Structure, Form, and Architecture: The Synergy

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Lecture – 22
Arch Structures

Hi everyone, welcome back to online NPTEL course on Structure, Form, and Architecture: The Synergy. So, today we are at lecture number 22 and this lecture is comprised of the different kind of arches Arch Structures, their uses in the building as well as different you know bridges.

So, previous like before we start this discussion on the arch that we have seen in the frame structure the advantage of creating the span and the load transfer from beam to column and the foundation. The advantage of using arch is something where the arch itself the profile, the curvature itself be is taking the load and most commonly it is taking the compression; the compressive load.

So, there will be not essentially the tension developed and if it is tied then definitely there will be some, but otherwise this is being used. And, with this arch form being used from so long from the history like we have seen many such examples from bridges, from different buildings. Even to create some small opening like window door arch form being used like, you know you know you know bigger manner and this lecture will be focusing on that. So, let us start this particular discussion or arch.

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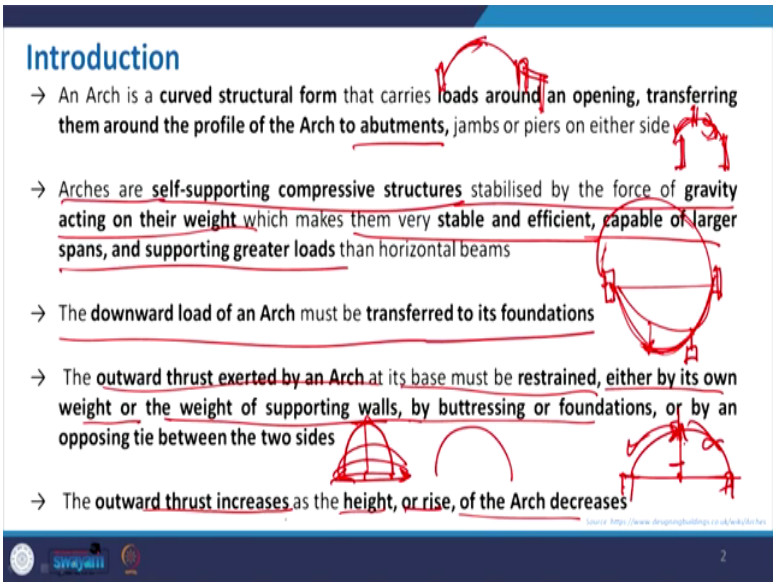

So, coming to the definition; there is no such distinct definition. So, discuss what exactly the arch and arch is a curved structural form that carries load around an opening transferring the load. All the load through their profile it is not giving like with the connection. So, this curvature itself is transferring the load of the profile of the arch to the abutment the support or the jambs or the piers.

So, basically if we have this particular support the piers, the arch is basically transferring load and most commonly it is very symmetric. So, that is why the load, the homogeneity of the material and the geometry is helping these arch to transfer the load like this.

Again, the arch of the self supporting compressive structures. As we I mentioned already in arch mostly will have the compression stabilized by the force of gravity acting on their weight which makes them very stable and efficient, capable of larger span and greater load. So, what

exactly it is? Like the arch form that we can create like we just start with the example of a chain.

So, suppose we have a chain and just it is having a length more than that. So, we just allow the chain to have you know sag. So, it will give you a particular form, we will discuss that the this catenary form or the parabolic form and then it is having the flexibility when you add some weight to it. So, it will change the form little bit then you can balance it and if you reverse this so, that will create the arch. So, normally it is with a chain or cable and now converting to the arch form.

So, it is geometry; the geometry we follow to create this arch will determine how it will transfer the load and this is very effective form of a structural element that can be used. The downward load of an arch must be transferred to its foundation how it will transfer that will have a this distribution both the side, ok. Gradually, we will also discuss with the like the components of arch and to the support and that support will transfer it to the foundation.

The outward thrust exerted by an arch at it is base must be restrained either by its own weight or the weight supporting of the walls. So, both the cases like it may be is like full arch or it may be something where the support to be there or else sometimes with the buttress. So, in some of the historic building we have seen the arch form and other thing is supported by the wall and in order to reduce the wall. So, we use the flying buttresses to that.

The outer trust increases as the height or rise of an arch decreases. So, what exactly it is the rise is basically this particular height like if it is a flat beam column structure and then we try to give the bend. So, if you reduce it then thrust will be more. So, if you make your arch like parabolic, it will be the great one if you make it flat in and so it will give the outward thrust more compared to the height. So, that is why it says that thrust increases as the height or rise of this decreases.

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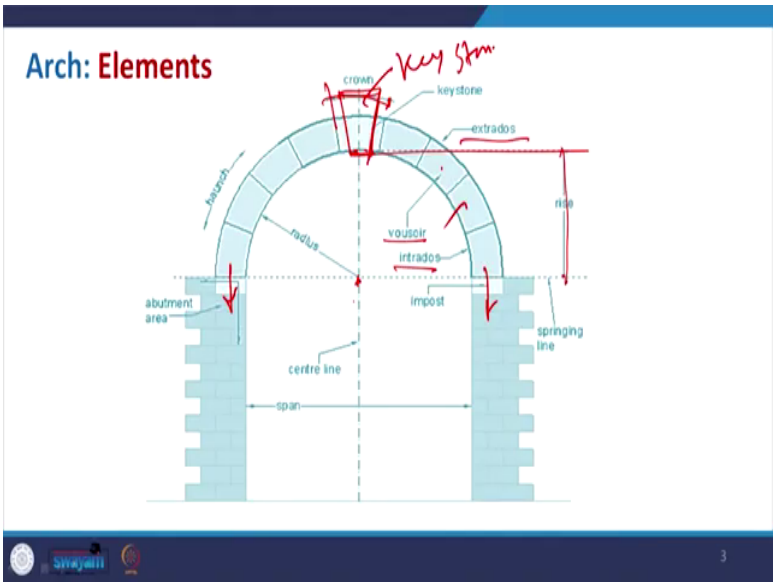

Now, coming to this particular schematic where you have different components. So, at the curvature you have the internal curvature call intrados. The extrados is the outer curvature then you have this abutment or area well like it is being supported to the piers, and the rise as I mentioned it is basically the distance between your internal curvature from that particular horizontal line.

So, where it is being supported and then you have different kind of elements. So, mostly like in history; so, this arch were form to due to the with the brick masonry or stone masonry and then you have a crown at the top. And also some you use this particular stone, we also refer at this is the key stone.

So, this is basically the key stone and this area is basically your crown and this is your haunch, then in between the lays of the components are also called vousoir. So, and this is the effective

span. So, this kind of structure mostly being used to create the opening sometimes even in the window and depending on the rise, you will have different kind of arches we will be discussing that as well.

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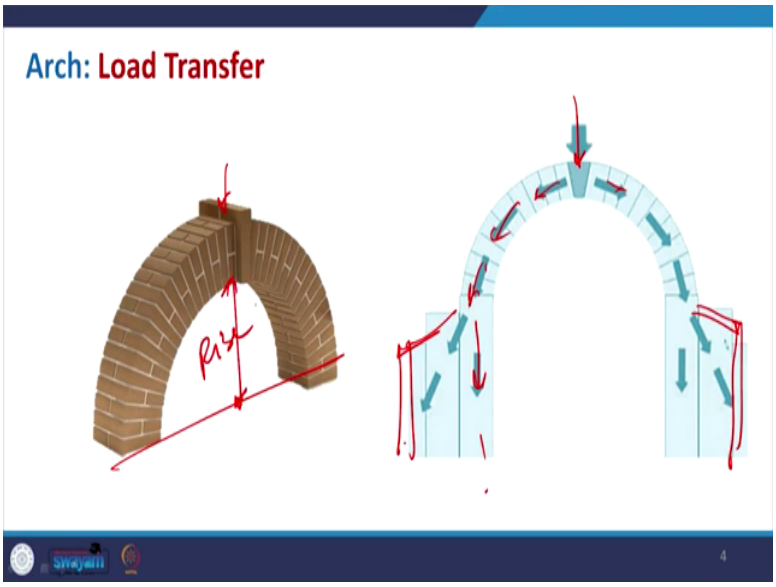

So, how load is transferred? So, load imposed on it will be transfer symmetrically and that will transfer to the ground, sometimes if your wall is not capable to do it. So, we can also use some flying, but tresses or some other support which will eventually distribute the load and this symmetry is very important in order to do that. So, here also this is the same similar thing. So, in a 3D form so, you can see the how the bonding being made. So, in this case this is basically your rise.

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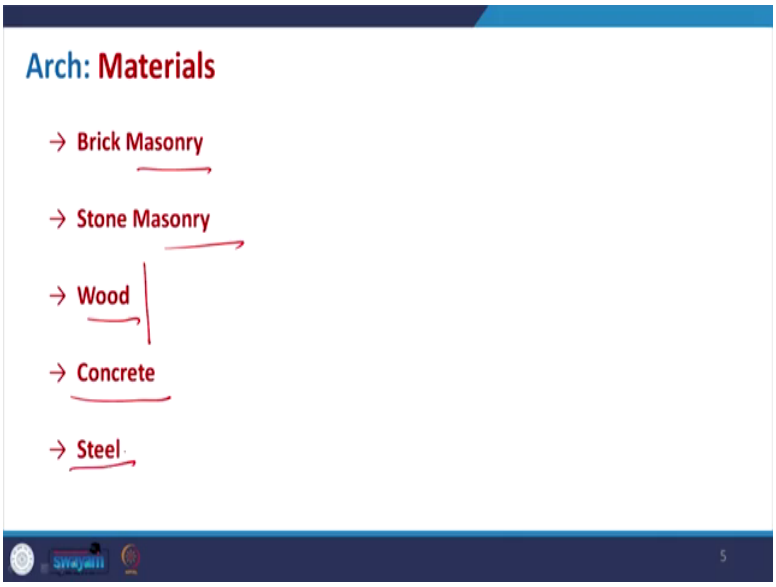

Now, coming to the material that can be used. So, any material can be used, but normally the material used in the history or in the recent times, the beat masonry, the stone masonry, sometimes the wood being used is very not that much easy to corrupt the wood. So, like different seasoning is ward or making two pieces, the button how you form this particular arch. The concrete arch is also possible with the proper reinforcement and all and then steel arch is being prefabricated and can easily be made as per the requirement.

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Now, let us go through some of the beautiful arches. So, some this is very natural arches that being formed that due to some you know airflow and all these being created.

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So, it is you can see that how it is being sustained and this is something where mostly arch being used for making the bridges like maybe it is small or maybe large, but big masonry was used to create this arch which will help to distribute the load effectively. So, this is being used earlier, and then the revised form of these like where in this picture you can see those areas are filled with masses to you know support it more.

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So, in that comparison; so, here you can see that particle members they are tied up with this particular arch where the concrete being used huh. Here the big machinery being used or the stone machinery being used and in this case it is the concrete arches.

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Now, coming to the two examples; the two famous places like one from the Mumbai and Delhi; the India Gate and Gate Way of India there also is not acting like a on the support to the bridge or something, but here it is just representing the door way. So, this is also very attractive. So, here you can see that how it being formed in both the cases.

And, looking into these two pictures you can identify the geometry of the arch in this case it is more semi circular, but in this case it is not, it is something different. So, there they are creating a point. So, it is point edge arch at the same time like if you take this. So, this particular arches so, it is coming to the equilateral arch that will discuss, and then different ornamentation, different type of other arches; segmental arches will discuss in that.

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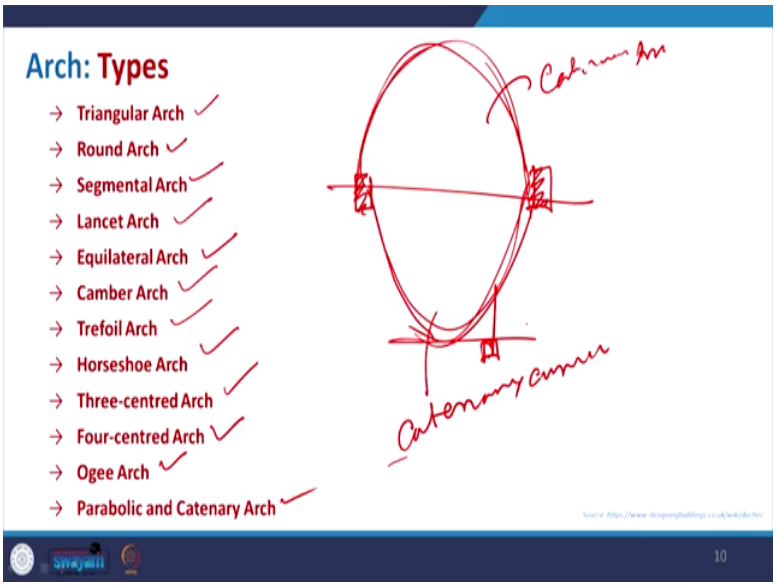

Now, the type of arch is based on the geometry. So, there are like quite a number of different types that being used. But, most commonly the way we can classify the arch is something like the triangular arch, the round arch, segmental arch, lancet arch, equilateral arch, camber then trefoil, then horseshoe, three-centred, four-centred; you can even increase the five-centred, six-centred arches then the ogee arch, then one of the important one is your parabolic and catenary arches.

So, this is basically where again I am referring the example that you just take a chain and just let it like seg due to its weight. So, you will get some shape like this, this is the best possible way and if you add some load to it; so, it will readjust and try to give the shame. So, this catenary form is very useful and when you reverse it with the material so, that will give you the arch. So, this is your what we call is your catenary curve and this is your catenary arches.

So, normally when this particular is free only carrying the self weight and all we refer at the catenary, but when that is been taking some weight of a deck or something then we just call it the shape is changing a little bit ah, it will be parabolic then then the parabolic arch will form.

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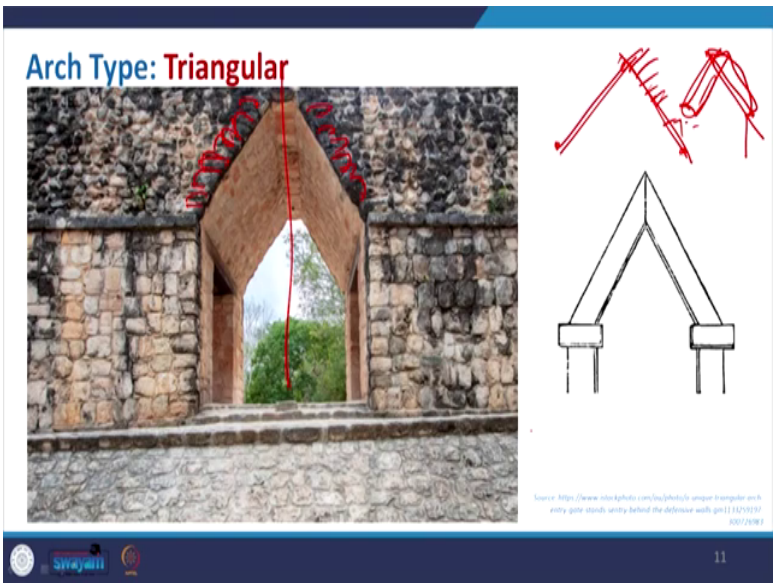

So, let us see some of the examples. So, the triangular it is very simple form where two members just being supported like this where it can be a combination of brick or sometimes earlier even this arch was formed with a single stone. So, two stone keep putting together in this alignment which give this particular form.

So, this is door that particular door way, the opening is formed with this and if you see it carefully; so, this is basically you know ramble work of the stone masonry with lime concrete.

So, that is been created and again the symmetry to maintained; so, that the load will be distributed uniformly. So, this is the triangular type.

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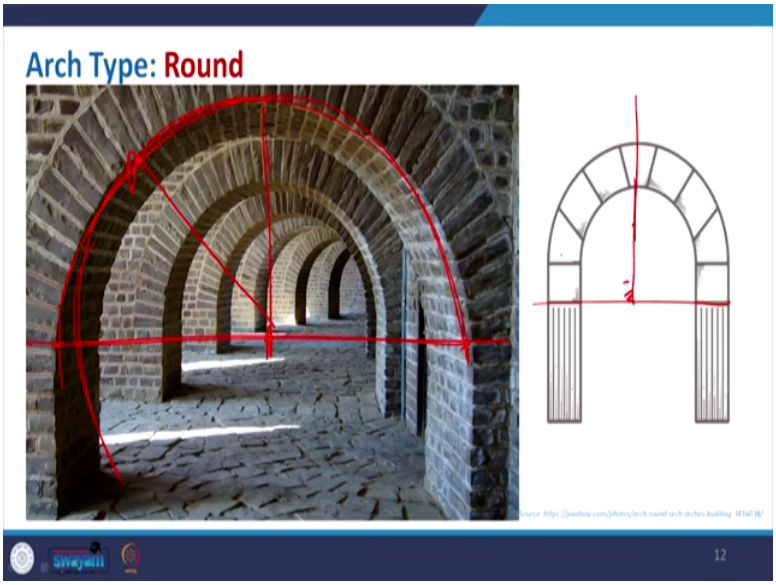

Then coming to the round type it is basically the form of this arch is giving or giving you a completeness of the circle. So, here in this case you can see can compare it, this is basically a semi circular thing where the centre is been fixed at this particular you know by section of this particular horizontal line and this radius is been rotated.

So, this is giving a round form and many at times like it is giving the symmetry. So, what we discussed in the example of India Gate where we found this kind of round arch so, that arch is being formed like this. And, here also if you see the distribution and the number of bricks the masonry layout it will be having the symmetry. So, again this is your centre so, then this will be your rise and it is giving a form of around.

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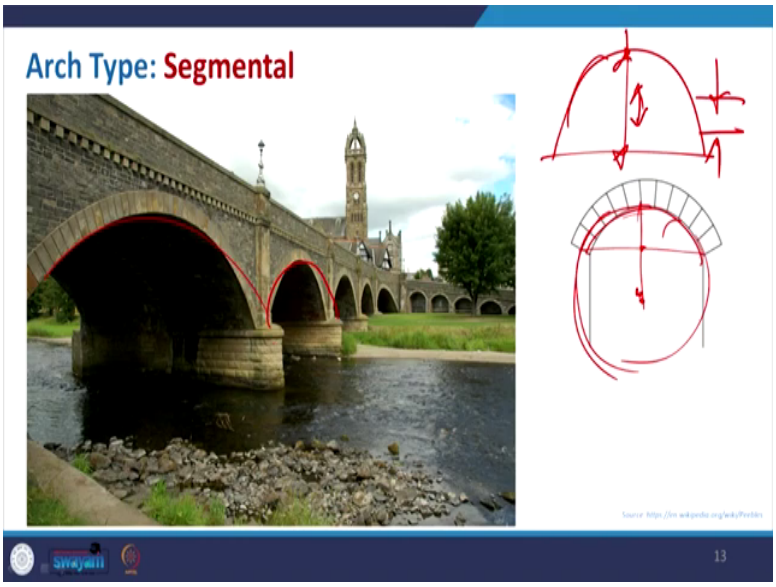

Now, coming to the segmental arch it is basically when you have a semi-circular arch and then you try to put pressure. So, you just try to make it little bit the, you know rise of the arch being reduced both the side. So, you just squeeze and then it will create the segments. So, in this case basically what you can see that it is the centre of this arch is now not at this, it is shifting someone like to complete it. So, it will shift it form that particular line.

So, the segmented arch being also used as because like it will essentially it will ah, you know decrease the rise of the arch and wherever you require this. So, in this case also if you see that it is not exactly the semi-circular, this is the segmented arch being formed in this particular bridge.

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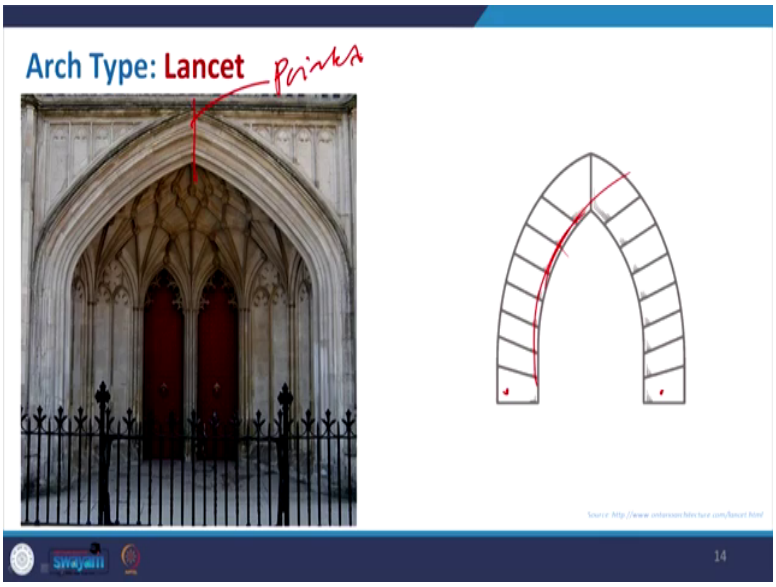

Now, coming to the lancet arch or it is also the pointed arch system where again like it is something not giving your you know single centre. So, this particular form that being created. So, that will have centres somewhere here and then it will have centre like this. And so, it is basically a pointed arch and being used a normally in if you see the byzantine and the post gothic architecture, then this kind of arches being used most commonly.

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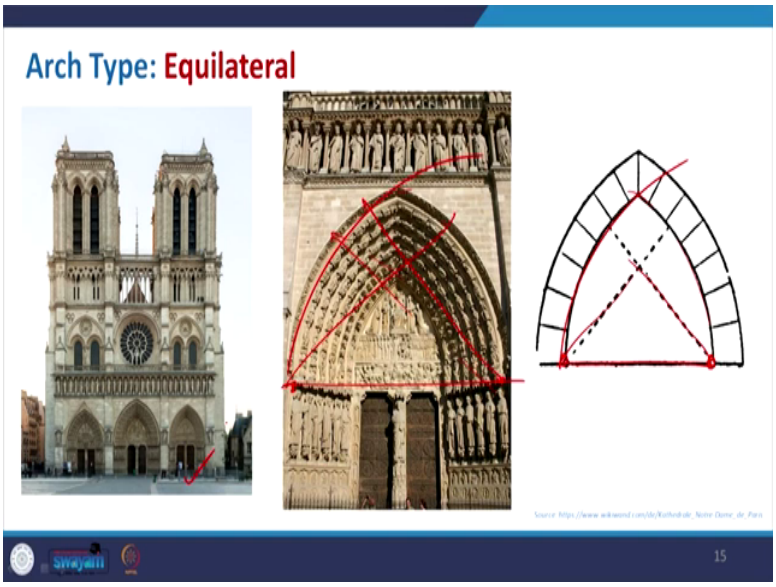

Then coming to the equilateral that we also found in the you know your Gateway of India in Mumbai. So, where the arch is formed it is similar to the one like the lesson lancet and, but here it is something where like the span wherever the both ends are considered to be the centre of the arch and then that will be forming this particular structure.

So, in this case also if you find; so, basically if you just make the circle. So, this is basically creating the equilateral triangle and then this arch form is called your equilateral arches that you can see here. This example of the charge and mostly like those kind of arch is being used in the roman, byzantine and then not the roman the byzantine and gothic architecture.

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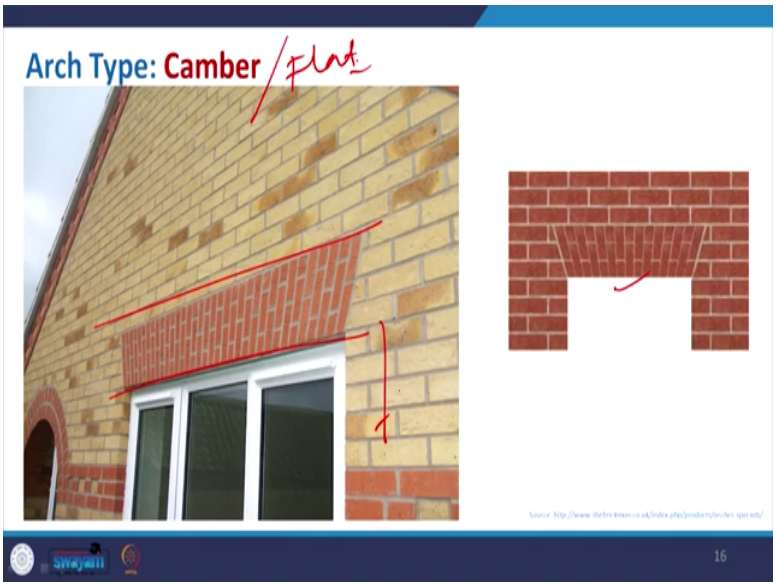

Coming to the, you know camber or the flat arch. So, most commonly in the area like in Germany and also this kind of architectural treatment been seen where like normally the you know the linden part of a window or something where this kind of flat arch been used to decorate it. Sometimes they can go with a similar material to give the structure the similar look or sometimes they can make a variation with the brick texture or the colour to have it. So, this is the flat arch.

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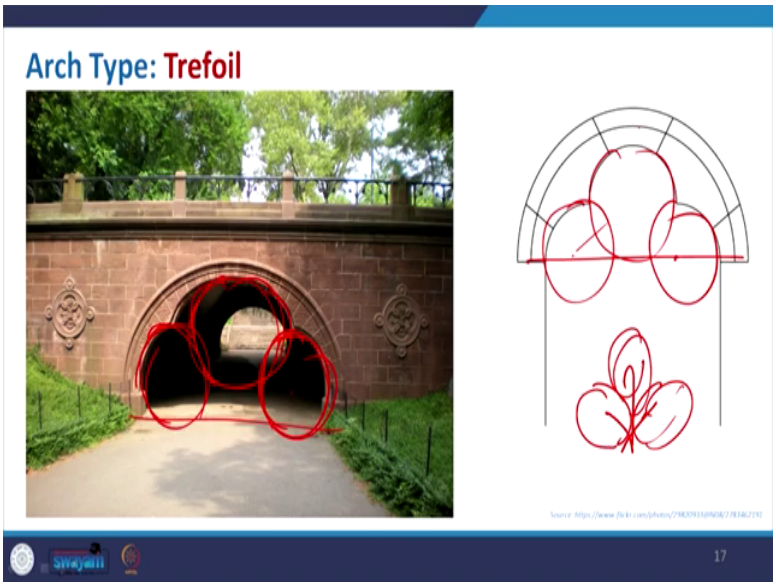

Now, coming to that the trefoil arch is similar to like what we can see the leave the foil of a tree. So, where it will form like this kind of you know structure. So, three circles like they have been using so, where the symmetry to be maintained. So, in this case also like if you see like and they are maintaining this particular geometry to create this. So, this is also some ornamentation to the art arch form that was used.

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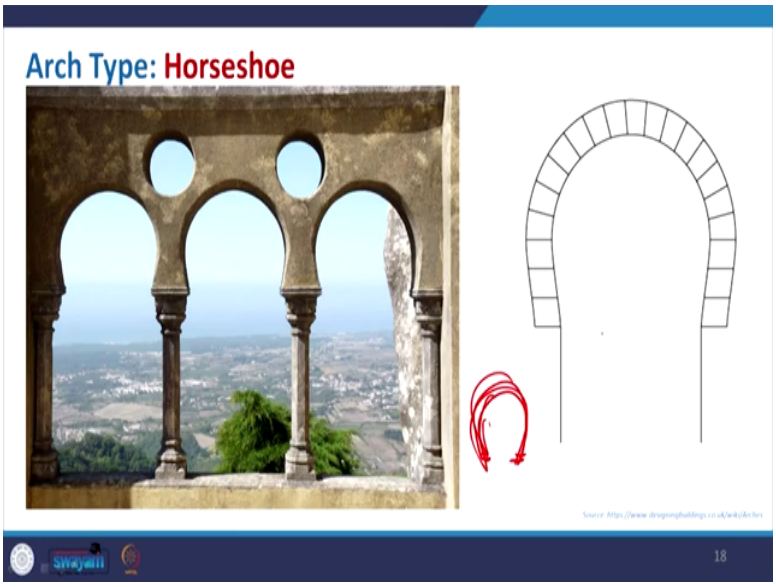

Now, coming to the horseshoe. So, in this case horseshoe is basically the profile that we have this kind of magnetic like horse magnet horseshoe arch where this being formed like this. So, this is again very useful and many many examples that we can get from this; the formation is same. So, this is a schematic where it will look like this.

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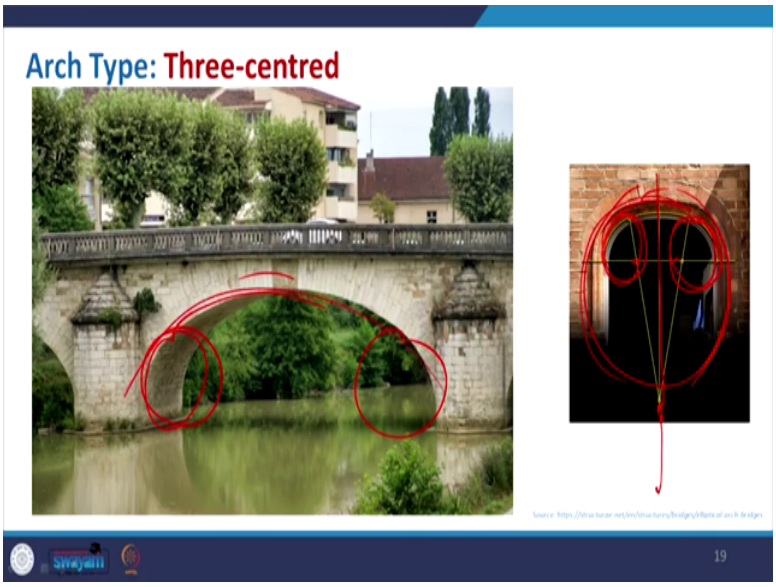

Then see three cantered arch is something where you can get something like where it is not basically the trefoil kind of, but here it is where you have the arch form. So, here you have a circle then you have circle here. So, two points and then basically what you have your connection like with the same perpendicular line and you have a bigger circle. So, in this case the arch is controlled by three points and then that is why it is called three cantered arch and here you can see the example of this.

So, where the three centred arch when you go a like you know deeper and deeper your upper portion of the arch will be flatter and all. So, if sometimes you require this kind of you know arrangement of arch you can go with that where here also you can get this. So, this is a very bigger circle with a centre at the bottom.

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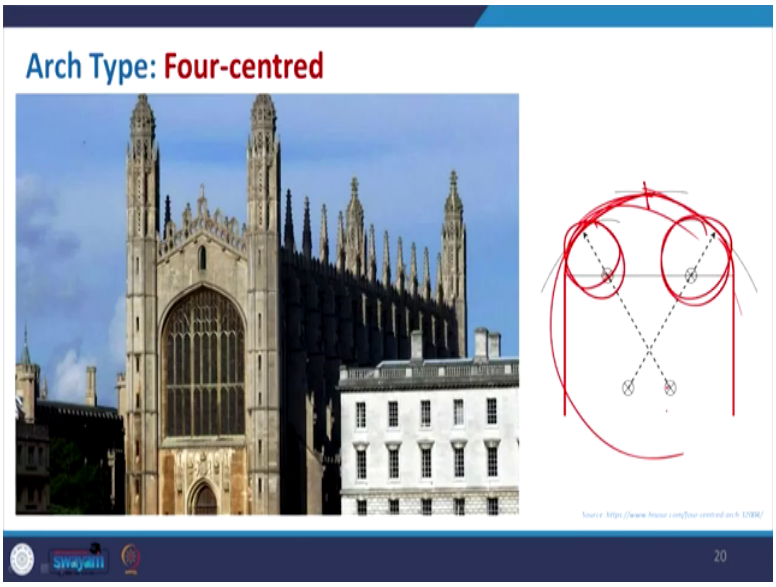

Now, four-cantered arch is something where like it is something again you can control it where you can go for a pin joint and you can create it. So, here you can see it with this centre we can have the circle in these two position and then controlling this you can have a bigger one like this and you can have a bigger one like this. So, controlling it like how you if you increase the number of you know points then you can create different geometry. So, this being used to the four centre arch in again the charge mostly in charges or this places this is being used.

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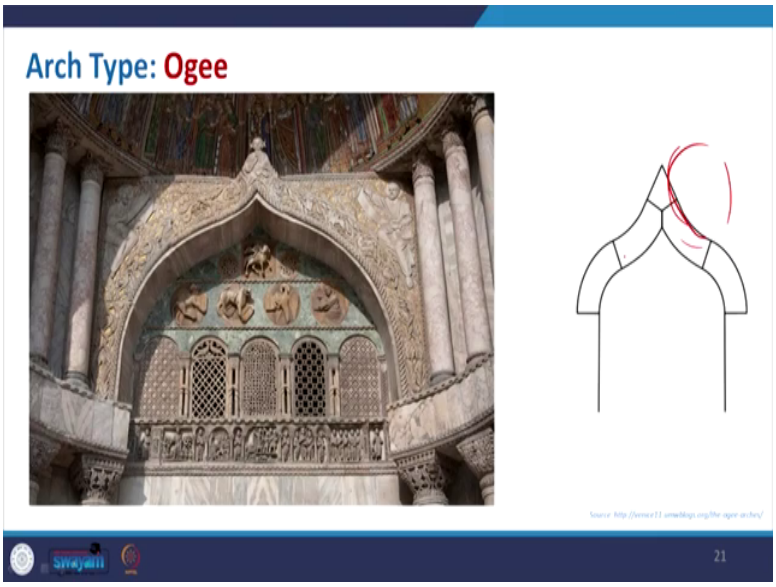

Now, the ogee arch is looking something where like not at the same direction, the arch is form in the other direction and give some you know dynamic form; so, this is the ogee arch being used. Now, coming to the parabolic and catenary arches.

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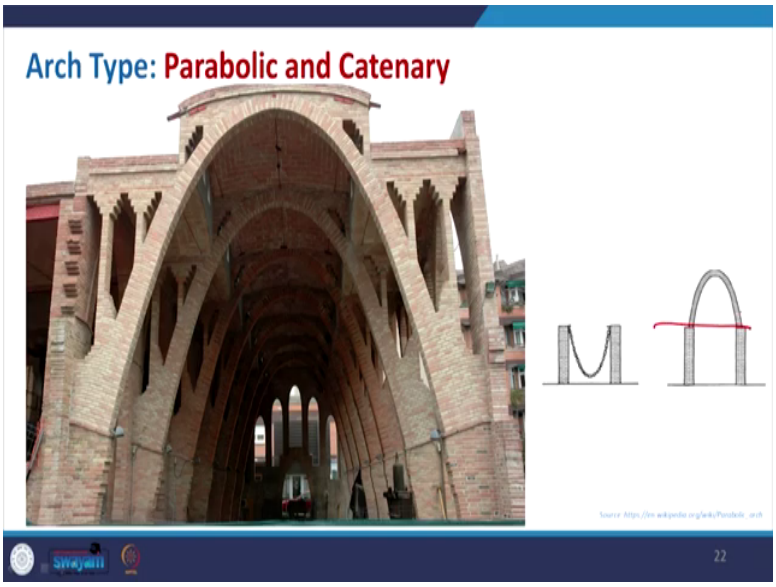

So, that we already discussed that if you compare with this chain and all is just the reverse of that will give you this catenary form.

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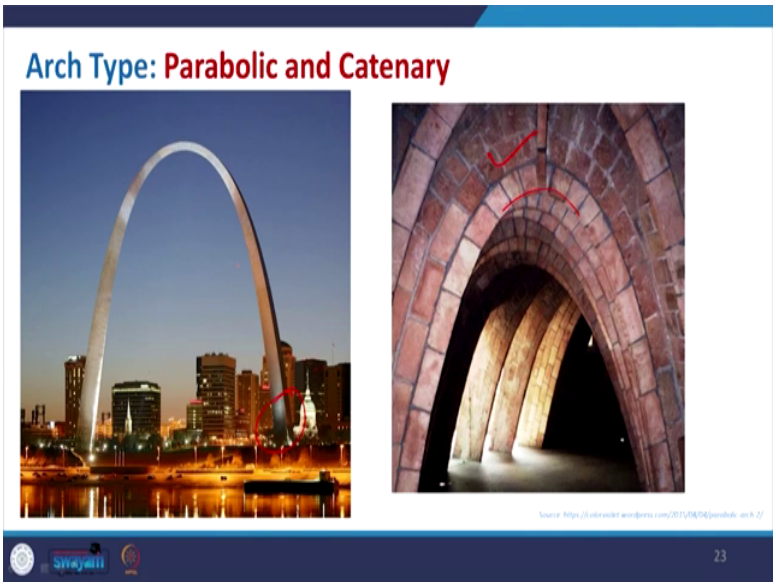

So, this is one example that is make with the machinery, now you can see this is again like this is the great arch where there also you can use the, you can see the masonry here it is something where made of some different materials. So, this huge structure is self supporting and really creating something interesting space over there.

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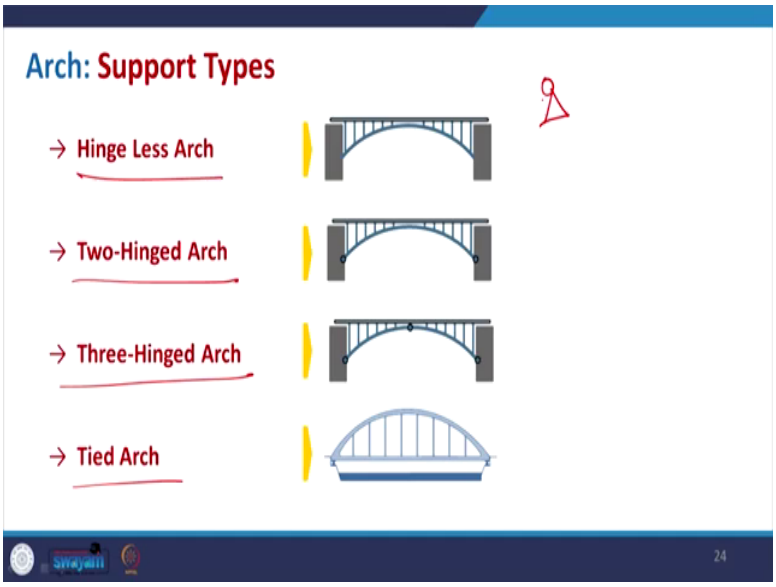

Now, coming to the support. In this support what we can have that hinge less arch where it is being just fixed then you have the two hinge arch. And, this reference is these particular examples are related through the bridges, because it is being used; so, you know bigger manner in creating those bridges that we have seen in some of the examples that the segmental arch or maybe some densities it is your lancet arch or something. So, then you have three-hinge arch and then tied- arch.

So, looking at the schematic here, you cannot see some pin joint or something it is also referred as a pin joint. So, in the frame structure we discuss the fixed joint and the in joint here also it is the same.

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Now, coming to the hinge less arch where this arch is formed and it is just fixed fix to the ground. So, it is fixed with the ground and by which it is transferring the load, again symmetry to be maintained that is there in the hinge less arches.

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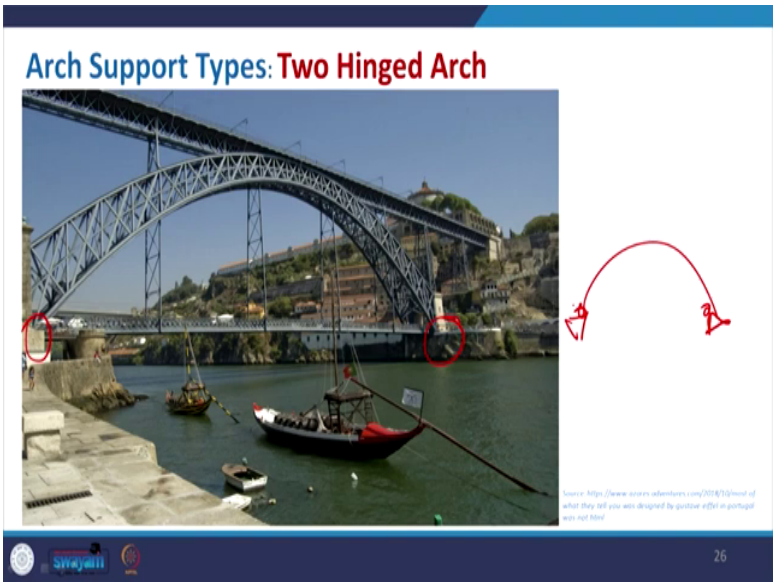

Now, coming to the two hinge where two hinge is being provided the two support if you really go through it. So, at this end so, that being supported with hinge. So, then compared to fix this is the two hinge joint and being supported.

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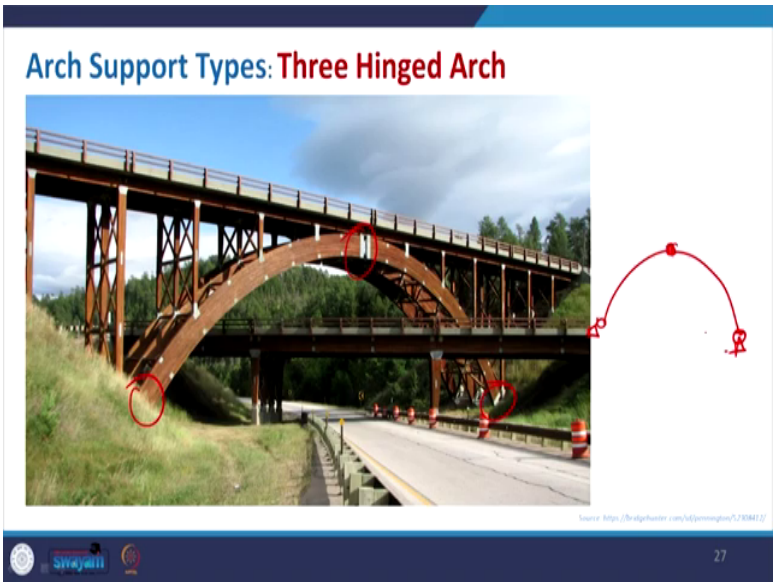

Now, coming to the three hinge joint along with the two hinge at the support both the ends. So, one hinge is also provided. So, basically it is giving the joint like this. So, it is the application of three hinge joint and this is just to create a bridge to create the overpass on a particular expressway.

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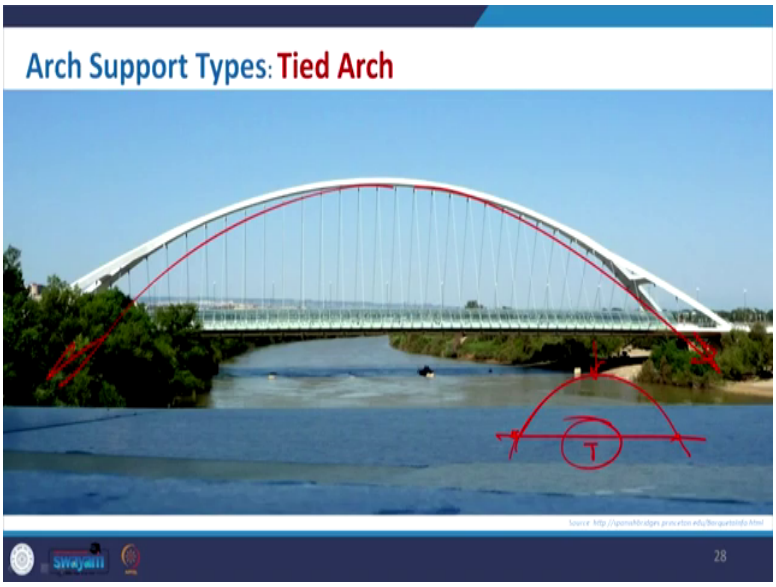

And now coming to the fourth category that is the tied arch where along with this support you also tie this particular member to the bridge. So, in this case you know though this will the comprise because of the tight so, tension will be developed at this portion. The earlier case if it is not tied; so, it is full of compression, giving support to the you know the bottom of your arch that will transfer to the ground.

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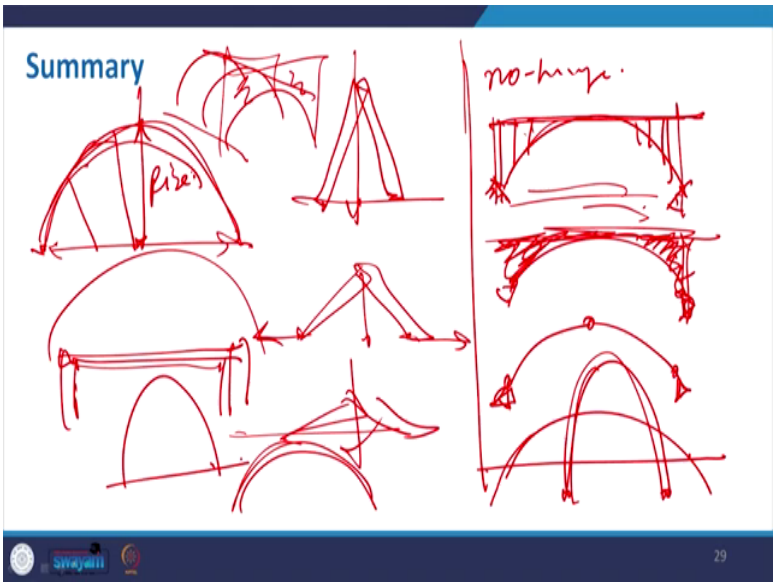

Now, coming to the summary. So, arch is having advantage because it is basically depending on the geometry of the arch, it is distributing load through it is curvature to the support the piers or and finally, it will go to foundation. And the advantage that with arch you can create the large span and there is a relation if you know decrease the rise of the arch; that means, the lateral the outward thirst will increase.

So, in that case we can say that compared to a beam and column. So, the arch is a better form which can actually reduce some horizontal load. So, this is something where you can actually experiment with taking two books and you just make this alignment of the books like this, then it will be more stable.

Now, you just lowered the rise of that and you just make it little flat. So, what you will feel that it will have a, you know increasing the horizontal force and if you make it even flat it will collapse. So, this is the very basic example where you can experiment with.

So, depending on the rise increase in thrust the, we know outward thrust will increase if you decrease, if you lower down the rise of this. So, like in the this is something where like you can understand that with change in rise how like the arch outward thrust will improve the horizontal force will added to that. And that is why, the based solution to it is just go with this parabolic form and all, and some of the buildings even the buildings designed by Antoni or Gaudi and all, they have like used those architects, they have used this particular form.

Now, in the second part of the presentation what we discussed is basically the support condition of the arch bridges. So, we first discussed about the no hinge bridges where like this particular arch form is being just supported with the fixed end just you know across the river or some locations. And in the to hinge system those being supported with pin joint or the hinge joint and compared to that like when we have gained a pin in between. So, it is converted to your three pin joint and also we discussed that not only this joint along with that we also have some examples.

Some bridges where this arch is tied with a horizontal member. So, depending on the support and depending on the situations we can really go and we have seen a very good number of examples where the arch being used so nicely that overall aesthetics of the bridge or the structure is really appreciable. So, the advantage of arch that what we discussed that we can go for the higher span, but the limitation to the arch is whenever you use this arch form.

So, definitely the top portion of that arch is basically where you have to compromise with the space. So, whenever in any structure like you know you have some you know hanger or something where you just repeat this arch form of the frame and then you just cover with the light material, but you cannot use this particular volume with the very regular structure. So, then you have to make some arrangement and then you can support it with something.

So, the bridges you have seen that sometimes you just use some tension members to create this or sometimes even like you just feel this portion that we have seen that brick masonry and that earlier that we can feel this portion to support the structure ever on top of it.

So, like that here we conclude the advantage of arches and the material that can be used sometimes we can have this you know arch form. On the frame for the window or door which is made of wood that can be done or with a steel that is very possible or else sometimes also we have seen the catenary arch that here the huge catenary arch being formed with some material like the concrete and steel.

So, there is no such constraint with the material that can be, but this has advantage over a like your simple beam column structure, but proper geometry to be maintained the you know shuttering of the arch is very crucial where in frame structure it will be very easy to support it, but for this you have to support it with proper care. The centring of the arch the shattering that improve the structure to be built to make the arch form and the symmetry to be mentioned maintain is very critical, otherwise it will give more advantage in the structural form.

So, here I conclude and you can go through many examples and I advise you this you just go through different kind of you know support joint arches being used in that you make a comprehensive list and we can discuss over it and enhance the example list of each of this type. So, these are the further reading that you can go through and also you can go through those you know website link given in the respective slides.

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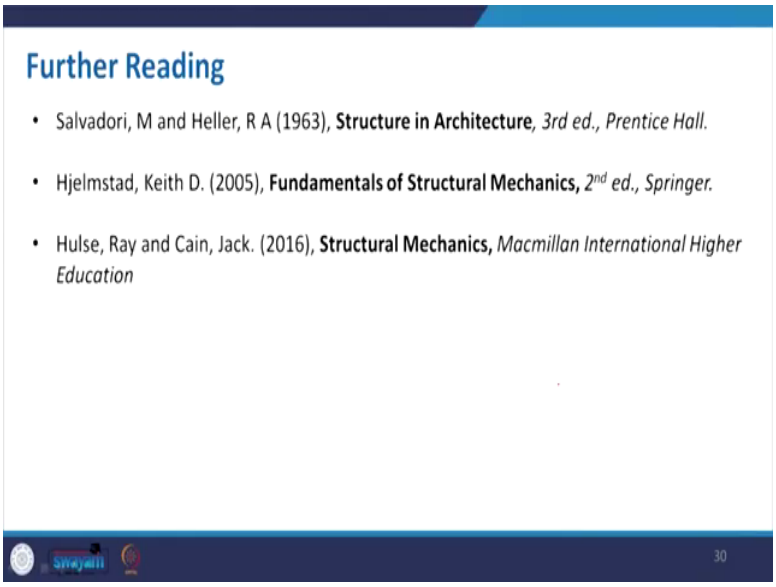

So, with that I end of this lecture here, the next will be discussing with the vault which is also derived like from the arch basic form in the upcoming lecture. So, thank you for taking part in this particular course and we will be again meeting on lecture number 23 that is a vault structure.

Thank you.