Structure, Form, and Architecture: The Synergy

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Lecture – 29
Membrane Structures

Hello everyone. Welcome back to online NPTEL course on Structure, Form and Architecture: The Synergy. Today, we are at lecture number 29 and we will be talking on Membrane Structure. So, before that, in last two lectures we have discussed on the straws, space frame and the folded plade structure. And today we are discussing, like we are going to discuss about the membrane structure which is also alternatively known as fabric tensile structure.

I have touched upon few things when we discussed about the tensile structure, but in this lecture we will focus on different application of that, different form that we use for this membrane structure and the application. So, without wasting more time let us get started.

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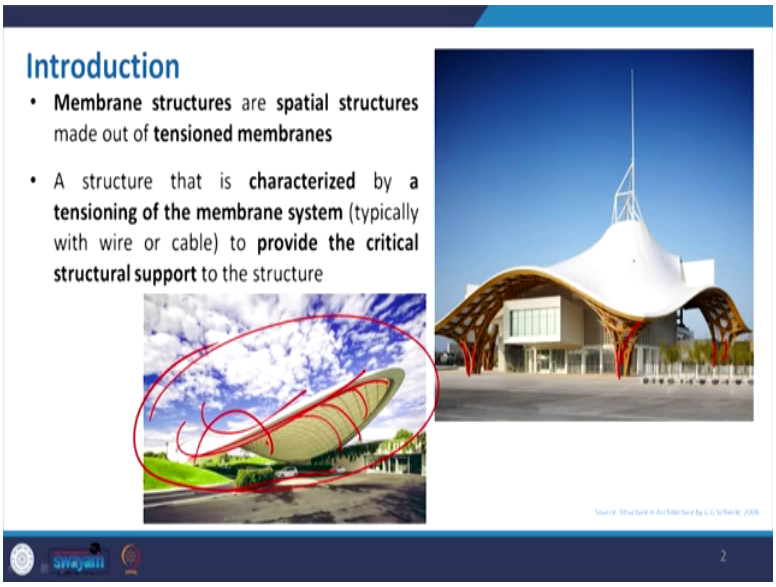

At the introduction what exactly the membrane structure? So, it is a special structure and which is made out of tensioned membranes. So, membrane structure or fabric structure is one kind of tensile structure. So, the component that we have in this is membrane or fabric in one and the other is the structural support that may be a mass, that may be a cable, that may be a rope. So, we will see that different kind of support system as well.

Now, at the same time alternatively like there is another way of defining it, as structure that is characterized by a tensioning the membrane system, typically with as I mentioned the wire or capable to provide the critical shape or structural support to the structure. So, in this image if you see the slide. So, I have given you two options, one first start with this particular picture.

Here you can see that how the curve being generated and a thin membrane which may be of cloth like material we will discuss on that as well like different kind of materials that are being

used to make the fabric for the tensile structure and how beautifully this being created. So, here again you can get the curvature in opposite direction and if you recall our earlier discussion that on the anticlastic and synclastic curvature, so I am sure that you all can understand that this is the curve in opposite direction, so it should be your anticlastic curvatures kind of form and it is making a hyperbolic shape.

And this structure is very light in weight and being supported. So, this particular roadway being you know very beautifully covered without intermediate support. So, that is the beauty of this kind of spatial structure. We discussed about the dome, we discussed about the space frame and folded plate where this kind of you know space creation is possible without much vertical support in between. So, depending on the fold that we have seen that how we can make those structure steep enough to resist against the applied load.

And here it is basically very light structure and only it is being stable with proper tension with the you know tensile members or the cables. Here this is another one where you can see that there are you know columns which basically making a framework and everything is we covered with a fabric.

So, this is another example and I am sure that all of you must have seen in some videos or maybe in real life this kind of structure, it may be applied for a small sit out area or maybe near restaurant or maybe in some of the you know a temporary construction that to be you know made with this membrane and structural support which create the proper tension to hold it, to hold the shape and it is very useful.

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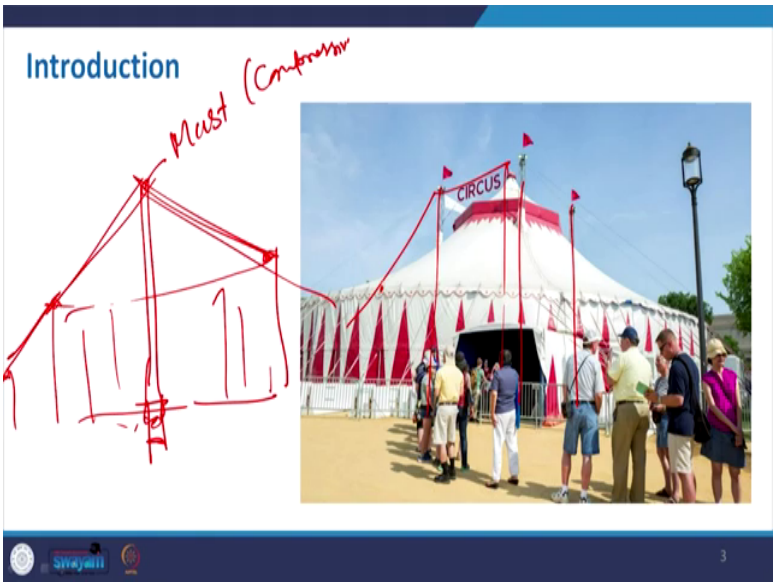

Now, to make it more simple this is I think all of us have some experience of you know watching circles and all and we know the tent. So, how it is been formulated if I want to make a cross section of that, so there must be a single compressive mast that when we discussed about the tensile structure that there will be some mast which is basically your compressive mast which is anchored, to the ground.

And then from there different cables are being placed and this particular cloth, here the cloth is referred as the membrane or fabric that being given the tension and form being created. So, you do not require any other vertical support here. So, the stain like structure is a tensile structure and the membrane we use we can create the form. So, this is a very good example, the way I thought and I should show it to you, so that you can easily correlate with this example and the concept of fabric structure.

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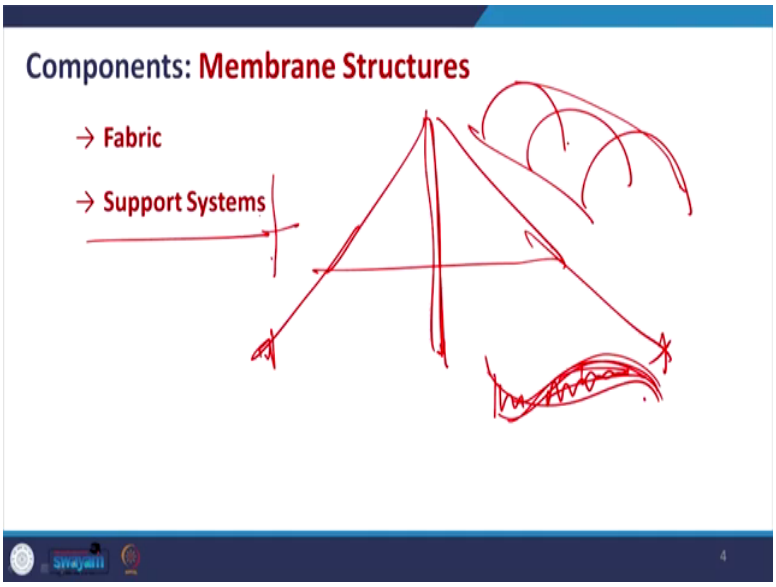

Now, coming to the component as I already mentioned overall fabric structure or membrane structure is the one and one of the component is your membrane, very thin like material and which the membrane normally being used in the biology where the tissue and cells being discussed. So, like that here also it is very thin cloth like material and then the other component is your support system.

Now, in the support system it may be of a single mast, it may be just the tension cable like we have seen the earlier example. Like here along with the mast here we have the 4 mast if you just can see through. So, we have this post and we also have a central post and then this is given tension to the all cable. So, this particular formation, this kind of in internal volume form being created, so that it can help us for solving the purpose of creating this circus tent and all.

Now, coming to the support system. There are different kind of support system. It may be just you know with the mast support only with a single mast we just anchored this particular membrane to the ground. This can be one option. It may be not a single mast, it may be with a particular arch form. So, we create multiple arch to create a tunnel and then we just cover with the membrane. So, this is one kind of form where we can use the arch or sometimes instead of a single arch we can also go for the space frame.

So, the last discussion in the previous lecture when we discussed about the space frame. So, spatial space frame where we have seen some kind of curvature like this where you know different members they create the space frame and not in a particular shape, but with a dynamic shape and then we can cover it with a thin membrane. So, then it will become a membrane structure as well as the space frame structure and the space frame will act as a supporting system to that. So, we will have some more slides on this. Will, I will come to that.

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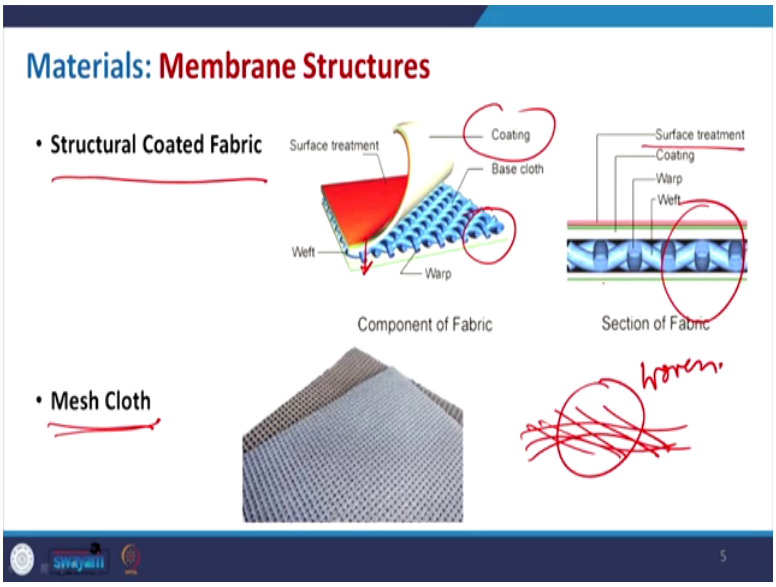

Now, coming to the membrane. So, broadly we can if we can classify them. So, it has two category, category number one is your structural coated fabric and the other one is your mesh cloth. So, what exactly they are? So, structural coated fabric is again it is having the mesh. If you see this is a typical cross section of that particular image, where you know this is basically the vertical and horizontal like your two way x and y direction the fabric are they are actually like make this arrangement and this woven form is then protected with a structural code.

So, in this case the base cloth is similar, but in order to increase the strength of that the coating being provided. So, different layer of coating may be provided to have better insulation, to have better thermal resistance because as we use this as for the exterior, so it will get exposed to the rain, it will expose to the snow in the context where like snow fall is there and also with the extreme heat.

So, rainfall then the you know heat from the sun and as well as the wind and other things. So, your structure your member should get a protection and for this will get some help from this different level of coating. So, the top layer is the surface treatment which will help to make this intact. Compared to that the mesh cloth is just this inter part. So, they are interlinked. So, interlacing they are like forming these interlacing form, so they tangle with each other and that will give some kind of steepness to the membrane.

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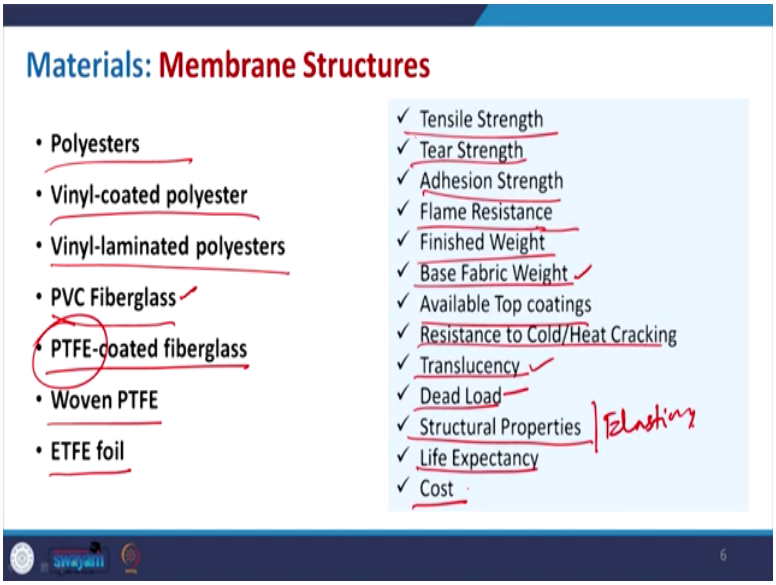

Moving forward the available materials in the market. So, we have polyester, we have vinyl-coated polyester which is better than the normal one, then vinyl-laminated polyester, PVC fiberglass that can also get a paint and it is useful. Now, these are the materials the woven PTFE or ETFE they are really being helpful. Now, what exactly the PTFE? That is your poly tetrafluoroethylene. So, this is the full name of that. So, these are having better

response towards like extreme variation of the weather and all. So, these are very useful material having better resistance again the heat and cold breaking and all.

So, looking at the material. So, normally we should focus on certain criteria to select a material for fabric tensile structure or membrane tensile structure. So, what are those points? These are listed here. So, we will first see that the tensile strength which is the base or the backbone of this kind of structure. As I mentioned that this is stable you know they get stability due to proper tensioning.

So, the tensile strength to be measured then the tear strength is also important because when you put the tension and all, there will be lateral movement, there will be some you know force acting from the top. So, due to that what will be the strain that the that will tear the membrane so we have to check that threshold whether it is with the permissible limit it or not.

Then also, the addition strength to be measured the flame resistance is one of the important criteria as because these are normally being used in public gathering to make a convention hall, maybe a you know circus tent and all. So, for extreme heat or due to some you know fire case how this will help or how it will resist against those odds that should you know taken into consideration, should be taken into consideration.

Now, the weight this is very important. Like, if you use only the mesh cloth or you use mesh cloth and then the structural coatings, so finish weight that is this like yourself weight of the membrane that also need to be considered as because we are not giving much support, so it should not be too heavy, so that it will sag or not giving the satisfactory result.

Then the base fabric weight is exactly like where you do not add any coat, then what is the weight of that you know per square feet or something like that in the unit. Then available top coating, whether the fabric that you sell it can be coated with something or no it is not convertible with any coating, so you should just use it for the purpose. So, that flexibility we have to check.

That resistance to the cold and heat cracking is another important parameter. So, cold is for the cold region and heat. So, expansion and contraction, so these to be taken care of while selecting a material for the membrane. Then translucency is another parameter because most of the cases we use it to welcome the diffused light like you will not get the radiation, but definitely with the translucency you can maximize the daylight use to the interior space.

So, we should also look for such kind material, like when this translucency is available. Then the date load definitely this is overall the load that being imposed the self weight. So, that should be minimum was without compromising the resistance of stability. Now, the other structural property like how it will expand do when we apply the tension, the elasticity of that material is another important component to that.

Now, the life expectancy is also you need to consider because when you invest though that these are the favorites or maybe the cost of construction is comparatively cheaper than the wall construction or the roof construction, but then also it will not sustain for a longer duration unless otherwise it is maintained periodically or maybe it is very well coated with some structural fabric or something.

Then, it will extend the lifespan of this and the cost. Any implication anything you go and purchase from the market, costs definitely will play a crucial role that whatever the available options to you which one will be cheaper and also satisfying most of the criteria probably you will go for that kind of material.

So, in your in my left hand side towards like this what we have the right hand side of your slide you have all these available materials and the left hand side of the slide you have all the criteria which you should look for selecting a membrane materials for the structure. Now, move ahead. As we discussed the two components are very important for the membrane structures.

So, one is your fabric that we discuss, the type of materials, the coated structurally coated materials or the mesh cloth and then we discussed about the available materials, then they are

deciding decision criteria and other thing how to select them. Now, move on to the second part that is the support. Depending on the support we can categorize these fabrics tensile structure or the membrane structure into 5 categories.

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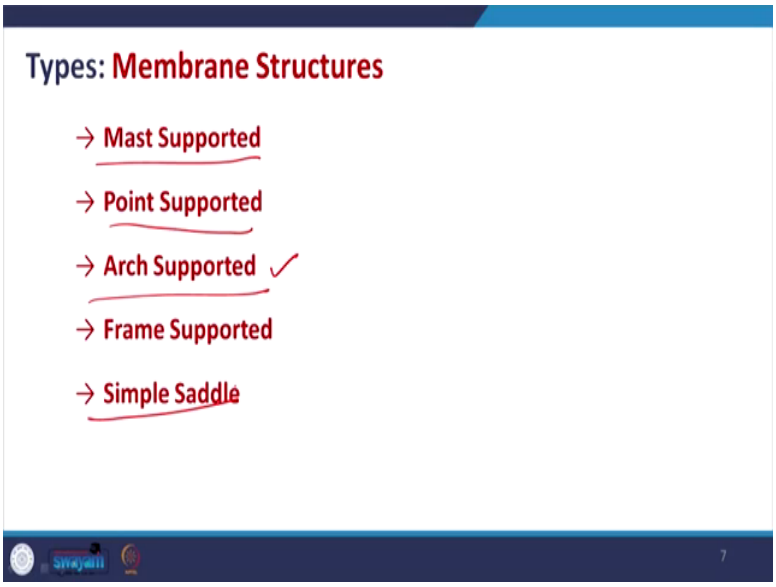

So, one is your mast supported. I just have tried to draw something to explain you like with the circus tent. The second one is the point supported structure where there is not a single mast, but with the tension cables so we can create different point and we support the structure, not with the mast. Then the arch support is in state of a mast we provide different arches made of say some wood or maybe in any material we form the arch and then we cover up with the membrane that is possible.

So, that is into the category of the arch supported. Frame supported is basically we referred to the any frame. We can make the rectangular frame or something or space frame and then we

use the membrane, so that it will be in this category. And then other point is the simple saddle where the multiple points are required to give the stability. So, to understand it better let us go through the examples.

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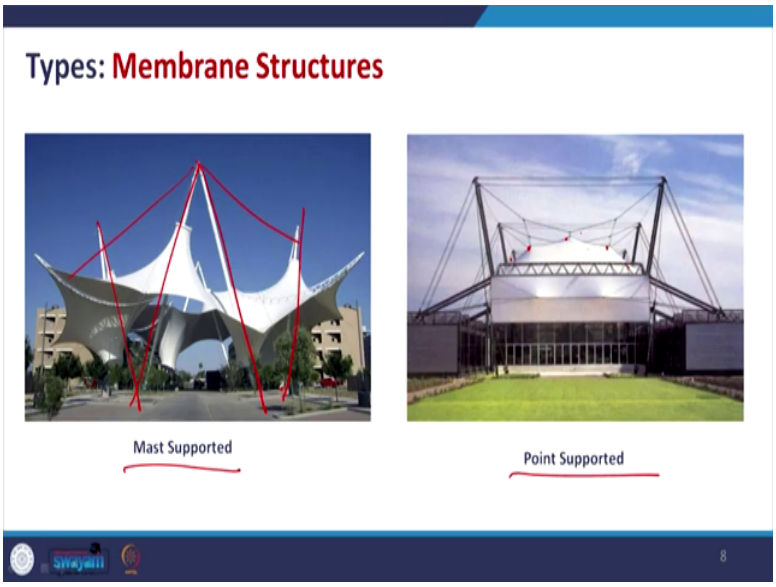

Coming to the first point that this example is very common and I think now you are familiar with this image that is something from the Arizona state university and campus. So, there you can see the membrane and the mast, ok. So, this comprehensive mast being placed and this is actually grounded. Well, and then remaining part is basically the cable. In this image if you see carefully, so very very you know thin cable they are actually making those membrane stable with a minimum mast and all. So, this is mast supported.

Now, coming to the point supported here you cannot see at the middle there is any you know mast in the middle like this. So, you have the support at the end and then from there the

different cables they are creating the point. So, due to that; due to that due to that combination you can get different points and that is giving a form of a dome, whatever the desired shape that we are looking for membrane structure.

So, this is again some different arrangement, this is point supported. And the main difference here that if you see that the mast is placed at the center. We are getting this conical shape, and we can also say that this being similar to the circus tent that I have shown you and here there is no such mast. So, we have the support at the end which is not a part of this you know the volume and then from there through cable. We are creating some tension points and we just hold the structure. We give the shape of the fabric structure. So, this is the second category.

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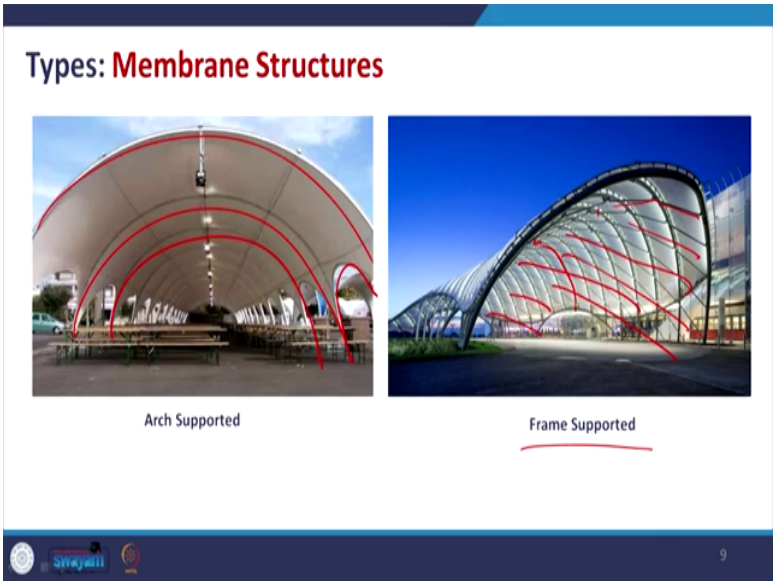

Move with that this is very clear that here you can identify that different arches being placed and then we just use the membrane to cover it up. And here you can see that to create the

opening, lateral opening, so the membrane is cut in such a manner. So, it is creating a vault, barrel vault kind of form in this. So, this is arch supported.

Now, coming to the frame supported. It is again arch form, but here you can see that they are creating different you know structural greed in this and here also you can if you zoom it out, if you see that it is not a single arch form. So, here frame being used to create the overall volume and this cloth or membrane is being you know attached for creating the overall fabric structure. So, this is frame supported membrane structure.

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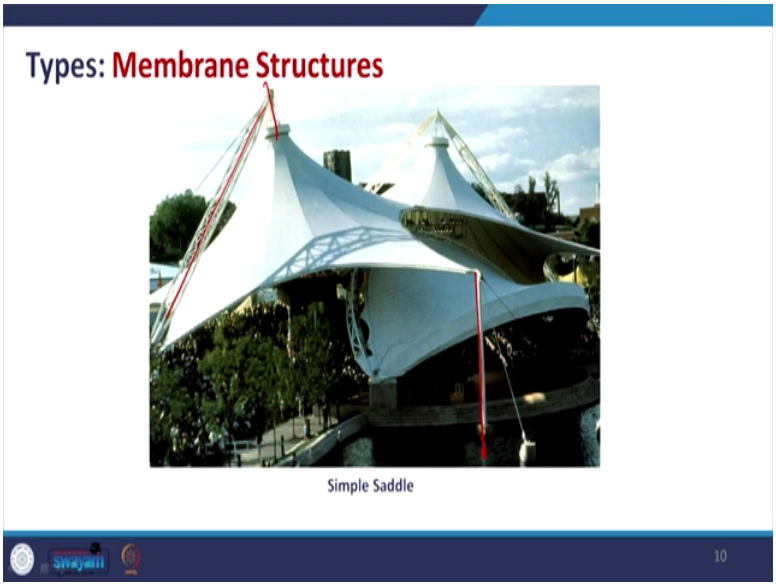

Coming to the simple saddle. Here you can see that we have the mast, we have other support and in order to make the continuative between two curves and all, so there are some angular support as well. So, this is the category of simple saddle.

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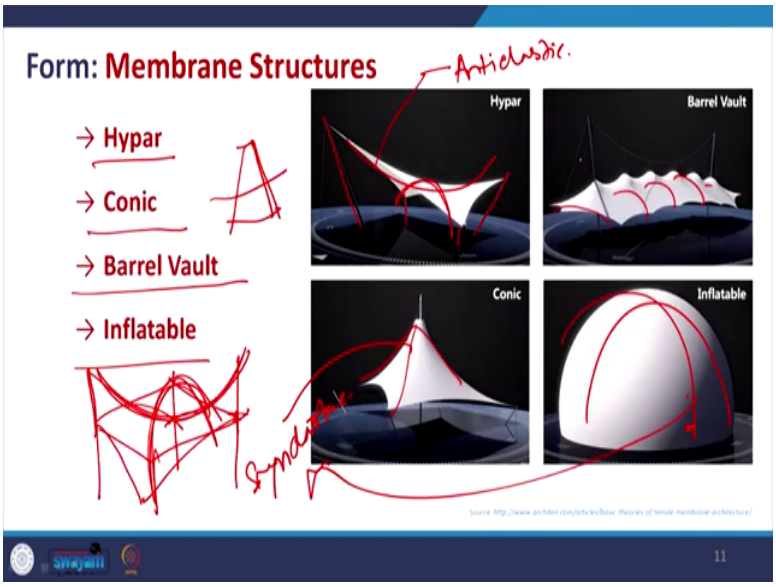

Now, in this case if we see by the form like how we can make some classification of the membrane structure in terms of form. So, we have 4 defined category. So, out of that like first one is your hypar, then the conic, barrel vault and inflatable. So, before we discuss in detail each of them, this is something like summary of all this type.

So, first with the hypar. Hypar is basically we can say that when like the support are being placed in different height and then we give different tension to the different you know portion of the cloth or the membrane or the fabric and we create a form of say hyperbola or hyperbolic paraboloid something like that. So, that is basically leading towards some anticlastic formation. So, what exactly?

So, here the example if you see that this is a piece of membrane this white color being supported with 4 different support, but they are first of all inclined and second they are having

different height. So, here you can get this length, here you can get this length. So, these are not uniform. If they are uniform so that means, they are basically creating this kind of structure. So, all heights of the; heights of the supports are at the same level.

So, we get a very simple form where it is very flat. But at the same time the moment I reduce it, so it will try to bend here, the opposite side it will try to bend here, but at the same time this will try to hold it at the original position. So, that will create a curve. And when you increase the height farther, so that will create a curvature in this direction and this will create the curvature in the opposite direction. So, here also if I want to draw, so one curvature is in this direction, the other is in the opposite direction.

So, now, I think you can understand what kind of curvature it is. Can you guess? it is, you are right. That, this is basically your anticlastic curvature which we have discussed during you know our earlier discussion where we discussed about you know the form, the sale structure. Now, coming to the conic. So, conic you just try to recall it by the example of cone. So, cone is some form like this and then you just cut a portion of that will be the conical. And in this case this is the example, now you see that the curvature is in the similar direction. So, here it will be your synclastic, right.

Barrel vault is basically the barrel form of that when you can see that multiple such arrangement together is creating a vault kind of form, then we refer it is the vault you know barrel vault membrane structure. The last but not the least, the inflatables one where again it is having the similar curvature all the all through, so this is again this is example of your synclastic curvature and mostly it is inflatable in terms because this is full of air.

So, this form being created through pressure difference. So, we add something. Like, if you blow a balloon then it will give a form and that will balance the you know exterior pressure and the interior pressure, and that will get some stability. And we will have discussion the next upcoming lecture we will be discussing thoroughly on the pneumatic structure where we will discuss this inflatable option once again. So, let us just understand. If you will to go to example, I just want to clean like give clarity to the definition of synclastic and anticlastic.

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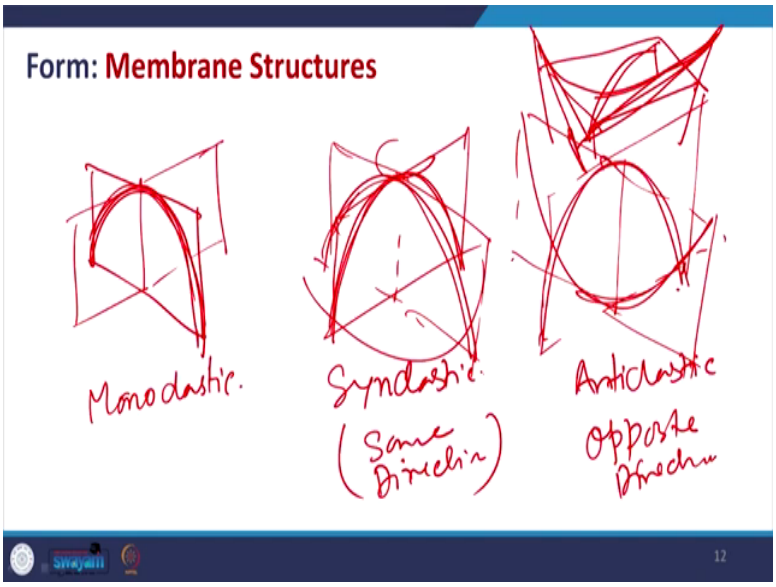

So, when you have two surfaces, and you have a curvature, in one direction only one direction. Though this is intersection, so this is basically the curvature, this is basically your monoclastic. Now, I draw it again. Now, you have a curvature for this surface as well as this surface. So, in both the cases if you see that the curvature is in the similar direction and then if you just multiply the plane users revolve this plane. So, what you will get? You get a form of a dome, right.

You may not get a dome, but you can get something of dome like. So, this is basically having the similar. So, this is your synclastic curvatures. So, same direction with two surfaces. Now, contradictory to that if I draw it again, so I have one curvature like this direction and the other curvature of this direction. So, they are conflicting each other, so then it is basically opposite direction. It is called anti; anti means opposite, so anticlastic.

So, we have to remember this term very carefully because these being used in the cell structure, this is being used in other kind of formation where this curvature is concerned to give the form overall form of the structure. So, like this if we take a piece of cloth and we put some low end support and then we put some high end support here and we just try to pin up, so basically that will give a shape and this will try to give a shape. So, we get a shape like this. The way we have seen here will get the shape of this hypar.

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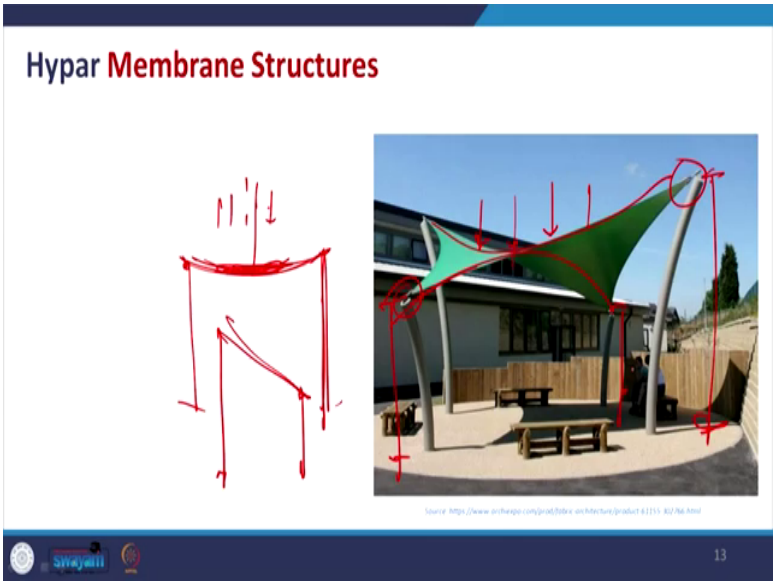

Now, move to the example of hypar. It is the same you can understand that why this curvature can be created. So, you get a clean curvature here and also get a curvature here they are opposite direction because the height they are placed, their inclination, their height, they are different, they are not same. If they are equal, so they will give a plane surface. So, this is the

criteria to create this shape. So, this looks very pleasant, it is typically pleasant, but along with that it will be very helpful to create the curvature.

If it would be flat then there will be formation like when there will be the heavy rainfall and all, so there may be a little sag. And then suppose many a times we have seen it like for a market or so, that you just make it with the polythene, without any slope the both the height are same. So, during rainfall and other thing, so whatever is basically accumulated here and that sag. So, it is not really welcoming.

In state of that if you have a high ride and the lower height, so you create the slope, you can drain out. And here the thing is you create the curvature both the direction, so the load applied on this due to this snow and all that can be easily distributed, they can easily drain off and that can be easily distributed. So, this is very you know good application of the tensile structure along with the membrane and the structure is very simple. Like if you want to just make it for the installation you can simply use such kind of cloth which can be little expanded due to this tension and all and can get this kind of shade or [FL] we can refer.

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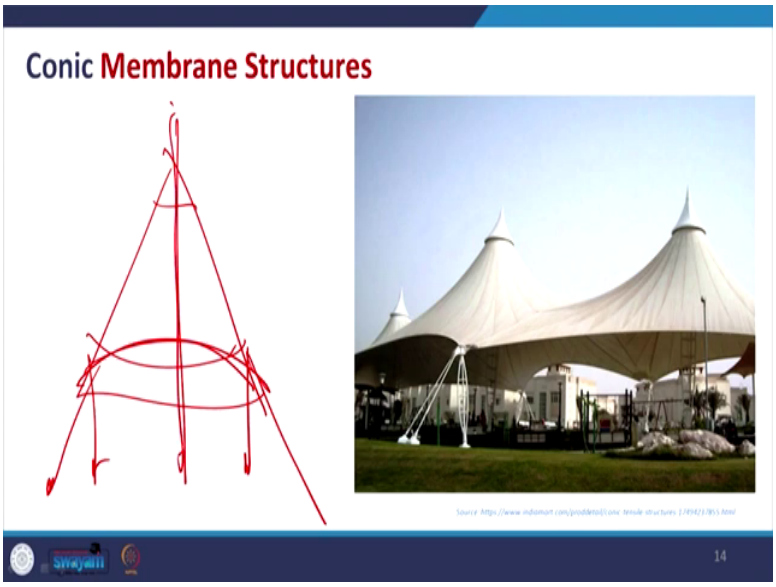

Now, coming to the conic membrane structure, this is the similar like a cone maybe the truncated cone, so this form being created. And in order to put the tension, so we create the support from the bottom and these are the post. So, this we create. And the central point definitely in order to give this shape you have a mast. So, mast support is most of the examples that we can get from the mast support fabric structure these are the conic.

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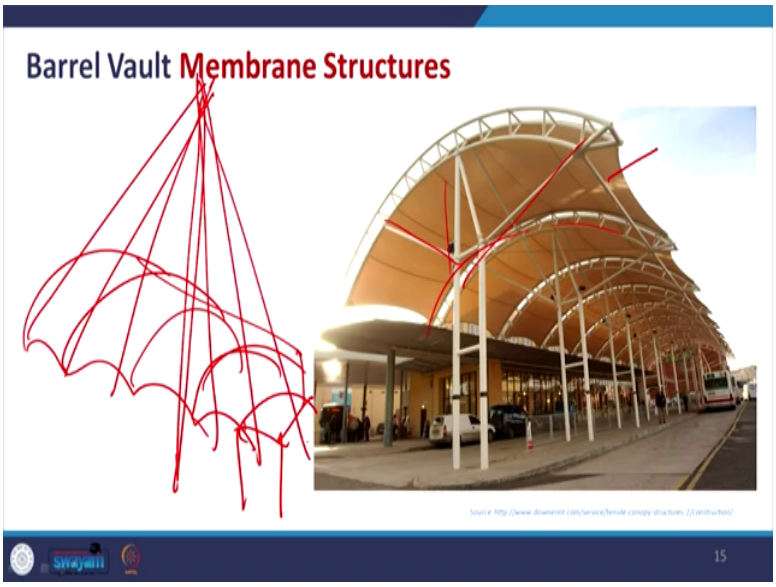

Coming to the barrel vault, I have shown there one example and here it is another. This is normally being used for a parking. Here it is in the case of the parking bay of this you know the bus and all. This is the waiting area. So, a regular formation of this arch which is very symmetrical, they being repeated and to provide the shade and all some fabric being used.

So, basically this is something like this that being created, very uniformly and these are the form. So, you can get any form of that. We do not require mast to support it, we can also sometimes have a centralized mast and then we can support it with the tension cable. So, this is also possible.

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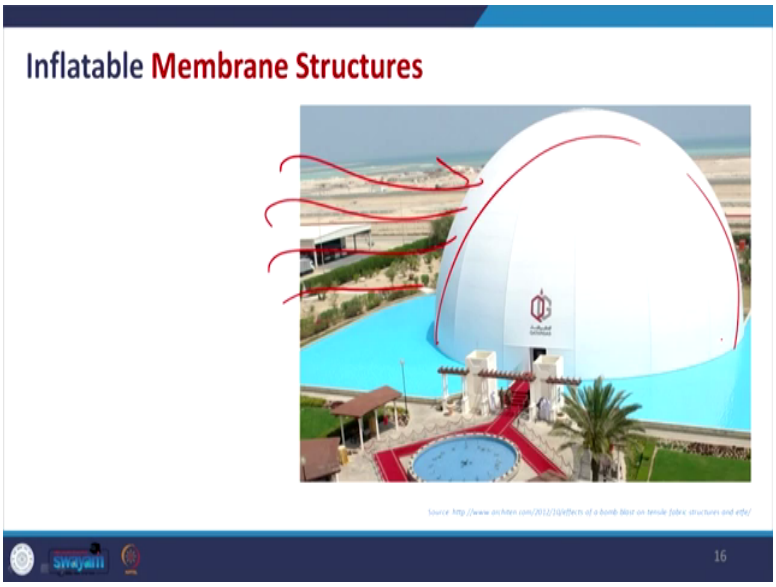

Coming to the last category the inflatable where the structure being made with the help of air to give the form. So, initial form being made and then we inject air to maintain the shape. So, this is also very important structure to create temporary. And the main advantage of this kind of structure is the moment the purpose is solved, if you want to dismantle its very easy you remove the air, you can fold it, it we can easily transport to the other place.

It is not very much permanent or heavy as because the light structure the only disadvantage that we may have like due to heavy wind, so this may differ some of the you know its initial form. So, the interior fitting of the lighting and all that we need to take care of.

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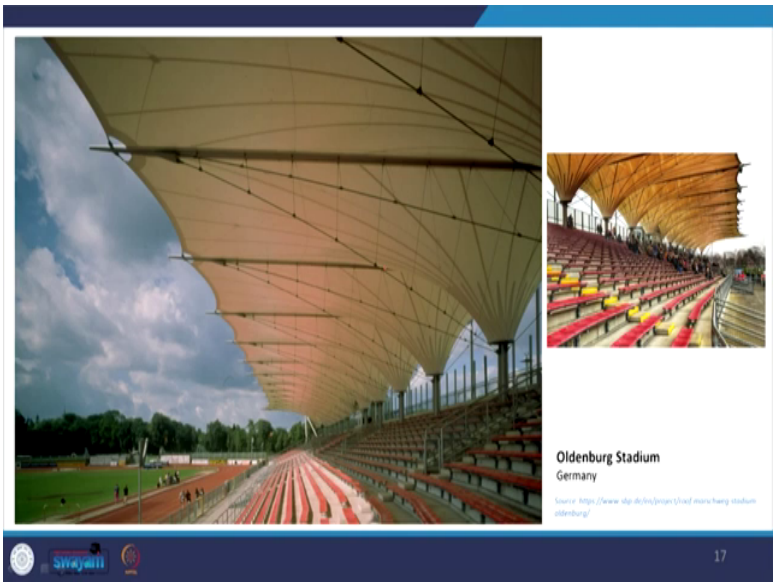

So, coming to some examples, this is mostly being used for the sports stadium or the roof of the post sports stadium. So, here the stars being used and the membrane is being used to cover it up.

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This is example from Germany. This again I am repeating this example in different context, and here today it is just because to show you this use of your membrane and the tension members to create this beautiful form and architecture.

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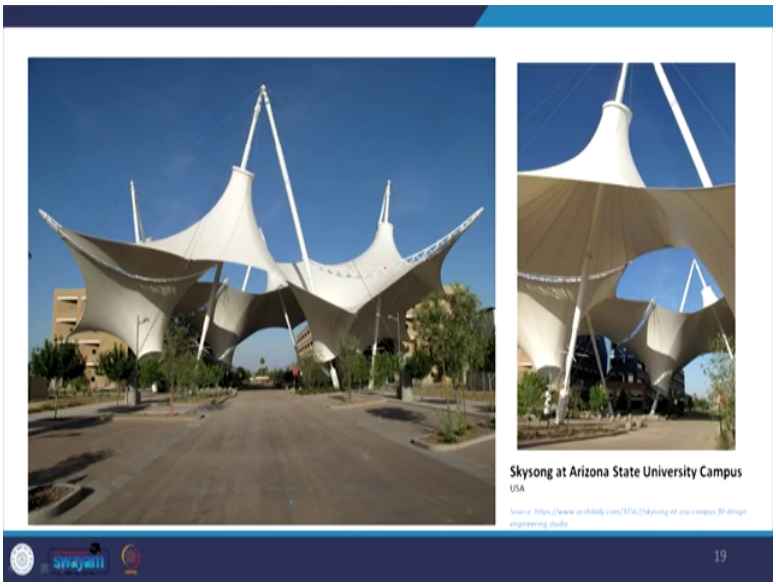

There it is again from the Arizona State University that I have depicted there. So, central mast and the support.

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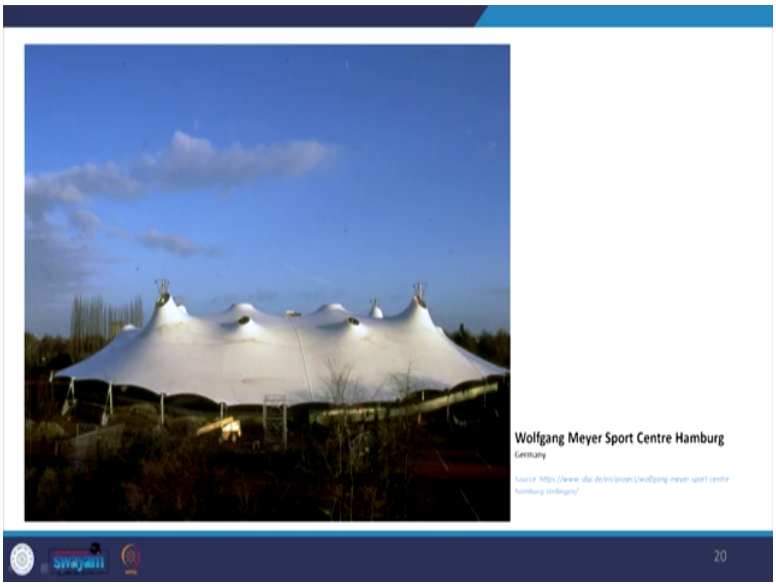

Now, this is again a sports center. And here you can see that the conic form being created the overall dome being created and these are getting the supported. So, you have a like surface and you just spoke somewhere. Sometimes you may use it to get some puncture like to give some area to welcome the light inside.

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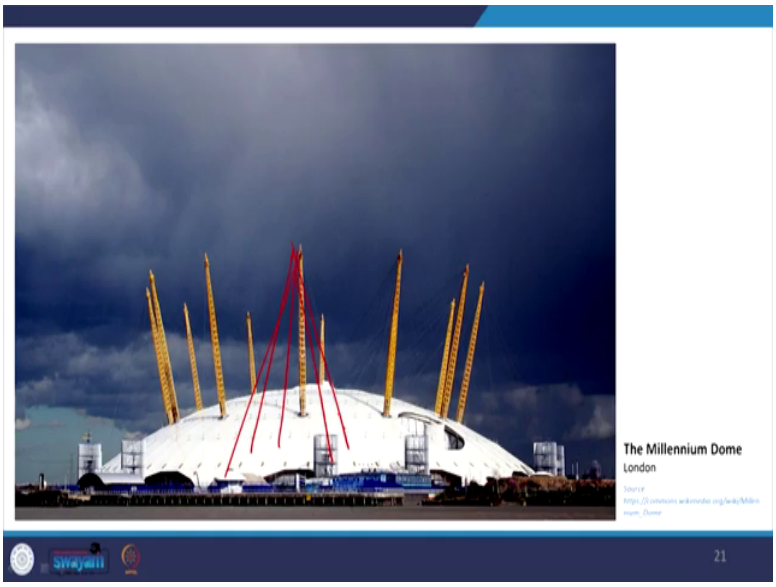

So, this is another example. This is the million dome. You can see that how beautiful it is the huge dome being created and strategically by calculation definitely, this mast are provided and the whole surface is being supported with some tension. So, this is holding the overall form, so that you can minimize the number of support inside and we can have the columnless space.

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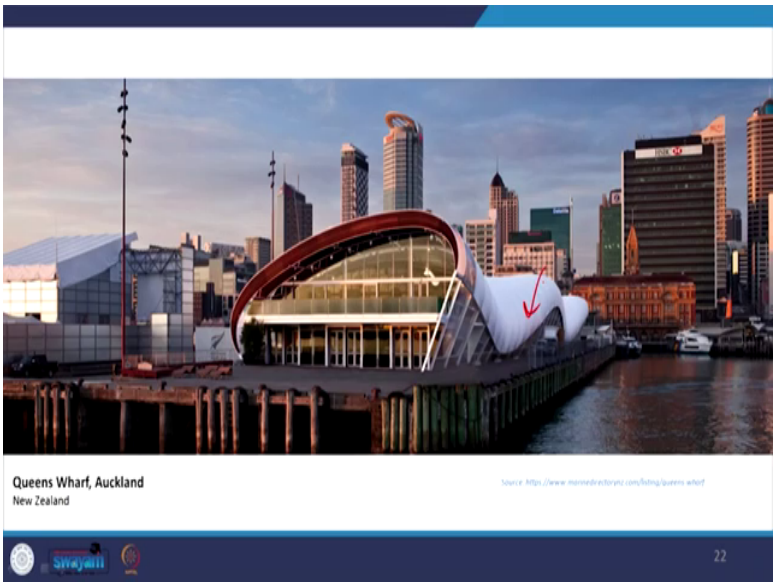

This is another example of a port fair is being created and you the use of the fabric is also shown here.

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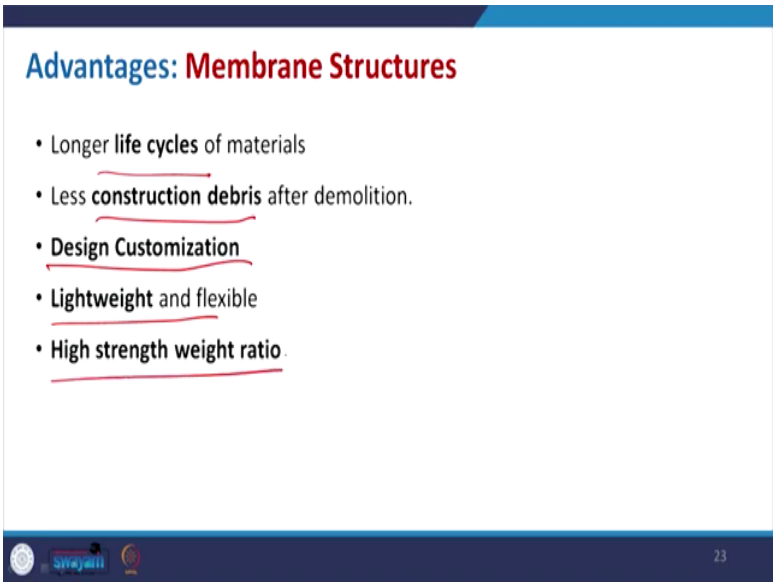

So, coming to the advantages. It has advantages considering and the longer life cycle because like you can you know just dismantle it quickly and you can transport it, less construction debris because it is nothing to like break and so you can dismantle is easily, and whenever you require you just go and you know plug and play kind of concept.

Design customization is also there, you can design about different you know angle, different direction, different curvature and that is possible with this lightweight and very flexible to use that already mentioned. High strength to weight ratio comparing the weight of the membrane which is very less, but that can also get a good you know strength. And when you use the membrane which is structurally coated this will again be higher than the normal one.

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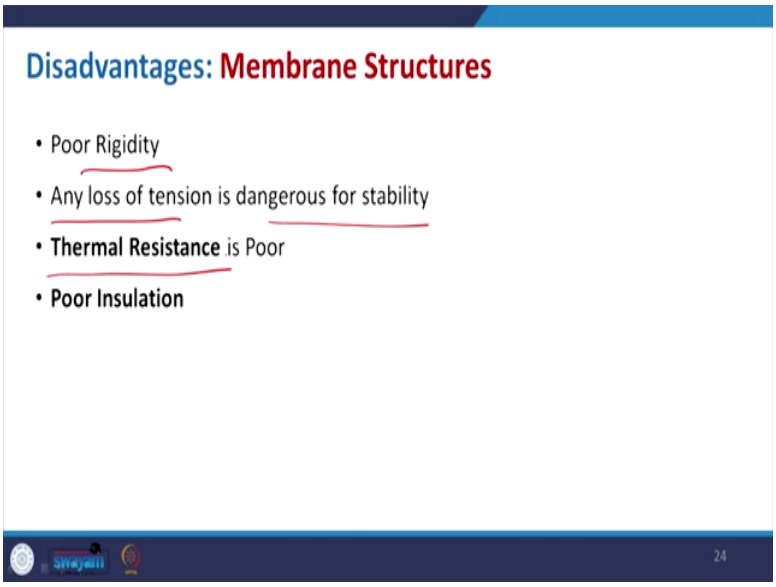

Now, along with these advantages there are few disadvantages that I mentioned that the poor rigidity. When there is a high wind blow or something, so it cannot perform well then any loss of tension as because the tension is the main fundamental to give the shape. So, if there is any damage to any part of that, so the whole structure will collapse within a few seconds or something. So, this is one of the criteria which we need to take care of this is not exactly the disadvantage, but yes, we have to take proper care of that when we execute it.

Thermal resistance is poor as because of the team member, so there is problems. So, proper HBSC system to be adopted for better result. Now, poor insulation again due to the thin one. So, but now for the coating and other thing in recent time, if you use this your you know poly tetrafluoroethylene kind of material or some coated material, so this insulation can be improved.

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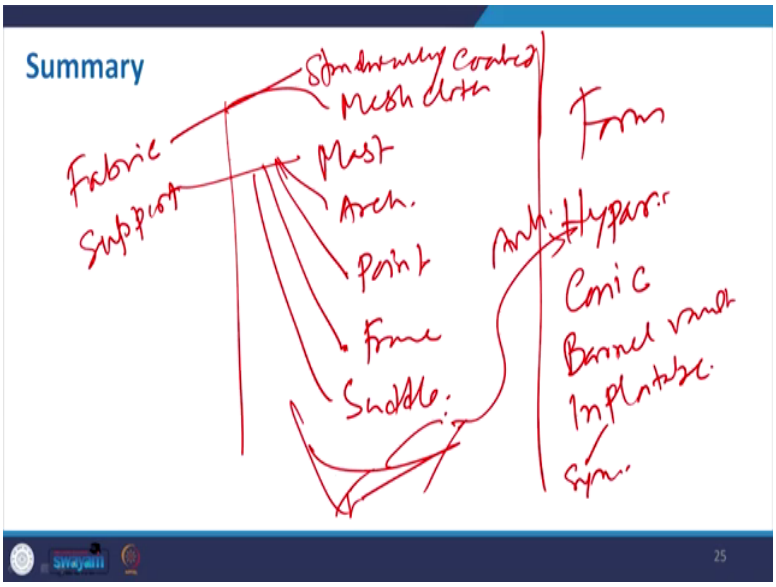

So, with this like we complete this section. So, here basically if we summarize quickly, so two members, one is your fabric and then we have support, right. In fabric we have discussed that you know structurally coated and then you have your mesh cloth and there are different list of a figure and how like we decide those different criteria to select it. In the support, it may be of mast supported, it may be of arch supported, it may be of point supported, it may be of your frame supported or maybe it is saddle, ok.

And regarding the form of that what we discussed, one is your hypar, second we discussed about the conic, third one that we discussed about the barrel vault and last but not the least is your inflatable structure. So, air inflatable is basically your synclastic curvature and hypar is basically where you have this kind of member. So, you get the anticlastic curvature.

So, the advantage is definitely it can cover the last band with the minimum weight, minimum investment, but there are problems with like having poor resistance to the heavy wind and other thing that we need to take care of that. With that I conclude here. These are the some reference like you can go through and you can get some insight to this topic. And also you can go through the link I have provided with that this lecture end here.

So, upcoming lecture will be discussing on the pneumatic structure that is something we discussed the inflatable structure. So, we will discuss more on that. So, this is a end of this lecture. Thank you so much for taking part into this course and we will meet you soon.

Thank you.