Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 30
Anchorage Systems for FRP Strengthening

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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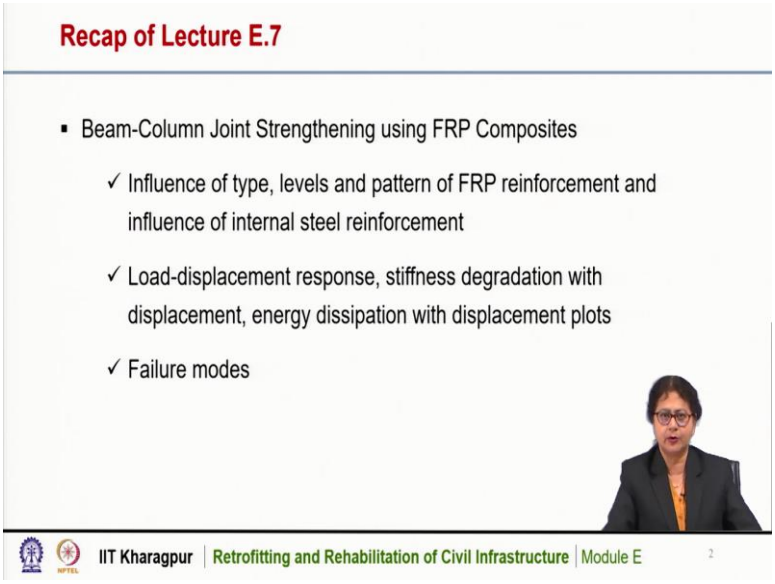

In the previous lecture, we have discussed the beam column joint strengthening using FRP composites. We have discussed the influence of several parameters on the response of beam column joints, like the type of FRP reinforcement, the levels of FRP reinforcement and the different patterns of FRP reinforcement on the beam column joints.

We have discussed the influence of internal steel reinforcement and the detailing. The responses were discussed in terms of load displacement plots, stiffness degradation plots, and energy dissipation with displacement plots. We have also discussed the various failure modes of the beam column joints that are strengthened with FRP composites.

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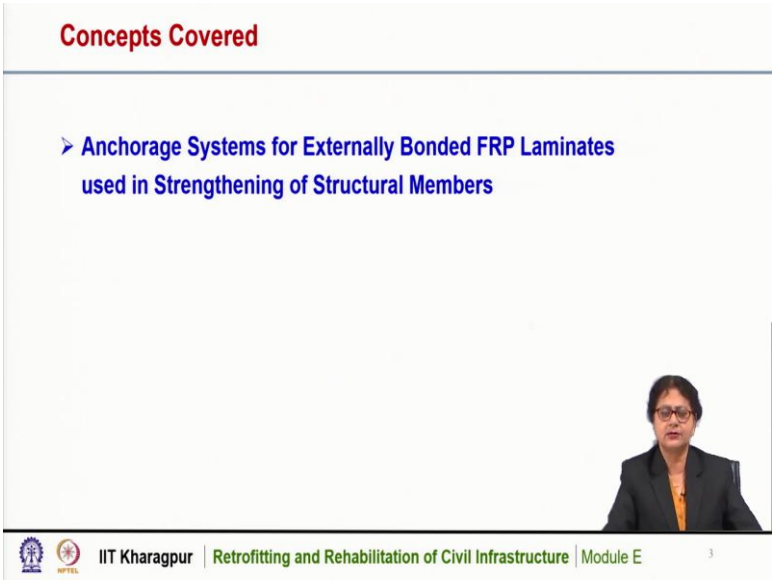

Today, we will discuss anchorage systems for externally bonded FRP laminates used in strengthening of structural members.

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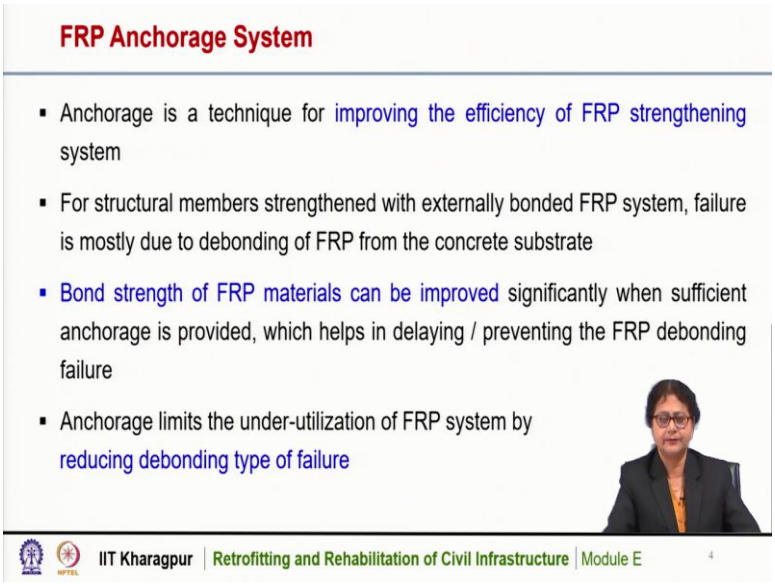

Anchorage is a technique for improving the efficiency of FRP strengthening system. In recent years, the interests have been grown on the use of anchorage in FRP retrofitted members. For structural members which are strengthened particularly with externally bonded FRP system like with FRP strips, or FRP laminates or FRP sheets.

The failure may be due to debonding or it may be due to rupture of fiber or it may be due to crashing of concrete or yielding of steel. We have seen in the previous lectures that in many of the cases the failure is due to debonding of the FRP from the concrete surface. So, debonding is

one of the most common type of failure that has been occurred on the FRP strengthen members.

By using anchorage, we can reduce the debonding type of failure in FRP retrofitted members. Bond strength of the FRP materials can be improved significantly when sufficient anchorage is provided, which actually helps in delaying or preventing the FRP debonding failure. And that is why in recent years, anchorages have been used so that the debonding type of failure is delayed or restricted.

In an FRP retrofitted member, we have seen that the failure may be due to debonding or rupture of the FRP. In case of FRP retrofitted member, the failure may be due to debonding or rupture of the fibers. In a FRP retrofitted member when the strain in the fiber exceeds its ultimate strain there may be rupture of the fiber. But when there is debonding type of failure, the strain that has been developed is much less than the ultimate strain of the FRP.

So, there is underutilization of the FRP system, when there is debonding type of failure. And this debonding strain is generally much lower than the ultimate strain of the FRP. So, we cannot use the full capacity of the FRP system when the failure is due to debonding. So, by providing a suitable anchorage, this type of debonding failure can be prevented or delayed.

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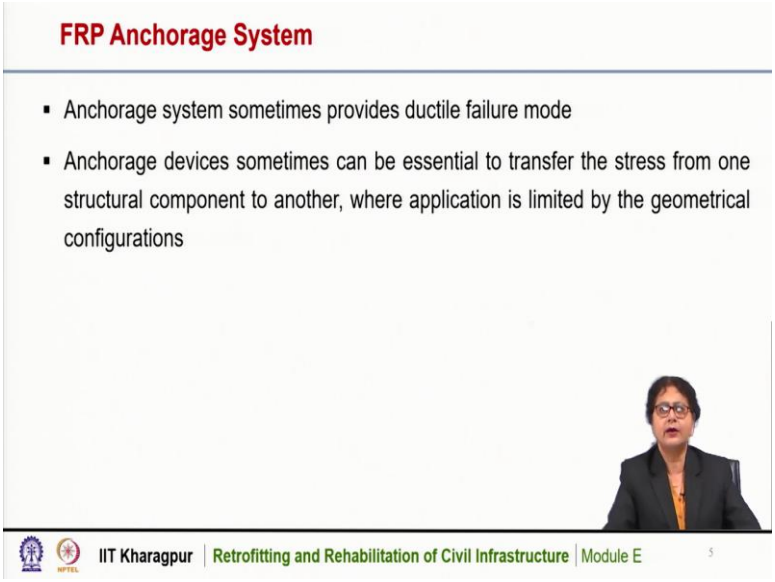

Anchorage System sometimes provides the ductile failure mode because the debonding is delayed. So, to some extent, we can get a ductile failure mode of the FRP system. Anchorage devices sometimes can be essential to transfer the stresses from one structural component to another where application is limited by the geometrical configurations.

In some of the FRP retrofitted members, there may be geometrical restraints. And in those cases, anchorage devices are essential so that the stress can be transferred from one component to the another. So, anchorages are used nowadays in recent years in the last decades and that helps in the improving of structural capacity of FRP retrofitted members.

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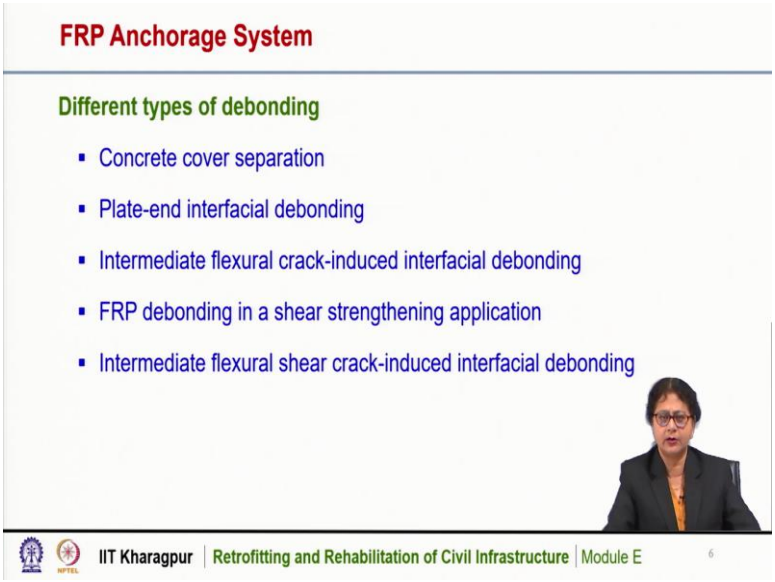

We have seen earlier that there may be different types of debonding and based on the type of debonding actually the anchoring system has been developed. The different types of debonding of the FRP strips or sheets are concrete covers separation or it may be due to plate-end interfacial debonding, intermediate flexural crack induced interfacial debonding, FRP debonding in a shear strengthening application and intermediate flexural shear crack induced interfacial bonding. So, different types of debonding may occur in a FRP retrofitted member.

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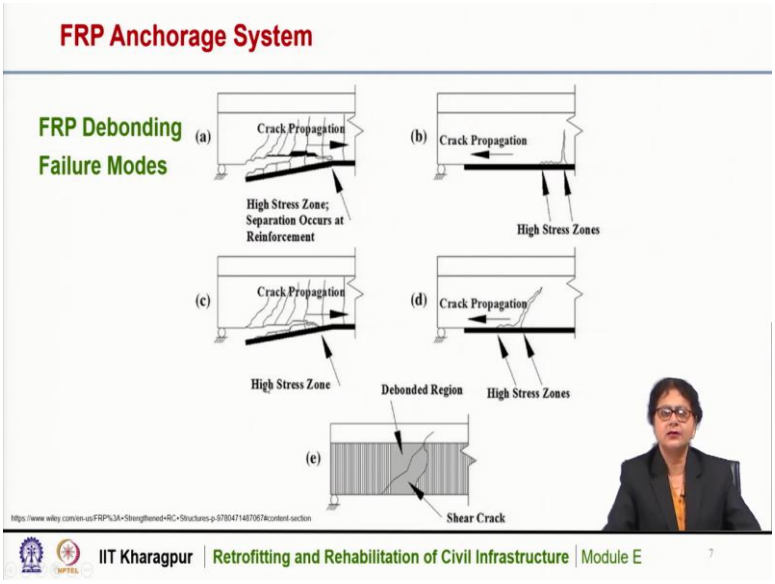

And these are the schematic diagrams of the different type of debonding in FRP strengthen members. We can see here that in this diagram cracks are appeared on that member near the support and there is a separation of the cover concrete.

Here also, we can see here that this is the high stress location and there may be a debonding at this location. This also shows that a number of cracks appeared on the member and these are the high stress location and the FRP is debonded here near the end. This also shows that this is a typical flexure, shear crack that may appear on this member and because of the propagation of the crack there is debonding at these locations.

And this is a typical shear crack that is shown in this schematic diagram and this is the location of the debonding. So, this is the debonding region that we have also discussed earlier and under the application of load these shear cracks may appear and debonding at these regions may initiate. So, these are the different types of debonding failure that may occur at FRP retrofitted member.

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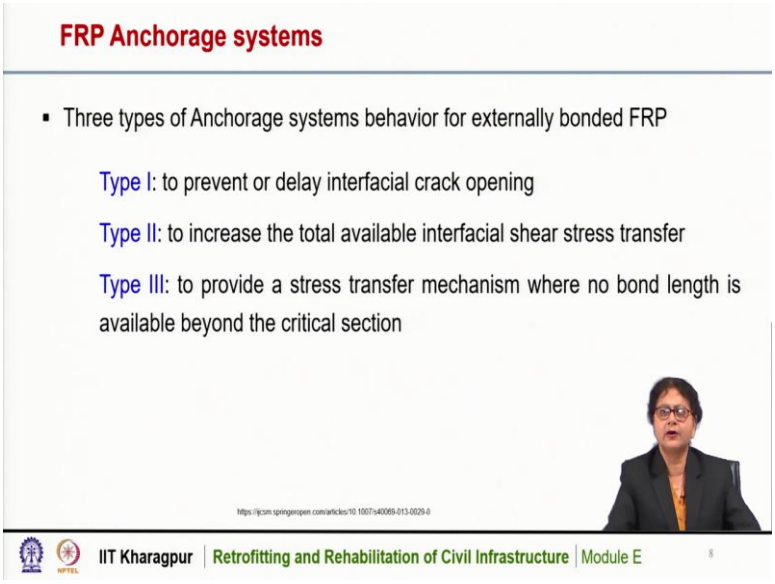

Based on the type of debonding different types of anchorage systems have been developed. So, three types of anchorage systems behaviour for externally bonded FRP have been developed. One is type 1 to prevent or delay the interfacial crack opening. Type 2 is for increasing the total available interfacial shear stress transfer.

And type 3 anchorage is to provide a stress transfer mechanism where no bond length is available beyond the critical section. So, depending on the type of structure, the availability of the length and the possible failure mode due to debonding different types of anchorage systems have been developed.

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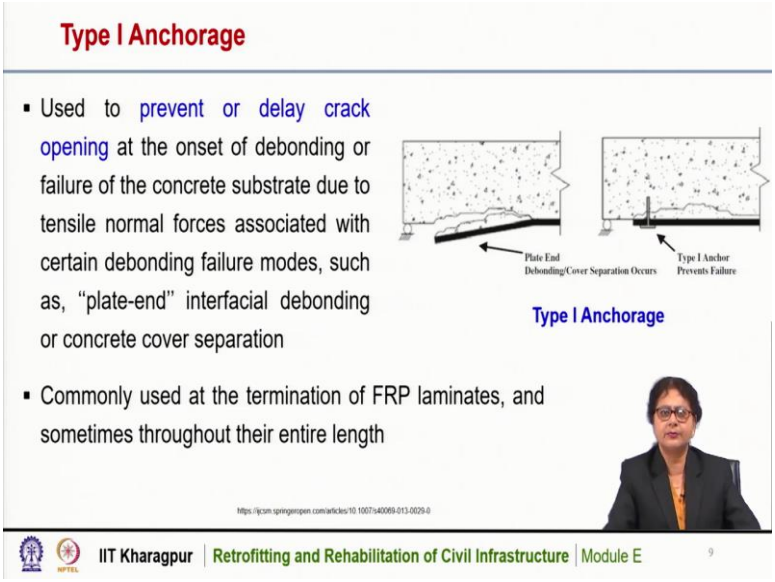

This is the type 1 anchorage. This is used to prevent or delay the crack opening at the onset of debonding or failure of the concrete substrate due to tensile normal forces associated with certain debonding failure modes such as plate-end interfacial debonding or concrete cover separation. So, we have seen that there may be interfacial debonding, concrete cover separation and to prevent that type of debonding and crack opening, we can provide type 1 anchorage.

This is commonly used at the termination of FRP laminates and sometimes throughout their entire length. So, here we can see the schematic diagram of the debonding and the type 1 anchorage. This is the concrete member and this is the FRP laminate that is used to improve its capacity and this may be the debonding type of failure along with some concrete cover, the laminate is separated and cracks appeared. So, to prevent this type of demanding, we can provide type 1 anchorage, you can see here at this point near the end of the laminate, we can provide type 1 anchorage that may prevent this type of debonding failure.

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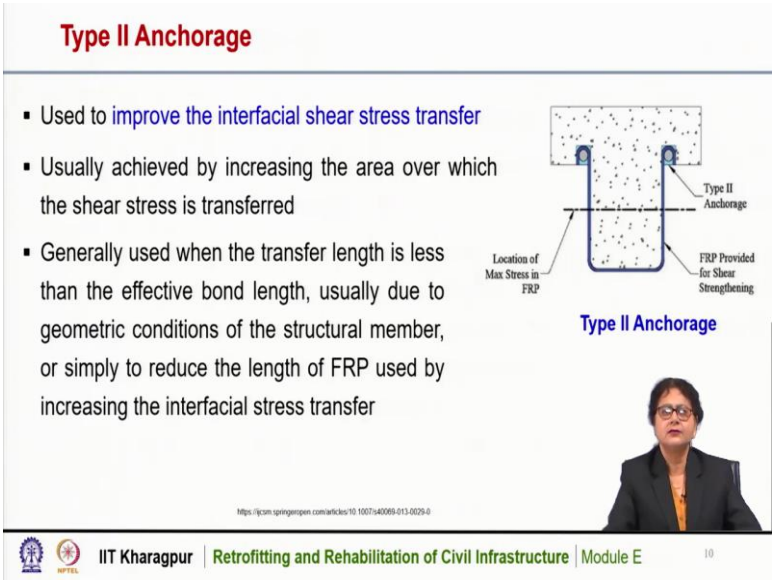

This is type 2 anchorage; this type of anchorage is used to improve the interfacial shear stress transfer. We have seen that for shear strengthening we can provide the FRP strips, two-sided or three-sided new strip also. So, here this type of anchorages are used to improve the interfacial shear stress transfer. Usually achieved by increasing the area over which the shear stress is transferred.

And generally used when the transfer length is less than the effective bond length. Usually due to geometric conditions of the structural member or simply to reduce the length of FRP used by increasing the interfacial stress transfer. So, here we can see that this is a typical concrete member and on three-sided it is strengthened with FRP strips.

So, this has been done to improve its shear capacity and this is the type of anchorage that is used. So, this is the location of maximum stress in the FRP and these are the anchorages that are used. So, this increases the area over which the shear stress is transferred. And thus, there may be less chance of debonding in this type of member.

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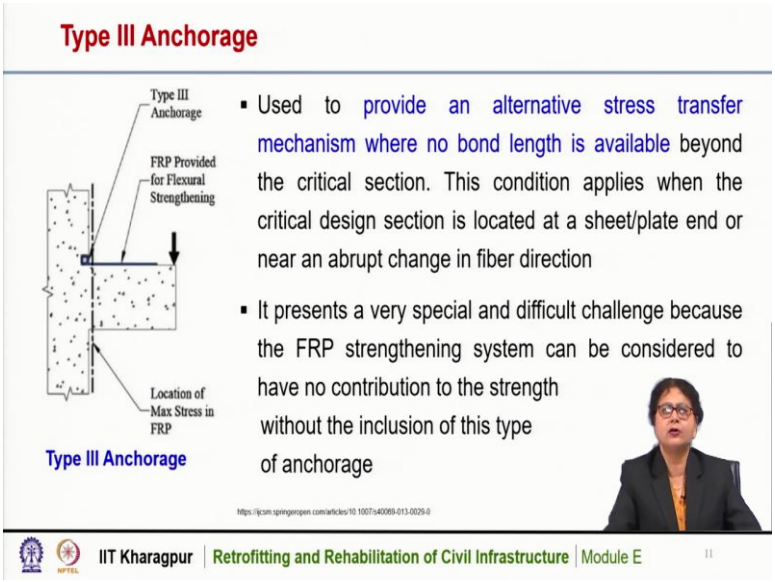

This is type 3 anchorage. This type of anchorage is used to provide an alternative stress transfer mechanism where no bond length is available beyond the critical section. This condition applies when the critical design section is located at a sheet or plate-end or near an abrupt change in the fiber direction. So, here we can see that in this schematic diagram, this is a concrete member which is connected to this member here.

And this is the FRP that is to be provided for flexural strengthening. Now, here we are having less bond length and here to reduce or to restrict the debonding type of failure we have to provide this type of anchorage. So, this is type 3 anchorage that is provided and here it is required from geometry consideration that we have to provide some anchorage so that debonding failure is delayed or prevented.

It presents a very special and difficult challenge because the FRP strengthening system can be considered to have no contribution to the strength without the inclusion of this type of anchorage. So, in some cases, the geometry of the structure may be such that we are getting very less length for a bonding the FRP strips.

So, in that case, we have to take some additional measures so that the debonding type of failure is prevented. So, in that case, we have to provide the anchorage and here we require this type 3

anchorage and that helps in preventing the debonding type of failure. If we cannot provide special arrangement or this type of anchorage, then FRP will not contribute significantly for the improvement of strength.

So, in such cases we have to provide the type of anchorage on the structural member so that the contribution of the FRP is achieved. So, these are the three different types of anchorages that are used depending on the geometry of the structural member and the type of failure it may have.

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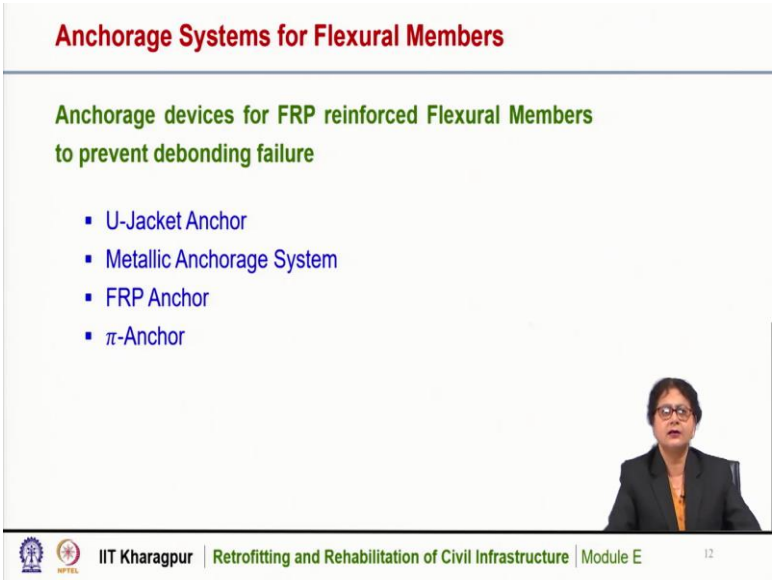

Now, we will discuss the anchorage devices for FRP reinforced flexural members to prevent debonding failure. We have mentioned earlier, that anchorages are used to improve the performance of the FRP retrofitted members and particularly it is suitable for the EBR system that is the externally bonded FRP strips or sheets when it is used to improve the flexural capacity or shear capacity of the members.

Here, we will discuss the anchorage devices which are used for flexural members to prevent debonding type of failure. So, four different types of anchorage devices are used for FRP reinforced flexural members that are U-Jacket anchor, metallic anchorage system, FRP anchor and π-anchor.

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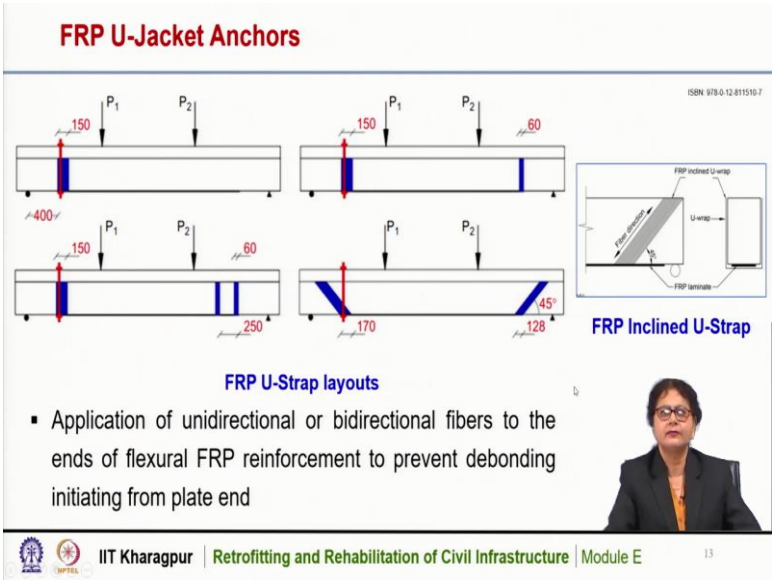

This is FRP U-Jacket anchors. We have seen that in these schematic diagrams, so this is a simply supported beam and it is strengthened at its bottom at the tensile face of this beam and this is the FRP sheet or strip that is attached to the bottom or tensile face of the member. Now, to prevent the debonding type of failure, we can provide U-Jacket anchors. The application of this U-Jacket anchors is that it is unidirectional or bidirectional fiber composites.

And they are placed at the end of the beam members either on one side or on two sides, either perpendicular to the length of the member or making some angles. So, application of unidirectional or bidirectional fibers to the ends of the flexural FRP reinforcement to prevent debonding type of failure and that may initiate at the plate-end and that is why it is provided near the end.

So, here we can see that this is the FRP strip that is provided for improving the flexural capacity of the member. So, we can provide this FRP U-Jacket anchor at the end. So, this is the FRP U-Jacket anchor, it may be provided on one side and another side it is the strip, here in one side it is provided and another two side you can provide U-Jacket two numbers. Here, it can be placed at some angle. So, generally 45 degree we can place it and then the anchor. And this is the schematic diagram of the FRP inclined U-strip.

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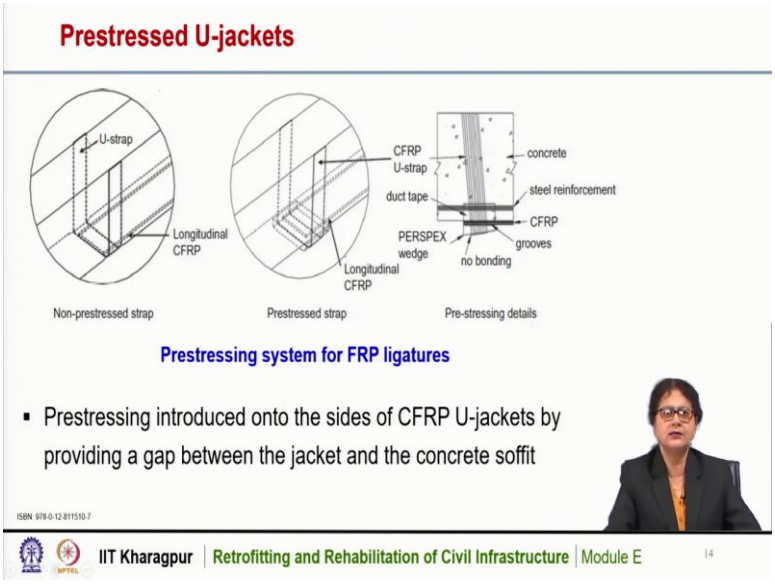

FRP U-strips can also be used in prestressed member which are retrofitted with FRP strips. In case of prestressed members, prestressing introduced onto the sides of CFRP U-Jackets by providing a gap between the jacket and the concrete soffit. Here, we can see that this is the U-Jacket on a FRP retrofitted member. So, this is the member the line diagram is shown here and this is the U-strip and this is the longitudinal FRP that is provided for improving the flexural capacity.

So, this is the non-prestressed strap and this can be provided at the end of the laminate. So, here is the prestressed strap here we can provide this type of U-Jacket by providing a gap, we can see here by providing a gap between the jacket and the concrete soffit and this is the details of the prestressing. So, here we can provide this CFRP U-strap. This is the main reinforcement and this is the CFRP reinforcement and then this U-strap can be provided with a small gap here. So, in case of prestressed member also we can put this type of anchors for preventing the debonding type of failure.

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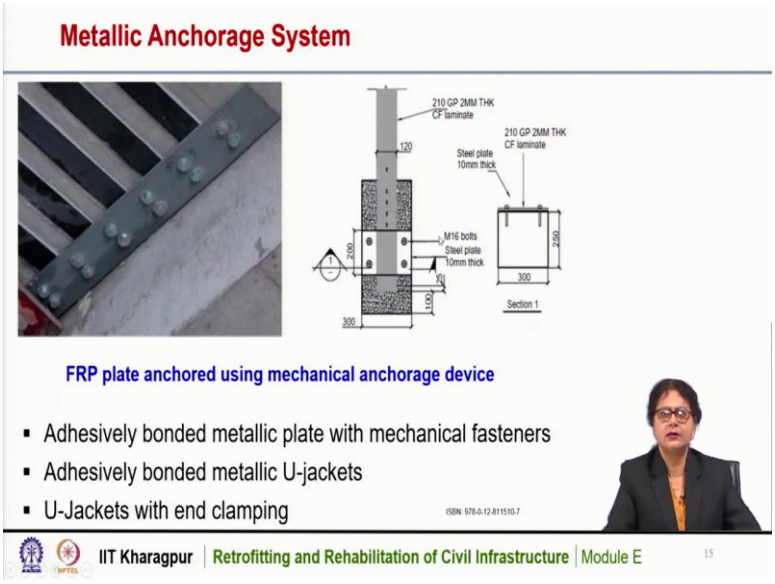

This is metallic anchorage system. This is also quite popular and this is used to prevent the debonding type of failure in members. Here, the metallic plates are adhesively bonded using mechanical fasteners. Adhesively bonded mechanical metallic U-Jackets are used and U-Jackets are with end clamping. So, here in this picture we can see that, these are the FRP strips which are provided on a slab member and this is the metallic anchoring system.

So, this is the metallic anchorage system and it is provided with bolts or end clamping and that is attached to the FRP strips. So, this is the schematic diagram of the system. We can see that this is the concrete member and this is the FRP strip and it is attached with this metallic anchorage system. So, this is the metallic anchorage system with the bolts and that is attached to the concrete and the FRP member. So, thus it provides bond to the member and prevents or delays the debonding type of failure.

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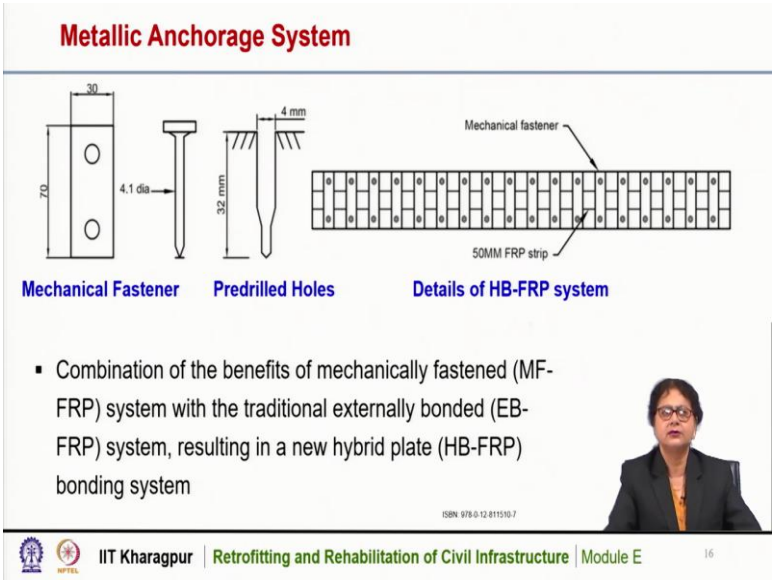

This is also another type of metallic anchoring system. It is a combination of the benefits of mechanically fastened system with the traditional externally bonded system that is externally bonded FRP system resulting in a new hybrid plate bonding system. So, here it is actually a combination of the metallic anchorage system and the FRP anchorage system. This is a typical mechanical fastener with these are the bolts location and this is the bolts that need to be inserted through these holes.

And this is the predrilled hole through which you can provide this bolt and this is the details of the HB FRP system. So, this is the hybrid system with metallic anchorage system and the FRP system. So, here these are the mechanical or metallic anchors and these are the FRP strips. So, these are the FRP strips that are provided in between the metallic anchors and these are the metallic anchors that are to be attached on the existing member with bolts so that it becomes a hybrid system. And that is used to prevent the debonding type of failure to the member.

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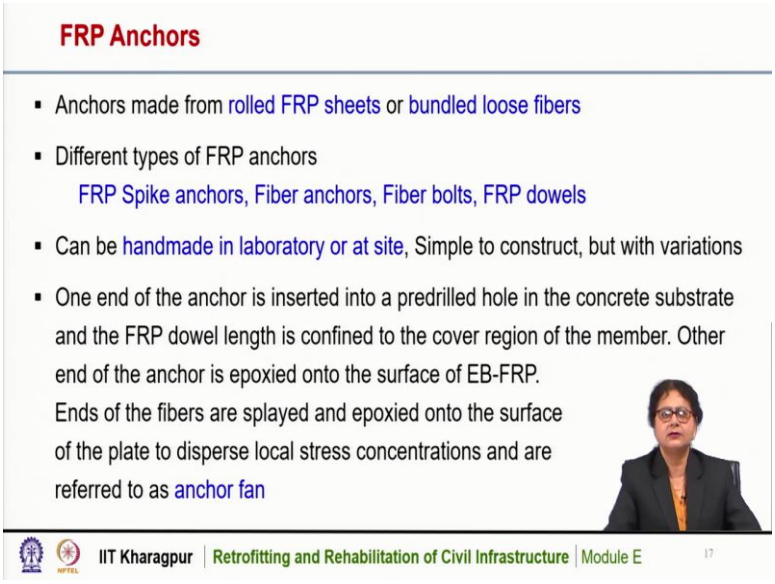

Now, we will discuss the FRP anchors. FRP anchors are developed recently and these anchors are made from rolled FRP sheets or bundled loose fibers. There are different types of FRP anchors, FRP spike anchors, fiber anchors, fiber bolts, FRP dowels. So, these are the different types of FRP anchors that are used. And this type of FRP anchors can be handmade in the laboratory or at site.

They are simple to construct and since they are made manually, so there may be some variations. Here one end of the anchor is inserted into a predrilled hole in the concrete substrate and the FRP dowel length is confined to the cover region of the member. Other end of the anchor is epoxied onto the surface of the externally bonded FRP. The ends of the fibers are splayed and epoxied onto the surface of the plate to disperse the local stress concentrations and are referred to as anchor fan.

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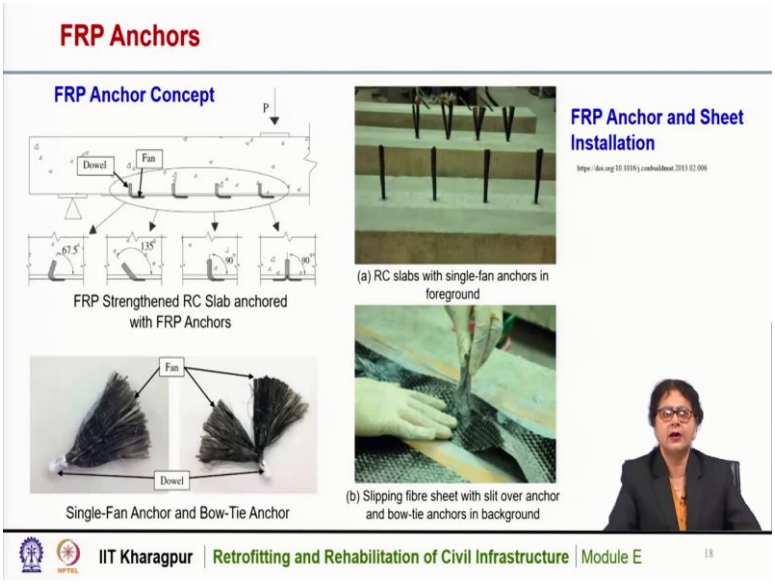

So, here are the pictures of the FRP anchors. So, we can see here that in these pictures that this is typical FRP anchors, and this is the FRP dowel portion and this is the FRP fan. So, here it is single fan anchor and this is double fan anchor or bow tie anchor. So, here we can see that this is dowel portion and this is the fan portion. Here it is one fan and here it is two and this is the FRP strengthened RC slab anchored with the different types of FRP anchors.

So, here we can see that this is the schematic diagram of a concrete member. And this is the support and this is the FRP plate or strip that is attached at its bottom to improve its flexural capacity. Now, we can provide this FRP anchors. So, here we can see that some part of this FRP anchor is inserted into the cover of that member and some part is outside. So, the dowel part is inside and the fan part is outside.

So, the dowel part can be inserted at different angles, we can see here a different angle it can be inserted into the cover concrete. And there is a fan part which is outside. And then we can put epoxy onto it and that is sprayed onto the surface and that reduces the stress concentration and helps in preventing the debonding type of failure.

So, here we can see that these dowels are inserted at different angles to the concrete and there may be fans which are outside. These figures show that the FRP anchors are placed on an existing concrete member and the fan portion is exposed. Here it is single fan and here in these specimens, double fans are there and single fan anchors in the foreground and backside it is double fan.

And here, it is the slipping fiber sheet with slit over anchor and bow tie anchors in the background. So, here we can see that the fans are exposed and it is epoxied and then it is placed on the surface so that it reduces the stress concentration and provides the anchorage. So, this is FRP anchors that are used to improve the bonding of the FRP retrofitted members.

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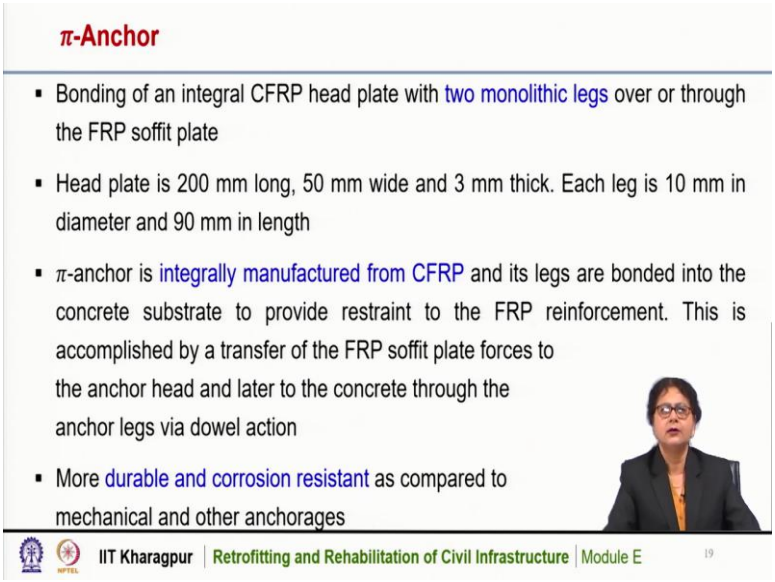

π-Anchor is also a new type of anchor. Here, the bonding is done by an integral CFRP head plate with two monolithic legs over or through the FRP soffit plate. So, π-anchor is of the shape of the letter π and it has one head plate with two monolithic leg. The head plate is of dimension 200 millimetre in length and 50 millimetre in width and 3 millimetre in thickness, this is the typical dimension.

The legs are of 10 millimetre in diameter and 90 millimetre in length. These are the typical dimensions depending on the type of structure it is used. π-Anchor is integrally manufactured from CFRP and its legs are bonded into the concrete substrate to provide restraint to the FRP reinforcement. This is accomplished by a transfer of the FRP soffit plate forces to the anchor head and later to the concrete through the anchor legs via dowel action. π-Anchors are more durable and corrosion resistant as compared to mechanical and other anchorages.

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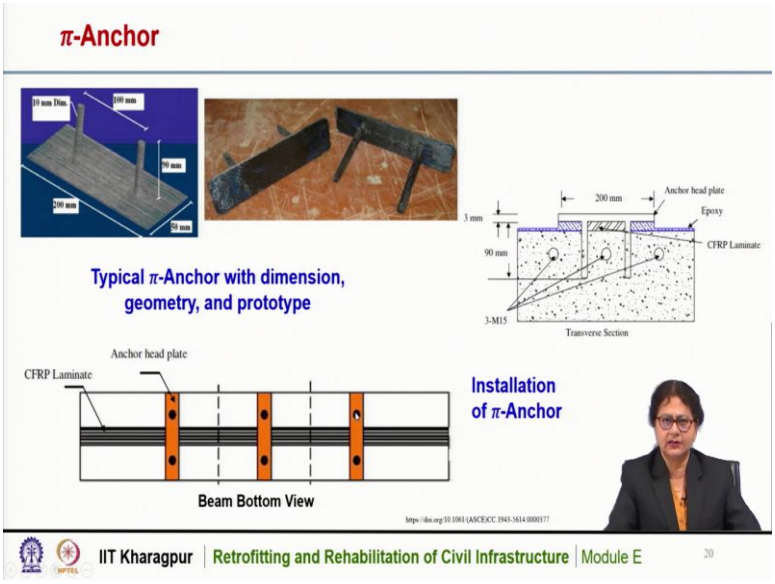

These are the diagrams and schematically shown the π-anchors here. This is the π-anchor which is made up of FRP. This is the head and these are the two legs. So, here we can see the picture of the π-anchor with the dimension and the configuration and this is the bottom view of the beam with π-anchors.

So, this is the beam and this is the FRP strip which is attached at its bottom for improving its flexural capacity and these are the π-anchors that are to be provided. So, this is the π-anchor and these are the locations where these legs can be inserted. And this is the section, we can see here that this is the concrete member and there are holes.

And this is the FRP strip, which is provided for improving the flexural capacity and then we can provide this π-anchor. And these are the two legs which are inserted into the concrete member and that provides the anchorage. So, π-anchor is quite effective in improving the bond between the FRP and the existing concrete.

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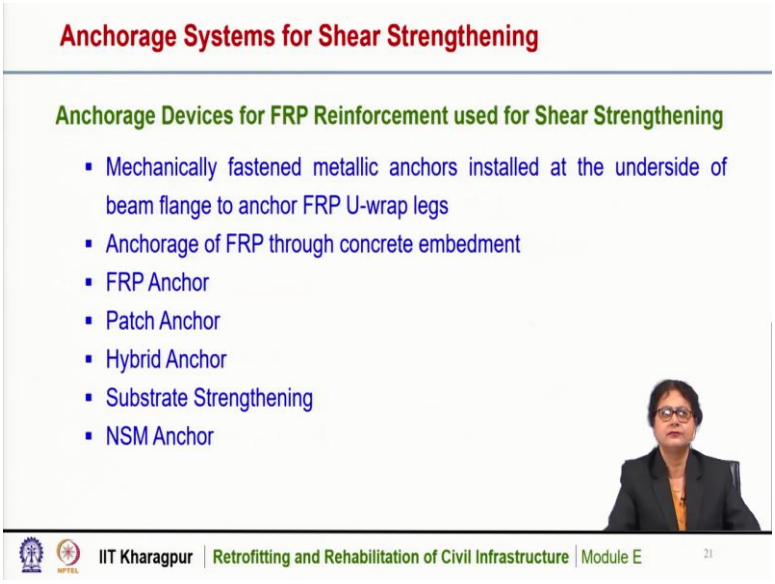

So, we have discussed the different anchorage system for the flexural members, where we have the FRP strips or sheets or laminate for improving the flexural capacity. Anchorage system is also used for shear strengthening and in members where it is strengthened for its shear capacity. So, there are different types of anchorages that are used for shear strengthening purpose.

And these are mechanically fastened metallic anchors installed at the underside of beam flange to anchor FRP U-wrap legs. Anchorage of FRP through concrete embedment. FRP anchor, patch anchor, hybrid anchor, substrate strengthening and NSM anchor. So, these are the different types of anchors that are provided to members which are strengthened for shear.

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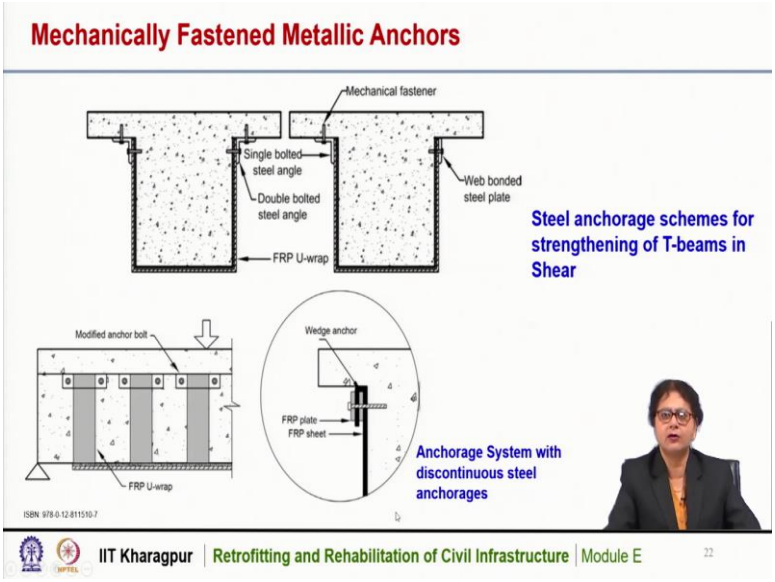

This is mechanically fastened metallic anchors, we can see here that this is a typical concrete member and this is the FRP U-wrap that is provided to improve it shear capacity. And these are the mechanically fastened metallic anchors, that are provided we can see here at the web or at the flange and then it is bolted. So, here this is typical mechanical fasteners that are used to improve the bond between the FRP U-wrap and the concrete.

And this is the member and the FRP strips, these are the FRP U-wraps that are provided to improve the shear capacity, these are the mechanical anchors that are provided with anchor bolts to improve the bond between the FRP and the concrete and this is the detail for that. So, we can see here that with this type of detailing and by providing this type of metallic anchors, the bond between FRP and concrete can be improved when it is strengthened for its shear capacity.

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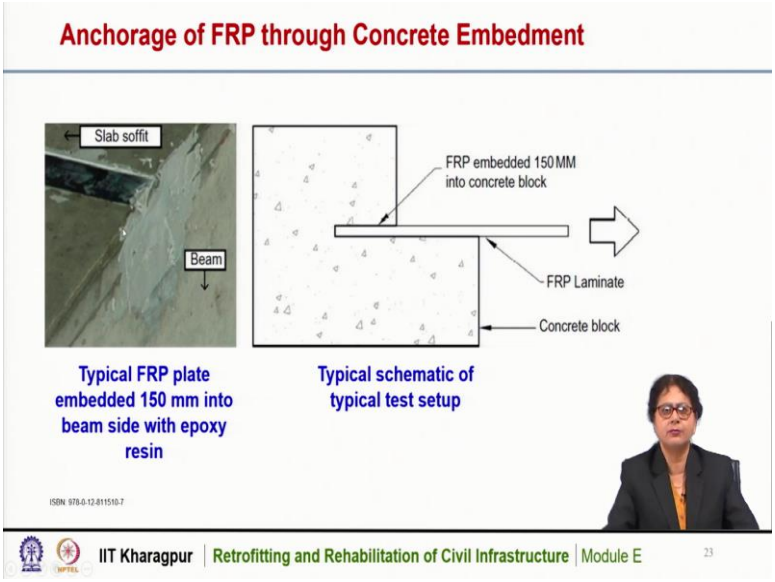

This is anchorage of FRP through concrete embedment. So, here this is the FRP, that is embedded into concrete blocks. So, sometimes it is difficult to do add proper bond length and, in that case, we can embed the FRP strip or FRP plate inside this concrete member. So, here we can embed this FRP at least 150 millimetre into the concrete blocks so that proper anchorage is achieved.

Here is a picture of a typical FRP plate embedded 150 millimetre into the beam side with epoxy resin. So, here we can see that this is the FRP member and it is embedded into this existing concrete member using epoxy resin. So, this is anchorage of FRP through concrete embedment.

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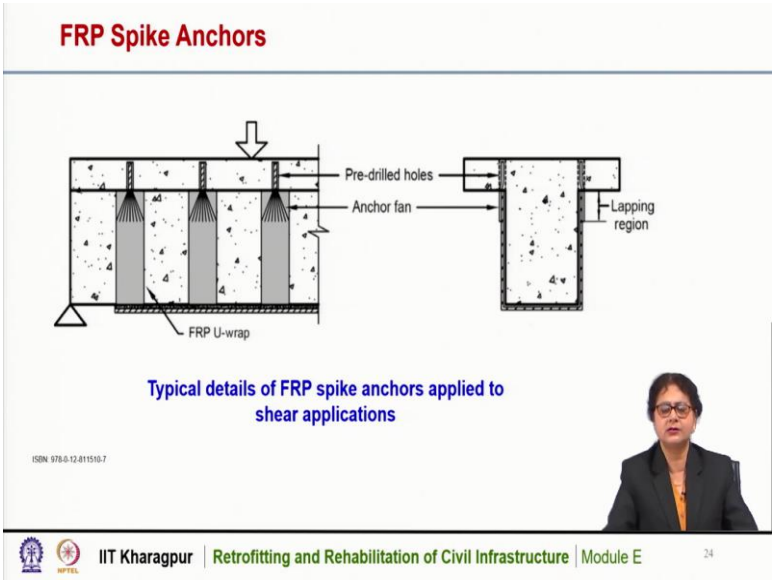

This is FRP anchors or we call it FRP spike anchors, what we have seen for the flexural members, here also this type of FRP anchors can be used when the member is strengthened for its shear. So, these are the U-wraps, FRP U-wraps we can see here intermittently it is provided to this member. And these are the FRP anchors.

So, this is the dowel portion of that FRP anchor and this is the spike portion or the fan portion. So, here while drilling holes we can insert this type of FRP anchors. So, the dowel part is inserted into the concrete member and then the fan part is there outside and then we can put epoxy on it and the anchorage can be placed. So, these are the different schematic diagrams for that. So, this is the part which is the fan part of the anchor and that is outside on the surface and then it is to be placed with epoxy.

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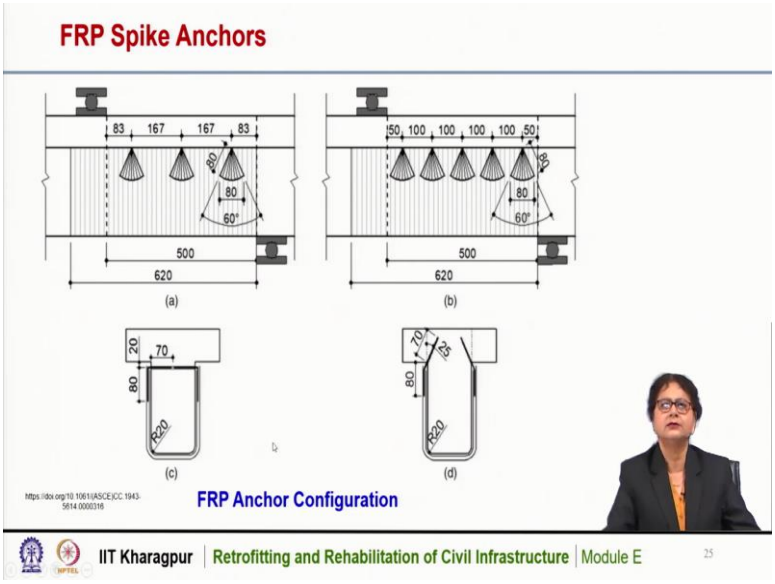

These are some more diagrams of the FRP spike anchors. We can see here that on this member when it is strengthened with this FRP and this type of different spikes are used. So, the angle of this fan can be of different and the spacing also is different depending on the type of structure and the FRP.

So, here we can see that the center-to-center distance between the two FRP anchor is 167 millimetre, whereas here it is 100 millimetre depending on the type of structure and the length of the member. And here is the cross-sectional view of the members. And you can see that these type of FRP anchors also can be of different angles so we can insert the dowel at different angles as well.

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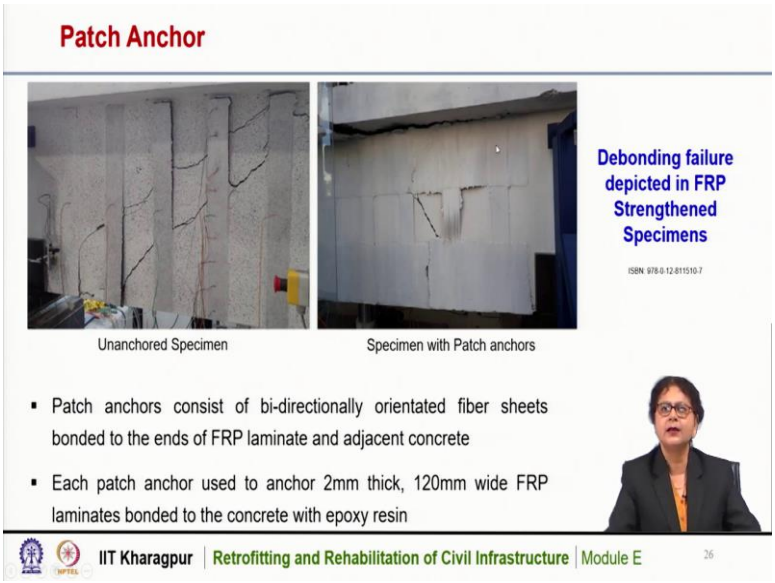

This is patch anchor. Here in Patch anchor, it consists of bidirectionally oriented fiber sheets bonded to the ends of FRP laminate and adjacent concrete. So, patch anchors consist of bidirectionally oriented fibers and they are like a small sheet. Each patch anchor used to anchor 2-millimetre-thick 120-millimetre-wide FRP laminates bonded to the concrete with epoxy resin. This is approximate dimension.

Here in this diagram, we can see that this is an unanchored specimen, the beam member is strengthened with FRP strips for shear strengthening, we can see here that the FRP strips are provided intermittently. And this is a typical shear crack that has been developed on the member and there is debonding, we can see here that debonding at the end is clearly observed. And here this specimen is with patch anchor.

So, these are the intermittent FRP strips that are provided to improve its shear capacity. And these are the patch anchors, these are the patch anchors with bidirectional fibers and they are provided at this end and also at this end. So, significantly the debonding type of distress is reduced particularly at the ends. And the failure is also delayed due to the installation of this patch anchor.

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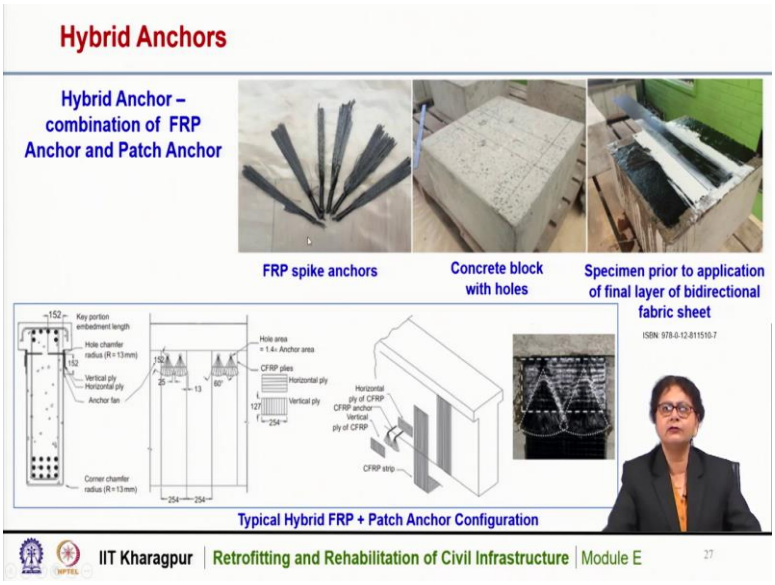

This is a hybrid anchor. And it is actually a combination of FRP anchor and patch anchor. So, here is the FRP anchor with these spikes or fans and dowels. So, this is the FRP anchor and along with this we can use patch anchor. So, this is a concrete block and here first this type of FRP anchor is placed for improving the bond between the FRP laminate and the concrete.

So, these FRP anchors are then provided on the FRP strips. So, here we can see that these are the FRP anchors that are provided on the FRP strips of the member, the specimen prior to application of final layer of bidirectional patch anchor. So, first the FRP anchors with spikes are to be placed and then we can place the patch anchor over it.

So, here we can see that this is the fan's location and over it the patch anchor is to be placed so that the bond is achieved. So, these are the diagrams we can see that it is schematically shown that this type of FRP anchors are provided and this is the type of patch anchors. So, it consists of bidirectional fibers and that is to be placed on this portion. So, this is the hybrid anchor which consists of FRP anchors and patch anchors.

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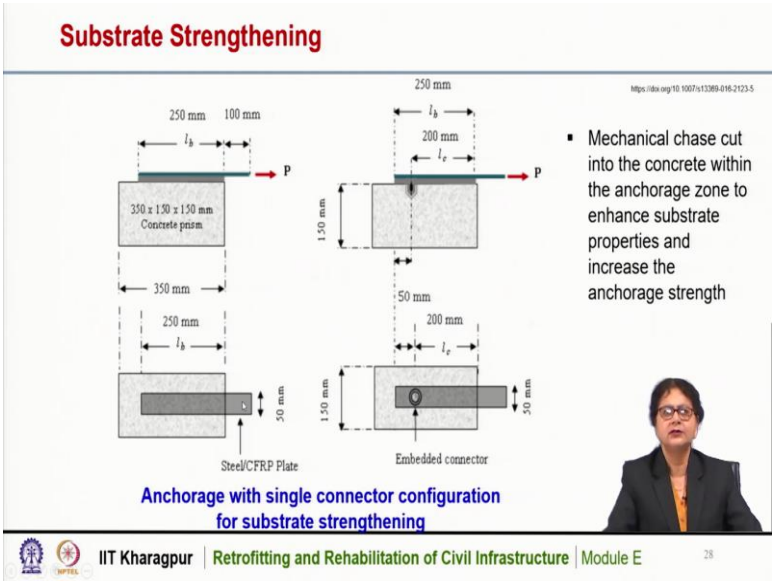

Then comes the substrate strengthening. Here, we can see that this is a concrete prism and over it FRP strip for improving its shear capacity. So, sometimes if the bond length is inadequate, we can provide this type of connectors. So, this is the plan view of the member with FRP strip or plate. And if proper bond length is not available, then we can use these embedded connectors.

So, this type of embedded connector can be used and that improves the bond between the substrate and the FRP. So, this is substrate strengthening. Mechanical chase cut into the concrete and within the anchorage zone to enhance the substrate properties and increase the anchorage strength. So, by providing this type of embedded connector, the bond between the FRP and the concrete is improved.

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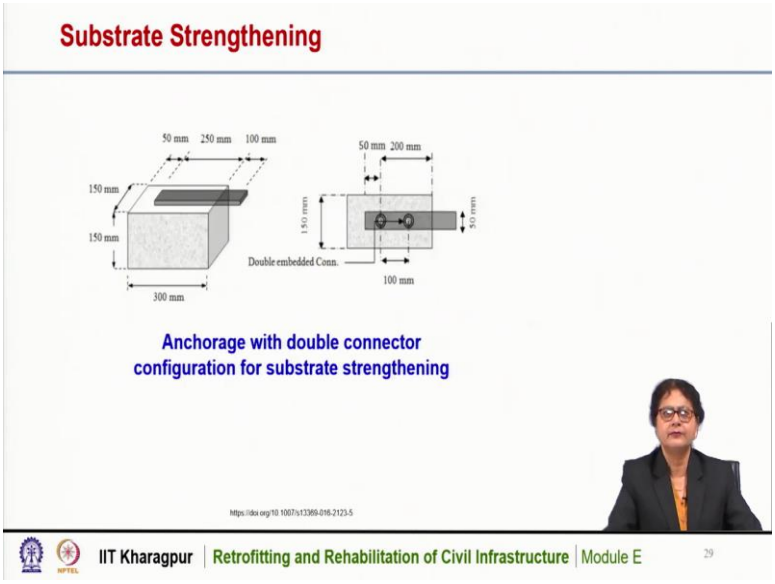

This is another picture with double connectors. So, we can use single connector or double connector depending on the type of structure and the amount of FRP to be provided.

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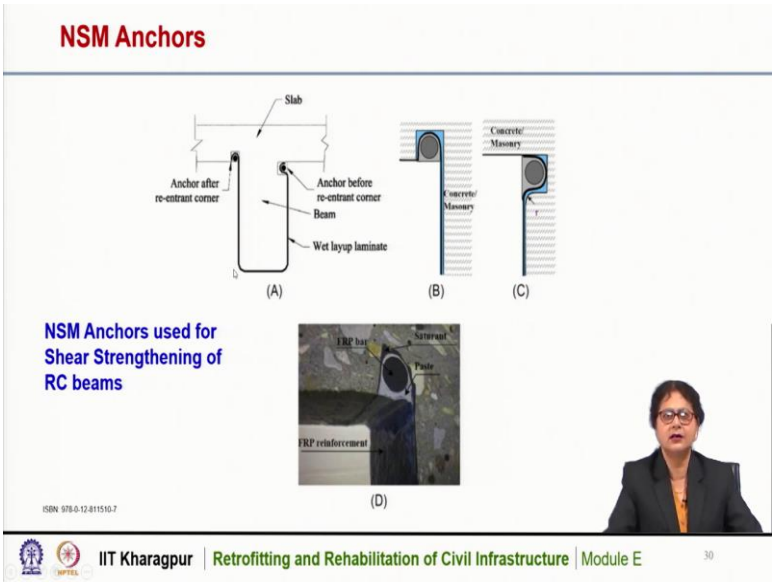

NSM anchors are also used. We have discussed that NSM is also used for improving the flexural capacity or the shear capacity. So, here in this diagram, it is shown that the NSM reinforcement has been used for improving the shear capacity and this is a typical U-wrap NSM that is used. And here also, we can provide NSM anchors, so that the bond between the NSM and the concrete substrate is improved.

So, this we can see that this is the NSM and this way the anchorage can be done or it can be done like this. So, these are the different diagrams and figures, which shows that NSM bars

also can be placed with proper anchorages for improving the bond between the NSM and concrete in shear strengthening of members.

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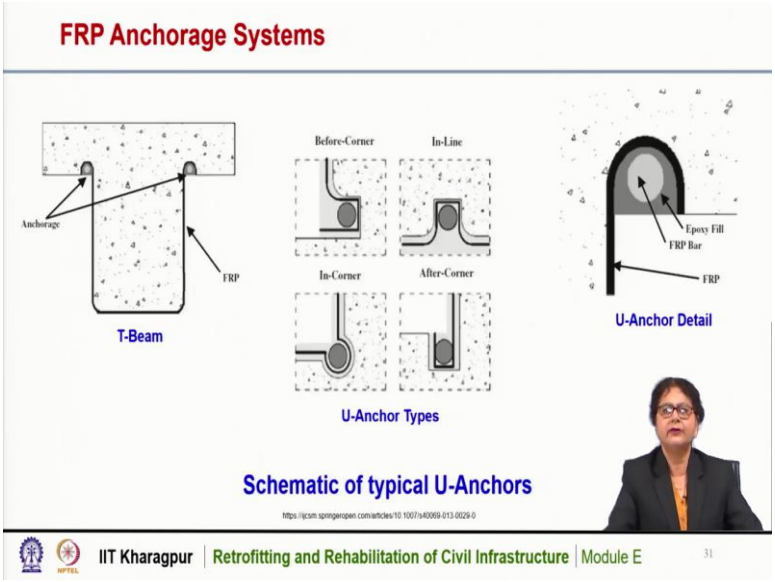

These are the different other types of U-anchors. We can see here that this is a typical FRP strip or NSM. And this type of anchorage is used for improving the bond and that type of anchorage may be of different shapes and configuration, we can see here that may be round or that may be of non-circular section with different dimension depending on the type of structure and its geometry.

So, these are u-anchor types, different types of U-anchors, and these are the FRP rods that are used. So, and this is the U-anchor detail. So, this is the FRP member that is provided and this is the FRP bar and this is filled with epoxy. So, this is the U-anchor detail and these are the different configurations of U-anchors that are used on different concrete members depending on the type of structure and the anchorage that is required.

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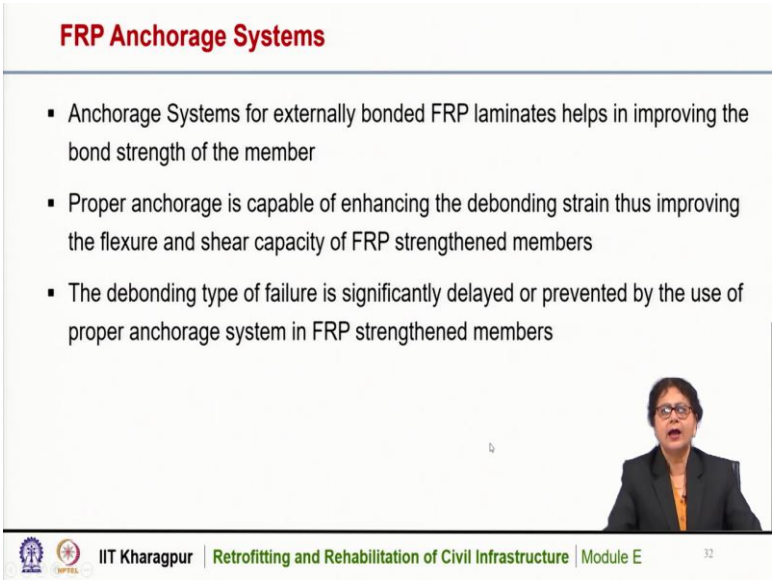

So, anchorage systems are used for externally bonded FRP laminates and it helps in improving the bond strength of the member. By proper anchorage, the member is capable of enhancing the demanding strain, thus improving the flexure and shear capacity of FRP strengthen members. So, the proper anchorage can improve the flexural and shear capacity of FRP strengthened members. The debonding type of failure is significantly delayed or prevented by the use of proper anchorage system in FRP strengthened members.

So, anchorage is recently being used in many of the FRP strengthened members to improve the bond between FRP and concrete. And this type of anchorage actually delays the debonding type of failure, and thus the capacity of the FRP strengthened members also increased. However, more investigations need to be carried out to understand completely the behaviour of anchored system of a FRP retrofitted members.

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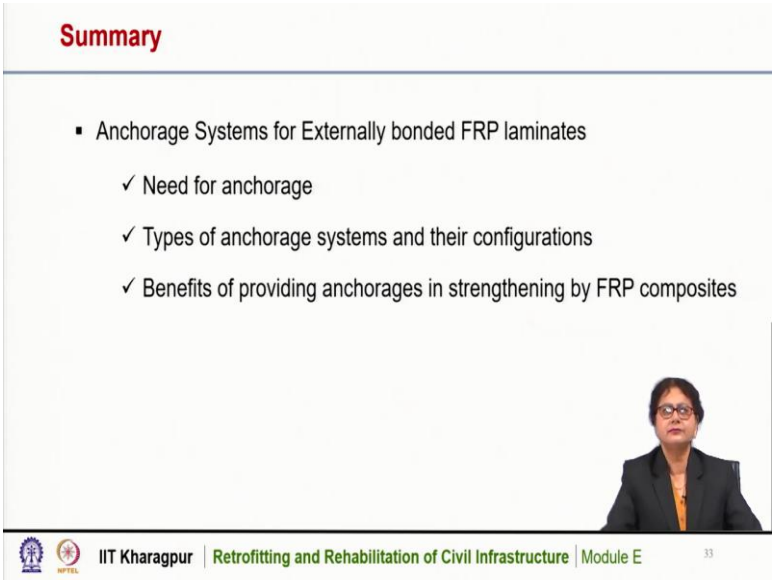

So, to summarize, we have discussed today the anchorage systems for externally bonded FRP laminates. We have discussed the need for anchorage, the types of anchorage systems and the different configurations. And what are the benefits of providing anchorages in strengthening by FRP composites. We have discussed that the anchoring systems are used for members which are strengthened for flexural and shear capacity improvement. So, different types of anchorages are used for different purposes.

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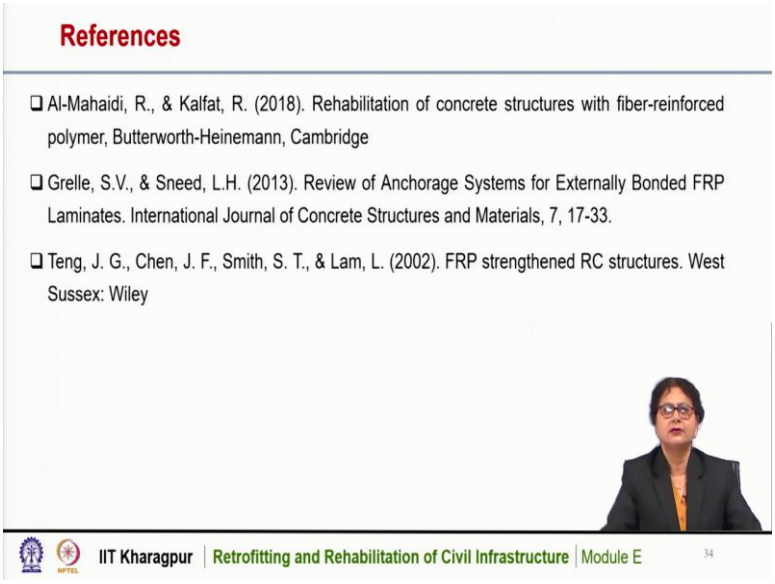

These are the reference for today's lecture. Thank you.