Retrofitting And Rehabilitation Of Civil Infrastructure
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Lecture 56
Retrofitting Techniques For Structural Elements (Contd.)

Welcome to the fifth lecture on retrofitting of concrete structural element. We have discussed several aspects of retrofitting in our previous lectures. And today in this particular lecture, we are going to talk about some retrofitting techniques using another kind of material, which we have not discussed so far in that details, if you remember that while talking about materials earlier, we have stated that, we can use different kinds of materials namely concrete, steel and other materials for retrofitting aspects. Now, in this particular lecture, I intend to take you to another kind of material, which is used very extensively these days, which is fiber reinforced plastics or in short we talk about a FRP.

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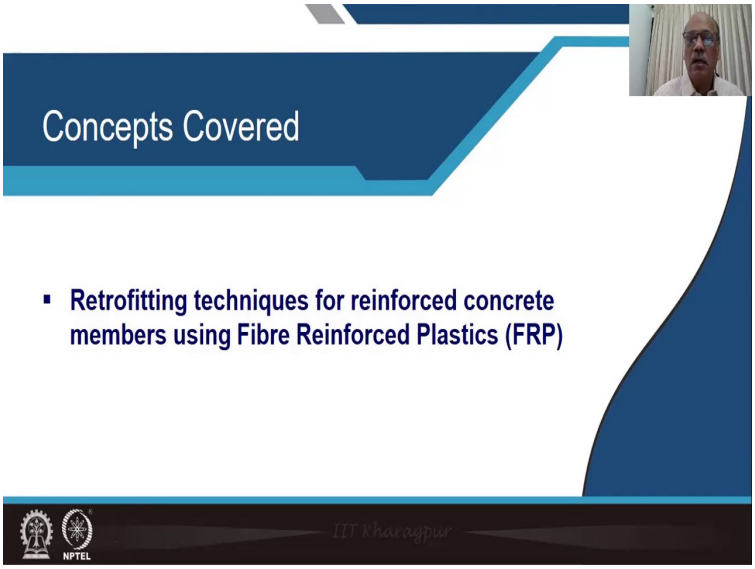

Now, FRP is used extensively for repairing and retrofitting process for concrete structures. And, I like to discuss with you certain aspects on this particular material, how this can be used for repairing and retrofitting on concrete structural element. So, this is the objective of this particular lecture, that retrofitting techniques for reinforced concrete members using fiber reinforced plastics, how these are used, how these are applied in an appropriate manner and finally, how do you get the desired results to achieve the strength in an appropriate manner.

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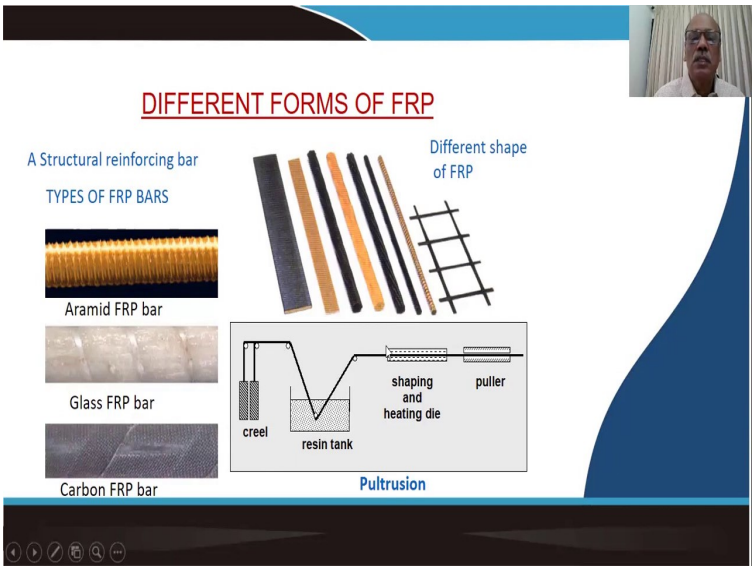

We all are aware of the different advantages of FRP both advantages and disadvantages, one of the major advantages of FRP is a very high strength with respect to weight. So, weight to strength ratio is substantially large in comparison to other competitive material.

FRP is obtained in different forms, in terms of bars, in terms of cloth, you get fiber cloth, which can be impregnated in epoxy and you get thereby a FRP cloth. So, different shapes, sizes, thicknesses, they are available and they are made out of different kinds of fibers, it could be Glass fiber, it could be Carbon fiber, it could be Aramid fiber.

And to make it stronger, it is taken through the resin, the individual fibers can be taken through the resin and it can be pulled so, that you get the desired shape and size as per the requirement. So, FRP, different sizes are available in the market, which can be, depending on the requirement in the structures, we can obtain that and make use of it in an appropriate manner.

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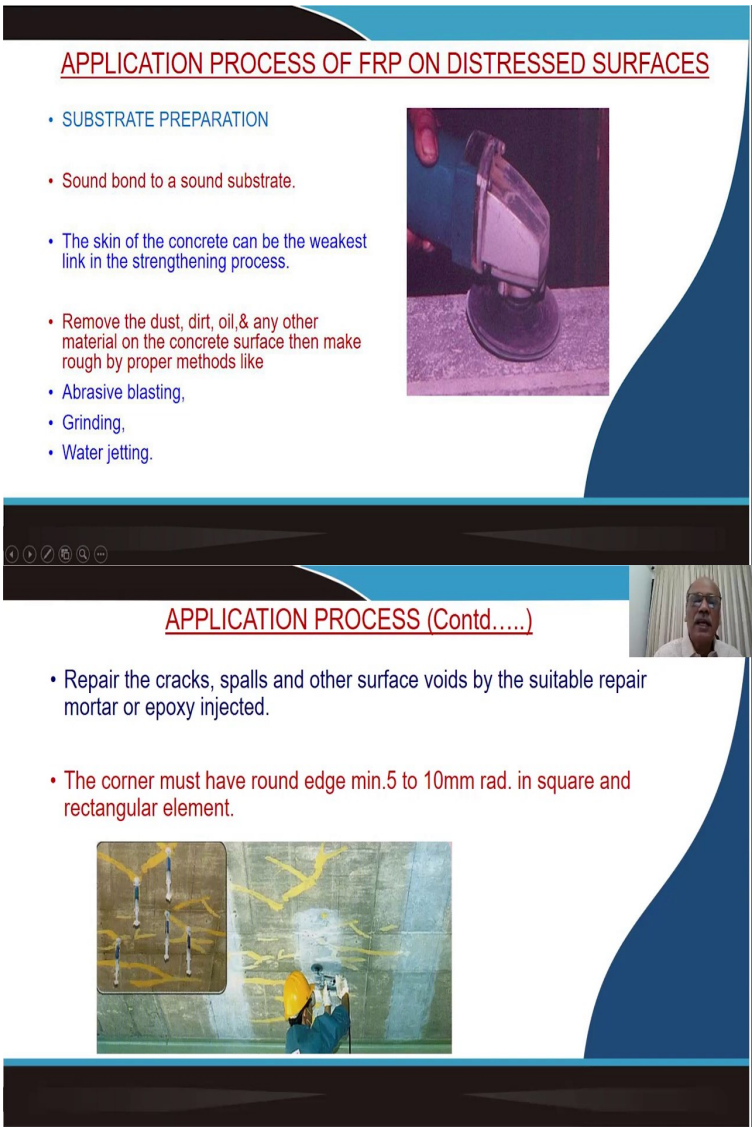

Now, what I am going to discuss with you today here is, how FRP can be applied on the surface or what is the process through which we adopt FRP on the concrete structural element for strengthening the concrete structural member. So, the concrete surface on which we apply FRP we call that a substrate. So, we need to prepare the substrate in an appropriate manner.

So, that we can create an appropriate bond, between the FRP material and the substrate concrete. So, the concrete skin has to be prepared well, so, that we do not create a lack of bond between the two surfaces. And because that is the weakest link, if you do not create the bond then the effectiveness of FRP in strengthening the member will not be achieved.

So, what is needed is that the surface first, if you have loose material that is to be removed, you need to clean, you need to remove the dust, the dirt, oil or any other material on the concrete surface and after cleaning it, make it proper and make a little rough surface. So, on that you can apply epoxy or epoxy modified mortar in an appropriate manner.

So, that you can create a bond between the two surfaces and these can be done by Abrasive blasting, it can be done by Grinding, it can be done by Water jetting. So, first the surface has to be clean thoroughly by any of these methods which are available with us and once you clean the surface, then onto top of that, we go for different processes to apply the FRP as a material.

So, once you clean it, if there are cracks, naturally the member when you are going to repair and retrofit is expected that there are cracks on those surfaces. So, what you do is that you repair the cracks by applying suitable grout material like a cement slurry grout or epoxy mortar if the cracks widths are large, so, that they are repaired in an appropriate manner and if you have this member section which is rectangular or square in nature.

Normally the corners where there is a chain in two places, those corners are the sharp corners and if you try to use FRP material at that corner, the concentratiom of stresses being high at the corner, there is probability that the FRP can get distressed at that particular junction. So, normally, thus sharp corners are advice to make it rounded.

So, you can create some kind of a sampling at the corners and make it round and it says that you can make a round edge of a having a radius of 5 to 10 millimeter. So, that you can take smoothly the FRP over the surface and thereby the FRP does not get distressed when you wrap on the concrete substrate. So, you clean it, clean it by any of the methodologies that we have talked about, fill up the gaps of the cracks by grouting or mortar.

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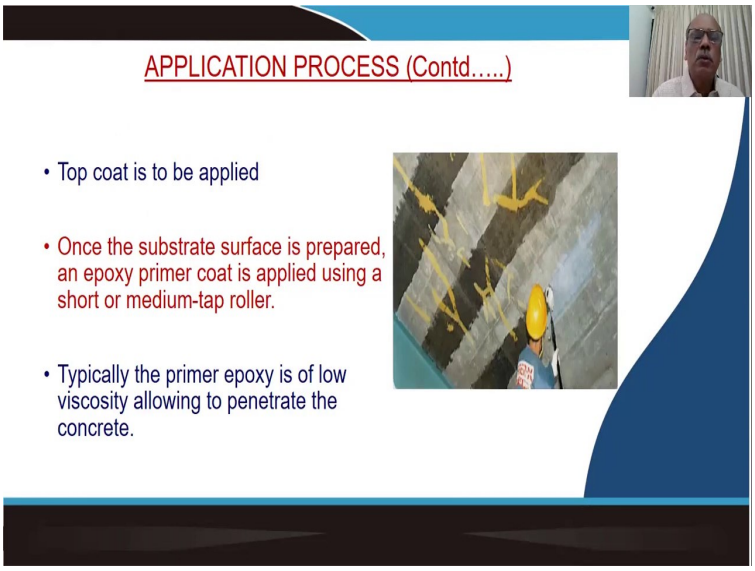

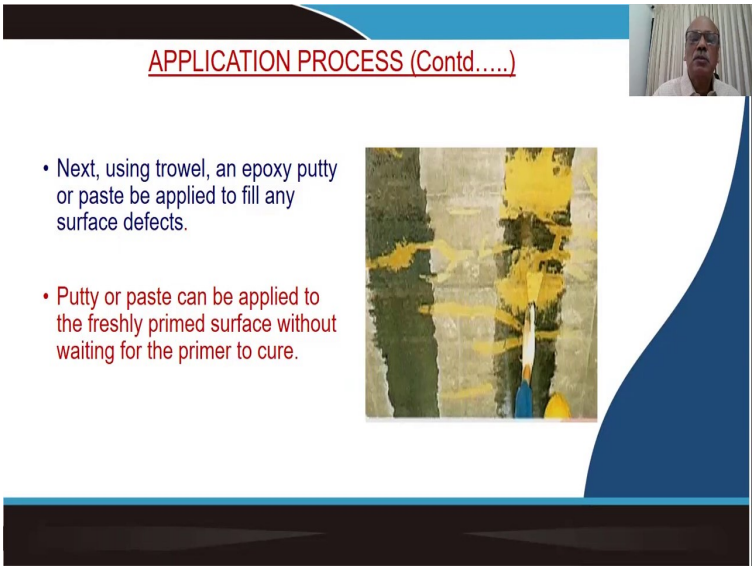

And then subsequently what you need is that onto top of that prepared surface, you will have to apply a coat of epoxy. So, if you have to apply the epoxy primer coat in such a way that if you have finer cracks that epoxy we will penetrate through that and that can be allowed if you use low viscosity epoxy.

So, that the finer cracks get filled up with the epoxy and the surface becomes smooth with the application of this on the epoxy. Now, once the epoxy is applied on the prepared surface, all you can do is that you apply now an epoxy putty or paste to fill the gaps if you have any undulation of the surface defects after application of the epoxy paint means the liquid you try to apply the

epoxy putty so that the surface can be made smooth by any undulations any gaps can be filled up by the putty.

And the interesting part is that this putty can be applied on the freshly applied epoxy primer because it does not matter even if it is in a green state. Because, the epoxy putty will get, the gaps will get filled up with that putty and that can be applied after applying the epoxy primer immediately.

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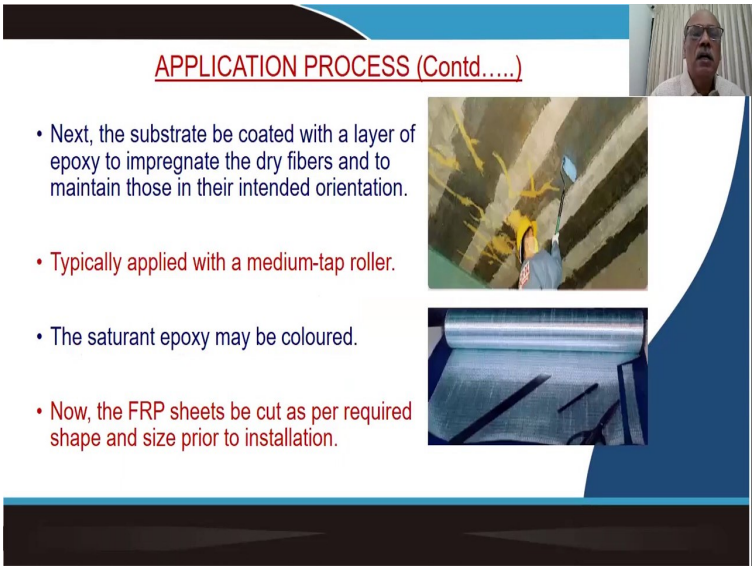

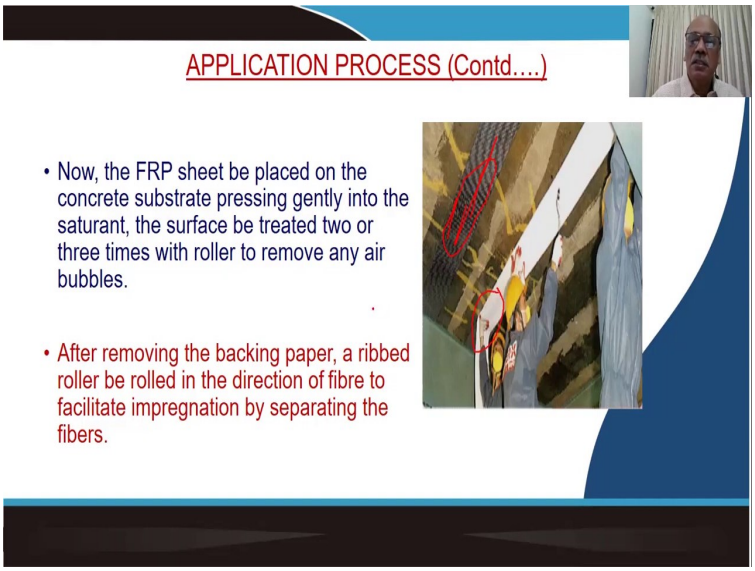

Now, once you do that, then your surface is now ready to accept the FRP material on it and since you have applied epoxy. And the surface is already wet, then what we need to do is that we try to find out that what is the shape and size of the FRP that we need to place on the surface. So, before placing the FRP what normally is done that with the medium tap roller this epoxy is rolled over the surface. So, that any gap, any undulations will get filled up and you will get a smooth surface for accepting the FRP material.

So, FRP cloth which is available in the market fibers impregnated with the epoxy or without epoxy when you get the fiber cloth. So, fiber cloth has got two shape and sizes as you need that is to be applied and after cutting the FRP sheets from the available cloth, these epoxy sheets are applied on the surface.

So, since you have already placed the epoxy as a primer material, so, it is ready to accept the FRP cloth onto top of it. So, apply the epoxy and then brace with the roller so, that 2 to 3 times so, that the cloth gets, one day on the surface through this epoxy and also when you apply the roller 2 to 3 times on the surface the epoxy will try to penetrate through these fibers and thereby a bond will get created between the fiber cloth and the concrete surfaces.

And normally we know when you buy the fiber cloth and you bring it as a sheet, you will find that some backing paper is given on the surface of the FRP and so, after you apply this FRP on the concrete surface, this backing paper can be removed. So, that as you can see over here that in this in this particular case, the surface looks like that having a FRP and this color demonstrate that the fiber that has been used is a carbon fiber.

So, see FRP has been used for placing in the beam surface. Now, here as you can see, this is the backing paper which is being removed and after you remove that, it will come to this surface. So, epoxy gets penetrated in the fiber, fiber gets attached to the substrate and thereby its effectiveness start acting on this.

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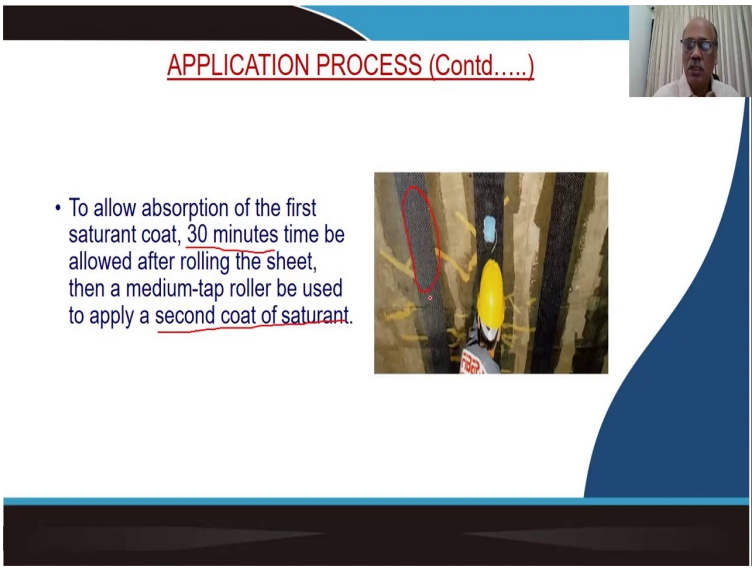

So, first you allow this epoxy to get absorbed and also to penetrate through in the FRP then maybe at around after 30 minutes, what you can do is that you can roll it again and apply a second coat of saturant which is epoxy on this surface. So, you can apply another coat of epoxy and allow these to be cured.

Now, the interesting aspect is that the FRP which is available in the market are available in different thicknesses. So, depending on the requirement of your thickness that you need from your design calculations, you can apply a number of layers of epoxy, I mean FRP material using epoxy, so I am talking about one layer of FRP material with epoxy on the substrate.

But if you filled you need to provide 2 or 3 layers of that, then after providing epoxy again another layer can be provided in the similar fashion. So, multiple layers can be provided. But keep in mind that when you are providing these layers between the two layers, try to take the roller 2 to 3 times in such a way that no gaps are created between the layers and from the between the first layer and the substrate.

Because if you have some air gap, that will be the source of, cause of damage from that particular point. And in long term the distresses can happen in the FRP system on those places. So, you will have to ensure that no air gaps exist either between the substrate and the FRP layer, or between if you are using multiple layers of a FRP between two FRPs. Now, this has to be ensured and this should be done in an appropriate manner.

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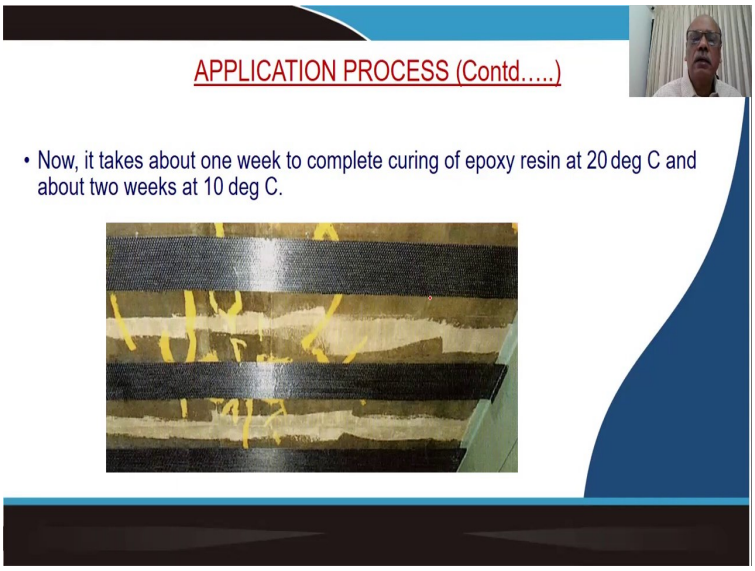

So, after you complete this, then you allow these to cure. Normally, it takes about a week time for temperature at around 20 degrees centigrade. So, let us say in an ambient temperature from around 20-22 degrees centigrade, in a week's time you expect this to get cured and achieved the strength.

But if the temperature is low, then you need little longer time for curing and say over two weeks time it requires in the range of temperature of 10 degrees. So, you need to be careful in observing this that you get proper curing of the material and the FRP gain strength to carry the load.

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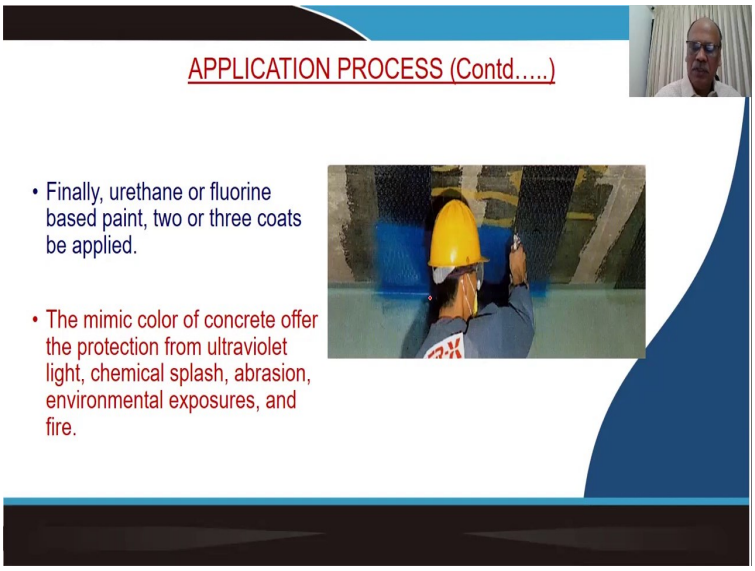

So, after you complete these and after the curing process is completed then you can apply 2 or 3 coats of paints so that the FRP gets protected against ultraviolet rays because in presence of ultraviolet or when it gets exposed to ultraviolet rays, the FRP material normally deteriorates. So, it is better that to prevent these FRPs deteriorations from ultraviolet ray from chemical actions or from environmental actions is better to coat with appropriate paints.

So, that these FRPs can protected. So, these are the steps through which so, irrespective of the concrete structural members that you are using, whether it is beam or slab or column wherever you are wrapping in it should be, the same process should be followed, so, that you can achieve the effectiveness in the FRP.

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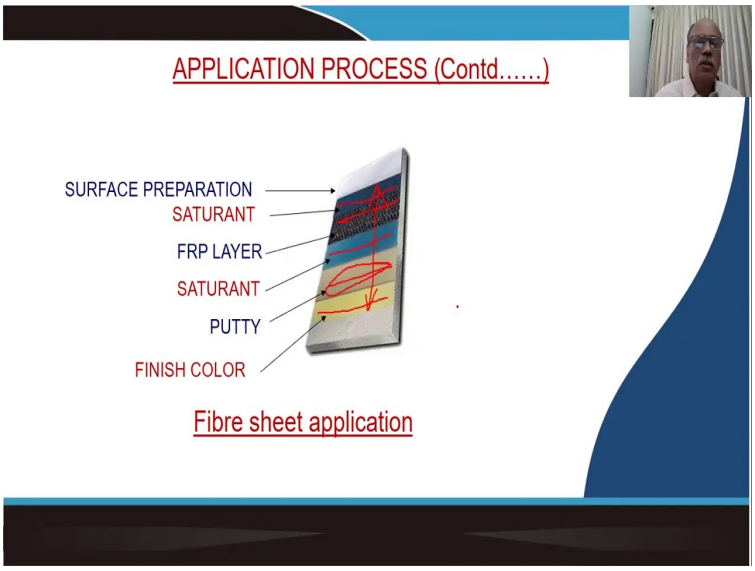

And just to show you different layers that we provide in this FRP system along the thickness you have the substrate you prepare the substrate first to apply the epoxy as a saturant in this then you have the FRP layer then again you provide the saturant that so, that it penetrates through the FRP and then creates a bond between the substrate and the FRP.

Then you apply, put it to take care of any analysis that you have this putty is using epoxy material again and then once you complete that, you provide a finishing color on top of it. So, this is in the direction of the thickness that it happens and this entire thickness here it is little accelerated, this could be of the order of around 2 to 3 millimeter.

Of course depending on the thickness of the FRP that you are using, because the rest of the thicknesses are in micron level and, thereby you can achieve that thickness to strengthen but, and think about it the material as a weight is going to be very light whereas the strength is expected to very high. So, strength weight ratio is substantially high for this kind of material over steel or any other retrofitting material that we normally try to use. So, this is in general the process through which we try to adopt, the FRP in the system.

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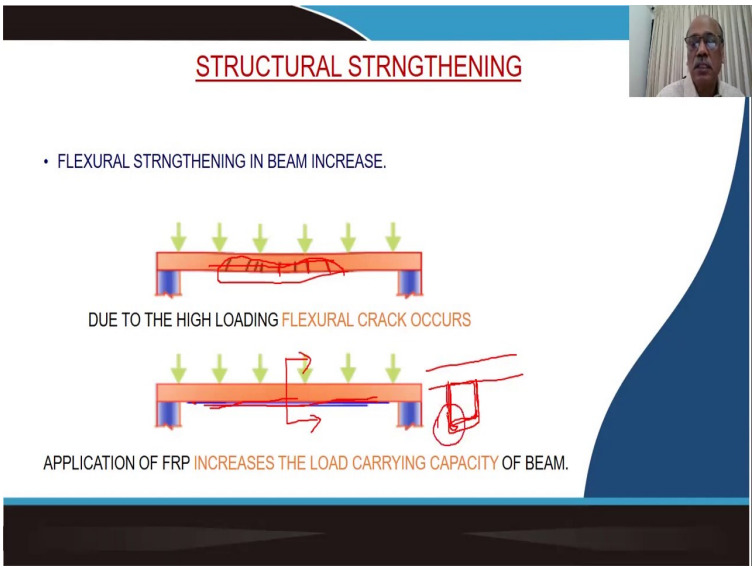

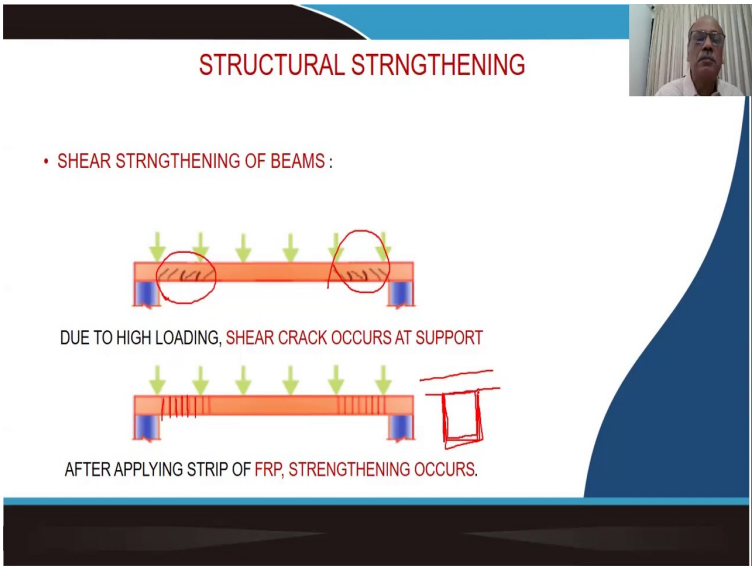

Now, as we were discussing earlier that you get the stresses of different forms in different structural members and we need to strengthen them in an appropriate manner. So, that you get strengthening and here we are using FRP as a material for strengthening. Now, say for example, in a beam.

When it is a simply supported beam and it is loaded, in the transverse direction, say uniformly distributed load and because of overloading you observe that the bottom fiber, which is under tension cause crack, and these are the tension cracks, because of the flexure which is developed, because with this being the zone of high flexural stresses.

Now, when such kind of things happen, it means that if you calculate the bending stresses, as My/I , with the increase in the bending moment, what you need to do is that you need to increase the moment of inertia. So, you by using these FRP, you can do that and, thereby you can achieve better strength and this also act as a reinforcement, as it happens in reinforced concrete.

You try to provide a steel member within so, when there are cracks, the stress gets transferred to the steel and steel carries in. So, here on the external surface when you are using FRP, the FRP as a material, is able to withstand that tensile stress and thereby the concrete gets rid of the tensile stress to a large extent.

And, you do not get cracks along length and is able to take more load or carrying capacity of the member can be enhanced by retrofitting using FRP as a material. So, you can do the flexural strengthening by providing either layer of reinforcements on I mean FRP cloths on the bottom surface or in the cross section if I look into the cross section here.

What you can do is in the cross section you can wrap. Now, the cross section is like a rectangular one. And in practice, it is expected that you will have a slab at the top. So, three surfaces on the beam are available this, this and this surface and you can provide FRP on all three sides and keeping in mind that these corners we try to make it sampled a little circular one.

So, that when you wrap with FRP these corners do not get stress concentrations and cracks over there. So, on three sides as in the form of U you can provide the FRP and you can strengthen these flexural or against flexural stresses, sometimes what happens is you get beams which are, deficient units here, and you get shear cracks generated in and here is the support.

So, in these zones, if you want to strengthen as that we try to resist here, you provide the stirrups. So, you can provide, these FRP a strip on the side, so that you can strengthen this zone, with FRP and thereby it can carry the shear effectively. So, now, either you can provide on two vertical sides or again you can provide the strip in the form of a U as I was showing you in the previous case.

In this particular case also, you can provide a FRP in the form of, strip. So, assuming that you have a slab on the top of the beam, so, you three sides are exposed. So, you can provide a stirrup in the form of U and take it like this effectively, because the side stirrups are going to be more

effective in carrying the shear. So, we try to provide in terms of strips as it has been shown over here on the side. So, this can be taken in the form of U and take on the other side or you can provide two strips on either side as well. So, these kind of strengthening actions can be done using FRP and with the epoxy.

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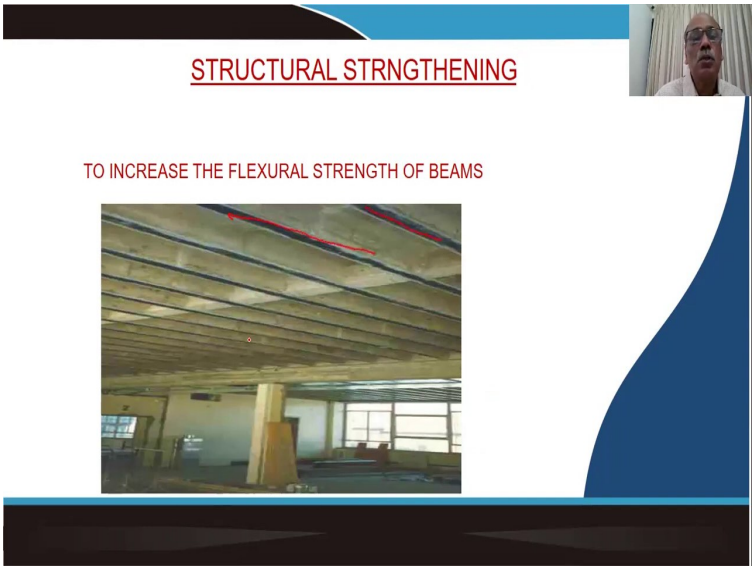

Now, this is a kind of a repairing technique that has been shown that you have a series of beams to carry the load. And as you can see over here, that soffit of the beam a FRP material has been used at the soffit of the beam FRP the material and it is been used to enhance the carrying capacity of the beams in flexural actions.

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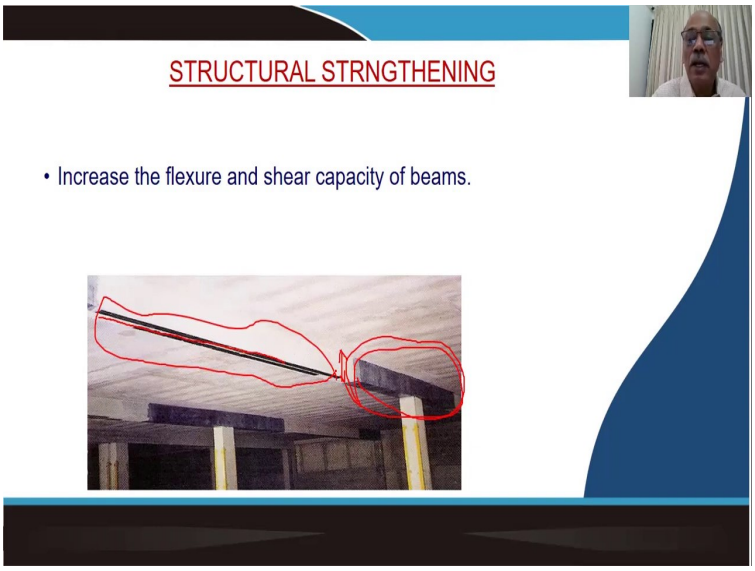

To increase the flexure and shear capacity of beams, we can use simultaneously if you see in a beam unit to increase both the flexural action as well as the shearing action. So, what do you need to do is both at the central zone as well as on the support zone you need to provide a FRP. Now, as you can see in this particular figure here.

You see this is the depth of the beam and in this beam and you have a slab onto top of it. Now, in the bottoms of it you see here in the central zone, the FRP material has been provided as a plate or a strip to enhance or to take care of the tensile stresses that will be generated. Whereas, closer it to the support that you can see over here in this support the continuous FRP has been used on the sides taken on the bottom and then taken on the other side as well.

So, in this particular zone, possibly the beam was badly affected, because of the shearing action. So, the continuous wrapping of this particular zone has been done using FRP. So, both the shear zone as well as the flexural zone has been provided with a FRP to strengthen these beam and you can effectively increase the carrying capacity of the member. So, the strengthening actions can be applied in such cases in such form, and that is what has been shown over here.

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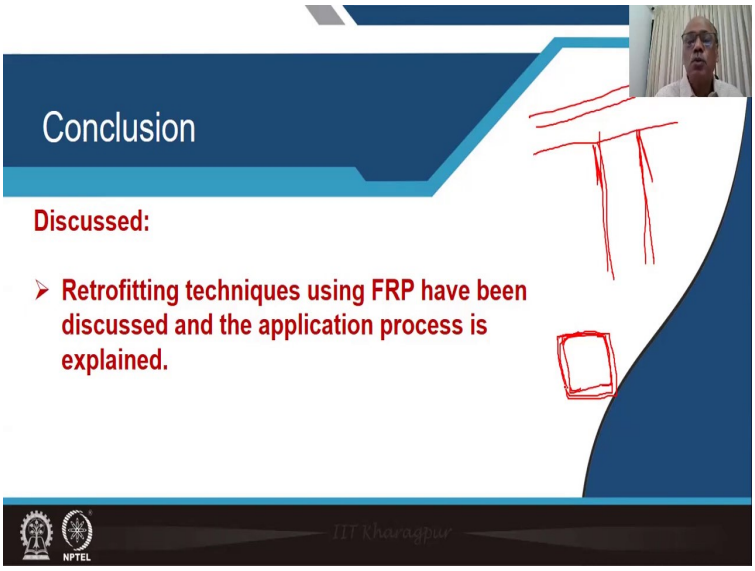

So, in general, what we have tried to do in this is that we have tried to give you an idea of using fiber reinforced plastic or FRP as a material for retrofitting the concrete structural members, whether it is beam member or column member or slab member, in fact for each such cases, now, in this case. I have given you example with reference to the beam and I have shown that the how you can strengthen the flexural zone of the beam member, how you can strengthen the shear zone of the beam member using FRP.

So, likewise, supposing if you want to strengthen the slab and the central part of the slab which is under distress and you want to enhance. So, first you need to relieve the slab from the loads to by making some supports, and then the steps that I have spoken about that, prepare the substrate, clean the substrate, provide the epoxy mortar to smoothen the surface, apply epoxy, then apply the FRP layer, apply epoxy again so that it gets saturant, gets penetrated within the fiber. And then apply a putty on top of the surfaces to make it smooth and then apply a paint.

So, these steps that I am talking about is equally applicable, even if you are going to strengthen the slab, the horizontal diaphragm member for that matter. So, when we are talking about application of FRP in a system in a structural member, whether it is a beam, whether it is a column or a slab, everywhere, we can make use in fact column members to get a confinement in the column member. In the, we can rap, for column members, what happens is, you say this vertical column that you have, and you have a beam member which is running.

And also let us say you have a slab into it. Now, supposing if you feel that this column is in distress and you want to enhance the strength of this particular column, you can provide a FRP on all four sides. So, in the plan, if you look into that this is the, let us say the square cross section of the column, you can start your FRP from this side, take it through on this side, take on the side, take on the side and wrap it over here.

So, you can wrap on all four sides. So, this will give kind of a confinement to the system only aspect that you need to keep in mind that it is preferred that the corners of these columns if they are rounded, then you will get better effectiveness of the FRP otherwise, these corners are the source of concentration of stresses on the FRP surface and there is a potential danger that FRP might get damaged or distress at that particular location.

So, you can use FRP as a material on all four sides and wrap it in an appropriate manner. So, that you get a confinement of the compressive member and thereby you can increase the load carrying capacity of the column member. So, basically, I have tried to give you an idea of how different structural members can be retrofitted using FRP as a material and the application process of FRP has been explained in this particular lecture.

And about FRP we have already given you some glimpse about the properties of the FRP, its modulus of elasticity and how the strength, the ultimate strength of it yield strength of this member and, you can choose appropriate material, whether it is a glass fiber reinforced or a carbon fiber reinforced depending on your requirement depending on the type of distresses you have.

And you can very easily or effectively use this kind of system in practice. So, that is all for this lecture over here. And I hope you have understood the application of FRP. Thank you very much. Thanks for your attention. And we are going to discuss some more aspects on this as I will go along. And, we will see that different kinds of techniques, when we use particularly using FRP as a material, how effective those are in repairing the material and retrofitting the structural system. Thank you.