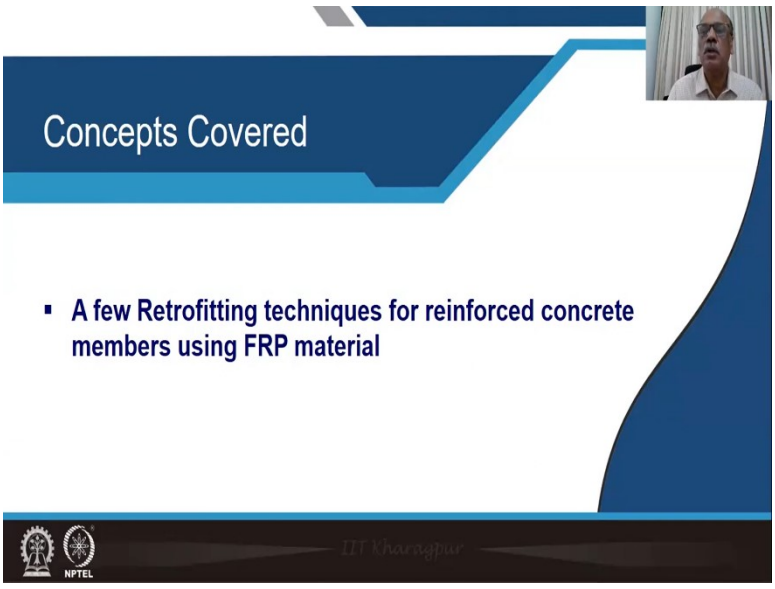
Retrofitting and Rehabilitation of Civil Infrastructure
Professor Sriman K Bhattacharyya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 57
Retrofitting Techniques for Structural Elements (Contd.)

(Refer Slide Time: 00:38)

Welcome to the sixth lecture of the module on Retrofitting of Concrete Structures. In fact, if you remember in our last lecture, we spoke about the application of FRP in retrofitting of concrete structural element. And today, I would also like to continue on the usage of FRP in concrete structures for different kinds of elements.

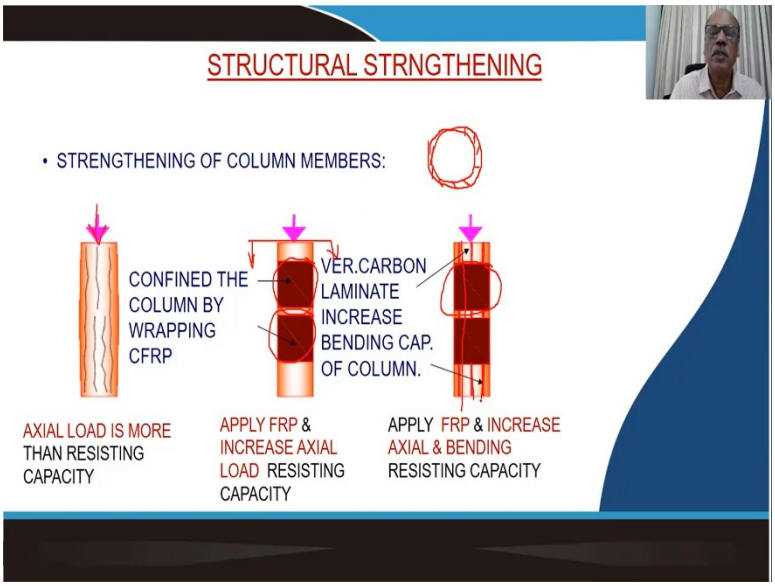
(Refer Slide Time: 01:08)



And in fact, if you do recollect that towards the end of my previous lecture, I was talking about that how to apply FRP as a material for column members having said that FRP can be extensively used for retrofitting of beam members, it can be used for retrofitting of the column members as well and I just gave a glimpse of how the column members can be retrofitted using FRP as a material.

So, today I am going to talk about the retrofitting techniques using FRP as a material for retrofitting columns, slabs and the beam column joints how those can be repaired retrofitted using FRP as an external material.

(Refer Slide Time: 02:04)



Let me start with the column member and as we did last time, say here, you have the column member which is subjected to axial load as it is shown over here. And when the axial load goes beyond the capacity, the carrying capacity of the concrete column, concrete eventually cracks and this is what you can see over here.

Now, if column gets distressed because of this axial loading, what are the options that we have as we have seen in earlier cases, we have spoken about that if a member gets distressed because of the excessive loading, then you have two options with you, either you reduce the level of the load, the carrying capacity of the member gets reduced or you strengthen the member in an appropriate manner, so, that it can carry the load.

So, you have two alternatives with you and at this particular case, we are trying to strengthen our member and that is what we are trying to look forward to that what are the kinds of techniques that we can adopt so that we can strengthen the member. So, here the member

under consideration is reinforced concrete column and we can as we have said that you can wrap the column using this FRP, this is what has been shown over here that you can confine the existing concrete using the wrapping, so, in the plan view, if I take a view from the top of this what you see is that considering that the column is a circular column, so, in the plan, what you see is the circular profile.

Now, this particular column is provided with a wrap which is of FRP on the entire surface of it and the surface preparation as we have spoken about earlier that the concrete surface has to be clean using appropriate technique and after tearing the surface you have to roughen it so that when you provide the epoxy adhesive on top of it, it can adhere, it can fill the cracks, whatever you have and then once the saturant is placed onto the surface, then you wrap this with the fiber cloth. Either it could be glass fiber or it could be carbon fiber depending on your requirement and then you wrap this in an appropriate manner and allow that to cure for some time so that it gets strength and it can give confinement to the concrete.

So, in this process what you can do is you can enhance the load carrying capacity of the column member any member impact which is loaded under compression if you can confine it by some elements your load carrying capacity gets increased to the largest. Now, alongside this considering the fact that if the load is not absolutely axial, if there is some amount of bending, if there is some eccentricity of this axial load which will attract some bending moment also is the column member apart from the axial load in that case, this confinement alone may not be adequate to carry the load.

So, what we need to do is that, alongside this confinement as it is shown over here it is a partial wrapping of the column with FRP, we try to provide the strips in the vertical direction, you can have strips like this as it is shown over here. So, these are the strips which have been provided all along the periphery of this. Now, this will enhance the flexural capacity of the member. When it will try to bend it will enhance its strength, those FRP strip. It has to bend along with the concrete. So, naturally it will give resistance.

So, when you want to enhance the carrying capacity of the column member, both in the axial, both as axial capacity as well as flexural capacity, what we need to do is that we can provide strips of FRP in the vertical direction at suitable interval in the periphery and also, we can provide wraps at intervals so that it can confine the concrete in an appropriate manner.

Now by providing these kinds of arrangements, you can expect that the load carrying capacity of the member whether axial or eccentric to the extent it can carry the flexural

stresses will be effective in carrying the load. So, this is a kind of a technique that can be adopted for the compression members as well. In the previous case, we spoke about the application of FRP in the beam. So, here, this is what I wanted to demonstrate to you that even the compression member of the column members can be retrofitted using FRP as a material.

(Refer Slide Time: 07:36)

Now, this is just to show you that this kind of FRPs are used in practice and as you can see here, you see, you have two columns side by side which is running like this, this is one and this is another one. These two columns are at the expansion joint. You can observe the expansion joint over here.

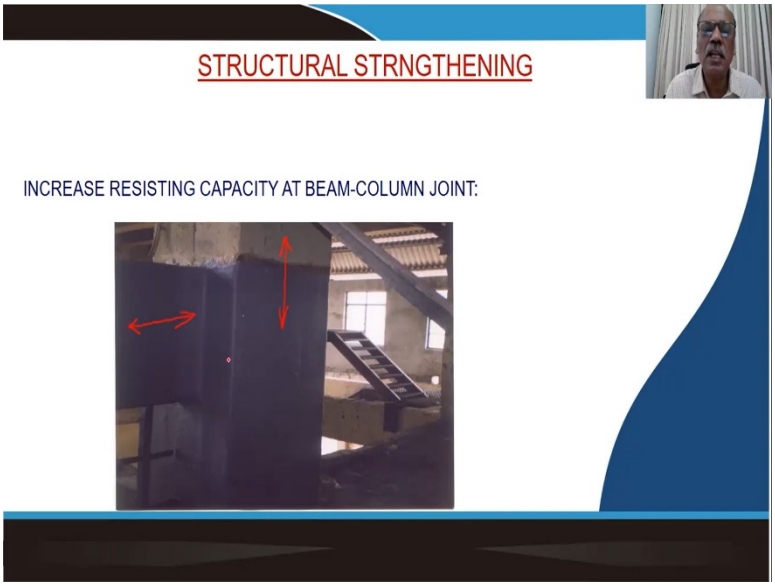
So, on either side of the joints, you have the column member and now, here you can see the person is wrapping carbon fiber all in all along the column periphery and this is what has been shown over here, you see after applying the epoxy the FRP is being wrapped on the column surface. So, this gives you the confinement of the column member and as a result, you can enhance the carrying capacity of the column member.

One aspect you must note over here, if you remember last time, I had told that when you try to wrap in a member particularly when you have a column member which has sharp edge or even in the beam where two surfaces meet, you have this corner as a sharp edge. Now, if you want to wrap FRP in this sharp edge, what happens is this particular point, there is a concentration of stresses and there is a possibility that FRP at these junction might get torn up because of the over stressing.

Now, to avoid that, what we try to do is that the corner of this joint, we try to give a little sampling you know is rounded off at this, so that the FRP cloth can smoothly run over this from one side to the other side. And thereby the concentration of stresses can be reduced to a large extent and this is what has been done over here. If you look into this place, the corner has been rounded it up over here and the FRP has been taken over the surface and thereby the life of the FRP has been enhanced by making this corner sampling.

So, this is a small thing but it carries a lot of weight and this is what has to be, this small detailing has to be looked into in an appropriate manner to achieve the success of this kind of technique that you adopt in member. So, in practice in fact, it is used very extensively and this has proved to be quite successful in retrofitting the column members.

(Refer Slide Time: 10:15)



Many a times we are talking about that how are you going to retrofit the beam column junction and this is one of the examples that you see over here, you have the column member which is running in this particular direction. And we have the beam member which is over here as you see in this particular direction and both the surfaces of the beam and column in this particular case has been wrapped with FRP material using epoxy as adhesive. So, by doing so, you can in fact strengthen the junctions beam column joints which are vulnerable which are important.

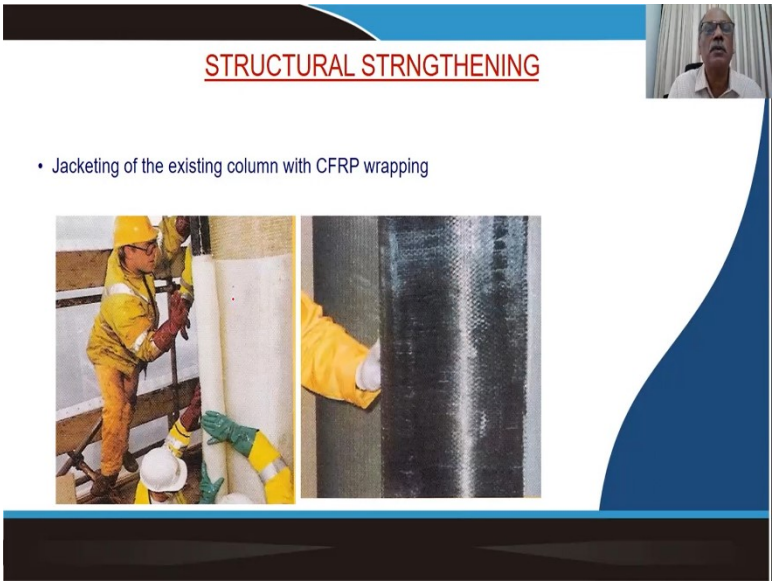
In fact, one aspect that must been observed over here is that when you have the member and let us say the beam is connected to the column, if you look into the load transfer mechanism, what happens is let us say if the beam is holding the slab on top of it, from the slab the load comes on the beam, from the beam it goes to the column.

Now, when you are wrapping external material onto top of it, your load transfer mechanism remains unaltered. So, actually, the external wrapping that you provide on the member is basically you are trying to wrap up the whole thing but the load transfer happens through the core material that you have on this. So, the external casing or external FRP material that you provide, it gives you actually the confinement and by confining effect, you are trying to enhance the carrying capacity of the member.

As such directly, this external casing is not loaded from the external sources as such. So, this is one point which is worth noting. In fact many a times when we try to simulate these kind of situations in the laboratory and try to transfer the load, mind that, we should always try to test a member either a column member or a joint that by applying the load through the core of the member and that external wrapping or the shell that you provide that also should not be loaded simultaneously along with the core.

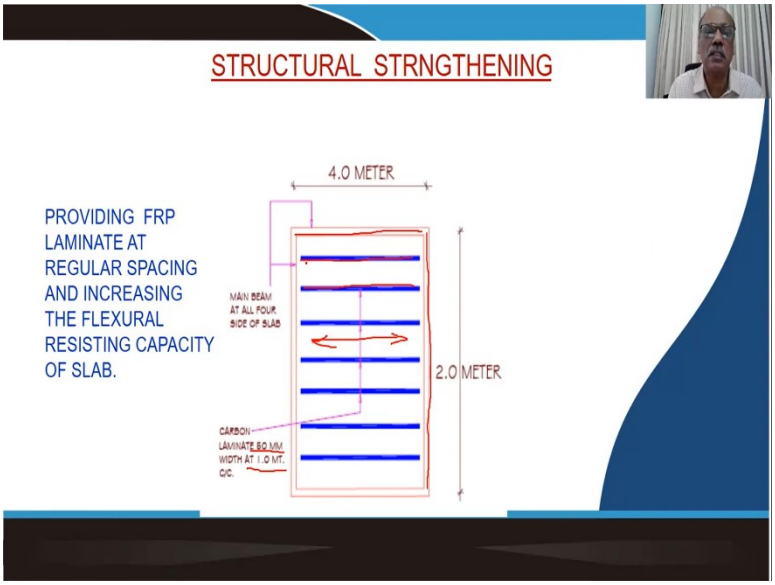
Because when you try to do that you have two dissimilar materials which have been loaded and their deformation characteristics are going to be different. As a result, the load transfer mechanism is going to be different than what you are expecting. So, on these aspects, you will have to be a little vigilant and accordingly you should apply the strengthening measure or the retrofitting measure on the structural members.

(Refer Slide Time: 13:09)



This is another practical applications that are being done that the cloth is being wrapped on this side you see these black colors is the carbon cloth, carbon fiber wrapping and this could be glass fiber or any other fiber which has been wrapped on the surface of the columns by applying the epoxy adhesive.

(Refer Slide Time: 13:36)



Apart from columns, in fact, we can strengthen the slabs as well and in the previous cases, I have shown that yes, the FRP strips can be used very effectively in strengthening the slab. Now, as it is shown over here, this is the plan of the slab. This is the width which is shown as 4 meter and this is the length of the slab which is shown as 12 meter is a kind of a one way slab spanning across this. So, when it is spanning in this particular direction so, because of the loading, we expect that the flexural actions will take place, that the tensile stress will be introduced into the surfaces.

So, to strengthen that now to take care of the tensile stresses the FRP strips can be connected on the surface as it is shown over here. And these FRP strips are provided at a distance here it is at a distance of 1 meter and it is shown as that laminate of 15 millimetre wide or 60 millimetre wide at a distance of 1 meter centre to centre has been provided.

Now, since it has been specifically talked about the width and the spacing that indicates that you need to apply appropriate design methodology to this. So, you can always calculate the amount of stresses that are getting induced because of the loading and the member that you have further what amount of strengthening that you need to carry the load effectively without exceeding the stress of the member of the material. So, that can be calculated that can be estimated and accordingly, the size of the FRP strips that you need to provide that can be calculated and also, you can calculate what will be the spacing at what interval you will have to provide these strips.

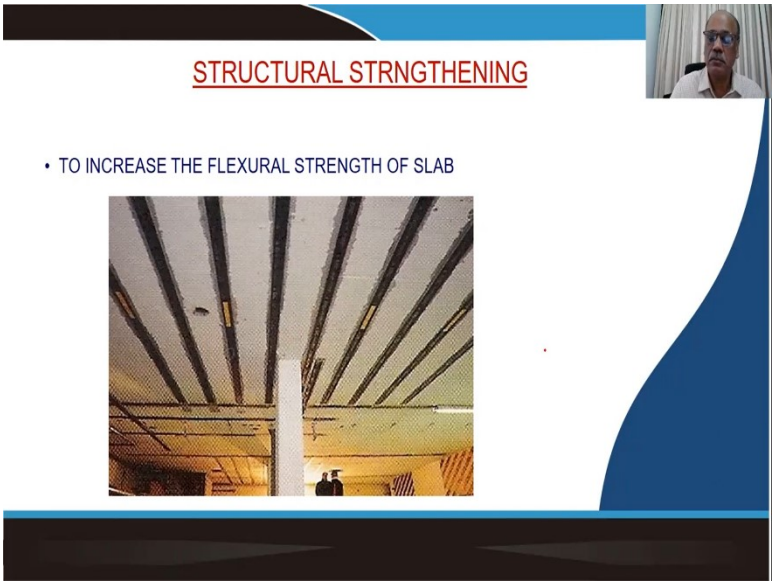
Now, you have two options either you can provide the strips, if you feel that strips can take care of the additional stresses that are coming due to flexure means they can give you

adequate strengthening of the slab, you can provide the strips at intervals or else if you feel that on the entire surface you can provide the FRP material on the surface and the entire area can be strengthened using FRP. So, that is also is a possibility.

So, depending on your requirement, depending on the load that the member has to carry, depending on the amount of stresses that is getting generated we need to estimate that what is the amount of FRP that we are going to apply and whether we need to give in spacing at intervals or we need to provide a continuous cloth over the surface.

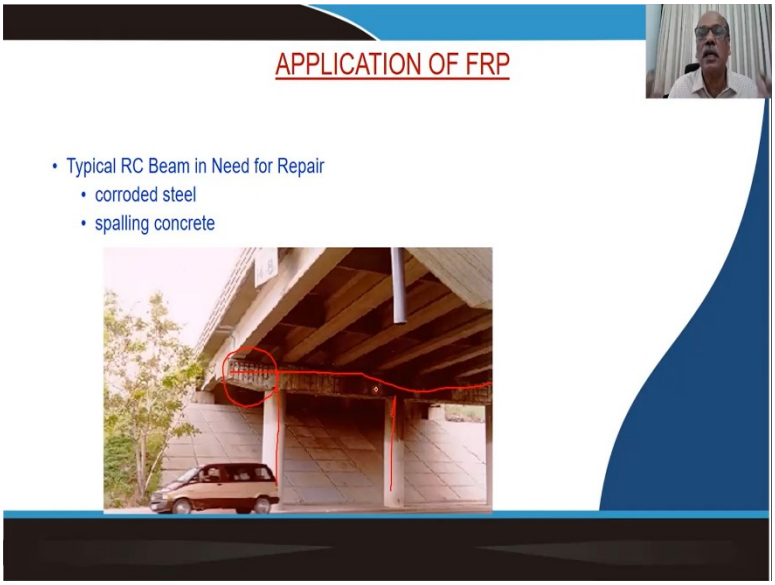
So, these aspects enhances the strengthening capacity or the load carrying capacity of the member to large extent. So, this can be explored, this can be used very effectively in strengthening the structural system.

(Refer Slide Time: 16:53)



So, in practice, how it is being done, it is shown over here. Here you can see this is the column member and the slabs which are supported and how these slab members are strengthen by using these FRP strips at close interval and this is going to give you a very effective load carrying capacity of the member. So, it enhances the flexural strength of the slab to a large extent. So, this is what has been shown over here by which you can enhance the strength.

(Refer Slide Time: 17:33)



Well, I thought to show it to you that in practice what are the kinds of distresses that we observe. These pictures show you that underneath a bridge deck how the beam member has got corroded. Now, you can see over here that we have column piers is here, another pier here and these two piers are getting connected by the beam. And here as you can see that this part is cantilever as a projection and from here to here it is supported on this. Now, as you can see over here the reinforcements are exposed, we can see the reinforcing bars and now the surfaces are quite open as you can see over here.

Now, the point is that the concrete cover because the bars are corroded there is a debonding between the reinforcing bars and the concrete cover and in the process the concrete cover has fall down. The concrete cover has cracked and fallen off from the concrete surface and thereby it is exposing the reinforcements that have been provided in this beam.

Now, if this structural system is kept in this particular form, then it is expected that the corrosion of the bar will keep on increasing, the volume of the bars will enhance, it will get debonded from the concrete, the bond between the concrete and the steel will get loosened up and the concrete will gradually spall from those because when it does not have a grip, then concrete gets cracked at the interface between the steel and the concrete. It is expected that the concrete will fall up from the surfaces.

So, spalling of concrete will happen and slowly the structure will lose its capacity to carry the load and eventually it is going to collapse. So, it is very important that it should be attended and appropriate measures should be adopted so that you can strengthen the structure in an appropriate manner and thereby you get proper retrofitting of the system and can be put in

use to carry the load. And that is very important and essential. Now, how are you going to do this? If you remember the steps that we had spoken about earlier considering the fact that we are going to retrofit this using FRP now there are several ways by which we can retrofit this.

If you remember, we have discussed about different schemes and you can think of those schemes and very effectively in an innovative way, you can come up and adopt those, one of those techniques to retrofit this. Now, here, we are going to talk about that how this structural system can be retrofitted using FRP as the wrapping material or the external material.

(Refer Slide Time: 20:43)

Now, you see, this is an exaggerated view of the cantilever part of the beam member. And as earlier we had said, that the surface has to be cleaned, made free of dust and any oily substances that are existing on the surface has to be removed by water jet or by grinding the surface system has to be smoothen and then you need to apply some kind of a putty which could be cement epoxy putty kind of a thing which can be put on the surface, the surface can be made smooth, so that you can apply epoxy adhesive on the surface in an appropriate manner.

So, first thing is that the concrete surface has to be prepared, it is to be clean, it is to be made free of all the dirty materials the dusts, darts, etc. and then you apply a primer on the surface by applying putty.

When you are applying the epoxy primer, you expect that because the viscosity of the material is low, it will penetrate through whatever cracks it has and also the surface will get saturated with that material, epoxy material and also, if there are wider cracks or there are

undulated surface, those surfaces can we made plain with the applying putty again with the application of the epoxy and that will help you to regain the surface. So, that is what is required to be done.

(Refer Slide Time: 22:23)

And once you do that, then you can apply FRP on the surface and as you can see over here other surfaces have been provided with FRP and the column members has been wrapped with FRP. Now, there are techniques, there are equipments that are available which can be used to wrap FRP on the column surface by automatically. Instead of by manual intervention through the equipment, you can wrap the FRP system onto the surface of the members.

So, this is what has been done over here as you can see, this equipment is being used to wrap carbon fiber wrapping on the column and also the concrete surfaces, in our previous figure as I was showing you that the reinforcements are exposed, the concrete has spalled up.

Now here you see by applying the retrofitting measure you could cover up those aspects and you can strengthen it. Now it will be ready to carry the load. So, you enhance the confinement of the concrete member you enhance the carrying capacity of this and again, you have already been told about I am not going into the detail that you need to calculate precisely what is the thickness of the FRP that you need, what is the thickness of the wrap that you need to get the confinement and mind that by just single layer of FRP which are available in the market may not give you the adequate wrapping.

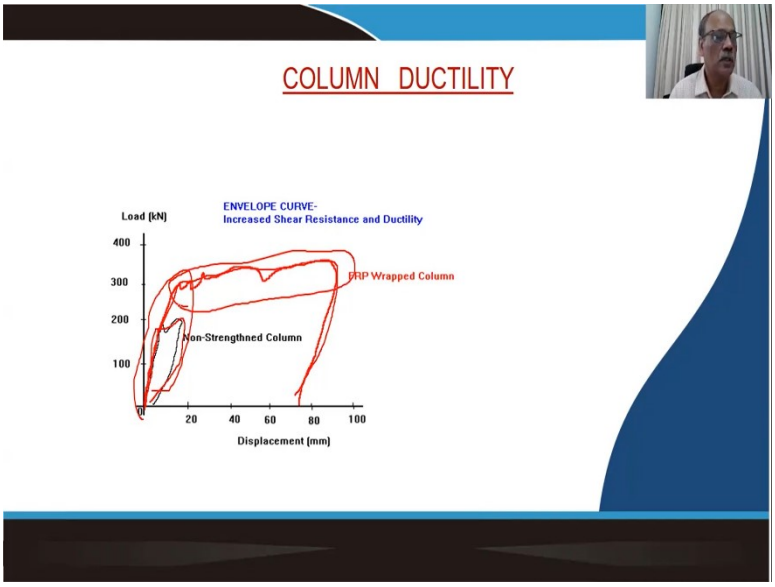
So, what you need to do is that you may have to go for multiple layers. So, depending on your requirement, depending on the thickness that you need to carry the stresses, you need to

apply FRP in an appropriate manner and if needed you can use multiple layers but make sure that when you use multiple layers, the gap any gap between the two layers are to be avoided because those are the places from where actually the problem start for debonding or additional stresses start getting generated from there.

So, when you apply FRP it has to be done very carefully because the carrying capacity of the member, the strengthening of the member depends on the kind of quality that you will have the way it will be wrapped and there should not be any kind of gap between the surfaces between the substance concrete substrate and the FRP or between two layers of FRP, you will have to ensure that you do not create any kind of gaps.

So, then it will be able to carry the load which are being transferred to the surface. So, this is what we try to look forward to. We try to achieve this so that you get strengthening of the system and it can carry the load the way you desire. And this has proven very effective in carrying the load. In many places for strengthening members, it has been used very effectively.

(Refer Slide Time: 25:52)

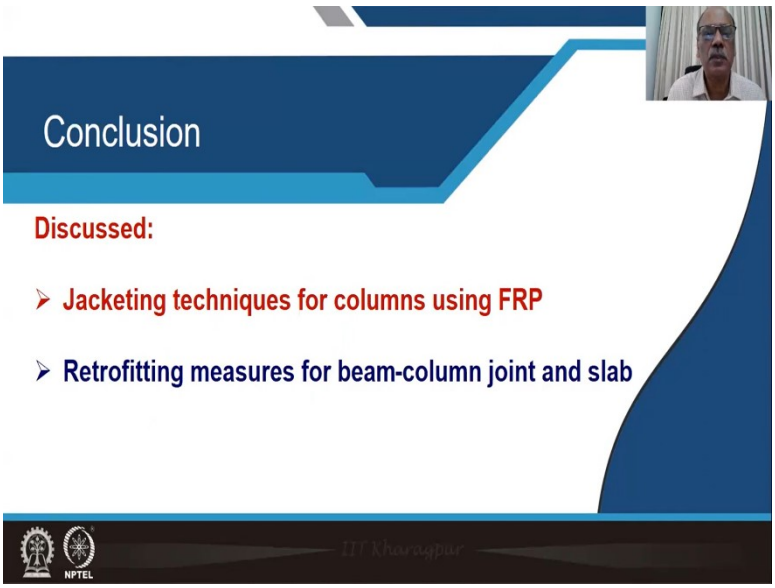


Now, if you carry a test in the laboratory and both in terms of wrap system and unwrap system, you get this kind of you see if you load and unload you will find that it will go and it will come back when the column is not strengthen with FRP but when it is strengthened with FRP it has more load carrying capacity. Also it can undergo large displacement in the load before it really comes down to the I mean if you carry out cyclic load into it.

Now, what it shows is that not only the strength of the system gets enhanced but also you get large amount of ductility in the system that it can undergo large displacement before really it collapses. So, by applying FRP, you get large amount of load carrying capacity. Load carrying capacity gets enhanced many fold than what you had in the beginning and also you get appropriate ductility in the system and if you can make the system ductile, what you gain is that under seismic action, the member can undergo deformation before it really collapses. So, introducing ductility in the system is one of the requirements for the seismic design.

So, by adopting FRP in the system, you can achieve that kind of ductility and can be very effective in usage in the area where you expect seismic load. So, you need to look into from that perspective as well on the usage of FRP and it is being used as I said extensively for repair or retrofitting work for the structural system.

(Refer Slide Time: 27:45)



So, in this particular lecture, what I wanted to demonstrate to you is that how you can jacket or apply jacketing technique to the column members using FRP as a material. In our earlier lectures, I have spoken about that you can do jacketing using concrete as a material or you can carry out jacketing using steel as a material.

Now, here primarily we were focusing on that you can apply jacketing technique using FRP as a material. And the advantage is that, that when you use FRP you get in comparison to the weight you get much larger strength. So, strength to weight ratio is substantially high for FRP system in comparison to the ceiling or concrete for that matter.

And also, we have discussed that how beam column joint the slabs, the columns, beams, they all can be repaired or retrofitted using FRP technique or using FRP as a material. So, FRP fiber reinforced plastics it could be carbon fiber, it could be glass fiber and comparatively carbon fiber is expensive than glass fiber.

So, if for such situations glass fiber can be used effectively, we try to make use of the glass fiber. However, if in any situation you feel that you need stronger material to be brought in then we need to adopt the carbon fiber as the wrapping material with which you can gain substantial strength and I have shown that you get even the ductility in the system.

So, FRP has advantages. Though I have said that there are disadvantages too. FRP when it gets exposed to ultraviolet ray, it degrades. So, if we can apply appropriate paint on the surface so that it does not come in contact with the ultraviolet rays directly and as a result, you can save them from the environmental effects. So, appropriate measures are to be taken if FRP is being used for the external surfaces of the structural member and care has to be exercised properly.

(Refer Slide Time: 30:11)

So, this is what I wanted to demonstrate to you and give you information. I hope you have understood the concept behind usage of FRP in the structural system, both in terms of columns, slabs, junctions and the beam.

Thank you. Thank you very much for your attention and we will try to look into some more aspects of strengthening of member particularly when we are talking about strengthening for seismic actions. We will explore that. We will demonstrate that how members can be

strengthened when systems are vulnerable against seismic or the structures have got damaged because of the seismic actions. Alright.