Retrofitting and Rehabilitation of Civil Infrastructure
Professor Sriman K Bhattacharyya
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture 46
Review of Materials and Test Methods

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Hello students, welcome to the third lesson of the module that we were discussing which is on overview and today in fact, we are going to talk about review of materials and test methods. As you have seen in the last two lessons, we have discussed aspects on retrofitting and rehabilitation of civil infrastructure. And we have spoken about the steps that we need to adopt while retrofitting structural system.

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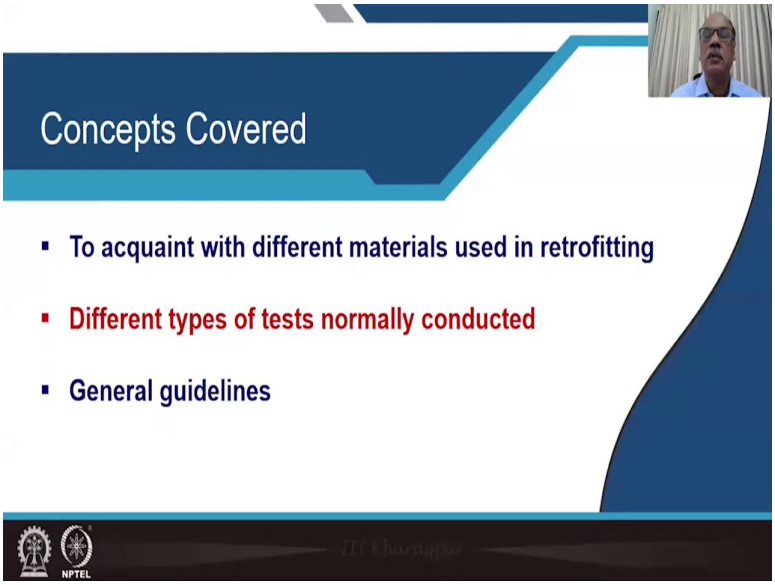

Now, in this particular lesson, we thought that we will acquaint you with different kinds of materials that we normally use while carrying out the retrofitting operations for civil infrastructure. Also, we have spoken about, while we are talking about the steps that are required to be adopted, that we know we need to carry out different kinds of tests on the structure to ascertain the kind of status of the structure, the health of the structure, existing structure, so, that we can adopt appropriate retrofitting measures based on the conditions of the structure, so, we need to carry out certain tests.

So, we look into the kinds of tests that can be adopted for different kinds of materials on different kinds of structural systems about that we classify. So, we are going to discuss those in this particular lesson.

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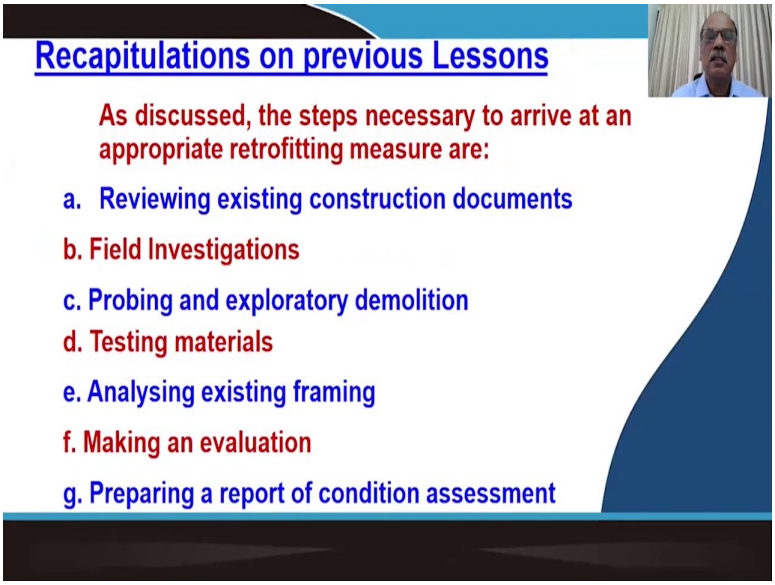

And again, just to remind you, that in the previous lesson, we have spoken about the steps that are necessary for arriving at the appropriate retrofitting measure for civil infrastructure system, and for that, the seven steps we have described, and we have already discussed these steps. Today, what I am going to do is I am going to talk about this particular part of it that testing materials, what are the kinds of materials that we adopt, and what are the kinds of tests that we normally adopt for different kinds of structural system.

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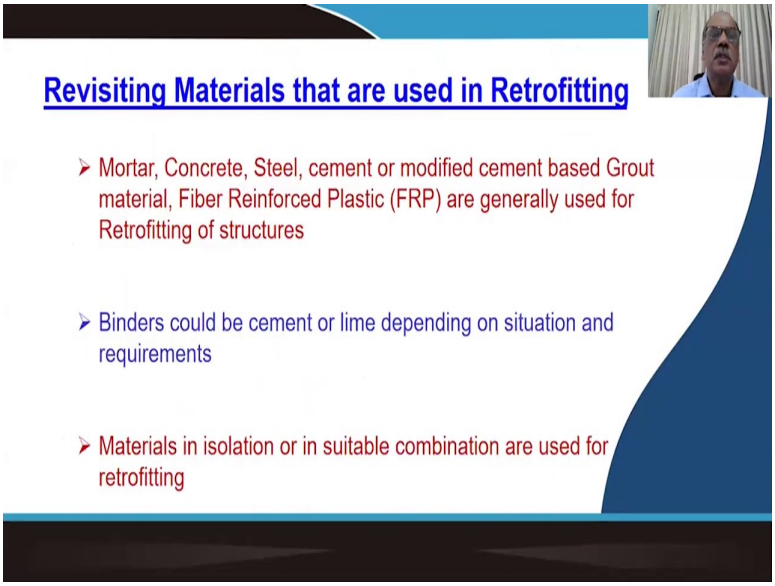

Now, broadly I am sure that all of you are well acquainted with different kinds of materials that are adopted in civil infrastructure system. Most of the structural systems are with concrete or steel framing, and we use masonry as a pillar system when we go for a frame

structure. Also, we have systems which is solely out of masonry systems, either brick masonry or stone masonry systems.

So, thereby, broadly we can group the structural systems as masonry structures, the concrete structures and the steel structures and of course, it is expected that any structural system that you get either will be one kind of these or combinations of these that are normally adopted. Accordingly, the kind of materials that we need or that we normally apply or adopt to go for the retrofitting are the mortar.

And these are of course, you need a binder and aggregate to create a mortar and the binder could be of different varieties. So, we use mortar, we use concrete, and concrete when we talk about this is a heterogeneous mixture of the binder, fine aggregate, coarse segregation and of course, along with water, we use steel both reinforcing steel as well as the structural steel, if we are going for a system with structural material steel, then we use structural steel.

And when we will be going for the details of retrofitting, you will see that if you have cracks in the structural system, it is important that we feel up those cracks in appropriate manner. And many times, we adopt kind of slurry, cement slurry mix which is kind of a non-viscous element which can be injected into the structural system and we normally call this as a grouting material, so, cement grouting we do adopt.

These days for retrofitting operations we are using extensively material which you call as a fiber reinforced plastics FRP and this is different kinds of fibers we use which are high strength fibers with light weight and these are impregnated with some kind of resin, normally epoxy resin we adopt. And this fiber reinforced plastic materials are suitably applied or adopted in structural system, so, that the structures can be strengthened in an appropriate manner.

So, we will look into some properties of those, because I will impose plastic being a relatively newer material in comparison to the non-conventional concrete steel that we use in structural system. And as I said that when we use mortar, particularly when you try to look for the structures, which are kind of edited structures, the old structures in earlier days the mortar that used to be used was with lime.

So, many times lime sand mortar are also used. So, depending on the requirement you may adopt cement sand mortar or it could be lime sand mortar as well. So, you need to look into those aspects as well in terms of binder property. And eventually depending on the kind of

distresses the structures you need to adopt appropriate retrofitting measure and it could be not necessarily that you can use one material only, it could be combinations of different kinds of material.

In a place you may adopt the grouting cement slurry grouting maybe modified with the epoxy and then the FRP as an additional standing method. So, you need to adopt combinations of the materials to retrofit a structural system in an appropriate manner.

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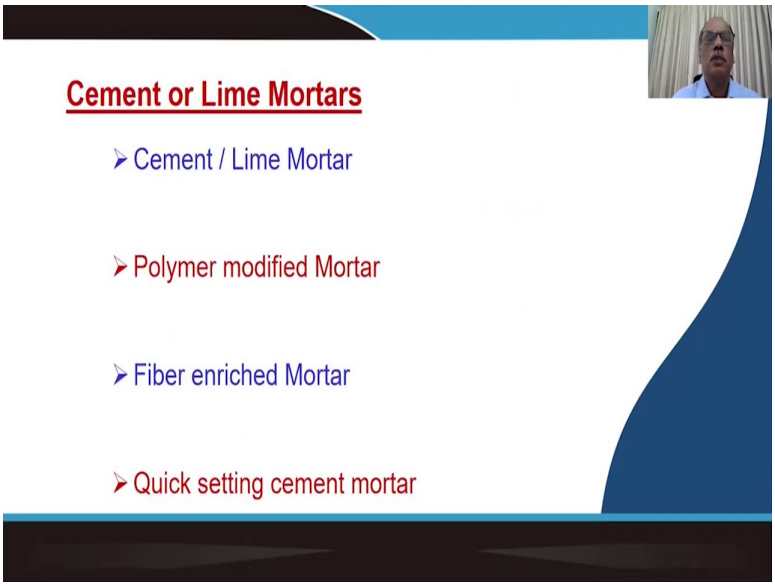

So, when we talk about mortars, again I have said earlier that we can use cement or lime as binder. So, you can use cement or lime mortar depending on the requirement that you need to adopt in a structural system which you are going to retrofit. These days we are using mortar modified with a polymer, this we do primarily to get a better property, better characteristics or filling up the cracks or joining elements in an appropriate manner.

Also, to achieve some amount of flexibility in the cement lime mortar system, we use the polymeric material, so, that it can undergo large deformation when it is needed. Also, many times we try to retrofit structural system in a place where you kind of be expect repeated loading and repeating alternative stresses.

So, there we try to adopt model which is mixed with fibers, thereby these fibers help you to prevent the kind of tensile stresses that may get generated because of the loading system, so, fiber in these mortars are also used. Also, with it many times you use quick setting cement mortar, which is basically hydrous magnesium phosphate and comprising a liquid and a powder mix together so, that it sets quickly and that kind of a mortar also is used in practice.

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When we talk about concrete and cement base material, is widely used material, construction material, that you were aware of and we use even concrete for our retrofitting purposes. And depending on the situation if it is possible to cast the element or if you are adopting certain or you are sending certain elements if you can use the ordinary concrete, when I say ordinary concrete, it means that mixer of binder, the cement, fine aggregate, coarse aggregate with water, and you can use the these to enhance the strength of the existing systems suitably placing this concrete into the structural system.

But, many times it may so, happen that the thickness of the concrete layer that you need to adopt in the existing system may be such that you cannot use large size of aggregates and thereby achieving a concrete of the appropriate strength becomes a typical job. So, there we try to adopt a concrete system with lower size of the coarse aggregates and also, we try to use different kinds of polymeric material along with this, we adopt system which is called the micro-concreting.

So, micro-concreting is also one of the mechanisms that we normally adopt when we try to go for the retrofitting. As I said that the infrastructural system is subjected to repeated loading or alternate kind of loading when you expect the compression and tension kind of stresses generated, all kind of impact the structural system is subjected to, there fiber reinforced system, fiber reinforced concrete is of great use.

The placement of the fibers or use of the fibers in the concrete to a large extent it helps in arresting finer cracks that are generated either because of the shrinkage or because of the

repeated kind of loading. So, thereby the fiber reinforced concrete system is also useful and many times we do adopt, we do use fiber reinforced concrete for retrofitting purpose.

Self-consolidated concrete, we make use of this, again we use different kinds of superplasticizer, so that the workability of such kind of material can be enhanced to a large extent. And these kinds of concrete is like a flowable concrete, if you have a space, you have a space constraint where you were pouring the concrete in a retrofitted system, there this kind of concrete is useful.

And the name itself it signifies that it is self-consolidated, it means that it gets settled, consolidated, and then gives the strength gradually. And thereby, you do not have to use as such any external element to compact or consolidate as such. As for concrete system, when we pour concrete, we need to adopt some kind of vibrating material, so, that the concrete settles or consolidated in the place where you are pouring, so that there are no pores internally and that way you get the requisite strength.

Now, the advantages that you get in some self-consolidated concrete is that, you do not have to adopt any external element to vibrate, the concrete itself is prepared in such a manner that it gets settled and thereby it gives you minimal pore within and gets a better strength. Many times, the surfaces, to improve the surface of the existing system we use the mortars or the concrete forcefully applied on the system through an equipment which we normally call as a guniting system.

So, this is called a shotcrete or guniting, which is adopted on the distressed surfaces, so that you can you can enhance the strength of the existing system and thereby the load carrying capacity can be enhanced to a large extent for that particular structural system.

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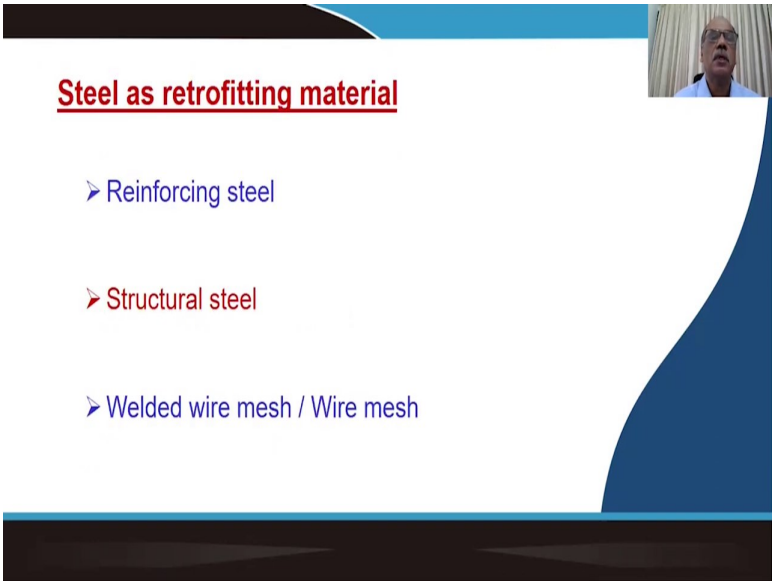

Steel is extensively used as retrofitting material both in terms of reinforcing steel as well as structural steel. For the reinforcing steel as you know that both internally as well as externally it is used, as you are aware that for reinforced concrete system, we use reinforcement as a material to take care of the tensile stresses in concrete structural element.

And when we need to carry out the retrofitting, because many times you will observe that or reinforced concrete system the distresses do happen because of the corrosion of the steel and if that happens, and if the steel loses its volume and thereby cross-sectional area gets reduced, where you may have to bring in additional steel elements so that you can strengthen it. So, we make use of reinforcing steel additionally to retrofit structural system.

As I was talking about FRP, in fact fiber reinforced plastics also used in part form and many times it has been explored to use in a retrofitting system. Also, many times we make use of reinforcing steel on external system and those kinds of strengthening it could be in terms of pins or post tensioning system kind of element that can be used and there we do use reinforcing steel.

Structural steel as it gets differentiated from reinforcing steel is that, if you are creating a load carry system using the steel as a material, we use structural steel to a large extent and structural steel are available of different strength, different capacity and we try to make use of those even in the strengthening of the existing system. When many times the concrete structures are also retrofitted or strengthened using steel elements to enhance the capacity or low carrying capacity of the system.

So, not necessarily that structural steel as a material of retrofitting is used only for steel structural system, but it can be used for concrete structural system as well. Most of the time you will find that when you are expecting any structural system where it is a combination of concrete and masonry, at the interface between the masonry and the concrete typically, you will find that a crack generates.

The reason being that you have two dissimilar material and you have different kinds of temperature phenomena, so, in case of thermal expansion and contraction a crack generates at the interface between the concrete and the brick mason. So, what for systems when you apply the mortar as a plaster material on the surface, normally it is good that if we can plaster the surface with an application of the welded wire mesh a finer mesh which you call it as chicken wire mesh, if we apply that along with a mortar, then the mortar impact against strain and thereby, the cracks are prevented to a large extent.

So, many times when you are encountering cracks in a structural system you want to repair and even those cracks are of non-structural type, they are not generated because of distresses of other aspects, those cracks can be repaired with the mortar and those mortars can be reinforced with this minor wire meshes, steel wire meshes and that helps to a large extent.

Then we will be looking into infact some of the retrofitting systems of using mortar with the steel wire meshes either welded wire mesh or chicken mesh. So, these as the material also is quite helpful in that sense.

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As I said that fiber reinforced plastics, in short, we call it as FRP, FRP is used extensively these days in the retrofitting of civil structural systems. And we use different kinds of fibers to create the fiber reinforced plastics, in fact, typically, these fibers are used in the form of a cloth and these cloths are impregnated with resins, again kind of epoxy resins we try to adopt and thereby we can create the fiber reinforced plastic cloth, which can be used for strengthening or the retrofitting of structural elements.

Now, that typically the kinds of fibers that we try to use, the carbon fiber which has very high strength, in fact, when we talk about the material, we talk about the strength to weight ratio. And FRP is in contrast to the steel as a material, if we make a comparison with has very high strength to weight ratio. So, we try to use carbon fiber or glass fibers or Aramid fiber and thereby we try to create an element a structural element, which is useful for retrofitting. And typically, you will hear these abbreviated terms CFRP or GFRP, which is used extensively in our civil engineering structural system.

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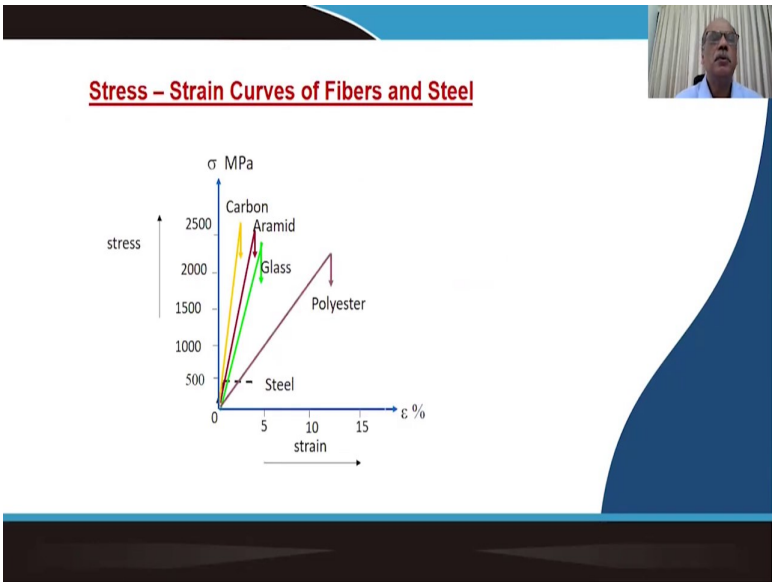

If you look into the typically the stress of fibers and make a comparison with the steel. In fact, you can see here that the carbon fiber has a very high stress and comparatively less strain, it means that the longest percentage is much less in case of carbon fiber. In fact, typically, for all three kinds of fibers, carbon, aramid, glass, as you can see, that compared to steel or the polyester the strain is less and thereby it indicates that its extension capacity is relatively less.

So, kind of brittleness gets generated with these materials, however, the strengths of these materials are much higher in contrast to the steel that you can see from here. Steel is at this particular level that we are talking about, whereas, the carbon, aramid, glass, are much higher in that we have. So, when we really try to use these kinds of materials and impregnated with resin, epoxy resin, we get a material which is having very high strength in comparison to the steel.

If you make a comparison of a steel versus of this kind of material, maybe 5 millimeters steel of let us say 500 MPa stress capacity, the strength can be replaced with for say 0.006-millimeter kind of thickness that we talked about the CFRP. So, know that way the carbon fiber reinforced plastics are very strong and weight wise if you make a comparison naturally, these are much lighter in comparison to the steel.

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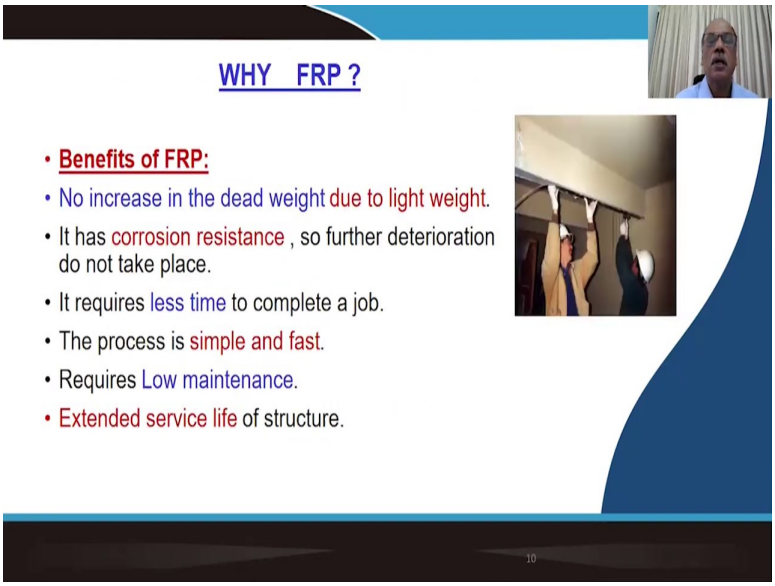

So, the benefits primarily that we get when we make use of FRP or the fiber reinforced plastics that there is no increase in the dead weight due to light weight as I am saying repeatedly that its weight is much less in comparison to the steel if we make a comparison with the steel or the material which we are going to retrofit namely concrete.

So, the weight is very-very less. The major advantage is that for reinforced concrete structure, normally the problem is the corrosion of the steel and if we use this FRP naturally the moisture ingress to the steel reinforcement gets reduced to a large extent and this FRP is a corrosive resistance and the thereby the deterioration of the concrete structural element can be adjusted to a large extent. So, that is an advantage of using a FRP.

It is very simple to adopt and use. So, it takes much less time in comparison to other kinds of materials that we adopt for the repeating the process is simple and fast, as I said. Maintenance wise, yes it takes relatively less maintenance in comparison to the other material. And naturally the service life of the structure can be extended to a large extent. Well, it has some disadvantages as well, particularly if FRP is exposed to ultraviolet ray it deteriorates with the impregnation of ultraviolet ray on the surface and it becomes brittle, so, it is to be protected in an appropriate manner.

Also, you know going particularly in civil infrastructure when you try to adopt any material ,the user always tries to look for that, whether these materials are recommended by the Board of Indian Opinion standard or not. So, we will have to have an IS-code or Indian standard code for this. So, that FRP as a structural material can be recognized, though it is gaining popularity in its use to a large extent today.

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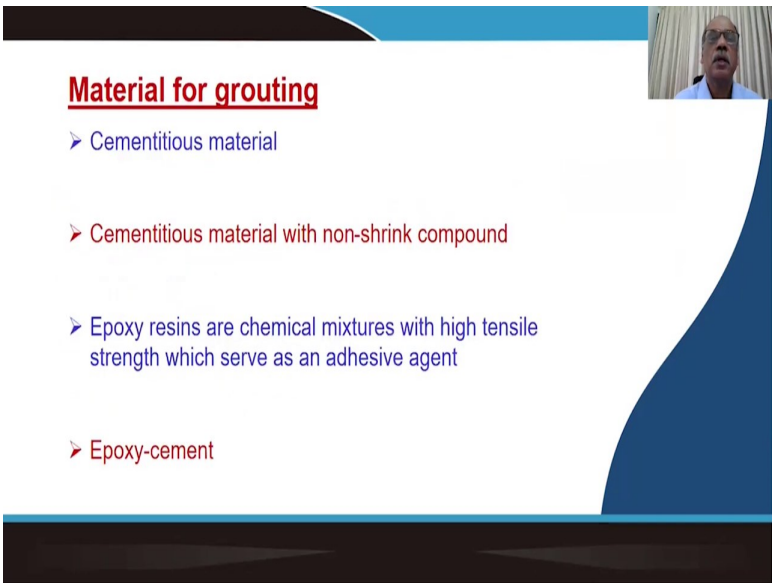

Also, as I said that in when we will be going actually for the retrofitting access for concrete structural element, you will find that if you have cracks of smaller width, larger width, we normally try to make use of the grouting material to seal those cracks in the first step and different kinds of grouting material are used, it could be a cementitious material, we create a cement water slurry and those slurries viscosity is generated in such a way so, that it can be injected, it can be sent within the cracks thereby it can seal the crack and the structural system.

Normally when you use cement water slurry and if you place it, it undergoes kind of a shrinkage and because of that the volume decrease is there and that can cause some gaps still remain within the crack zone. So, normally when we try to use the cementitious material, we try to use the non-shrink compound along with several kinds of non-shrinking compounds are available in the market these days and we can make use of non-shrinking compounds mix properly with this cement-water slurry and these can be used for sealing of the cracks through the grouting system.

Epoxy is a material which has been used extensively and this epoxy resins are basically a chemical mixture with high tensile strength and this serves as a dissipation. And epoxy can be mixed with cement and the epoxy cement mortar, epoxy cement grout, can be used in the retrofitting system to a large extent. So, grouting material, cement based grouting material along with non-shrink compound or epoxy-based systems are used to a large extent in the retrofitting cases.

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So, having given an overview about the kinds of material that we try to use, when you go for the distributing system, let me just tell you about the tests that we normally adopt. As you know, I had told you in the beginning that when you try to retrofit your structural system, you need to undertake, you need to understand the present behavior of the structure, present characteristics of the material that you have in the structural system.

Now, some of the aspects can be visually looked into and you can get certain basic information from the visual inspection, but apart from the visual inspections to understand the

basic characteristics of the material or whether there are any distresses within the system, you will need to carry out certain tests and those based on those test data you can take the influence of the control and influence on the system.

So, what do we the kinds of things that we need to know for the masonry system is how hard the masonry surface is, whether there are any hollowness in the system? So, we try to adopt different kinds of instruments, several kinds of measurement system by which we can find out the hardness of the surface.

We tried to adopt stress wave technique by which we can make out whether the wall is a solid wall or there are holes within it or there are certain gaps created by some means, for some reason we need to look into that. We adopt endoscopy test in which these days you can insert a camera, a small camera through a wire and in that it can go inside, take picture and we can show that what is the kind of state or the status inside the system.

So, you can get an idea that how is the mortar, state of the mortar inside, whether there are any gaps voids within the wall system or not. So, in the masonry system, you can detect the different parts within the masonry wall system using endoscopy test. And also, you can adopt petrographic examination, which is kind of a chemical test that you can adopt by taking some of the materials.

Now, petrographic you can group them as a nondestructive test or a destructive test, if you are taking the material from the surfaces where you do not have to really disturb the structural system as such, you can call it as a petrographic test, which is nondestructive. But, if you have to take out the material from within, then naturally you need to create some kind of disturbance in the system. So, some destruction is necessary and that is why we can group them as a destructive test as well.

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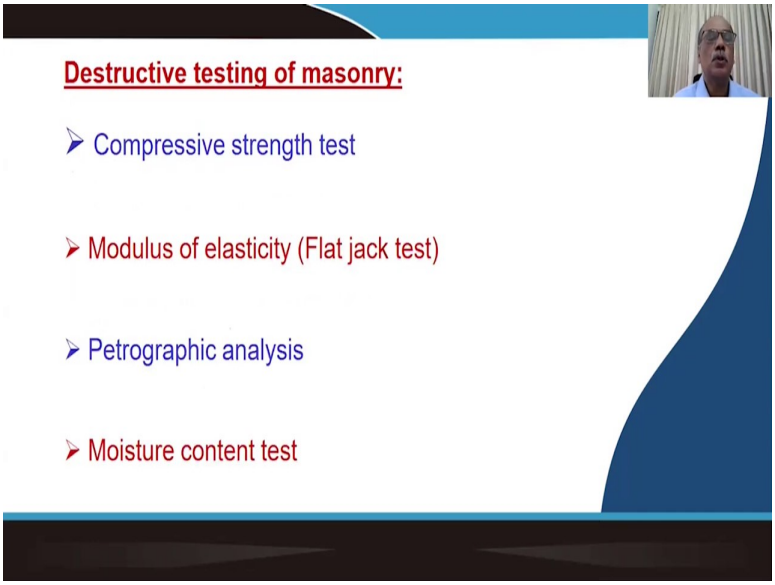

So, that is why it is listed in destructive testing of masonry. Masonry for compressive strength test, we need to carry out, in fact we will be talking about in detail about the Flat Jack test, when we talk about the masonry retrofitting or masonry system. Primarily, we try to find out the properties of the existing masonry system, we try to calculate the modulus of elasticity, which we can use in our analysis.

So, to establish the modulus of elasticity of the existing material, we do adopt the flat jack test, details of which I will be talking about this when we go into the details. As I said the petrographic test analysis also can be grouped under destructive test, if we want to get the chemical properties, properties of the material, we need to carry out chemical test from within the masonry system, so, we need to create some kind of a disturbance in the structural system to extract the material from within and so that we can carry out petrographic tests of the materials of the masonry system.

Then, we also do try to find out the moisture content in the masonry, both in terms of brick masonry, stone masonry. And the mortar that we use, because moisture particularly if you are using lime mortar, moisture plays an important role on the masonry surface. So, we need to to look into those as well. So, these are the kinds of tests that we need to carry out or adopt for masonry system.

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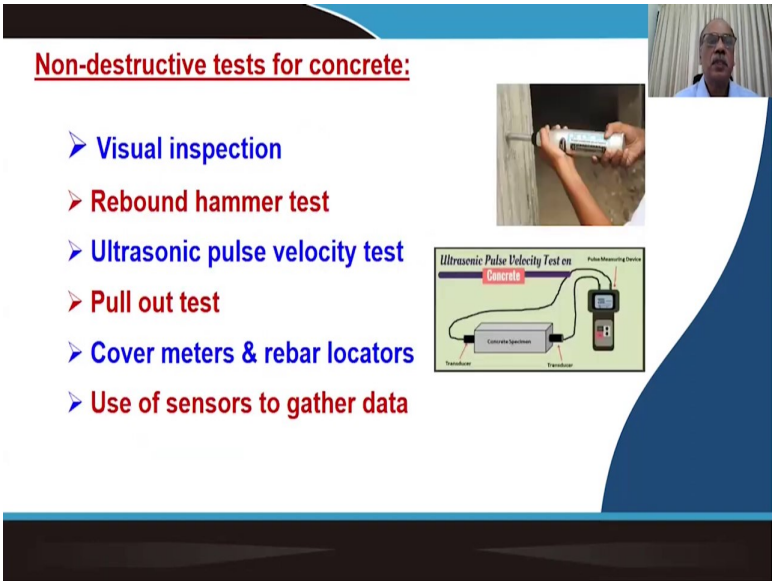

Likewise, if you have concrete structural system. We try to adopt different kinds of tests or we do recommend test to find out the existing strength or the strength of the existing concrete structural system. Visual inspection of course, is one of the aspects which will give you an opportunity to look into the surfaces in greater details, whether there are any cracks, whether there are any corrosion of the rebars, there is spalling of concrete.

So, those immediately you can detect, even if there are cracks, what are the kinds of cracks you have, how the cracks are, what they are representing, what do you infer from those cracks?. Those basic things can be extracted by this inspection. But if you have to establish that, yes, what is the strength of the existing system, then you need to carry out rebound hammer test. In fact, I am sure that you have already been spoken about the details of these test, so I am not going into that. So, they were already acquainted with the rebound hammer test.

Ultrasonic pulse velocity test, where we try to send the wave from one side through the transducer and then we try to pick it up from the other side and if there is any discontinuity, then the wave will take time to be gathered on the other end. So, naturally by that time, you can find out whether there are any discontinuity in the concrete surface or not.

So, we adopt rebound hammer test, we adopt ultrasonic pulse velocity test, we try to adopt pull out test. From the surface if you put an element and try to pull out you will know that what is the amount of load that you have to exert to pull out certain part of the element from which you can assess what is the existing strength of the system.

We use cover meters or the rebar locators, if you remember in the beginning, I had told you that if you want to retrofit a structural system, first thing that we try to find out is whether there are documents available, the design drawings are available or not. Now, if you do not have the documents readily available, then many times what we do is that we need to reconstruct that drawing, we need to prepare the drawing again based on the existing system.

Now, if you have a reinforced concrete structural element, naturally, it is not possible to know that what are the kinds of reinforcements are existing inside the structural elements and to find out that we normally use the rebar locator in a structural member and then try to detect that what are the kinds of bars within, what are the numbers or what are the diameter. And also we use cover meter to find out that at what depth reinforcements are, what is the concrete cover for the reinforcement that are existing?

So, these are used to gather the data, so that we can prepare a drawing if the documents are not available for the system. And then we try to use different kinds of sensors like say strain gauges, accelerometers or different forms of strain gauges to acquire the data and understand that what are the kinds of stresses that are getting induced into the structural system, because of the loading that the structural system is subjected to.

And these data will be helpful, if we analyze them in an appropriate manner to understand that what is the kind of stresses that are getting generated because of the present state of loading, and if there are distresses whether those distresses are happening because of overstressing of the system or not. So, these days or these data generation are helpful to take a decision on the or to gain an understanding of the state of the structure, which are going to be retrofitted.

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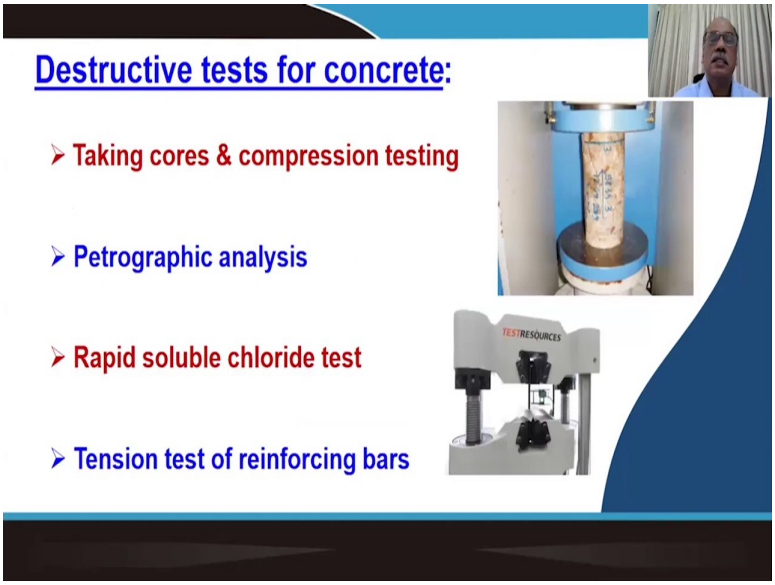

Destructive tests for concrete, many times we need to adopt ultrasonic test or by impact hammer, we may not be able to judge properly the strength of the concrete. So, what we normally try to do is that we try to extract a core from the concrete, we try to extract the material out of the existing concrete structural elements and those cores in the form of a cylindrical specimen they are tested in a universal testing machine to understand what is the strength of the existing concrete system.

So, this is a kind of a destructive system that we adopt that we got the code from the existing structural system and we test them in an appropriate manner. We do carry out petrographic analysis the chemical analysis of the concrete samples that we take. Rapid soluble chloride test this is a kind of a durability test that we do in case of, if you have a corrosion in the system, we try to understand that.

Many times, we cut off the reinforcing bars, of course we need to extract from a place where it is not getting over stress or under goal stresses as such. And those reinforcement samples are tested in a tensile equipment to understand what is the stress-strain property and thereby we can extract or you can evaluate the value of the system. So, we do carry out some destructive system for the structural elements to understand that what are the kinds of strains that are existing.

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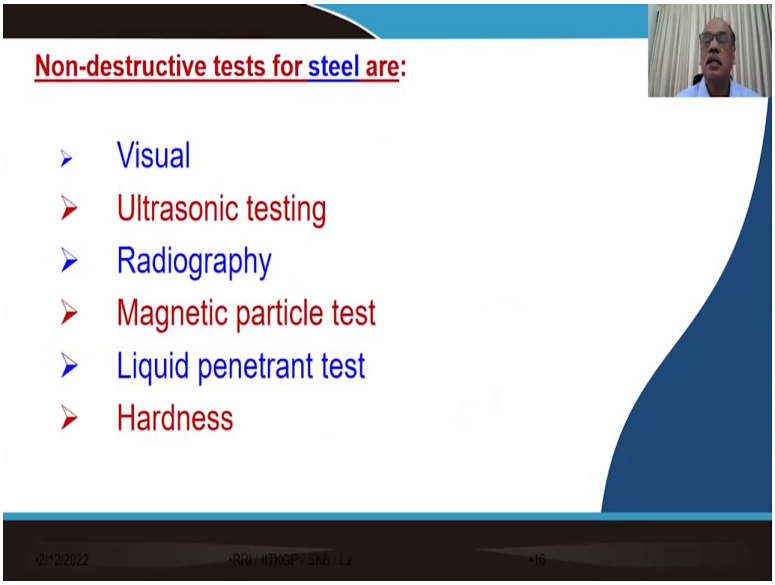

Likewise, for steel material we do carry out different kinds of nondestructive test. Visual testing is of course is one. We do carry out ultrasonic testing for the steel material as well. For steel which is a little different type of tests that we adopt rather than concrete our radiography or magnetic particles test, liquid penetrant test, or hardness these are typical for the steel material.

We do carry out radiography, which is kind of X-ray to understand the internal state of the structural system. If there are cracks, through using magnetic particle tests we can detect that, we can detect even liquid penetrant using liquid penetrant test that whether there are surface cracks in the steel surfaces or not. Hardness is a test that we do carry out on a sample on the surface that whether the steel material has a surface hardness has there or not.

Also, we do carry out some destructive tests for steel. And we do take samples out of the steel structural element, we do carry out chemical tests and from the samples we do try to carry out bend test to understand what is the flexural strength. We do carry out tensile test, we do carry out compression test, we do carry out impact test and also fatigue test.

So, again these are typical of the steel structural system, the steel structural elements are extracted from the existing structural system and do we do carry out these tests we normally recommend these days to understand that what is the present state of the structural system, what is the present, how the behavior is, so that we can make use of the properties that we get from the test in the analysis, and based on that we try to predict, how is the state of the structural system is?

In fact, I am going to discuss with you about the analysis methodology. So, you please try to understand that, we refer different kinds of tests, we adopt different kinds of tests for different types of structural system and all those structural systems we try to gather this data, basically these data we need to use for our analysis purposes. And in fact, that is what I am going to discuss next that what will be the analysis methodology? How do we extract different data, how do we get those different data for analysis, so, that it can be analyzed in an appropriate manner?

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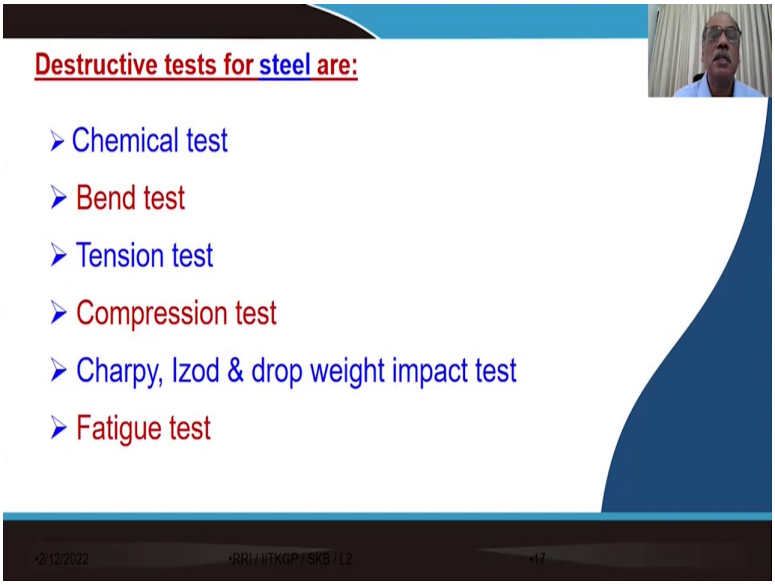

So, in this particular lesson, we have looked into the kinds of materials that are used for retrofitting purposes and the tests, the different kinds of tests that are normally adopted for different kinds of structural systems, like masonry, concrete or steel structural system. So, I hope that you get an idea, that we do extract the materials from the structural system, we try to carry out the tests, we try to gather this data, and based on these data, we try to make use of these data in our analysis.

And thereby we try to interpret from this analysis what is the kind of state of the structural system? So, in the next lesson, I am going to discuss about the analysis methodology. How do you analysis structural system by making use of the data that you have gathered from these tests?

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Alright, thank you. Thank you very much.