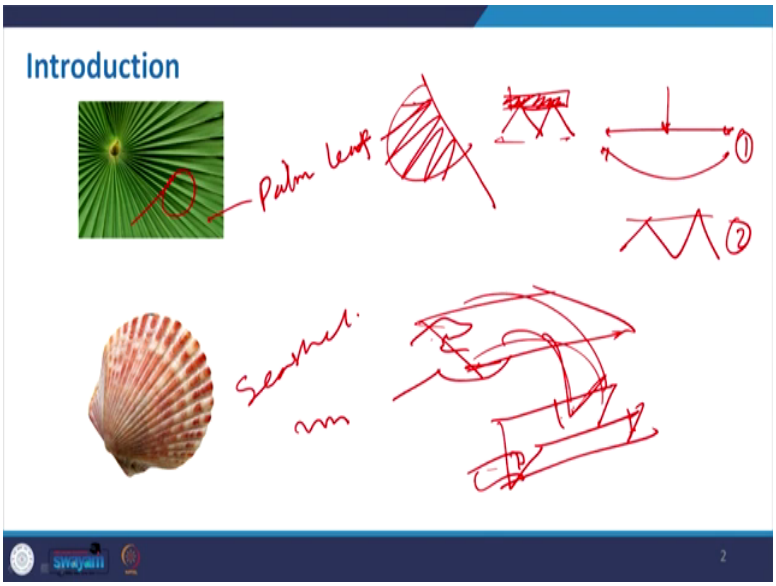
Structure, Form, and Architecture: The Synergy

Prof. Shubhajit Sadhukhan
Department of Architecture and Planning
Indian Institute of Technology, Roorkee

Lecture – 28
Folded Plate Structures

Hello, everyone. Welcome back again to online NPTEL course on Structure, Form and Architecture: The Synergy. In last lecture, we have discussed on the advantages of truss and space frame for different uses, different application as like for the bridges, for the buildings and for large span structures. Similarly, now there is another structure added to this category that is the folded plate structure. So, today our focus at lecture number 28 will be your folded plate structure.

(Refer Slide Time: 01:02)



So, let us get started. Now, before like discuss about the folded plate structure and its component, its technical detail let us understand some of the folded plate structure which do exist in our nature. So, this is basically a palm leaf and here we can see that nature that how it is been made and like or the applications, sometimes even for the you know hand driven fan we use this leaf when it is get dried up and it is giving a good stability, this is one. And, if you really have experience of that those edges they are quite stiff and you can it can really hold a good load on top of it.

If we just make it flat if I make this section flat it is nothing but very thin plate where like applying load will make the bend, but where I just this is option 1 and option 2, I just make a fold. So, it is all of a sudden you know it will increase the capacity of resisting the load on top of it. Similarly, the structure that also we have that is the sea shell, so, in this case also we see that particular structure which is make it more stiff and very strong for like which is act as a protection for this particular creatures in the nature.

So, we can get inspired from that we can develop something. So, in case of like a single piece paper if you try to just hold it so, it will try to bend. So, you cannot really hold it like this, but if you just try to just make a fold and again hold it so, it can have the capacity to take the load. So, let us just do not go by this particular sketch and we have to believe it. So, let we can we just try this out.

(Refer Slide Time: 03:27)

So, I have a very plane piece of paper. This is a particular cartridge paper you normally use for the drawing sheet, it is little bit thicker than the normal Xerox paper, but then also whatever we have just set whatever I have set so, based on that. So, I am placing this in front of you and try to hold it from one edge. So, it is very difficult like if I want to hold it like this I cannot because of the self weight and because of non availability of the end support it is having this particular deflection.

Now, even if we just try to support it from both the end then also you will get the bending right. Now, in place of that I just not make a fold just give a notch here and now it is stable right. So, if you can see from this direction it is stable up to certain distance and again it is trying to get this particular bend and now, I can put a load like I can put this pen so, it can

easily hold it. If I just put something bigger than that so, it is not able to because I can understand it is not.

Now, in that case if I just make a fold like this now it is more stable now if I want to put this load then also it is heavier than that, but I can definitely increase the load more than that. So, this is just a slide changer I put it there. So, it can hold this load. We cannot imagine this can be possible with a paper when it is having no particular fold.

(Refer Slide Time: 05:27)

Like that I just want to improve that so, I can have this kind of folded plate it can easily be made with the stream kind of paper and now I just want to test it. So, now, if I want to put this particular duster, see, no deflection and now if I remove it this is basically a stone and it is very heavy you can see. Now, I just put it there see again there is no changes and not only like

it is giving support to my hand, but if I want to up lift it as will that no such support then also it can hold it. So, this is advantage of the particular you know folded plate.

(Refer Slide Time: 06:25)

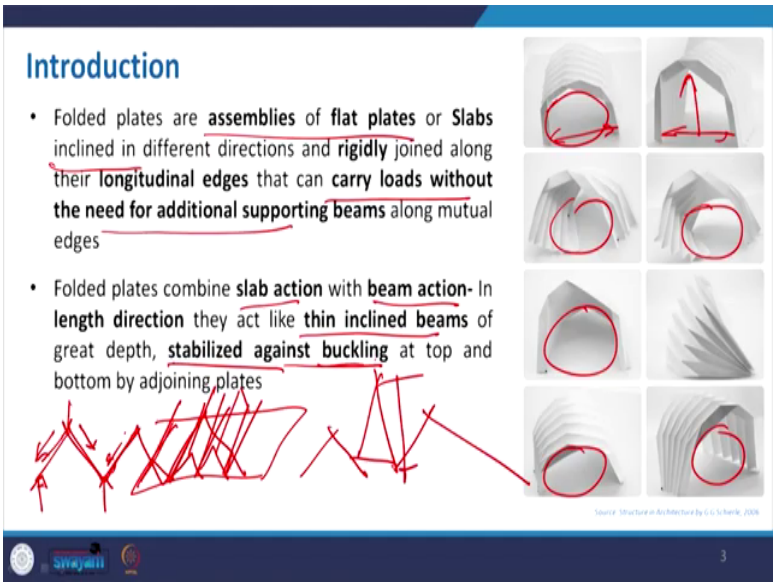
Now, if I want to make it more complicated like it is a single fold and definitely we do not have a end support this is another made of that it is a letter M just coincident. So, now, if I want to put this load say it can easily hold this load, but which is normally if you just consider the thickness of this particular paper it is not possible. Now, replace this paper with some good material like some concrete, some timber it can do excellence to carry the load and for long span as well.

(Refer Slide Time: 06:58)

Because, for this kind of span if we just give support end to end like I just put this two wall and then I want to hold it. So, let us see how it can. So, I just try to demonstrate this ok. Now, see this is again stable. So, it is possible.

So, now, move on to the next thing.

(Refer Slide Time: 07:27)



So, basically folded plates what exactly it is that in I have just shown very simplistic form, but here you can see various form made of paper. So, it is related to the origami where like different fold can give you different result and here it is basically the formation the form that being created and in all cases you can get that some volume being created. So, this particular volume being created, this volume being created which is having no other obstruction. So, this is advantage of the folded plate structure.

So, what exactly it is the folded plates are assemblies of flat plates or slab. So, plate or slab it is alternatively been used inclined in different direction definitely it may be inclined in this or it may be something different may be members are not equal as well and rigidly joined along their longitudinal edges. So, basically when you have this paper we just divide it and just make

a fold. So, the same paper is fold is squeezed and then carry the loads without need of additional supporting beams in most of the cases.

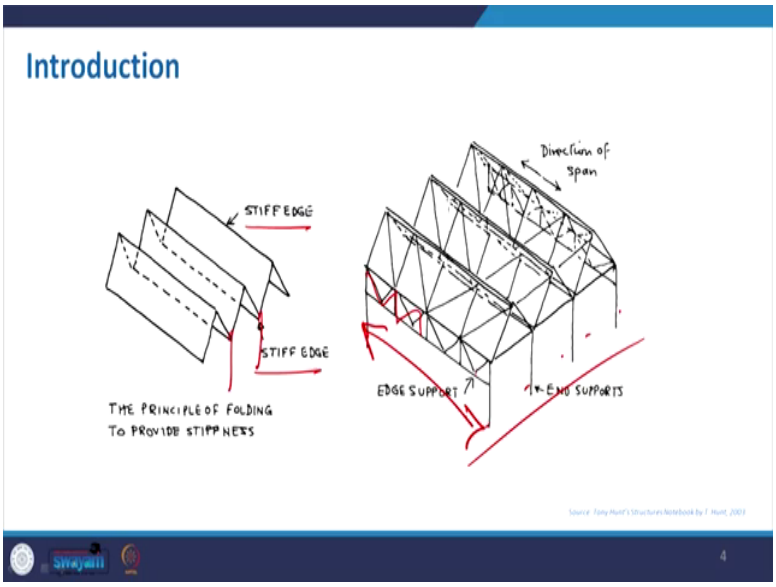
Folded plates combine slab action and beam action together. What exactly it is like whenever in a folded plate load been applied. So, first it will transfer the load through the shorter edge and then here you have the support. Now, as because we have multiple such so, the connecting members also get some balancing out the resultant reaction to that. The thin inclined beams of greater depth whenever you make it increase the depth, it will be you know your more rigid it will give you more steepness.

I give you another example say for like you are studying you are on a study table and just you want to rest so, you can just place like this right. So, in this case like if you try to spread it so, after certain time you will fall, but if you just make it stable like this. So, that will give you more stability you can do you do practice or you just test it and you will get the similar results. So, when you make it very flat when you actually decrease the depth so, it will not you know give you much steepness compared to where you have larger depth.

And, then sometimes you know this particular layer they are stabilized and then it resist again the you know your buckling. So, whenever you have this member again so, it has a certain level of carrying the load and as because it is having some self weight so, it can also be flattened. So, for that if you just fix both the end with the beam then this will be more active.

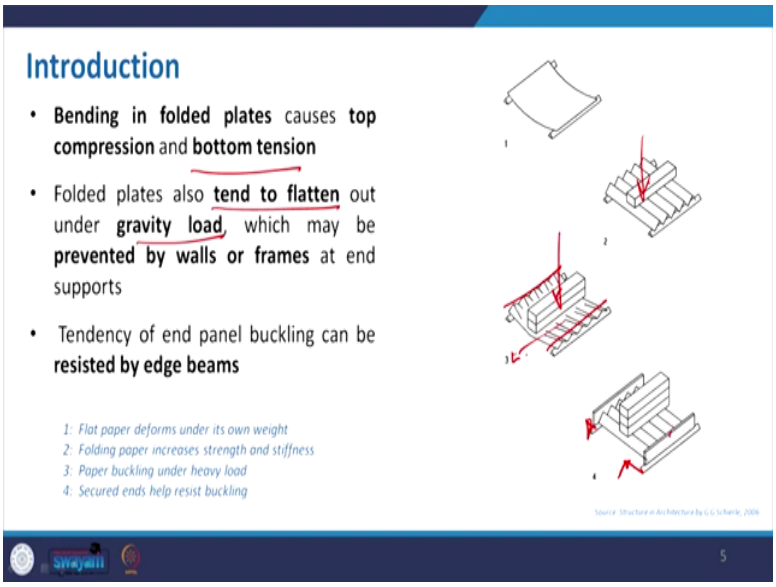
So, this is another advantage of the folded plate so, that can be developed.

(Refer Slide Time: 10:57)



Now, coming to the fold thing again the edge are formed and this is basically the stiff edge and when you just make it multiple so, we have end support to be provided here and then the edge support at the end where you can use some truss, we can use some beam as well and the span been like this. So, the span that you have to create in this direction where you have multiple members in this directions. So, only in one direction you have to put here this particular edge support or edge beam can solve the purpose of you know holding the end load.

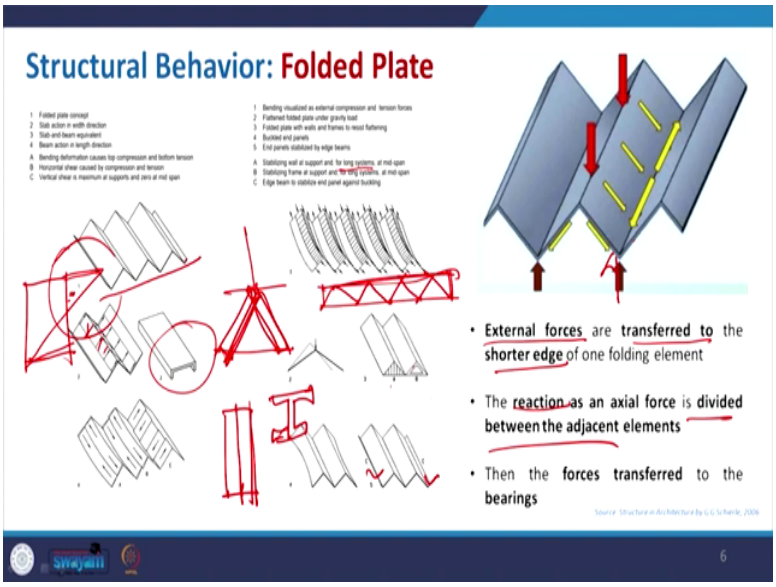
(Refer Slide Time: 11:40)



Now, again the similar thing with the support this is a single sheet can have the bending when you make the fold it can hold some load, but when you add more load the way I just tried with lighter one and the heavier one and then it fall. But, if you support this end condition then it can again can resist more load on to that. Now, this is basically the bending and fold plate cost compression and the bottoming tension similar to your truss and then it will trend to flatten out due to gravity load.

So, how you can solve it out? You can give support from this you know edge and which can stop. So, it is basically the flatten out due to gravity load or the applied load to this, but this can help it to still intact.

(Refer Slide Time: 12:39)



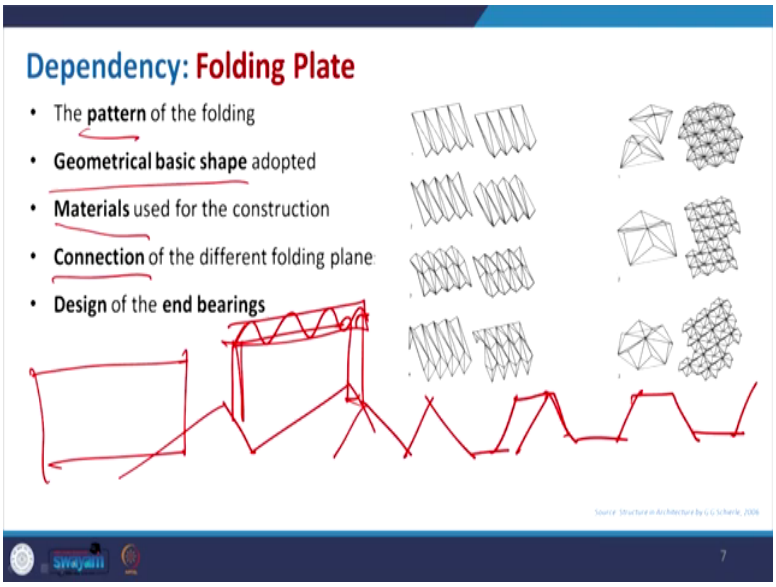
So, here it is basically the folded plate structural behavior how it happen. So, load applied on this so, external force are transferred to the shorter edge first and then the reaction that generate that is divided between the adjacent elements. So, the component will be divided, the vector will be divided that load the vector analysis or you know you can get this distribution and then finally, the force is transferred to the supporting columns.

Now, in this sketches which has been taken from a book that is mentioned here also as well Structure in Architecture. So, in this case it is just the formation where the folded plate how it been formed from a single paper this figure to where it is been shown how the load been distributed at this particular shorter edge, but at the same time with the span what we have is basically the shear, we have the bending shear as well as the axial shear and in order to stop that what you need to do we have to put the edge support.

So, it can be of the option 1, which may be a just you know some frame or may be it can be a truss or just it can be a edge beam to support it, the way like I have shown here ok. And, this is something what is showed that it is equivalent to this particular space where like if I have this member then I just cut this portion and I can make this fold. So, may be the area the volume that like area that can covered so, within that I can make more rigid it can hold much more load to that.

So, it is again optimization of the structural section where this can be you know converted to the folded plate as because previously also we have discussed whenever we have this rectangular section. So, if you see the bending fold so, there also the outer fiber will get the maximum stress, but at the you know inner portion or interior portion is having under stress means which is not able to carry that. So, then we can go for optimization of that on the I section is one of the result of that. So, we can go with this folded plate.

(Refer Slide Time: 15:23)



Now, dependency the how folded plate will be efficient or what it will depend on the pattern of folding. So, it may be very regular folding or it may be something different. So, half fold and maybe it is eccentric folding, so, here you can see different kind of folding being placed the geometric basic shape that will take it may be a rectangle or just simple fold or it may be a triangulation by which you can accumulate and it can make geodesic dome kind of structure.

The material, definitely the material plays important role to take upon the decision of the shape and pattern because ultimately it the you know safety is structural safety is one concern and for that like it may be concrete, it may be timber, may be plastic, may be glass some corrugated sheets been also made with this pattern. So, this case like the material used for the construction also the you know it will depend materials will affect the decision on the type of the folding plate that.

The connection of the different folding plane is another important thing. So, it may be of simple edge to edge connection it may be something like where it is more flat connection. So, this corrugation can also be possible where something plat is been done or maybe it is something which is very much eccentric in that. Design of end bearings whether will go for supporting it with a continuous wall or just the support like column. So, and then the edge beam is been supported the truss or up beam.

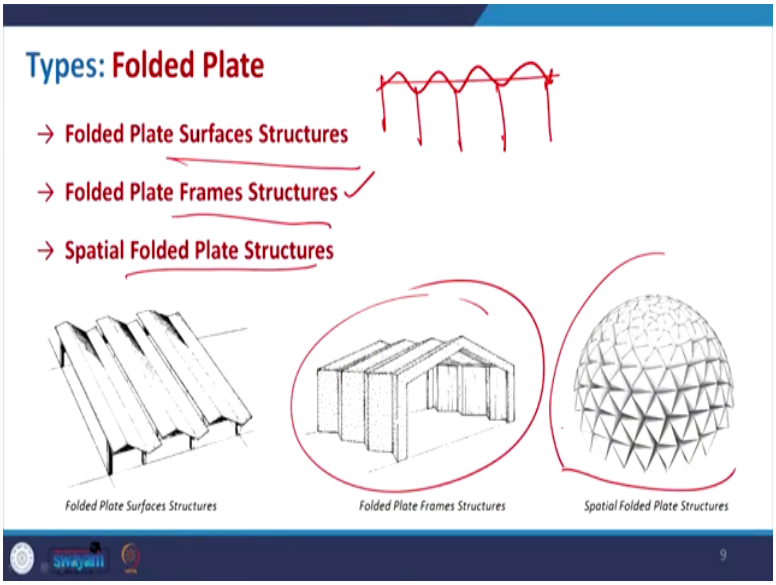
So, that depends depending on that folded plate you know the characteristics that will depend.

(Refer Slide Time: 17:20)

Now, the materials as I mentioned wood can be used; steel is definitely be used; reinforced concrete will be a very cheaper if it is been made for like mass scale application. Aluminum can also be used to you know reduce the weight of self weight of the structure; plastic, glass

can also be used, some corrugated sheets and all already available in the market in form of folded plate.

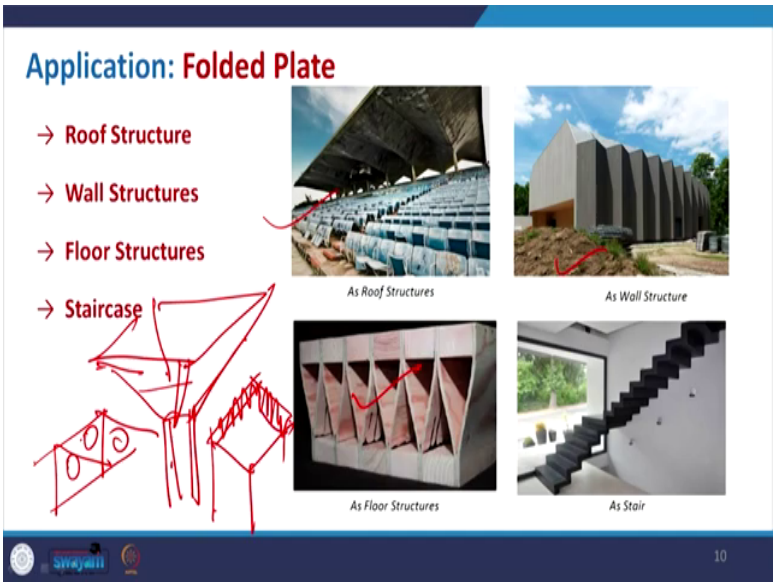
(Refer Slide Time: 17:49)



Now, coming to the types; so, basically it is been divided in three types. One is the surface structure, one is basically making a frame or portal and then you have the spatial. Now, in the plate surface; that means, only the roof instead of flat now we have this particular folded plate done. So, this is representative thing and where the end will be supported by may be a column or something. At the same time where we can have a frame; so, the whole structured been folded so, here if I take this example. So, this is the same member getting the fold the roof and the wall as well. So, this is basically the category number 2 so, which is very similar to the folded plate frame structures into this category.

And, the spatial folded plate is basically getting a different form like this is one option where we can get different kind of folded dome. Some different kind of dome can be formed with this it may need not to be only the triangle, but it can go with the pentagon, you know hexagon combination or else it can be some different formulation, but with proper you know calculation that can give us this kind of results.

(Refer Slide Time: 19:20)



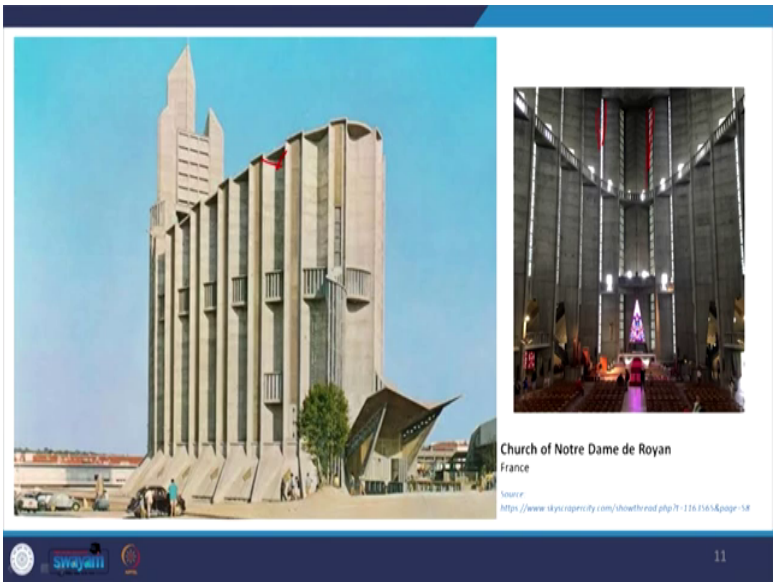
Application of folded plate definitely it can be used at the roof structure for stadium or may be many a cases some railway stations we can have this kind of you know structure or may be for the parking many a cases we can get this kind of you know umbrella roof structure like basically if you get. So, this is holding a particular span so, this can be possible.

It can also act as the wall structure here you can see that how the folded plate been used, we will get a pictures of that as well then it can also be used. A floor this is something interesting

where like if you have some you know insulation or some services to be taken between the floor, then we can use this kind of system. So, where this hollow part not only basically reducing the material, but also it will help to run all the services. So, this can be of this floor structure or else sometimes nowadays you can see this kind of stair as a folded pattern.

But, again the application can be of more like even some of the cases in construction for the sheet pile we also use this kind of folded plate which will give the steepness to resist against the lateral force. So, there may be the all the strain be you know put for the sheet file in the internal area. So, then we can have this particular sheet file as the folded plate.

(Refer Slide Time: 21:08)

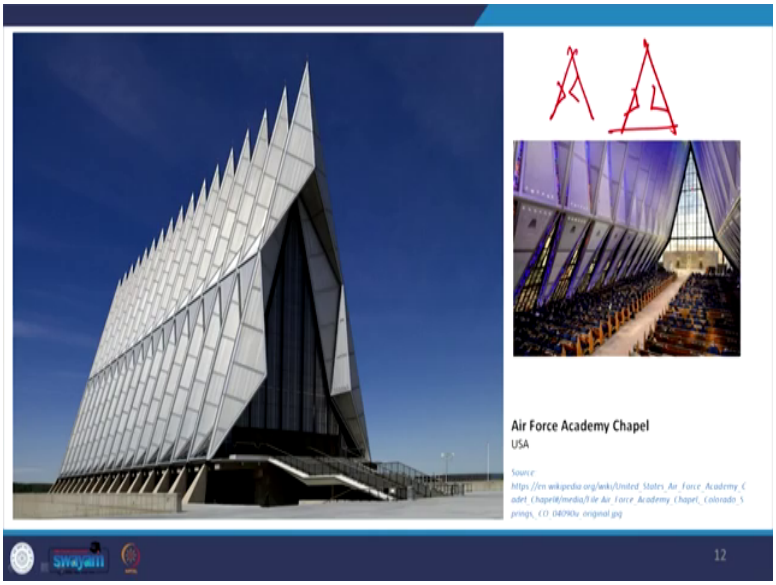


Now, we will focus on some of the examples and try to understand the beauty of using this folded plate and many a cases it is been used for the churches and chapels. So, here this is a example of church of Notre Dame and it is the example from France. This is the exterior view

of that you can see that how the wall is getting that particular fold and this is basically the interior.

Now, the interesting part of that with the fold is the nice application of those glasses to welcome the light from outside. So, this ambiance inside is really interesting. So, this folded plate the outer structure looks very pleasant and interior like ambiance and the expense is even better than that with the application of folded plate.

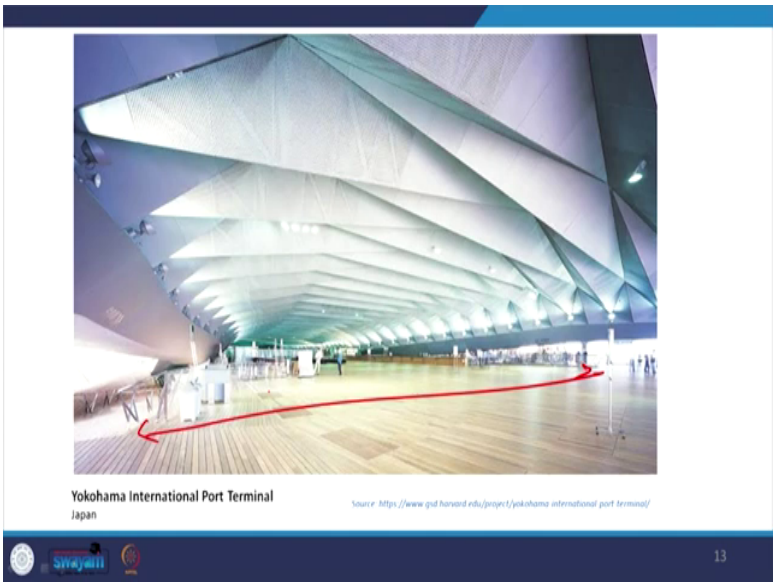
(Refer Slide Time: 22:12)



And, this is a very famous if you search folded plate architecture. So, this will be the first result that you get this is Air Force Academy Chapel in USA and again it is nice example of like if you just compare with the typology it is not the roof, not wall itself like it is the triangle, but the fold and all other thing you can get it some here like how the fold been made in this particular structure.

So, and this is the nice interior view where the intrigues is supported with some steel members and it is one of the you know greatest example of the successful use of folded plate structure.

(Refer Slide Time: 22:55)



Move on to the next one this is Yokohama International Terminal where most of the terminal buildings they need huge span to be covered without much restriction because of the heavy flow and also have good feeling of the volume. So, either they can go for the space frame or it may be the arches of the shell structure, but this is something where the folded plate being placed as the alternative and the final output is in front of you. It is looking amazing with this particular you know cut with the very nice line and you can imagine the span that it holds without any vertical support. So, this is again a successful application of folded plate.

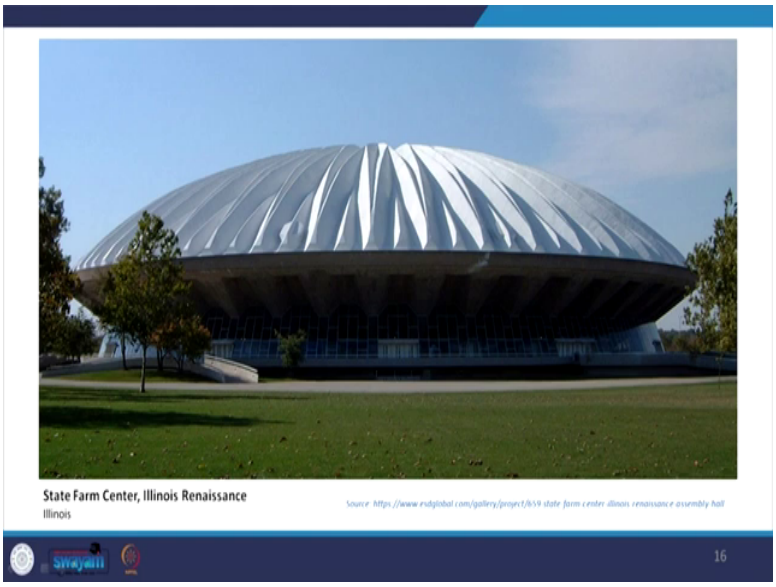
(Refer Slide Time: 23:35)

Now, coming to the Tempodrom, that this example I have given long back as well. So, this is one multipurpose arena and again the structure been made the outer structure is basically the fold. And, here along with your straight line that finally, it is also taking shape of a curve and this is the interior that is also very well decorated. This is forming a form of like some petals kind of ambiance and it is very much regular and it is formed in a circular form. So, this is another example of the folded plate structure which is looking very good and solving the purpose.

(Refer Slide Time: 24:20)

It is basically the corrugated sheets nowadays we use the for the covering. So, this is available with some you know instead of tin or asbestos nowadays we get this particular form and it is been placed as the wall as a folded plate. So, the example in that category like the folded plate wall so, this is another example added to that. This is the Sint-Ritakerk this is again a church and here you can get this particular nice very simple, very much simple structure just the fold on it and then you get this nice ambiance inside with the sky light at the top.

(Refer Slide Time: 25:07)



Now, coming to this is the State Farm Center this is the assembly hall in Illinois campus. This is making folded plate domical structure. So, this entire set being made with that and this is something where like spatial form of folded plate takes structure that being placed here.

(Refer Slide Time: 25:36)

This is Sports Center in Switzerland and you can see that how beautiful it had been made not only the roof, but as well as the wall. So, this is the category where the frames not only the you know roof been used or may be the flat surface, but here it is making the portal instead of a very typical post beam connection. Here it is getting your folded plate connection in all the direction even the roof, even the wall and you can see that solid void specially at the night time you see this particular representation where like the solid void and application of the dark the use of this concrete and the illumination it is giving nice view that redeem been maintained.

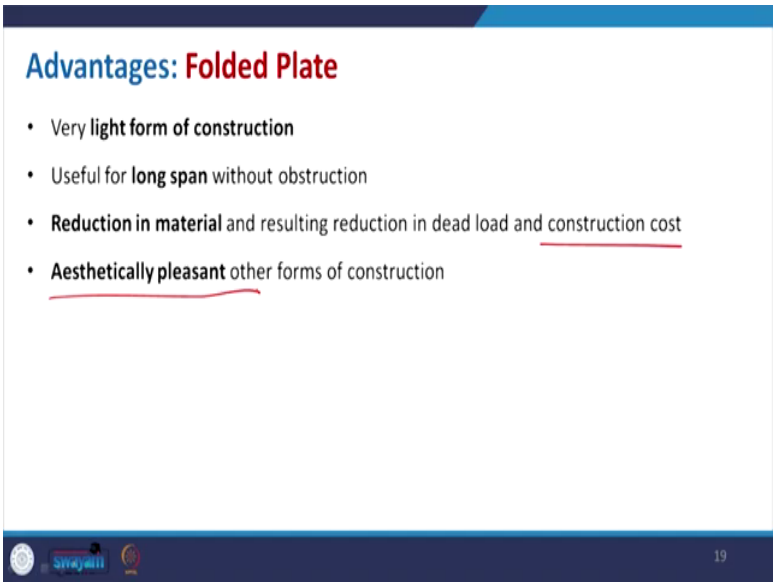
And, this is very important for folded plate structure when you arrange those plates you need to maintain proper geometry, proper symmetry f it is required for the structure then only you can get the desired result. So, application of folded plate texture been used in multiple area.

So, we have seen charges we have now the sports arena and then we have a multipurpose hall there as well.

(Refer Slide Time: 26:54)

Now, this is a bigger application of that folded plate structure or very light structure. You can see that how this been made. This is a stadium in sports stadium in China whether like where this entire thing been covered with a you know semi translucent material where the light can easily penetrated, but it can also provide the straight to the spectator watching the sports activity. So, this is again a beautiful application of the folded plate how it is been made and here the glass material been used. It is also possible with the use of the steel and glass we can go always it need not to be timber or maybe it should always to be like made of your concrete, but also the glass steel which can have this application.

(Refer Slide Time: 27:59)

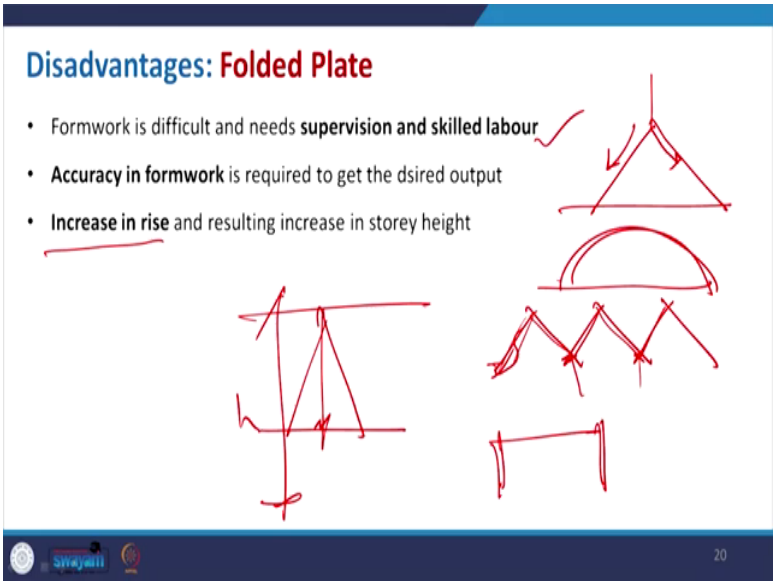


Coming to the advantages of folded plate we have seen the advantage of the folded plate. One is very light because of the reduction of the thickness of the slab useful for long span without obstruction this is similar to the space frame, but yes here also we can apply the same reduction in material and resulting reduction in dead load and construction cost as well. So, the moment you reduce the thickness of the structural member definitely it will reduce the dead load and that material cost definitely reduce the construction cost provided that you are applying it to the mass skill not at very small level project where may be things will not really be proven right.

Aesthetically pleasant, definitely the example that we have seen this one or maybe the previous one; maybe the day time or the night time it is giving really nice view, point of the architecture

that been created. The interior space been maintained without any compromise compromisation and also the light and shade part in to it here also it proves the same thing.

(Refer Slide Time: 28:58)



Coming to the disadvantages like framework is difficult; definitely when you make this structure it should be very accurate as because like the load will transfer to the each adjacent members. So, say I want this to be very much uniform. So, all that connections to be very properly executed, then the shuttering to be you know very much appropriate and also it needs proper vision and skilled labour as well. So, that is the point that we should look into. This is not exact the disadvantage because to get something really great we have to do this, but still a like compared to the traditional post beam can be easily erected it needs some more attention to get the desired result.

Then accuracy in form work or shattering is just I mention that is very much required because of the shattering the wave may final outcome will be same if we use the concrete because concrete will take the shape of the shuttering. The form work you give accordingly that will if there is some undulants undulations and then the concrete will take the same thing. So, we will not get very nice you know experience, nice view on the inside.

But, more than that that may lead to the collapse of your entire structure which is also true like in the previous lecture we have discussed about the space frame where like it is very beauty that the small members connected together will have very good resistance, but any failure any failure at any part of that member will like be a catastrophe for the entire structure so as to for this folded plate structure as well.

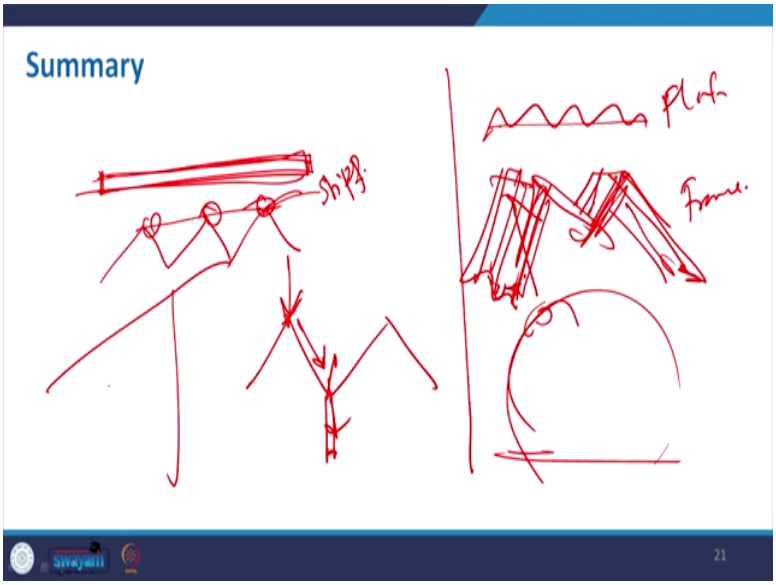
And, then on the problem is they are as well the increase in rise and definitely the folded plate, but in order to get this it is contradictory to each other like definitely you if increase the rise then the total height the effective height of the building will also increase. So, if there is a height restriction of a building or you have to optimize the height given you have to make multiple floors. So, this option may not be good solution for all this like archistras this will not be, but whenever you have that particular freedom you can easily go with that.

And, what is also a need to be mentioned that I probably not mentioned in the previous lecture that is for all your truss or any pitched roof kind of construction where the slope been maintained or maybe it is round or may be a pointed. So, it will not only take care of the structure, but as well as like it will also take care of the perfect drain off of the rain water or may be if it is in the cold region so, drain off of the snow.

So, this is useful you know form that can be used for some climatic purpose as well, but also with a visual purpose so that synergy that we need to make between the structural form section and the purpose of your structure and other thing that can be easily blinge. And, slowly when we just discussed so, started discussing about the post beam structures and now move to this particular you know folded plate the shell structure and other thing.

So, we have seen that good application and the final product which are very famous in you know in the world is really giving us nice experience and also you know increase our interest to know about the application of that and definitely whenever we get a chance to do it specially for the student pursuing architecture. So, for them in their design like wherever like we can see get a chance to design a you know parking lot or may be a shopping mall or may be a sports stadium, indoor stadium we should definitely try this out to get a better result because it will solve the purpose of long span as well as it is giving some kind of you know esthetic beauty good form to the architecture.

(Refer Slide Time: 33:43)



So, with this I just conclude here and in the summary again like what we have explained that in place of very you know state of simple plate if we just make it fold so that all will actually increase those points. This is making this thing more steeper and then the load will be distributed like when the load is given it is converted to the side load and then it is going to the

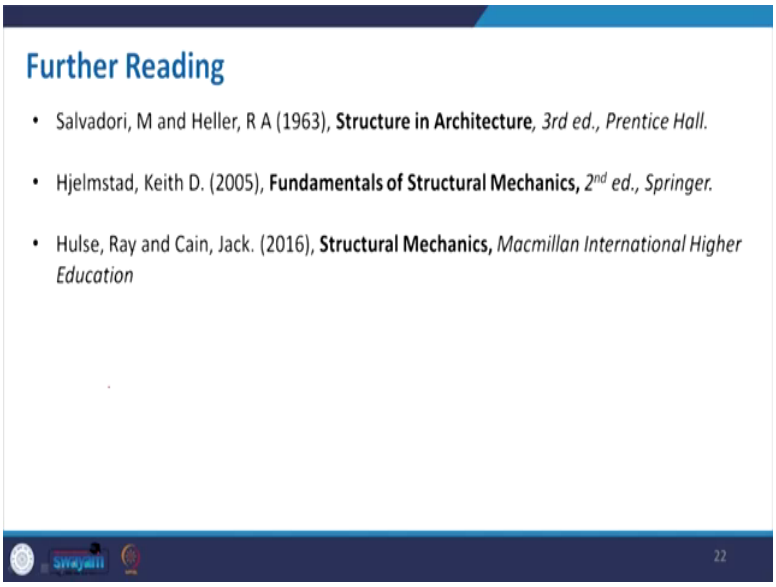
edge and transfer to the support. And, for that it can be of like you have the plane surface, you may have like what just I have shown like something like with the roof as well as your wall together.

So, if we just make it something like that just mind my sketches here I have shown you like similar to this which is basically the frame or the portal, this is basically the flat and the spatial is basically your this folded plate dome that some of the applications are already there. So, this is very useful and the material the concrete can be used but, for that the form work should be very much perfect.

And, if not then if you use the steel and all it will become little easier, but the perfect execution is required how join this and how you give the in support to stop the bending or the failure due to the gravity load that how you go for the edge beam on the support, whether we support it by the wall or we entirely make the building like the example we have seen that the Sports Center that in Switzerland there we have seen how beautifully they have done it. Most of the chances they have used it and they also used those solid void thing to welcome the light to maximize it.

So, there are applications that we can really think of and we should try to apply in our design like specially for the students they can apply in their academic design who are professionals. They can also think of where the purpose is done, but definitely for this kind of application you need to little bit of bigger project so that the cost know which may be the you know the form on that to be made in some module. So, that will be cost effective and for the small also you can try with different materials, not only concrete we can think of some glass or some PVC material to have nice look that can be done.

(Refer Slide Time: 36:39)



So, these are the reading materials that you can go through and also you can follow up the links given in this PPT, so that you can know more about this, you can know about the buildings that have shared with you and you can definitely add on more and you should do that. And, you just share with me some of the examples that you found or wither you have visited the place or you have gone through some of the articles, sites, internet sites and then you can add on. So, I would like to see those input from your site.

And, then moving to the next lecture we will have the Membrane Structure. This is again a very beautiful structural system and be very useful will be discussing on our next lecture and till then like I would like to thank you all to take part very actively in this course and we will be meeting in our next lecture.

Thank you.