Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 58
Seismic Strengthening of Structural Elements

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Welcome to the seventh lecture of the module on Retrofitting of Concrete Structural Members. Well, in last few lectures we were talking about the retrofitting aspects using FRP as a retrofitting material. And we have seen different kinds of techniques that can be adopted using FRP for retrofitting different types of concrete members, namely beam, column, slab, beam column junctions and you have noted that how these FRP can effectively be used to strengthen the concrete members of different forms.

And also, we have discussed about the techniques of applying these FRP on the destressed surfaces and how those structural members can be strengthened to carry the loads that we desire. Now, in this particular lecture, we intend to take you through some more aspects related to retrofitting of concrete structural members, namely we are seeing the seismic strengthening of structural members.

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Now, when we talk about seismic strengthening, we have spoken about the strengthening measures that we need to adopt on distressed structural members but I have already explained to you that there are two aspects when we talk about the retrofitting of the systems or strengthening of members, namely, that if some members are distressed because of some actions let us say seismic action in this particular case that we are trying to bring in to the account that because of earthquake because of the seismic actions different structures have undergone distresses of different forms.

So, the structures which have really not gone to the collapse state but have undergone some amount of these stresses, we need to strengthen them in an appropriate manner using different techniques. So, this is one kind of strengthening techniques to bring back the distressed structures which were damaged because of earthquake to a form in which they can carry the load and further usage can happen. So, this is one aspect of it.

The other aspect is that we said that there are structures which were constructed earlier and with the provisions of certain provisions that have been stipulated in Indian Standards and applying those relevant clauses which are applicable for taking care of the seismic effects, those were designed.

Now, subsequent to the design of those and the construction of those structures, let us say, there is a change in the seismic codes whereby the codes might have stipulated certain additional aspects which were not covered in the previous code based on which the construction had happened for the structural system. So, for such systems, they are deficient in seismic actions so far as the changed total provisions are concerned.

Now, if that happens then what is the remedial measure? All we can do is that we can identify the structural members which are deficient against seismic actions and we can strengthen them

in an appropriate manner by using the techniques that we have learned so that they can carry the seismic loads effectively that are expected in near future if at all it happens. So, these are the two aspects that we need to consider while trying to retrofit the structural members against the seismic actions and that is where checking structural members against seismic actions is important.

Important from the perspective that the structures or the places where the seismic actions have not happened but the structures are positioned in a place which is seismic prone, in future there might be some seismic event in that case to safeguard such structures against a seismic actions, we need to take proper precautions, we need to adopt appropriate strengthening measures so that the structures can be made resistant against the possible earthquake events that can happen and can cause damage to the structures. So, that is where we need to go for the strengthening of the reinforced concrete members depending on the requirement.

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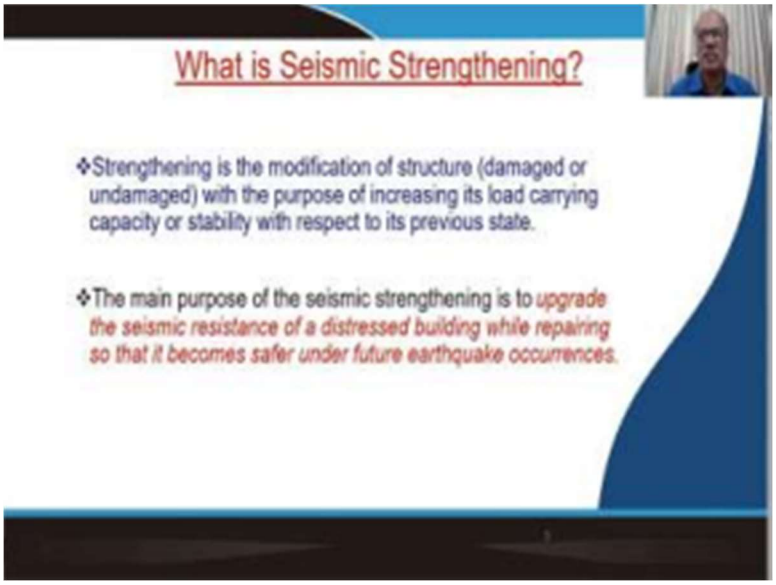

So, basically, what we are trying to answer to that, what is seismic strengthening? When we talk about the term called strengthening, the strengthening is nothing but the modification in the structure that we are trying to address. The structural member could be damaged or undamaged as I said that it could be undamaged but it is deficient in carrying the proper seismic load that is stipulated as of the present criteria or stipulations.

So, if that scenario happens, so if we try to apply this modification in a manner so that it can carry the intended load which we expect on the structures to come, it can carry it safely without causing any distability or instability in the system and you know, is certainly an improvement over the previous state that we had. So, in that sense, that is what in general we mean by strengthening.

And when we talk about seismic strengthening, when we are qualifying the strengthening with a term called seismic it means that we need to strengthen the structural members against seismic actions. So, that means a structure which could be deficient against the possible seismic actions in the area, we strengthen the structural members by adopting suitable retrofitting measures in such a way that they can resist the seismic action in an efficient manner.

So, or if for any reason, the structural members have undergone distresses either because of the seismic actions or any other things, we can also repair them, retrofit them to bring back the structural members to its near original capacity, to carry the intended load. So, this is what has been stated over here.

The main purpose of the seismic strengthening is to upgrade the seismic resistance of a distressed building while repairing so that it becomes safer under future earthquake occurrences. So, either earthquake has happened in a particular area and because of that the structures have undergone distresses and those structures are required to be retrofitted to bring it back to its normal operation or you need to improve upon some structural system which you feel are vulnerable against the seismic actions.

So, this is what we mean by seismic strengthening. And our job is to strengthen structural members, the requisite structural members or the structural systems as a whole in such a way that the structure can carry the load effectively and efficiently.

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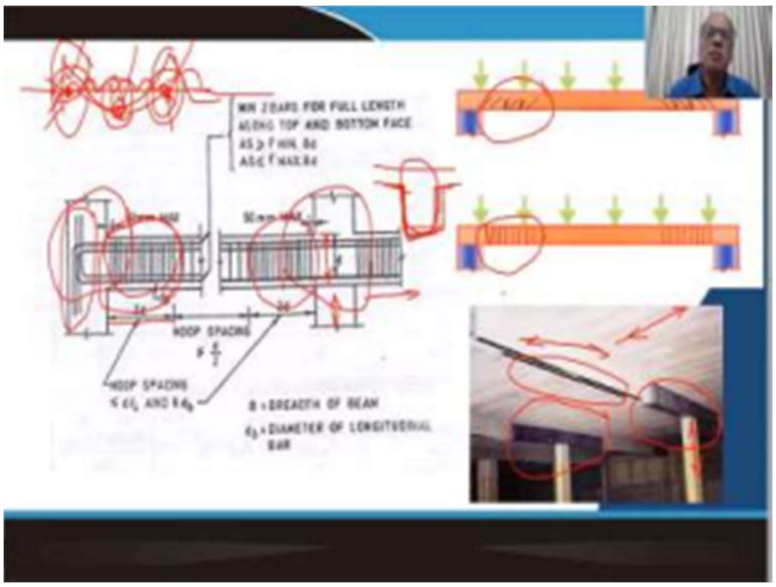

Now, let me talk with reference to a beam system. Let us take a beam. This beam is a continuous beam as you can see, this is the column member which is carrying the load and the beam is connected with the column at this end and it is continuous what is particular column and it is

continuing in this direction as well.

So, if you have such kind of beams and when these are subjected to the seismic actions which are basically inducing lateral load in the framing actions, then what happens the junctions between the beam and the column which is kind of having a fixity as you can see the detailing of the reinforcement over here the both the longitudinal bars, longitudinal bars from both from the bottom as well as from the top they are integrated with the column members in such a way that it creates the appropriate development length and thereby it creates a fixity between the beam and the column over here.

Now, if you have a system like this that the beam is fixed at this end and continuous over other column member it is like if I draw a system which is something like this that this member, a member is fixed at this end and you have a support over here over which it is continuous and also it is continuing there may be further spans in this.

Now, if this member is subjected to uniformly distributed load over here, now, what happens is that you get a bending moment which is something like this that you have a negative moment at the support and positive moment then at the support again a negative moment and have a positive or something like this. So, what it means is that you have negative moment here, you have negative moment here and you have positive moment at the mid-span over here.
Now, these are the positions which are vulnerable. Now, let us say if you keep on adding the load and during earthquake, you get the lateral load into the system. So, when such load comes, now these areas the supports and mid-span these are the areas where the stress level keeps increasing because those are the points where the moment increase further or in a faster rate. So, in those places you expect the stress level also to go up.

Now, in the event the load is such that the stress levels in these zones go to a point where some kind of beyond a point it goes away some kind of plasticity starts forming. In these zones, you get some kind of system which we call as a plastic hinge and the moment carrying capacity goes to the plastic moment level.

So, if such kind of thing happens and if the centre also forms a plastic hinge then the whole system becomes a mechanism and it leads to collapse. Now, that is the reason that the zones when we expect the moments to increase because of the loading which happened all of a sudden during the earthquake as in terms of lateral load. Now, those zones we like to strengthen them additionally to safeguard against seismic actions.

And this is precisely what has been shown over here. This is the codal provision from the

detailing code of earthquake. It is stated that the zone which is closer to the support, the beam member which is in the close vicinity of the column where you are creating the fixity over a distance of 2d, where d is the effective depth of the beam member you see, it is shown from here on the top edge of the beam up to the reinforcement level, excluding the cover.

So, this is the depth d which is considered. So, over a length of 2d you have reinforcements or the stirrups which are confining the longitudinal reinforcements and the concrete within the core of this stirrups provide this at a spacing of whatever is written over here that d/L and $8d_b$, where d_b is nothing but the diameter of the longitudinal part. Now, here what it means is that you need to place the stirrups at a very close spacing. This is kind of a strengthening when you get lateral load, the moment suddenly reaches to the plastic moment also you get the shearing actions in this in which it fails.

So, we need to strengthen those support zone in an appropriate manner so that it can carry the lateral load very effectively. So, this kind of detailing are prescribed. Now, the question is that when you are trying to strengthen an existing beam member, always it may be difficult to apply these kind of stirrup systems if it has not been used in the original during the original construction.
So, if it is possible if you find that you have a free beam member where you have access and you can remove the cover concrete part and apply the additional stirrup across the core concrete with the longitudinal reinforcement, then it is preferable that we go for them but in the event if it is not possible, then what we can do is that we can strengthen this member by using additional material on the outer periphery. That means on the existing system we can try to bring in the reinforcements, the stirrups as I had shown it earlier assuming that you have slab on the top of it and then you have the beam member which is coming like this.

So, in this event to wrap the stirrup all around the beam is a difficult proposition because you will have to punch through the slab. Now, in that event what we can do is we can try to strengthen the three sides with part of the slab in such a manner that we can get some kind of stiffening in the zone nearer to the support.

Now, what are the alternatives that we have by which we can achieve this and if you remember, we had discussed earlier that we can use jacketing technique using concrete. We can use jacketing technique using steel as a member. So, those are possibilities but at the same time what you can do is that you can strengthen even this kind of a system using FRP, fiber reinforced plastics and it could be any of the fibers either glass fiber or carbon fiber and this is what has been demonstrated over here as you can see that the member if it is distressed or you

want to strengthen this particular zone, you can adopt this kind of FRP in strip form.

You can have strips of FRP as it has been shown over here either on all three directions you can take in the form of wrap in the form of big U or if possible if the slab does not exist, if you have a beam which is running straight, you can have wrapping over the all four sides. That is possible or else as it is shown over here you see this is a system where you have the slab which is running along this and you have the beam member which is running along this. So, you see these beam member also resting in the column which is shown over here.

Now, this particular zone if you see the beam which is nearer to the column support have been strengthened using this FRPs. Black colour show that this is a carbon fiber which has been used to wrap and these wrapping has been done on all three sides because fourth side you have the slab and it is not accessible.

So, as I was telling you over here, that you have three sides on which you can wrap FRP and that has been wrapped over here to strengthen this particular zone, near the support zone and also you see over here in the central part, the bottom soffit of the beam has been provided with the fiber strip which can strengthen the flexural zone.
So, the beam as it is shown over here that in the support zone, you need to have close spacing of the stirrups in the support zone, here you need to have close spacing of the stirrup. Likewise in the central span also you need to have closed spacing of the stirrup. Now, of course, this is a flexural zone, these stirrups you need more to prevent the shearing actions at the support. So, these kinds of FRP wrapping helps to a large extent to enhance or to strengthen the beam members which are susceptible or vulnerable against earthquake actions or if those members are damaged because of earthquake actions like the one which has been shown over here.

So, FRP is very convenient material for such kind of strengthening, but apart from FRP as I have stated earlier that you can make use of concrete, you can make use of steel, any of these materials but the main objective is to strengthen these beam members, beam members and they can resist the seismic actions effectively by such strengthening. So, that is the objective and that is how this objective has to be made with.

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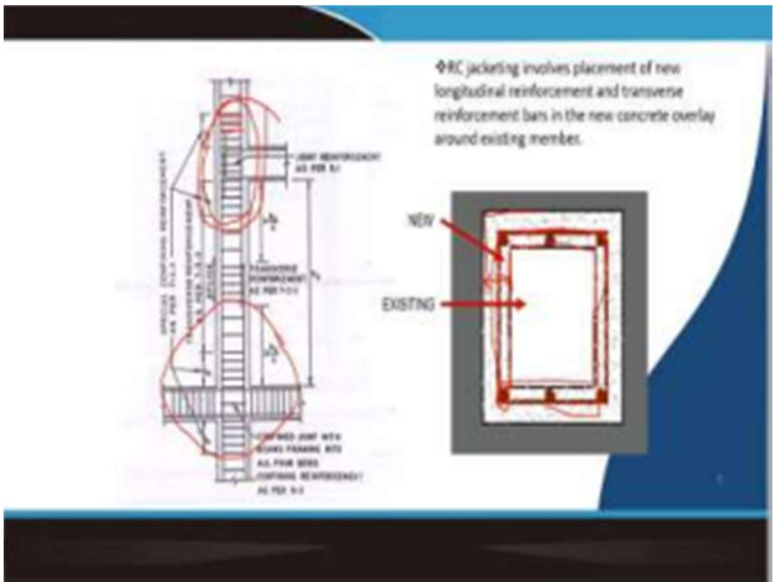

Likewise, if you see that again, when we try to detail out in a normal circumstance, when you try to detail out a beam column junctions and the column is to be the earlier in the earlier case, I had shown that how the beam is to be strengthened in the beam column junctions. So, likewise in a beam column junctions, the column member also has to be strengthened and this is what has been shown over here, you see that the stirrups have been placed at a very close spacing and there are stipulations again in the given code as given over here that you need to create the special confining reinforcements or the stirrups. In fact, these stirrups help the concrete to be confined in that zone and as a result because that is the zone where you expect the moment to the cross the elastic stage faster. So, we need to strengthen that.

So, many times you will find in the detailing that the stirrups are avoided at the joint for the concrete to go in in this beam column junction. But from earthquake point of view, it is recommended that you must provide the stirrups the reinforcements in an appropriate manner so that you get proper confinement at the beam column junction.

Now, here alongside the strengthening of the beam member, you need to strengthen the column as well. And again, I come back to the same point, here also you see that both beam and column strengthening has been shown by adding the stirrups and also here in the confined zone on all four sides, you should have the confining impossible and this kind of treatment, if as I said earlier that is possible that you can use concrete if you find that these junctions are accessible, you can provide reinforcements from external surfaces and then you can apply concreting you can do that and that kind of jacketing is ideal and this is what has been shown over here.

In fact, I have discussed with you the reinforced concrete jacketing several times and you know how to do it. If you have an existing column member or even existing beam member you have in this form. And then we adopt additional reinforcement to it and then try to provide some

kind of stirrups and these stirrups can be put as I said that you can have like U stirrups on both sides and then you can bring it from both sides and then apply concrete in this particular zone and this is what has been shown over here that in this zone between these two the existing surface and the new surface the concreting has been done.

So, this is the thickness of the concrete jacket that has been provided over here. So, you can apply concrete jacketing of course, with the concrete system, if you apply concrete jacketing then it is appropriate. Now, one aspect I must state you over here that when you are applying concrete jacketing eventually you are increasing the thickness of the existing column member and if you are continuing this jacket for the entire length of the column and you are reaching to the foundation level, you will have to be careful that you have adequate width available for the footing to transfer the load.

If not you need to strengthen the footing as well so that the additional strengthening that you are applying to the column member can transfer the load effectively through the footing to the soil pillar. So, you need to take appropriate actions on this and if this providing additional reinforcement and concrete if it is not possible, then what you can do is you can always apply FRP again as an external element.

Of course, alongside these as I said earlier, that you can apply steel plates to strengthen these steel plates, steel members can be added along with this by suitable connection or else you can make use of FRP to wrap in the column member and the beam member. And finally, you can achieve the strengthening of the members in such cases. So, that is also a possibility.

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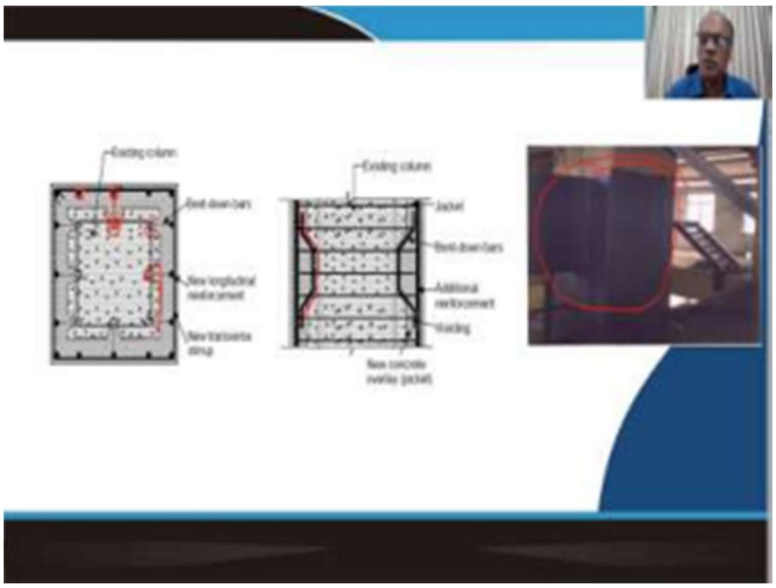

Well, these are again the kinds of jacketing techniques, the concrete jacketing techniques that

have been shown over here and as you can see here is that this is the existing column, the existing reinforcements have been opened up by making some these kind of notches by removing the concrete in this particular zone and the existing reinforcement that have been exposed up and the new layer of reinforcements have been adopted as you can see over here, these are the new reinforcement and also some kind of connectivity has been created by the new reinforcement and the old reinforcements like by using a hook. Hook kind of stirrup have been used.

So, this gives you additional connectivity between the existing concrete and the new concrete and then you apply the new parts, new transverse reinforcements or stirrups and then you provide concrete so that you can strengthen the existing member. So, this is also another form of detailing that has been shown that some part of the existing concrete has been removed and a bent up bar has been used, so that you get a connectivity between the old concrete and the new concrete and this is in the longitudinal direction of the column member.
Now, alongside this as it has been shown over here, you can see that a beam column junction has been strengthened using FRP. So, as I said, that either you try to make use of concrete as it has been shown over here or you can make use of steel members to strengthen the columns and the beams and also you can make use of FRP to strengthen the junction between the beam and column.

So, these are the possibilities by which you can adopt the strengthening measure and this strengthening measures really will be helpful in resisting the seismic actions and of course, the thickness, size and all for these additional bars or the FRP they are to be designed in an appropriate manner so that it can resist the loads that we are expecting from the seismic event. That is how it will be the seismic strengthening of the system.

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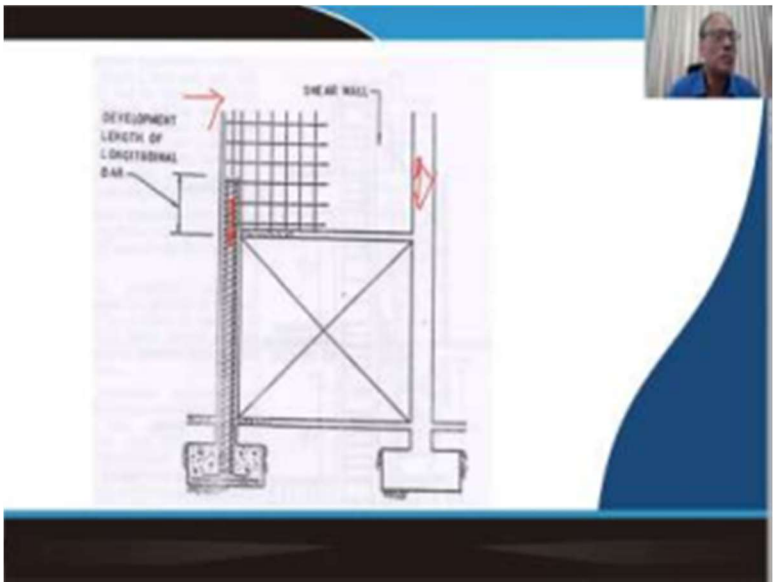

Now, earlier I had explained to you that we make use of a system which we call as a shear wall. Shear wall is basically a system which is connected in a framing system between the columns to resist the lateral load in terms of bending, though we call it as shear wall but actually the load transfer mechanism that happens in shear wall is basically through the flexural actions or through the bending actions. When such frames are subjected through these lateral load to this wall system, the whole wall system carries this load in terms of flexure or bending and distributes the load between these framing system.

You have a framing system, here you have a column member here and also you have a column member here which is part of the frame and this framing system gets the load from the shear wall and gets distributed. So, that is the advantage of having the shear wall. Now, if you have an existing shear wall in a framing system and if the shear wall has undergone some distresses, then we can apply the repair or retrofitting technique to the shear wall system by if need be by providing additional layer of reinforcement and applying jacketing technique.

Or else sometimes what happens as I was telling you in the beginning that you have designed a building and at that point of time the codal stipulations were such that you need not have to go for the shear wall action, but subsequently when the code stipulations were modified and the structure which you are looking into came in a zone when we expect some seismic actions to happen that means the building which was not provided with the precaustions for seismic event is now required to look into from that perspective.

So, if you have to strengthen such kind of structural system against the seismic actions, so, what you need to do is that you need to add additional shear wall, so that the framing system becomes safe against seismic actions.

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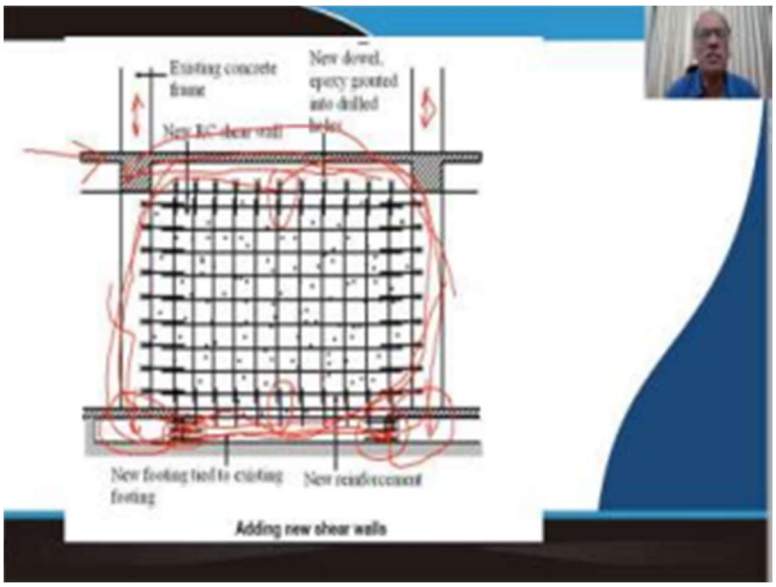

So, in such cases what you can do is that you can introduce shear wall within the existing system. Now, you presume that there was no shear wall in this frame here this is the column member. This is a column of the frame this is another column of the frame and the slab and the beam you can see over here. Now, so this is what has been put.

So, here also you have the beam member. Now here below this column you have the foundation system here which is getting load transferred through this foundation system and so is over here. Now, if in this region you feel that shear wall is to be introduced, so that the load can be distributed between the column members in an effective manner that can be done.
Now, here what has been demonstrated is that you can have some kind of dowels systems introduced into the existing and here this is one foundation system for the column and this is another foundation system for the column and another connecting foundation is being introduced between these two foundation system and here also some kind of connectors have been attached which are going in the existing concrete as well as getting into the new concrete and a concreting is done.

Now, to this side and to the side now, the reinforcements are getting anchored through the additional anchors which is getting connected between the new concrete and the old concrete. So, on both sides, the reinforcements are provided in layers and maybe on this side as well as on the far side.

So, you have two layers of reinforcements in both cross directions and the longitudinal directions and then you pour concrete so that entire area gets filled up with the wall and thereby you create a wall which is getting connected between the two columns and the beam system

and thereby this whole system become so rigid that in the event when you get a lateral load coming because of the earthquake action, the load gets distributed into this whole system and it can carry the load in an effective manner.

So, these kind of systems can be introduced in a framework and thereby you can strengthen the structural system against seismic action. So, that is how the seismic strengthening can happen in structural system. So, these are some of the techniques, some of the methodologies that are available with us which we can adopt appropriately depending on the requirement. Alright.

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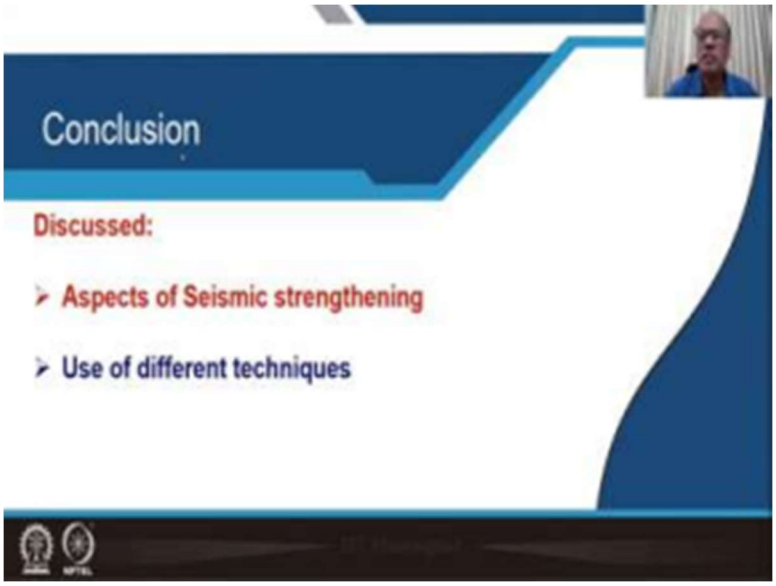

So, in this particular lecture, what I wanted to convey to you is some aspects of the seismic strengthening that can be adopted through different techniques. Some of the techniques we have already learned earlier and some of the techniques I have just tried to explain to you and using these techniques, you can effectively strengthen the members, the structural members, so that it can carry the seismic loads effectively or if there were distresses in structural members because of seismic actions, you can strengthen them in an effective manner to bring them back to normal situation so that it can carry the load.

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So, thank you. Thank you very much for your attention. And in fact, in this concrete retrofitting system, the retrofitting of concrete member, we wanted to demonstrate to you that how different retrofitting techniques can be adopted in an appropriate manner so that you get load carrying capacity as desired for the structural systems. All right. Thank you. Thank you very much.