Maintenance and Repair of Concrete Structures
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Lecture - 29
Structural Strengthening & Stabilization – 4 (Joints and Connections)

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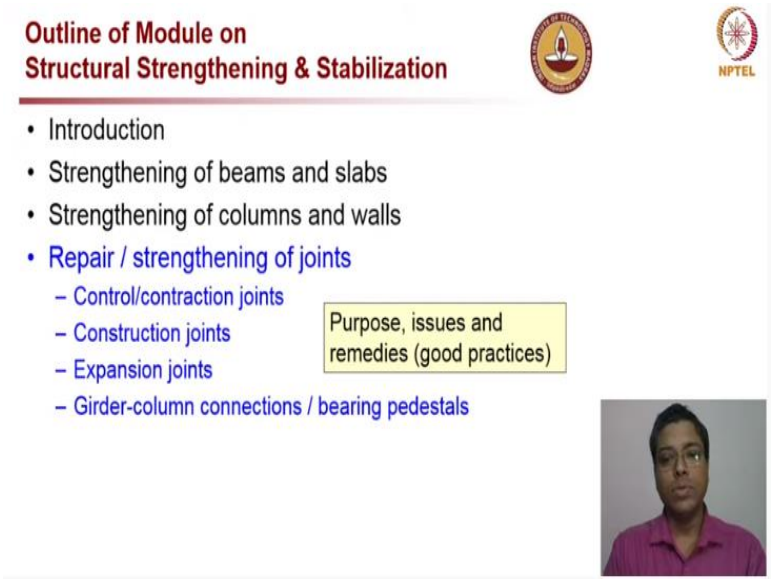

Hi, welcome to this lecture on joints and connection which is part of the module on structural strengthening and stabilization. So here we will look at basically the purpose and the issues faced and the remedies or rather good practices of various types of joints. So, when I say joints here, we are going to look at control and contraction joints and then construction joints and then also expansion joints. And then finally we will also look at the connection between the girders and columns and what are the various durability related issues associated with them or bearing pedestals and how we can repair them very briefly we will cover that.

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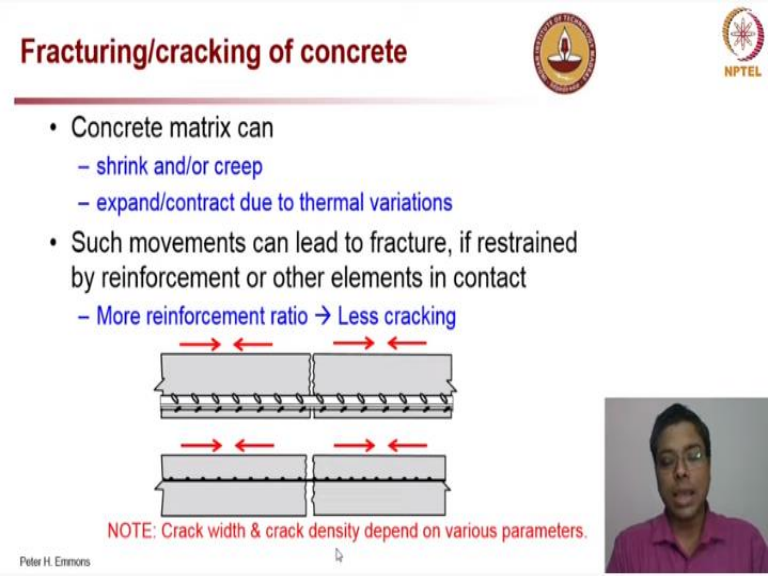

Now concrete we all know can crack and fracture and why it is happening because concrete can shrink or creep and here, I am not talking about the structural load-related issues but rather the material properties where mainly shrinkage and creep plays a major role especially in the long term and so concrete can expand and contract due to thermal variations also. Now such movements can lead to fracture of the concrete if the concrete is restrained by the embedded reinforcement or other elements in contact.

So for example very simple thing if you look at the pictures below you can see the one at the top has more reinforcement ratio than the one at the bottom and in such a scenario, we can expect that the one with the more reinforcement will have less cracking or to be precise maybe less crack width. But the crack width and crack density also depend on other factors, so I am not getting into more detail of those.

So these the red arrows here that you could spend these red arrows here indicate the direction in which concrete shrink the one on the left side shrinks towards the left and the one on the right side so that lead to the crack formation.

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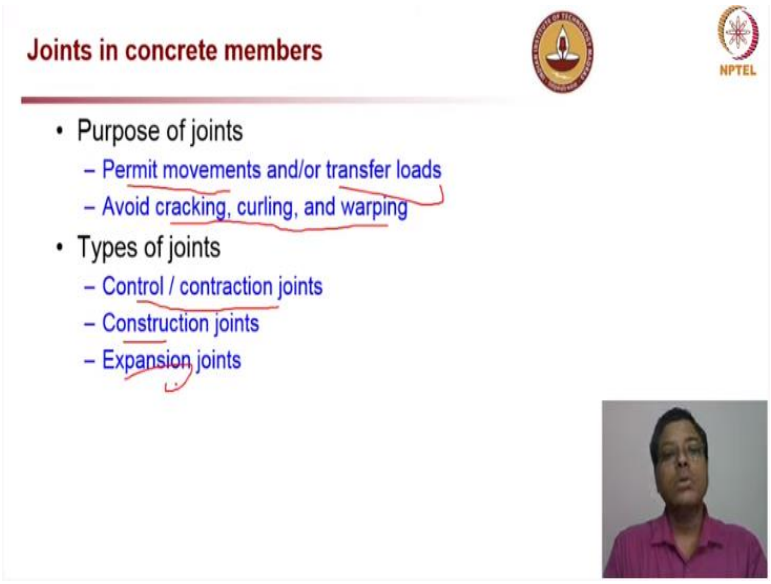

Now, what is the purpose of joints in concrete members mainly the idea is to prevent movement and or transfer loads. To prevent movements and or transfer the loads at the same time when we do this we also try to avoid cracking and curling and warping. But also, there are types of joints that we provide not to avoid cracking but to control cracking. So those types of joints are called contraction or control joints and then we have two more types of joints that have construction joints and the expansion joints.

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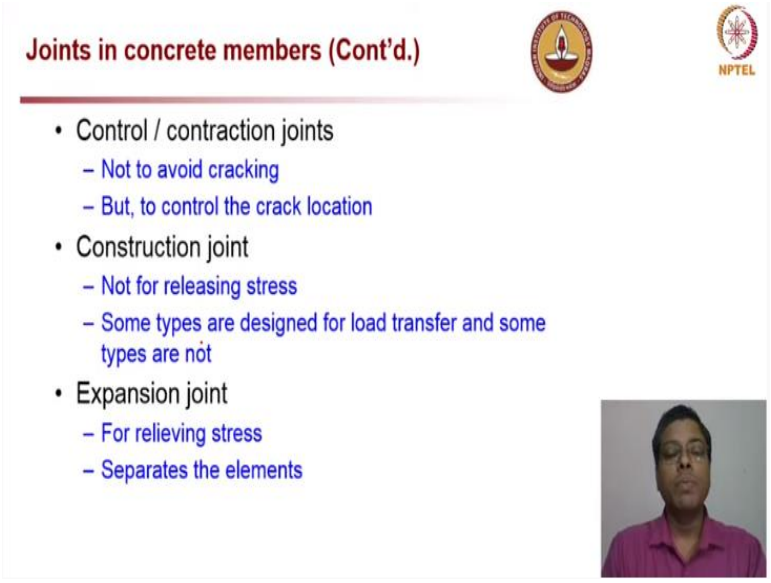

Now joints in concrete members so these be three types of joints control joints, contraction joints that can be combined, and then remember they are not to avoid cracking but to control the crack location. So, wherever we provide those joints we force the crack to happen right below that joint.

In the case of the second case of construction joint they are not for releasing stress there are for designed for load transferred actually through those joints the load can get transferred and there are also some types of construction joint where we do not expect the load to be transferred across the joint.

So, we will cover these things more detail later this slide just gives you a bit a summary of this. And the main purpose of the expansion joint is to relieve stress and it does that by separating the elements on either side of the joint and sometimes we also provide the expansion joint to prevent the generation of the stress. Especially when we talk about thermal-induced stresses.

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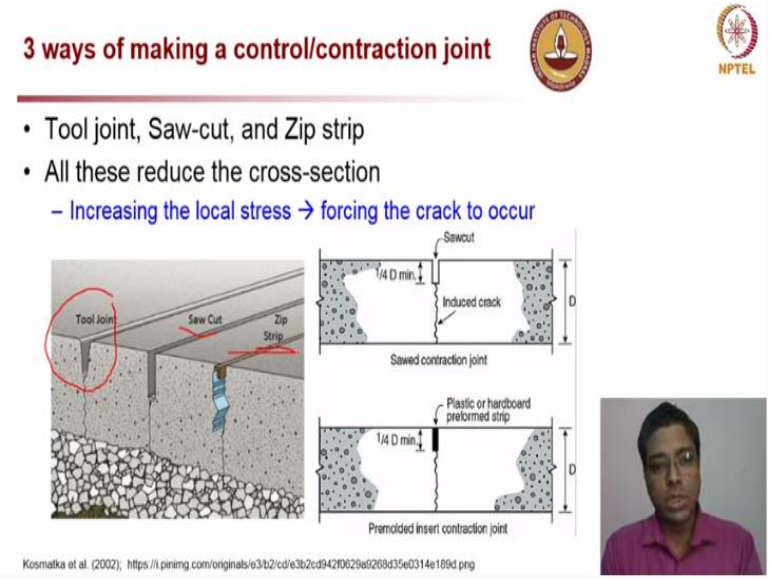

Now there are three ways of making control or construction so now we are getting into the first type of joint which is the control or contraction joints. Three ways by which we can do this is tool joint which is provided on the picture on the bottom left the first image which is this the tool joint and then the saw-cut which is this and then the zip strip which is the third one over here.

So you can see there are three types of contraction joints or the ways by which contraction joint can be formed but the purpose of all the three are same the idea is they reduce the cross-section of the available cross-section across that vertical plane which when the load comes will induce more stress right at that section and that section will lead to the cracking or it will crack before the remaining portion of the concrete.

So this is the whole idea, the whole idea of providing the joint is to reduce the cross-section which will eventually lead to an increase in the local stress and which will force that concrete right there to crack before the other parts of the concrete can crack. So that way we control the location at which the concrete cracks.

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So, these are the examples of good contraction or control joints slabs on the grade you can see three different ones. This one at the bottom left looks very good because it was made by a nice tool which has that particular shape and not just a trowel but a trowel with a particular shape with V groove in that and this type of joints can be provided or any slabs on grade kind of systems industrial floors pavements and the most important thing here are the providing adequate depth and spacing.

As I showed a picture in the previous slide so this is where on the right-hand side sketches you can see that where we are providing induced cracking and the depth one-fourth of the total depth of the element that is how it looks like this one here that is a typical or typical depth to which you have to cut. So that you can induce the crack right below that. The picture at the bottom also shows how the crack.

Once you cut the saw provide the saw-cut that portion should be filled with some material typically an elastomeric material or a hard plastic also is provided. But the idea here is it should not be a space for the soil to collect. So, it might not look good also, so you have to have that crack as it is.

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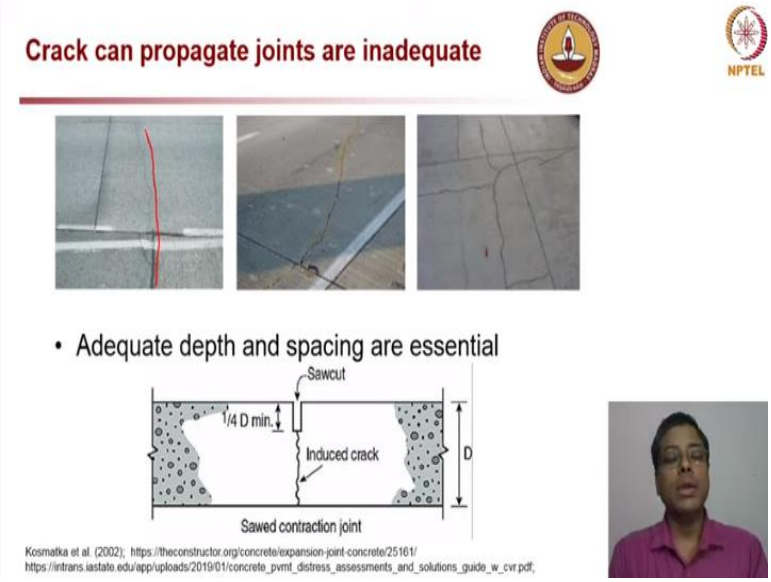

So, this is an example of a couple of examples showing inadequate provisions of these Saw-cuts. What you can see on the three photographs on the top is that the crack like for example here the crack follows here and then it just continues to propagate in this direction. So, when why that is happening because it is inadequate and the shrinkage on the other part of the concrete is probably more.

And then if we have, we were providing joint probably here, here like this then probably it could not have this crack would not have happened rather than crack would have occurred right below the new Saw-cut. Similarly, here also you in the second photograph also you can see that the crack the spacing of the Saw-cut is inadequate so when and the third photograph also very clearly shows.

So here if this the Saw-cut was properly provided something like this we can see something like this then you might not have had this much of cracking or the crack would be right below, and the structure will still look without like a look like a crack-free structure.

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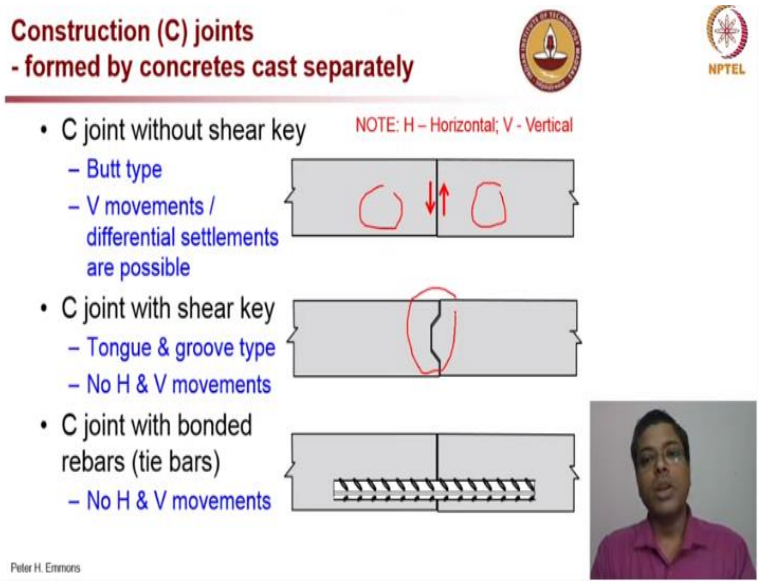

now let us talk about construction joints these are the joints that are formed by concretes which are cast separately what it means is. In the previous one when we talked about control or contraction join both the concrete on the left and right side of or either side of the crack of the joint was the same concrete cast at the same time. But here the concrete which is cast the one on the left side like this concrete is cast at a different time than this concrete.

So, the two are separate concretes the same design and all that but it has just cast at different times. So, you have a very clear joint between so in other words when this is done it is mainly to help the construction practices. So, to make it easy for constructing sometimes it is not very easy for casting monolithic slabs, etc. So, we go for smaller elements like in precast concrete and so that is major applications of all this and wherever you cannot really cast large sections in one go there we go for this type of construction joints.

So, the first one is a butt type joint where the vertical movements are allowed which also sometimes leads to problems like differential settlements, etc., which is indicated by those red arrows on the first sketch. The second one is a joint with a shear key, I am talking here, the joint with a shear key where it is like a tongue-and-groove type joint and I will show photographs later. So, in this type of joint neither horizontal nor vertical movements are allowed. Very limited movement.

But it is theoretically it is not really allowed they are supposed to stay together and prevent it from moving horizontally and vertically. And then C joint the construction joint with bonded rebars the one at the third also sometimes known as tie bars not that these bars are not extending like here. These bars are not extending they are only about maybe one to two feet across the joint. So, it is not like a continuous bar which goes through the entire under the structural element, but it is just at the joint like a dowel bar but not a dowel bar actually. So, no horizontal and vertical movements are allowed in this case also.

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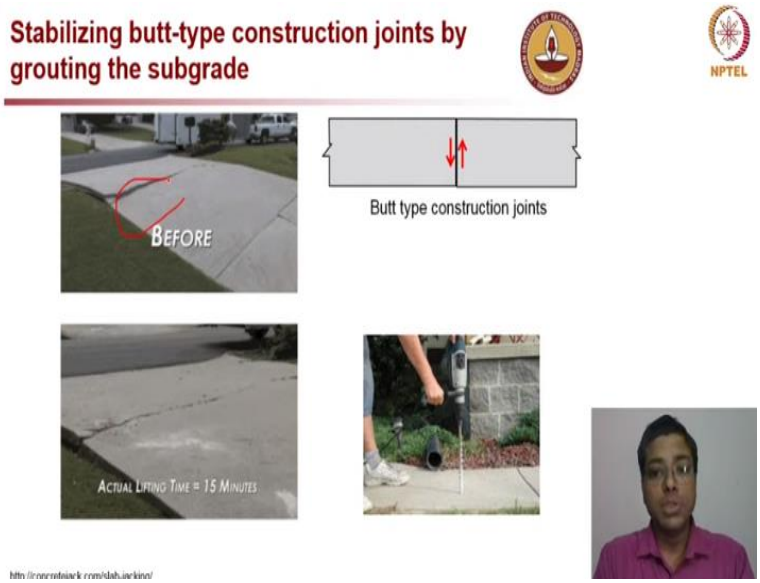

So, we will see one by one. This is the first one Butt-type construction joint basically stabilizes how to most of the time we have this problem when these types of joints exit, I already told there may be settlement-related issues. So, you can see the picture on the top left which very you can see a settlement right here and such problems can be avoided by drilling a hole on the like this here.

Drilling a hole here, you can see a drill a hole here and then grouts that subgrade below that slab and then so that that will lift up the slab and then make it look at uniform surface. So, you can see that bottom left picture there is not much settlement it is done by grouting.

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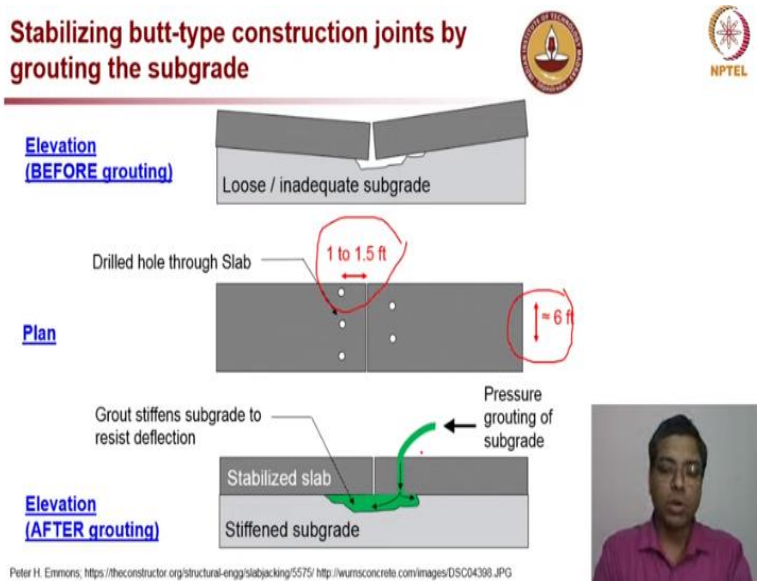

So, this is how it is done a sketch showing that the first image. it is the elevation of this butt-type joint system or like a driveway imagine loose inadequate subgrade is shown and because of that the slabs are settling, or differential settlement and it is an uneven surface. So drilled a hole through the slab. On the second, the plan image if you look at the plan drawing you can see there are five holes drilled or three on the Left slab and the two on the right slab.

It is just an indicating I am not saying how one should be 3 and one should be 5 or anything that is just that you have to drill holes on either side and the spacing of the hole from the edge. So, this is about 1 to 1.5 feet and whereas in the other direction, the spacing can be in the range of about 5 to 6 feet. So, the idea here is once you drill this hole you pump the grout the green color grout you can see the green color indicates the grout.

You pump the grout into the space below the slab and then allow the grout to stiffen and then make the ground stronger and it also helps to lift the slab upward and you get a flat surface or a horizontal surface as it is desired. So, this is the whole idea behind this grouting the subgrade and then stabilizing or repair practice like this.

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So, these are some examples showing how this is done it is not only theory in practice it is widely used, and we can use it in many places. You can see the picture on the left you can see lifting practice going on here and here also you can see the person is drilling a hole and then pumping the grout into the slab or the space below the slab and also not only the driveways there are also such kind of projects are done on typically on the approach road slabs etc. or bridges or anywhere where you have concrete slabs. These are done mainly on rigid pavement systems or wherever concrete slabs and you might have seen somewhere we have problems on one slab settling more than the others. So, if you want to level it this is a very good practice to adopt. Grouting the subgrade and polymer type grouts are used of different types of grouts.

And so that you can lift and really penetrate into the soil material below and stiffen the soil material and then make sure that until the surface of the concrete of both the slabs are even and that will also make the rider comfort that will increase the rider comfort.

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Again, examples of construction joint with the shear keys. This is the second type of construction join where we discussed this kind of shear key in couple of slides earlier where they are mainly used in segmental bridges slab on grade and also on tunnel linings. So, you can see here on the picture where you have segmental bridge you have shear keys like this is to avoid the vertical movement of these segments.

So, you can see here also lot of the shear keys. I have seen many places where these shear keys also are broken before the installation during the transport etc. And that is something which is very important, and the people do not some I mean sometimes they do not give much care to these shear keys. Because I have seen places where segments being erected without repairing the shear keys.

Let us say it is just, but it is not like that you have to have all the shear keys should be taken with care they should not be damaged. Because if it is damaged then the purpose of the design is lost and that is again when we talk about how to prevent its the concrete should be good enough to resist the impact load or the shear resistance of the shear key region should be good enough high enough so that they do not really fail.

So that is again designers' job to ensure that the good resistance is there. This is the second picture on the right side if you can see again a positive tooth here and let me show this one you can see the negative side of it. So the right side shows the tongue and the other side shows the groove so

it is a tongue groove system so that these slabs can be used for this is typical precast elements for roof elements or high-rise buildings. These kinds of elements can be used the one on the bottom it is showing basically you can see here this is lining for tunnel segments you can see the slight step on this and that kind of indicates the tongue groove system and the other side it will be negative so it matched cast very nicely. So, these are some typical examples of construction joints.

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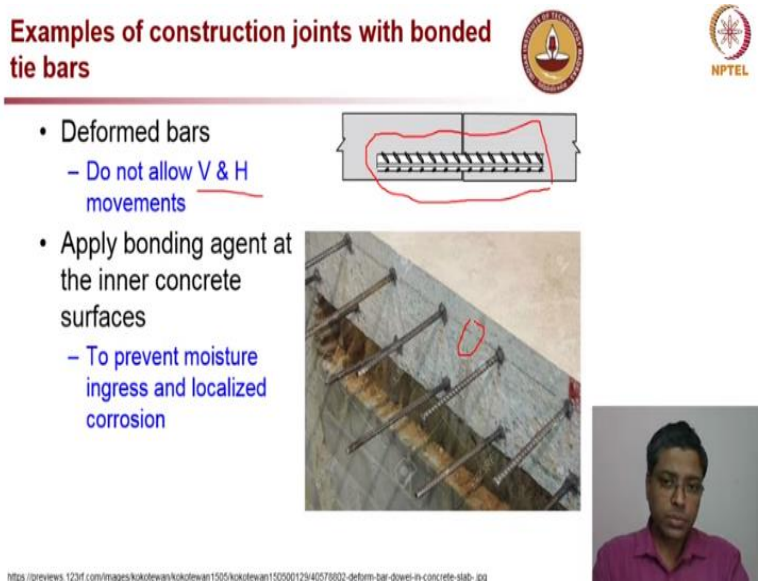

The second type of construction joins with the tongue groove system. Now examples of construction joints with bonded rebars or tie bars so this is the tie bar I was talking about earlier and it does not extend beyond a particular length typically one to two feet on either side of the joint. Now they do not allow either vertical or horizontal movement. Because the vertical movement is resisted by the shear resistance offered by the rebar and horizontal movement is resisted because of the ribs on the rebar.

So, they just do not allow any movement and this is a good technique which where you have difficulties in casting large areas and then you still want the same surface level to continue. So in such cases, these types of joints are widely used you can see the image here where this surface here is cast on one day and then after these bars are provided then the remaining part the bars will be embedded in the other concrete which is going to come.

Then they provide good resistance again both vertical and horizontal movement. One very important thing when we talk about this kind of joints is the concrete on either side even though they are cast at different times they should be very well bonded otherwise what will happen is the small gap or the cold joint which is formed between the two concretes will function like a fine crack in the system and the reinforcement at the crack at the joint will be exposed to moisture and then lead to localized corrosion.

So, to prevent such problems we have to ensure that these type of joins when we go for, we should make sure that adequate bonding between the two concretes are there and one thing which we can do is use bonding agents. So before placing the second concrete, you apply them in a bonding agent on these surfaces this surfaces here you have to apply the good bonding agent. And so, all these concrete surfaces which you see apply good bonding agent and then that will ensure that the concrete and apply sufficient quantity.

So that it does not lead to any sort of moisture leakage throughout this especially this region you have to really make sure that the water-resistance of the joint is very high. Otherwise, you will end up having localized corrosion and once localized corrosion is there then these bars will not play their role of shear resistance. They will be very weak in shear at that section. So that is something very important to note down when we talk about this kind of joints.

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Now in this kind of joints, I just put this picture to show that there could be unparalleled rebars you can see that these bars are not really placed in a parallel fashion. But in this case, because they are really designed only for vertical shear transfer and it is not expected that these bars will be an expansion joint type strength is movement in the horizontal direction so this could be in this case.

However, such the joints are NOT in such unparalleled dowel bars are NOT in the case of expansion for this kind of construction joint it is, but not for expansion joint.

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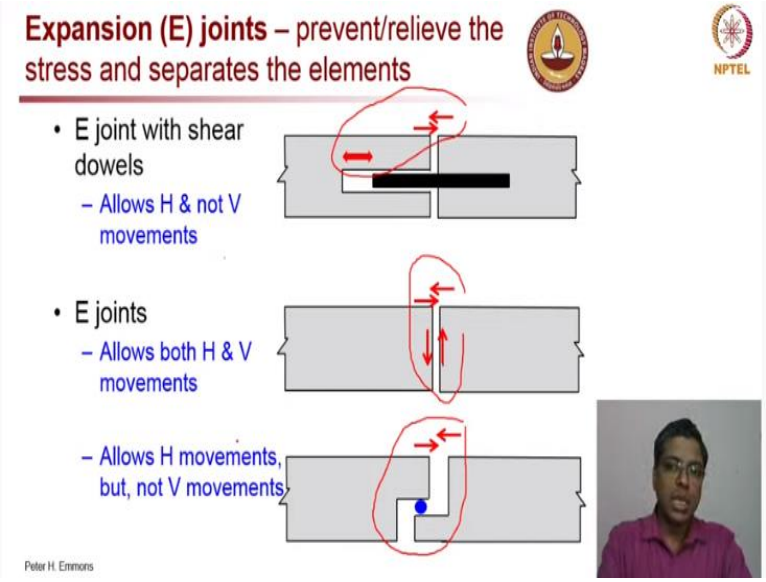

Now expand now let us talk about those expansion joints. There are three major types of expansion joints which I am going to discuss in this lecture. The first one is with the expansion joint with shear dowels and before getting into that there we already talked. They are mainly used to prevent or relieve stress by separating the elements . So there will be some space in between the elements which will allow space means either it could be an air space, or it could be a space which is filled with an elastomeric material or which does not develop much stress when there is a significant strain.

So, we will see how that is done one by one so the first one is an expansion joint with shear dowels where it allows the horizontal movement but not the vertical movement it is not designed for vertical movement. So horizontal movement is allowed like this you can see here that is allowed

and expansion joint in the second one it allows again both horizontal and vertical movement in this case here.

And then expansion joint in the third case where it allows only horizontal movement and not the vertical moment. So we will cover these three and in the second case, I must mention this even though when you talk about the second case the vertical movement is allowed but there are other systems which are put in place to prevent those kinds of vertical movements by other support systems which I am not going to talk here I am going to focus only on the joint area how they look and all that.

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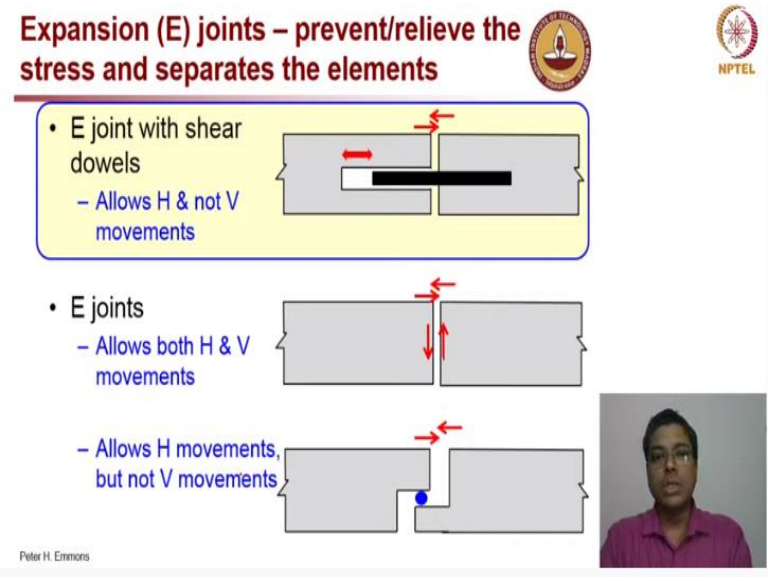

So, let us talk about this dowel bars or the expansion joint with shear dowels.

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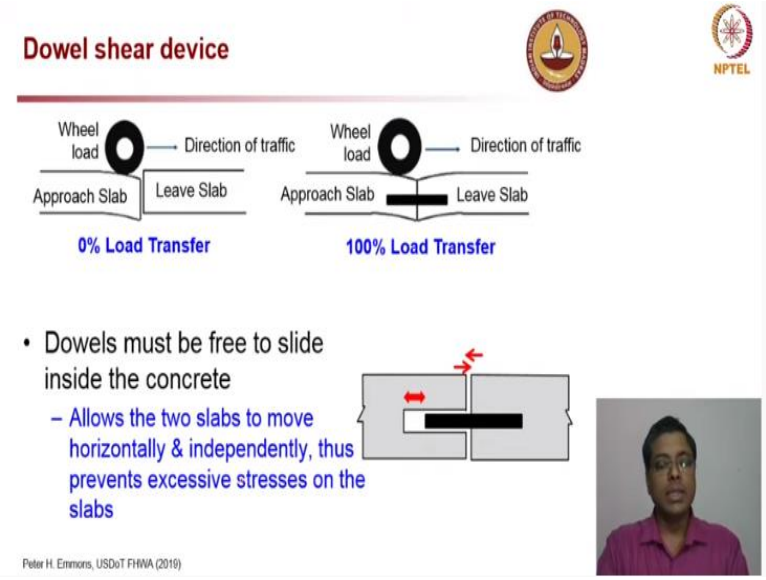

The picture on the top left you can see a wheel load moving towards the right and then is an approach slab and a leaving slab and where you can very clearly see a settlement over here. Now you can think about that we when hits the leave slab you will hear it is a discomfort to the rider and it might also damage the wheels in the long run maybe. But this is not something which is come which is good or comfortable for the rider. Imagine the case of a concrete highway if every slab you have this problem you hear this sound tuk tuk tuk tuk sound every slab and that is not something which is comfortable. So, you have to have a smooth transfer from one slab to the other. So that is shown in the second picture here which can be possible by providing dowel bar 100% load transfer from one side to the other and also you have a smooth movement of the wheel from one side to the other.

Now main thing about this dowel bar is it must be free to slide inside the concrete free to slide and it allows the two slabs to move horizontally and independently. It is very important it move allows the horizontal movement and also the independent movement of these two slabs. So, because of this, it does not allow the stress to be developed so it does not; so, there is sufficient movement possible. So, the two slabs do not come and hit each other, and it prevents that stress generation.

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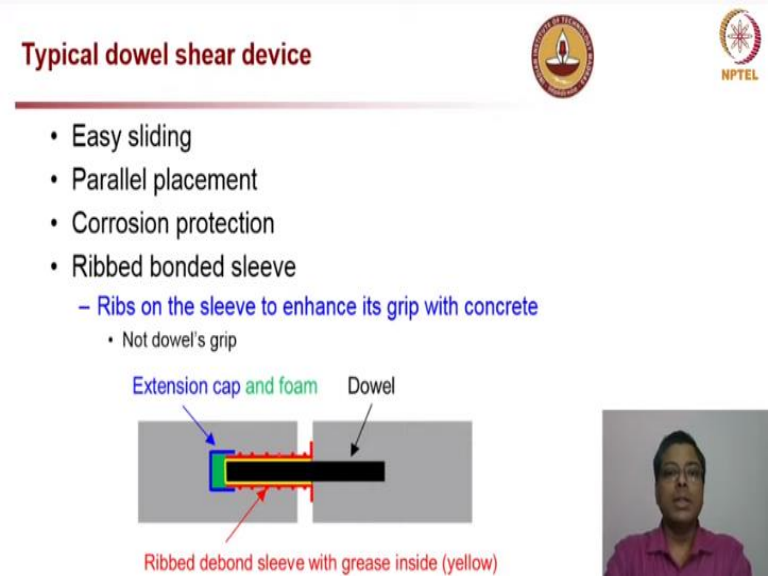

now typical dowel shear device looks something like this. This is the same picture which is shown on slide one also. So, you can see it is not just providing rebar at the intersection it is you have to have a smooth rebar which provides the easy sliding we call it dowel and then parallel placement is very important. If you have multiple dowel bars you have to provide them parallelly otherwise they will not function as a single system.

And it will the alignment of one will have an influence on the movement of the other . So, we will cover these details in detail later, but these are the 4 major things which we have to think about. Of course, it should have corrosion protection and also a ribbed bonded sleeve. So, the sleeve is very important may need to protect but why I put this as a fourth point is the ribs on the sleeve is also very important.

It is not just providing a sleeve but because then the sleeve itself might slide in the long run. So, this you have to keep the sleeve in the same position in relative to the slab on the left side so it should not move. So only the steel dowel should move inside so that yellow region here it indicates the grease and the red one is the ribbed sleeve and then the blue is the extension cap and then the green is the foam which is placed inside. So that the dowel can still move to the left without creating any stress and we do not want airspace there something some material should be there so that it is always better in the long. Because if you put air then the grease might flow from one side

and they will go and settle in that space, so you do not want any air space inside this that is the key thing.

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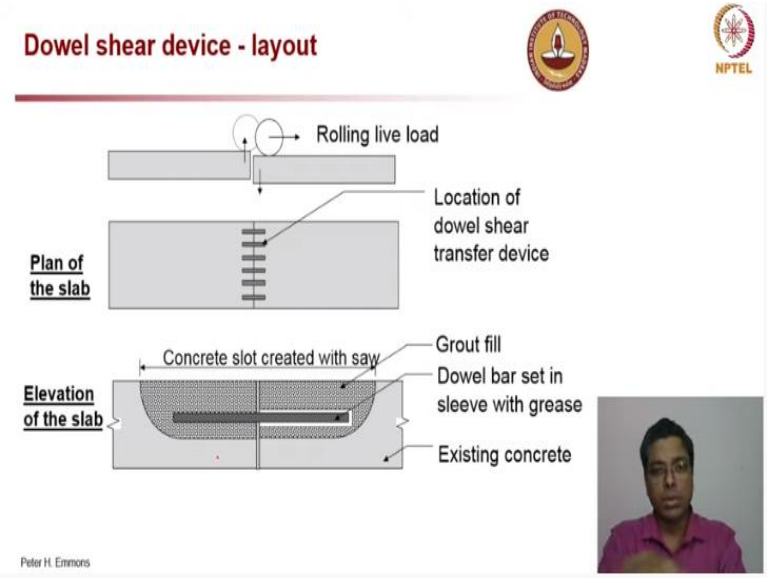

Now dowel shear device layout how this is laid out typically as shown on the shown earlier also the first drawing over here this indicates how that local settlement and how to fix the plan of the slab is shown here how to fix. So, this is the top view of the dowel systems you can see all those six horizontal darker regions indicate the dowel shear device or the dowel bars. And then how if you look in an elevation of the system how it will look.

This horizontal thing here is a dowel bar this one is the dowel bar and then that is then covered by a grout fill. So, this is a grout fill you can see grout fill and then existing concrete is this thing I am going to show you for a sketch a photograph of a practical application after that it will be very clear.

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How it is so you can see here these dowel bars slots are provided where depending on where the wheel path or where maximum shear assistance is required. So you provide this dowel bar there and then the second picture shows how the dowel bars are placed and then so you can see this blue thing here that is also to show that the center of the dowel bar. So that it is not misaligned and then finally that whole slot is filled with grout and then leveled and then that is the final structure.

You can see that a nice repair work being done here, and slots are filled with grout and after diamond grinding to ensure that there is no unevenness right where the slots are. So, let me go back to the other picture. So, if you can look at this again you will know very clearly how the system is . So, the concrete slot is actually filled with the grout this portion is filled with the grout after placing the dowel bar.

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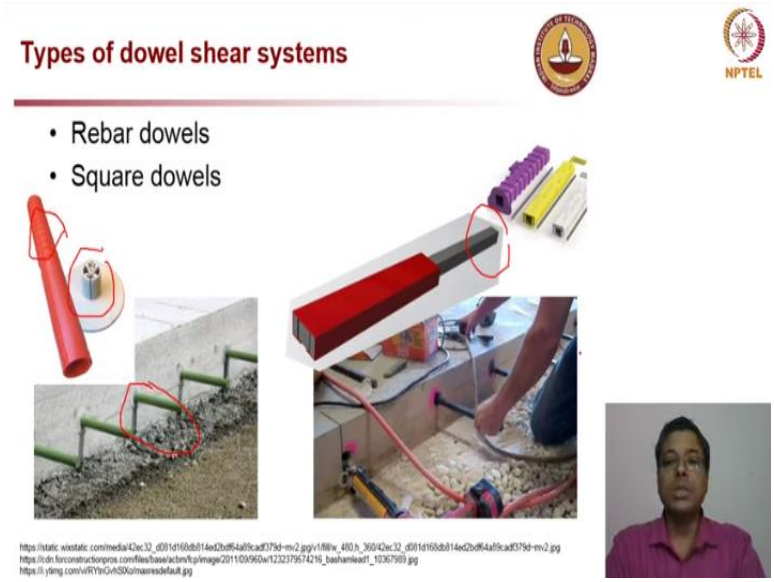

Now there are different types of dowel bars available the two of them rebar dowels and square dowels I will show two more in the next slide. But let us look at these two first. Rebar dowels are the most widely used one you can see the ribs over here as I discussed earlier, and this is the cap which is provided and then this is the rebar dowel how it will look and so that green color bar which you see there I mean it looks it is an epoxy coated dowel bar which there are problems with such type of bars I am going to discuss that later.

But as for a representation purpose I just showed this epoxy coated dowel system here so this should be covered with a plastic sleeve which will have a longer life and a cap and maybe you can put grease also inside and then the right one shows a square dowel you look at the shape of this it is a square not a circular one so essentially it is a highly shear resistant material which is steel provided here in different shapes, different cross-sectional shapes and here also this portion has grease inside. So, they really help in providing that shear resistance and at the same time allowing the horizontal movement.

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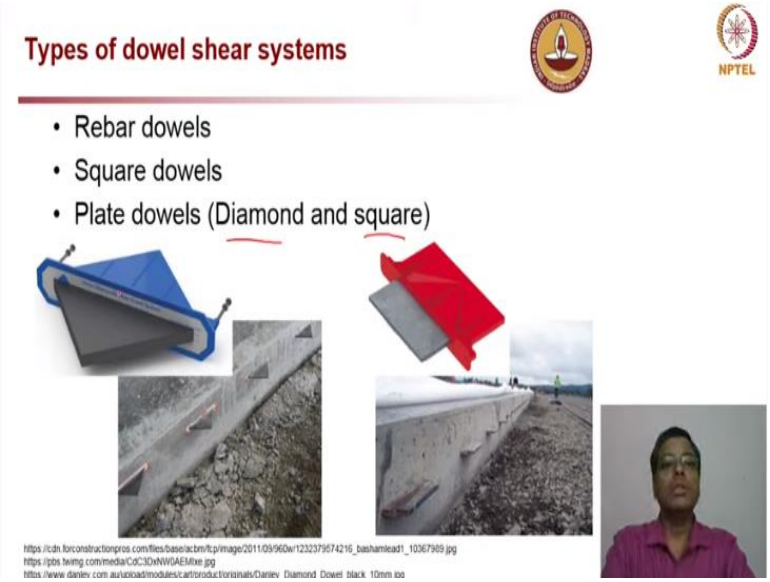

Now, these are two other type plate dowels where it also comes in general in diamond and square shape. So it is up to the engineer's choice what is the best for each particular project but most of them work in a similar way it depends on how much spacing etc. you need to have or how much movement you need to allow things like that. So here also in this dowel the plastic sleeve or in a plastic sheeting or covering you have and that if you provide enough grease inside that will provide enough flexibility or movement to the system.

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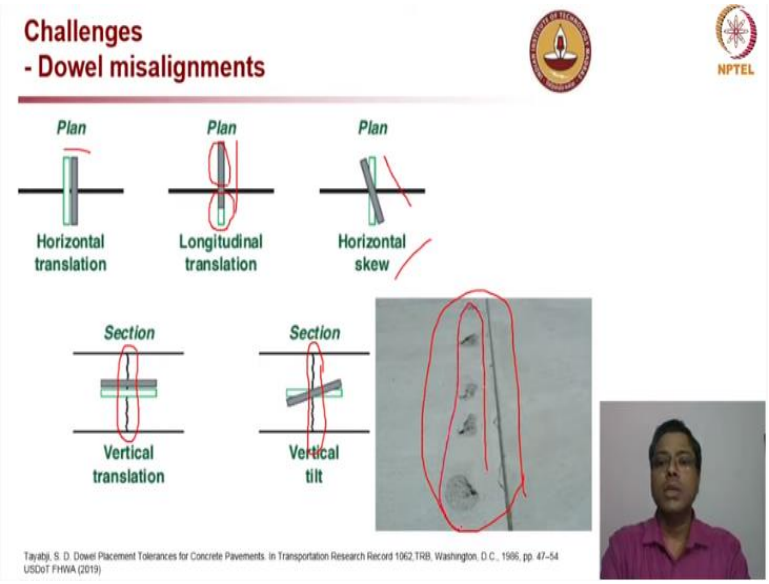

Now let us look at the some of the misalignment we are going to focus more on this rebar or the circular type dowel sphere systems in this lecture. The other three like the square and the plate dowels I just showed as an example to tell you that there are systems like that also available in the

market. So, dowel misalignment you can see here there are five different types of misalignment possible and they will have impact on the poor performance.

So first is horizontal translation you can see this unfilled rectangular region indicates the expected or the original location or where it is supposed to be, and the gray color region is where the dowel is actually placed. So in all the pictures it is like that all the diagrams so you can see here there is a horizontal misalignment and in the second case there is a longitudinal or in other words along the direction of the dowel itself.

In other words, on one side the thick horizontal black line indicates the joint so this dowel on one side you have less reinforcement than the other side than this side. So on the above the on one side you have more reinforcement than on the other side which is also not a good idea so you have to provide equal length of the rebar on to both sides of the joint and then here is the horizontal skew where it is kind of dowel is moving in that tilted I would not say tilt but horizontally it is not in the perpendicular direction to the joint.

So, these are all creating problems for the easy movement of in the direction of the dowel bar. Now vertical translation so this the bottom two sketches drawings are showing the elevation of the joint you can see this is joint now this is the joint and here also this is the joint you are talking. Now you can see here in the bottom left one you have vertical translation the dowel is actually placed slightly above than where it needs to be and the last the fifth image fifth diagram you can see that the dowel is in an inclined position.

So all these misalignments can lead to additional stresses when there is a movement of the concrete and it does not allow the dowel bars to move freely or slide freely inside the concrete that was the first requirement for a good dowel design dowel shear device. It should be allowed to freely slide inside the concrete.

So this misalignment if it is there it may lead to especially the horizontal skew and the vertical tilt they will lead to additional stresses and it might form something like this also you can see here especially on the left side you can see that these are mainly caused because of the vertical tilt and

while there is a movement they try to push the concrete and then damage the concrete surface. So, this is not something which is always acceptable.

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So, we have to see how to ensure that this is not happening. So parallel alignment of dowel bars are very much essential it can be done either in a manual way like it is shown in the left picture photograph or on the or use a dowel basket which is kind of an automatic system where you place the dowels and it ensures that all the dowels are placed in a parallel way like you see on the picture of photograph on the right side.

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So this is a picture showing how badly a dowel bar can corrode you can see here severe corrosion and even this bar is also started corroding this is actually an epoxy coated system with a cap etc. to prevent the damage on the corner but it did not really work out very well detailed study showed that these kind of bars can also corrode because even though it is epoxy coated we are using this for this is a system where the epoxy the coating surface is rubbed against the concrete on a regular basis.

As there is an expansion or contraction the concrete surface actually rub a is rubbing the epoxy coating and eventually because the epoxy coating may not be highly abrasive the system it will crack or the damage and then after that then the moisture will get in and then it will start the crevice corrosion and then or under film corrosion and that corrosion is much worse and you will expect localized corrosion.

So, this is not something which is recommended even though you will see in many places epoxy-coated dowel bars are used. I would request not to use such bars because even if at the time of placement even if they are very good coating. Because the design itself has this shear in parallel to the surface of the coating or there is a significant abrasion happening during the life of the structure there is a high tendency to crack this epoxy which will lead to corrosion in not very long period of time very short period you can expect this corrosion to happen.

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So what is the impact of that corrosion I have shown the same picture on this again on the left side because corrosion leads to expansive stresses the corrosion products have a larger volume six to eight times more volume than the steel then they expand significantly and because of that expansion the entire joint gets locked. So, the whole purpose of sliding of the dowel bars does not happen anymore.

The bars are now locked because of the rust formation around the bar and the space whichever is provided is filled with the rust and it cannot move anymore. Now what happens because the lock joint is locked right now the new cracks will form as you see on the second picture so you can see here the new cracks are formed here . So, these new cracks are formed and right where the dowel bars end.

So if you look at the **spacing here let me just erase this yeah** if you look at the spacing here from here to here it is the length of the dowel bar on one side or half the length of the dowel bar so exactly along that the ends of the dowel bar you can see the crack forming like right here . Now that is because all the dowels are locked now what happens is after these cracks are formed there may be a reduction in temperature or some shrinkage it can happen.

At that time what will happen is it will crack a widen that crack it will widen this crack this crack will get widened let me erase this so that you can see it. So, the crack will get widened and the third picture is also showing widened crack. The third photograph here you can see the crack is really widened I know it is a new crack which is formed is actually widened.

So, this is not something which we always want so and then eventually once that happens there is no more shear resistance for that location and then it will start deflecting and settlement and all that will happen.

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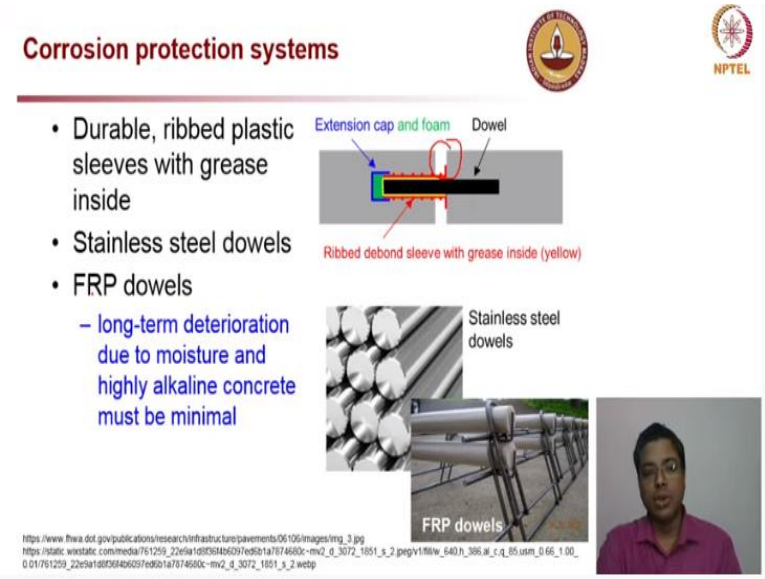

So what is the way out is either provide a steel dowel bar which is having a corrosion resistant steel and at the same time provide a durable plastic system which will have a ribs also to make sure that the **plastic is staying** the sleeve is staying in one place in relative to the concrete on the left side and provides some grease inside and a form inside at the end of the sleeve to provide a proper cap which is the green color and the blue color over there on the photograph in the sketch and then other way of doing is stainless steel dowels.

Before going further, I would also like to say that this portion should also be with some elastomeric material so that it if it is provided it will prevent the entry of other soil or water etc., to this to that intersection. So, this is very important to protect that intersection then also other ways are stainless steel dowels and nowadays we are also getting FRP dowels which are claiming to be corrosion resistant. Yes, metallic corrosion is not there because it is not a metal but at the same time you have to look at chemical deterioration of this FRP dowels .

So are they really resistant against the highly alkaline and moist environment which is present at the joints and what is the life of these dowels for that lifetime expected lifetime will this FRP stay in that is another big question and that must be checked before we straight away moving from steel dowels to FRP dowels. So, this must be put in the tender specifications etc., then only you will be able to really get that good quality product at the end .

Now let us summarize what are the key mechanical and durability features of good dowel shear devices. The dowel bar itself should have a smooth surface so that it can slide easily they should be placed in a parallel fashion otherwise if there are misalignments it is not going to function, and it will lead to mechanical damage or stress generation and local stress generation or prevent the sliding etc.

And then corrosion protection system you can use a corrosion resistant dowel material and at the same time use a good quality sleeve system or a corrosion protection system. Now what are those good qualities there should have a rifts which keeps them in place or provide good grip with the concrete the adjacent concrete and it is not to provide grip for the dowel but to provide grip for the sleeve .

Now enable the placement of the grease when you in place this is for a repair system. So there should be you should be able to do the placement of the grease and then cap to seal the grease and then good quality plastic for long-term performance and I would like to add this also this entire region should be grouted and if it if you are talking about a new construction then this region should also be perfectly protected from entry of moisture.

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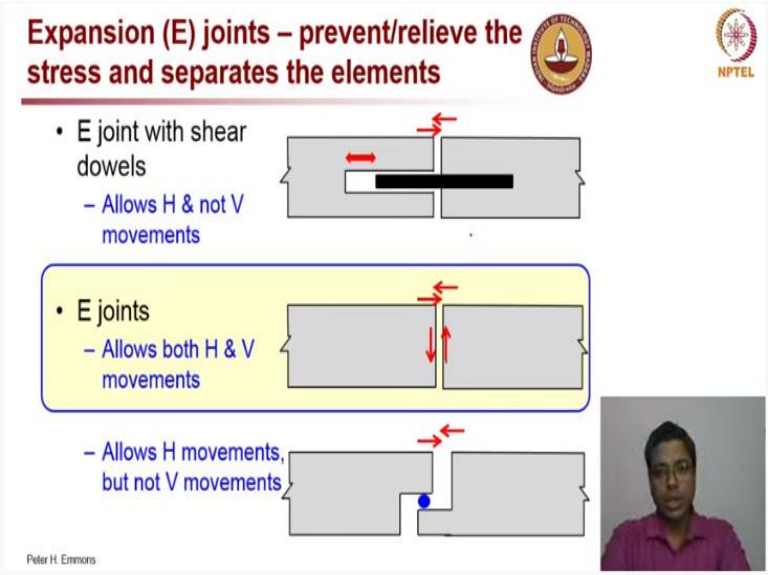

Now let us go into the second type of expansion join which is mainly free space we are not free necessarily a space between two concrete elements where it allows the expansion and prevent both horizontal and so allows both horizontal and vertical movements .

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So typically, this is how an expansion joint. I am going to focus more on a bridge structure in this section because that is where this is creating a big problem. So, I am going to show you a few slides with inadequate expansion joint systems. The first one here on the left side you can see a photograph where the blow of the photograph where the expansion joint itself is filled with debris like a soil or even the aggregate fine aggregate particles or the between particles from the road surface itself is coming and settling inside this expansion joint or the bridge surface is settling inside the expansion joint and the joint which is an unsealed joint and an open end.

So you can see that now actually speaking the when there is an expansion this material the debris inside the joint is not going to allow that expansion to happen and it will build the stress and eventually you can have scenarios like this significant blow up , so this is possible if you do not clean the expansion joint or keep it free of debris it is very important.

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This is also something similar happened you can see the girders also blowing up because of it so now you can imagine how much is that stress developed because of the thermal expansion so you have to provide sufficient space, or provisions for the concrete elements to expand without creating stress . So inadequate to overlay design is also another example sometimes I have seen places where the overlay is continuous without really having a joint. So that is not really a good practice you if you are saying an expansion joint it should look like an expansion joint.

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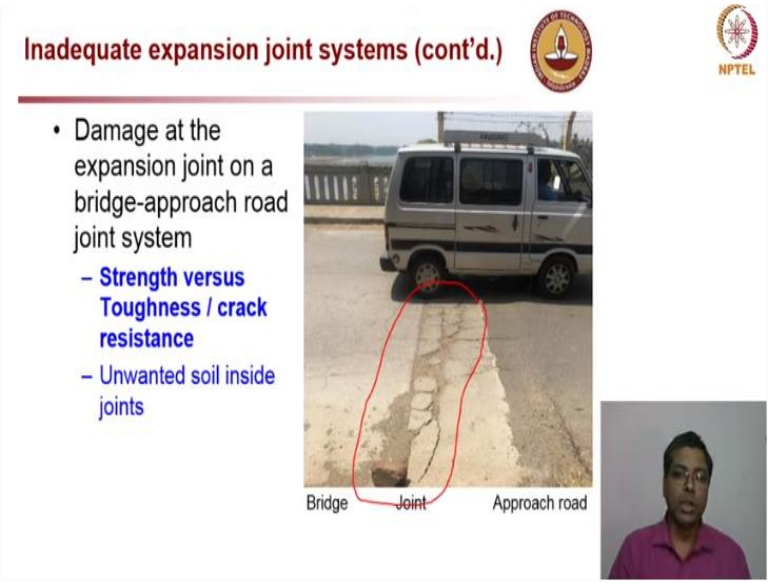

Now inadequate expansion joints damage at the expansion joint on a bridge approach road system you can see here where you have significant cracked concrete at the expansion joint. Here because yes, a strength is very important but at the same time toughness of the concrete is also equally

important if you want to prevent cracking of that concrete and also you can see unwanted soil, or inside the expansion joint.

So basically, this whole joint area is completely filled with soil which or sand which is going to prevent the expansion and then it is going to induce stress on the elements. So that is not something which we want to happen.

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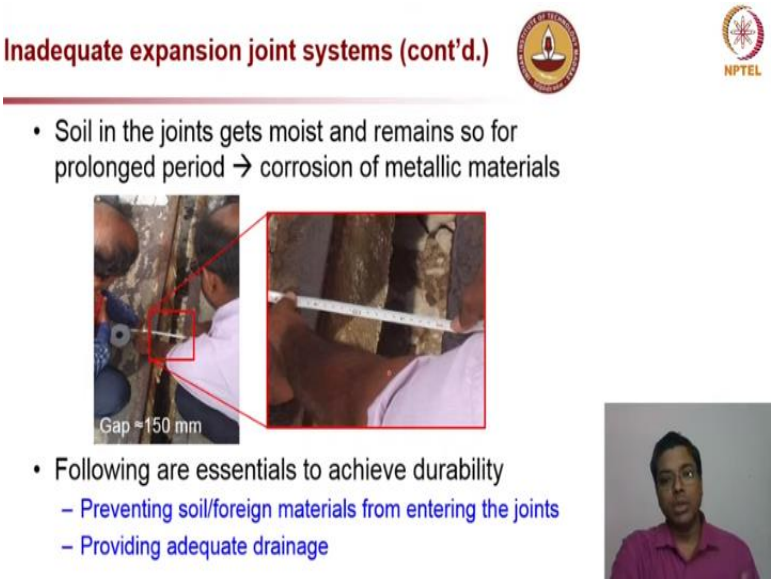

Yeah now I am going to show you other example of corrosion of expansion joints materials. Because in this particular case this is actually a photograph taken during the repair work or just before the repair work during an inspection we can see soil was filled in these joints and what happened is once the joint is filled with soil or debris during the rainy season or somehow if water gets in there that water will not drain out. It will stay there for long period of time which will then lead to corrosion of the metallic materials or the join system itself. So, which is not advisable to happen so what are the things which we have to do is. Make sure that these foreign materials or the soil whether it is soil or bituminous material from the overlay whatever that material we should not allow them to enter the expansion joint. If we allow them, make sure that there is a routine cleaning process and provide adequate drainage.

So that there is no water stagnation in that expansion joint. So this is very important now if there are expansion joints with open joints what we should probably do is, do something so that we

provide a sealant or some system so that either we prevent the soil or this material debris to enter that place that can be done by providing a sealant or make sure that we have a routine cleaning processes in practice.

That is probably the first one is more efficient and easier to practice because of the manpower shortage. The first one is probably more easy to practice rather than having somebody routinely keep on cleaning and then you need another person to check whether it is happening all that in a managerial perspective it may not be a good idea. So, it is better to see provide a sealant so that you can prevent this problem elastomeric sealant so that you can prevent this problem.

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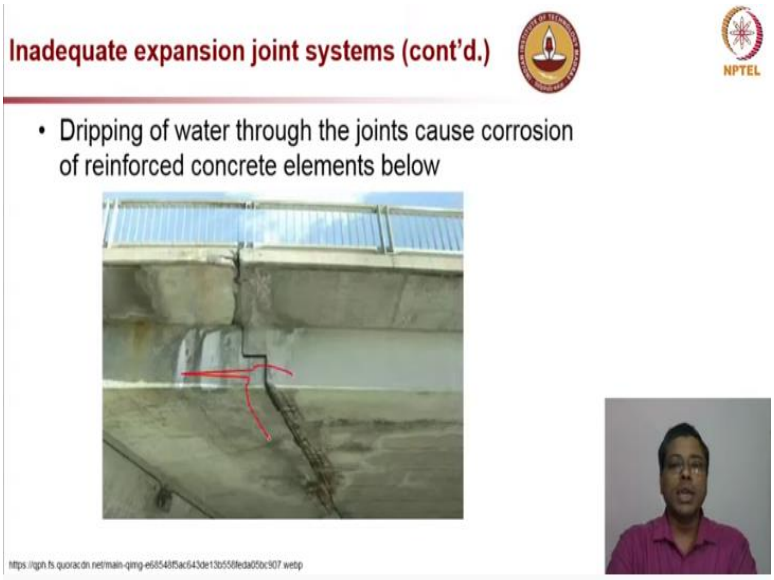

Now this is an example where when water stagnation this is an expansion joint you can see here; I will talk more about this type of joints later. But this photograph very I found it useful to show how the presence of water can lead to corrosion of the rebars. You can see right where that expansion joint at that rebars at those locations are corroding heavily this is not something which is good. So, this need to be addressed or we have to make sure that the water is drained off completely.

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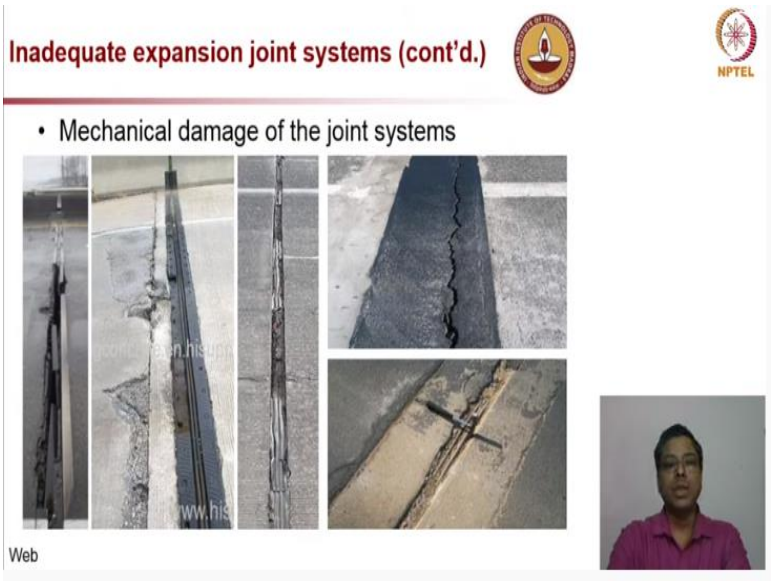

These are examples showing some mechanical damage because of improper designs etc. You can see complete misalignment of the different elements of the joints in each of these photographs and degradation and also here in the top right one this is an example where the overlay is kept continuous. So definitely it is going to crack like this in a non-uniform manner which is not supposed to be like that it. If there is a joint, it should be kept as a clean joint with some well-designed material in place not just filling up with the overlay material.

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So, to summarize what are the different problems which the expansion joints face. One is an inadequate width in some times which will lead to blow-up and other is the airspace of joints getting filled with soil or debris or aggregate materials from the fine material from the overlay etc.,

getting into the airspace and then the repeated loading conditions and cracking of the concrete. Because you might have fatigue and impact type of loading for which the toughness of the concrete or the material in that region should be high not only the strength.

Then the stagnant water and corrosion of metallic joints and so the water in the expansion joint if it stays there then that will give sufficient moisture for the metallic elements to corrode and so inadequate drainage system. Then water stagnates at the top surface of the bends or girder these are the elements which are below the expansion joint and that can also corrode. So, you have to make sure that the water is drained out completely from the bridge or the structure you are talking about and also some of the mechanical damages.

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So, let us see some good construction practices and repair so depending on the case I am showing here the technologies available. So as an engineer you can decide whether it is for new construction or for a repair so all these can be also adopted for repairing the existing system, so I did not want to really create separate things for that. So, I am just showing all the good construction practices.

Now first thing is filling the elastomeric material so strips as I showed earlier also there are open expansion joints those can be filled with the elastomeric materials which will allow the concrete to expand at the same time not allow them to generate stress or preventing the stress generation.

So very clearly, I want to say that you do not want an expansion joint with air and open if you are talking about an outdoor expansion joint you do not want air to be in the joint.

You want to fill that space with some other material which can expand and contract without really generating stress. So elastomeric materials are the choice here and what it does it prevents the soil or debris from entering the joints or gaps and at the same time it provides sufficient compressibility without generating stress on the concrete.

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now other option is if you are talking about slightly wider gaps then you can provide strip seal joint systems these are a little advanced joint systems is to play exclusively designed for this and it provides good drainage of water I am going to show more photograph and sketches in the coming slides you can see advanced systems here.

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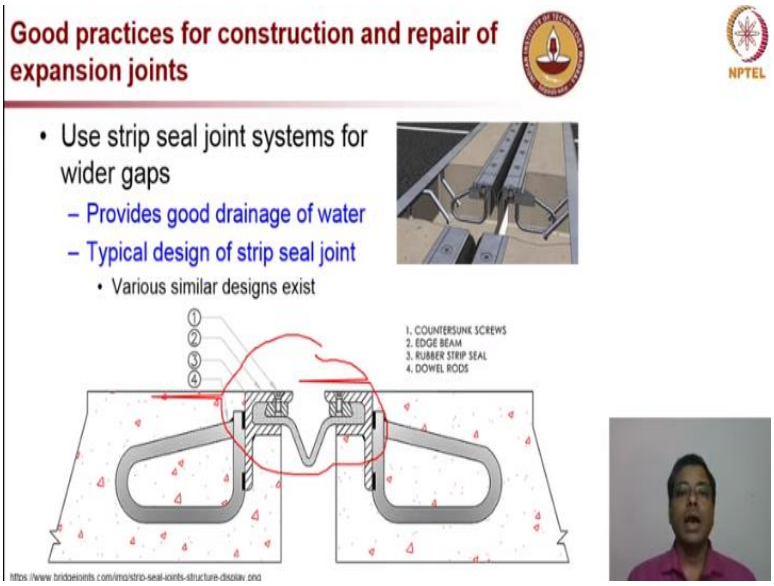

And this is how it looks so you can see here this this portion here. this is the portion which allows that expansion to happen at the same time contraction if they have expansion contraction to happen. But at the same time this portion here allows the drainage to happen so the water can drain horizontally and the transverse direction or along the joint it will drain and then it can be taken out of the bridge structure without allowing the water to fall onto the bends or columns below. this is very important, so very good designs provide good drainage system and especially useful for wide gaps when there is a requirement mainly for long span joints.

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So, these are some of the sketches showing typical designs like that you can see one on the left side. It allows significant compression and expansion so when you have a long span structures

these things become very useful to provide that large expansion or the gaps or width and here it is a moderate system where you can again enough space for water to drain. Here also water can drain easily, and it can take to the end of the joint.

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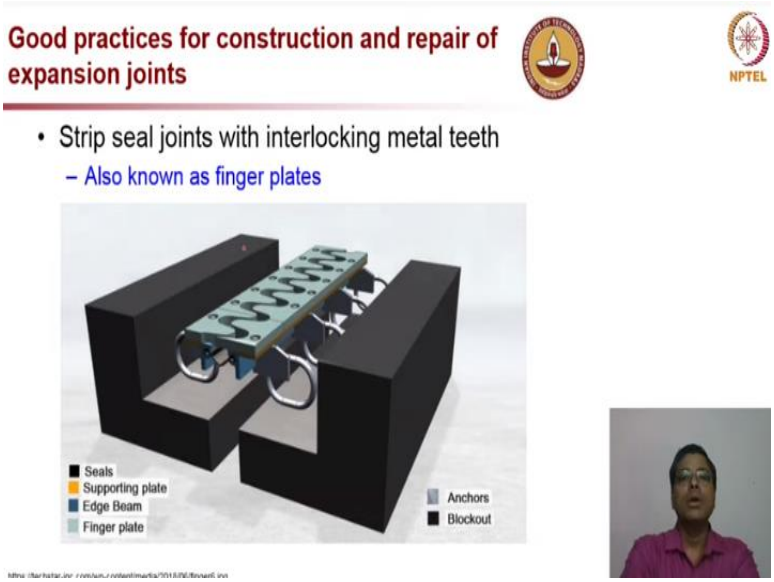

Now this is again another type of joint which are also known as finger plates where you will see a lot of interlocking metals look like again a teeth system interlocking metal teeth. So, this is also used when you are talking about large gaps or wider gaps.

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You can see these are the real examples. So, you can see here when you have wider gaps this kind of systems are very useful. Different sizes it comes in different sizes the length of the teeth will

depend on how much expansion you need to allow. At the same time why this heavy-duty steel because you want to ensure that there is no vertical movement. So, there should be a smooth transition the traffic should move easily without any vertical movement. So, these steel pieces provide that good support for the traffic the vertical support at the same time allowing the concrete to expand and expand as and when required.

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This is another good practice make sure that the expansion joint is extended by crossing the sidewalks and railings . You can see here it goes all the way to the end of the bridge or in other words all the way to the edge of the bridge not the end of the grid but edge of the bridge and this is a view from outside you can see here this joint is taking the water all the way to outside. It does not allow that water to fall on the girders bends and columns below.

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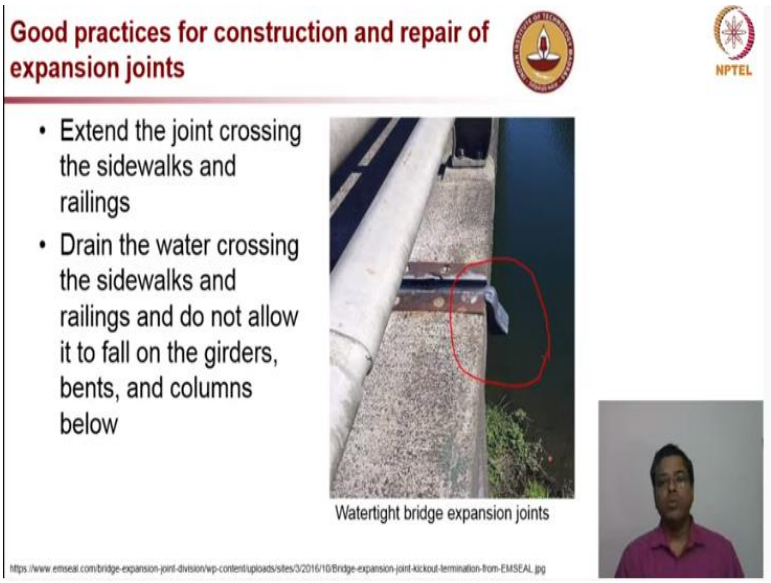

So then again, another example where you can see there is river below or a water body. So this expansion joint it carries all the water and then it is taken out and it is not allowing that water to fall on the girders, vents and columns below which is essentially making the bridge watertight or watertight bridge expansion joints. So, this is something which we have to really look for because if you look at the bridges most often the failure happens at the durability related issues happen at the expansion joints and we have to protect those systems.

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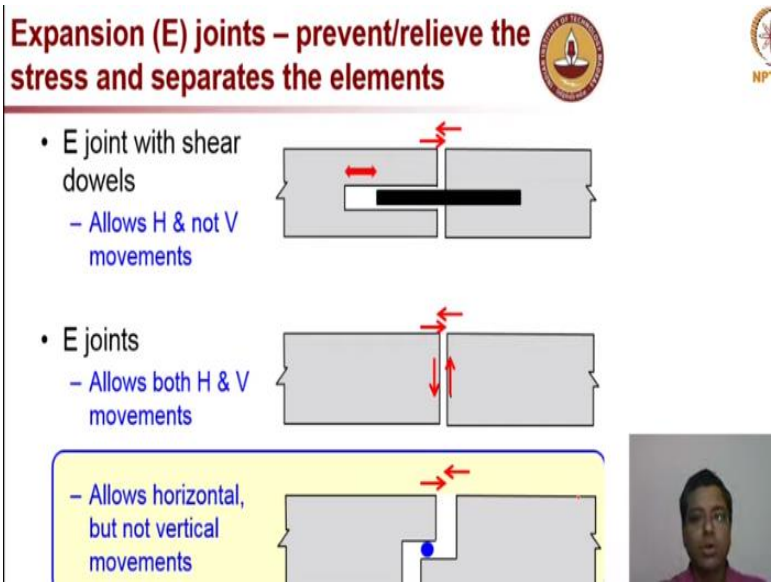

Now another type of joint is the expansion joint is the bottom one which allows horizontal movement but not the vertical movements.

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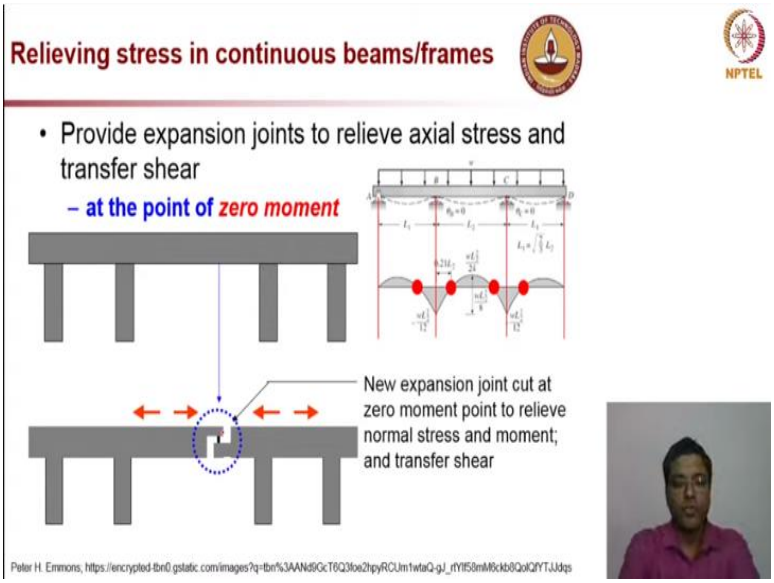

So, I am going to show example first the principle here the idea here is to allow this to create new expansion joint at the point of zero moment . So that across the joint there is no real requirement for moment transfer but there is a requirement for shear transfer. So, if you look at very carefully you can see how it is done, this step design. So, it prevents the vertical movement but at the same time allows the horizontal expansion of the system on the left and right.

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So some examples you can see here as a repair thing if already constructed you have to make this huge cut and large source are actually used in many places where designer might not have thought about this expansion or due to some problems in the construction material inadequate properties it is actually expanding and creating more stress. Then the one way of fixing that problem is cutting

this making this expansion join and then allow that strain but not the stress generation or in other words allow the concrete to expand. But provide in a free space so that concrete can expand and not really generate any horizontal stress. So, this you can see this is the type of joint we are talking about you can see here also I just showed some pictures so that it is clear for you . Now world over it is this type of joins are used you can see this step type design, and which is done mainly at the point where the moment is zero in a typical continuous beam system.

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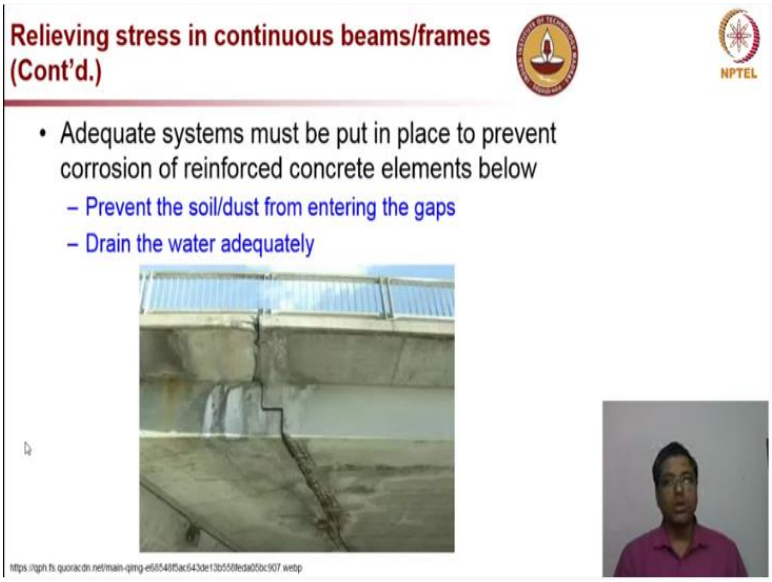

And you can prevent the stress generation however adequate system must be put in place to prevent corrosion of the reinforced concrete elements below how. I already discussed this, but we have to provide proper expansion joint on the top surface. So that it prevents soil dust or debris from entering the gap and at the same time with all the water is drained out adequately and not allowing to drip like what you see on this picture. So, this is not something which is this should not happen we do not want that corrosion to happen over there.

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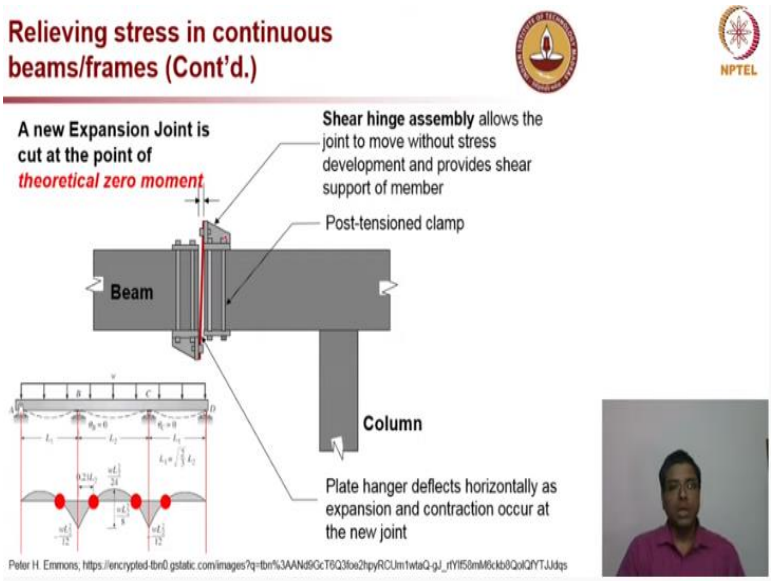

Now if you are talking about steel bridges steel girders with concrete decks. So, I thought this is also relevant for this picture because we are talking about concrete bridges even the girders sometimes might be made of steel. So in such cases what they go for is this similar practice again cut is made at the theoretical zero moment region and so that the moment transfer required is very minimal or it gets nullified at this new cut which is made.

And then it transfers all the shear from left to right and now how it is done is like basically make a clamp on both the elements. The beam is cut and then a clamp is made on either side and so the left side beam is actually hanging on the right-side element. The red inclined line here it indicates basically that hanging system this red inclined line indicates the hanging system plate hanger.

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So this is an example where you can see a plate hanger you can see a rod inside that red rectangle you can see a rod over vertical rod which is basically hanging the rights which is basically hanging supporting that system. So, there is a roller also.

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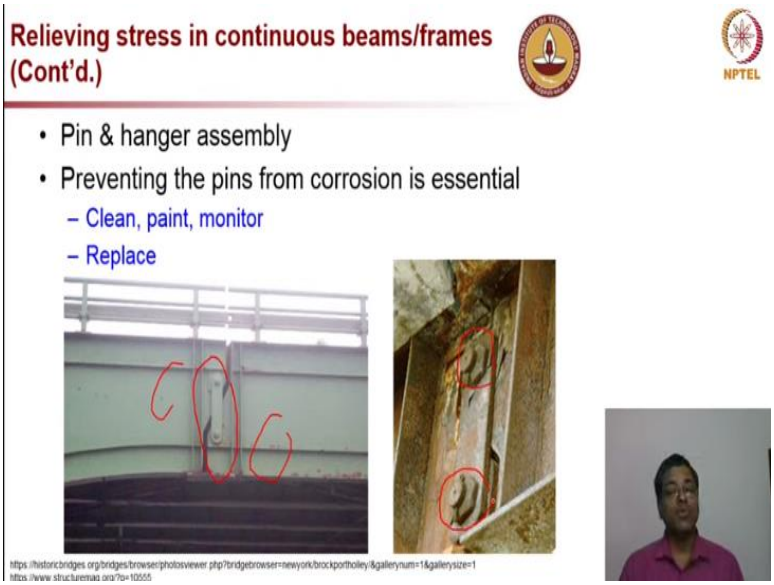

And now this picture is a plate hanger system where you can see the right-side element this element is hanging on the left element . So, this plate is under tension so now the plate is under tension and then you have two pins on the top and bottom of the paint of the plate. So that is this pin the corrosion resistance of the pin is very important because this imagine this is the bridge element.

So, you will have fatigue type of loading on this. so, corrosion fatigue is very important to consider in this and then these pins must be cleaned painted or monitored very well whether that is corroding or not they must be free of corrosion. Because they might fail due to fatigue also so fatigue corrosion is their key failure mechanism in this. So essentially my point is now the entire bridge is now hanging on these two pins or each girder is hanging on these two pins. So, their corrosion protection is very important.

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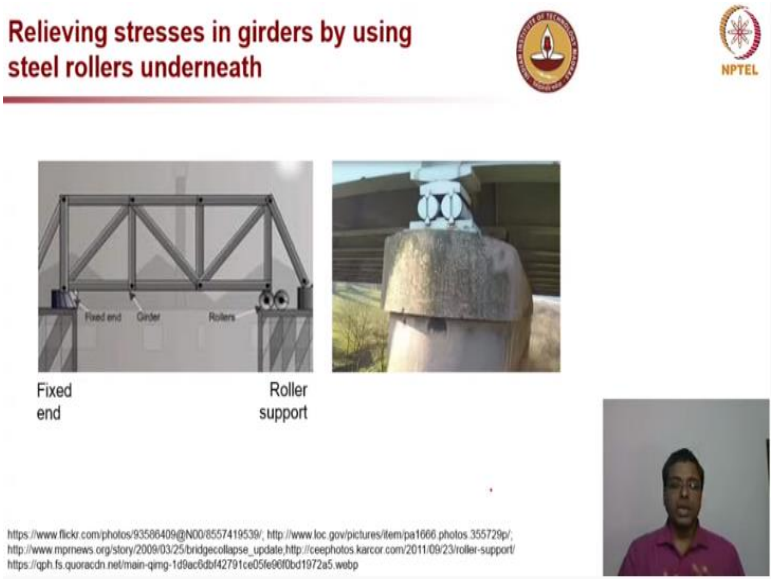

Now let me also talk a bit about the connections we were talking the relieving stresses in girders by using steel rollers. So, most bridges you will see that there are rollers or sometimes rockers, etc., to transfer the load from girder to the column and at the same time allowing that horizontal movement so that there is no stress generation.

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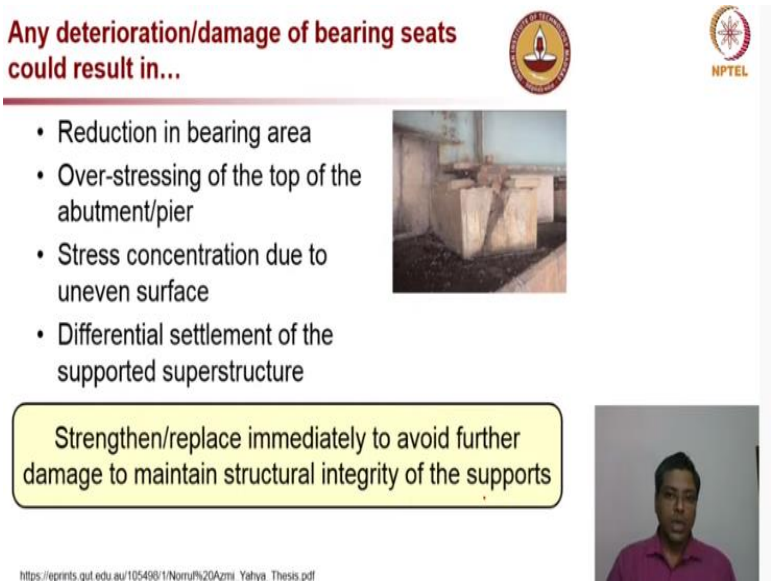

Now the many places we have seen these systems because we were talking about the significant localized the loading of this. Because when you provide that rollers it is essentially a local point load acting on the pedestal so that eventually leads to failures like what you see on the photograph here. So mainly because reduction in the bearing area it is a local load and our stressing of the top of the abutment of the pier or the pedestal and leads to stress concentration because of uneven surfaces etc., and then differential settlement of the supported superstructure.

When there is a movement like this the superstructure is also going to vertically there is a movement for the superstructure. So that might induce some other problems to the superstructure also. So before we leads to all such of all sorts of such problems, we should make sure that the pedestals are strengthened or replaced immediately to avoid further damage to maintain the structural integrity of the support and the both superstructure and sub structure elements.

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Now typically what we see is everywhere people use this neoprene packs typically we call it neoprene packs, they are basically heavy-duty industrial elastomeric bearings with steel reinforcement inside. Typically plate elements or laminates. So, we can call laminated or steel reinforced elastomeric bearings that is what is used. Basically, you have multiple steel plates which are sandwiched between the layers of synthetic or natural rubber and for further details you can look at this AASHTO LRFD of the bridge construction specification section 14 and 18 talks about this.

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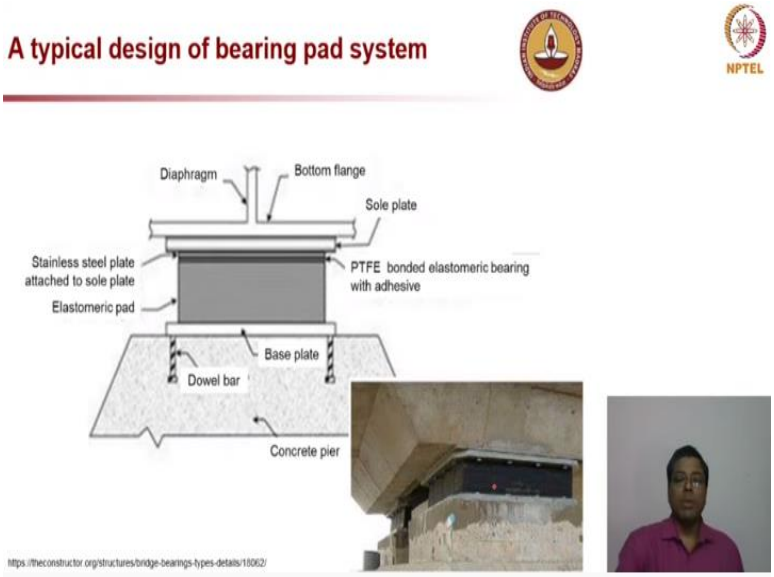

This is our typical design of elastomeric pad looks like. So you have a neoprene pad here with steel reinforcement and then there is a steel plate stainless steel plate at the top and bottom and

then which is supposed to give sufficient resistance against horizontal movement etc. and that is supposed to take the load.

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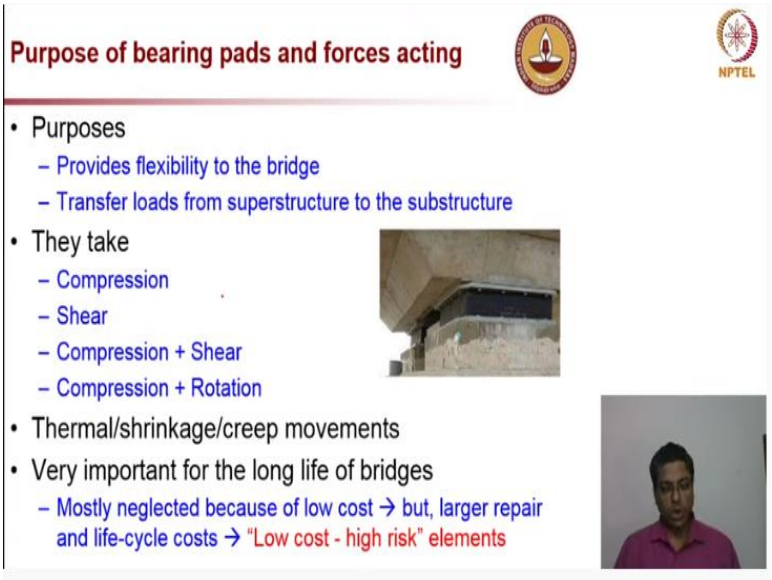

So, what is the purpose of providing this bearing pads is mainly to provide the flexibility to the bridge and at the same time it transfers the load from the superstructure to the substrate. So, flexibility is very important otherwise if everything is very rigid the structures different portions of the structure will tend to crack. So, you have to relieve the stress somewhere so that is what this flexibility means here.

So, these bearing pads provide that stress relieving mechanisms . So, they take compression load they take shear compression plus shear compression plus rotational. Now where are these loads coming from mainly because of the thermal shrinkage and creep movements of the movements due to thermal expansion shrinkage creep of concrete and which sometimes take longer time to showcase the problems.

I am going to show you some photographs of this later very important for long span of bridges and very important for long life of the bridges not only long span I miss told that I mean it is very important for the long life of the bridges. Mostly neglected because of low cost but larger repair and lifecycle cost might be the result. So, these are elements which are low-cost high-risk elements. So, enough care should be given for the for obtaining or for place in good quality neoprene packs.

Why I am emphasizing on this is many places we see that these parts are not given enough importance and leading to failure premature failure and leading to replacement. I have even heard cases where neoprene parts are being replaced in a frequency of 2 to 3 years so which is not at all good practice you should have longer life for this.

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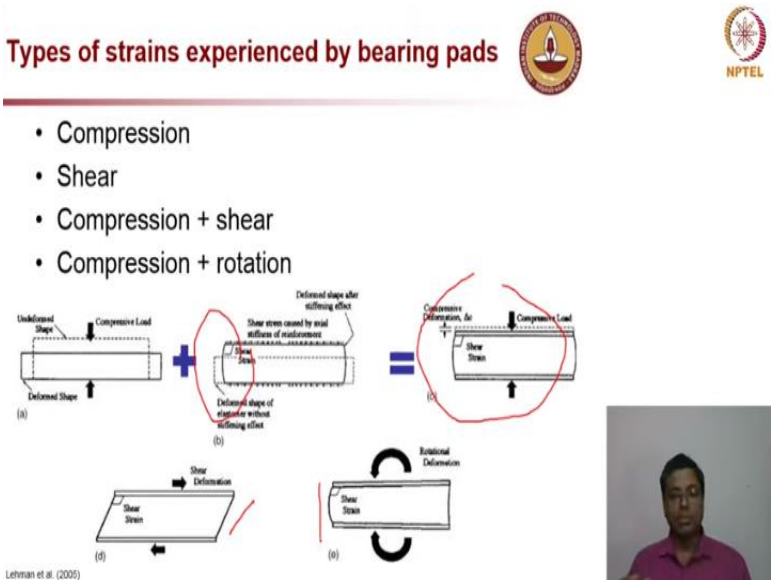

Now type of strain which these pads experience you can see on the first picture it is a pure compression and then in the second one slight bulging you can notice here which is indicating the shear in that region and so effectively you have deformation like this where both compression and shear are there. The bottom left you can see shear this one and then bottom right you can see rotation and shear .

So, these are different type of strains which are experienced by these elastomeric packs and they need to be resisting these for long period of time. Imagine the number of repeated loadings which are going to be happening on these bridges, so it is too large. So this prior element should be because why it is not recommended to replace them many frequent is because it is a huge job to replace these you have to lift the girder close the traffic lift the girder take the pieces out replace with a new one.

Looks very easy but very tedious procedures and is very costly repair practice itself is very costly. Even though the element replaced may not be very costly. So, it is better to provide good quality durable systems .

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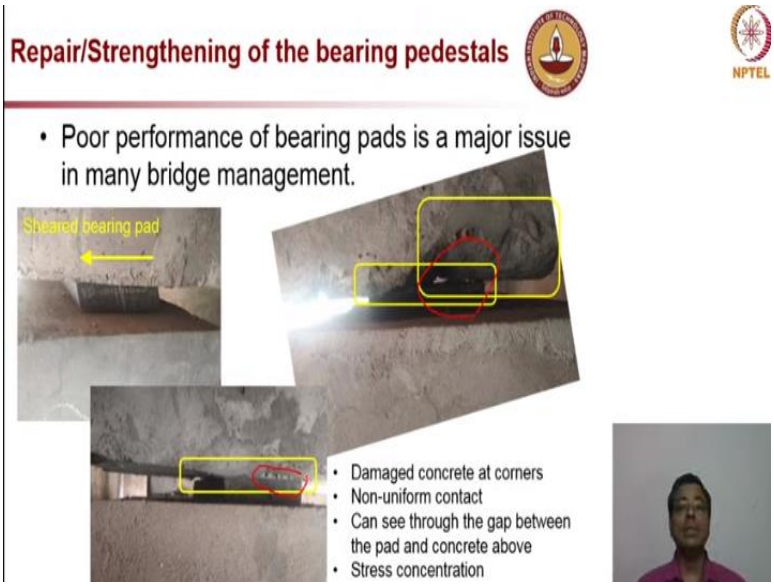

So, this is an example showing how badly these are done in some structures. So, you can see on the left side here very classical shearing of that pad towards the left. You can see on the right image you can see even the see-through I can see through this see here there is a wide gap here. So that is basically there is no contact in some portions of the pads are just sitting there is no contact to the girder above.

So, what it means is the portion which is in contact is now heavily overstressed or it is overstressed so that is something which need to be avoided so there should be uniform loading. Even on the bottom one also you can see there are some regions which are this portion here which is not in contact, so these are not, and I just wanted to show you an example of how badly these things are done in many of the structures.

So this at least when we go for repair, we should do a very good job in repairing them provide a good quality neoprene pads and at the same time treat that concrete in a better way rather than just placing micro concrete why I mentioned micro concrete. Nowadays most repair procedures they just simply say we place the concrete with micro concrete that is not the idea.

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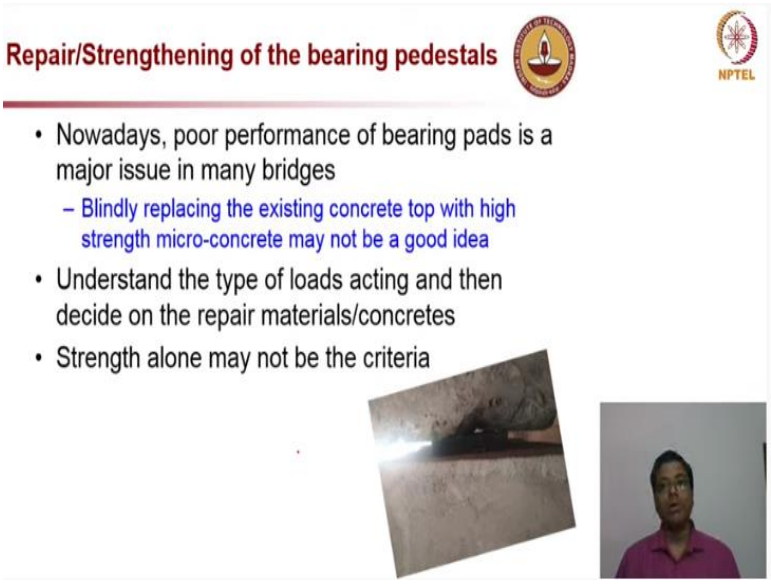

so blindly replacing the existing concrete top or that concrete element witness micro with high-strength micro concrete may not be the may not be a good idea because the problem in this concrete is not about the strength but it is about the resistance against the impact load. Because this girder they have experience they experience impact loads and because it is a bridge girder, so number of vehicles passes by and then you have impact and fatigue.

These are the type of loads which we have to look at. So, the toughness of the concrete should be very high. So, first thing which when we talk about repair of these things is, we have to understand the type of loads acting and then decide on the repair materials or concrete. Strength alone may not be the criteria we have to look at toughness also.

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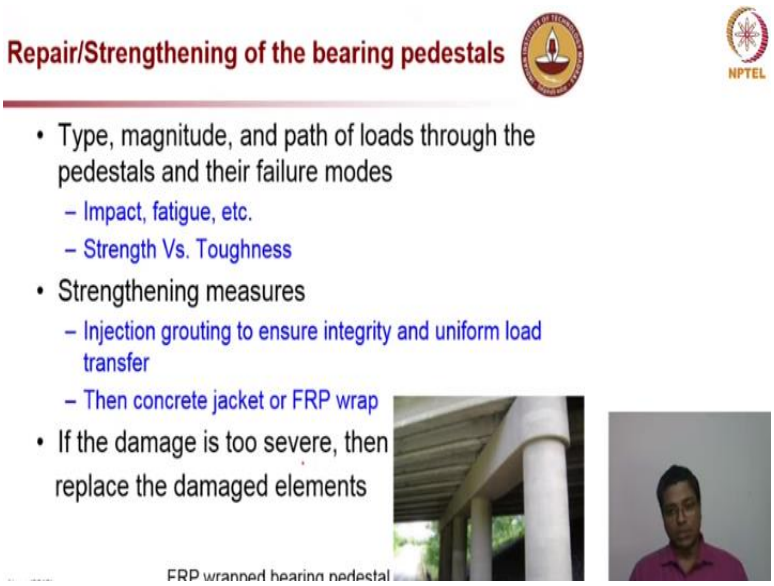

So here it is very clearly said the type magnitude and the path of the loads through the pedestal and their failure modes must be understood. You have to consider impact and fatigue loads strength is important but at the same time toughness of the material is also very important of the concrete material of the pedestal. What are the strengthening measures if you have already some cracks visible first thing is to inject the cracks with grout to ensure integrity depending on how much cracking is there?

If you are trying to retain the element this is the practice and so that once you inject the cracks with grout you can ensure integrity and uniform load transfer, then you can provide a concrete jacket or an FRP wrap it. If the damage is too severe then it is better to replace the elements rather than going for repair.

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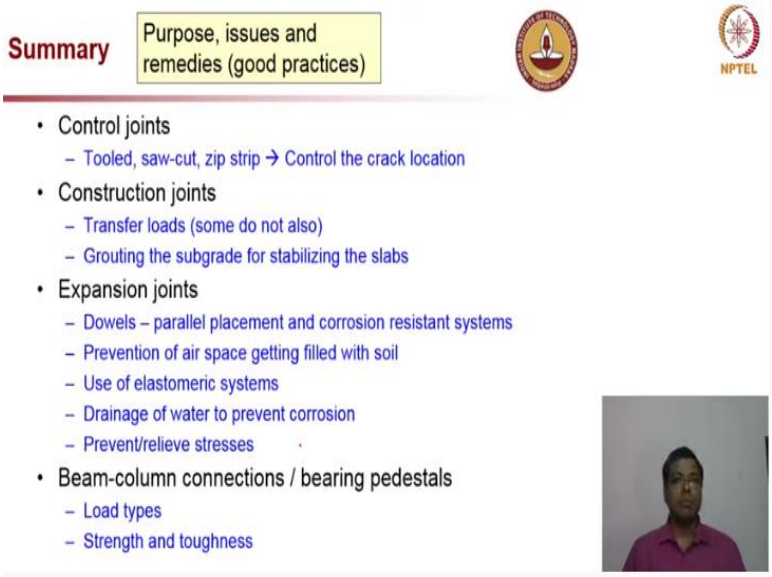

Now to summarize we talked mainly about different types of joints what their purposes are and what are the deterioration or damage mechanisms and then we also talked about remedies or good practices we talked about control joints, construction joints, expansion joints and also be in column connections and bearing pedestals.

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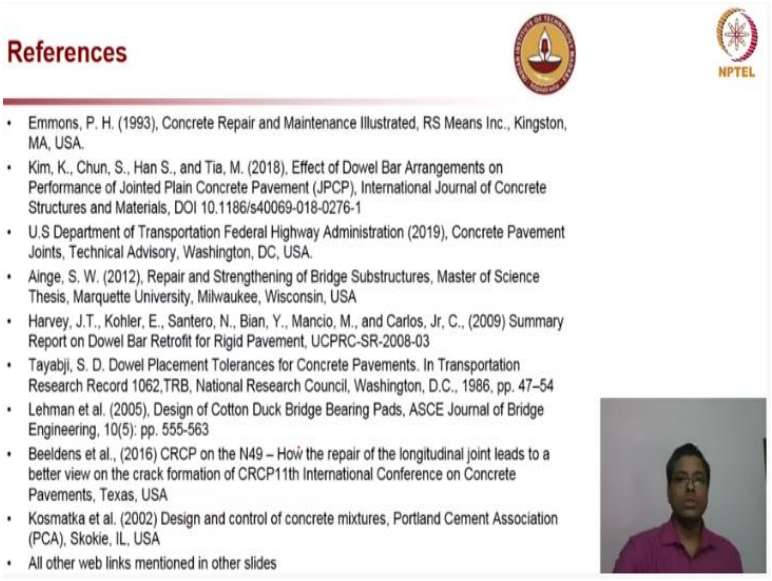

And these are the references which we used and also, I provided all the references website links from which various photographs were collected to make sure that you really understand and also feel that the theory is actually being practiced. Thank you.