Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 53
Retrofitting steps and Techniques

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Welcome to the second lecture of the module on the retrofitting of concrete structural element. Last time, we have spoken about certain kinds of distresses that we normally observe in case of concrete structural element. And if you recall, we spoke about the different kinds of tests that are required to be done for arriving at proper diagnosis for the distresses.

And in this particular lecture, we intend to start from there that based on the results that we have received from the tests how, do we carry them forward. So, this is what we are going to discuss today in this particular lecture.

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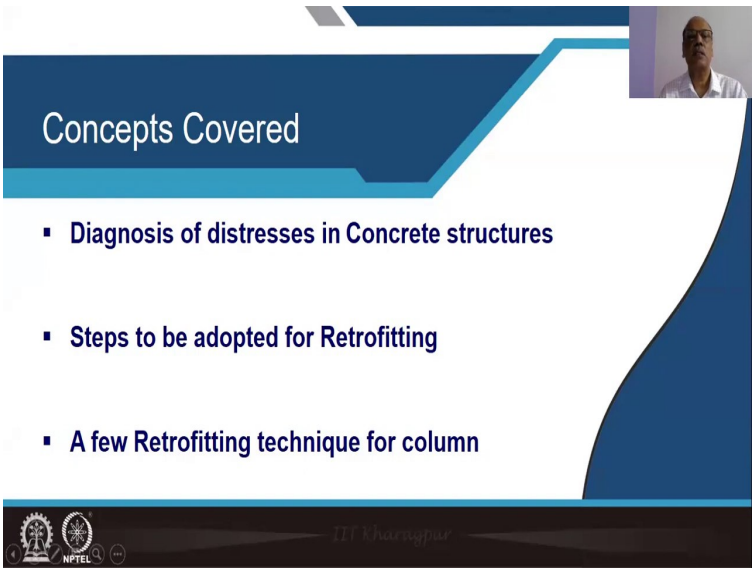

Well, as I said that we are trying to find out that the different kinds of distresses that we observed in concrete structure, how do we diagnose that if we find a distress in a concrete structures, as we have discussed earlier, that if it is crack or if it is spalling, or other kinds of distresses you find some kind of a shearing cracks that you have observed, or kinds of cracks which you can classify as a flexural crack, if those appear in the structural element, then how will you arrive at a conclusive point saying that this has happened because of this.

And if you remember, we said that you need to carry out different kinds of tests. So, once you have the test results before you, then it is important that how do we interpret those results. So, you need to understand the steps before you really arrive at what is going to be the retrofitting step. So, interpretation of the results, analysis of the structural system, those are to be adopted first, and based on the conclusive ideas that you get from this, you need to adopt certain retrofitting techniques.

So, in this particular lecture we intend to talk about these steps that how will you proceed. Also, I want to discuss with you a few retrofitting strategy, retrofitting technique which can be adopted for different structural elements. We will, as we will go along, you will see that how we do arrive at that and how do we interpret them in a manner.

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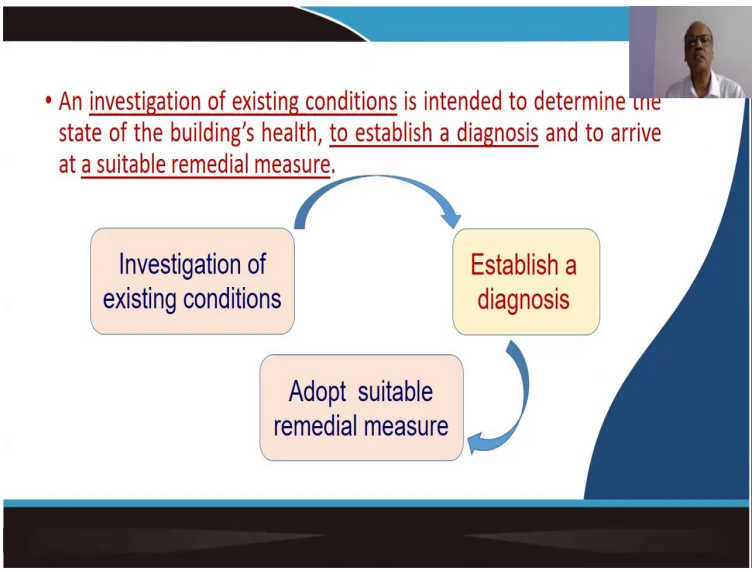

Now, I have told you earlier several times that we do try to carry out investigations of the existing system of the structure. This is basically, we intend to determine the state of the building's health, health monitoring and then we arrive at a diagnosis. And once we establish the appropriate diagnosis, then we need to attack that root cause to repair in an appropriate manner so that we can say the structure is retrofitted.

So, we need to adopt suitable remedial measures. And as I have explained to you earlier in the context of the masonry structures, we have discussed several techniques, and as I said that either a single technique or multiple techniques combined together need to be adopted depending on the state of the structure. So, investigation of the existing conditions.

And if you recall we have discussed different kinds of tests both in terms of non-destructive tests as well as the destructive test. Now, whatever are listed in the group of non-destructive or the group of destructive, it does not mean that you will have to adopt all the tests for the structural system. You need to either understand, from the visual inspection, when you see kind of distresses in a structural system, you try to visualize that what could be the conditions for which this kind of appearance have happened, why this kind of distresses have happened in the structure, what could be the possible reasons.

Now, if we can think in that particular direction, then we can say well, let us carry out these tests. And when we carry out the tests keep in mind that we have two aspects in our

mind. One is that we need to understand the behavior of the structure that how these distresses are happening and how it is propagating, and why it is happening. The other one is to establish some of the properties of the material in the existing structure, so that those material properties can be utilized to further analyze the structural system.

So, with these two basic concepts or the ideas in mind, we try to suggest that please go for these kind of tests in this structural system. And once you carry out these tests, and the results that you get, you can make use of this in interpreting suitably that what is the mean problem in the system and how to address that issue.

So, once you do that, then you need to identify that where the problem is. The problem could be in the column members, problem could be in the beam members, problem could be in the slab members, problem could be in the shear wall kind of a system, if you have. Problem could be in the foundation system, problem could be in the junction, at the interconnection between the beam and the column.

So, we need to understand in a localized manner as well that where the problem is. When you see a distress in a structural system, you see or you might say that it is a localized phenomena that has happened. That local phenomena which has happened has happened because of some global actions. And through test, through analysis we try to gather the data, both in terms of the local system, as well as in terms of global system.

And based on these combined effects, we try to interpret the results and come up with the diagnosis. So, again and again I am emphasizing on these points, these are absolutely important. You identify the kind of tests that would be appropriate for a particular kind of structural system. Somewhere you may go for ultrasonic test, you can go for a core test, you can go for a chemical test. But in some places you may say well we do not need to go for the core test, we can go for ultrasonic, we can go for chemical result, get the interpretation done.

So, it is absolutely on to the persons who are carrying out this has to understand that what are the kinds of problems that can exist and try to direct your test in that direction. Well, you can do a few tests extra if you are not very sure of what could be the issue, what could be the problem. And having more data and then analyzing them is of course not a problem, and also can be done.

So, it is not very certain saying that well you have to carry out only this, this test for this, this kind of structure. So, it cannot be that kind of a prescription or you cannot prescribe as such a priority without looking into the structural system.

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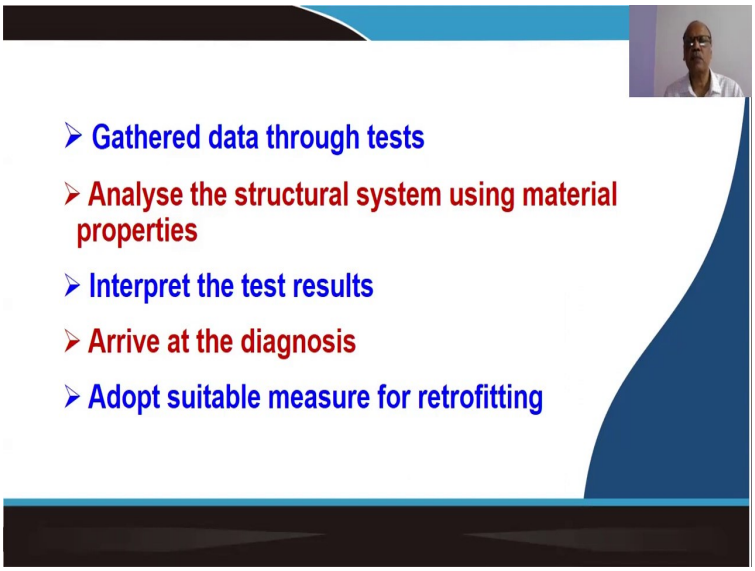

So, what I intend to tell you in this is that we have gathered now data. When you have suggested the tests to be carried out on the structures and based on those tests you have gathered the data. Now, once you have the data with you, the next question that comes that what are you going to do with this data?

So, the data has to be analyzed, the data has to be interpreted. When you get, let us say you carry out the tests on ultrasonic on concrete structures, and then at different points if you apply this, your sensors, apply it, send the pulse and collect it from the other end, and then in the process you get that what is the velocity of the wave that is being transmitted through the transducer.

Now, if there is no discontinuity in the structural system internally, it is expected the wave will be passing through smoothly, thereby time requirement will be less, velocity will be high. So, we say if we have higher velocity then the concrete is expected to be good. But if the velocity is lower, that means time required for the pulse to move takes more time if there are discontinuities.

So, there are discontinuities, your velocity is less. So, from these tests you can interpret saying that well, this particular concrete has this kind of qualitative feature. So, from the data that you collect from different tests, you will have to interpret and you will have to come up with the system, understand the system that how it is behaving now. That is one.

Second thing is you remember we were talking about the analysis of a structural system. Now, the structure that you are investigating, it could be of different kinds. Whatever is the structural system, you can always idealize them suitably. If it is a building structure, you can come up with a two-dimensional framing system, if it is a tank, you can come up with a system, if it is a bridge you can come up with a system.

So, you can idealize the framing system for the structure and the study. Then, from the test that you have carried out, you get certain characteristics of the material and the material properties can be made use of for analyzing the system, the idealized system based on the data that you will be generating or gathering from the test.

And that is very important. By getting the material properties in situ, this, that presently what is the property of the material, if I give you an example, let us say you had constructed the structure using a concrete of grade M25. Now, for a new M25 concrete has certain strength, has certain modulus of elasticity, and if you use those property and analyze the structural system, you will get certain kind of displacement components at different points.

Now, so after 20 years when you find some distress in the structural system, and you try to analyze the material, you try to extract some material, test it, and you get its properties. You get its strength, you can get its, modulus of elasticity, and if you make use of those in the analysis system, it is expected that there will be a difference between the previous analysis and the present analysis. And that is what we try to look forward.

With the material properties that we have present, we analyze the system. And like to see, at a particular point if we focus, what was the displacement or other parameters, other characteristics based on the actual feature of the structural system. And what is the present value based on the properties that we have at the present system.

So, the difference between the two will tell me that whether there is something wrong in the system or not. That is number one, and this response that you get is a global reference response. So, you say well, we find that displacement of this particular point is different than what it is expected to be.

So then you will have to find out that why this is happening, why the displacement is coming higher than what was earlier, that means there must be something wrong with some structural element in the infrastructure system. So, the structural element, maybe a column can go wrong, maybe a beam can go wrong, so there could be change in the stiffnesses, there could be change in the material properties.

So, now how do we arrive at that? So, now this global information that you are getting from the analysis, and the test result that you have in the localized level, so combinations of these two will help you to arrive at a suitable diagnosis of the problem of the structural system.

And this is where we need to focus on, we need to interpret the result we need to analyze the result and say that yes, this is the basic problem of this particular structure which has to be addressed. And once you address that, it is expected that the whole structural system will be okay. And that is what is our objective or goal in this whole study that we are trying to do.

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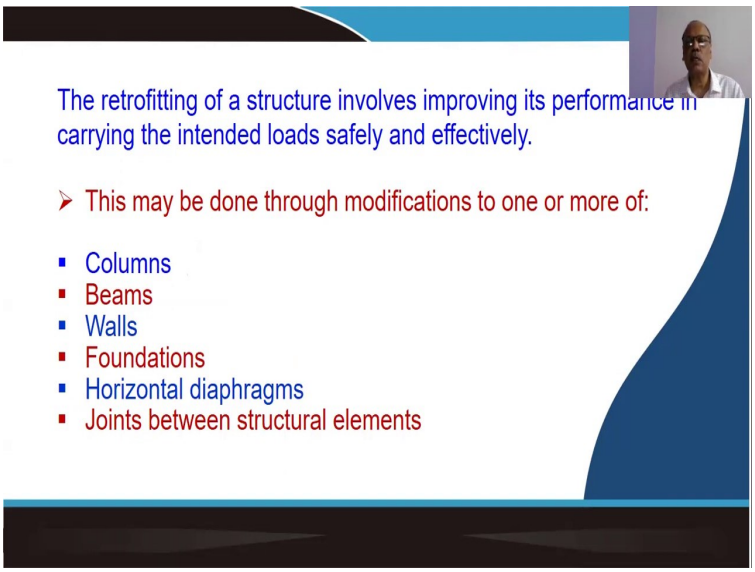

So, as I have told earlier several times that the retrofitting of structure involves improving its performance in carrying the intended loads. When you are trying to retrofit a structural system, you have diagnosed as either there is some distress because of some causes and you want to rectify that or you have identified a structural system which you think is vulnerable against certain kind of actions and you need to strengthen and upgrade it.

But in both the cases what you want the structure to perform, to carry the desired load safely and effectively. And this is what is our objective for the retrofitting of the structural system.

And a structure comprises of several structural elements. These are in terms of basic structural elements, could be columns, could be beams, could be walls, could be foundation, horizontal diaphragm, and the joint between two structural elements, that is very important, the connection between the beam of the column and several other things. So, we need to look into each individual cases in a structural system and understand that how they are, and if maybe you address those issues, so that the entire structural system is retrofitted in an appropriate manner.

Now, what I intend to do is that we need to discuss, I want to discuss with you few retrofitting techniques that we normally adopt for each of these elements one by one. And then, depending on the situation when you really address a problem in practice, you can

give a thought that whether that kind of retrofitting technique can be adopted so that you get the remedial measures.

And as I have said earlier, not necessarily that very strictly you will have to apply that particular technique, but you can take a basic concept from there, you can always innovate, you can always come up with new things and you can adopt suitably as long as the structural element is strengthened, as long as it is effective in carrying the load, it should be fine.

And finally, you should look into that whatever technique that you adopt, it should be effective, you should be able to carry the load safely and finally give you the desired results.

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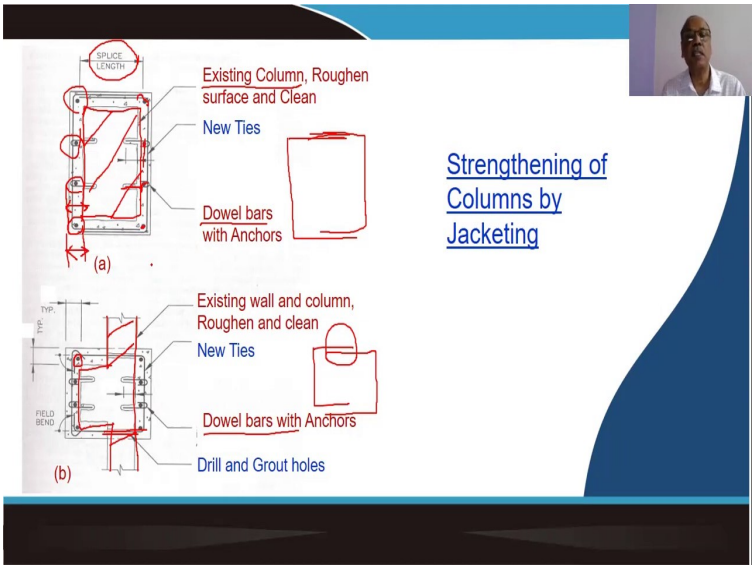

So, let us look into these techniques or some of the techniques that we try to adopt. Now, let us take this case, in the first instance that you have here, let us say you have a column. Now, you see this is the basic column that we have under consideration. And this is what is written over here, is the existing column.

What is needed is the external surfaces on supposing that this particular column, you have observed that there are some distresses in this column. And this particular column, needs to be strengthened, and it should be strengthened in an appropriate manner, maybe by applying an additional layer of concrete material along with the reinforcement.

Now, if that has to be done then what is intended is in this particular figure what is shown over here is that how this can be strengthened by using an external jacketing system to this column. What it means that you add an additional layer of concrete as you can see here that we have put additional thicknesses on the existing system.

So, the existing column surfaces are first of all are to be cleaned. Many a times you will find that there are, there could be some spoiling of the concrete from the surfaces. So, if there are loose material, those loose materials have to be removed, it should be scrapped properly and surfaces should be cleaned and it should be roughened.

And once you do that and in these columns, we will certainly have its reinforcements within, which we are not going to touch upon as such right now, but externally we want to introduce a system and connect the new system with the old system in an appropriate manner. So, this is what has been shown over here.

Now, externally, what is being done is first of all some number of vertical bars are being used, you see here, you see at this location, we have used at this location, we have used at this location. So, at all four or eight locations, rather, eight bars have been, vertical bars have been used in the column members.

And these vertical bars are to be held up, as it happens in a column, you have noticed, the vertical bars are tied with the stirrups. So, here also you have to apply the stirrups. But since this particular member is existing, this column is existing, so naturally you cannot tie a stirrup all along this bars.

So, what is done is that the stirrup is split into two. It is like U. What is done is one part is done like this, and the other part is done in this form, another U. And then there is a overlap of the two. See, this is what has been shown over here, and this is what is written as a splice length.

It means that this part of the stirrup, and this part of the stirrup, they are overlapping. So, you have two U-shaped ties which have been provided to connect all these vertical members, eight members that we have put longitudinally. And now to connect this old concrete with the new concrete, what has been done is, along with these bars, the vertical bars, hook has been provided.

It is kind of a anchor, we say, that these are vertical bars, we call it as a dowel bar, and these dowel bars are provided with the anchors, and this anchor is going inside the old concrete, as you see. And typically this length could be of the order of about 125 to 150 millimeter, depending on the size of the column that you have.

So, depending on the diameter of the bar that you have, so it is about 4d, 5d kind of a thing that you, or at least you can calculate that what would be the anchoring length of those bars, and you insert that much of length inside the concrete. So, these anchors will help you to connect the existing concrete with the new concrete that you are providing.

Now, after carrying out this, we need to provide an additional concreting over here. This is the additional concrete thickness that is provided on all sides, and this is what will act as a jacket to the system. Now, while providing this jacket, it acts as a confinement to the existing system, the existing member gets confined with the external member, and thereby the load carrying capacity of the whole system increases.

So, this is a kind of a technique which is very frequently adopted for strengthening the column member. So, the concrete column is further strengthened using the concrete member itself. Likewise, you have another scheme that we see over here. Again there is a column, you see, at this place, we have a column, and this column is connected with a wall.

This is a monolithic, it is a continuous system that we have. And here also the strengthening has been carried out by providing jackets on all sides. So, in the similar fashion as we were discussing over here, additionally, the longitudinal bars have been provided as you can see over here, these are the longitudinal bars.

These longitudinal bars are again tied with the new ties in the form of U on both sides. Again, it is in this form that you have a U bar on both sides like this. So, you have a overlap. And this is what we call as a splice, and effectively then, if we have overlap in an appropriate manner, then the whole thing, the vertical bars can be supported by these ties.

Second thing, which is very important that this aspect we have already discussed about the dowel bars with the anchors, so the vertical bars are provided with the anchors to

connect, to create a connect between the old concrete and the new concrete. Another important thing which is different from the top one is that here, this concrete is connected with the wall.

So, this wall as you see over here, is continuous with the column system. So, as you had in this place, the tie could go smoothly all around the bars. But in this place, the U-tie that we have provided, the U, one part, one leg of the U cannot pass through because you have a wall here.

So, what is needed in the wall, we create a kind of a hole by drilling, we create a drill in the wall, and through that hole we take the U-tie. So, that the stirrups can be provided effectively on all sides of the bar. Now, when you are creating this hole by drilling, naturally there will be a gap between the bar and the concrete.

So, we try to fill up this gap by using suitable grout materials, the cement slurry grouting material can be applied. And cement slurry grout can connect or can fill up the hole, so that you get a continuity, you establish a continuity between the tie bar and the concrete. So, the holes are grouted using suitable grout material.

So, again, this is a scheme where we apply jacketing, and this jacketing technique can be done to strengthen the column. Now, one point I must mention over here the thickness that you provide for the jacket, it varies depending on what is the size that you want to enhance. It could be of the order of around 75 millimeter, 100 millimeter to 150 millimeter.

And whatever you decide depending on the requirement, you need to provide the appropriate reinforcements to it, or the vertical bars, the ties and their diameters are to be decided, so that you get the effective system in carrying the loads. And wherever you create holes in the wall concrete, mind that those holes are to be provided with the cement slurry grout, maybe sometimes modified with the epoxy material to get a better flexibility and better connectivity between them.

So, these are some of them salient features of this kind of retrofitting techniques that are normally adopted in a structural system. Particularly, we are discussing about the strengthening of the column members by applying the jacket. In the concrete since the

thickness of the additional new concrete that you are providing is less, the size of the aggregates also is required to be less.

Instead of, in a normal concrete, we say 20 millimeter down aggregates, in these particular cases, you may have to go for a concrete with lower size of aggregates, could be 12 millimeter or sometimes around 6 to 8 millimeters depending on the thickness of the additional layer that you will be providing.

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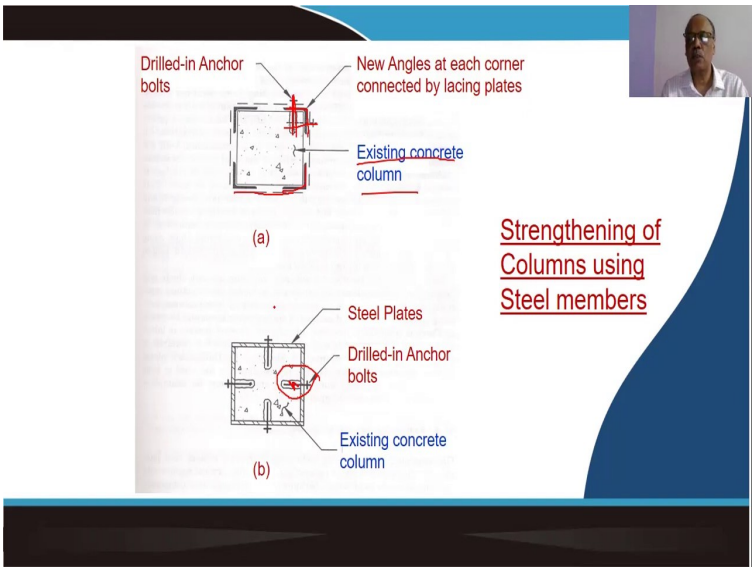

Another case of strengthening the columns, let me just discuss with you. There are again, I have brought in two features over here. Now, you see you have an existing concrete column which is under distress, and this can be depending on if you find that the strength of the existing column is not much, you want to enhance the strength of this existing system, what can be done is that we can fix some column, some angle members, steel angle members.

As you can see, at four corners four steel angle members are provided. And these steel angle members are connected by lacing in the vertical plane by lacing member, as we do in a built up column. And these columns steel columns are interconnected with the existing concrete with the anchor bolts. So, you drill in the in the existing concrete, and insert the anchor bolt, and then you can grout it.

And on the external surface, on the steel you can put a washer plate so that gap between the steel and the bolt can be filled up. So, you can have drilled in anchor bolts. And mind that, since you will be having anchor bolt on this side, you will have an anchor bolt on this side, so all you need is that you need to stagger it in the vertical plane.

One anchor bolt goes in this, another anchor bolt comes in this in a vertical plane. So, you have two perpendicular planes there, at a particular junction, and they will be one above the other. So, we provide two, four new angle members connected by lacing, and then connected by anchor bolt so that you create a system which is new. So, the existing concrete can be strengthened by using the steel members.

So, in this particular case if we like to create a confinement for the existing concrete column, we provide some steel plates in, as a box. And these steel plates, steel box can be connected with the existing concrete using these anchor bolts, drilled in anchor bolts. So, we create a drill, and then insert this and grout it, so that it can be filled in and covered, and we can create a connectivity between the existing concrete and the steel plate.

So, this kind of actions, wherein we have brought in different material, in the previous case, we had strengthened the concrete column using concrete element itself, but in this particular case, the concrete is being strengthened bringing in steel as an external element and connecting them together. So, you can apply any one of these kind of techniques to strengthen the columns. So, these are certain retrofitting techniques for columns, which can be adopted to come up with an effective retrofitting measure.

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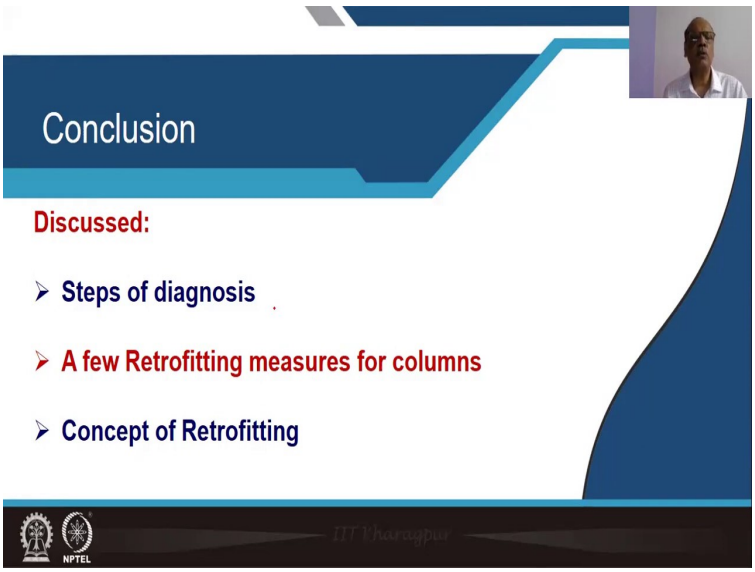

So, today, as we have seen that we have tried to discuss about that what are the different steps that can be adopted to arrive at a proper diagnosis and the retrofitting measures, that normally can be adopted for columns. And again, I am saying that is not that you need to restrict yourself to this only, you can think of suitable devices, but it should be supported by proper design and then only you can adopt it so that you can get an appropriate retrofitting measure.

So we basically tried to give you an idea about the retrofitting measures that can be adopted in a column system, if you diagnose that well, the columns in a structural system are in distress and those are to be strengthened to arrive at appropriate retrofitting measure for the entire structural system. So, likewise we will like to see other elements also in our subsequent lectures.

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Well, thank you. Thank you very much for your attention. We will look into some of those rehabilitation measures for the structural systems. Well, thank you for your attention and we are going to take up some more retrofitting measures or some other structural materials as we go . Thank you.