Retrofitting and Rehabilitation of Civil Infrastructure
Professor Sriman K Bhattacharyya
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture 52
Introduction

(Refer Slide Time: 00:42)

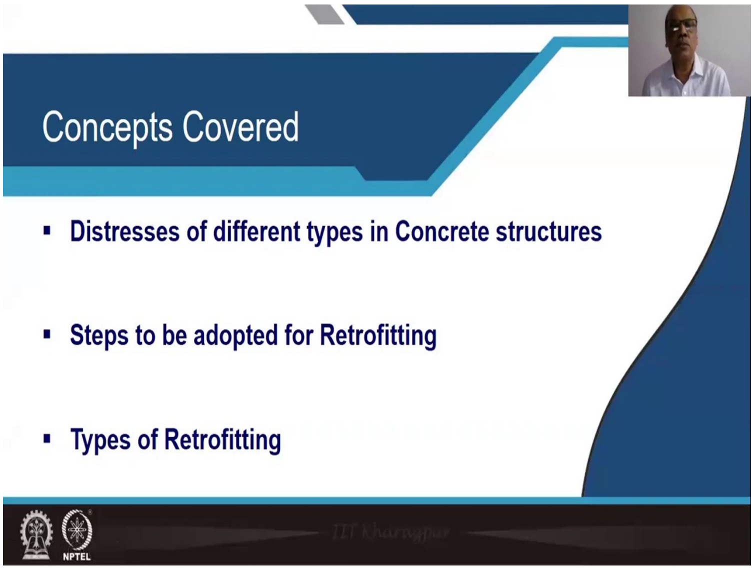
Welcome to this module of which we are going to discuss on the aspects of retrofitting of concrete structural elements. In fact in last module we have spoken about different aspects of the retrofitting of masonry structural systems. And we have noticed that how those are retrofitted, the masonry structures are retrofitted in an appropriate manner depending on the kind of distresses it has.

Now, in this module, we expect to discuss aspects on retrofitting of concrete structures. And in this particular lecture I will take you through some of the aspects, how do we diagnose distress, what are the steps through which we should go and how do we adopt appropriate retrofitting measure so that the structures can be put in practice or put in use for getting the expected load.

Now, for concrete structural system as you know, that a large number of structural systems are constructed making use of the concrete. So, concrete is very extensively used material in construction industry. And thereby, the concrete structures need more attention.

While yes, it is important to understand the distresses that the structures do suffer which are made out of different materials, but concrete being extensively used material, it is important that we look into the various kinds of distresses that we come across in concrete structures, and how do we diagnose them in an appropriate manner and how do we apply in a retrofitting measures.

(Refer Slide Time: 02:39)

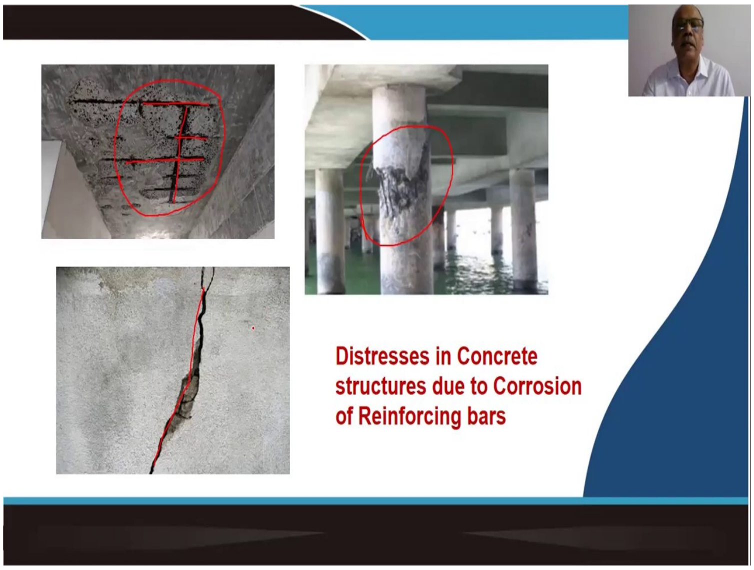


So, in this particular lecture, we are going to look into some of the aspects of those. So, this is what stated here that we need to look into the distresses of different types that we come across in concrete structures. I will just try to cite a few examples of the varieties of distresses that we observe in concrete structures, though there are many types of distresses that we normally come across.

And then you have to understand the distresses in an appropriate manner. When I say in an appropriate manner it means that you have to carry out proper investigations to come up with proper diagnosis of the same distress. And then how do we adopt a suitable remedial measure, so that the structures can be put in use. And as we have seen in case of masonry structural systems, we have tried to identify certain retrofitting technique, which are prevalent, which are available.

And we, if our distresses are of that kind for which are retrofitting measures have been discussed, they can be adopted, or we need to devise suitable methodology based on those basic concepts that we have. So, we will look into those as we will go along.

(Refer Slide Time: 04:04)



Now, well here as you can see, some of the pictures which shows the distresses in the concrete structural system, and you see in this particular picture, you can observe that this part of the concrete slab, this is the bottom part of the slab where you see the reinforcements are exposed. The concrete, which is the cover concrete below the reinforcement level, those concrete has pulled up from the concrete surface and the reinforcing bars are exposed, these are the reinforcing bars which are visible very distinctly, these are the reinforcing bars.

Now, what happens is when concrete, the reinforcing bars in the concrete, it corrodes because of various reasons, there could be some surficial cracks which develop because of shrinkage, because of temperature variation sometimes because of the overloading if the structure experiences some additional load, then what is, it is designed for. Through those cracks the moisture increase happens, and when the reinforcing bars comes in contact in the moisture, it gradually creates, or corrosion initiates at certain places.

And over a period of time, the reinforcing bars corrodes and when it corrodes, what happens is the volume expansion happens, and also the volume of the bar gets increased which exerts a pressure on the concrete and thereby the bond between the concrete and the steel starts loosening up, and the concrete in the process falls up. So the concrete below the reinforcing bars falls down. So, it comes up which we call as falling of concrete.

So, this kind of experiences we have gathered in many places, the structural elements shows distresses because of corrosion of the bar. In fact this is another example where you can see, this the pillar of a marine structure, how it has distressed. Marine structures, since the structure system is exposed to the water, or sometimes there could be level of water goes up and then again the water level goes down because of the tides and because of the wetting-drying situation, the bars, if there is ingress of the moisture inside the concrete, the bars come, gets exposed to the moisture actions and thereby corrosion takes place.

And when the corrosion happens, and over a period of time if it is in the, it is not noticed in the initial stages, it is not attended in an appropriate manner, then there is a possibility that the concrete starts falling in this form. And this kind of distresses you observe in the system. Also, you see, you must have noticed that many a places, the concrete structure cracks, and the cracks widen up, and these can happen for various reasons. It could be because of the settlement, because of movement, it can happen because of the corrosion.

So, for different kinds of actions, you find the distresses in concrete structures. And for reinforced concrete structures particularly, the corrosion of reinforcing bar is one of the important thing that we need to take notice of. And in many a places the concrete structures do undergo distresses because of corrosion of reinforced bars.

(Refer Slide Time: 07:47)

Now, this is another example of another structural system which we very frequently come across which is that of elevated water tanks. In elevated water tanks, again you store water. So, in the reservoir, if there are certain kinds of though, a lot of attentions are taken into account while designing or construction, there could be situations where there could be moisture increase because it retains water.

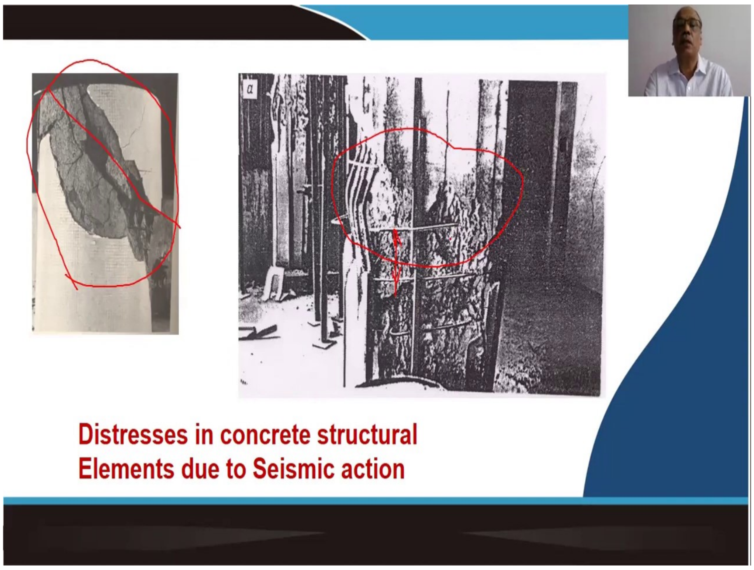
And if because of that the reinforcing bars start corroding, then you find distresses all over the places in the elevated water system. And as you can see over here that the bars, the structural surfaces have shown distresses, and a little closer view of this particular part of the water tank, the bottom of the tank, as you can see here, that the parts are exposed, the concrete has fallen down, the bars are exposed, and this is a kind of a distress that must be attended to, otherwise the tank, water tank will become ineffective.

One of the major elements that are present in such water tanks are, you see here a shaft which is holding the entire water tank here. Now, this shaft is actually hollow shaft, inside of which you have a spiral stair which allow you to go to the top for inspection level. Now, you see this is the closer view of that particular staircase, this is a closer view. And you see that the steps that are provided in this, how these are corroded and distressed.

So, these kind of distress are to be attended to if you really want this water tank to function, and its life can be extended. So, we need to look into in closer details. Now, most of the time what happens is if these are not noticed in the beginning, the distresses can expand and it sprays all over the places, and that is why it is important that we do carry out periodic maintenance of such kind of structural systems and try to identify whether there are any distresses.

And if there are any distress, you should try to identify why certain distresses have happened, and apply suitable remedial measures, but it does not expand to a level where you need major distresses have happened in the structural system. So, this is one of such examples where you will get this kind of distresses in the structural system.

(Refer Slide Time: 10:42)



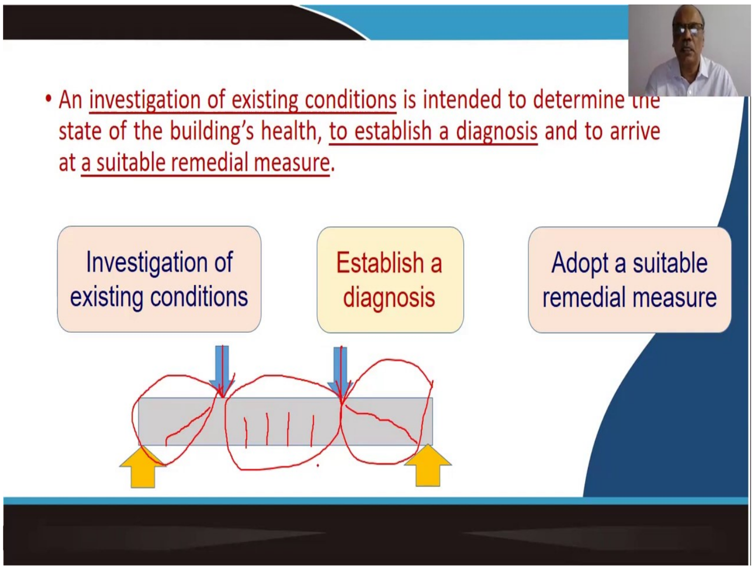
This is another example. We were talking about the earthquake actions or the seismic actions. Because of that you get lateral load in the structural system, and which can cause damage to structures. And as you can see over here, this is actually a column member supporting a deck, and you see this is a kind of failure that has happened which is attributed as the shear failure. Because of the lateral load the concrete has tried to split up.

So, and this happens because of many times poor detailing maybe because of the initiation of the corrosion of the reinforcing bars and loosening of bond between the concrete and the steel, and maybe the system had inadequate shearing strength. So, because of that it has a failed up in shear. Clearly, if you see this particular figure, here it shows that the detailing of the reinforcements are not appropriate.

The level of ties that have been provided, they are quite distance apart, and also looks like that the ties are not really as it should be as it is stipulated in the codal specifications. So, having some kind of a deficiency in the system, and when these systems are exposed to lateral loads, then it shows certain kinds of distresses.

So, many a times we have seen the different structural elements, concrete structural elements, columns, beams, slabs, they do undergo distresses when they are subjected to lateral load due to earthquake. And add to that, if you have poor detailing or inadequate detailing, then systems become more vulnerable and the failure can happen.

(Refer Slide Time: 12:40)



So, as we have discussed earlier for the masonry structural system, so that holds good for the concrete structural system as well. Clearly, distinctly, there are three steps. We say that we need to investigate the existing conditions, the existing conditions are to be looked into, are to be monitored, are to be investigated.

And once you investigate the existing system, you try to understand the system as a whole, you try to understand the kinds of distresses that have happened into the structural system, then you try to correlate that why this kind of distresses have happened, these distress attributes to what kind of cause.

And you remember when I was talking about the masonry structure system, I had stated that you will have to understand that what is the cause because what you see is the effect of that cause. So, from the effects, and as I said that this is an inverse problem that you are looking into the effects for some cause, so looking at the effects you need to identify the cause.

And I had given you an example which here also it stands that when you, if you carry out a test on a reinforcing beam, say reinforced concrete beam is tested, it is a simply supported beam and subjected to two point loads. You have applied the load here and a concentrated load, and also you have applied a concentrated load over here.

Now, when you apply two concentrated loads, let us say at one-third, one-third, one-third distances, what will happen is that your, this particular zone in which you will have the shear force present in this particular zone you will have shear force and the flexural load present, but in this particular zone it is purely, you will get the flexure. There are no shear forces over here.

And if you keep loading this particular structural system, you will find that you will get vertical cracks generating in this region because the bottom fiber will undergo tensile stresses, and when concrete will not be able to withstand the tensile stress which goes beyond the capability or the capacity of the beam, you will find that the vertical crack start generating.

Now, and if you keep on loading this you will find that you will get some kind of inclined cracks in this particular region where you will see that the cracks possibly are propagating in this type of form. Now, this gives us a lesson which we learned that if we see particle cracks in reinforced concrete beam members, we can say that well, predominantly because of the flexural action this kind of cracks have happened.

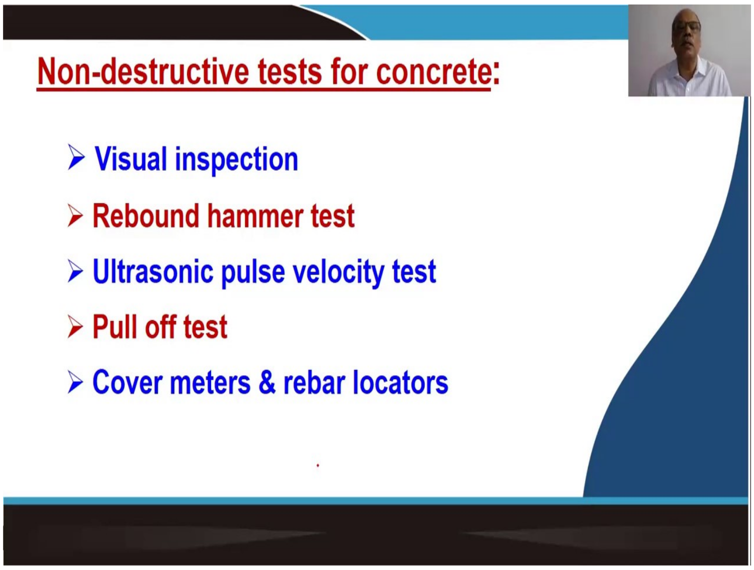
Or if you see inclined cracks, you say that well possibly combinations of flexure and shear have caused such kind of cracks. So, we try to create a database of ours from the phenomena that we have observed from the test that we have carried out. So, this depository of this expertise can be made use to diagnose a system looking into the distresses that have happened in the structure.

So, this particular step is very, very important, it has to be done very carefully, and once we identify that cause, then we can adopt the appropriate retrofitting measure, and then we can arrest the deterioration in the structural system. But again, I am repeating, mind that if we cannot identify the root cause of the problem and if we cannot really address that distress in an appropriate manner, then whatever remedial measures you adopt is not going to be effective as long as you are not rectifying the root cause of the problem.

So, distinctly, as earlier in the beginning I have spoken about seven steps that you need to do, and primarily in those steps what we do is that we try to investigate by suitable steps, and once we get our investigation result we try to map that, we try to find out that, well, these are the effects we have seen in the structure, what is the cause of this problem.

And then we try to apply a retrofitting measure to arrest that cause by which we can strengthen structural system. So, this is, these are the three clearly distinct steps as we have discussed earlier, and this is also equally applicable for concrete structural systems.

(Refer Slide Time: 17:45)



Having said that, now when we talk about the investigations in the concrete structural system, again we talk about different kinds of tests, and broadly, all the kinds of tests can be classified in two groups. One group we call as a non-destructive test, and another group obviously comes as a destructive test. And when we talk about non-destructive tests, what we mean is that we do not cause any destruction to the structural system as such.

We try to carry out certain tests which could be on the external surfaces itself, and those can be listed as visual inspection, of course is one of the aspects. It means you observed visually different components of the structural system, try to map what kind of distresses are observed, and whether there is some cracking, whether there is a spalling of concrete, whether there is corrosion of bars, at which places it has happened and which are the vulnerable places in the structural system.

So, while we carry out the visual inspection we try to identify whatever aspects are possible from the external inspection system. And then we, depending on a particular structure, depending on the kind of distresses we try to suggest that, well, what kind of our test we can carry out, so that we can identify the cause of the problem. And again I try to bring the analogy that we have discussed earlier.

It is just it can be compared with the human systems when they go for the medical test, the doctor physically, first, clinically checks the person and based on certain observations, then they say well, you please carry out these tests and the patient goes for the test, come with the test results and then doctor, looking at the test results try to interpret that what is the cause for which the person is not feeling well, and then try to give medicine for that diagnosis.

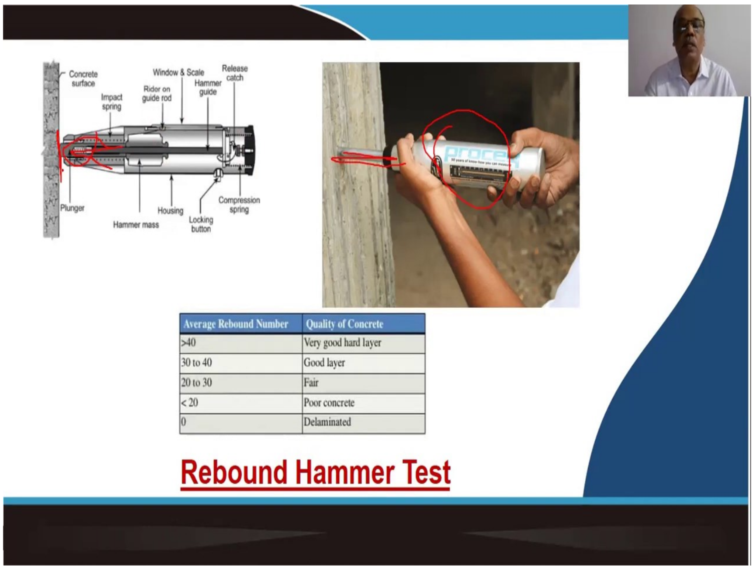
So, similar analogy can be applied over here. You look into the structural system, you try to understand the kinds of distresses that exist, and then for that particular system you suggest that what are the kinds of tests that can be done and carry out those tests and get the test results, try to interpret test results in an appropriate manner to corroborate that what is the cause that has caused these distresses, so that you can apply remedial measure for that particular cause by using suitable retrofitting measures.

So, we have listed as rebound hammer test, ultrasonic pulse velocity test, pull-off test, cover meters & rebar locators. I will just talk about those three in a little elaborate manner, but for cover meters & rebar locators as the name suggests that there are instruments available which can specify because, this, earlier I had stated that you try to look for the documents that are available.

If you do not get any documents like the drawings based on which this construction had happened, then you need to create that drawing, you need to create a document which is commensurate with the structural system. So, if it is a reinforced concrete structural member, which we are discussing now, we need to understand that how many bars are there, at what depth the bars are there from the bottom surface, so what is the cover thickness.

So, there are instruments available with which you can identify the thickness of the cover, you, there are instruments which can identify that the number of bars that exist and the diameter of the bars. So, cover meters and rebar locators help us in creating that kind of a document by taking measurements, if those documents are not available.

(Refer Slide Time: 22:00)



Rebound hammer test is a kind of a test where you can find out the surfacial hardness of the structural system. This is basically, you have a piston or a plunger which moves inside the cylindrical specimen, and is spring loaded. So, this plunger, when it is touched on the surface, and if you try to push and give some energy, impart on the structural system, the structural system rebounds on that impact that you create, and from which you can find out that how hard the surface is.

Normally, the results that you get using this rebound impact, rebound hammer, is we called as a rebound number. And if rebound number is higher, is of the range of 40 or so, you can say it is a very good or a hard layer, the surface is hard. And you get a qualitative measure that if it is very low then the concrete is very poor. So, you get a qualitative assessment of the concrete based on these rebound hammer testing.

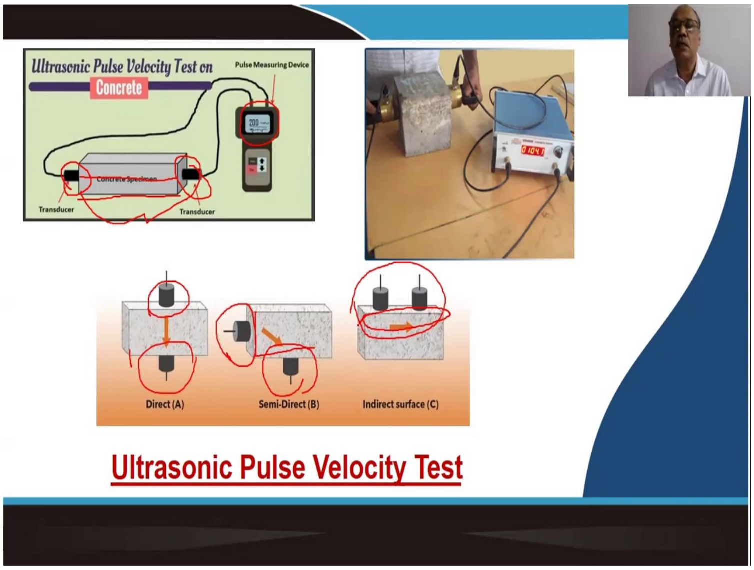
Again, as I said that the pictures or the photographs that I am showing over here, either I have picked up from net, or I have taken based on the works that have been carried out by our students. So, I thought, I put a disclaimer on that. So here, the details of the rebound hammer has been shown, that as you see in this particular picture, you see this as a external housing in which you have the plunger which is moving.

So, here you see this, the plunger is basically spring loaded at this particular location, and there are graduation, or there is a scale on which you get the impact number, and you try to push it after pressing on the surface on which you are trying to find out the hardness.

And once you press on the plunger, the concrete surface rebounds it back, and from which you can get a number which is normally call as a rebound number, and from which we can find out that whether the concrete surface is strong or not.

And we try to correlate that. You can calibrate the system with reference to the strength of the concrete from which you can assess that what could be the strength of the existing concrete. We try to find out how much strength still it is existing in the concrete structure which we are investigating.

(Refer Slide Time: 24:17)



We do carry out a test which is called as an ultrasonic pulse velocity test. What happens is in the concrete structural surface, if you have two distinctly clear surfaces available, let us say for a column member or two opposite sides are free and accessible, then what you can do is that from one side, you can send a pulse through a transducer, the transducer is attached on the concrete surface on one side, and using another transducer you can collect that pulse on the other side of the specimen.

Now, if the length of the specimen, then you can find out that how much time it is taking for the pulse to move from one end to the other, so that distance divided by the time will give you the velocity. So, basically as an output what you get as a digital display is the velocity of the pulse which is being transmitted and being accepted. Now, if there are no discontinuities, if you do not have any discontinuities in this concrete internally, then the pulse will move really through the internal surface and time requirement will be less.

And if time requirement is less, your velocity will be higher. So, higher the velocity, qualitatively you can say it is a better concrete. But if the pulse takes more time to move from one end to the other, it shows that there are certain kinds of discontinuities because of which the pulse is not able to move freely. So, thereby, what will happen is you will get a velocity which is lower. And if you get a lower velocity you can say concrete is of not good quality or poor quality.

Again, we can benchmark or calibrate against good concrete and then we can say that if these are in these ranges, then the quality of concrete is good. Now, here, three scenarios have been shown over here. Many a times, it may so happen that the structural element which you are investigating using ultrasonic pulse velocity, you do not get two opposite phases are exposed and in which you can fix the transducer to measure the, or to check the quality.

So, what you do, if you do not have, you try to see whether you have two perpendicular faces exposed and available to you or not, and then you can transmit the wave from one end, through the transducer, and then try to collect it from this expectedly because the pulse which is getting transmitted will flow all around and you can collect it over here.

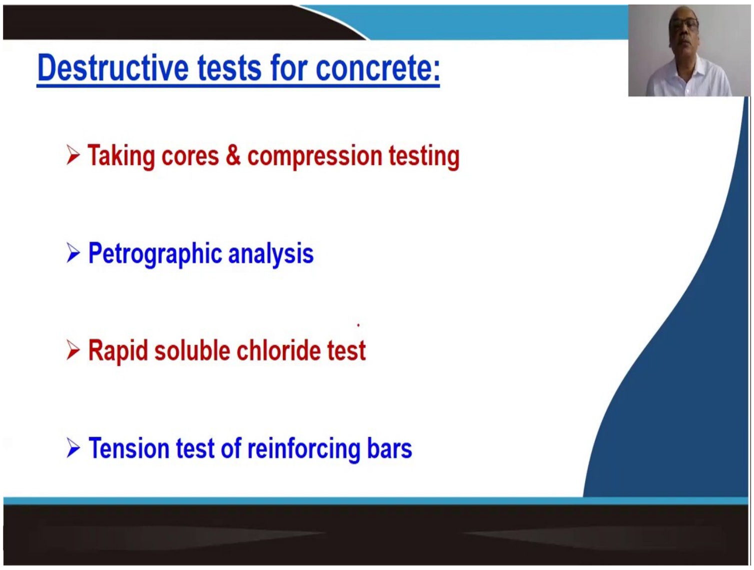
So, you can get some idea about the quality of the concrete in a limited region. You cannot get the idea about the whole area, as you could get in such cases. Or sometimes, if you find that all three sides are not accessible, only one side of the structural element is accessible, then we can provide transducer on the same surface itself. That means we transmit from one side and collect it from the other side. Now, by doing so, again you will investigating on a small region of it, not that the entire concrete can be commented upon about the quality.

So, sometimes if structural elements are not accessible freely, we may adopt to this and then we try to interpret by suitably adjusting, by based on the expertise, based on the experience and based on the repository that you have from which you can say that well this is the kind of systems or the quality of the material is of this kind.

(Refer Slide Time: 28:36)

There is another kind of a test which you call as a pull-off test, which gives you the strength of the surface. In this instrument you try to apply a force and try to pull off, and then what is the force that is needed to pull it off, and then you can find out the stress and the corresponding strength of the material or the concrete that you are investigating.

(Refer Slide Time: 29:03)

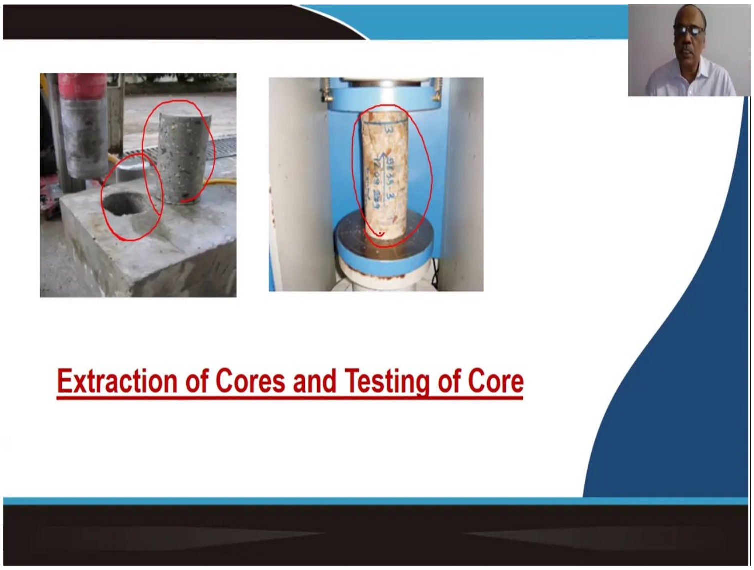


So these are different kinds of tests that you can adopt while going for the non-destructive test. Similarly, there are sets of destructive tests which can be adopted for concrete structural system. And one of the very important destructive test is that we try to extract some core sample from the existing structural elements, and then those cores are tested in a compression testing machine to understand what is the strength of the concrete.

We do carry out chemical analysis by taking samples from the existing concrete structural elements, which are, which you call as a petrographic analysis or rapid soluble chloride test, to understand its durability and its chloride content in the sample. And also, sometimes we try to find out the strength of the reinforcing bars, how strong they are, whether it is corroded or if it is corroded what is strength remaining.

So, we cut out samples from the existing bars. Of course, we take a sample from a place where we know that it is not going to cause much of a problem to the structural system, and in mind that when you do this kind of destructive test, and when you take out samples proper precautions are to be taken so that structure is supported in an appropriate manner and no more damages happen in the structural system. So, we do carry out tensile tests on the reinforcing bar, and try to understand what is the stress strain properties of that material.

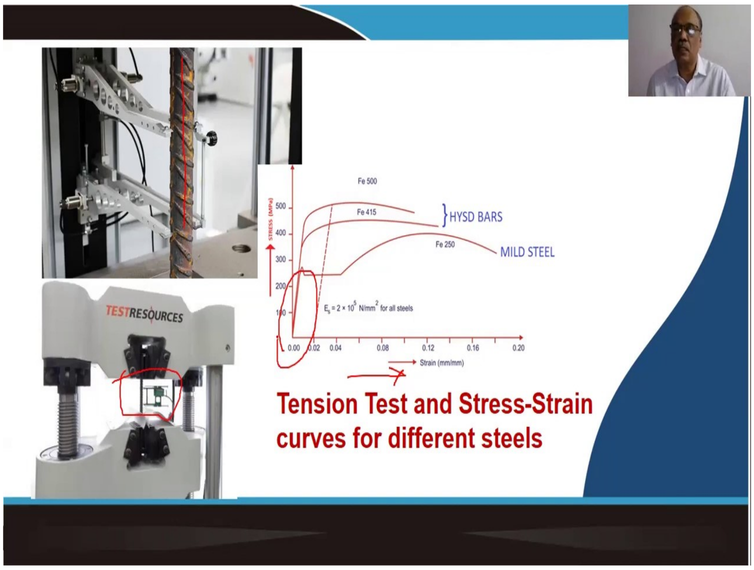
(Refer Slide Time: 30:31)



So, here, you can see that this shows how from the structural elements the cores can be extended. There are core cutter of different sizes, of different diameters, and depending on the depth of the concrete element, you get cores. And then this cores are tested under compression testing machine to understand that what is the strength of the concrete.

Normally, the length of the core is taken twice the diameter depending on what diameter of the core you are extracting. And if you do not get, normally, as we have, we say the 150 millimeter diameter cylinder we test it for carrying out the compressive strength. Now, for a lower diameter cylindrical specimens, you can suitably modify it by suitable factor to predict that what is the strength of the existing concrete system. So, core testing is one of the important thing from which we can find out the existing strength of the concrete.

(Refer Slide Time: 31:37)

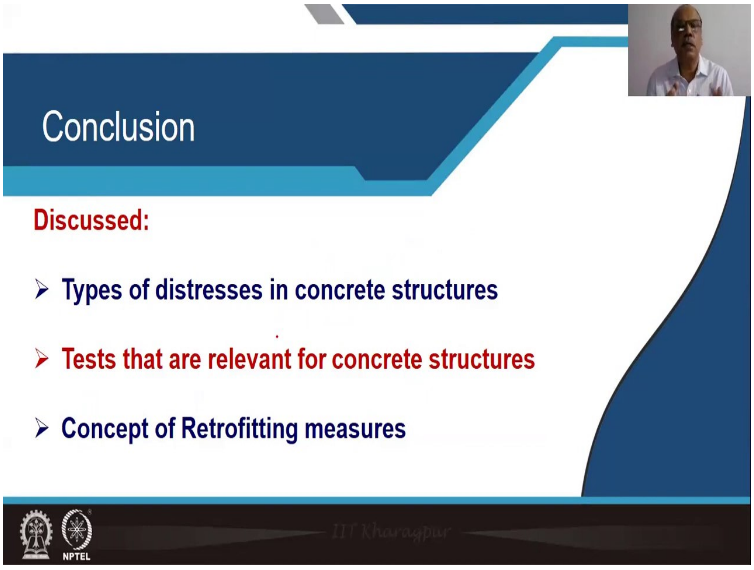


And so is for the reinforcing steel, you cut a sample of the reinforcing steel which from the existing structure, and that bar is hold under the clip with the gauge length, and then if you put in the tensile specimen, you pull this bar to find out that what are the stresses getting generated. I mean, how much extension is happening under the load, or thereby stress versus strain, you can plot it.

And so, here you see the plot of the stress and the strain. Strain is this axis, and stress is in this axis. Now, if you plot it you can get for different kinds of bars, you see that the different kinds of stress strain that is happening and from these stress strain properties, we can we can get the E value from the basic slope of these elements. And this E value, if you remember in the beginning, we spoke about the, carrying out the analysis of the system.

And there, we try to make use of this E value, so that we get the state of stress in the structural system based on the present properties of the material. So, based on these properties we try to understand that what is the existing stresses that is there in the present structural system, and accordingly we take actions depending on what is to be done, if we can identify the prime cause of the problem.

(Refer Slide Time: 33:16)



So, well, in this what I wanted you to have an idea about kind of distresses that we normally see in concrete structures, and what are the kinds of tests that we can adopt which are relevant for concrete structural system. And based on these test results we need to diagnose a system.

And as I have told you earlier that we do carry out the test on the material, we try to extract the material properties, those material properties we can use for the analysis of the structural system, and also, we try to understand the behavior of the system, we need to understand the resulting strength of the concrete member based on certain tests. So, both, qualitative and quantitative data will help us in diagnosing the problem, in carrying out the retrofitting measure of the system.

Now, as I have told you that if we can identify the problem, then we can adopt the suitable retrofitting measure. And this retrofitting measure we will look into as we have seen in case of masonry structures, that there are certain concepts which are available with which we can repair the masonry structures.

Likewise, I will tell you that there are certain methodologies which are available, certain techniques which are available which can be adopted to repair or retrofit a concrete structural system, either individually or in combinations of those systems, depending on the kinds of structures you are addressing.

(Refer Slide Time: 34:54)

All right, so, I stop here for this lecture, and then we will try to look into the different kinds of retrofitting measure as we go along.