Structure, Form, and Architecture: The Synergy
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Lecture - 27
Trusses and Space Frames

Hello everyone, welcome back to online NPTEL course on Structure Form and Architecture: The Synergy. Today, we are at lecture number 27 and in this lecture we will cover up the structure under Truss and Space Frame. So, previously we have seen the advantage of grid and then also we have discussed about several other structure dome volt and now even the shell structure we have discussed in the last lecture. Now, in this lecture we will try to focus on the advantage of using truss and then go for the space frame. So, let get started.

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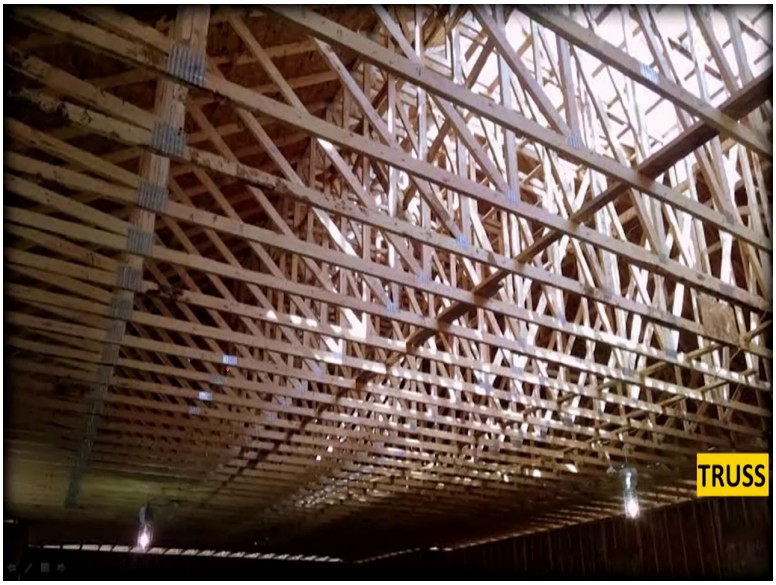

So, before we start anything just focus on this slide. So, basically this is a wooden structure where we can only see different members they are actually connected together and make a form. So, this kind of form is normally being seen in may be for temporary pandles or may be sometimes with your like factory warehouses and all and these are referred as truss. Here the member is made of wood, but that can be also made by some other materials as well, we will learn that in this lecture.

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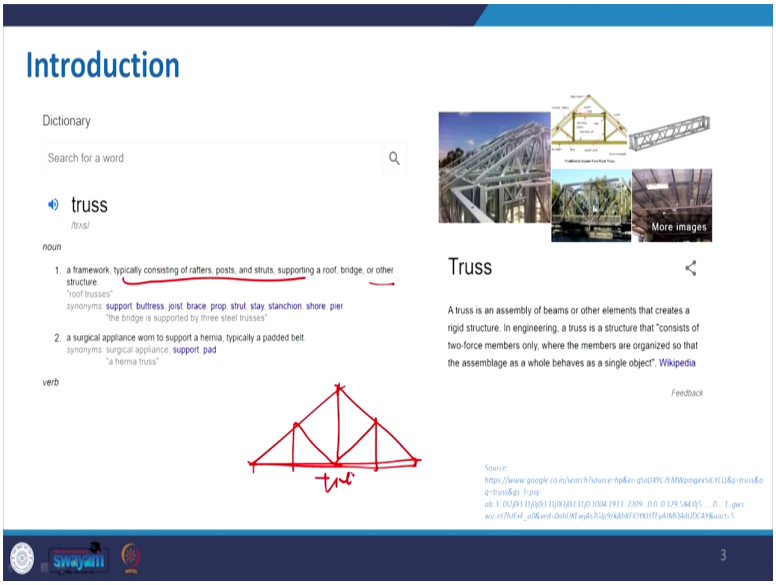

Coming to the definition if we just take a just go for the Google search from dictionary dot com or something, it says framework typically consisting of rafters posts and struts supporting a roof or breach or may be other structure. So, here it is basically framework. So, the framework is normally the we can refer to like something giving the skeleton of any structure. So, it look like a skeleton and then consisting of the rafter post.

So, these are the members of the truss that will discuss, post is basically like the way we support. So, if we just consider a triangular member, so, here we get this kind of post, it may be of your King post or Queen post will come to that and then basically they need to get a support through tie and this truss can be used for your roof of a building it may be also used for bridges mostly like many different kind of trusses being used over a like many years as the bridge to construct the bridge.

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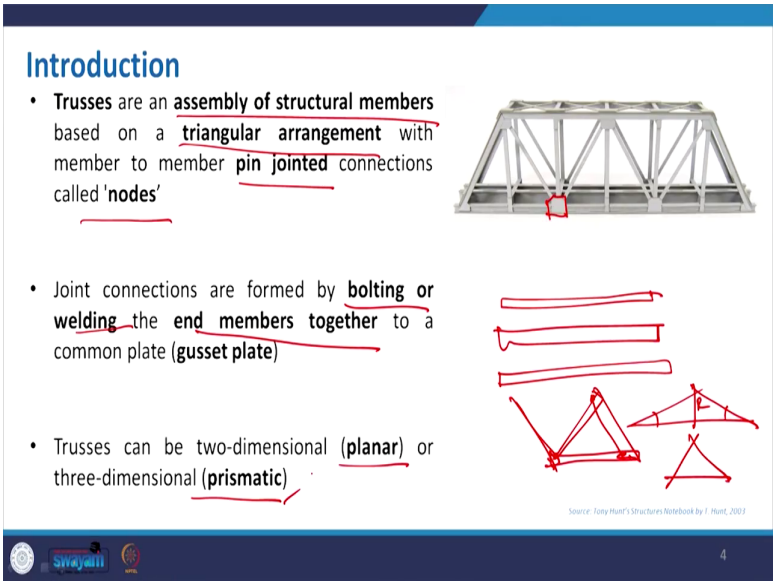

Now, coming to the definitions: so, trusses are an assembly of structural members, based on a triangular arrangement and member they are pin jointed and where they jointed, they are basically node. So, what exactly it is? Like, I will show you with the demonstration. Then the joint connection are formed by bolting or welding at the end members together with a gusset plate.

So, basically whenever we see a truss, so, basically we have multiple members. So, it may be I section, it may be wooden batten wooden lock and then when we just arrange those in a form triangular form we will make it more rigid it will make more stable with a joint. So, then this is truss.

Now, depending on the load that it can carry based on that the number of members will be decided, the arrangement will also differ. The angle will be determined based on that whether it will be having low rise; rise I think all of you now get to know about what is the rise. We have discussed the same thing about the rise when we discussed about the arches also when we discussed about the you know shell structure when you discussed about the dome structure we talked about the rise and then depending on the angle we can have it like broad angular very narrow angle to that.

Now, whenever the multiple members, suppose we take this example of model of a bridge; so, many members they are connecting; so, more than 3 members. So, with the help if you just try to see with a plate, it is been you know connected. So, this is basically called your gusset plate. Trusses can be two dimensional or may be three dimensional. When it is two dimensional we call it planar and then when three dimensional we call it prismatic. Now, before we go forward to know about different type of you know loads acting on the truss and how it can help, so, let us understand why that triangulation will help us.

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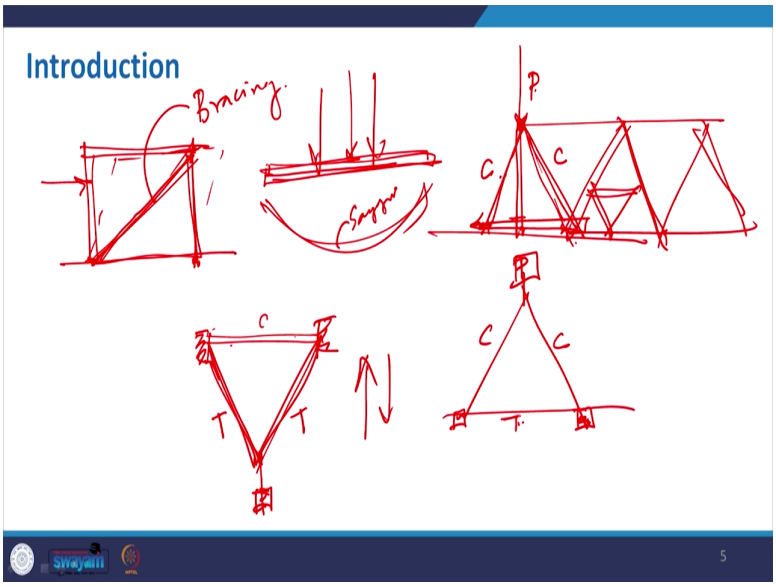

So, suppose we have a member we have a beam and then we have 2 post. So, post means structure that we have studied earlier. So, here due to the lateral force, so, it will try to bend right and after certain time it the joints and the members are not having that much resistance it will collapse due to this force.

Now, instead of that if we just make a tie at another member to it, so it will make it more stable. So, we also referred that as bracing earlier. So, it will help the structure form lateral like from collapsing due to lateral forces. So, this is becoming a member. So, when we just divide it, so it will become it will form like instead of like your rectangle or square, now we have 2 triangles. Like with this concept, we move to the truss.

Now at the same time if we have say particular plate ok, it will have a deflection when you apply some load from top of it, so it will like bent like this and it develop the moment sagging

moment. Now, instead of that we just make a fold and in this case what will happen? The load acting on that will be transmitted easily. So, in this member in this 2 member, the compression will develop and once we try to put it like to the pressure from the top it will try to go away. So, tension will be developed, in order to account we add a member to it; that is also. This is making a very simpler form of truss.

Now, you make the repetition with the adequate member then you get different kind of truss form. So, in order to make stability, you can add the post or else you can also go for different kind of truss arrangement. So, basically the triangulation, like this. So, I have this particular truss with me. So, different color showing different members and basically the bottom one the blue one that you can see it is basically acting on as t.

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The main reason if I just remove it, so, without that I have this member right. So, if it is just a pin joint, so on applying pressure it will try to go away from each other. So, due to completion the bottom will get the attention and it will try to go away. So, in order to resist that I add this members. So, I fix it. So, in this case all the members are equal and the angle formed is 60 degree, it will give you the best result desired result, but at the same time if you use this particular truss forms.

So, then the height is also very high consider the rise is very high and you can understand that for a small span it will not be really a good solution and in that case we can go for some other arrangement as well.

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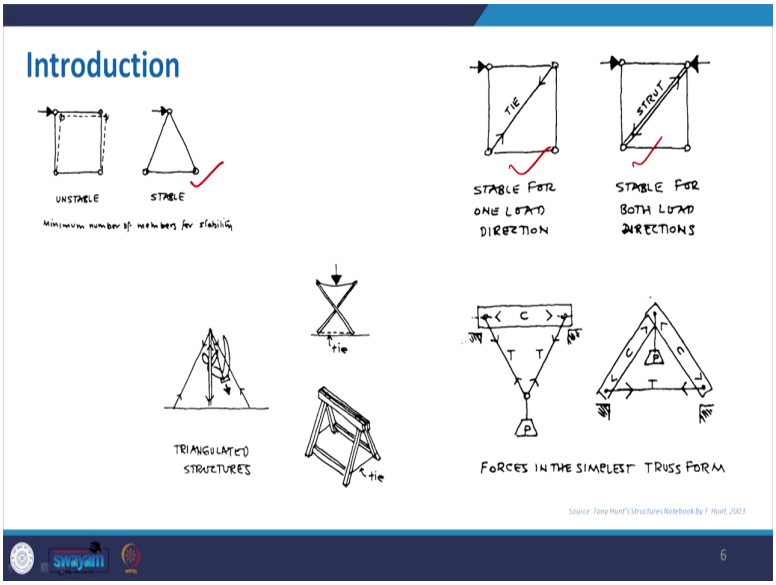

Now, what I have just explained? So, here is the same thing like in order to make unstable structure stable we can go with a triangulation and that advantage of tie and strut how they

can make it. So, that can be alternatively explained by suppose you take a chain that I have given the example earlier also. So, you take a chain and then put a weight at the middle.

So, it will really give you the stability, this particular form where like there is no member at all like we have these 2 members. So, due to this we have tension developed in this and here the compression will develop if you have tie. You just make it reverse, you just make it upside down then you get the form of your this is again P. So, a truss and then you can get it supported, you can make a tie.

So, this will be in compression this will be in tension for the regular truss. So, it is explained again here with the same thing like y compression and y tension. So, this is basically the forces in simplest truss form.

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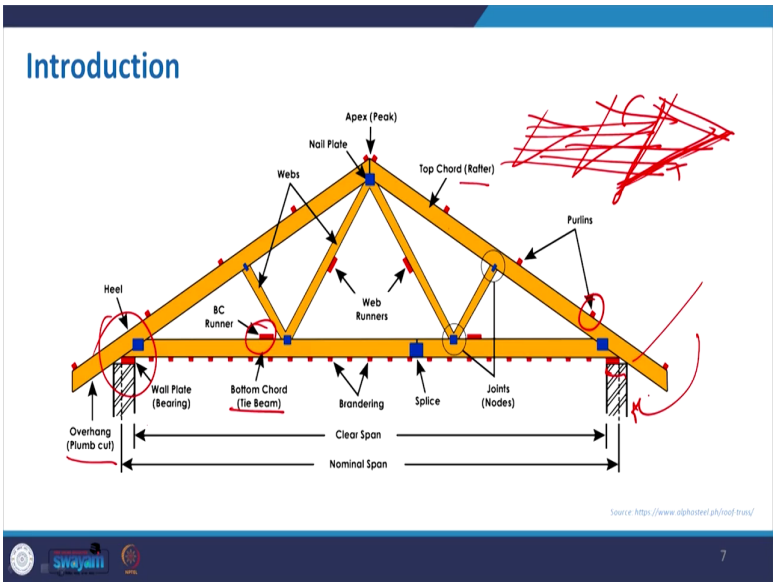

Now, coming to the different you know components of the truss, so, we have like top chord which also referred as the rafter that we have just seen in the definition. And when you have this truss; that means, it is not a single one, you have more repetitive one and then basically you add those particular truss with this member, this is called purlin and this is basically your rafter and then which is actually holding it, it is basically your bottom chord or also you can call tie beam and then all these are actually members.

Now, in order to give much support, also you can go with like your what we can say that these are basically your runner which will make this structure more stable and this is basically the clear span that we can get and nominal span is taken as center to center of the support and the arrangement being designed with that and overhanging part is also important due to this particular junctions.

So, the peach roof whenever it is being used for the buildings, so, this kind of truss being made, so that the rain water can easily be drained up with the slope and this projection will also help to you know have protect from the uplifting due to the heavy wind and also it will protect during the rain.

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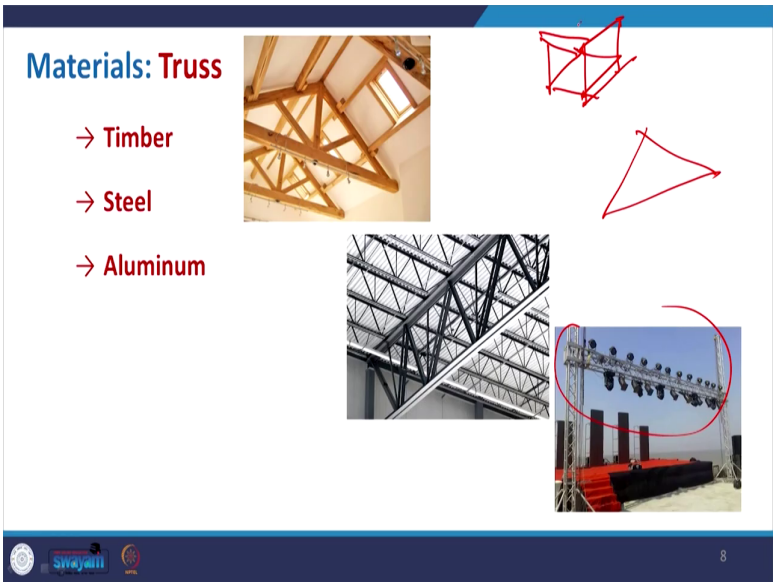

Coming to the material of truss, now, we have seen that timber can be used and it was used extensively in past even nowadays also for specially in the hilly region and the area where like light structure is recommended for the earth quake prone areas and also, they are also we can use it. Alternatively, we can go with a steel and aluminum frame as well, but normally aluminum frame is being used for the prismatic truss for making the temporary structures that I can show you and I think all of you are familiar with this kind of setup.

So, normally during the concert during a program faced in the college, we do this arrangement and it is very light in weight and that is why it is being really possible to you know make it in quick time and then it is not basically a single 2 D truss rather than then it will have like, suppose it is a post and then the triangulation in the post is making this particular truss is prismatic.

But most commonly for the industrial use and where the heavy span to be taken into consideration we go for steel sections and we make the truss out of steel. Coming to the types of truss, so, if you search in Google, so, you will get different kind of form of the truss and we have different names either based on the arrangement or based on like the person who has invented discovered or who actually proposed this kind of truss arrangement, but, basically based on dimension we have 2 D and planar.

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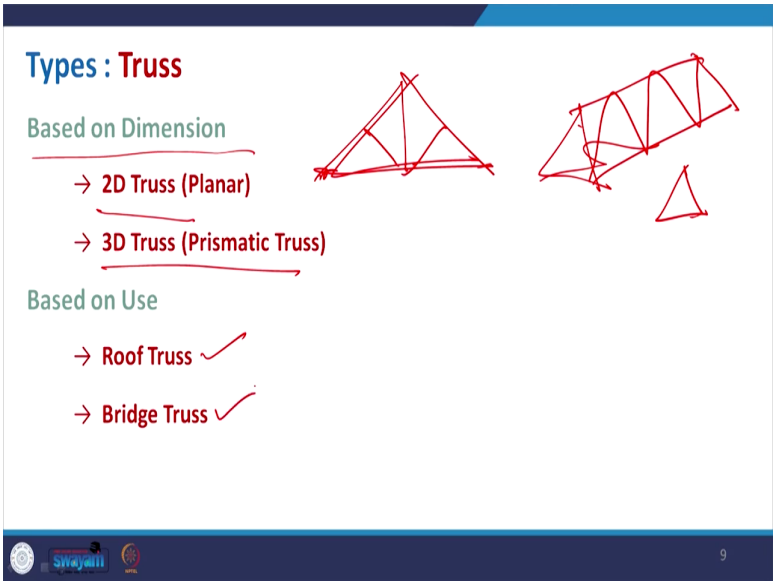

So, 2 D is basically what we were discussing about it and the 3 D truss is basically the prismatic truss. So, it may be of 3 members is running like this at the bottom. So, basically the cross section would look like prism. So, this is the prismatic truss based on use definitely we can make a category of your roof truss and the truss used for the bridges.

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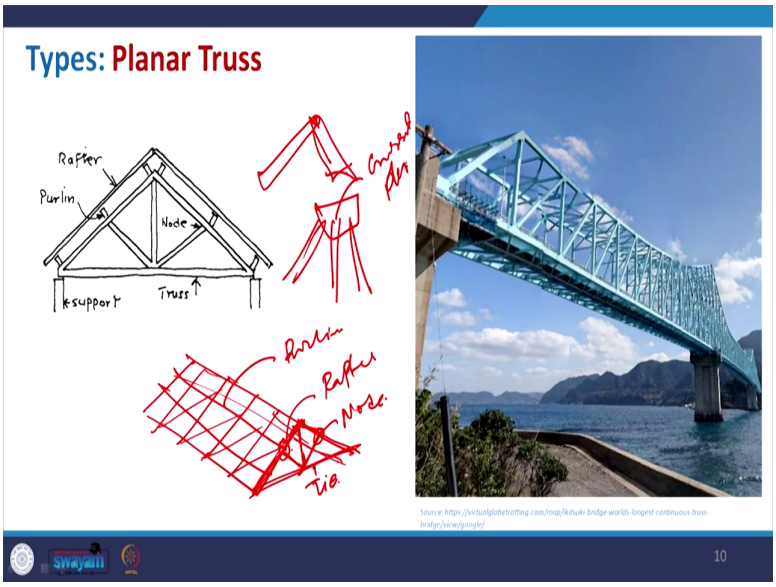

Now, planar truss is having the member like rafter purlin. So, I guess rafter and purlin is thing is very clear. So, if not again I am trying to show you in short. So, basically this is a page roof right. So, these are the members. So, what you have, multiple number of trusses. So, now, all this members are basically the truss member the bottom chord is also called as a tie and these angular member the upper is called rafter and in order to connect those we also have this direction member that is called purlin and whenever they joint the members we call it node.

Now, this node can be joined juts with the help of a pin very simple or else if you have multiple numbers, so, we can have a gusset plate and we can use welding, we can use revelt. So, there are many examples and here you can see that the use of the you know 2 D truss in this.

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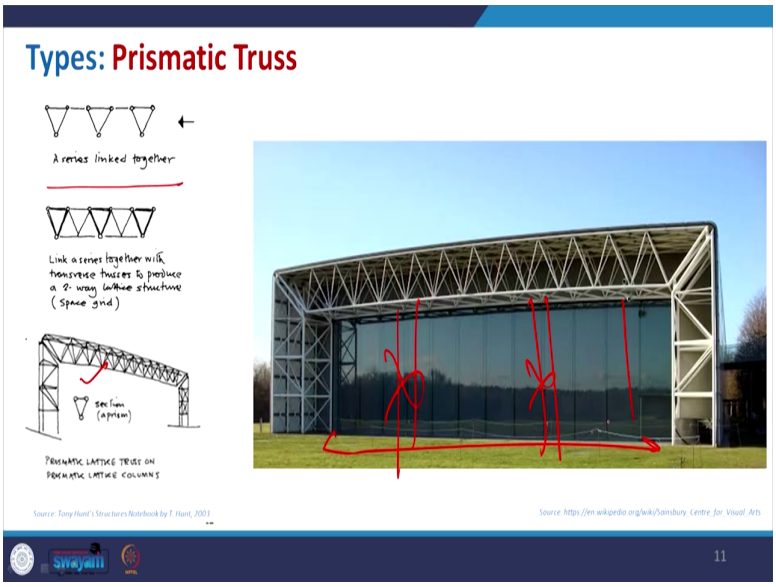

Now, coming to the prismatic truss, so, in this case like a series of such triangular truss being added and make a form of this. So, it is pretty similar to the example I have given for your concert set up musical set up and here it is another example where you can identify that how this prismatic truss used to create this span. So, there is no column in between in this structure. So, the huge span being supported with this frame and even this is very important that we can go for 3 D truss to have a column less space.

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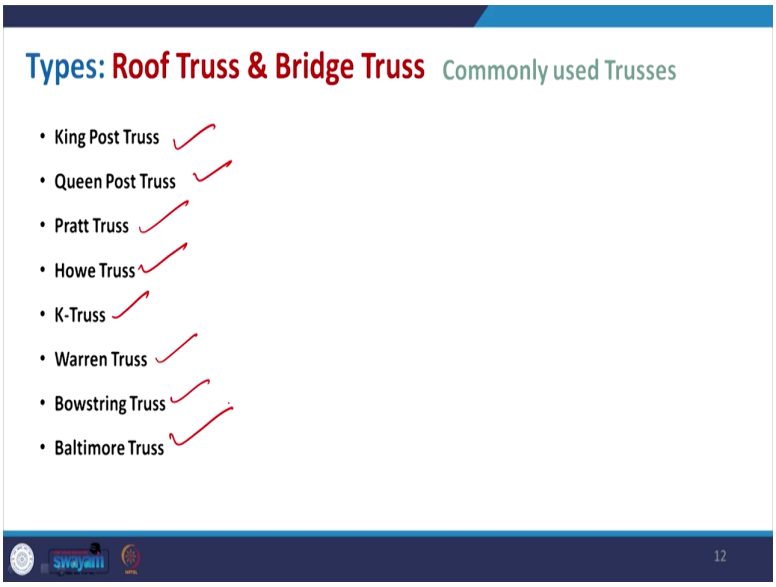

Coming to the types under roof truss and bridge truss commonly; so, I have listed very few in this category, but there are many more in into this, but most commonly used trusses are like King Post, Queen Post, Pratt Howe, then K-Truss, Warren Truss, Bowstring Truss and Baltimore Truss.

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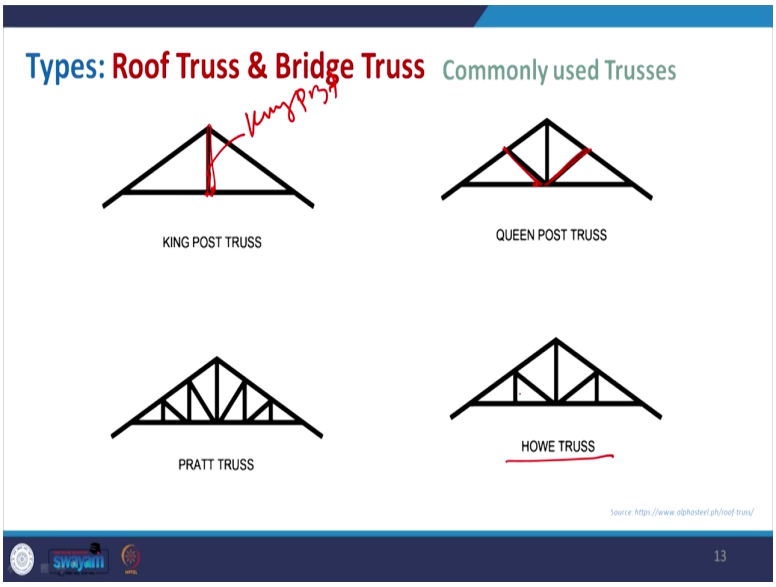

Now, in the King post is basically there is a central post. So, this is basically the King post. So, in the truss in the triangle only the centrally we have a member this King whereas, Queen along with the King we have some other angular member adjusting to the rafter this is the Queen post then Pratt is basically multiplication of that. So, we add more vertical post along with the angular. Howe truss is basically you have vertical members like if you add only 2 vertical members to the Queen truss it will become to this category.

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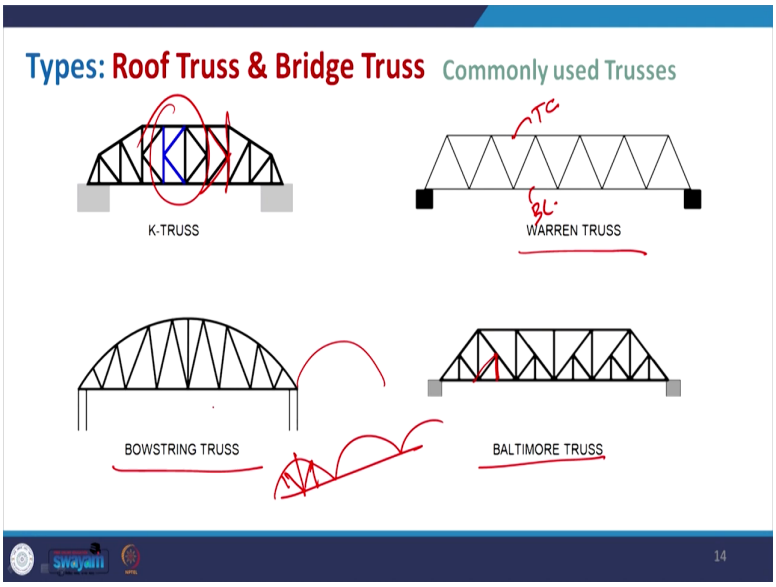

Now, K truss is basically the truss formation is very tough and, but the members will make a letter the form of a letter is basically the K, this is basically the other inverted K, whereas, the Warren truss is basically equilateral triangle they placed one after another. So, we have the members, we have a top chord and the bottom chord and then we have the members regular members.

Now, Bowstring truss is basically where it is not the rectangle or you know rectilinear form, here we are getting a arch form. So, this is also very common in the real bridges we have multiple of such, many bridges are looking like this and where we can see this kind of arrangement. Baltimore truss is very complicated, where it is again we are taking some vertical members and to give support to those angular members we add more small you know vertical post and angular post to make it.

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Now, here the few examples are there of the truss. So, here you can easily identify which truss category it is. Can you guess? I think all of you can get the idea; it is basically the K Truss ok.

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Move to the next example. In this case it is again in circular. So, again go back to the category. So, which one that example is? So, this is similar to the Bowstring truss.

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Now, this is something out of from the bridge and this example is a like I have given this example many a times, the Eiffel tower. So, this is basically a nice you know application of the truss steel truss and it is just some architecture means which we can refer in many cases, but along with that all the transmission towers, telephone towers ok, those are again being made with a help of the truss. So, this is Eiffel tower, but all other tower always like it is very similar to look like this, but those are made of truss.

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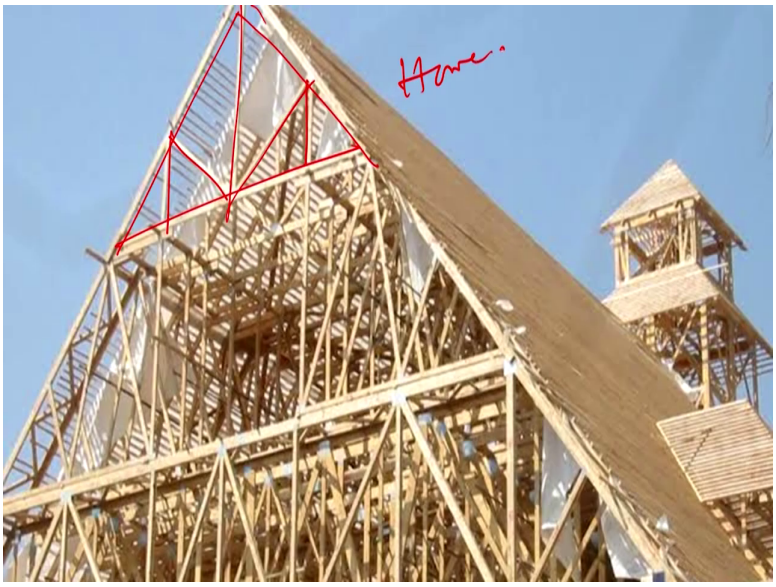

Coming to this basically this is a temporary structure being made and made of wood. So, here you can see the you know series of truss is being used. So, to give this form, it is not about single rise. So, we can get a particular truss in this ok. And can you refer or can you say this truss which category it is? So, if you see we have King, but along with that we have. So, this is not King not queen. So, additional to that we have. So, can again we go back to this and here it is something Howe truss and then also we have the additional thing.

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Now, the truss always need not to be with a triangle or you know trapezoidal form, sometimes it may be of semicircular form and here if you see that multiple trusses being used at the top you have some truss, but the bottom member it is not exactly the member, we get a section and then this is holding this space. So, this is for a station and you will get the similar kind of truss application in almost you know many railway stations.

Even if you consider the Howrah stations Howrah station in Kolkata, there also you will get similar kind of form and these are the truss being used in multiple layer to get the day light as well. So, in truss category there are something called not light truss. So, for a factory many a times we get this kind of truss form.

So, this is basically the truss being made and the light can enter through this particular pattern or sometimes we may also make it inclined. So, light can easily you know go inside and can help or maximize the day light.

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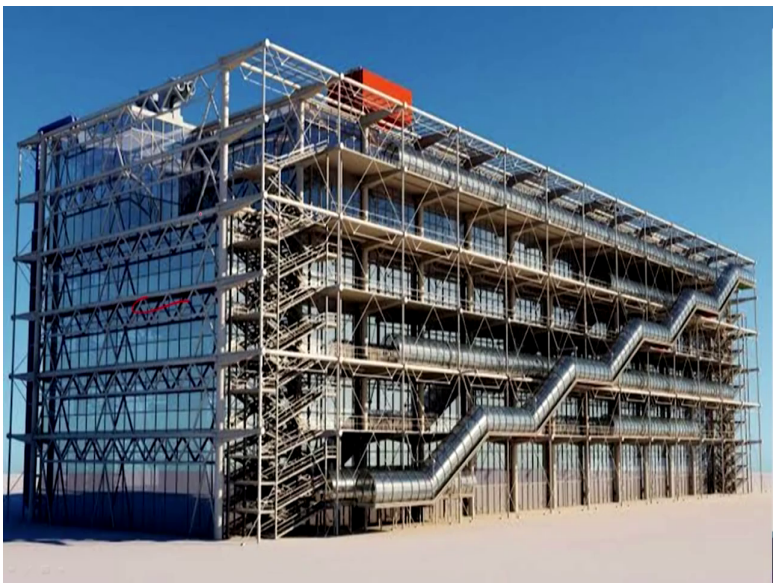

Now, this is another example. The modern building, where again the prismatic truss been used to support it and like this is one application shown in this.

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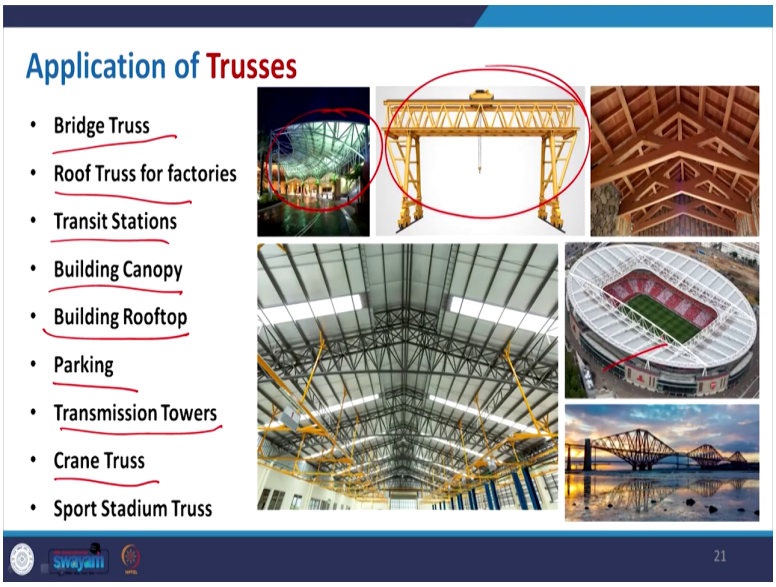

Now, application of truss is as we have seen almost, but this is I am summarizing it. So, it can be used for the bridge, it can be of the roof, many a time we go for the transit stations that refer to the railway stations, some metro stations then building canopy in front of the building we can get this kind of truss, building roof top; definitely sometimes for temporary or may be permanently we can use that roof top then for the parking area if it is a surface parking or so. You can have this shade transmission towers like have already mentioned during your Eiffel tower think the crane truss that we can get it, we can see in this picture. And then the sports stadium truss is also important. So, have this membrane structure and all we also use the truss to support it.

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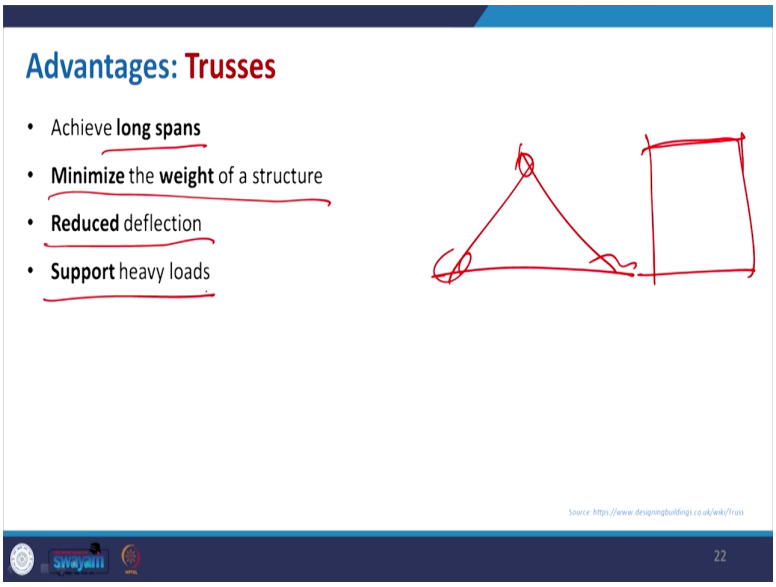

Now, advantages of truss is basically can be use for the long span and as and when required we can increase the members and make the truss little bit complex rather than the simple one, but that can hold the load. Now, minimize the weight of a structure as because it is just the member not any solid slab to be provided, we can go for that.

Reduce deflection as because it is giving more stability compared to the this particular shape because of the triangulation. Support heavy loads because of like support heavy loads compared to the equivalent section of like solid member.

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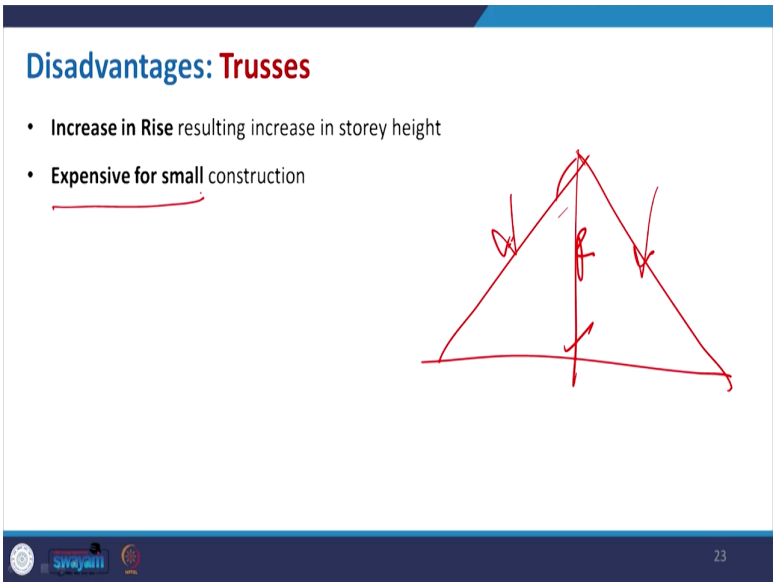

Coming to the disadvantage: increase in rise. Definitely in order to get better stability, we can we have to increase the rise and that is unnecessary increase in the height of the building. So, again this is one and the other disadvantage, we cannot use the upper storey because of this you know peach nature, this slope nature. Expensive for small construction, definitely for the small the truss will be expensive, but for the purpose like when we need to cover long span for commercial uses and other long the truss been repetitive so that then it will be economic as well.

Now, after that we directly move to the space frame. So, it is similar to the truss formation, but now the truss is not being in a planar or is very you know 2 D form.

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So, now go for like more 3 D kind of formation and this is one example. This is under construction building of Jahadith. I have shown this example previously also, the finished one, but this is under construction whereas, the member this is basically being used different tubes and they made some you know connection with some connectors and then form this space frame.

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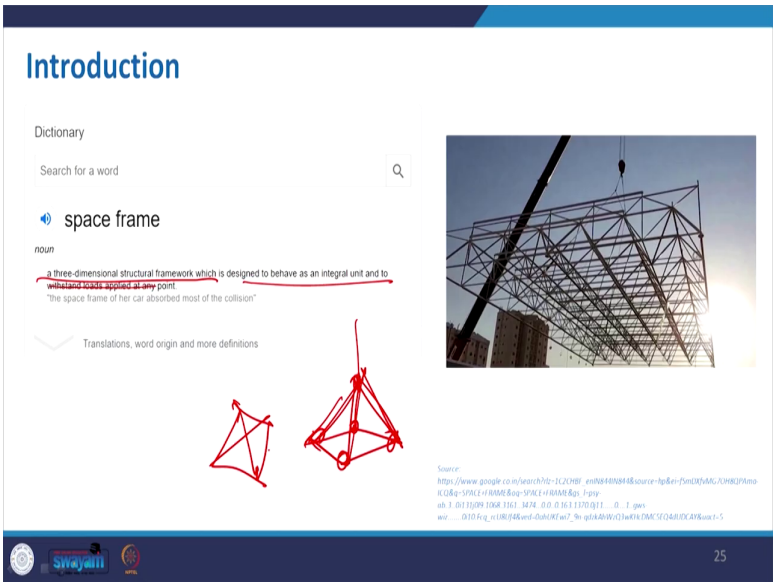

Now, space frame is three dimensional structural framework again. Other one is a framework this is three dimensional is designed to behave as integral unit and withstand loads applied at any points. So, the main beauty of that the members are so designed. So, we have to just make the shapes. So, it can be our pyramidal shape, it may be of you know tetrahedral shape. So, with any such shape articulation with the proper connector it will act very suitably.

So, the load distributed they will distribute to the next member and all more efficiently and more importantly the as because it is just a tube and many a cases been made with light material like aluminum alloy and all, so, the dead load of the structure will be less and that can cover of you know huge span without such vertical support in regular interval.

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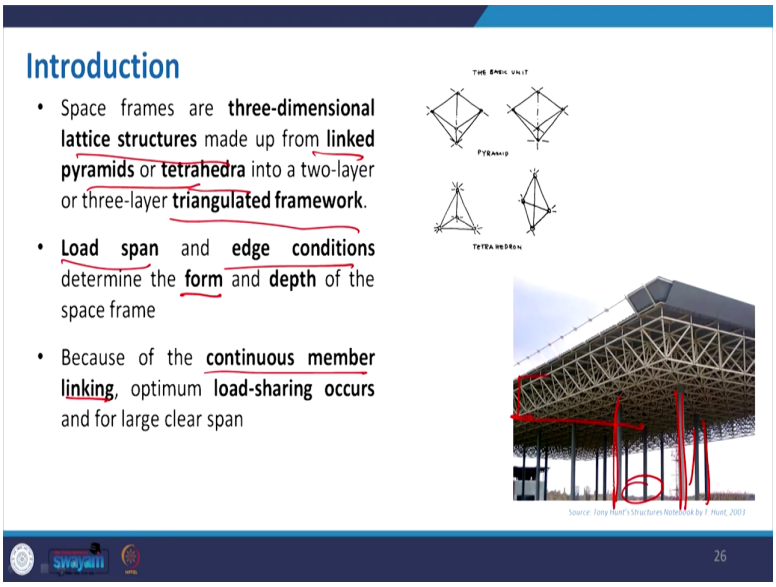

Now, space frames are three dimensional lattice structure made of linked pyramid or tetrahedra that already I mentioned like this and it is basically acted based on the triangulation method. Load span and edge condition will depend on the form and depth that we picked up, what should be the depth of this and the because of the continuation of member are linking. So, load sharing will be optimized like this kind of structure we have seen in recent time for the petrol pump, where like we only have this particular structure, many a time this is been covered with some alucobond or if it is open.

So, we can see that with very less number of vertical support. This whole span being covered with that roof and this is being covered with some like material, we can sometimes use some translation material which will allow light and the area underneath will be lighted.

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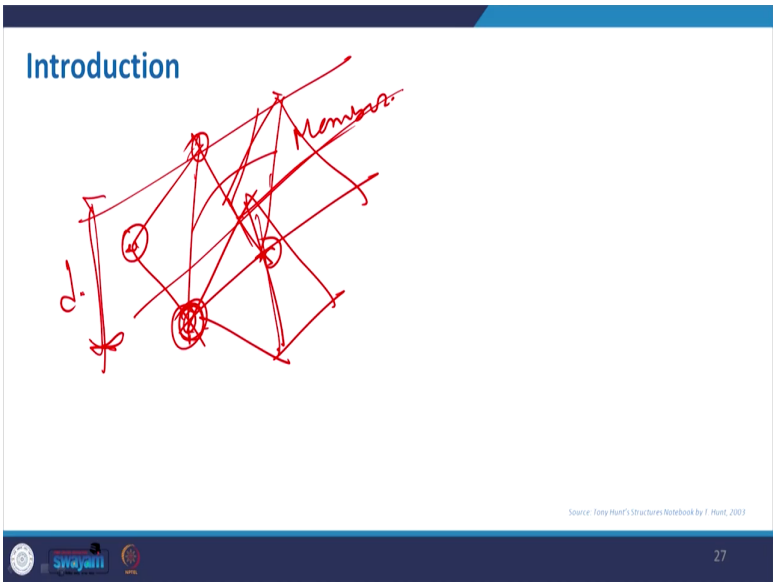

Now, in this case what exactly just we discussed that the space frame is three dimensional can be of the pyramidal shape. So, most important thing is to know about the component, one is the member and then the connector because, whenever you think about the connection, it is not only one or two members, multiple members and that need to be fixed in a right manner.

So, then like on top of it we can connect it very suitably, so that it can form this particular space frame and then the depth we get this height that will determine like how the load will be distributed.

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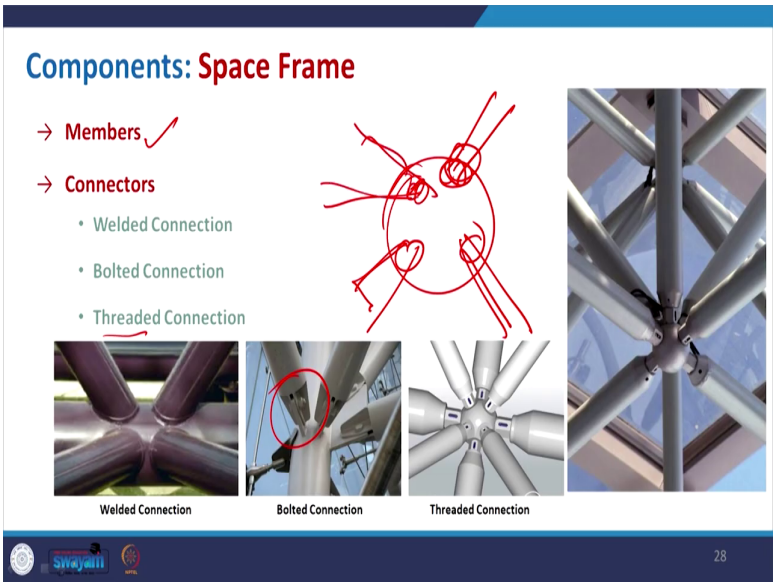

Coming to the component of space frame; so, we have members and then connectors, under connection the connection, may be made by welding, it may be connected by bolt or may be sometimes with the threaded connections. So, threaded connection. So, one by one the welded connection, the all the connections are getting weld with the members and then the bolted connection that you can see, if uses zoom this particular part then the members to the connector is being adjusted with the bolt.

And now in the threaded connection its technique where like those members are being fitted with you know hemispherical or spherical connector where we can make it. So, it is basically something the holes are there with the certain angle on this and we just fix it, we just fix it with that particular thread.

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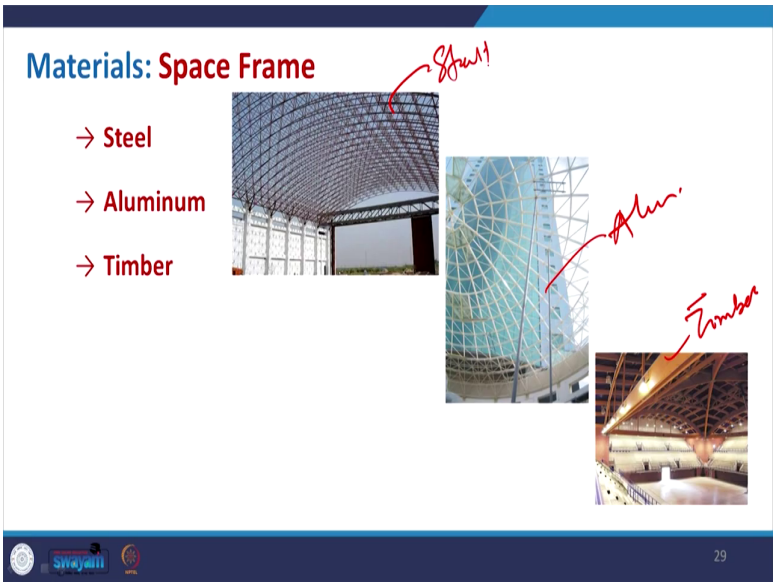

Coming to the material that the steel can be used aluminum can be used even timber can be used or some of the restaurant that they here this is indoor stadium where this particular space framing design with the timber and here you can see that the material is very light and aluminum can be used and here the steel is the material.

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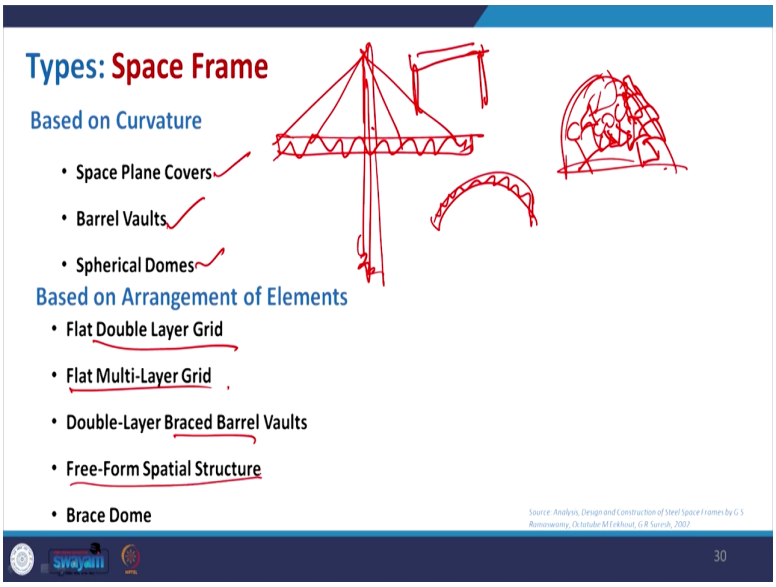

Coming to the types, now based on curvature we can divide the space plane covers then we can go for the barrel vaults construction as well and the spherical dome. So, space plane is basically that I referred as you know the cover may be for the petrol pump and all, it may be the supported by the end column or like it may be supported by the end column, but very few in number or else it may be supported with the cable, so, only a vertical post must at the center and it is being supported and this is been hold.

Barrel vaults where this members is bend and then we get this particular barrel form and the spherical dome is basically referred to the geodesic dome where the triangulation form they are actually making the dome. Based on the arrangement of elements, we can have double layer, flat double layer, flat multi layer means more than 2 then double layer braced barrel that where the double layer is bend through the barrel form.

Free form spatial structure can also be applied where it is not about the straight or the curvature it can get a free form and then the braced dome; so, basically that refer to the geodesic dome and all.

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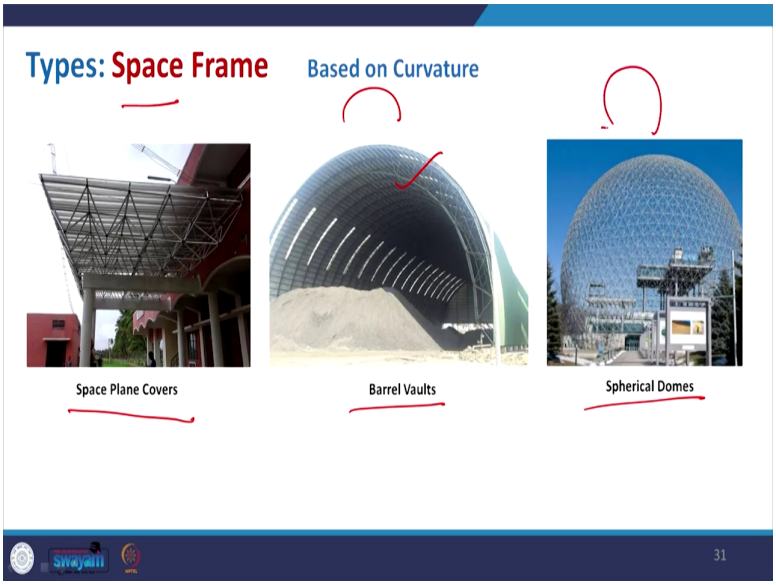

So, let us just quickly look into this. So, this is very clear about the where it is very plane and normally used in those areas where you can see that as canopy of a building the barrel vault. Here it is the space frame being used like this. Sometimes, this can also be used for like metro station or railway station to have leak and this is what exactly the space frame is being used to make the dome. So, this is based on the curvature like one is very straight then you have this curvature this is straight and here it is basically a spherical.

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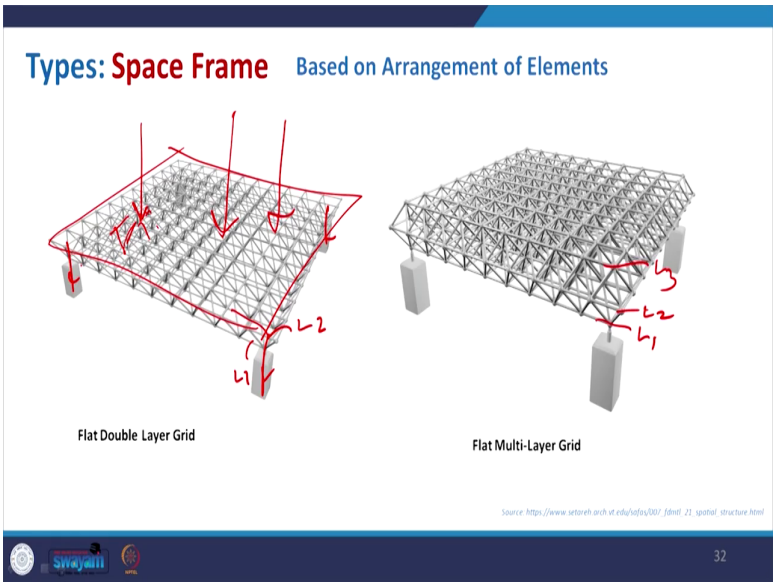

Now, coming to the arrangement elements, so, here you can see the double layer. So, this is layer 1 or this is layer 1 this is layer 2 and here you can see the layer 1, layer 2 and layer 3. So, how they are connected? So, definitely these will able to carry more load, but at the same time the self weight will also increase. This kind of structure if we design properly we can also just cover it with some material and we can use the upper floor.

So, load applied on this members they are just triangulated they are distributed and they will transmit to the end support. So, that is the load distribution. So, here it is more complex.

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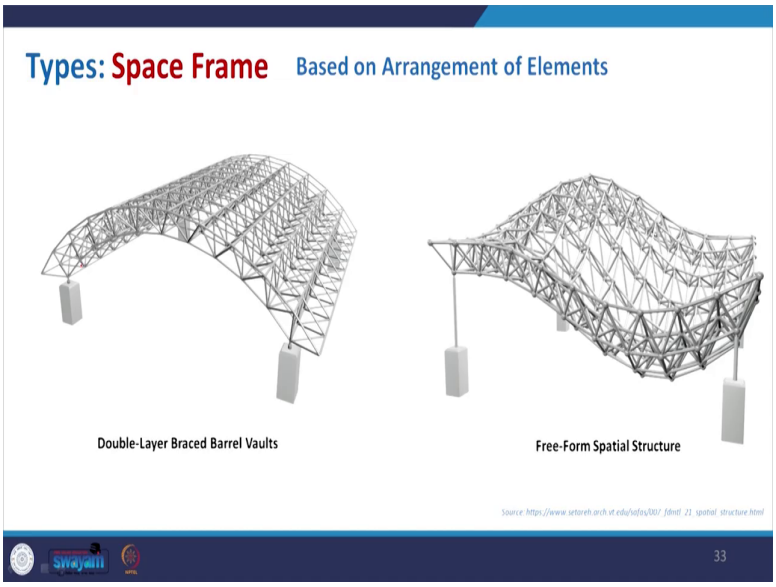

Coming to the barrel vault, it is the similar thing. If you just try to bend this in this direction, so, that will lead to your barrel vault and here as I mentioned that it is not exactly semi circular curve or may be something very state, so, it is a free form spatial structure.

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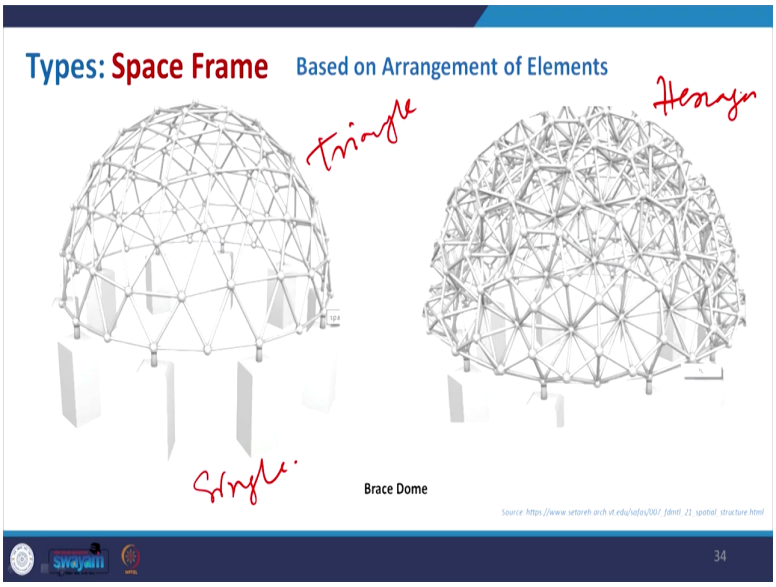

Now, compared to that the brace dome, so, that may be a simple one, like with only single layer only single layer can be just connected like this or else it may be a double layered where this hexagonal shape being added. So, here it is based on triangle and here it is hexagonal shape. So, that is giving this particular form.

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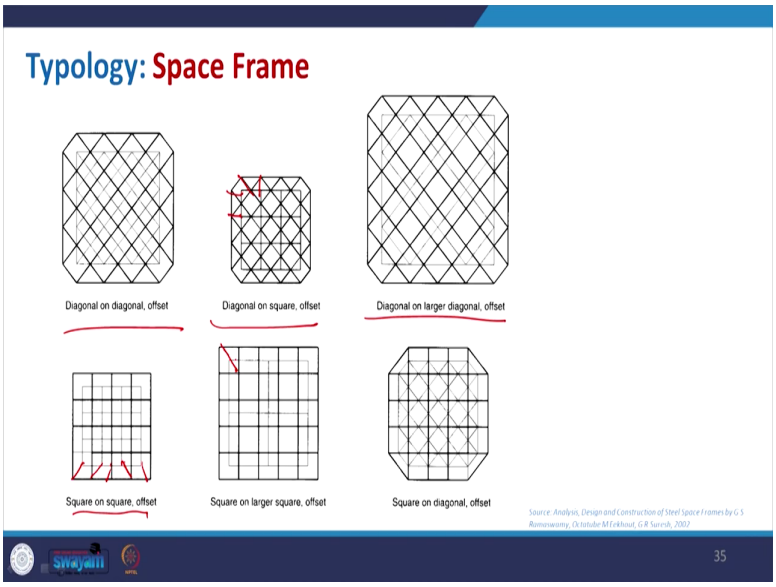

Now, the typology of space frame. So, how we make different layers? So, with layer may be diagonal or diagonal. So, the bottom one also diagonal the upper one is also diagonal, diagonal or square where the bottom is square. And then how we connect it? We basically connect those points with that. So, how it will look? So, it may be of the larger diagonal square on square offset then also you can get this connection of this particular point or else we can have other square on larger square can just get it connected or may be the square on the diagonal grid.

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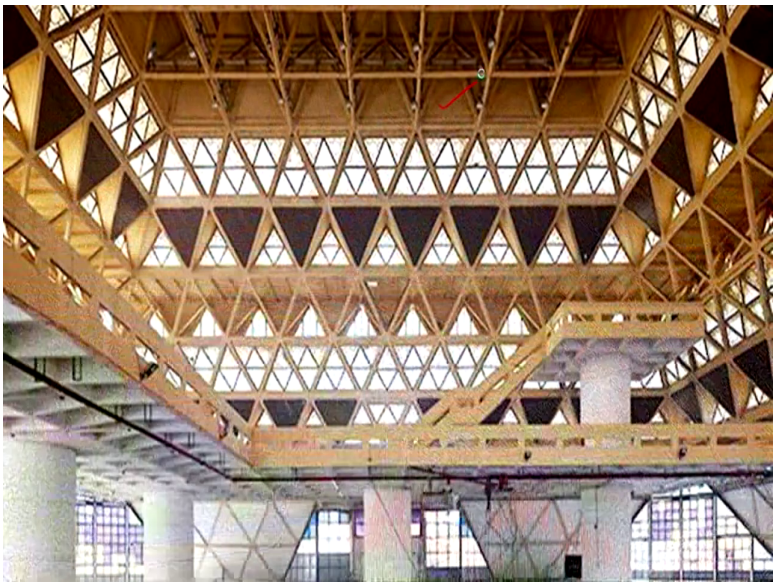

Now, this is one example from Pragati Maidan, recently been dismantled. So, the here also we have seen the use of like your space frame at the top.

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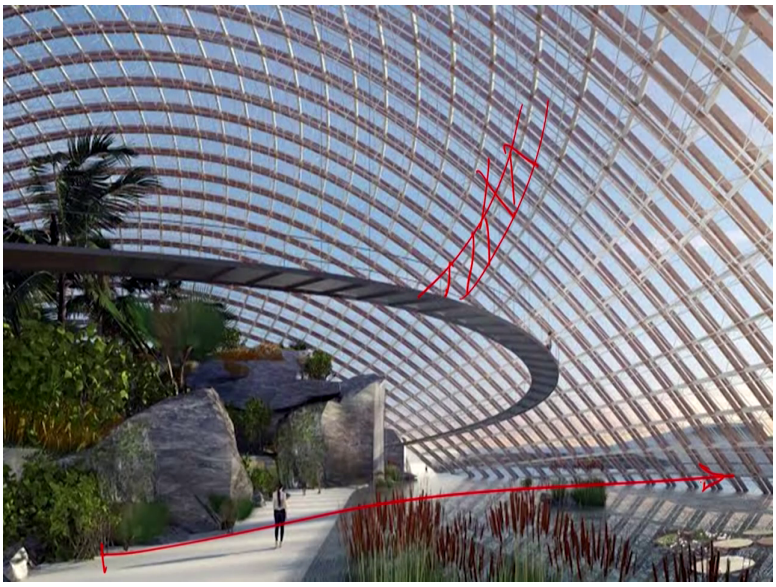

In this also if you see this image very carefully along with those prominent members there are very thin members along with which is basically nothing but the space frame holding this entire volumes. So, this is really interesting here it is a domical form, but with due to space frame it is able to hold this much of span. So, this is beauty of using space frame.

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This is another example. This is next to your air force you know chapel in US next to that. So, here also the space frame being used, but in a diagonal form.

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This is from one particular station where you can easily identify the point and here it is if you just understand the connectors. So, it is basically the threaded connection that is being made and here it is again making a form where it is not a circular. So, it is connecting in a dynamic form to give this particular shape and how the triangulation is made and if you see it carefully all the members their cross sections are not equal.

So, it is depending on the load, the main members and the supporting members that will be decided. So, it needs good computation and engineering to come up with the right solution for that and that top covering will also, you know depending on top covering how the material will be used. So, this material and the cross section will be decided.

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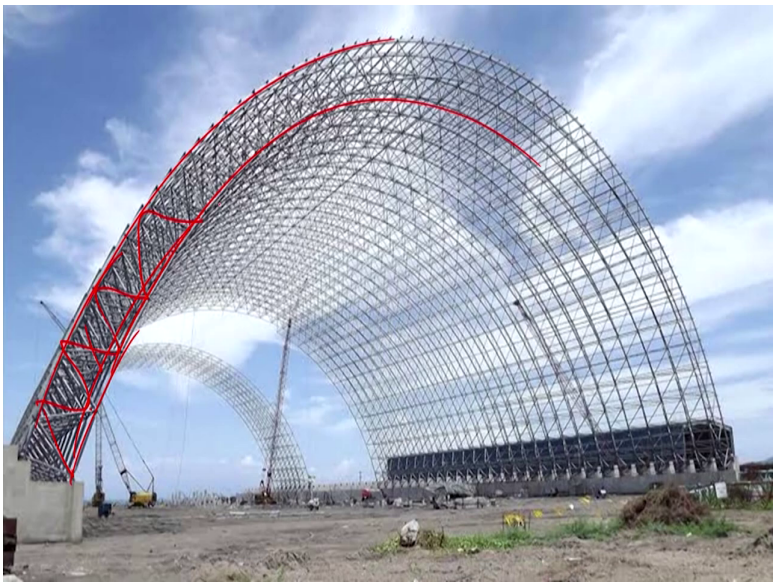

Now, this is again a huge structure made of space frame and here it is again if you follow up that thing, it is basically double layered barrel. So, this is a single layer and double layer and how they are connected to each other all the members. So, this is really very interesting to make any hanger for the layer curved maintenance and all. So, this kind of thing can be applied even for the you know some auditorium we can use it.

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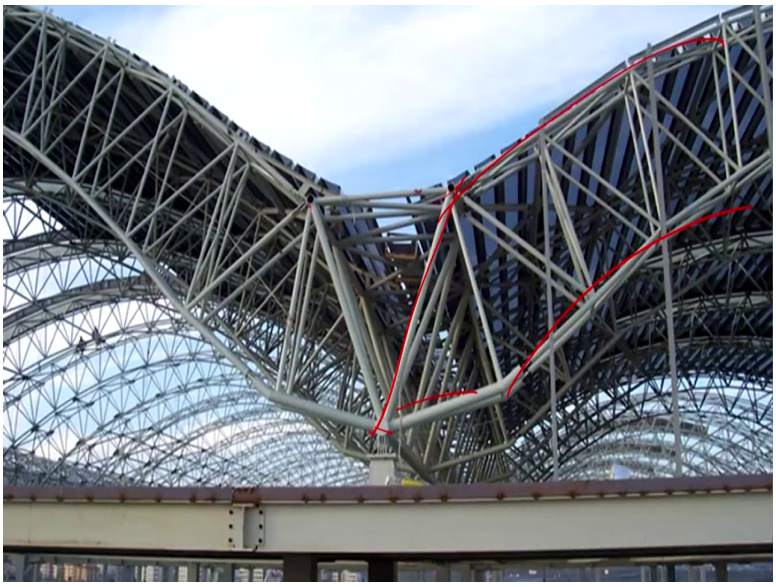

This is where you can see that how, it is not a form like 2 wings kind of form being adjusted with this.

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And this is the geodesic dome that already we have seen this is another picture of that. Its loop, so perfect and due to the space from the spherical, but it needs accuracy.

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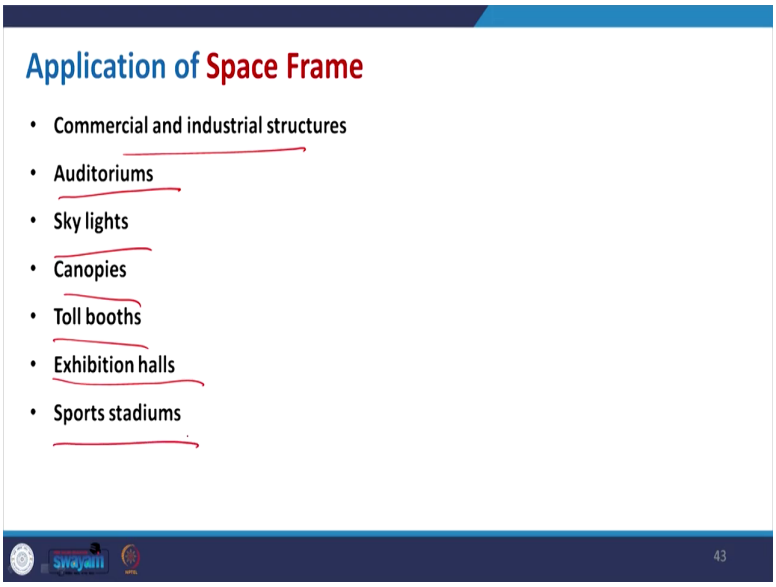

So, for that like the application already we know that commercial industrial structure, auditoriums, sky lights, sometimes to in insert the light, the canopy is building canopy is, toll booths for the small structure, exhibition halls, the sports stadium as well. So, wherever the truss being used then you can also go for the space frame.

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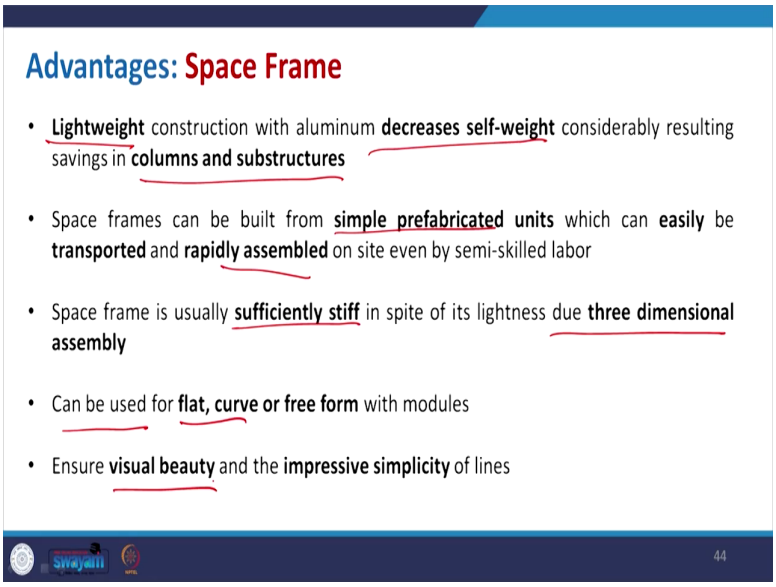

Now, advantage is similar to the truss. It is lightweight and then that is why the it decreases the self weight or the date load and less number of columns. At the same time, it is basically a prefabricated unit can be easily transport at the dismantled form and then you just club them together to get the form and that can be done with semi skilled labor as well. So, this is a very rapid construction. Then this is sufficiently stiff to carry the load, so, there is no compromization on that. And its can be flat curve or free form that we have discussed and the visual beauties definitely.

If you see that dome made of that is perfect execution. Coming to the disadvantage of this particular part is again for small span it will be expensive. So, we should not really try this kind of thing for a very small solution, it can definitely if you just want for the aesthetic purpose,

but if we want is at the structural member, wherever we it took over a large span with light structure this is one of the greatest option.

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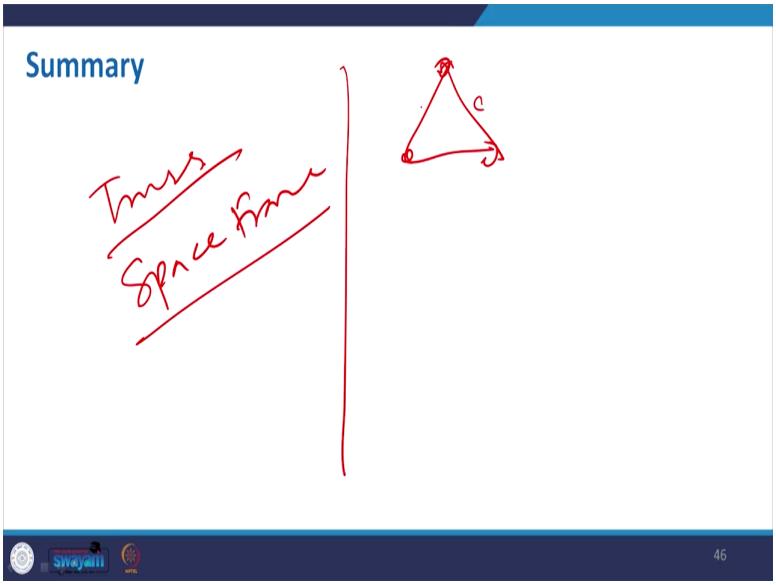

Now, coming to the summary, already we have summarized the truss and then the space frame both are acting with the similar triangulation method which is giving a more rigidity more steepness to the structures and then based on that we have discussed the different application of truss and space frame, where like basically the whole members like the members of truss or space frame they are taking compression and tension and they are balancing out it, so that the structure will maintain the equilibrium condition and for that I have shown you very limited photographs of the buildings as because within this lecture we have to cover 2 topics.

So, I would suggest you that you go through a you know internet, go through read several articles and books and at more examples real life examples or if you have visited some place

you have seen similar kind of structure do hear that with me in the forum and definitely I would love to see those and discuss over it.

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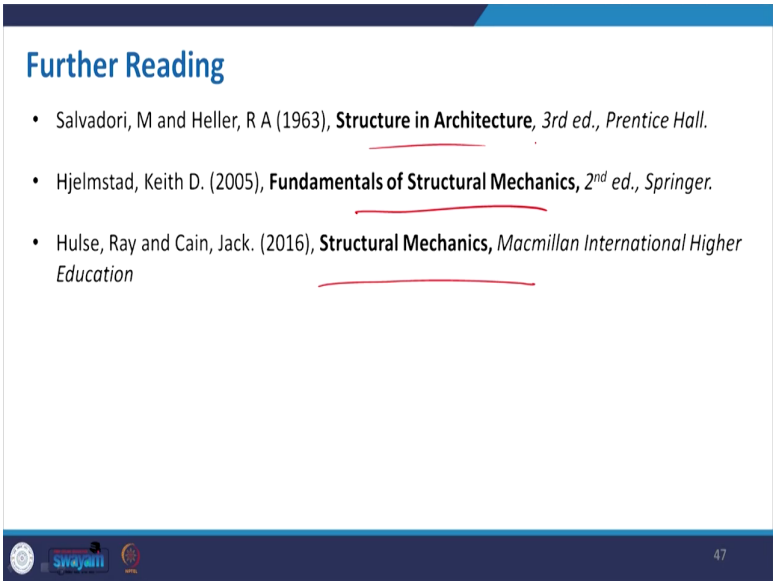

And these are the study material already being given in different slides, you can follow of those books and you can definitely refer others than these as well. So, with that I conclude here and will be discussing the next topic that is folded plate structure in lecture number 28, which will be again a very useful and interesting structural member, structural arrangement that can help us to make good architecture.

So, we will see that how architectural form and folded plate structure they blend in the next lecture. So, till then I again thank you all for take part in to the course and I will be waiting for the next lecture to you know discuss more on the folded plate structure.

Thank you.