Retrofitting and Rehabilitation of Civil Infrastructure

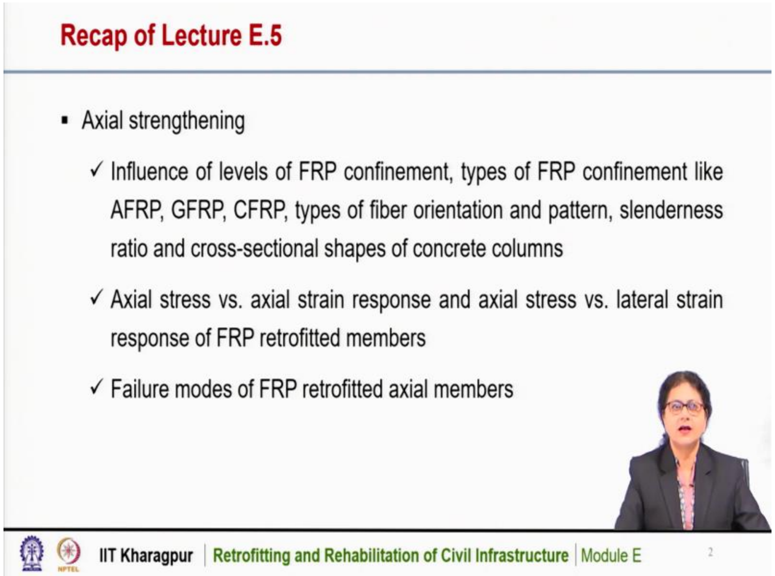
Professor Swati Maitra
Ranbir and Chitra Gupta School of Infrastructure Design and Management
Indian Institute of Technology, Kharagpur

Lecture 28

Near Surface Mounted FRP Reinforcement

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.

(Refer Slide Time: 00:44)



In the previous lecture, we have discussed Axial strengthening of existing structural members, we have discussed the influence of different parameters on the response of the FRP retrofitted members, the influence of levels of FRP confinement, the types of FRP confinement like AFRP, GFRP or CFRP. The influence of types of fiber orientation and pattern, the concrete parameters that is slenderness ratios and cross-sectional shapes of the columns were also discussed. We have discussed the responses in terms of axial stress versus axial strain and axial stress versus lateral strain of the FRP retrofitted column members. We have also discussed the failure modes of FRP retrofitted axial members under those parameters.

(Refer Slide Time: 01:45)

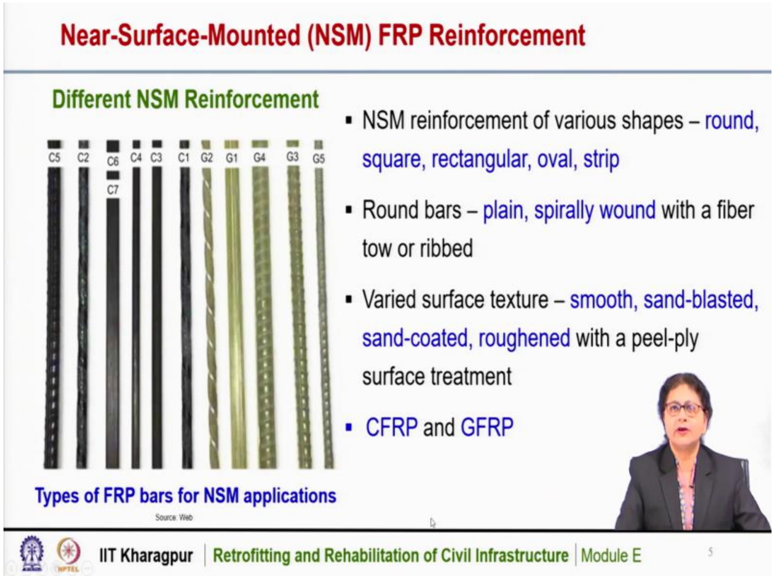
Today, we will discuss another type of strengthening measures using FRP, that is near surface mounted FRP reinforcement in strengthening of existing structural members.

(Refer Slide Time: 02:01)

Near surface mounted technique is suitable for improving the flexural and shear strengthening of existing structural members. The technique is successfully used for many years with conventional steel reinforcement, and now, it is used with FRP reinforcement. In this technique, the grooves are cut into the concrete cover of reinforced concrete members. And then, FRP reinforcement is bonded, they are in with an appropriate groove filler. The groove filler is generally epoxy based or cement grout.

The technique involves cutting a shallow groove in the surface of the member in the cover and then cleaning the groove, after that installation of FRP reinforcing bar or strip or plate and then levelling the surface. So, here in this technique, we cut a groove of suitable depth, within the cover of the reinforced concrete member and then the groove is cleaned and after that, FRP bar or strip or plate is installed, and then it is filled up with epoxy paste for proper bonding and then levelling the surface. So, this is the technique and this is a typical picture of saw cutting of groove for placing the NSM reinforcement. So, NSM is also a technique for improving the flexural and shear capacity of existing members.

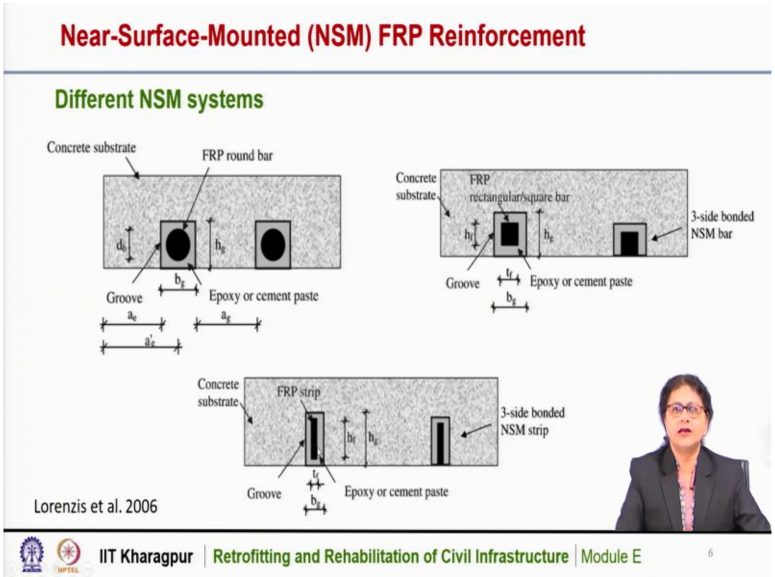
(Refer Slide Time: 03:47)



There are different types of NSM reinforcement that are used for this purpose. NSM reinforcement maybe of various shapes, round, square, rectangular oval or strip. So, mostly the round bars are available, but we can also use square bars or rectangular bars, even strips or if FRP plates can be used as NSM reinforcement. Here is the typical picture of the different types of FRP bars for NSM applications.

The round bars are generally plain or it may be spirally wound with the fiber toe or ribbed. The square or rectangular bars generally are plain. The surface texture may be varied, it may be smooth, or sandblasted or sand coated or roughened with a peel ply surface treatment. This is required for proper bonding of the FRP with the concrete substrate. The FRP reinforcement bars are generally made up of CFRP or GFRP, that is carbon fiber reinforced polymer composites or glass fiber reinforced polymer composites. These two FRPs are generally used for NSM reinforcement.

(Refer Slide Time: 05:13)

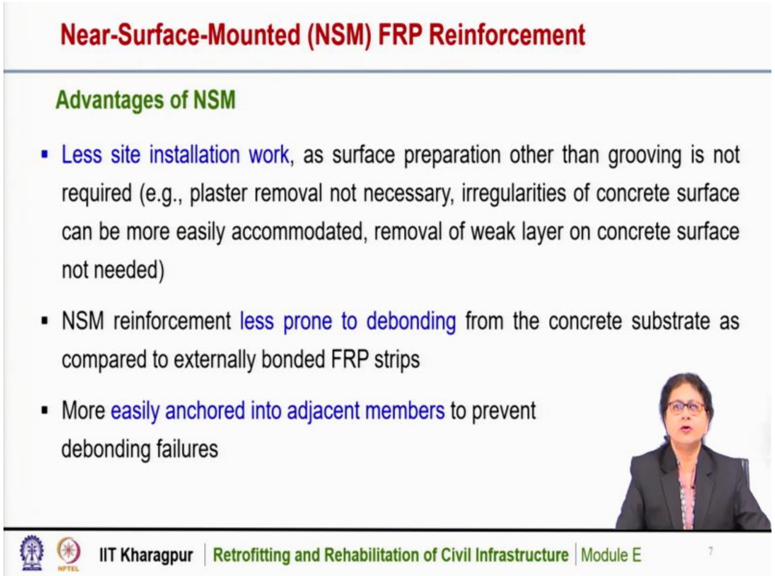


There will be different NSM configurations or systems. Here are the schematic diagrams of different NSM system, we can see here that this is a concrete substrate, that existing member and this is the cover and a small groove is cut on the cover and then we can place the NSM bar into it. So, this is the groove, that may be of definite dimension and then it is to be cleaned and epoxy paste or cement paste is to be inserted and the bars are then installed. So, this is a round bar that is placed within this groove. So, these are the typical sketch of NSM round bars when it is placed in a concrete substrate.

The NSM bar may be placed in one number or two number or even more depending on the dimension of the concrete member. Here this schematic diagram shows that square bars are used. So, here the square bars are placed within this groove we can see here this is the groove and this is the square bar or rectangular bar is placed here in this groove. It may be placed with epoxy or cement grout all around the bar or it may be three sided. The epoxy or cement grout may be placed three sided or all around the bar.

FRP strip can also be used as NSM reinforcement. We can see here that this is the FRP strip that is placed within this groove. This is also FRP strip placed within this groove and here also the epoxy material may be placed around this strip or it may be placed on three sides of this strip. So, these are the typical NSM configurations that are used for improving the flexural or shear capacity of the members.

(Refer Slide Time: 07:30)



There are several advantages of NSM. NSM was not used earlier so much. But nowadays, more interests are growing on NSM because it has several advantages. The advantages that it has less site installation work as surface preparation other than grooving is not required. Even the plaster is not required to be removed, irregularities of concrete surface can be more easily accommodated, removal of weak layer on concrete surface also not needed. So, there are several advantages we need not do much surface preparation other than preparing a groove on the surface. So, less site installation work.

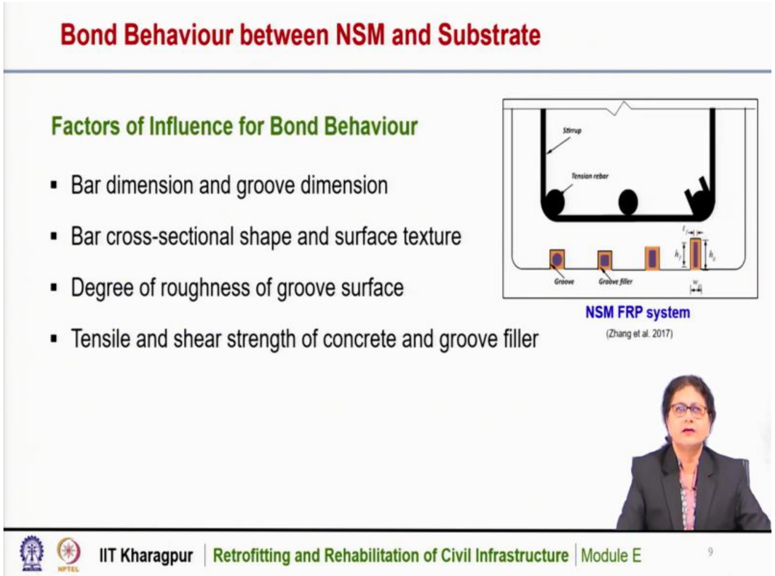
NSM reinforcements are less prone to debonding from the concrete surface as compared to externally bonded FRP strips. As compared to the externally bonded FRP strips, NSM reinforcements are less prone to debonding. Though debonding occurs in case of NSM reinforcement, but the chances are much less as compared to externally bonded FRP strips. NSM is more easily anchored into adjacent members to prevent debonding failures. So, sometimes proper anchorages are used so, that debonding failure is minimized. So, that can be done much easily in case of NSM.

(Refer Slide Time: 09:07)

NSM reinforcements are more easily pre-stressed. So, this is also another advantage for NSM, retrofitted members. NSM bars are protected by the concrete cover and so, are less exposed to accidental impact and mechanical damages, fire etcetera. Since they are covered with some amount of epoxy or cement grouting. So, they are not exposed like the strips placed on the existing members.

Less time is required for the erection at site because it does not require much surface preparation. So, overall time required is less. The aesthetic virtually is unchanged of the strengthened members. So, here since only very fine groove are made and on that, NSM bars are placed and then it is filled up or covered. So, there is very little change in the aesthetics of the member.

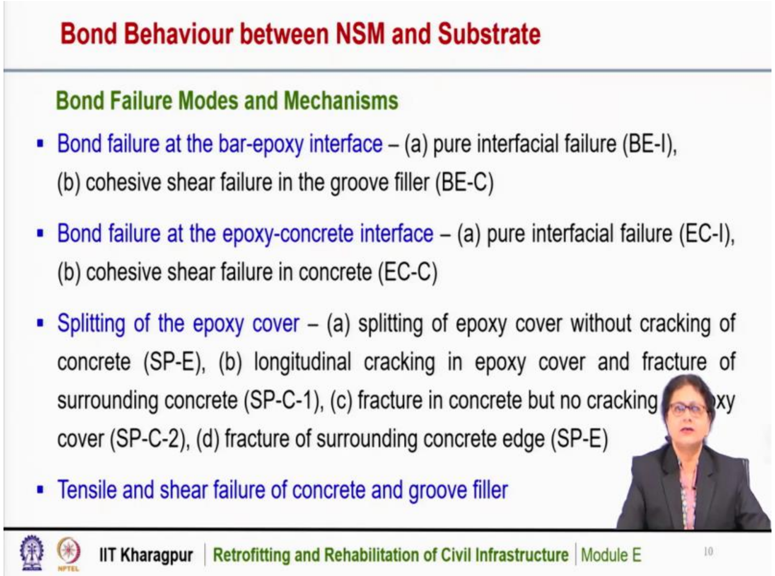
(Refer Slide Time: 10:12)



Now, it is important that, there should be proper bonding between the NSM FRP reinforcement and the concrete surface. So, this is a typical diagram of NSM FRP system, we can see here that this is a concrete member with the existing steel reinforcement and the stirrups and this is the covered. So, there are different types of NSM FRP system as we have shown earlier that the bars could be rounded or square or rectangular or even strips. So, depending on the dimensions of the NSM bar, the grooves also have different dimensions.

So, as we have seen here in this schematic diagram, the dimensions of the groove depend on the strip or the round bar or rectangular bar. There are several factors that influence the bond behaviour of the NSM FRP bar and the concrete. The influencing factors are bar dimension and groove dimension, bar cross sectional shape and surface texture, degree of roughness of the groove surface and tensile and shear strength of concrete and groove filler. So, these are the influencing factor depending on which the bond behaviour of the NSM FRP system depends. So, this we will discuss in detail.

(Refer Slide Time: 11:51)



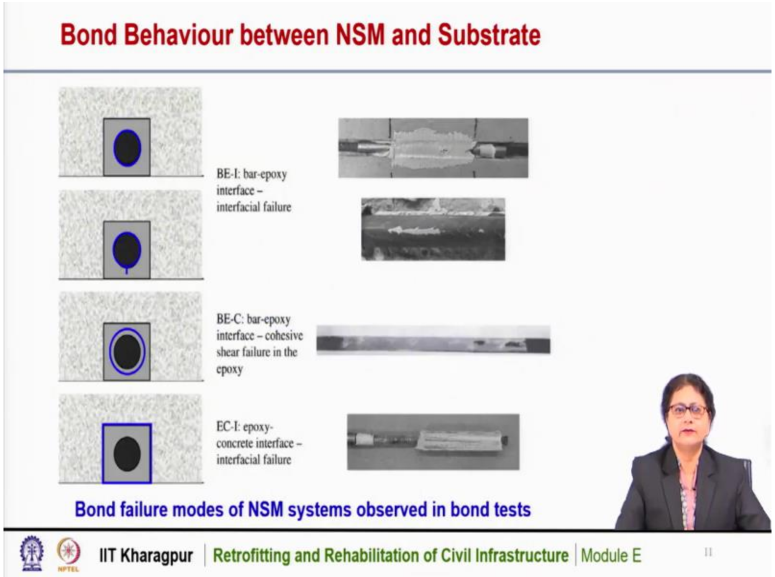
In case of NSM FRP system, there may be bond failure and that bond failure may be of different types. The bond failure may be at the bar epoxy interface, the FRP bars are placed within the groove and epoxy is generally placed as a groove filler. So, there may be a bond failure at the bar epoxy interface and that may be of two types, one is pure interfacial failure and another is cohesive shear failure in the groove. So, there may be a bond failure at the bar and epoxy interface. The bond failure may be at epoxy concrete interface.

So, that is also another region where there may be a bond failure and the epoxy concrete interface, there may be pure interfacial failure or cohesive shear failure in concrete. So, here also there may be two types of bond failure at the epoxy concrete interface one is pure interfacial failure and the other is cohesive shear failure in the concrete.

The bond failure may be due to splitting of the epoxy cover. That may be of different types. Splitting of epoxy cover without cracking of concrete. So, that is one time another type, another type is longitudinal cracking in the epoxy cover and fracture of surrounding concrete. The another one is fracture in the concrete but no cracking in the epoxy cover and the other one is fracture of the surrounding concrete edge.

So, in this type of bond failure, there is splitting of the epoxy cover. That splitting maybe without cracking of the concrete. So, splitting of epoxy cover without cracking of concrete. Another one is longitudinal cracking of the epoxy cover and then the surrounding concrete may fracture. Another type is fracture of concrete but no cracking in the epoxy and other one is fracture of the surrounding concrete edge. There may be another type of bond failure that is tensile and shear failure of concrete and groove filler. So, these are the different types of bond failure that may occur in case of NSM system.

(Refer Slide Time: 14:16)

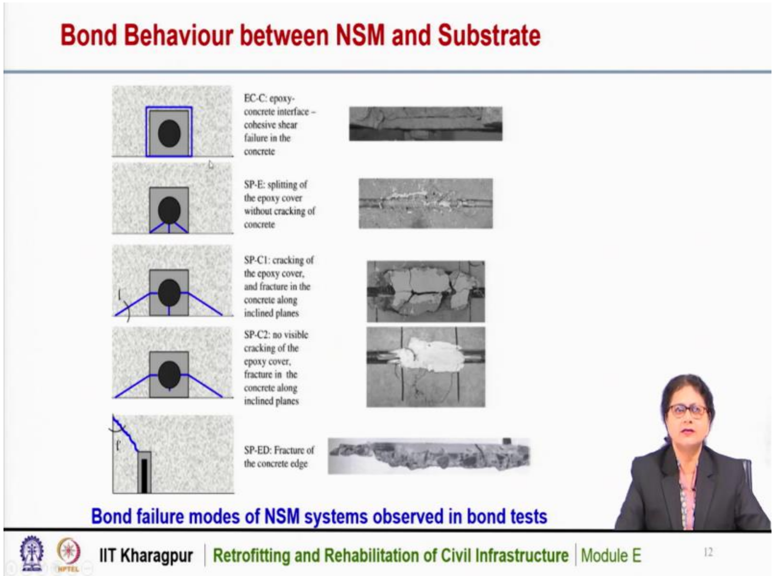


These are the schematic diagrams of the different types of bond failures of NSM system as observed from different bond tests. We have seen that, in this picture, this is the bar epoxy interface. So, this is interface failure and that is at the bar epoxy interface. So, we can see here that this is the groove and within the groove there is epoxy and this is the FRP bar. So, the interface may fail at the bar epoxy interface. So, this is the bar epoxy interface. Here this is also a debonding type of failure.

But here it is the bar epoxy interface due to the cohesive shear failure in the epoxy. So, the epoxy may fail in shear at this location. So, this is also interface, this is due to cohesive shear failure in the epoxy and this is another type of debonding failure. This is epoxy concrete interface. So, this is also interfacial failure, but it is an interface of concrete.

So, this is concrete and this is the epoxy. So, it is at the interface of epoxy and concrete and these are the typical pictures of these types of failure, interface failure, different types of interface failure, at the bar epoxy interface or the cohesive shear failure in the epoxy or the interface failure at the epoxy concrete interface.

(Refer Slide Time: 15:54)

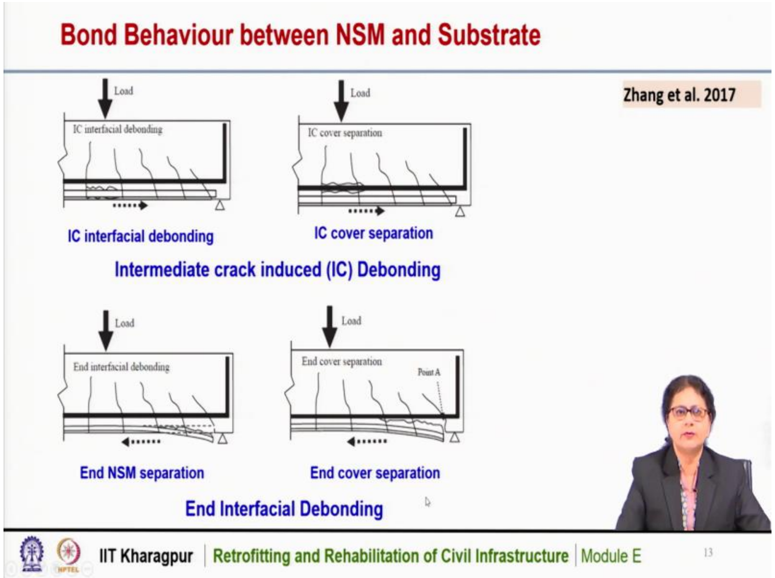


These are other types of bond failure, we can see here that this is the epoxy concrete interface failure, this is due to cohesive shear failure in the concrete. So, in the concrete, at these locations the concrete fails in shear at the interface of the concrete and epoxy, this is splitting of the epoxy cover without cracking of concrete. So, here these types of cracks appeared in the epoxy. So, the splitting of the epoxy cover occurs without cracking of the concrete. So, concrete there is no cracking.

This is another type, that is cracking of the epoxy cover and fracture in the concrete along the inclined planes. So, here cracking of the epoxy as well as cracking of the concrete, fracture of the concrete along these inclined planes. And here in this case there is splitting of covere but there is no visible cracking on the epoxy cover, but fracture in the concrete along the inclined plane. So, here the concrete fracture along these plains, but there is no cracking in the epoxy.

So, splitting of cover may occur and this is fracture of the concrete at the edge. So, here also this type of cracking may occur and that may cause bond failure of the NSM system. And these are the typical pictures of these different types of debonding. So, this is due to the cohesive shear failure in the concrete, this is due to the splitting of the epoxy cover, this is due to the fracture in the concrete and this is also due to the fracture of the concrete and this is due to the fracture of the concrete and the edge. So, these are the different bond failure modes of NSM system as observed from different bond tests.

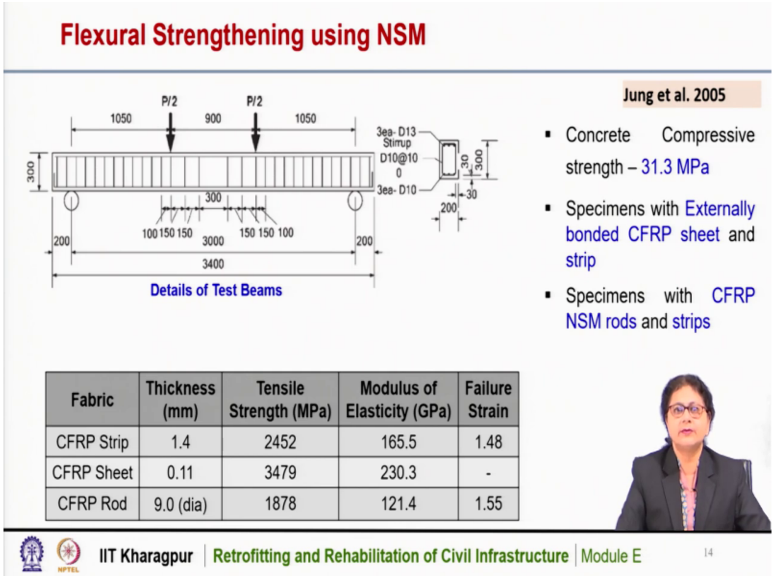
(Refer Slide Time: 17:58)



These are other views of the different types of debonding failure. This is the intermediate crack induced debonding, we can see here that this type of interfacial failure or debonding type of failure occurs. So, this is the reinforcement and this is the NSM and there may be interfacial failure at the NSM and epoxy at this interface. This is also debonding type of failure at the interface we can see here, that the concrete and the epoxy at this interface it fails. So, there is cover separation due to this type of debonding.

This is end NSM separation here and this is near the support and due to the interfacial debonding near the support the NSM separates at the edge. So, we can see here that there is separation of the NSM bar at the edge due to interfacial debonding. And here is also another type of interfacial debonding and this is due to the cover splitting or separation, that is also at the end and this is the epoxy and the concrete interface and the cover separates here. So, these are the different types of interfacial debonding that may occur in case of a NSM system.

(Refer Slide Time: 19:38)



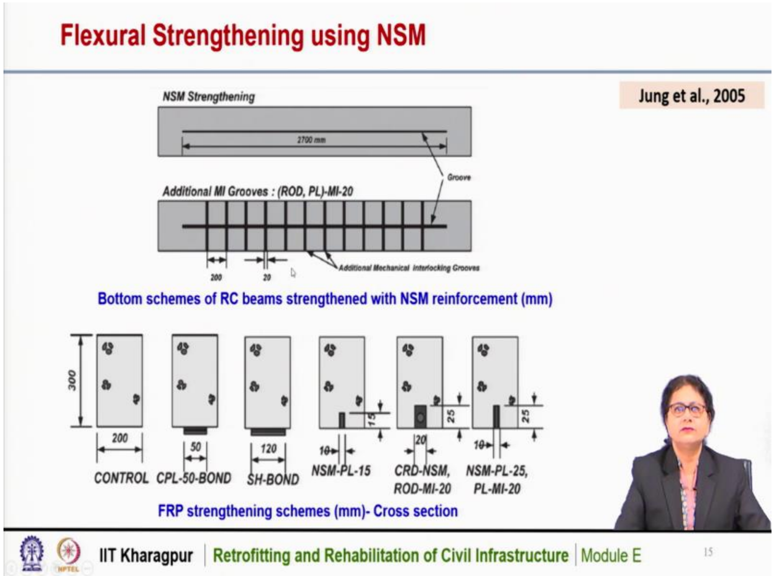
Now, there are different types of investigations on NSM and recently different types of investigations have been done to understand the complex behaviour of the NSM system. So, NSM is an efficient technique for improving the flexural capacity of the members to understand the different parameters on the load displacement responses of the NSM strengthen members, different experiments and analytical works have been done by the researchers.

In this research, a number of concrete beams have been tested. The strength of concrete was 31.3 MPa and the dimensions are given. The cross-sectional dimension of the beams were 200 × 300 millimetre and the length also is given here, it is approximately 3 meter and in this beam different types of strengthening system has been done. So, specimens were strengthened with externally bonded CFRP sheet and strips and also with CFRP NSM rods and strips.

This has been done to compare the responses of the externally bonded system with the NSM system and different types of CFRP strips and sheets have been used. So, we can see here these are the properties of the FRP reinforcement. The properties of CFRP strips are given here which is of thickness 1.4 millimetre having tensile strength of 2452 MPa whereas, the CFRP sheet having a thickness of 0.11 millimetre and the tensile strength is 3479 MPa.

The CFRP rod is also used as NSM and that is of diameter 9 millimetre and tensile strength of 1878 MPa. Other properties are also given here. So, a number of beams were tested and strengthened with CFRP strips or CFRP sheet as externally bonded reinforcement or as NSM with CFRP rod.

(Refer Slide Time: 22:09)

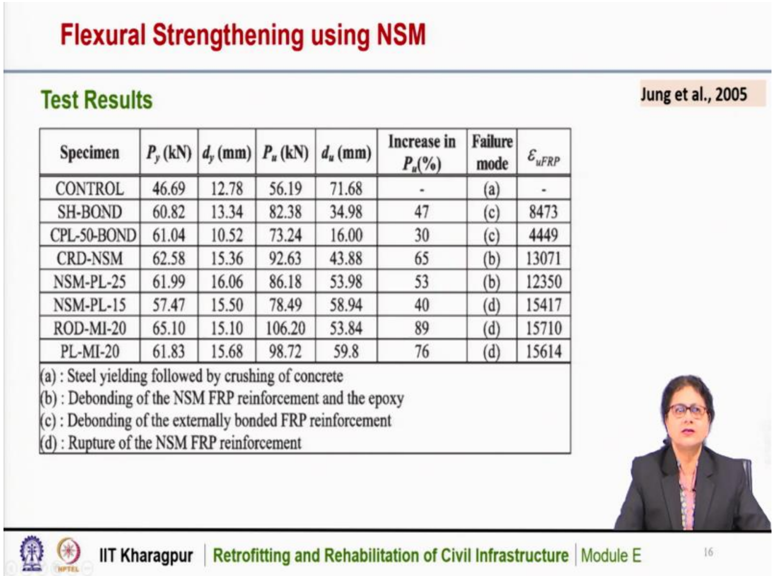


These are the schematic diagrams of the different strengthening systems. This is the bottom surface of the beams strengthen with NSM reinforcement. So, in some cases, for the strips, only one NSM rod or strip is used and in some cases there is an additional anchorage that is used for better bonding. So, additional grooves are cut and these NSM bars are placed with Anchorage. So, that improves the bonding between the NSM and the concrete substrate and some system is having without any Anchorage System.

So, that is also done. So, here this is the control specimen, that is without any FRP reinforcement. This is a system with FRP strips, externally bonded FRP strip, all dimensions are same for the beams and this is the beam with CFRP sheet as externally bonded reinforcement. This is beam retrofitted with NSM and here there is no Anchorage.

So, this system has only one NSM reinforcement and it has no anchorage. This is a beam strengthened with NSM and this has anchorage like this and this is also an NSM strip with Anchorage. So, these are the different NSM system that has been tested to see the responses of the FRP retrofitted members.

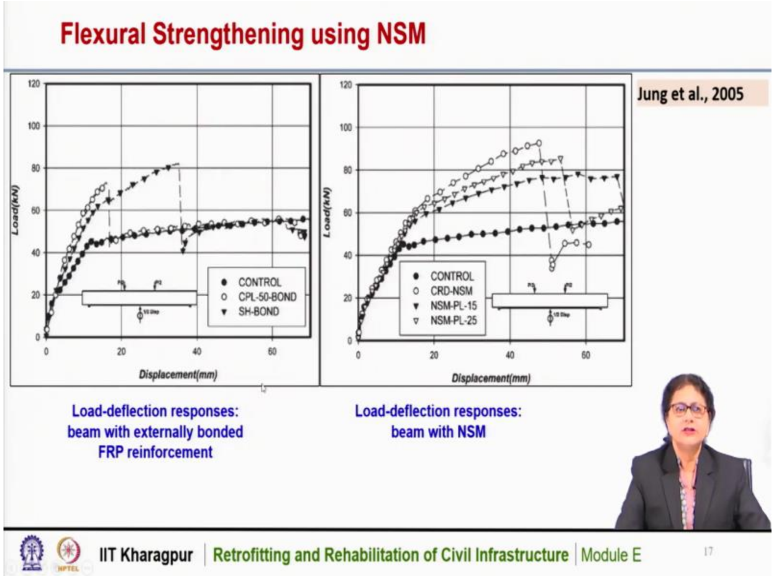
(Refer Slide Time: 24:03)



These are the test results for control beam for externally bonded beams. These two are externally bonded beams and these are the NSM retrofitted beams. So, here we see that this is the ultimate load for the beams. We can see here that for all the beams which are retrofitted with FRP either externally bonded or with NSM, the strength increase is significant as compared to the control beam. So, for the control beam, the ultimate strength is 56 kilo newton whereas, for the FRP retrofitted beams, they are much higher and these are the improvement in percentage.

So, there is a significant improvement in the ultimate load capacity of the members due to FRP reinforcement. And the strain is also significant in all these cases. Now, we can see that these are the responses of the externally bonded members and these are the responses of the NSM retrofitted members. So, we can see that the NSM retrofitted members show higher strength as compared to the externally bonded members. So, this shows that the NSM system is much effective as compared to the externally bonded system.

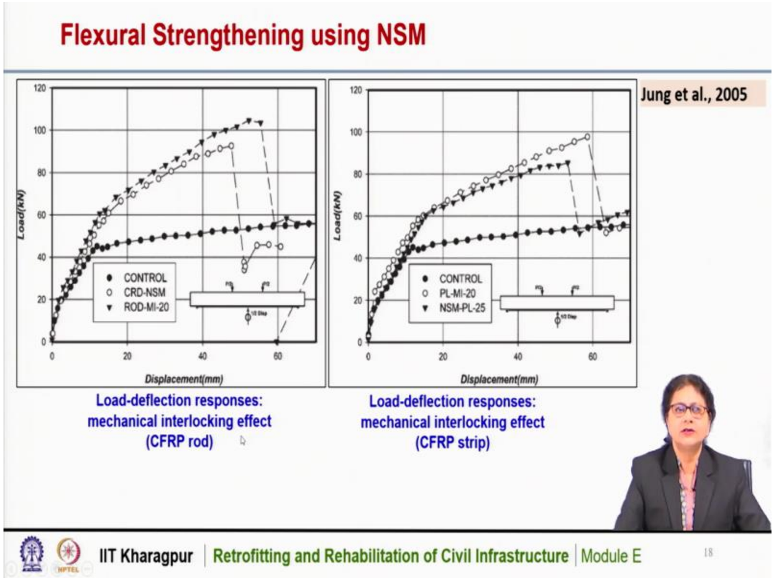
(Refer Slide Time: 25:40)



These are the load deflection responses of the beams with externally bonded FRP reinforcement. This is the response of the control beam and these are the responses of the externally bonded members. So, we can see here that as we have seen earlier also that there is a significant improvement of the load carrying capacity of the externally bonded beams as compared to the control beams. However, the strain or the displacement at failure is much smaller. In this case, this is the load displacement response of the beams retrofitted with NSM. So, here also we can see that there is a significant improvement of the load carrying capacity of the NSM retrofitted members.

So, this is the response of the control beam and these are the responses of the NSM retrofitted beam. So, these are the NSM retrofitted beams and these two are with anchorages. So, here it shows that there is a significant improvement in the load carrying capacity of the members, but the displacement is less as compared to the control beam. So, the strain at failure is much less as compared to the control beam. So, the ductility is less as compared to the control beam in case of NSM system or externally bonded system.

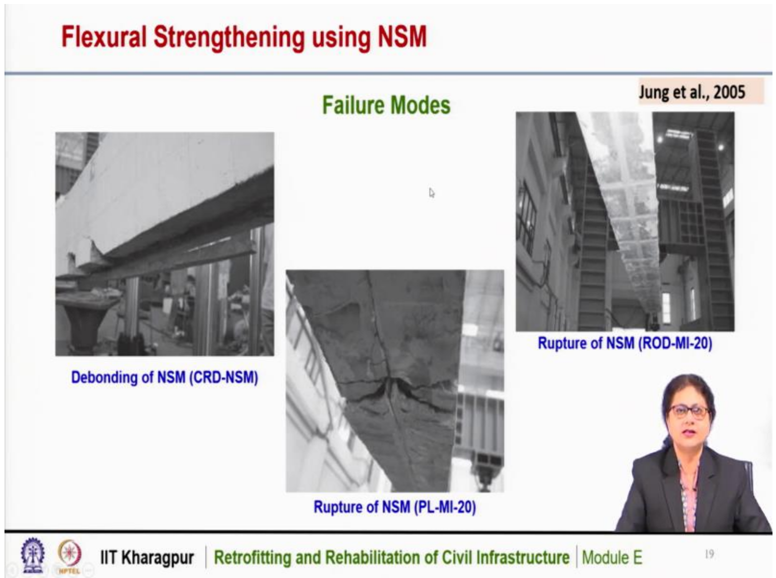
(Refer Slide Time: 27:13)



Here is the load displacement response and the effect of mechanical interlocking effects. So, here this shows that this is the control beam and these are the responses of the NSM beams which have anchorages. So, here it shows that when there is anchorages, the improvement is higher and also the displacement at failure is improved. So, this shows that the proficient of mechanical anchorage improves the bonding between the NSM and the concrete substrate. This is the load deflection response of the mechanical interlocking effect of CFRP strips.

So, here also we can see that there is a significant improvement not only in the load, but also of the strain at failure or the displacement at failure. So, the NSM system can be an effective system for improving the strength of the members and the anchorage system helps in improving the bonding between the NSM and the concrete substrate.

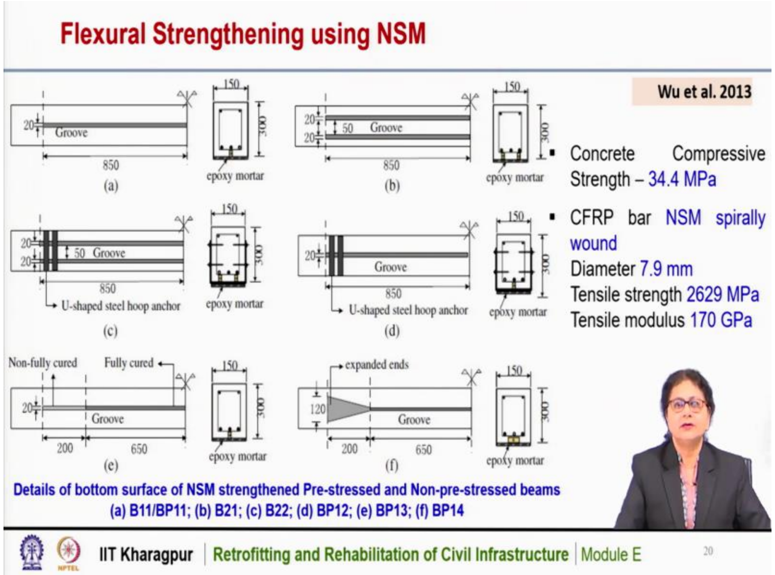
(Refer Slide Time: 28:28)



These are the failure modes of the beams that are tested by these experiments by the researcher Jung et al., in 2005. Here it shows that there is debonding of the NSM. This is without Anchorage System. So, here the NSM bars were placed and with increasing load the beam fails due to debonding of the NSM. So, clearly it is shown that there is debonding of the NSM bars. The system with anchorages, the NSM with anchorages here the failure was due to rupture of the NSM.

So, here in these cases in these two cases where there are anchorages the bonding has been improved. So, finally, the beams failed due to the rupture of the FRP. So, here it shows that there is rupture of the NSM or the FRP strips and here also there is rupture of the FRP strips at the bottom. So, here the anchoring system helps in improving the bond between the concrete and the NSM. So, the failure is due to the rupture of the FRP.

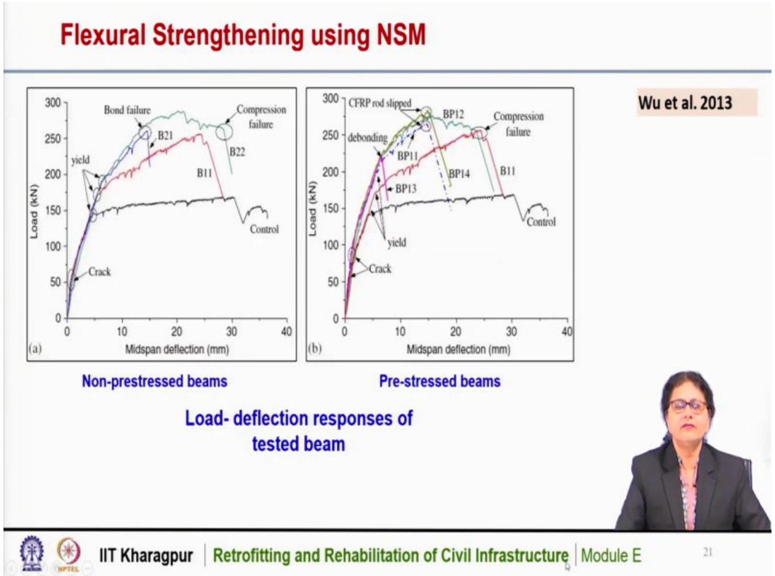
(Refer Slide Time: 29:52)



In this experiment, there are different types of NSM system or configuration have been explored. Here, the beams were pre-stressed as well as non-prestressed. The concrete compressive strength was 34 MPa and CFRP bars were used as NSM and those bars were spirally wound, the diameter of the CFRP bars were 7.9 millimetre and the tensile strength was 2629 MPa. The tensile modulus is also given here 170 GPA. So, these are the different types of NSM strengthen beams this is the groove that is made here. It is one single groove and one single CFRP bar is used, whereas, here it is two bars as NSM has been used.

And here also some two strips of CFRP are used and here also it is like this. And some of the systems are pre-stressed. These are the notations of the tested beams. The notation with P indicates that these beams are prestressed the others are non-prestressed and the first numeral indicates that the number of NSMs. So, here this shows that this is B11 that is the beam which is non-prestressed and one NSM. Similarly, this beam has two NSM b2 and 1 this is also non-prestress. So, similarly, the other notations have been used and these are the cross sections and this is the CFRP bar that is used as NSM.

(Refer Slide Time: 31:58)



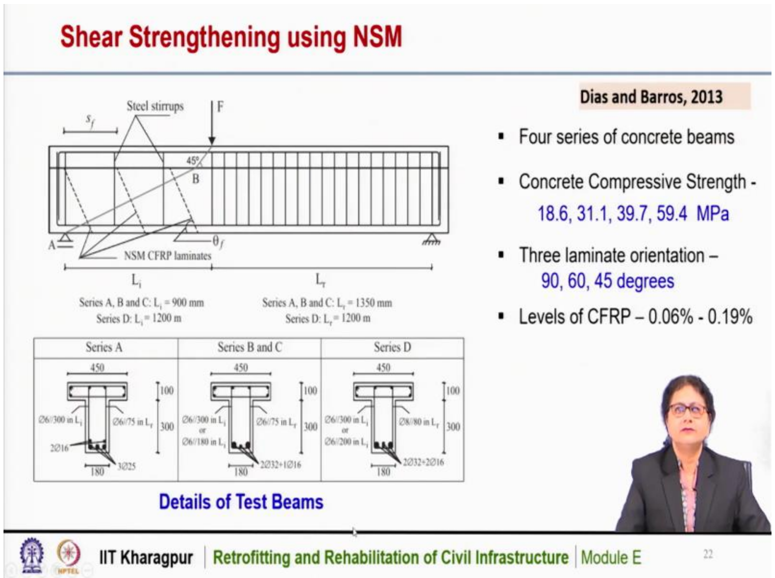
These are the responses of the tested beams; this is for non-prestressed beams and this is for prestressed beams. So, this plot shows that this is the response of the control beam and these are the responses of the non-prestressed beam. So, in all cases, it has been seen that there is a significant improvement of the load carrying capacity of the NSM strengthen beams, we can see here that there is a significant improvement as compared to the control beam.

However, some beams fail due to bond failure. Though the strength is much higher, but it fails due to bond failure. Whereas, in case of these beams there is no bond failure because of the NSM and here it fails due to concrete crushing or compression failure of the concrete.

So, these are the responses of the NSM retrofitted beams. These are non-prestressed and here in these locations the steel may have yielded, but still it is capable of taking higher load and ultimately some being failed due to bond failure and some due to compression failure. These are the responses of the prestressed beam. We can see that there is a significant improvement of the prestressed beam, which are retrofitted with NSM. This is the response of the control beam and this is the response of the prestressed NSM retrofitting beam.

So, here also we can see that there is a significant improvement in the load carrying capacity of the NSM retrofitted beams. The beams failed due to debonding or due to rod slippage or due to compression failure of the concrete. There is a significant improvement in the load carrying capacity beyond the yield point you can see here these are the locations where the steel yielded, but is able to take up higher loading. So, with NSM retrofitting, the beams both non-prestressed and prestressed are capable of carrying higher load.

(Refer Slide Time: 34:29)

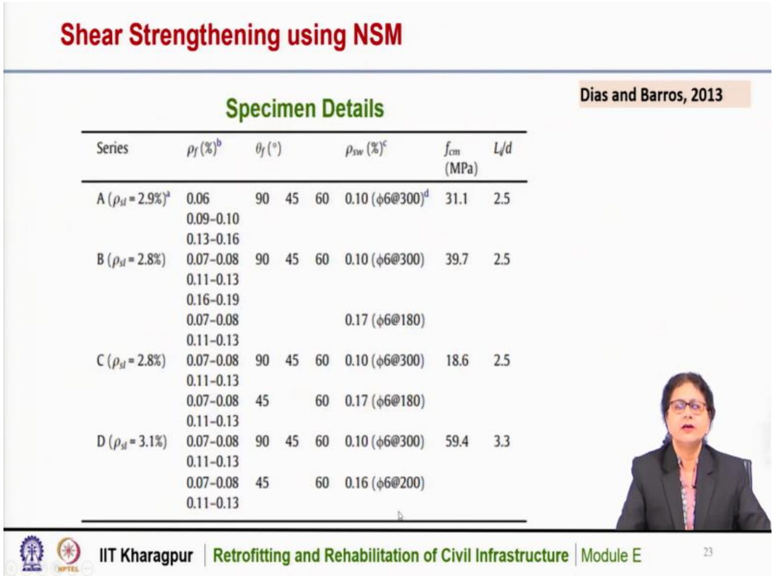


Dias and Barros in 2013 carried out extensive experiments considering different parameters of NSM retrofitted members. Here four series of concrete beams were tested. Series A B C and D and these were T beams, different compressive strength of concrete was used 18.6 to 59.4 MPa and the NSM was also of different types.

Different levels of NSM enforcement were used from 0.06 percent to 0.19 percent and three laminate orientations of the FRP was used 90 degrees 60 degree and 45 degrees. So, this is the schematic diagram of the test beam, we can see here that this is a simply supported beam and these are the steel stirrups, location with reinforcement at the top and bottom and these are the schematic diagram of the NSM.

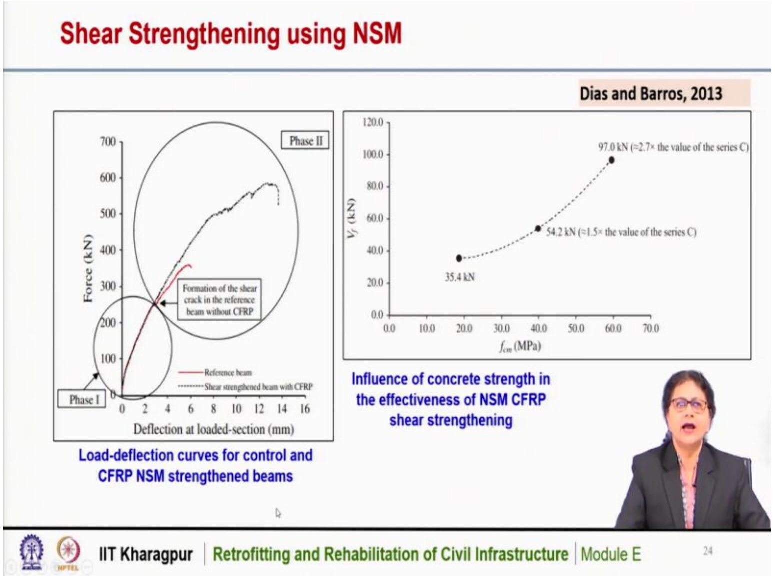
Here in this case, the experiment was done to investigate the shear strengthening of the existing members. So, NSM is also effective in improving the shear capacity of the existing members and in this experiment that has been explored. So, these are the NSM bars or NSM CFRP laminates and which were oriented in different angles, 90 degrees, 60 degree 45 degree and their combinations and these are the typical reinforcement details of the four series of beams.

(Refer Slide Time: 36:22)



These are the specimen details as given by the researchers. These are the four series of beams with different steel reinforcement, and these are the different orientations of the FRP laminates 90 45 60 And they are combinations as shown here. And these are the percentages of FRP reinforcement in the beams. In four series of beams, there are different reinforcement percentage of CFRP with different laminate orientation and these are the different concrete strength. So, these are the different strengths of concrete 18.6, 31.1, 39.7 and 59.4 MPA for the four different series of beams.

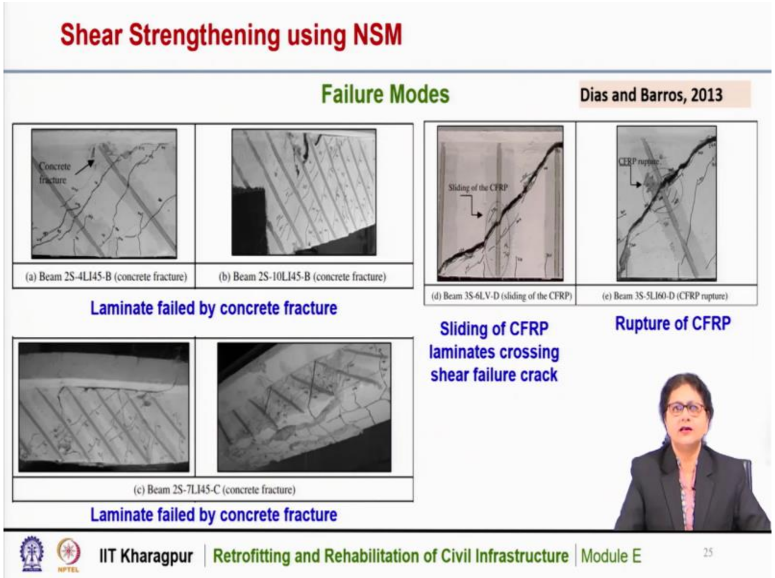
(Refer Slide Time: 37:20)



These are the responses of the control and CFRP NSM strengthened beams, here we can see that the force versus deflection of the control beam as well as the CFRP retrofitted beams. So, here we can see that there is a significant improvement in the load carrying capacity of the NSM retrofitted beams as compared to the control beam. So, this is the response of the control beam and this is the NSM retrofitted beam. So, there is a significant improvement in the load carrying capacity of the beam. And similarly, other responses were obtained.

The experiments were done with different concrete strengths and it has been seen that when the concrete strength increases, there is an improvement in the shear capacity improvement of the NSM retrofitted members. So, this graph shows the influence of the concrete strength in the effectiveness of NSM CFRP shear strengthening. So, as the strength of concrete increases, the shear capacity of the member also increases significantly as compared to the lowest FRP retrofitted members.

(Refer Slide Time: 38:45)

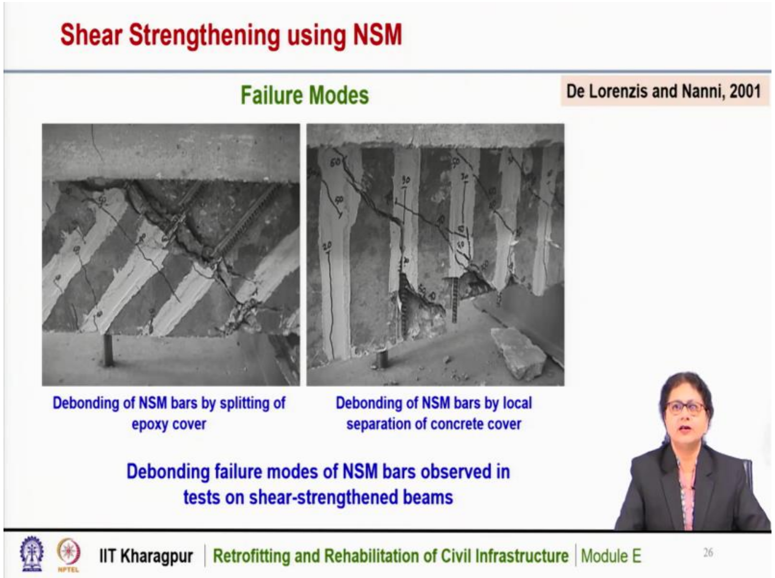


These are the failure modes of the different types of NSM retrofitted members. Here in this case, it is the laminate failed by concrete fracture. So, here we can see that different laminate orientations were used in the different series of the beams. So, these beams failed due to concrete fracture. So, here we can see that the concrete fractured and the system failed. This also shows that the beam failed due to concrete fracture and due to the concrete fracture, the laminate also failed.

This picture shows that similarly, the beams with least FRP reinforcement fail due to concrete fractures. So, here also we can see that the beams failed due to concrete fracture and consequently the laminate also failed. Here in this case the failure was due to sliding of the CFRP laminate, crossing the shear failure crack. So, this is a typical shear failure crack and the laminate failed due to the sliding of the CFRP.

Here in this case the failure was due to rupture of the CFRP. So, we can see here that this is the CFRP. So, the failure was due to the breakage of the CFRP laminate. So, these are the different types of failure modes that are generally observed in NSM strengthen beam when they are retrofitted for shear strengthening.

(Refer Slide Time: 40:36)



These are some other type of failure modes as observed by other researchers De Lorenzis and Nanni in 2001. Here also we can see those different types of debonding failure occurred in case of NSM retrofitted members. Here we can see that the debonding of the NSM bars by splitting of the epoxy cover. So, these are the NSM bars and the failure is due to splitting of the epoxy cover over these bars.

Here also in this picture shows the debonding of the NSM bars by local separation of the concrete cover. So, locally the concrete cover failed and there is a separation of the concrete cover from the NSM. So, that causes the failure of the NSM retrofitted members. So, these are some of the debonding failure modes of NSM bars, observed in tests on shear strengthen beams.

(Refer Slide Time: 41:41)

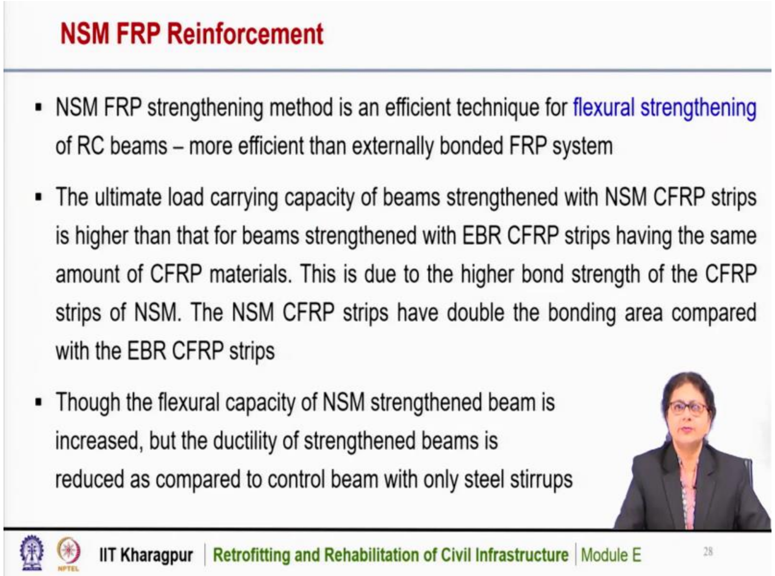
So, from the various researches carried out on NSM FRP retrofitted members to improve the flexural and shear capacity. We can summarize that, different shapes of NSM FRP can be utilized for strengthening. We can use round bars, square bars, oval bars, rectangular bars or strips as NSM reinforcement. So, different shapes of NSM reinforcement can be used for strengthening purposes of the structural members. NSM CFRP strips are superior to NSM FRP bars of other sectional forms for example, round or square bars due to larger perimeter to sectional area ratio of the former.

So, we have seen that experiments have been carried out by researchers to investigate the performance of round bars or square bars or rectangular bars or strips. And it has been seen that the strips perform much better as compared to square or round bars or rectangular bars, because the strips have larger perimeter to sectional area ratios. So, the bond between the NSM and the concrete substrate is higher in case of strips as compared to round or square bars.

That is due to larger perimeter to sectional area ratio, it is superior in performance. There may be four debonding failure modes in case of NSM retrofitted members. Bond failure at the bar-epoxy interface or there may be bond failure at the epoxy concrete interface. There may be splitting of the epoxy cover and tensile and shear failure of concrete and groove filler. The NSM retrofitted member may fail due to debonding and there may be four different types of debonding failure. The debonding may be at the bar epoxy interface or it may be at the epoxy concrete interface.

The debonding may be splitting of the epoxy cover and debonding maybe also due to tensile and shear failure of the concrete and the groove filler. There may be other types of failure modes in case of NSM retrofitted members, that is due to FRP rupture or due to concrete crushing or due to steel yielding and with these the FRP laminate may fail and there may be the failure of the NSM system.

(Refer Slide Time: 44:34)

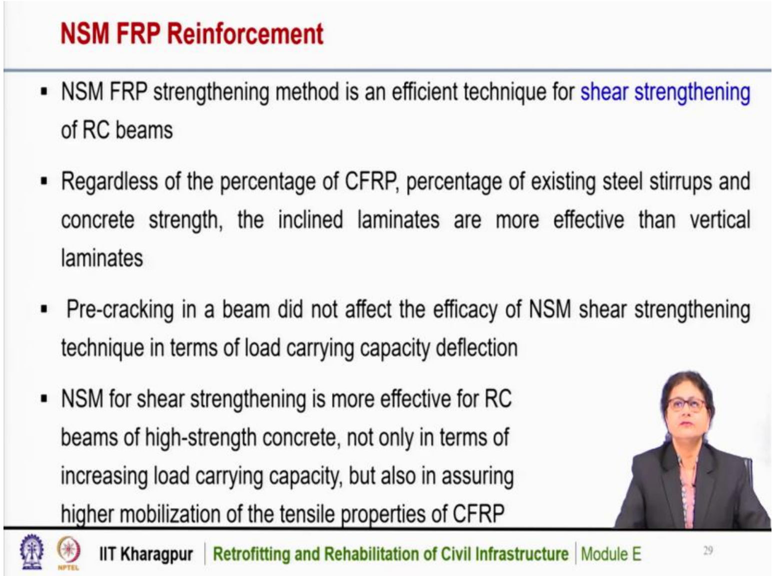


NSM FRP strengthening method is an efficient technique for flexural strengthening of RC beams and it is actually more efficient than externally bonded FRP system. The ultimate load carrying capacity of beams strengthened with NSM CFRP strips is higher than that of beam strengthened with EBR that is externally bonded reinforced CFRP strips having the same amount of CFRP material.

So, the NSM system is better performing as compared to the EBR system of having same amount of CFRP materials. This is due to the higher bond strength of the CFRP strips of NSM because we can have the two sides of the strips can be used for bonding, whereas, in case of EBR it is only one surface that is used for bonding purpose.

So, it performs better the NSM CFRP strips as compared to EBR CFRP strips. The NSM CFRP strips have doubled the bonding area compared with the EBR CFRP strips, though the flexural capacity of NSM strengthen beam is increased as compared to the control specimen, but the ductility of strengthen beam is reduced as compared to control beam with only steel stirrups. that has been observed from the experiments that though the flexural capacity is increased, but the ductility of the NSM strengthened beam is reduced as compared to the control beam.

(Refer Slide Time: 46:19)

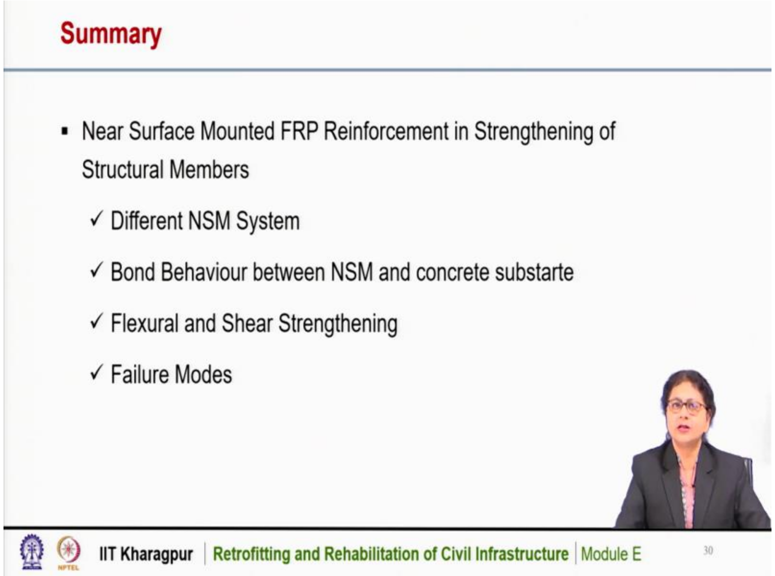


NSM FRP strengthening method is an efficient technique for shear strengthening of RC beams as well. Regardless of the percentage of CFRP the percentage of existing steel stirrups and concrete strength, the incline laminates are more effective than vertical laminates. So, several experiments have been carried out with different FRP orientations.

And it has been seen that the incline laminates are more effective than vertical laminates. Pre-cracking in a beam did not affect the efficacy of NSM shear strengthening technique in terms of load carrying capacity deflection. So, this is also another important observation that if the pre-cracked beam is strengthened with NSM then it behaves similarly with the non-cracked beams.

NSM for shear strengthening is more effective for RC beams of high strength concrete not only in terms of increasing the load carrying capacity, but also in assuring higher mobilization of the tensile properties of CFRP. So, NSM for shear strengthening is more effective for RC beams of higher strength concrete. So, as the concrete strength increases the effectiveness of NSM FRP system is better, not only in terms of the load carrying capacity, but also the utilization of the tensile capacity of the CFRP strips. So, this shows that the NSM is an efficient technique for improving the shear capacity of existing beam members.

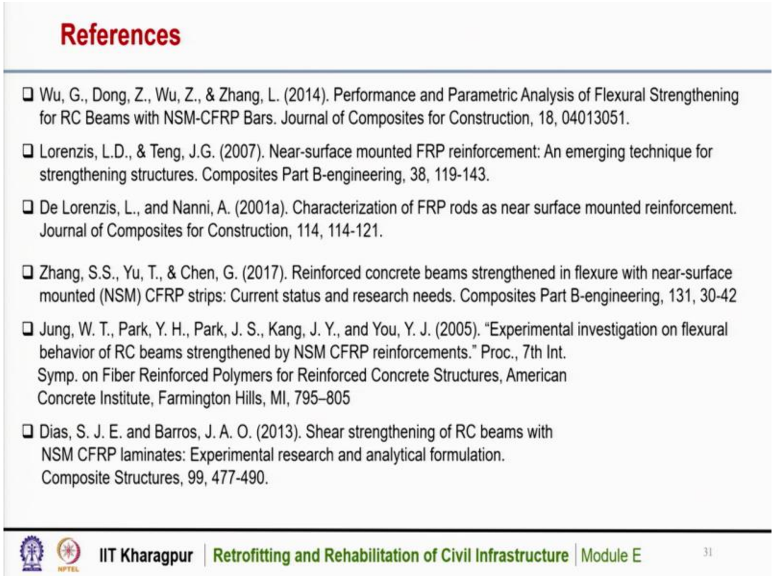
(Refer Slide Time: 48:04)



So, to summarize, we have discussed near surface mounted FRP reinforcement in strengthening of structural members. We have discussed the different NSM systems, there are different types of FRP reinforcement. We can use round bars, oval bars, rectangular or square bars or even strips as NSM reinforcement in existing members and there are different NSM configurations also, depending on the type of bar used. So, different NSM systems have been discussed. The bond behaviour between NSM and concrete substrate have been discussed. There may be different types of bonding between NSM and the grooving material or the NSM and the concrete.

And the behaviour depends on what parameters that we have discussed. We have discussed the flexural and shear strengthening of existing members using NSM FRP reinforcement and the different failure modes for flexural and shear strengthening also have been discussed. So, this shows that NSM is an efficient technique for improving the flexural and shear capacity of existing members and that is why there are more and more use of NSM in recent years.

(Refer Slide Time: 49:34)



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