Structure, Form, and Architecture: The Synergy

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Lecture - 26
Shell Structures

Hello everyone, welcome back again to online NPTEL course on Structure, Form, and Architecture. Today, we are at lecture number 26 and it is all about the Shell Structures. In previous lecture 25, we have seen the advantages of grid structure over the large span and how it can be used and for different decoration purpose as well as to you know give large span support without any abstraction.

So, similarly the shell structure is having much advantage for this large span again. And, with this it is similar to the previous one, but definitely the form will make by curvature. So, we will discuss various issues on shell structures, we will discuss different types of curvature and also some applications with some examples. So, let us start it.

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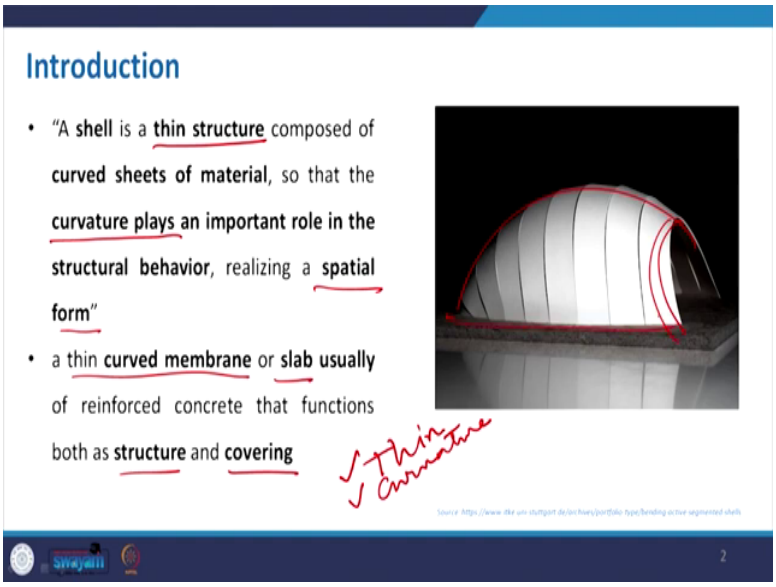

So, if you see the definition of shell structures from different sources it says, a shell is a thin structure composed of curves sheets or material, so that the curvature plays an important role in the structural behavior, realizing a spatial form. So, basically two important terms that, we should see; one is very thin structure is one right; the second is your curvature.

Now, looking back another definition, another explanation of this structure, where it say, a thin curved membrane or slab usually of reinforced concrete that functions both as structure and covering.

So, both the definitions is having similar what one is definitely thin and the other one is your curvature. So, these two will make the form which is definitely, existing as spatial form that it will make and that can be used as a cover or that can just be used as a structural member.

So, now, we proceed with that and here you can see that image where, it basically giving form of a shell. But, before we go into the engineering part of that, as I mentioned in very first lecture of this course, that whatever we design, whatever we develop the structural elements that is a very much inspired from the nature.

So, this kind of structure do exist in nature and we just take that particular form, take that particular phenomena and do some engineering to just make a prototype of that. But, before we discuss that natural you know shells and from where we are inspired, let us also know the transfer of the load.

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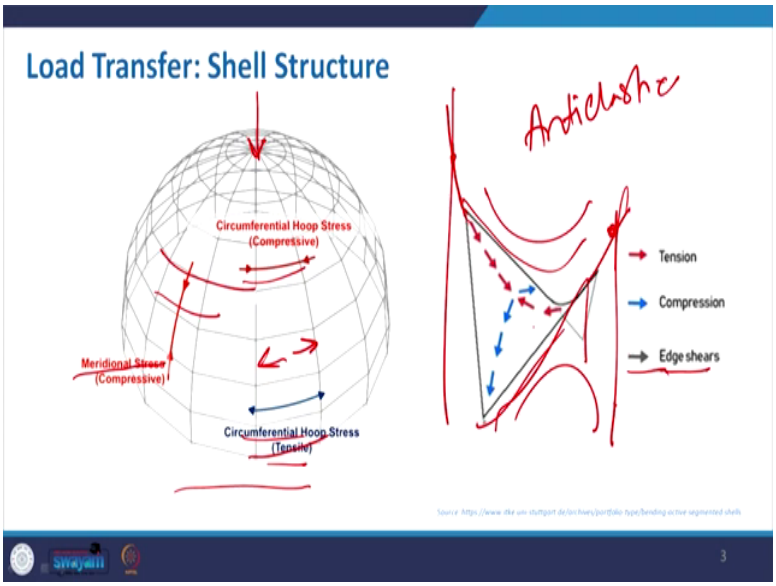

It is pretty similar these diagram is actually a common to you now, because I have given these in a the you know, that presentation where we covered dome structure. So, similarly here we will not go by the form of the dome, because the curvature in one case can make dome, in one

case it may you know just develop and arch sometimes may be a bolt, sometimes even making some structure like this, which is basically anticlastic curvatures. So, we will come to that what is anticlastic, what is other type of curvature, but this kind of form being created.

Now, in this case definitely the compression you can get for the circumferential hoop stress and then what we have in the meridional Stress, which is again the compressive where it can you can get this members how they are you know pressing to close to each other. Now, if I put pressure on top of it and try to just match it to the ground. So, this will act like this.

So, this will be in compression, but the lower fiver where the circumferential hoops at the lower part of the dome, it is having tension. They will try to grow go you know away from each other. So, this is why here the tension being developed.

Now, in this case where the two curvature you can see one curvature in this direction, the other curvature in the other direction. And, that is why it is called Anticlastic, where both are of the similar direction we call it sinclastic.

Now, in this case if you see that, the member in this direction is in tension. So, sometimes you know we have also discussed the this point is just being supported if you consider this as membrane. So, this is being supported with the massed with the cable. So, that is tension whereas, the other will balance it with the compression.

And, also at the edge we have the shear in both direction like, you have the force and then you have the edge, shears in this structure.

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Now, as I told you that we are inspired by the natural elements which do exist in the nature and these are some of the shell structure. So, in this you can start with the egg shells or it may be the sea shells, we have nut shells and then this is something where we familiar, this is basically the coconut that particular shell.

So, you can consider the form this is nothing, but a dome you just replicate it in change the material and put concrete and reinforcement you can get it. This oval shape also you can use it with the some materials.

Now, the advantage of that in bow all the cases if you see the thickness is a very very small thickness, but it is strong enough and give a good shape or form. So, these shells are basically for those particular creatures. So, they are giving support, they are protecting them at the same time what we make for our structure, like the shell structure that is giving the protection

as well in terms of building.Now, let us go through some of the examples and just try to relate. This is one example form Sydney Opera House from Sydney Australia.

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In this case also this shell form, which is very naturally placed with the water body and all it gives us very beautiful view, but along with that also it creates nice interior. So, here it is nothing, but if you compare it with some of the shell structure, you get the similarity how it being formed?

So, the thickness if you just browse through the different construction phase photographs and all will say that is very small thickness and holds long span. Similar kind of application is also there we do not need to go abroad.

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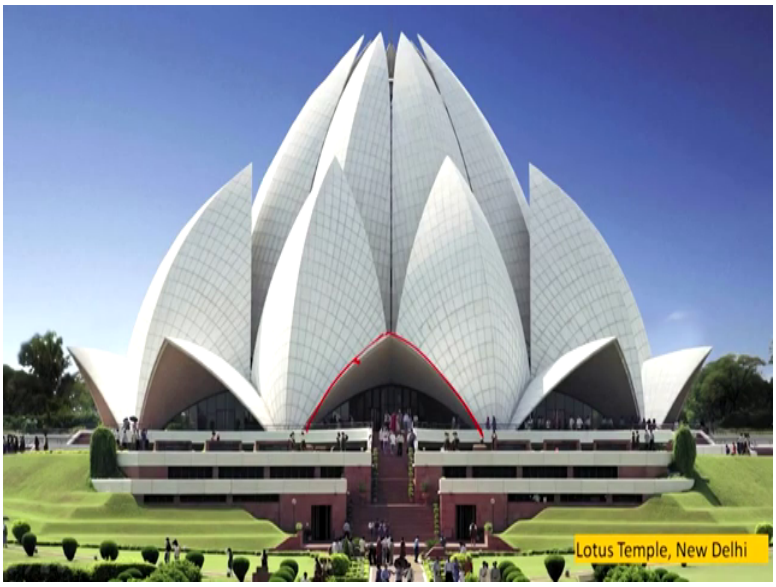

So, in India itself Bahai temple or also referred as a Lotus temple, which is giving a form of a lotus. And, here you can see the thickness and how it is being placed to you know get this span and at the center if you just visually, you know get the visual appearance or something from inside you will get the large volume light being created with this petals, which is again made of a concrete and steel.

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Now, this is one example from Spain where this is actually Oceanografic Museum or Valencia Aquarium also referred. So, here you can see the thickness. So, with this minimum thickness with the curvature proper geometry, we can get this kind of structure.

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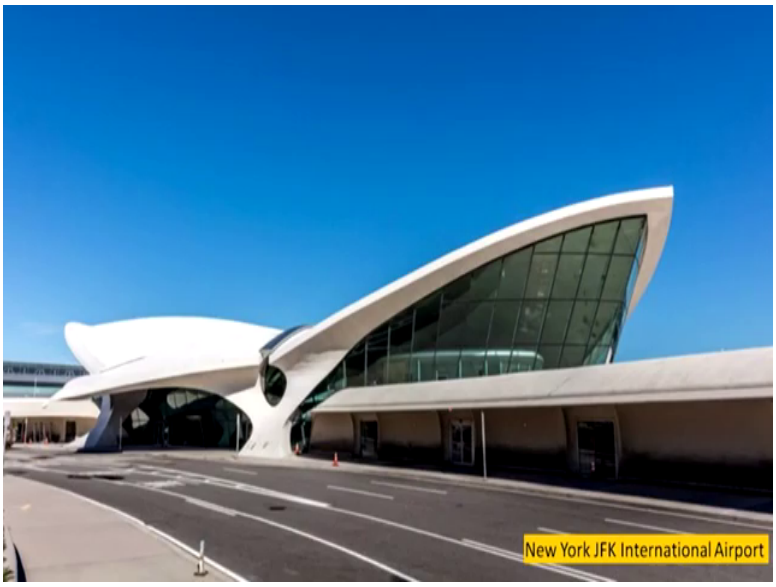

This is the example of TWA Terminal of New York, J John JFK International Airport. Again this terminal building used using the shell structure.

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This is one auditorium at MIT campus. So, here also it is something met with the shell create a huge volume inside.

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This is one example from the creation of Zaha Hadid, it is Heydar Aliyev Cultural Centre. Again here this particular thickness of the shell being used and create some very beautiful structure.

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Coming to this is something we discussed with the curve and all and here it is the folded plate structure. So, one particular lecture, I remember, I think you can also follow up that, I have shown one example with a paper like a plain paper and the folded paper.

So, the thickness of the paper is nothing when you make it flat probably, it will not hold much load, but when you make the fold. So, that is basically can able to sustain, can resist more load and that is why that is making the form of this folded plate structure.

So, this is again a shell structure. So, shell structure is not basically a form, shell structure is a very thin, it can be membrane, it can be folded, it specially being created with some curvature. So, with proper geometry we can really go for this. And, obviously, you need the materials to

support it. So, definitely with a concrete and steel you can do this kind of optimization to make more efficient shell structure.

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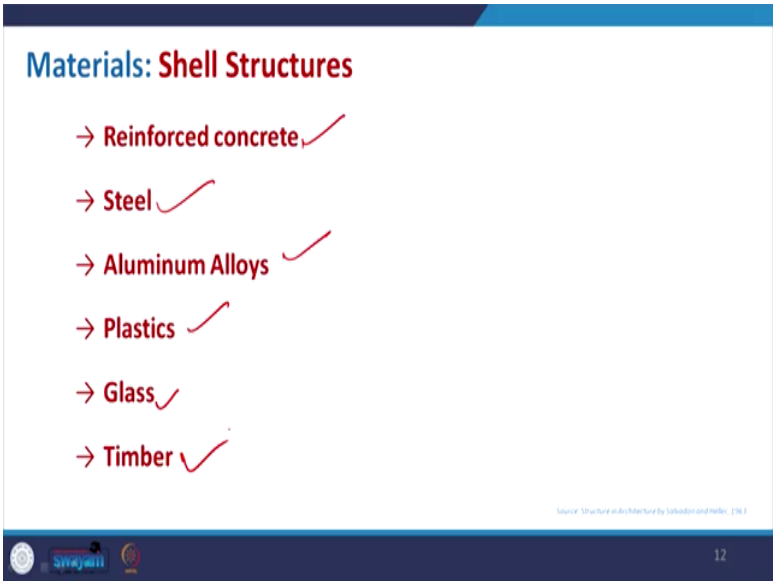

Coming to the materials, so reinforced concrete is one already mention steel can be used the steel and glass, then plastics can be used for some demonstration aluminum can be used and also timber.

So, many cases like some structure being made with the timber or proper timbering, it can give us nice result. Coming to the typology of shell structures, this is very important and we have to understand. So, one by one we will try to understand it. So, that in upcoming slide, I have not given more sketches we will try to understand with the sketch, what exactly they are.

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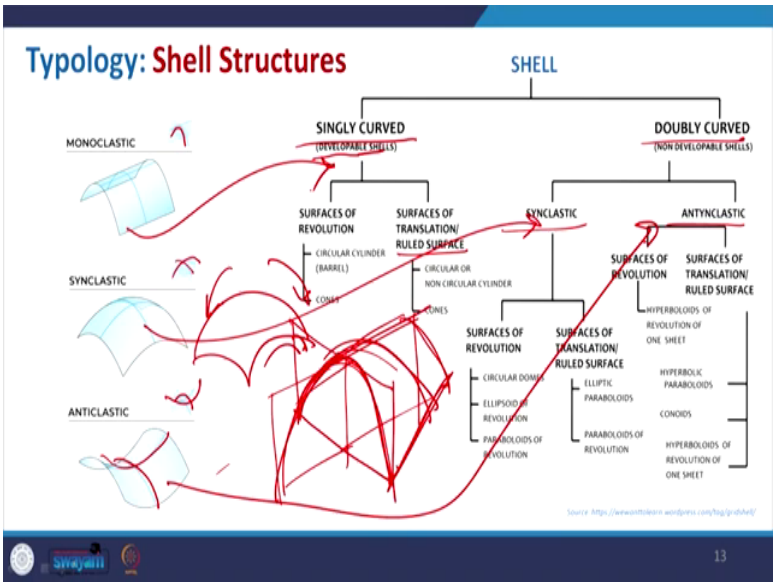

So, shell structure being divided based on the curvature; one is your single curved, one is your doubly curved. And, whenever you have single curve you have always a chance to go for development. So, developable, developable shells and un non developable shells.

So, these are two category, then on the singly curved you have the surfaces of revolution. So, with revolution like, if you have some particular profile and you just make revolve it. So, then by that what form you will get that is basically the surface of revolution.

Surface of translation or ruled surface is basically, where one surface other surface they are actually blanged they are you know merged together to form and translate from one shape to other shape. The ruled one where some kind of elements is being repeated in a particular pattern to give this.

Now, again the similar kind of thing that, we can go for doubly curve where more than two curve being used to make the shell structure. And, depending on their direction we have synclastic and anticlastic again synclastic will have similar surface is of you know revolution, and surface with the translation, and your rule surface and again this is a same category.

So, if you just follow up. So, basically based on the surfaces we have two category; one is your revolution, other is your translation or the ruled surface. But, depending on the curve again we have say, you know single double and in double you have two.

So, in this particular slide, what you can see very carefully, these are very nice illustration and it will clear the idea of your monoclastics synclastic and anticlastic. So, start with a monoclastic here you can see that two surfaces, they are crossing each other, but the form that being created only use one site.

So, basically if I try to zoom this particular part is something like that and now only this particular surface, we create a curvature. So, this is only one direction ok. And, single curve. And, now we just extend it, so, we get the form of this kind of thing. So, now, it can be of a circular for, or it can be of a elliptical, or may be hyperbola.

So, when you go for this kind of form it will essentially lead us to the Barelwald or those point it as (Refer Time: 14:41). Now, coming to the synclastic where the same example being given, now it is not only the one direction, but the other direction ok. The other direction are also they are having the curvature.

So, basically if you get this form is basically you will get this form is basically you will get something like this. So, a surface you just try to curve x direction and y direction and they are in the similar fashion. So, here if it is basically like downwards. So, anticlockwise or clockwise you take one particular direction for both the curvature. Coming to the anticlastic yes similar to the other one you have this curvature in this direction, but the other one is opposite direction.

So, in this you can get this kind of curvature, where one is your convex, one is your concave. So, in this case if they merge together they will form the anticlastic. So, this anticlastic category is coming here, cynclastic here and then this is basically singly curved. Now, but because of the formation due to the surface they are also having much classification.

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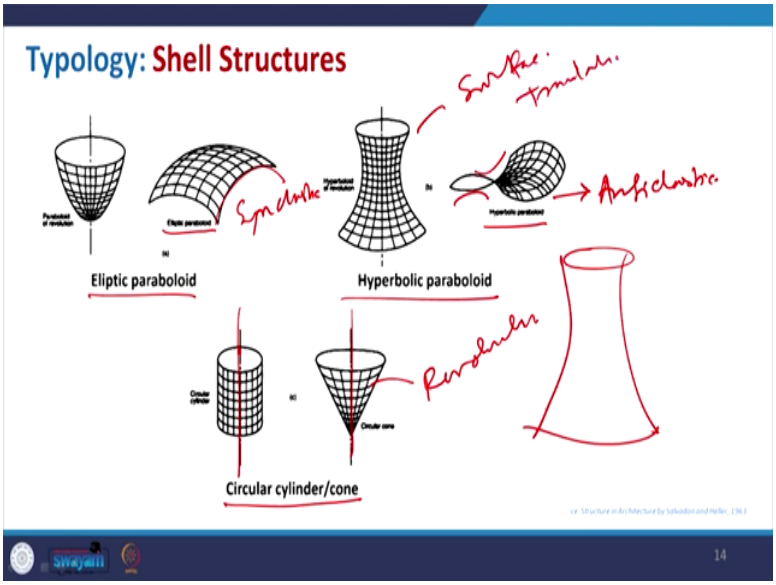

Now, here if you see the formation, where it is like elliptical or may be hyperbolic or circular. Now, circular is making of a form of cylinder or may be cone, if you just pull all this points to a particular apex it will give you.

So, hyperbola you can get this example and looking at this view ok. If, I draw this you can identify this are something very common you know for the any plant and on the cooling tower is make something like this. And, this can make a tint or something.

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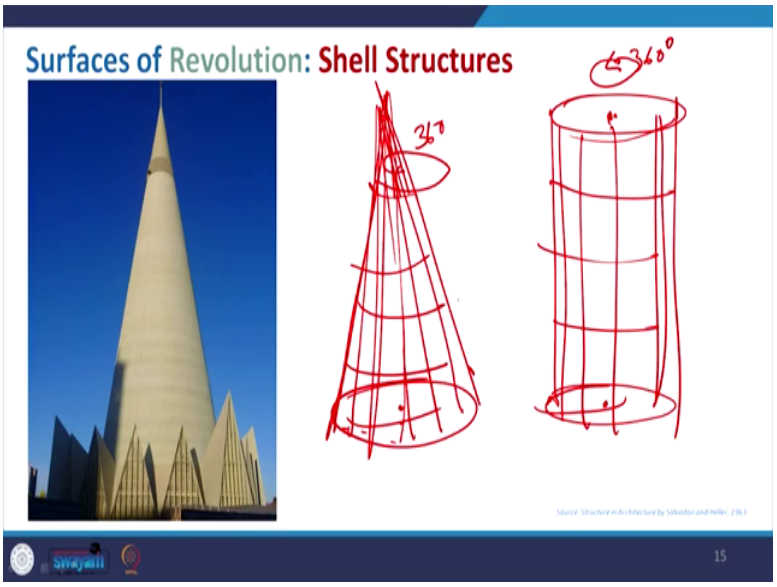

Now, coming to the surface revolution shell structure as we have seen the cone, in this case this is inverted cone, now this cone being formed. So, how it is being formed? So, you have a circular base, you have a height, then you just make a sight of the cone and then you just rotate it 360 degree ok.

So, it will give you this particular revolution and you get this form as a conical form. Now, instead of that you have a circular base, you have the similar kind of top, you just connect those and just with the reference to the center of the cylinder or the circle here, you just make a rotation not rotation is basically revolved 360 degree. So, you get a form of cylinder.

So, this are two forms and here basically we have to remember both the cases the inside is hollow. So, only we have a thickness and then we get this form.

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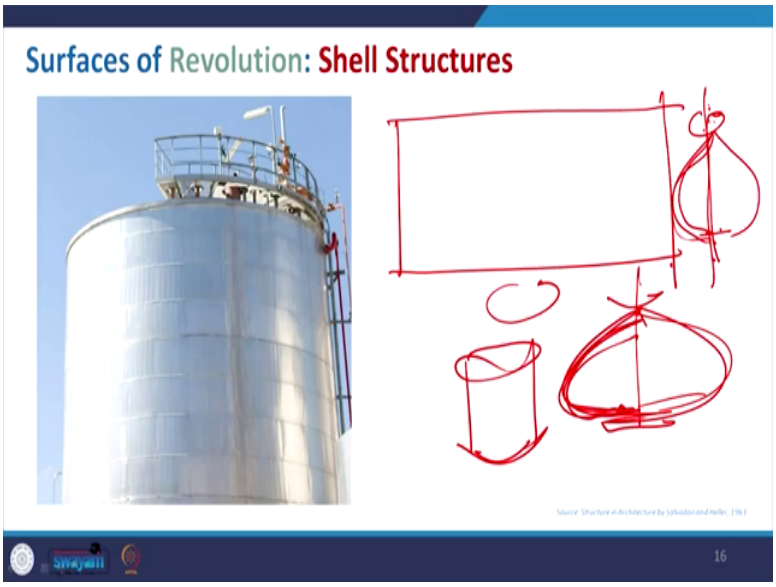

So, here this is this kind of tank being is basically, you know what we call rectangular thin sheet and that is basically rolled to get the form of this particular cylinder. So, this is surface revolution, due to revolution this kind of thing happen. Now, only I have explained it with cone and cylinder, but it may be of a different shape where like you can have some elliptical rotation ok. So, we get a surface like this and then make a rotation.

So, basically that will give this form of a dome. So, earlier in dome the lecture where we discussed dome, we discussed about the onion dome. So, that can also be formed like this. So, where this profile is very important and one axis and then the revolve of you know 360 degree will create this form.

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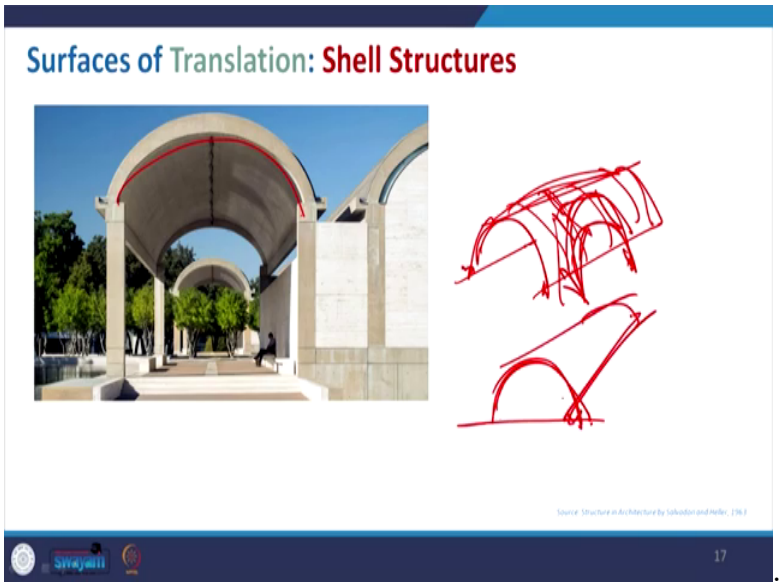

Now, coming to the Surface of Translation. So, surface of translation is basically where you get this kind of barrel what. So, you have one curvature one arch and then you extend it and create this arch form.

So, this is one translation that we can see. Now, in state of one you can have the both direction. So, then you can have your another you know kind of volt into picture. Yet this example that I have given here, this is basically creating a arch and this particular covery to the path way.

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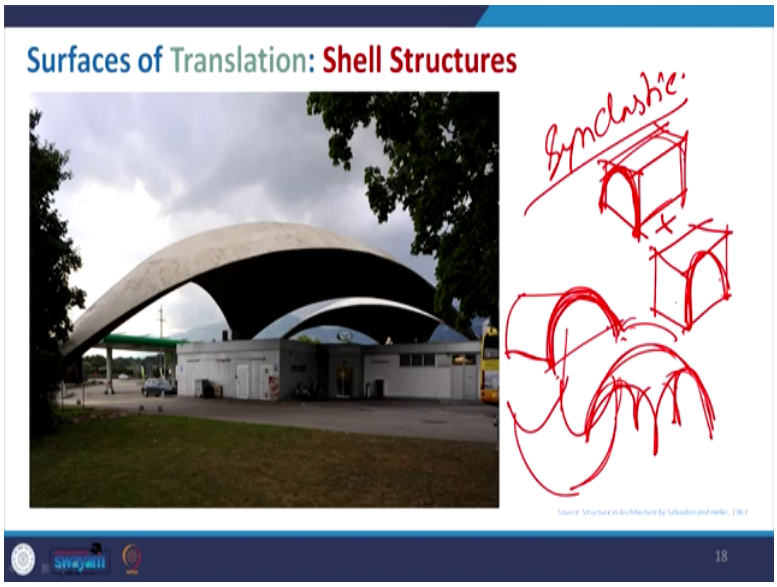

Now, coming to the translation again, where the earlier one is just the monolithic because only the curvature is in one direction and we just extend it. But, in the this example, it is basically the example of your synclastic.

So, synclastic curvature; that means, wherever you have one particular surface, one particular curvature, in one direction and the other one of the same direction. So, to make it clear to you just let me show you, how we can?

So, this is one direction for my cube and we take the similar profile and then this is another direction. Now, if you add this two, if you know add this two forms. So, this is making this valve and this is making this valve and we make the combination of that. So, that is basically

giving you the form like this. So, all this corners is visible and you get this. So, in all the cases the curvature is in the same direction, that is why it is called synclastic.

So, here it is the translation of surfaces two surfaces they are merging together. And, that can be reverse as well, so we can have surface something like this, something suspended that is also possible. So, I am showing in this direction.

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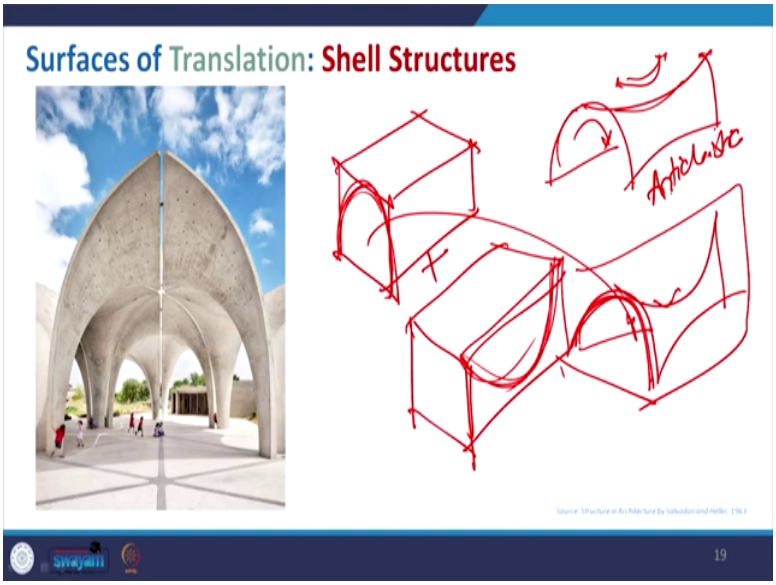

Now, in this case the curvature is something where we have to add, this is one direction ok, the other curvature is of this direction. If, you merge this so, basically that is creating a form which is something like this ok.

So, if you can just try to imagine. So, this form is like this and this curvature is followed this. So, this kind of form that the final form should look like this. So, here this is having a

curvature in this direction and here the curvature is in the opposite direction. So, we call it anticlastic curvature. So, there are many examples of anticlastic curvature, where the hyperbolic parabola being used or two parabola they merge each other in opposite direction as translation.

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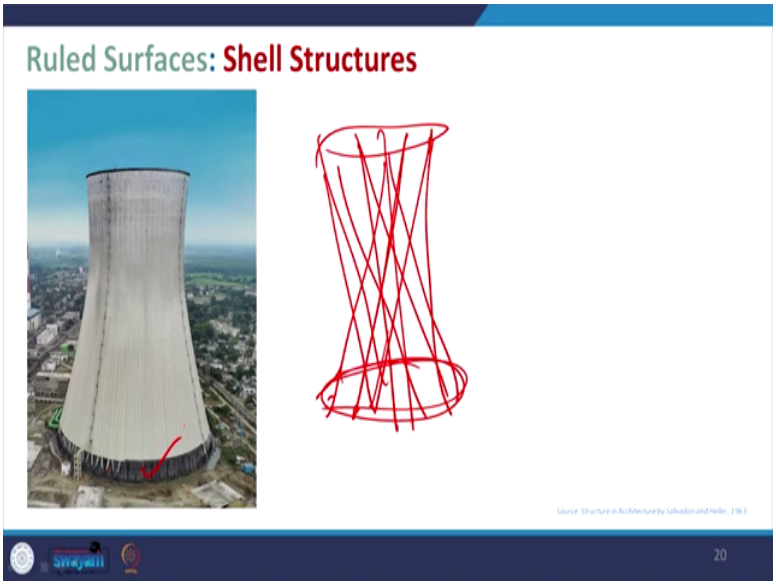

Now, the rule surface is something where you have a circular base or something, then you just decide one member and you just rotate it in a different pattern. So, that is giving a form of this, like you rotate this particular element with the similar angel and it will give you a form of a twisting tower. So, here also you can see similar kind of this is a example of cooling tower. So, this is your rule surface.

Now, before coming to the advantage and disadvantages of shell structure. Let us clear this like whatever we have discussed and the examples that we have seen. Now, go back to those pictures and let us give the type that we have seen.

Yes, so specially if I just ask you about this. So, this curvature what is the category? So, we have how many one is your surface that is revolution due to revolve, one is your surface translation the other is surface ruled. So, in this case it is the category of I am I am sure that all of you can get it, this is surface translation.

So, surface translation. Now, about the curvature this second level category. Here you can get this direction very good, but at the same time you are getting this direction. So, you have multiple curvature. So, this is example of doubly curved.

So, surface translation doubly curved. Now, you have to assign it is anticlastic or synclastic, because monolithic monoclastic is the only for the single curve, singly curved shell structure. So, as because we have different direction so, this is basically example of anticlastic curvature right.

So, there are examples if you go through the work of Felix candela you will get many application of this kind of form ok. Now, in this case what would be your answer? So, this is something where again we have one curvature in this, one curvature in that side.

So, again it is surface translation, then doubly curved and then in this case this is at the same directions. So, basically the example that we have taken there, it is similar to that. So, this is basically your synclastic curvature right.

Now, coming to this now it is being clear, in this case you have two surfaces two hyperbolic paraboloid is example of anticlastic. And, in this case it is elliptotic paraboloid it is your cynclastic clear. So, anticlastic and synclastic form this two example it is clear to us. And,

again here the surface these are resultant of your revolve or revolution and here it is surface translation.

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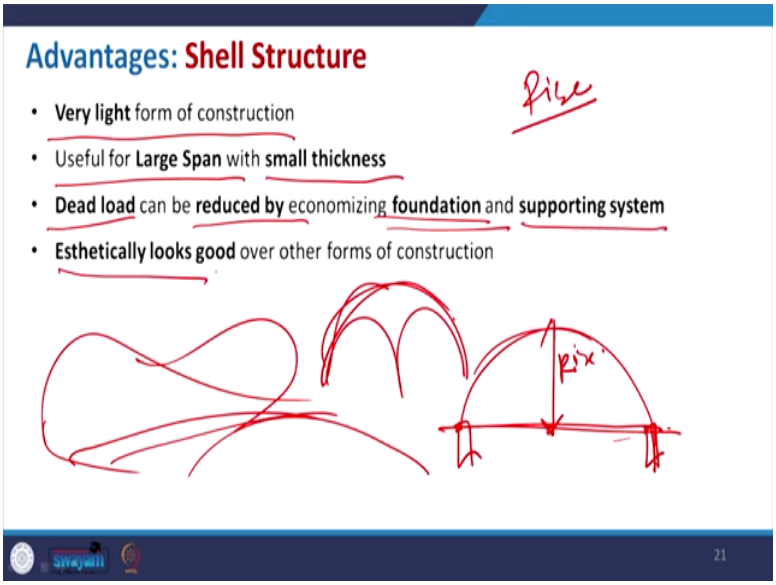

Now, coming to the advantage of shell structure it is very light form of construction, because again the thickness of the material is less. Useful for large span with small thickness very minimal thickness, sometimes even the span of 60 meter can have of only 60 mm or 75 mm thick you know structural thickness of the roof.

Dead load can be reduced by economizing foundation and supporting system as because this whole system will depend on the curvature. The way you make the curvature that depends on that how you can get the rise. So, the rise you know that we discussed earlier, when you discussed about the arch.

So, whenever you have this forms, so rise is form this particular abutment so this is the rise. So, wherever the vertical support, so this is your rise. So, this rise how you will make, whether you can go for a flat, whether you can go for something very organic, whether you go for very systematic regular shape or the design that you will follow, we can definitely reduce the date load.

Esthetically looks good over other form of construction definitely. So, if you see those buildings those you know Lotus temples, Sydney opera house, each of the buildings it speaks it is beauty. Like with very first of all that particular form that attracts me, but second the second is the application of the sales structure to create the large span with the less amount of material and propagate executed.

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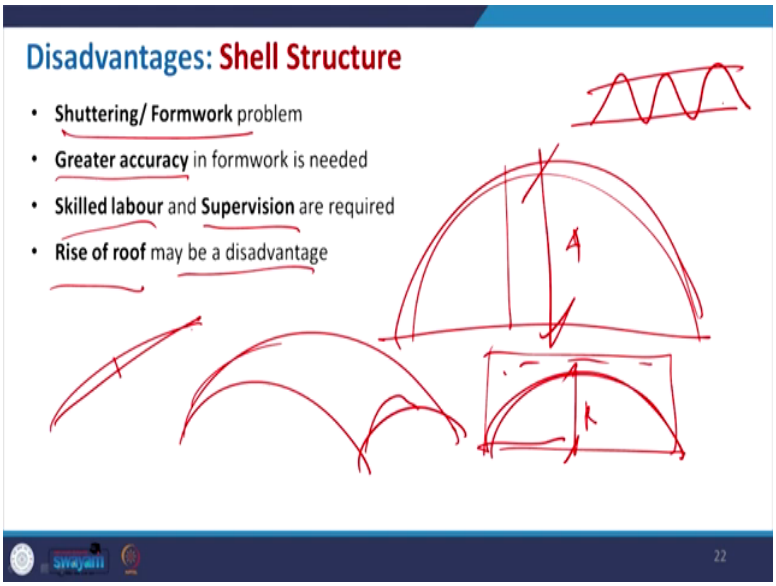

Coming to the disadvantages of shell structure, shuttering and formwork is problematic as because it is taking a huge span. So, just remember if you can go for a height of say 4 storey building, how you can really go for this shuttering? It is very complicated and also it needs proper execution and formwork to get these smooth surveys. As, because the load being transferred with the curvature, so this formwork is basically very important to determine the curvature in a right way.

So, that the load can be distributed the way we want. Then, greater accuracy of formwork is required as I mentioned like it is all sustained with the curvature. So, it is important that how you form it. So, if there is some disbalance so, the equilibrium will be disturbed and this structure will not be that much stable, which is not really desirable.

Skilled labour and supervision is required to achieve those kind of accuracy, then rise of roof may be disadvantage, because many a times see whenever we use the sales structure it cover a last span like hanger or something, but definitely we cannot use the upper portion of it. And, this rise sometimes like to get the proper shape, proper stability, geometric stability, we this rise is giving something extra. So, may be we do not require it.

For that sometimes it can also go for a low rise or almost flat kind of sales structure or else we just go for the folded plate structure, that is basically maintaining the rises well and as we will have a discussion on the folded rate structure. Separately that is why I am not extending it in this particular sales structure. Folded plate structure itself will have you know lecture, after you know in the next few within next few lectures we will see that.

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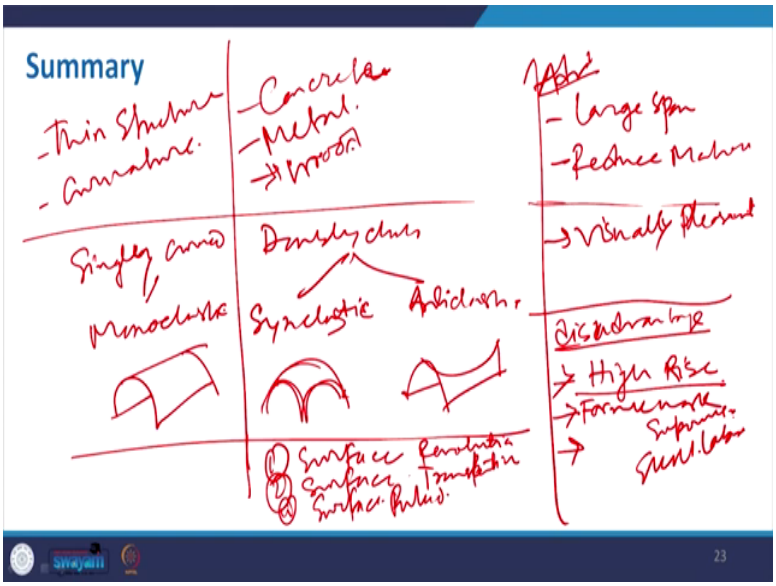

Now, coming to the summary already like I have discussed it twice in this lecture, but then the final is summarized form the sale is basically, a thin structure, important thing is your curvature and then based on that we have seen different application, from Lotus temple to your TWA terminal, then Sydney opera house. Now, coming to the category that we have so, one is your single singly curved and then we have the doubly curved.

In doubly curved we have synclastic and anticlastic. And, here we have basically monoclastic only one side. So, that means, in synclastic it is the form where the curvature being made in this similar direction, anticlastic where the curvature being made in different direction and monoclastic is only one direction more representatic of a bold.

Now, again to create this form each will have different surface you know different curve surface, curvature of the surface. So, one of that is basically the surface revolution, where the profile being just revolved, then you have surface translation, where different curvature like concave convex they merge together and different way. Like once two concave merge

together will get the synclastic, where one concave one convex that will really form the anticlastic.

And, then the surface ruled where it is giving a form of a twisting tower, a cooling tower that I have shown. And, the regarding the material again concrete being extremely used, extensively used in this kind of shell structure, then you have your metal, like steel, aluminum and other thing and then we can also get some example of the wood to make this shell structure beautiful..

The application the advantages that we have seen that again the large span, then again reduce the material and no doubt about it is looking visually pleasant. Now, coming to the disadvantage again high rise sometimes not many times you prefer this kind of volume that we have seen in say some volume in your Lotus temple in Delhi, or may be in sometimes that particular thing dome structure helped us to get the good feeling with the large volume and all.

So, along with the high rise sometimes also the problem is with the formwork. As because this shape of the shell structure depend on the curvature and all. So, formwork is very essential. The perfect execution of the formwork will determine the final shape of the curvatures. So, this is very important and needs supervision and skill labour as well.

So, that we need to look. So, it has the advantages disadvantages for any structure definitely there are particular application, there are some gains, but at the same time, if we do not take proper care of that during execution, during design, or during material selection, may be our target will not be fulfilled. So, with that I conclude here with shell structure, I have shown some examples, but there are many personally shell structure I like very much, even many of you like this kind of shell structure around the world.

So, what I suggest you browse through the internet get more examples and time to time keep posting. So, that I will also get to know about some interesting shell structure around the world and that can always help both of us like all of us to know more about the type and more examples in different category of your synclastic anticlastic or monoclasic, curvature form

shell structure. And, different materials like nowadays not only concrete metal, but also some new innovative materials can make it happen.

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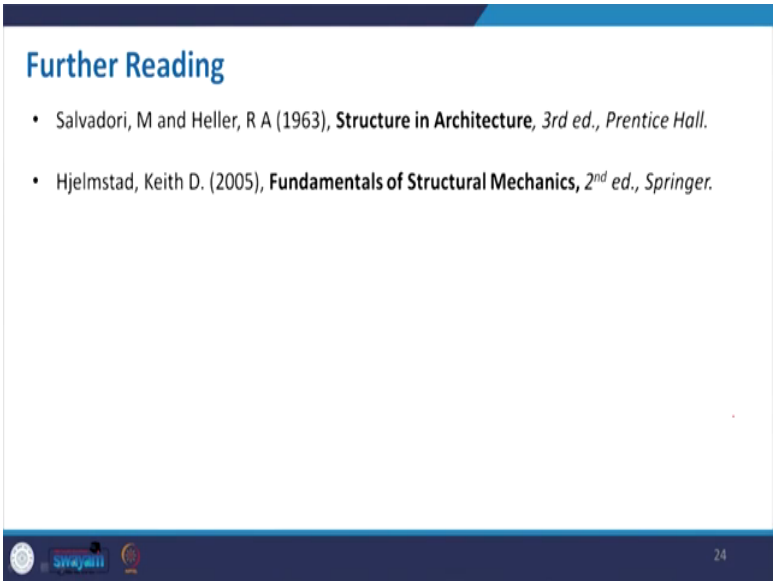

So, with that I stop here and these are the further readings that you can go, you can also browse through the link internet link that I have given in some of the slides, where you can read more about that particular structure, to know about the material, the formation and again that will link redirect you to some more examples. So, that is useful I sincerely request you to do that.

Next, we will discuss about the trusses and space frame again it will be some useful structure which will be helping us to you know design large span structure. So, we will be discussing on the next lecture till then, I would like to thank you again to take part in this course.

Thank you.