Retrofitting and Rehabilitation of Civil Infrastructure
Professor Sriman K Bhattacharyya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 55
Retrofitting Techniques For Structural Elements (Contd.)

Welcome to the fourth lecture of the module on Reinforced Concrete Structural Element. In fact in our previous lectures, we have spoken about different aspects of retrofitting techniques of columns, beams. And today we expect to look into some more aspects of the retrofitting technique of beam element, beam slabs. And also we would like to take up a case study where, the beam column junctions can be retrofitted and different stages of retrofitting techniques that can be adopted through different steps, I would like to discuss with you on that.

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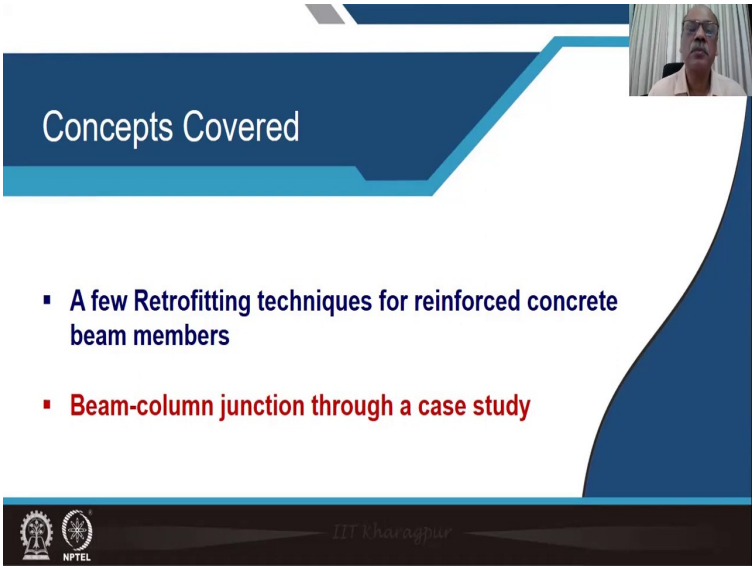

So, as I said that, we will be talking about some more retrofitting techniques of reinforced concrete beam members. In my previous lecture, I have given you some examples of retrofitting techniques of the beam elements or the beam members, how they can be done, how they can be strengthened in case of, distress that we observe.

And depending on the situation, depending on the structural system, you may have to make adopt one of these kinds of techniques that you have learned. However, as I have said, again and again that not necessarily that you need to adopt this kind of technique, because that is not unique always by nature. But, you can get an idea of what are the ways by which that retrofitting

can be done and you here can always come up with some innovative ideas, some modifications of the existing systems in an appropriate manner.

So, that finally, the retrofitted element should be able to deliver the goods, it should be able to carry their load satisfactorily without causing any distresses at all. And also I would like to demonstrate beam column junctions how it can be retrofitted along with the column members and the beam members. So, that you get back to its original form or getting the load.

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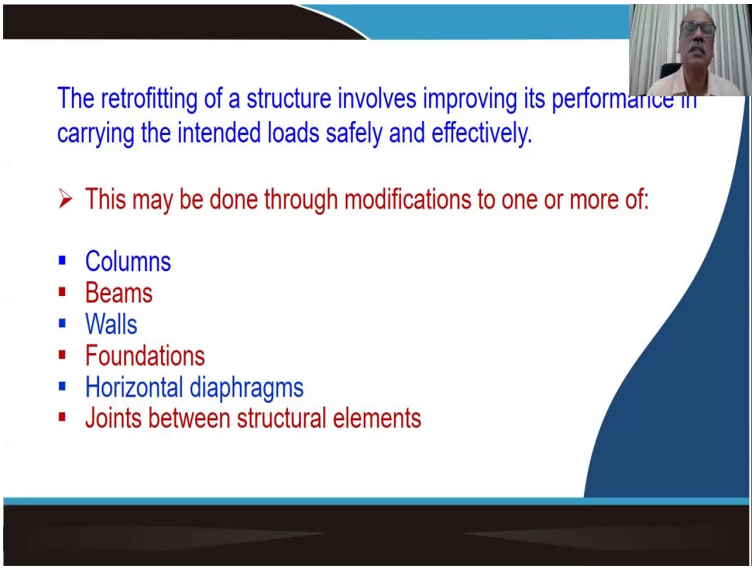

Well, this particular slide I had shown it to you earlier, and again, I am saying that, when you are trying to retrofit a structural system, it involves improving the performance in carrying the load i.e., load carrying capacity. So, that it can carry safely and effectively and depending on the kinds of distresses that you have in a structural system, any individual members, a column, beam, slab or multiple structural elements may have to be retrofitted repaired, so, that the whole structural system can be brought back to a particular shape. So, that it can function effectively and carry the load safely, that is the intention which I have said in the previous cases also.

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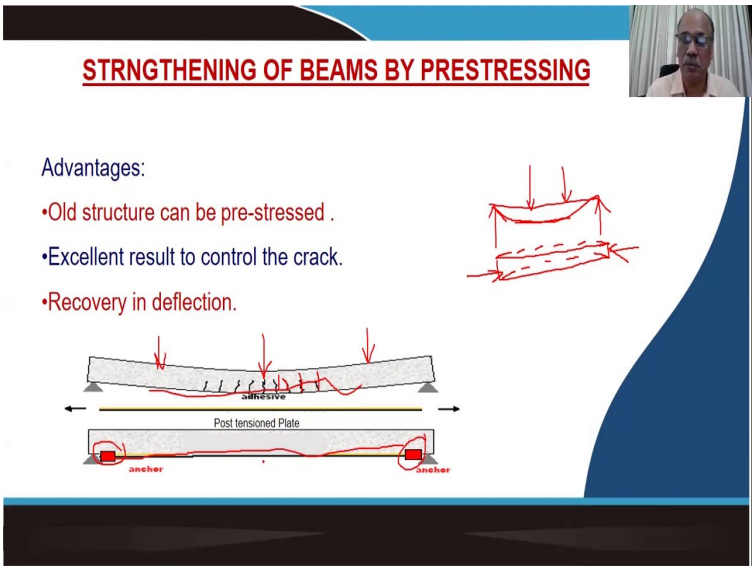

Let us take the example of a beam element or a beam member precisely is that, if you find that this is a simply supported beam, I have just taken a simple example. And this simply supported beam is subjected to some kinds of loading system on span. So, under loads because of the flexural action, the bottom fiber will undergo tension. It will show the sign of distresses as you can see, these cracks have been generated in concrete. Because, concrete is weak in tension it cannot withstand tension beyond a particular capacity.

And, if we like to strengthen this beam in earlier cases, we have spoken about the jacketing technique. We can use concrete as a jacketing material, you can use steel as a jacketing material, you can bring in some other material which we will be discussing, which we call as a fiber reinforced plastic FRP that how they can be used for jacketing.

Now, whichever material that you adopt, you can use them effectively to relax the beam element or the beam member. So, that you can strengthen them, now, in this particular case, what has been demonstrated over here is a technique called pre-stressing technique and all of you I am sure that are aware of the pre-stressing techniques that are adopted in pre-stressed concrete members, when a beam member, again take the simply supported beam, when it is loaded, the bottom fiber undergoes the tensile stress. So, in case of pre-stressing, what we try to do is that, we apply the predetermined load in such a way that the bottom fiber of the beam will be under compression.

Now, if you do that, if you introduce compressive stresses in a beam member, let us say you have a simply supported beam. And, as you know that, because of loading, when it is loaded, let us say it is span, because of loading, it will deflect I am exaggerating it like this. So, the bottom fiber will be under tension. Now, what we try to do is that, in the beam member, if you look into the beam, let us say if I draw its configuration, this beam member, we try to introduce some amount of forces in such a way, so that we can introduce some amount of compressive stresses at the bottom fiber of the beam, that means, by applying these force, the beam will try to move up, it is like this. So, what happens is that bottom goes up, and thereby you have some amount of compressive stresses generated, well, I have exaggerated the configuration over here. Now, if that happens, and when the beam will be in action in this particular position, when you apply the load, the bottom fiber is expected to undergo tensile stresses.

So, because you have already introduced some amount of compressive stresses in the beam member, when the tensile stresses get generated, because of the loading, first, the initial compressive stresses will get compensated by the induced tensile stress. So, it will come to a zero level nullify level and then further tensile stresses will get generated. So, in the process, the load carrying capacity of the member gets enhanced.

So, by using this particular principle, what we do is that if a beam member an existing beam member, subjected to loads have shown signs of distresses like a crack, we can introduce our pre tensioning system in this beam member, we can attach an anchor at this end we can attach, anchor and this end and through this anchor, we can insert a material, it could be tensioned wire or it could be tensioned plate, through which we apply a pull.

Now, if we apply a pull, then this tension which will get applied to these, beam member, we will try to keep an uplift force and this uplift force in turn will try to cause some amount of compression at the bottom. So, bottom fiber will undergo compressive stresses. So, already introduced tensile stresses because of the loading, which has caused the cracks, if you try to introduce the compressive stress from the other side, then the tensile stresses generated by the load will get nullified. And in the process, you will get a system where the beam will come to a state where the tensile stress is within its capable limit.

And you will find that the if the cracks were within the elastic range, the cracks will disappear, and then by applying some kind of a grouting, you can seal the cracks or the openings, so, that the moisture ingress do not happen the reinforcements do not get corroded. So, this is a technique which can be adopted and the existing structures can be repaired using this pre-stressing technique and this is a very good technique to control the crack and in fact you can recover the member deflection. So, by applying the pre-stressing process in the system, you can repair the beam members very effectively.

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But the different kinds of anchors that are available and that can be put in place are like this as you can see over here it is a kind of a plate which is fixed on the surface of the beam and here you have an arrangement through which the anchor plates or the anchor cables can be taken in and the tensile pull can be applied on to these members.

So, this is also a mechanism of anchoring or the anchorage which can be fixed onto the beam or the slab surfaces and through these you can insert the pre-tensioning material it could be a plate or it could be a wire, which can be pulled and which will eventually apply force onto the top of the member. So, these kind of techniques can very well be adopted and this kind of anchorage systems can be developed and are available also readily and these can be implemented in practice to strengthen the beam members.

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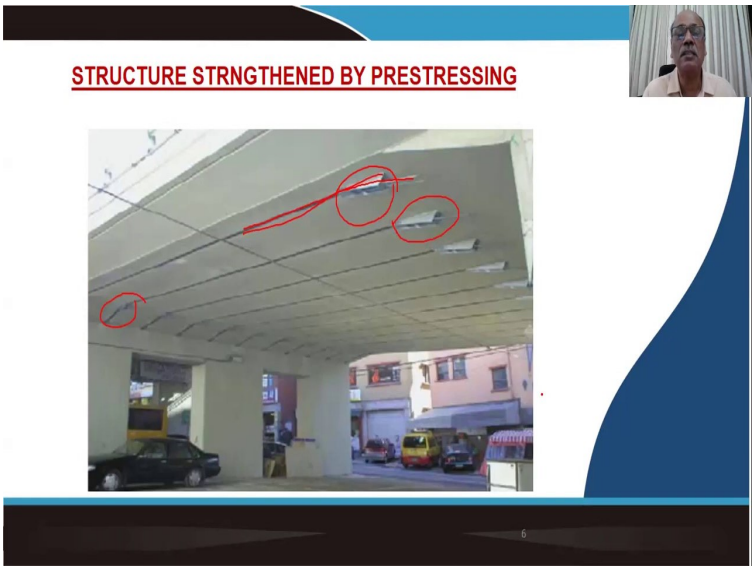

So, here I have shown you a figure where you see this the anchorage has been fixed on to the slab surfaces and the anchorage cable has been taken through this anchorage, I mean, the pretension cable has been taken through this anchorage which can be pulled on both sides, we have fixed this anchorage and then you can pull it. So, eventually it will apply a force onto the surface which is on the reverse direction and thereby will have stresses induced into the structural member.

Which is different than what is actually happening? Because, of the load and because of this reverse direction of this stresses. So, originally induced traces will get compensated and eventually the member will come to a position where the actual level of stresses because of is less and this kind of techniques can be adopted for beam members, for the slab members, or any horizontal diaphragm members, which are to be retrofitted.

So, I believe this is a very good technique that can be adopted, but it has to be done very carefully. Because in a distress member when you fixed the anchor in position. You have to be very, very careful. That the connectivity between the anchorage and the original member gets created in an appropriate manner and then while applying the pre-stressing pull it has to be done carefully. So, that the load transfer gets in the member. So, these aspects have to be taken care of while doing the pre-stressing technique or strengthening the member.

So, this is one of the retrofitting techniques that can be adopted in repairing the distress in the beam members or in the slab members. So, the techniques that we have seen earlier the techniques that we have learned earlier. So, this is again an additional technique which can be adopted, repair the reinforced concrete structural members.

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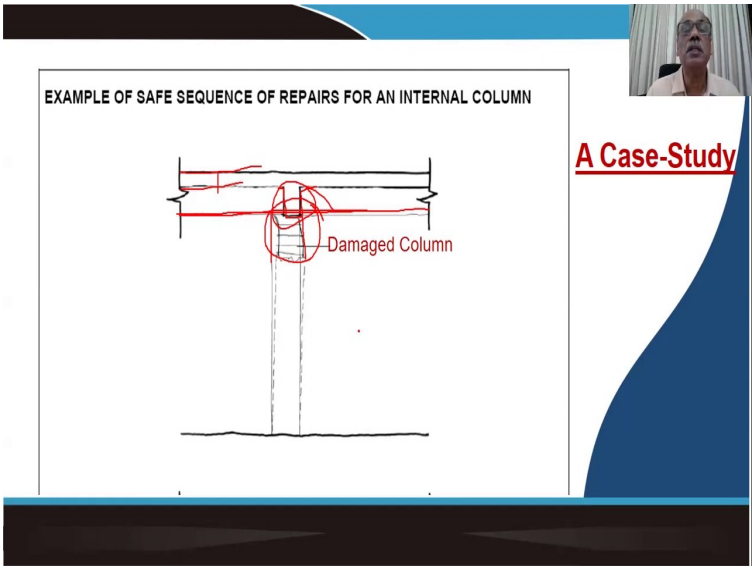

Now, let me talk about a case study, where a beam column junction can be repaired, you see this is a system where this is basically a slab as you can see and this is the bottom part of the slab. So, this is the thickness of the slab and the slab has a beam, this is a beam which is running in the longitudinal direction is a perpendicular to the screen.

So, this is the beam which is running and also along the direction of this slab, this is the beam member which is running through and through and you have a column member which is placed here. So, the entire system, the beam this particular longitudinal beam is connected at the column beam junction and the beam along with the slab is running in this particular direction.

So, at a distance apart there are columns to support the other side. So, now, by any chance, we find that this particular zone at the interface between the beam and the column has got distresses in fact you have beams into two perpendicular directions one is going in the cross direction another in the longitudinal direction. So, there are two beams at a junction along with the vertical column member. So, all three members where they are joining together at the top surface of the column, we find that there are some amounts of damages that have distresses introduced.

Now, the question is that, unless this column is repaired in an appropriate manner, unless this damage is repaired in an appropriate manner, this structural system will not be able to carry the load effectively. So, it is very important that we address this issue and repairing now, the question is that how are you going to repair this because one aspect has to be realized that when this column has undergone distresses.

So, naturally, the load carrying capacity of this column has reduced and, as if you do not pay attention to this gradually the beam members also will get affected it will undergo deflection and eventually it will lead to the collapse. So, it is very important that immediate attention is paid to repair this particular damage in the column system.

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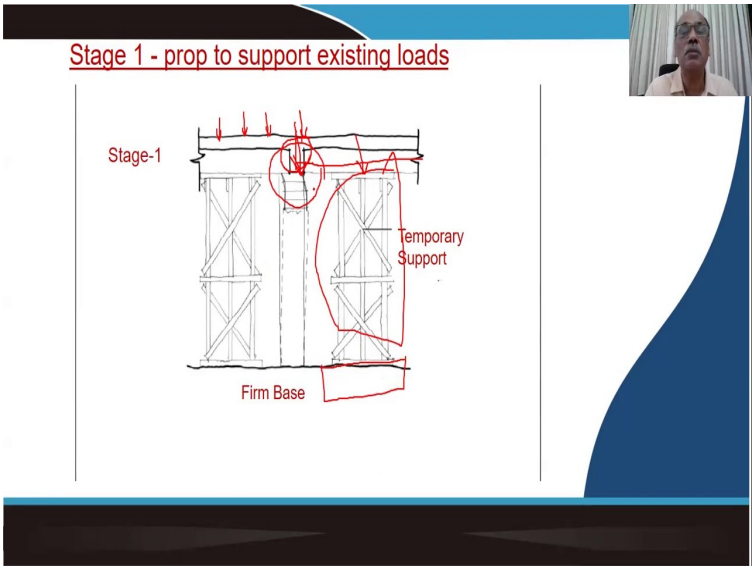

So, what is to be done as a first stage is that we give a support to the beam member, because, what is the load transfer mechanism normally, you will find that loads are getting transferred from the slab in terms of live loads or whatever big loads you have these loads from the slab system in a distributed manner get transmitted into the beam.

And this beam eventually transfers the load into the column member also, if you look into this particular beam which is running in the cross direction, the end of the beam since it is resting on this column, this will also transfer the load in this column. So, the load that is coming from this beam system to this particular column by providing proper support to these beams, the load in the column can be reduced.

So, the first step is that we try to create some kind of temporary supporting system for the beams and the slabs. So, the load which is getting transferred onto this column, can be reducd to a large extent. So, this is the first thing that we need to do and mind that when you create these temporary support, this temporary support also has to be designed in an appropriate manner.

So, that the loads that are coming from the beam and which is getting transferred to a column now, we would like to transfer to this particular system. So, naturally this system has to be designed to carry those amount of load and mind that this whole temporary system has to be placed on the found ground provided this found ground can take this amount of load if needed to be.

We need to create a foundation system for this over which this temporary structure is to be built. So, creating a temporary support is equally important when you are carrying out the retrofitting operation. So, this is the first step in the retrofitting stage that we create a temporary support for the infrastructure the load which is getting carried by the column now, we are transferring to the end of the temporary support. So, this is the first thing that we need to do.

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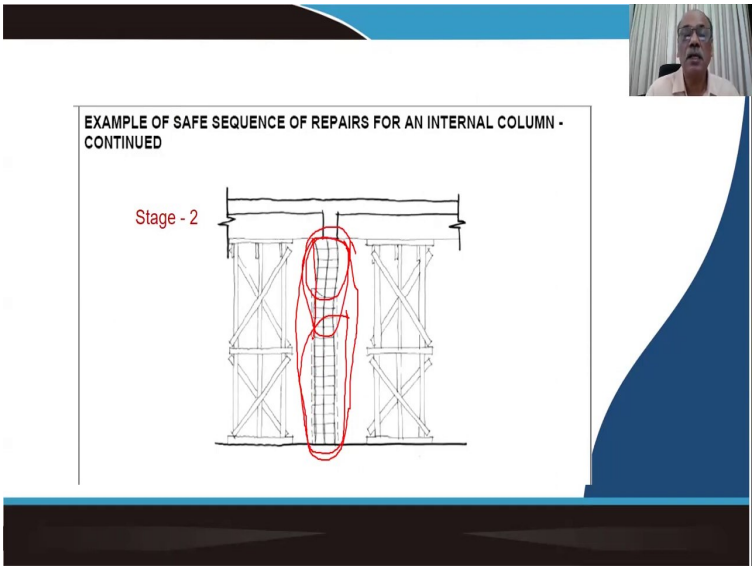

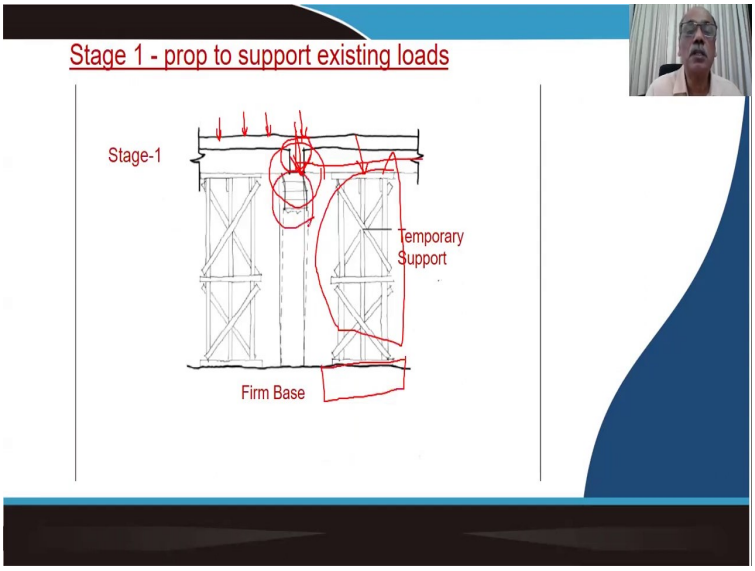

Second thing is that after you place the temporary supports in position, then we try to pay our attention to the column member which is in distress. Now, here as you can see that in the previous case here, you see only this part of the reinforcement was exposed, the concrete got spalled up from there, but in this case.

Now, the balance concrete part has been removed, the covered part of the concrete has been removed and the reinforcements are exposed. Now, in this place, as you can see, the column also has tilted, it is not aligned with the original configuration. So, it is important that we try to align them in an appropriate manner and try to bring in and in this process the reinforcements in this zone also might undergo distress.

So, what we try to do is that if needed we can remove this part of the reinforcements and bring in new reinforcement and connect with the original existing reinforcement. So, the bottom part of the reinforcements which is unaffected, we keep in position, the top part of the reinforcement we can remove it and bring in new reinforcements and connecting with the existing one. So, this is the second step that we do this operation.

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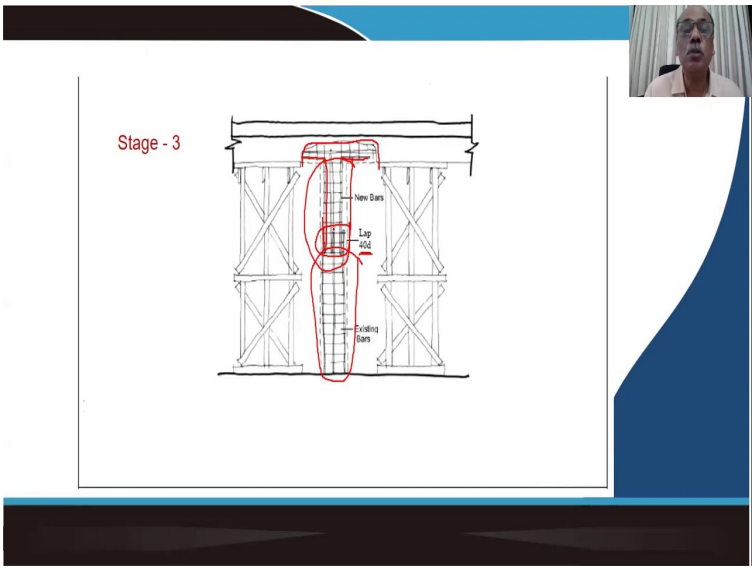

And in the third stage you can see this that you have the existing reinforcement which are there in the column and then we bring in newer reinforcements in this and give a lap of the new reinforcements and the old reinforcements this is the lap zone that has been shown and in comparison, we normally required 40 times the diameter of the bars.

So, that is the lap length has been provided for continuity. Now, these new bars also to have a grave, we like to insert in the beam member. So, to do these insertions in the beam, you need to remove the concrete from the covered zone of the beam and that is what has been done over here. As you can see, that this part of the concrete from the beam has been removed thereby the exposing already the heavy reinforcements in the beam member they are getting exposed.

Now also this column bars are taken inside this beam member, so that you get continuity in the beam member and thereby you can create connectivity between the beam and the column effectively. So, now, at this stage, what has happened is you have removed the loose concrete you have added the reinforcements you have cut off the, which is damaged reinforcements already and by doing this.

You have now added additional reinforcing element into it. Now you will have to provide some kind of a shuttering material to this column. So, that you can pour concrete to things you will have to do, now, we will have to create shuttering for the column members and then you will

have to pour concrete. Now, how are you going to do that, to do that next stage, we go to the next stage.

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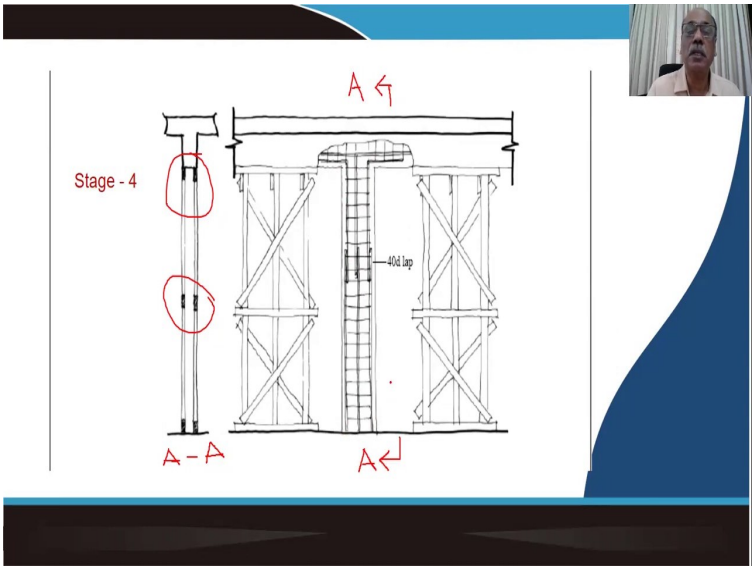

Where, we try to provide some kind of a supporting staging on either side of the column member. So, now, you see this, the side shuttering has been provided, but still you can see the reinforcements from the face. Now, the front reinforcement also I mean front part of the column also has to be provided with a shuttering and this is the side view if I take a section here you will get a view like this.

So, this is the cut that we are taking across and if I call this as let us say A, this also as A, so, this is actually view A-A, this is A-A. So, this source column this is the lap reinforcement part and at this junction we have connectivity with the reinforcements. So, now our job is to provide appropriate shuttering material and put concrete inside the column so that the column gets concreted within.

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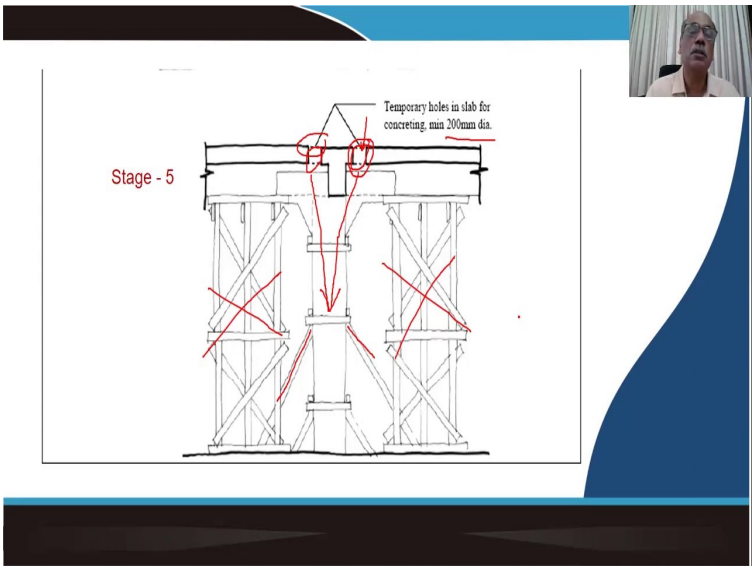

So, in the next stage what we do is that here we provide the shuttering material to the column and to the beam. But once you provide the shuttering naturally all four sides gets covered these are the clamping material that has been provided also in some kind of a temporary support has been given, so that the column member does not get moved or displaced.

Now, once you have this shuttering in place, now, the next question is how you are going to pour the concrete. Now, what do we do is that in the slab, we create some kind of opening, let us say the temporary hole, which is around 200 millimeter in diameter. And through these holes, we try to pour concrete, through this we pour concrete and the concrete eventually goes down through this.

So, concrete comes through this and thereby the whole column member along with the part of the beam gets concreted. So, at this stage when you have provided the centering into it and try to pour concrete into it, the whole thing gets concreted. So, now that after the whole concreting is done.

Eventually you will have to repair this part of the slab as well the opening that has been made in the slab also has to be concreted and once that step is complete, the whole job is done. Now after then, you will have to give timing for curing you will have to do proper curing. And then finally, once it gain the strength, you can remove this temporary support that you had provided earlier. And once these temporary supports remove then the whole system gets back in position.

So, this is what is the process, if you look into the stages through which we have gone to retrofit this particular kind of system is that first identify the distress, see which element is to be repaired in this case it was beam and the part of the, in this case it was column and the part of the beam and then the damaged reinforcements we have removed.

We have added new reinforcement, new reinforcements have been connected with the old reinforcement with the appropriate overlap or lapping and then, we have inserted the new reinforcements within the beam so, that you get a connectivity between the beam and the column we have provided the shuttering material and then we have pour concrete into the shuttering so, that the column get cast as a new column.

Now, a very important thing is that you need to create a temporary support, the temporary supports have to be designed for the loads it has to carry, because the load which is getting transmitted into the column has to be eventually transferred to this temporary supports. And once the complete job is done, you can remove the temporary support and, you can restore back.

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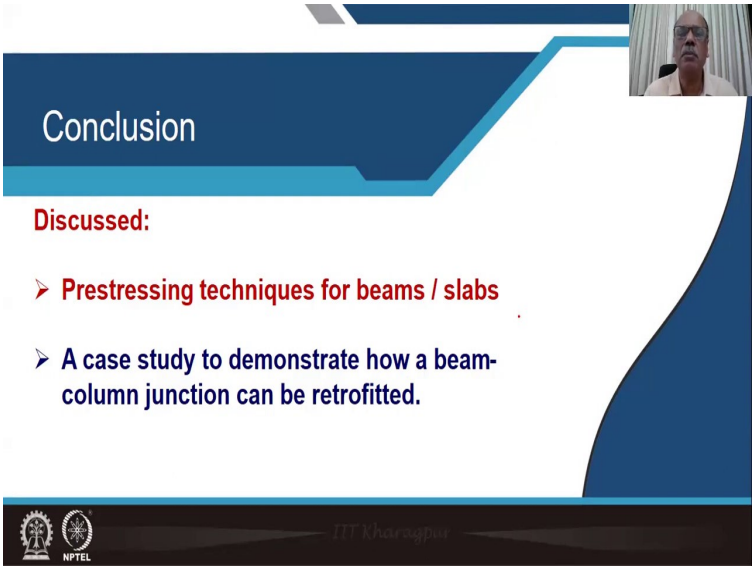

So, that is the kind of a system that we can get by carrying out the retrofitting of columns. So, in this particular lecture, what I wanted to bring it to you is a technique, the pre-stressing technique which can be adopted for strengthening the beams or the slab kind of members and pre-stressing is very effective when you provide, the beam surfaces or the slab which is horizontal in nature.

For horizontal type surface, it can be effectively implemented in transferring or creating the reverse stresses and thereby, you can bring it back to its normal form and load carrying capacity can be enhanced. And I just wanted to take the example of a beam column junction to demonstrate that how in the event of de-stresses in a beam column junction, how those kinds of things can be repaired.

So, you see through these lectures, what we are trying to bring out to you is that how different members like column members, beam members, slab members either in isolations or in combinations of these, how they can be repaired by using different kinds of techniques which are prevalent and are adopted.

They can be used in an appropriate manner to repair them to strengthen them. Finally, mind that our objective is that these techniques when you adopt, it should be effectively able to repair those individual members. And finally, as a system, it should be able to carry the load for which it is designed for the purpose, for which we have designed the structural system. And that is the idea of creating the retrofitting system.

So, we will look into some more cases like different kinds of materials, I have spoken about that we have used concrete as a material, we have discussed that we have used steel as a material and you have seen that we have adopted different techniques by using concrete and steel, we will try to explain to you that if we use relatively the newer material, which is fiber reinforced plastics.

We call a FRP and the fibers could be glass fibers or the carbon fibers and they are effectively used which are quite strong and lighter in comparison to the steel or concrete and they are effectively used in strengthening different kinds of structural members. So, we will look into the effectiveness of such FRP systems in carrying out retrofitting or strengthening the structural system. Then, thank you, thank you for your attention.

And I hope that you can understand the techniques that we are talking about. We are the different kinds of retrofitting techniques that we are adopting, how they can be implemented in practice to repair or restore back the structural system.