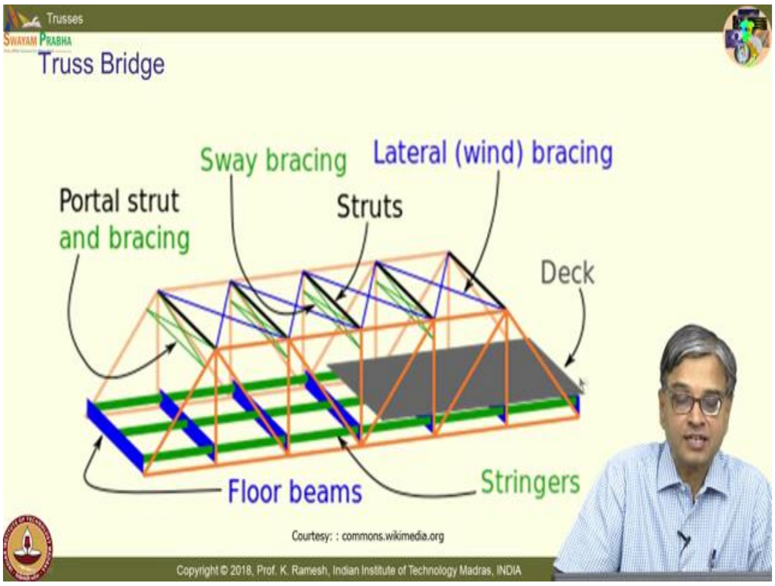

And you know we had seen in our introductory lecture, failure of Tacoma's narrow bridge. And I said that was because they have not taken into account the effect of wind forces while designing the bridge. And you could see here a typical design of a bridge truss with lateral bracing like this. And you also have sway bracing like this, we would see this is available in practical structures.

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In the bridge that we saw on the Pamban bridge this also has these members to support wind forces. And you could see that these are very very light compared to the basic members they are very very light which you could easily recognize.

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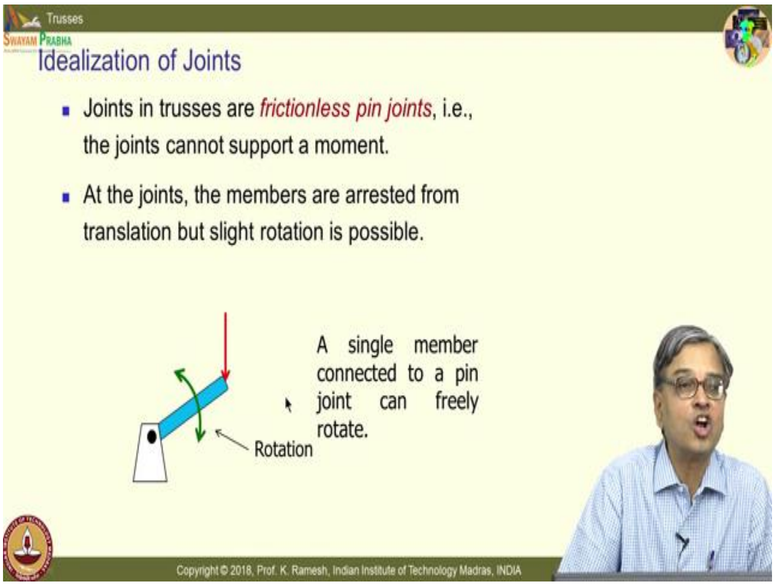
And how do you idealize a joint in a truss? See I have been telling you in this course we have physical systems. We idealize them in a particular way for us to solve. The challenge lies how do you idealize it correctly when you are faced with a physical system.

For a given application depending on the loads and various other considerations your idealization may be justified. Say when I have a pin joint it can move very freely, a single member connected to a pin joint can freely rotate; it cannot support a load. However, when I have an array of members connected by pin joint, we would see what happens to them, how the members are connected is very important. So, what you recognise is, when you have a pin joint, the translation is arrested rotation is not arrested its free to rotate; How to construct a truss?



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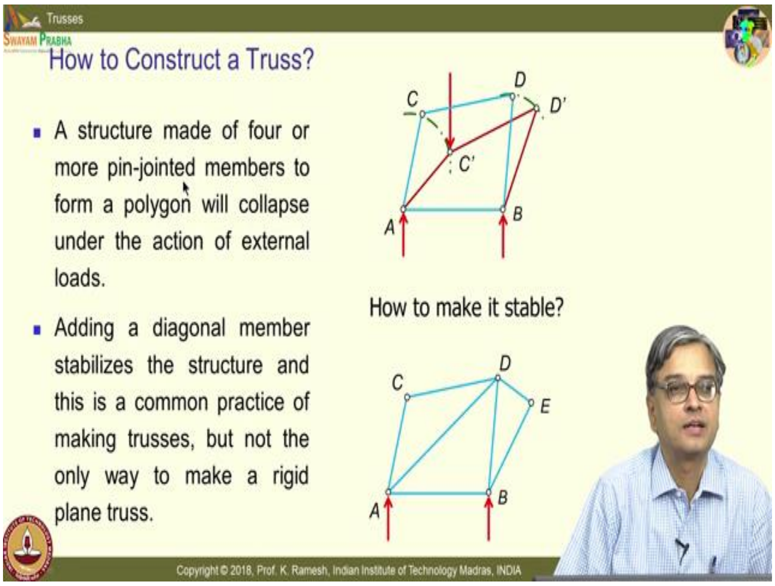

I have four members here as I told you earlier that when I put a circle you recognize that you have a gusset plate which helps in connecting it, and no member is continuous through a joint. Suppose I apply a transverse load at C, what would happen to this? It would simply collapse; it would simply collapse like this. It cannot sustain the load; how to make it stable?

The trick is put a diagonal member I put a diagonal member; this structure becomes very strong. And you could have additional triangles and continue to make a good truss, looking at from an animation is not that convincing. It is desirable that we go for a practical experience by looking at a demonstration.

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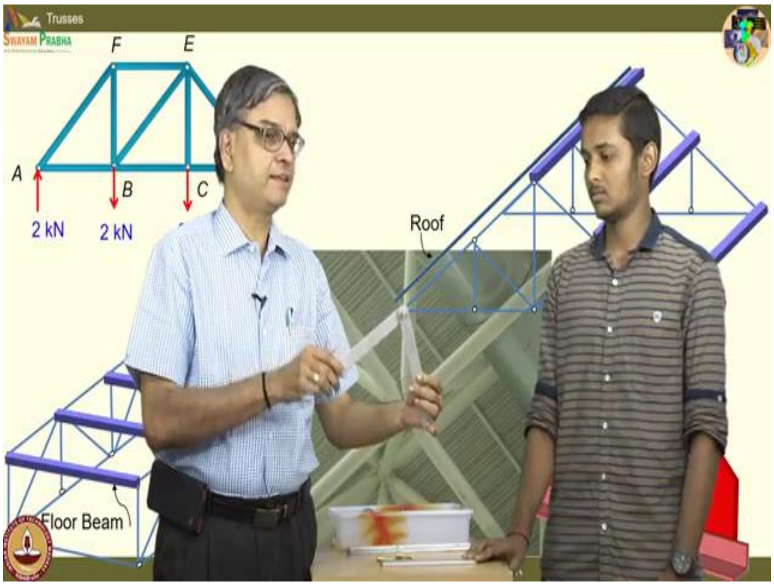

I need a volunteer from a class to help me in the demonstration, say I have just inserted a pin and you could see clearly that I can move this member very freely. It does not prevent me from moving it and that is how we have understood what a pin joint is.

Now, I will make a four-bar member with pin joints;

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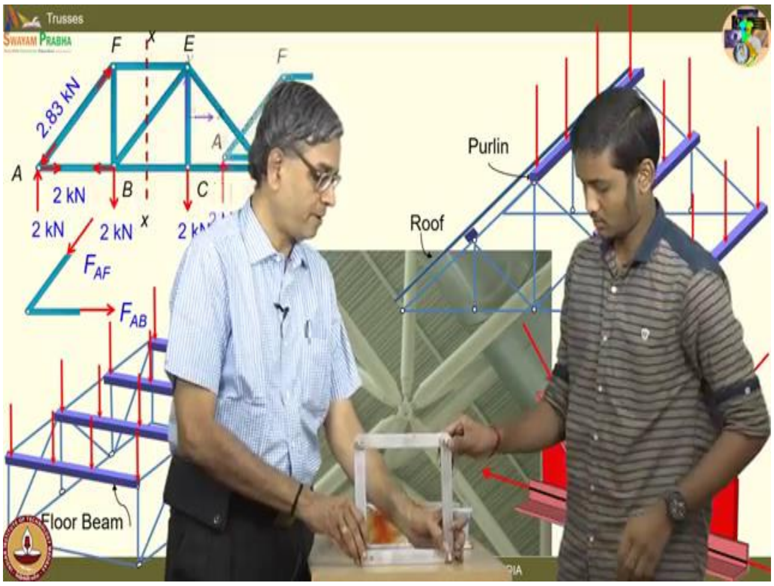
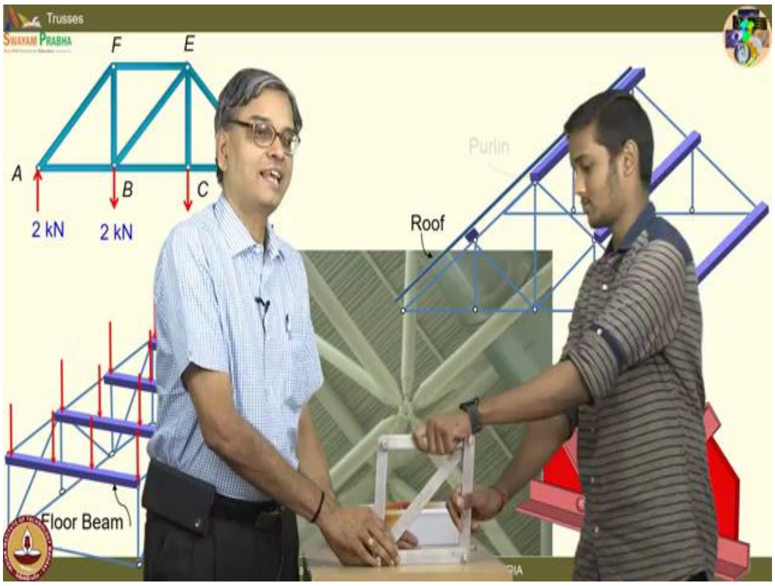


Now, I have the four-bar member that you saw in the animation. Now, what I will do is, I will apply a small force here; I am just applying with a finger I cannot apply any force with finger that is significant. Is it able to withstand? It is not able to withstand, it just oscillates. And some of you are doing engineering drawing you have a nice mini drafter which employs this, and you call this as a mechanism.



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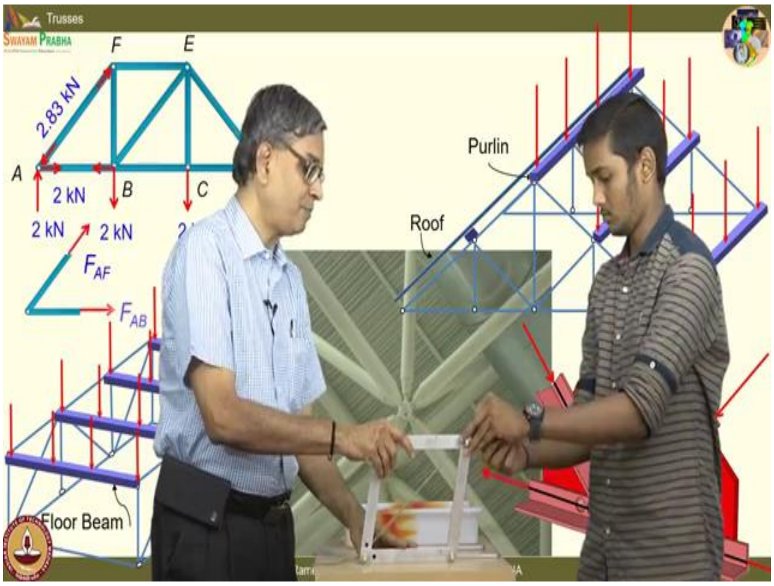
And now what I am going to do is, I am going to put a diagonal member; can you take the diagonal member? Insert it, insert from there, insert from there. And now look at; can you press it with your might? Press it. Does anything happen to this? It is very strong; just one diagonal member makes all the difference; mind you that this is again a pin joint. It allows rotation but collection of pin joints in an orderly fashion like this makes the structure extremely strong.



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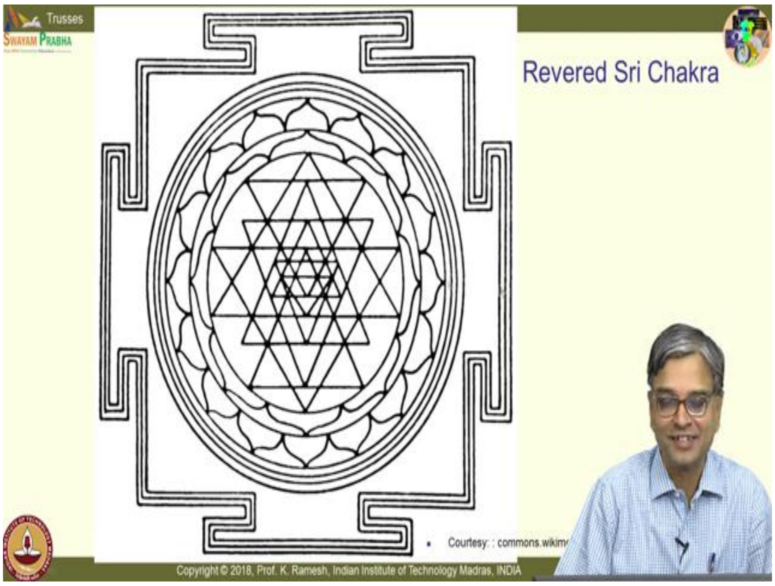
Now, what we will do is I will remove this diagonal member which is very thick as good as the members forming the truss. Now, would replace it by just a string, see this is for your cross bracing.

And what I have here is the cross bracing can take tension; a string can take tension, but will collapse in compression; it can take tension. So, what you have is, you have a you have two members like this which takes care of wind forces in any direction. So, the cross bracing is always thinner than the actual member.

Even a simple string can do the job, I can have a metallic wire which will replace the thick bar which I have used it earlier as long as I am interested in arresting the effect of wind effects. See we have seen that a triangular shape can hold any amount of force, so,



it can resist it is a display the enormous amount of power.

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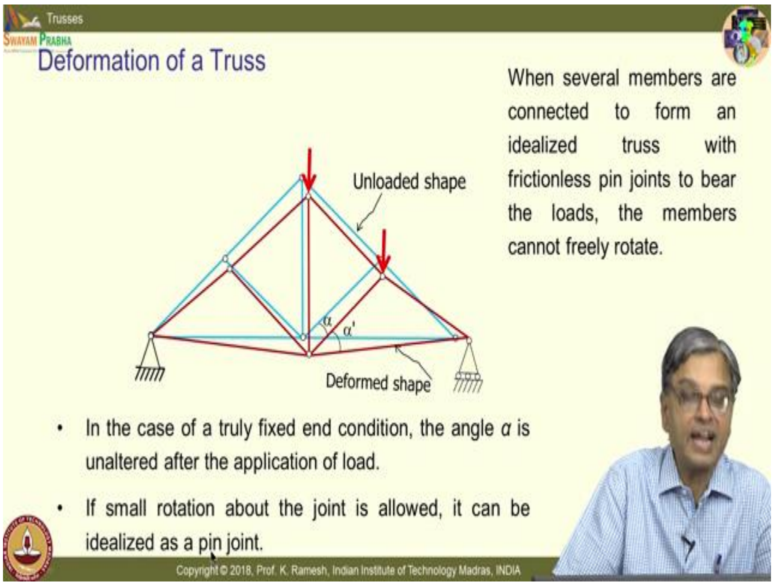
And it is very interesting to note that we have a Sri Chakra that is being worshiped by several thousands of people. It is nothing but collection of triangles, it is very amazing we say attribute this to power shakthi. So, it is a very nice to see that.



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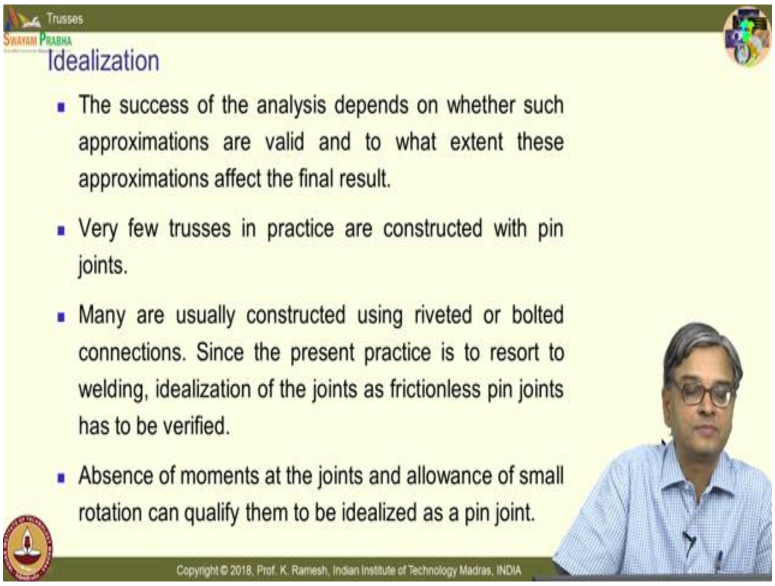
We have just now seen a simple four bar mechanism and also made it as a triangle by putting a cross member we have made it as a triangle. Let us take a roof truss and we would like to see what would happen when I apply a transverse load, how does this deform.

Even though from your idealization point of view you say the members are rigid in reality they are basically elastic members. Under the action of tension and compression, they can elongate and contract and being a pin joint, it will allow small rotation.

And now, I show an exaggerated picture what would happen under the action of the loads; make a neat sketch of this. It is an exaggerated fashion what you find here is on one side I have a pin joint; on another side I have a roller support. And I want to you to observe that there is a provision for this to move horizontally that is why you need to have a roller support here.

And the members get deformed like this, whatever the original angle that was alpha between the members in principle can change slightly. Suppose I have these joints are made by welding where I am able to maintain a truly fixed in condition. The angle alpha will not change, but in practice even though you have riveted and bolted connections, you can observe a small variation in the angle alpha. Looking at from another perspective a small rotation about the joint is allowed it can be idealized as a pin joint.

So, where I am taking you is, when I see a physical system which is constructed all together differently for the purpose of mathematical analysis. You will have to reduce it to a simpler model to aid your quick analysis which is reasonably accurate for the given application.



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As I mentioned you earlier very few trusses in practice are constructed with pin joints, the only truss which I could see in our near vicinity is what you have in central station. When you have the next opportunity to visit the central station the old part of the station is completely built on pin joints, you have a rod they have just inserted pin.

And you have that roof standing for many be 100 years, when you have an opportunity please go and have a look at it. Many are usually constructed using riveted or bolted connections since the present practice is to resort to welding idealization of the joints as frictionless pin joints has to be verified. Absence of moments at the joints and allowance of small rotation can qualify them to be idealized as a pin joint, so, that is what we are going to look at.

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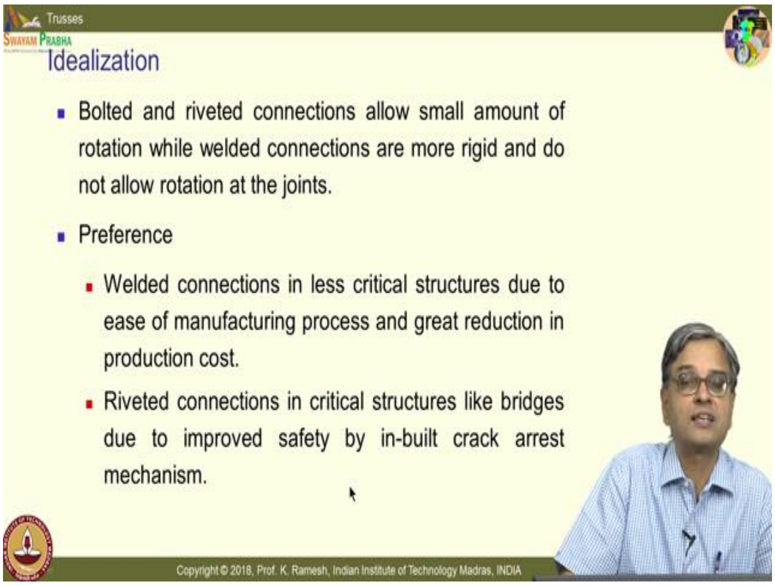

If you compare between the bolted and welded connections to an extent bolted and riveted connections allows small amount of rotation, while the welded connections are more rigid. So, you will have a preference like this, welded connections are used in less critical structures due to ease of manufacturing and great reduction in production cost.

So, you have to weigh in between the application and the cost that you are ready to spend. These days welding has phenomenally improved in initial stages they had several issues on the strength of the welds and their fatigue characteristic so on and so forth.

Now, welding is a very matured process, people can control the parameters so effectively. We would also see some bridges apparently developed with welded connections; you would see those examples also. In general, riveted connections are to be used in critical structures, like bridges due to improved safety by in-built crack arrest mechanism.

The advantage is when I have a riveted hole if there is a crack that has developed in the structure, it would propagate and come to a halt at the hole. So, there is an inbuilt crack arrest mechanism available in riveted construction. And when you go home for your mid semester recess, you would see in the many railways bridges they are all riveted connections. Keep your eyes open, peep your head out and then see what those are.

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So, I have riveted connection like this, this is the Brooklyn bridge in New York. And you could also see some segments they have a bolted connection. In another section they have a completely connected with bolts.

So, you have both bolts and riveted connections are in use, but from analysis point of view you would do it as a pin joint and make your life simple, why you do it? The results are reasonably close to actual reality. Now, you have a sophisticated finite element software have come where they could model it as a frame and do a better analysis.

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And you have a pedestrian bridge, this could be a welded construction. This is indeed a welded construction, so, it is a less critical structure.

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And you also have another roof which is again a not a significant structure. So, you have all these joints are welded, and I was amazed to see when I visited Niagara recently.

I was travelling in a bus, this complete bridge is welded; and it is also in a nice colour, blue colour. This is the window in which I am taking the photograph so I get this message. And it is a just 2 to 3 kilometres away from Niagara, this is just crossing that bridge.

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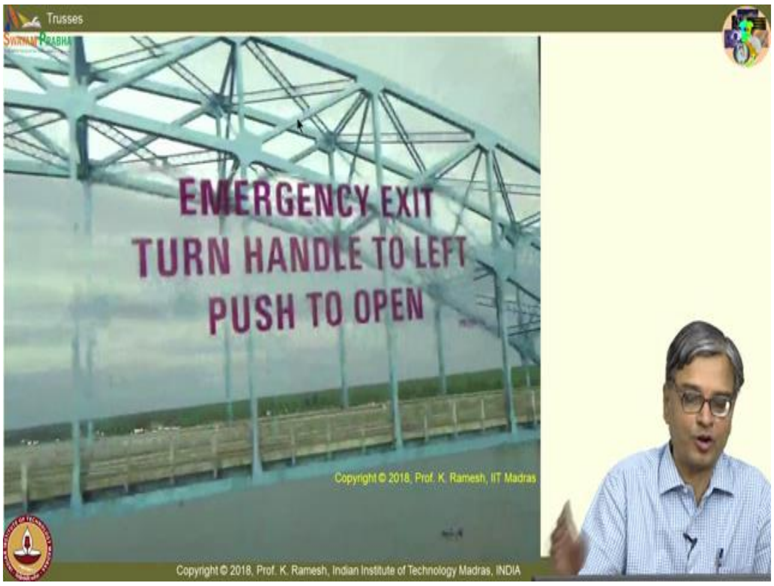
And here again you could see the cross bracings to prevent damage due to wind loading, the resonance was precipitated mainly because of wind loading. So, people have learnt from experience, and they have accommodated this in wherever the future designs that they have employed.



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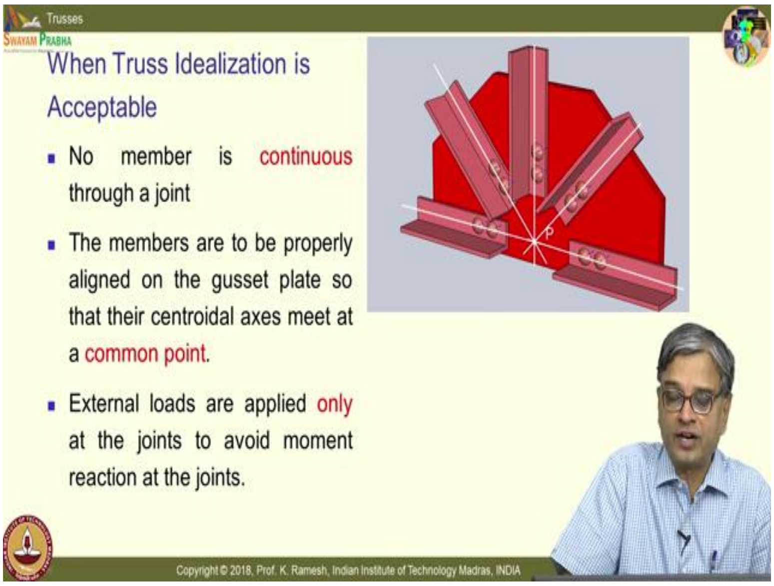
When truss idealization is acceptable? No member is continuous through a joint, we should satisfy that. The members are to be properly aligned on the gusset plate so that their centroidal axis meet at a common point that is what I have shown it here, they meet at common point.

I have seen some of the welded structures; they do not meet at a common point when you put then in practice they will not behave like a truss. You cannot take that kind of a risk in critical structures; critical structures have to be manufactured correctly. You cannot have one manufacturing and then do another analysis. And another important aspect is external loads are applied only at the joints to avoid moment reactions at the joints; this we would see. So, I am going to revisit how a roof is loaded and how a bridge is loaded.



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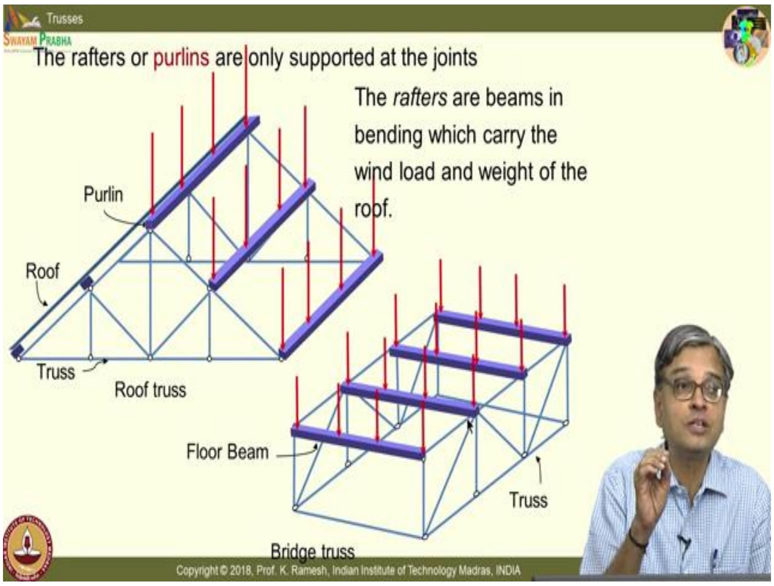
I have this as a roof truss and what I have is I have these rafters and these rafters are cleverly supported only at the joints. They are also called purlins, and they take the wind load and the load due to snow. So, these rafters bend whatever is the reaction is transferred at the joints to the truss.



So, if I have to idealize this as a truss, I should apply loads only at the joints; that is cleverly done by a combination of beams and trusses. Here you have a road and you call that as a floor beam, and floor beam is having a transverse load. And this floor beams are supported at the joints of the truss. So, you have to ensure not only construct it, but while loading also you must ensure that loads are applied only at the joints. They go together until then you cannot analyse the structure as a truss.

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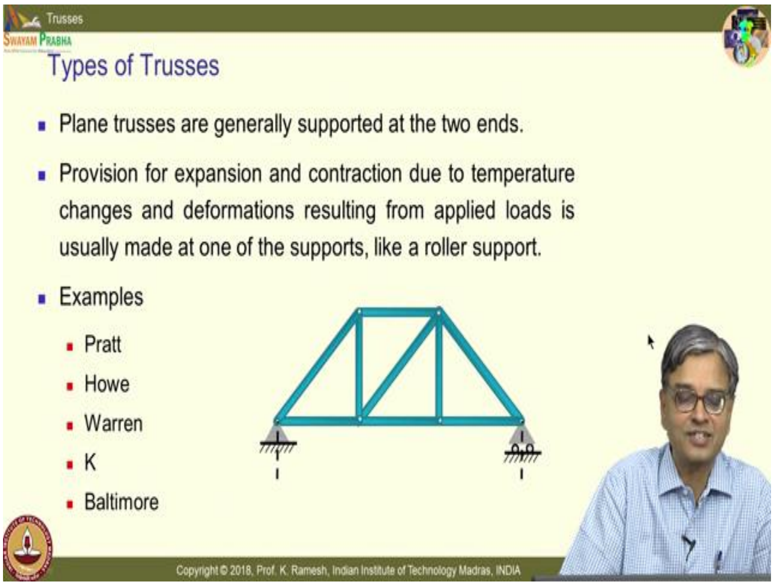
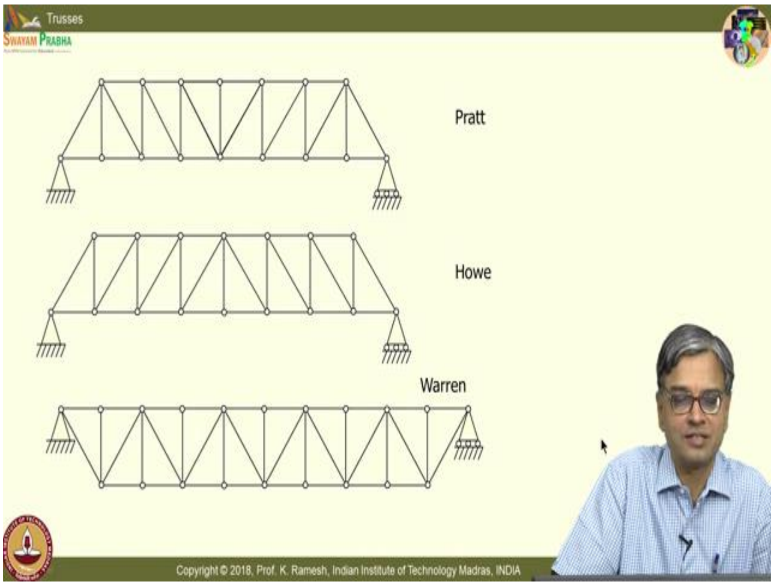
And you should notice that plane trusses are generally supported at the two ends. And I have a support like this, it is a symbol; you should be able to interpret this symbol correctly; what is the symbol? This is a pin joint. And how is it supported on the other end; this is on a roller support.



It is very important, provision for expansion and contraction due to temperature changes and defamation resulted from applied loads is usually made at one of the supports, like a roller supports very important in all of these constructions. And the trusses are also named after several people Pratt, Howe, Warren, K, Baltimore. You will see them; very small change you know the western society always wants to have copyright.



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Let us see the two trusses, I have a Pratt truss, like this; and I have only one modification the central member is instead of put at down; it is put up it is called Howe truss. And I have a combination of these two; I call it as a Warren truss. So, it is all basically array of triangles arranged in different ways for different applications. Also, from the point of view of appearance symmetry beauty all these aspects also go into this.

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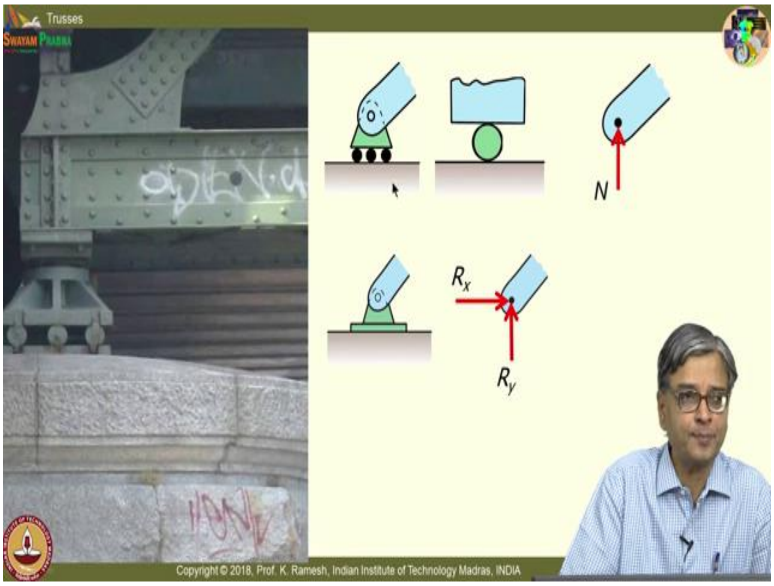

So, we have seen in one of the classes earlier, how a huge truss bridge is supported on rollers. And from analysis point of view we need to know what are the unknowns that we have how do we model these supports. We have already seen; the roller support can be replaced by a normal force acting on the member.

On the other hand, when I have a pin joint, I can have two forces, because I do not know which direction the force is. So, I have a force component *R*x and *R*y at the joint. And later on, we would also see trusses which have pin joints at both ends, they are difficult to analyse. But we would postpone it for the moment, but usually you will come across the truss always with a pin joint at one end, roller support at the other end.

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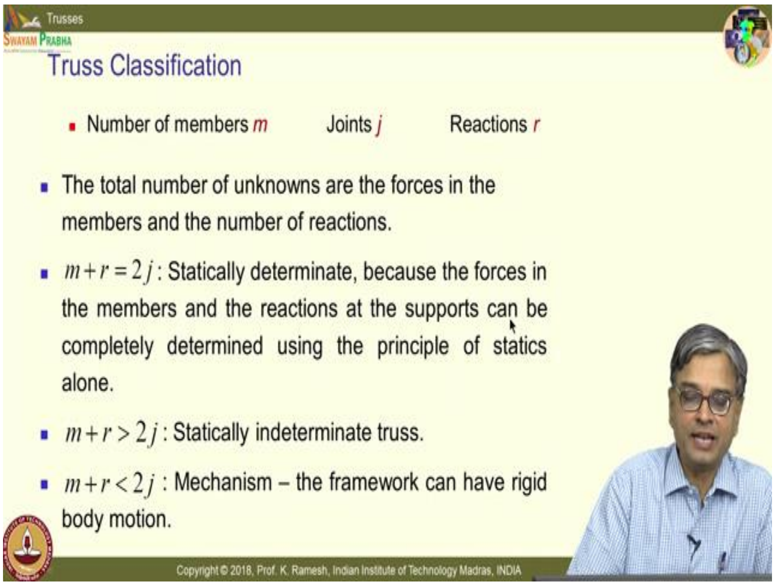
And you should know how to interpret the symbols correctly, and this shows two bridges I told you that accounting for thermal effects is very important. You have the Pamban bridge which is a rail bridge, adjacent to that you have a road bridge; I could get photographs of what have they done for the thermal behaviour. And you see on the bridge, on the road you have this kind of steel mechanism which interlock each other.



So, they can allow expansion and contraction, so, temperature variation accommodation is not trivial. People have to provide engineering solution, without engineering solution the structure will not have its life, lot of money is spent on this.

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And how do we classify the trusses, I can count the number of members as m, I have number of joints as j, I have number of reactions as r. I could have a relationship between them; what are the unknowns? I need to find out the forces in the members, and I need to find out the reactions.

These are the unknowns in the problem, if I have unknowns, I should have equal number of equations to solve for them. At every joint when I idealize this as a pin joint I am talking of a planar truss, how many equations can you write from the principle of statics. You have three equations

$$\sum F_x = 0 \quad \sum F_y = 0 \quad \sum M_z = 0$$

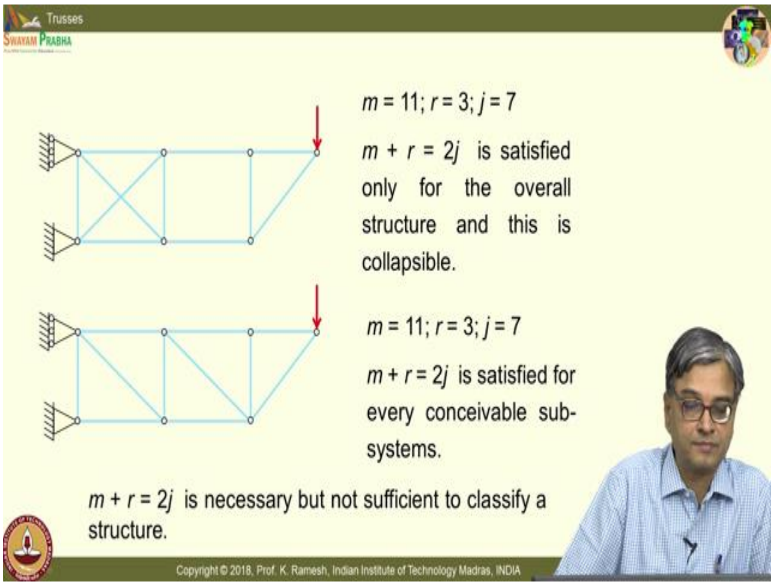
of these three how many you can write per joint. I can write only 2, because I have a concurrent force system.

We have already said the members have to be aligned properly at the joint and apply load only at the joints, so, I make the system as concurrent. So, writing moment equation is not going to give me anything extra. So, I can write per joint only two equations. The total number of unknowns or the forces in the members and the number of reactions, and if I have $m+r=2j$; I call that truss as statically determinate.

It is as simple as from whatever the knowledge that you know right now, you can attempt to solve the problem. Because I have the number of unknowns and number of equations are identical, I can also get a unique solution no problem. Suppose I have $m+r>2j$, I cannot solve the problem only based on the knowledge of statics.

I have to bring in additional information from the deformation picture where I go and accept that these are not rigid and deformable. But in this course, we would basically confine our attention to rigid body mechanics. So, I need to have additional equations based on deformation. So, they cannot be solved using the principle of statics, so, we call the match statically indeterminate.

We have seen $m+r=2j$ and $m+r>2j$, what is the natural third equation? It is $m+r<2j$ and you have already seen how the truss was behaving. It was behaving like a mechanism; do we need mechanism? Yes, definitely I need mechanism. If I have to draw parallel lines in my drawing, I need a mini drafter; mechanism is also useful truss is also useful. And whenever I say a condition, I have already told you that you should look for whether they are necessary and sufficient.



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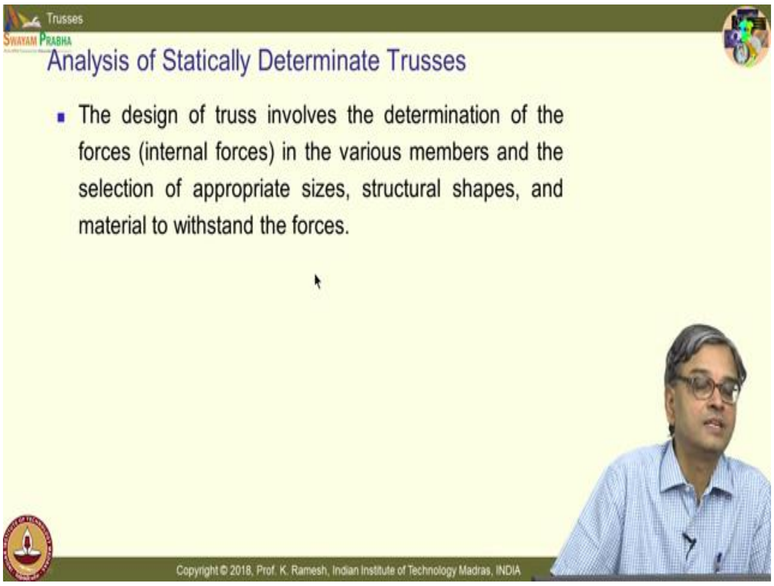
Suppose let me take a truss like this, I have number of members as 11; I have (1 2 3 4 5 6 7 8 9 10 11) 11 members, how many joints I have? I have (1 2 3 4 5 6 7) 7 joints. And I have one side supported by a pin joint, other side supported by a roller, so, I have 7 joints.



So, $m + r = 2j$ is satisfied, can this truss be stable? It cannot be stable. Unless I have the members arranged in this way; the truss will not be stay stable. So, what you will have to look at $m + r = 2j$ is satisfied for every conceivable sub-system.

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So, it is very important. How do we go and do the analysis of statically determinate trusses? The design of truss involves the determination of the forces in the various members and the selection of appropriate sizes, structural shapes and material to withstand the forces. This we would take it up in the next class.

So, in this class we have looked at what is a truss and how the joints are made, what are the manufacturing processes available for us to construct a truss. Physically they are very complex, but from analysis point of view we reduced that as a pin jointed truss. We have seen enough justifications of it and I also emphasized that they have to be supported properly; thermal expansion and contraction is not a trivial issue. You need to take into account for that, and when you are having a bridge truss; wind forces are very important.

We also saw the cross bracings used in several practical structures, and the cross bracings are of much smaller cross section than the actual members forming the truss. We have also seen a demonstration where I had used just a string to show how the cross bracing helps in arresting the effect of wind forces. Wind forces keep change the direction that is why you have bracing on both the diagonals. Thank you.