Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 31
Installation of FRP

Hello friends. Welcome to the NPTEL online certification course Retrofitting and Rehabilitation of Civil Infrastructure. Today, we will discuss module E. The topic for module E is Retrofitting using Fiber Reinforced Polymer Composites.

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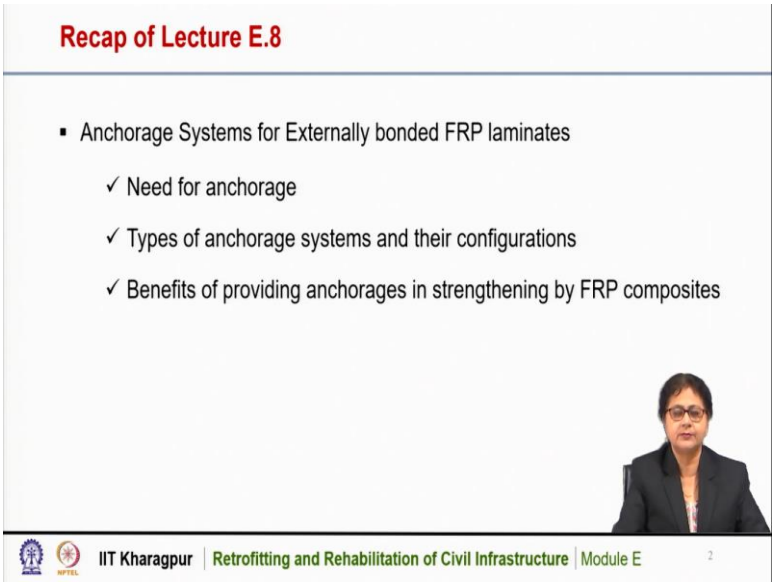

In the previous lecture, we have discussed the anchorage systems for externally bonded FRP laminates. We have discussed the need for anchorages, the types of anchorage systems and their configurations in the structural members. We have discussed the benefits of providing anchorages in strengthening of FRP composites.

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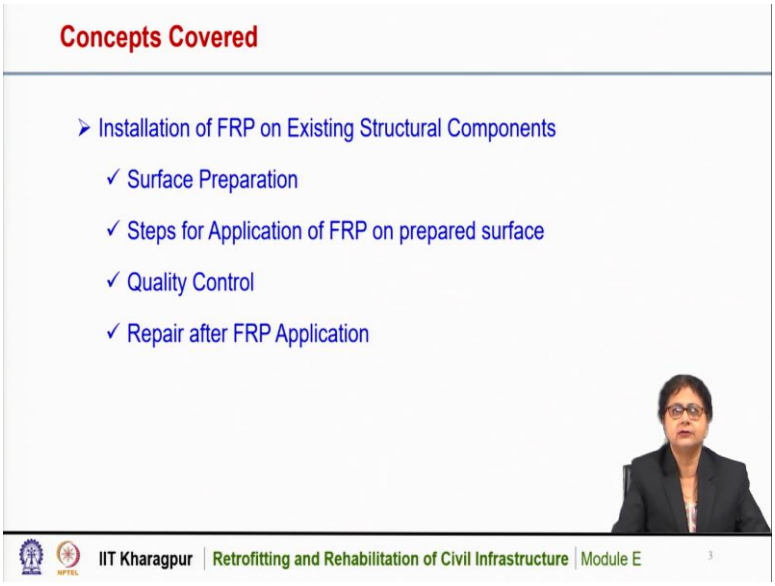

Today we will discuss installation of fiber reinforced polymer composites on existing structural components. We have seen that fiber reinforced polymer composites have excellent properties in terms of tensile strength, high modulus and that is why it is used for improving the flexural or shear or axial capacity of structural members.

Several experiments have been done on structural members like beams, slabs, columns or joints that are retrofitted with fiber-reinforced composites, different types of FRP, with different amount of FRP or different orientation of FRP, to understand the stress strain response of these members. And it has been seen that FRP has the capability of improving the load carrying capacity of the structural members.

So, by seeing these excellent properties, FRPs are used on real life structures. And they are used to improve the flexural capacity, the shear capacity and the axial capacity of beams, slabs, columns or joints. Today we will discuss the installation of FRP composites on existing structural components. In real life structures, how we can install the FRP composites for improving their capacity? We will discuss surface preparation, steps for application of FRP on prepared surface, quality control for the application of the FRP and repair after FRP application.

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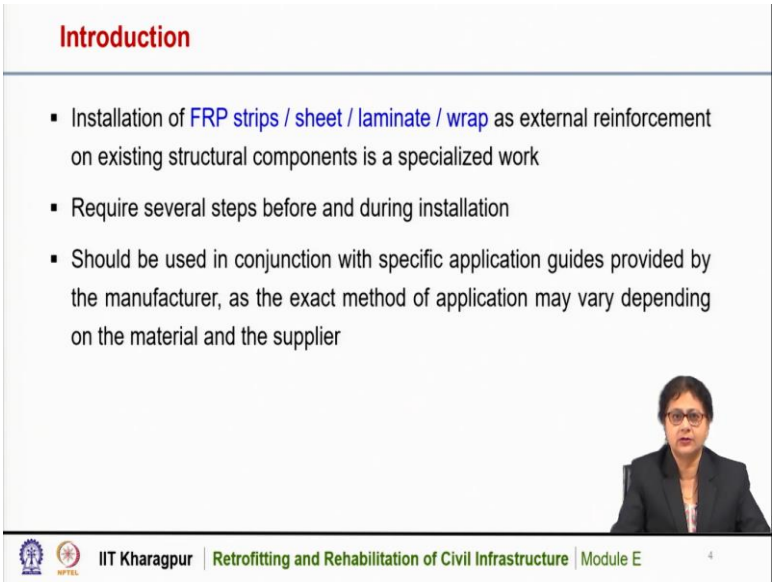

Installation of FRP strips or sheets or laminates or wraps, as external reinforcement on existing structural component is a specialized work. FRPs are generally available as rolls or strips or plates or laminates of different sizes. It may be pultruded or hand layup and those materials are used for the retrofitting purpose of existing structures.

However, it requires several steps before, during and after the installation. And it should be used in conjunction with specific application guides provided by the manufacturer, as the exact method of application may vary, depending on the material and the supplier. For any FRP composite, the properties are given by the manufacturers. And sometimes, how it can be installed that is also mentioned. And that we should consider while installing the FRP composite on a real-life structure.

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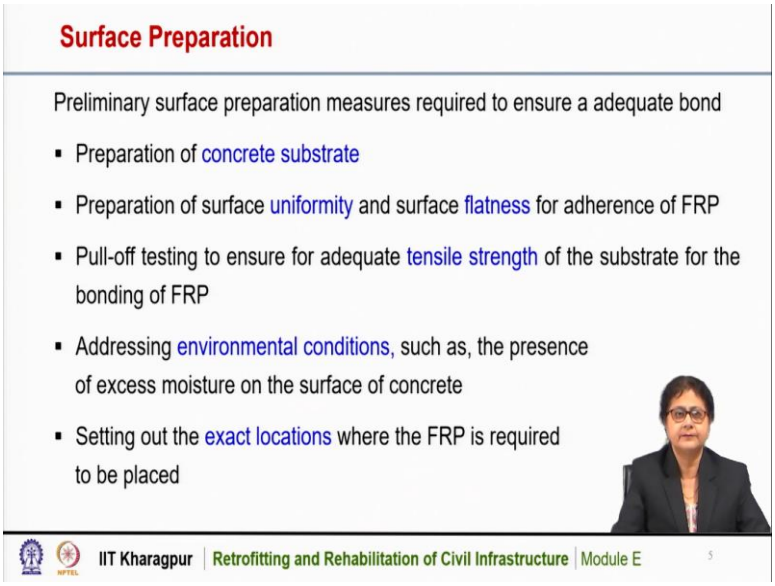

Preliminary surface preparation measures are required to ensure an adequate bond from the FRP to the existing concrete member. So, we need to prepare the surface properly. So, that adequate bond is achieved and the potential of the FRP is achieved. So, the steps are preparation of the concrete substrate. Then preparation of the surface uniformity and surface flatness for adherence of the FRP composite.

Pull-off test can be carried out to ensure the adequate tensile strength of the substrate for the bonding of FRP. We should address the environmental conditions such as the presence of excess moisture or high temperature for the installation of the FRP on concrete surface. And then setting out the exact location where the FRP is required to be placed.

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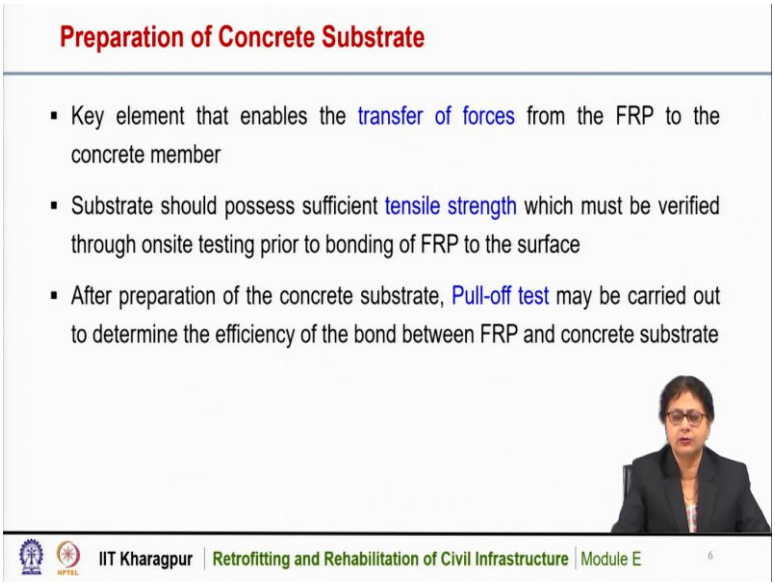

So, for the preparation of concrete substrate, we should follow certain steps. The key element that enables the transfer of force from the FRP to the concrete member. So, the concrete substrate is the key element that enables the transfer of forces from the FRP to the concrete member. So, it is important to prepare the concrete surface properly.

Substrate should possess sufficient tensile strength which must be verified through on-site testing prior to bonding of the FRP to the surface. So, we need a proper surface preparation so that the FRP can be placed and bonded properly and adequately and it should achieve sufficient tensile strength. After preparation of the concrete substrate pull-off test may be carried out, to determine the efficiency of the bond between FRP and concrete substrate.

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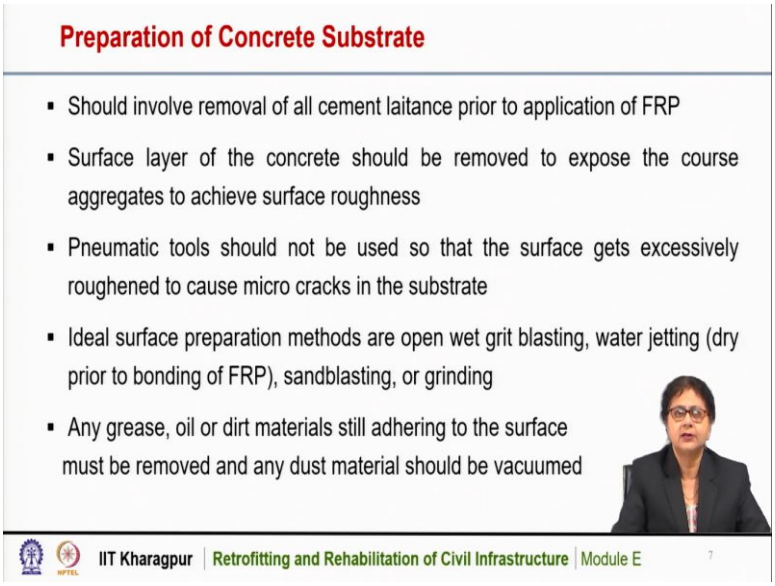

Preparation of concrete substrate should involve removal of all loose materials, cement laitance, etcetera prior to application of the FRP. Surface layer of the concrete should be removed to expose the coarse aggregates to achieve surface roughness. And that gives a better bonding.

Pneumatic tools should not be used so that the surface gets excessively roughened, to cause micro cracking on the substrate. So, we should make the surface rough, but proper care should be taken so that excessive roughness should not cause micro cracking on the surface. Ideal surface preparation methods are open wet grit blasting, water jetting, sand blasting or grinding. When we use water jetting, we have to keep in mind that the surface should be dry prior to the bonding of FRP.

Any grease, oil or dirt materials, if those are still adhered to the surface, must be removed. And any dust material should be vacuumed. So, the surface needs to be cleaned. And for that purpose, we can use several methods like wet grit blasting, water jetting or sand blasting or grinding, so that we can get a uniform surface.

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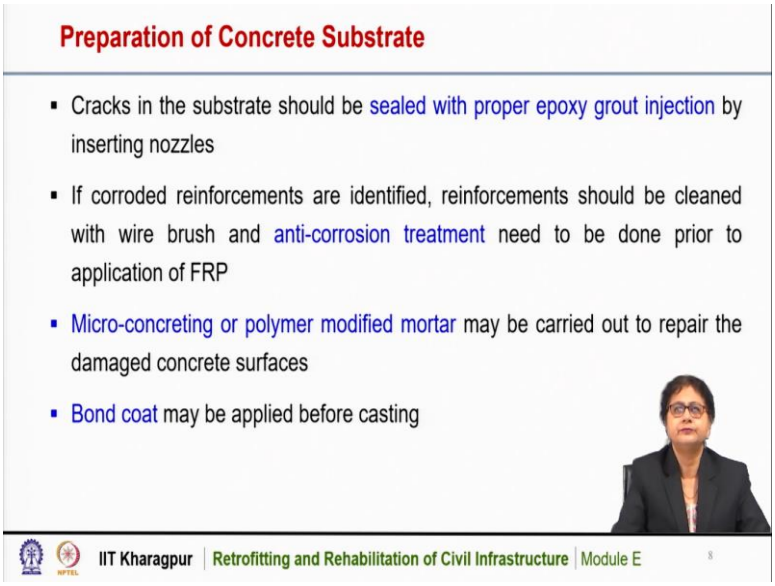

Cracks in the substrate, if they are present that should be sealed with proper epoxy grout injection by inserting nozzles. We have discussed that how the epoxy grouting injection can be done. So, here also before putting the FRP, if the cracks are there, that should be sealed with proper epoxy grouting injection.

If corroded reinforcements are identified, the reinforcement should be cleaned with wire brush and anti-corrosion treatment need to be done prior to application of FRP. And if there is a loss of reinforcement area, that reinforcement may be replaced also. Micro concreting or polymer-modified mortar may be carried out to repair the damaged concrete surface.

If there are spalling on the concrete surface or there may be loss of significant amount of material, that can be repaired using micro concreting or by putting polymer modified mortar on the surface. And then we can go for application of the FRP. And a bond coat may be applied before casting. So, we can use a bond coat also on the prepared surface for the FRP application.

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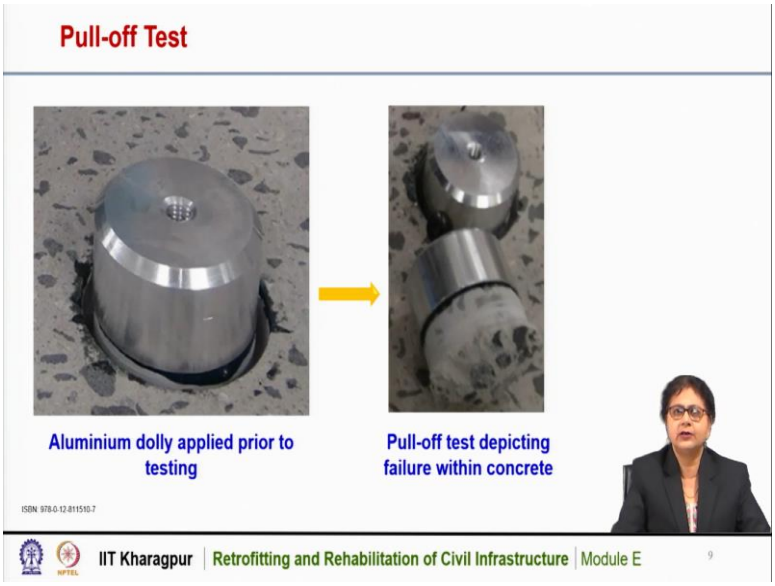

This is the picture of pull-off test. We have discussed earlier the pull-off test is used for determining the tensile strength of the surface. Here, we can see that this is the aluminum dolly that is applied prior to testing. And it is a partial coring that has been done and then it is pulled. So, this pull-off test has been carried out and from that test, some amount of the material is coming out with this pull out force with this aluminum plate. So, that depicts the failure within the concrete, and by correlating we can find out the strength.

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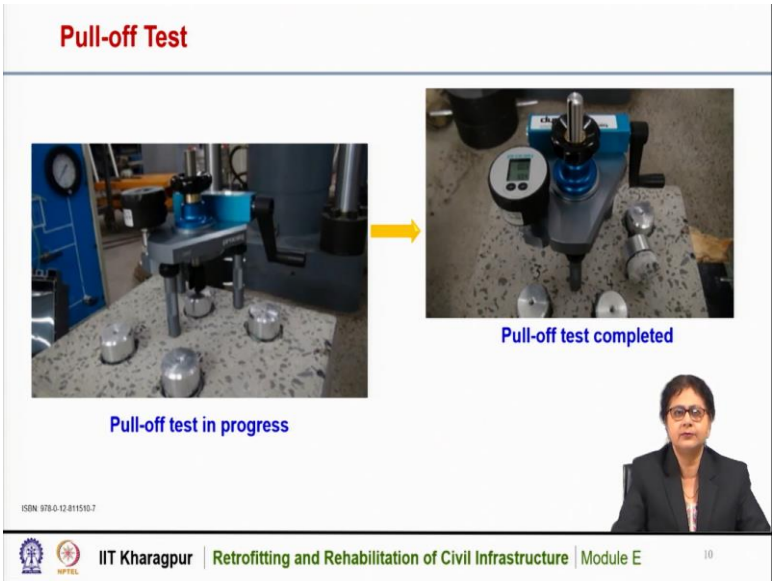

This is the picture of pull out test in progress. We can see that this is the equipment limpet that is used. And these are the aluminum plates which are used for carrying out the test. And

this is the picture when the test is complete. So, by this test we can determine the tensile strength of the substrate. And it should be sufficient to take up the FRP on it.

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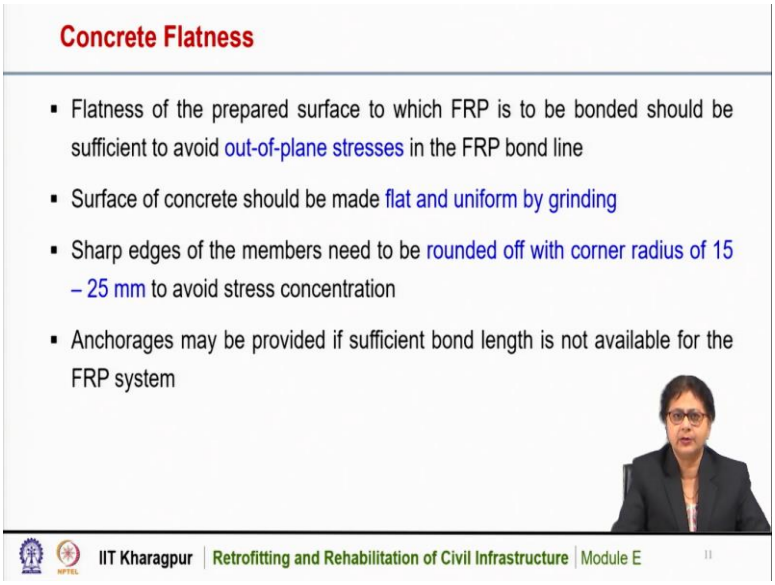

The concrete surface should be flat and that has to be done. Flatness of the prepared surface to which FRP is to be bonded, should be sufficient to avoid out of plane stresses in the FRP bond line. The surface of concrete should be made flat and uniform by grinding. Generally, grinding is used or we can use other methods.

As we have mentioned earlier, sharp edges of the members need to be rounded off with corner radius of 15 to 25 millimeter, to avoid stress concentration for non-circular sections. And anchorages may be provided, if sufficient bond length is not available for the FRP system.

So, we need to prepare the surface and the surface should be flat and uniform and that we can do it by grinding or sandblasting or water jetting, so that it can take the FRP on it. If there are sharp edges for rectangular or square sections, the corners need to be rounded off with corner radius of about 15 to 25 millimeter so that stress concentration is minimized.

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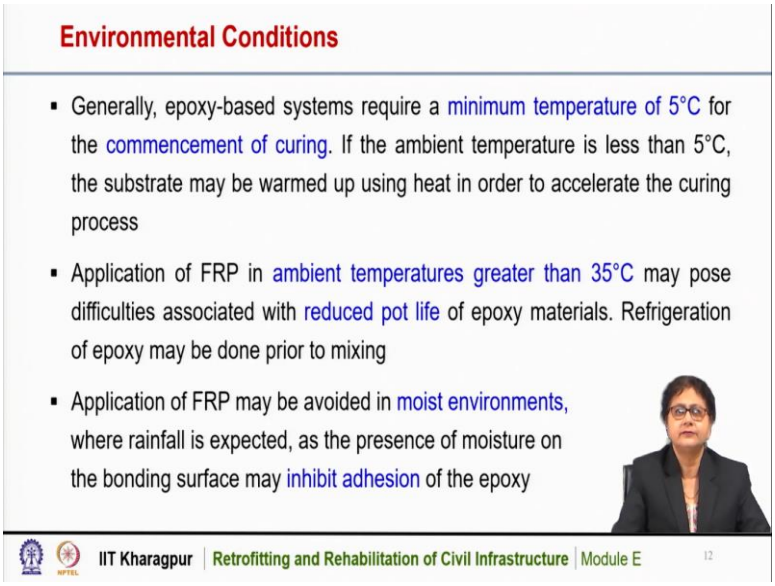

We also need to see the environmental conditions while installing the FRP. Generally, epoxy-based systems require a minimum temperature of 5 degree centigrade for the commencement of curing. If the ambient temperature is less than 5 degree centigrade, the substrate may be warmed up using heating, in order to accelerate the curing process.

Application of FRP in ambient temperature greater than 35 degree may pose difficulties associated with reduced pot life of the epoxy material. So, we need to take care of the environmental conditions and need to see the minimum or maximum temperature for the epoxy material, particularly. And if the temperature is higher, then refrigeration of epoxy may be done prior to mixing.

Application of FRP may be avoided in moist environments, where rainfall is expected, as the presence of moisture on the bonding surface may inhibit addition of the epoxy. So, we should avoid moist environment or if it is snowing or so, in that case, we can avoid the installation of FRP on the surface. Because, that may reduce the adhesion of the epoxy.

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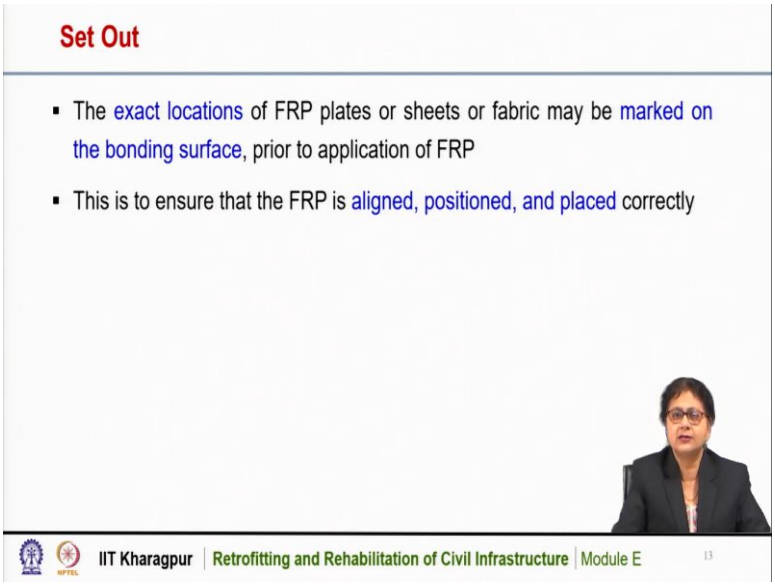

Then we need to set out the FRP. The exact location of FRP plates or sheet or fabric may be marked on the bonding surface, prior to application of FRP. So, we need to mark on the surface, the proper location where we want to put the FRP and then only we can place the FRP. This is done to ensure that the FRP is lined properly, positioned and placed correctly. So, a proper marking is necessary on the prepared surface and only on that location, FRP is to be placed. So that they are properly aligned, positioned and placed.

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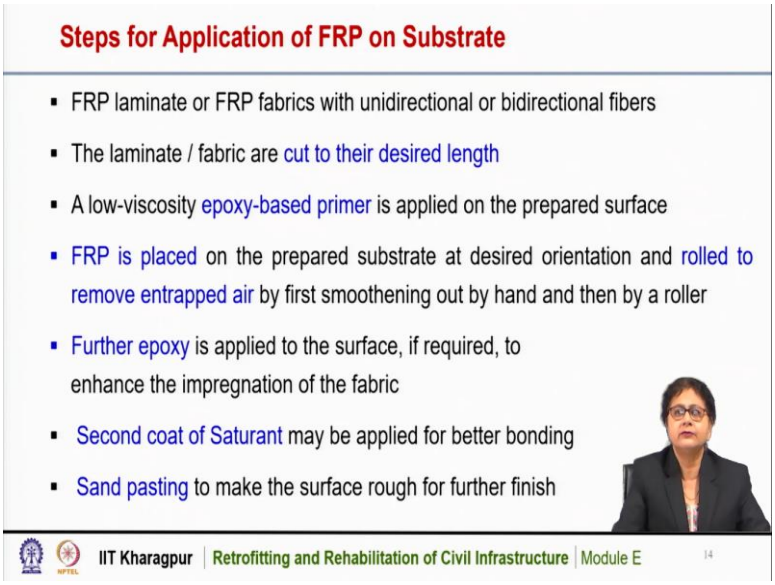

Now, we will discuss the different steps for application of the FRP on the prepared substrate. FRP is available as laminate or fabric with unidirectional fibers or with bi-directional fibers.

The laminate or fabric, if it is available, either in rolls or as plates that needs to be cut to their desired length for the application.

A low viscosity epoxy-based primer is first applied on the prepared surface. Then the FRP is placed on the prepared surface at desired orientation and rolled to remove the entrapped air. And that can be done first by hand, manually and then by a roller. So, the FRP when it is placed on the primer surface that needs to be placed properly, rolled and that is done initially by hand and then by roller. And this is done so that there is no entrapped air or void in between the FRP and the substrate.

So, it is very important that the FRP should be placed firmly on the surface and there should not be any air gap or void in between. If there is entrapped air or void then proper bonding will not be achieved. And the FRP will not be used properly or to its full capacity. Further epoxy is applied to the surface, if required to enhance the impregnation of the fabric. So, the fabric that is to be applied is to be properly impregnated with epoxy resin and if it is not adequate then we can add further epoxy on the surface.

Second coat of saturant may be applied for better bonding and after that a sand pasting is to be done to make the surface rough for further finish. After this sand pasting, we can do plastering on the surface for a better finish. So, these are the steps for the application of the FRP on the prepared surface.

First a primer is to be placed on the prepared surface then the FRP which is cut at desired length and width that is to be placed on the primer surface with proper orientation and then that is to be pressed initially by hand and then by a roller. And this is done so that there should not be any air gap in between.

And if there is air gap that causes lesser bond to the FRP and the surface. If required we can put additional epoxy so that the fabric is fully impregnated. And a second coat of saturant may also be applied for better bonding. And after that we can put sand on the prepared surface and then we can do plastering.

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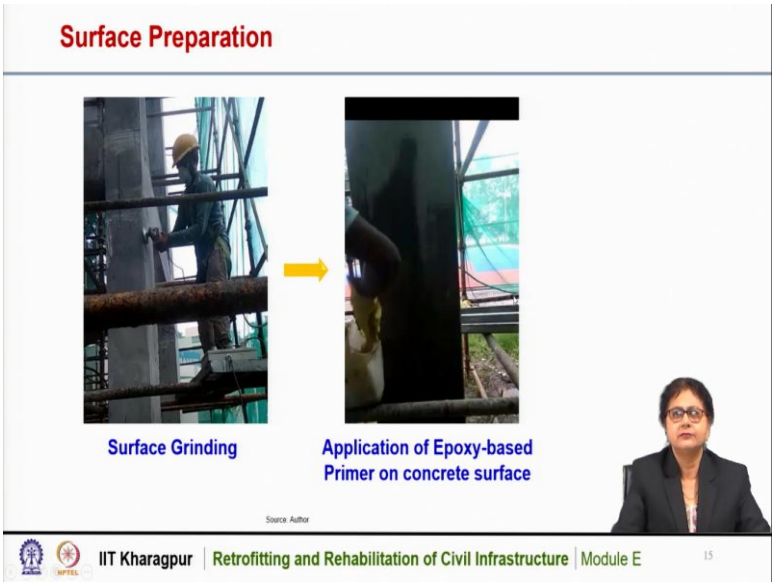

These are some of the pictures of the installation of FRP on actual structures. We can see here that surface grinding is done. This is the surface is prepared and that is done by grinding. So, here, we can see that this is an existing structure. The surface is prepared and it is made uniform and flat using grinding. And after that, it is the application of epoxy-based primer on the concrete surface. So, this is the surface it has been grinded and then the epoxy-based primer is applied.

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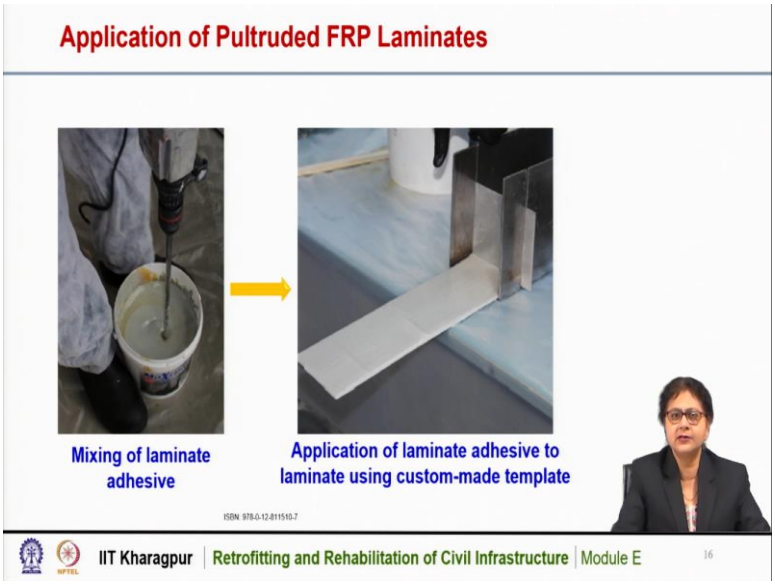

These are the pictures of application of pultruded FRP laminates. Here is the mixing of the laminate adhesive. So, the adhesive is mixed, the epoxy resin that is mixed here and then it is

to be applied on the surface. The application of laminate adhesive to the laminate, using custom made template. So, this is the laminate that is to be placed on an existing surface using this adhesive.

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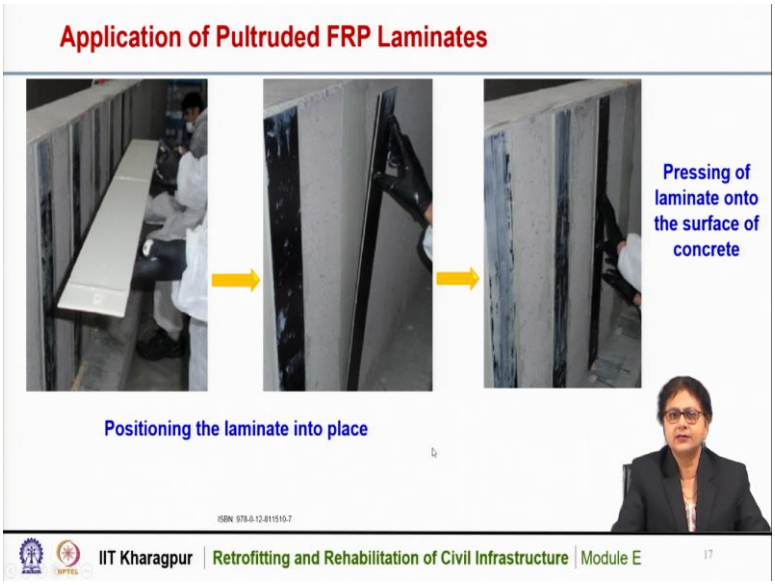

These laminates are pultruded laminates and you can see here that these are the laminates which are to be placed on the existing surface, which has been prepared for taking this FRP laminates. So, here are the positioning of the laminates into the surface at proper place. So, these are the laminates of desired width and length and they are placed with epoxy resin.

So, we can see here that these are the laminates and epoxy resin is applied on the surface and then it is pressed and here we can see that pressing of the laminate onto the surface of existing concrete. So, these are the pictures of the application of pultruded FRP laminates on existing surface.

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These are the pictures of the application of FRP fabrics on existing concrete members. These are the roles of FRP fabric at site. Here, we can see that these are the carbon fiber reinforced polymer composites. We can see here that they are generally black in color and available in roles. And this is also another picture of the FRP composite. And this picture we have taken from a site where an ROB is being retrofitted with carbon fiber composites. So, these are the roles of FRP fabric at site.

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And then we can impregnate the FRP fabric with saturants. Sometimes we require this pre-impregnation of the FRP fabric with saturant prior to put it on the existing surface. So, here

that has been done. This is the FRP fabric and the resin is put onto it and this is the fabric with saturant.

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These are the pictures of the placement of the FRP sheet and fabric on the concrete surface. We can see the positioning of the FRP sheet onto the concrete surface. This is the surface where the FRP sheet is to be placed and here the placing of the FRP fabric on the concrete surface. So, these are carbon fiber fabric, that are used here for application on this existing concrete surface.

And then it is pressed properly. Initially, by hand and then by roller and with that it is properly placed on the existing surface and the bond is achieved. So, it is very important that the laminate or the sheet or the FRP fabric need to be placed and pressed properly on the existing surface. And again, then we can place saturant over it so that proper bonding is achieved.

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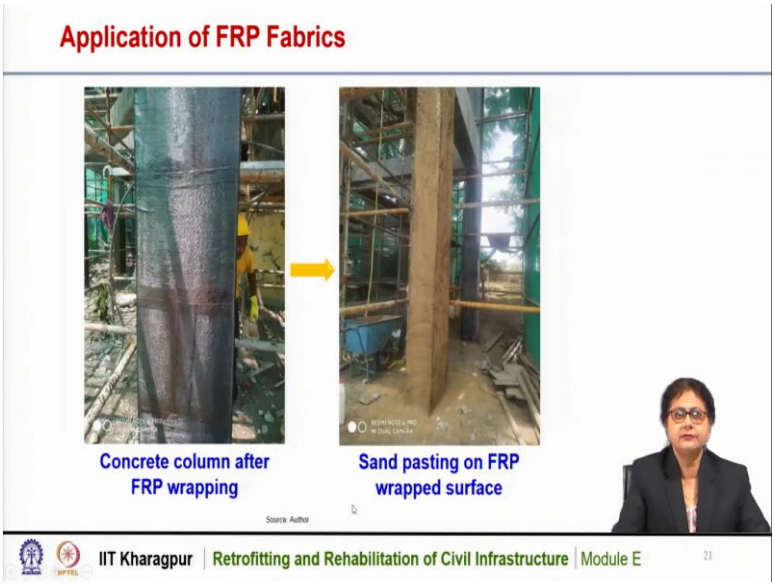

These are some of the pictures. This is a concrete column, a circular column, after FRP wrapping. This is a water tank being retrofitted with FRP. These are carbon fiber composites and this column has been retrofitted with FRP wrapping. So, just after wrapping is over, the photograph has been taken from a site in Kolkata and after the placement of the FRP composite, sand pasting is done on the wrapped surface.

So, this is a rectangular column. It has been wrapped and then sand pasting is done on the wrapped surface. And after that plastering can be done. So, these are the steps we have seen. The photographs of the installation of the FRP fabric or laminate on existing surface.

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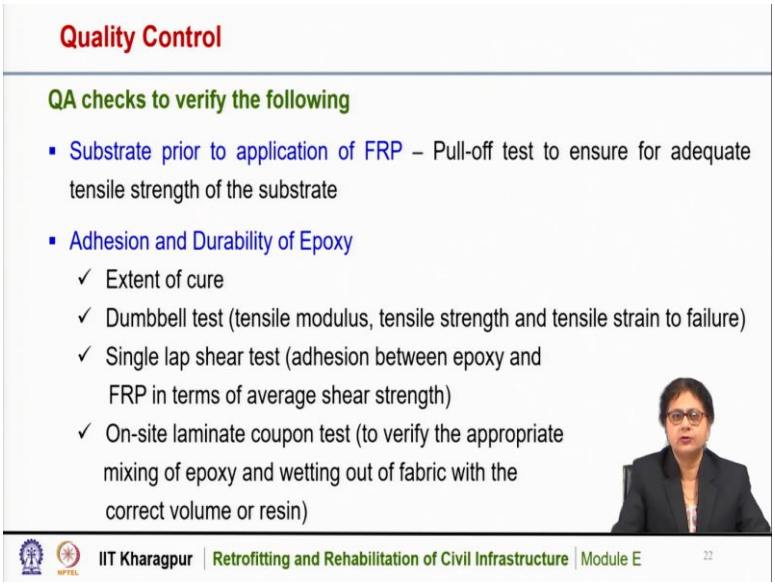

Now, we will discuss the quality control. It is very important that the FRP should be installed properly. And there should not be any air gap in between and that ensures proper bonding of the FRP to the existing surface. There are several checks, quality control checks or quality assurance checks to verify several components.

One is substrate prior to application of FRP. We need to check the substrate prior to the application of the FRP and for that pull-off test can be carried out to ensure that the surface achieved proper tensile strength, to take up the FRP on it. So, for the substrate, it is important that it should achieve sufficient tensile strength and for that pull off test can be carried out.

Adhesion and durability of epoxy should also be checked. For that we need to check the extent of cure. What is the time for the epoxy for curing? So, that need to be checked. Dumbbell test can be carried out to determine the tensile modulus, tensile strength and tensile strain to failure of the epoxy.

So, dumbbell test can be carried out on the epoxy to determine the tensile modulus, tensile strength and tensile strain to failure, single lap shear test can be carried out to determine the adhesion between epoxy and FRP in terms of average shear strength. Onsite laminate coupon test can also be carried out to verify the appropriate mixing of epoxy and wetting out of fabric with the correct volume of resin.

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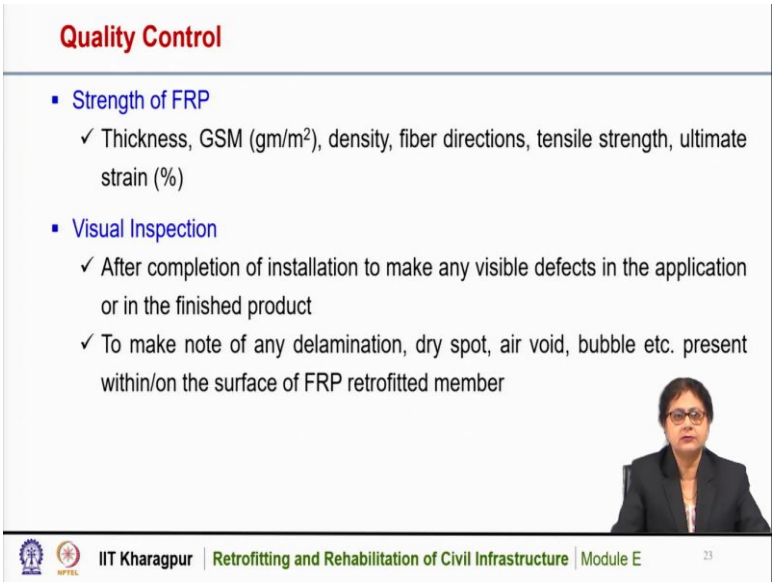

For the FRP, we can carry out several tests to determine the tensile strength, the ultimate strain, the tensile modulus of the FRP, the thickness, the GSM that is gram per meter square of the FRP, the density, the fiber directions generally are given by the manufacturer. However, it is always desirable to test the FRP to determine its tensile strength and modulus values. And also, we can carry out a visual inspection after the installation of FRP.

After completion of the installation, we can make a visual inspection, to make any visible defects in the application or in the finished product. So, if there is any defect that is visible, that need to be noted. And we should also note, if there is any delamination or dry spot or air void, bubbles etcetera, they are present within or on the surface of the FRP retrofitted member. So, if those things are there, we need to note it down and a corrective action need to be taken.

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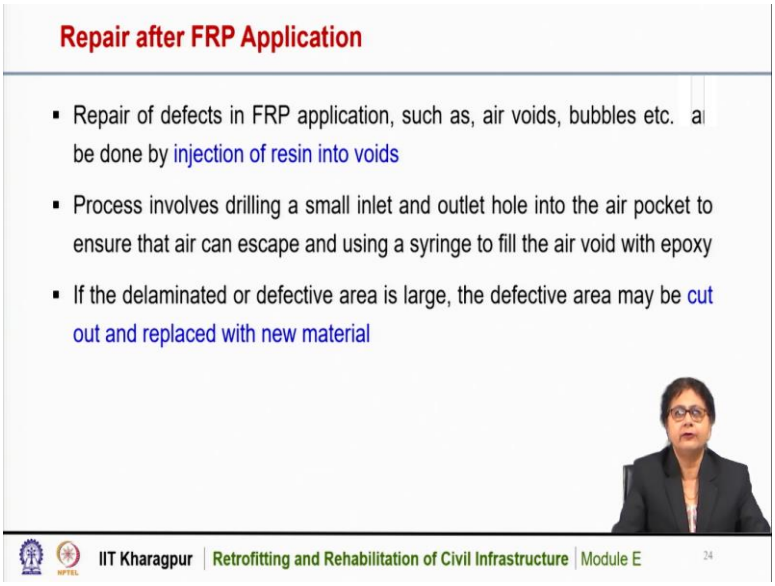

So, if that type of delamination or defect or air void or bubbles are visible on the surface, after installation, then a repair measure is necessary. So, repair of defects in the FRP application can be done by injection of resin into the voids. So, if voids are visible or bubbles, air bubbles are visible then we can use epoxy injection so that the voids are filled up.

The process involves drilling a small inlet and outlet hole into the air pocket, to ensure that air can escape and using a syringe to fill the air void with epoxy. So, if such air voids or bubbles are visible, then we can use injection of resins so that the voids are filled up. If the delaminated or defective area is large then the defective area may be cut out and replaced with new materials. So, if there are small voids that can be rectified by epoxy injection, if the defect is large or delamination is large then that portion need to be cut and then that is to be replaced with new material.

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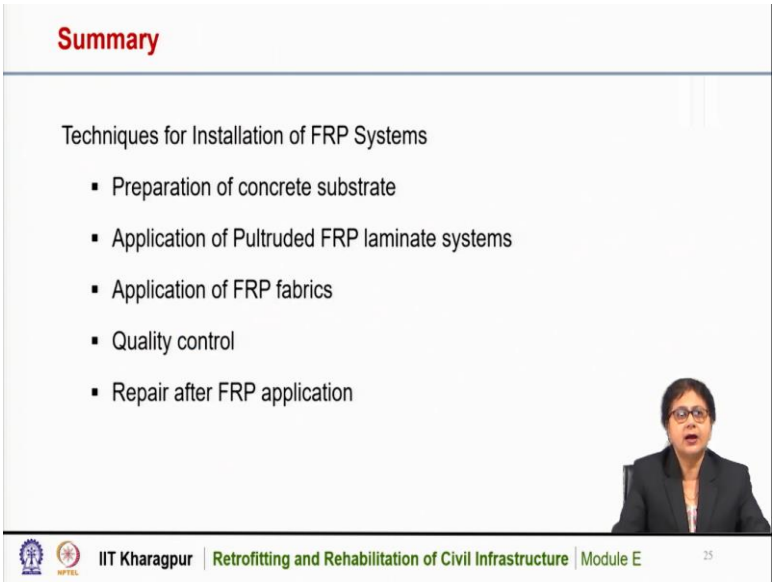

So, to summarize, we have discussed the techniques for installation of FRP systems on existing concrete surface. We have discussed the preparation of concrete substrate, the application of pultruded FRP laminate system, the application of FRP fabric on existing concrete members, the quality control and repair after FRP application, if any defect is visible.

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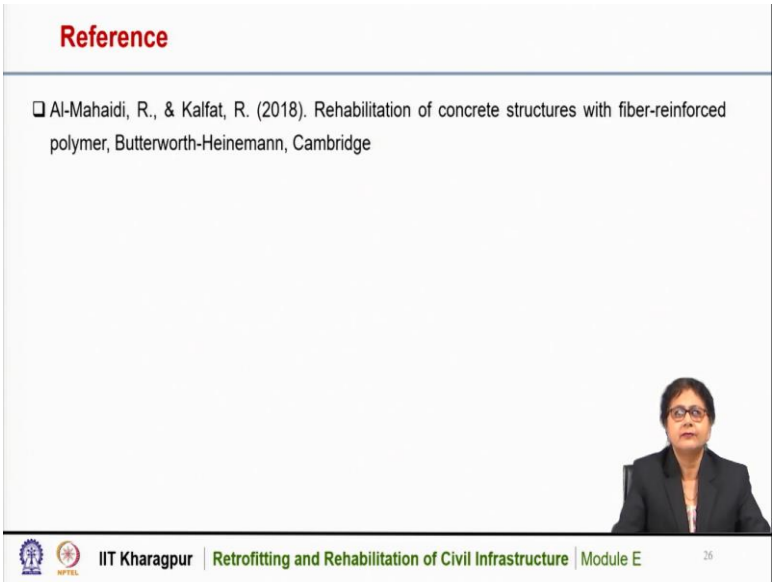

This is the reference for today's lecture. Thank you.