Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 26
FRPC in Axial Strengthening of Structural Members - I

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 fibre reinforced polymer composites.

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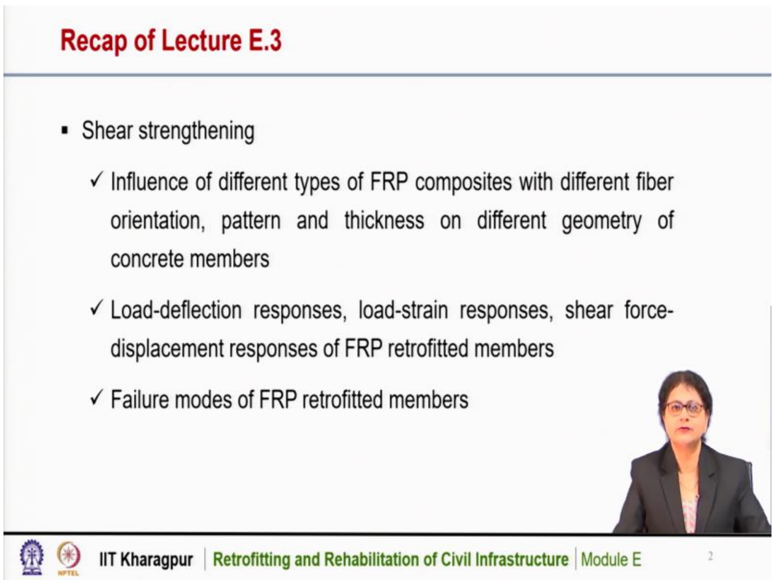

In the previous lecture, we have discussed shear strengthening of structural members, we have discussed the influence of several parameters on shear strengthened beams. The different parameters were different types of FRP composite, with different fibre orientation, different FRP pattern, different thickness and different geometry of concrete members.

The responses of the FRP retrofitted members were discussed in terms of load deflection plots, load strain plots, shear force displacement plots of the FRP retrofitted members. We have also discussed the failure modes of FRP retrofitted members.

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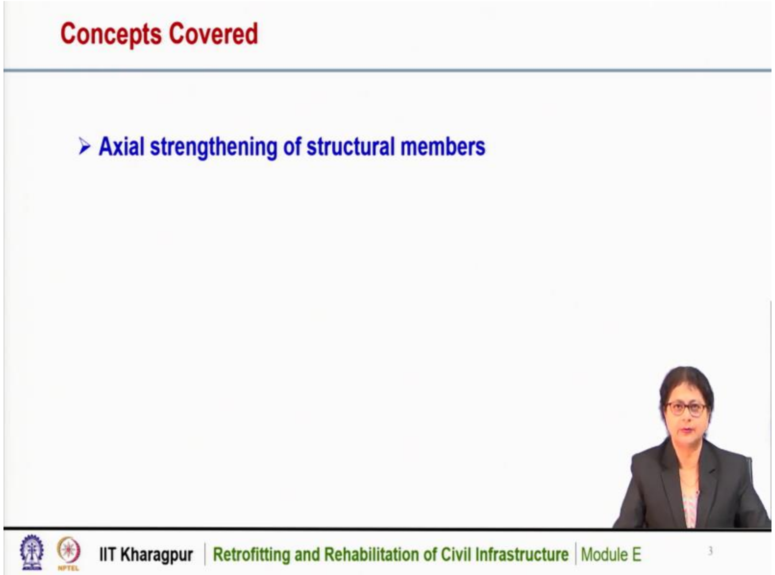

Today, we will discuss axial strengthening of structural members using fibre reinforced polymer composites.

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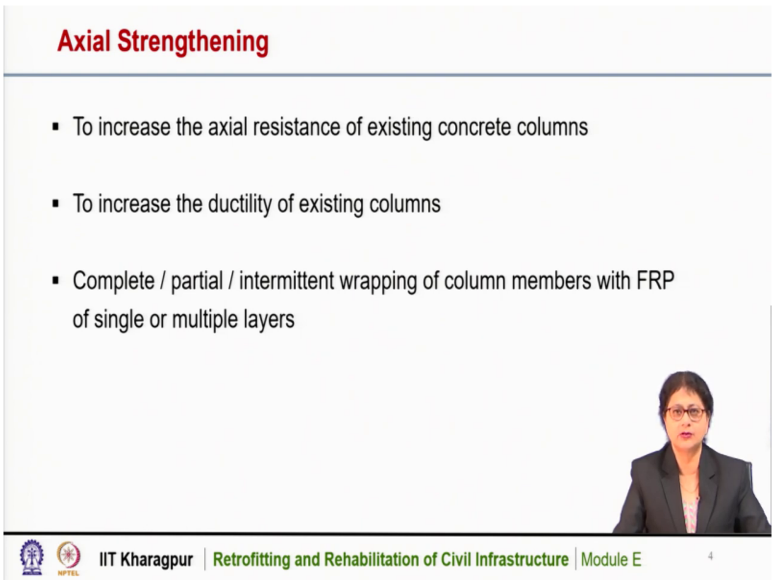

Axial strengthening of structural members using fibre reinforced polymer composites is aimed to increase the axial resistance of existing concrete columns. It is also aimed to increase the ductility of the existing concrete columns. And the axial strengthening is done by complete partial or intermittent wrapping of column members using FRP composites and with single or multiple layers.

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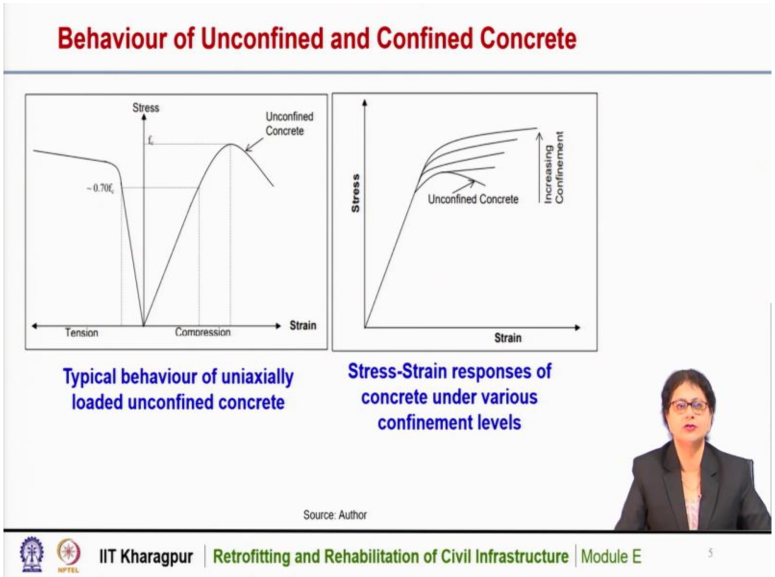

It is well known that the strength in axis of uniaxial strength of concrete is attainable. This is possible when the concrete is under multiaxial state of stress and under lateral confinement. When the concrete is under uniaxial stress, there is an increase in the axial strain of the member. Along with the increase in the axial strain, there is also increase in the lateral strain of the member due to Poisson’s effect.

As the stress increases, there is increase in the axial stress as well as the axial strain. The initially the increase is shown here, you can see here the increase in the axial strain with respect to axial stress and this is the increase in the lateral strain with increase in the axial stress. However, after sometime when the stress increases further, there is more increase in the lateral strain; that means, there is a lateral expansion of the concrete member due to Poisson’s effect.

And when the stress reaches about 70 to 80 percent of its uniaxial strength, the cement phase starts cracking and with this, there is an increase in the rate of lateral strain and we can see here that there is further increase in lateral strain with respect to the axial stress. So, with lesser increase in the axial stress, there is more increase in the lateral strain of the member. And this is shown here and because of this radial increase of the concrete member, there is an increase in the volumetric expansion of the concrete and this volumetric expansion can be restrained if concrete is confined laterally.

Now, when FRP is used as a confining material, this FRP restraints this lateral movement of the concrete. This lateral expansion is restrained by the FRP and FRP provides a lateral confining pressure to the concrete member. This lateral confining pressure depends on the stiffness of the confining material and with this, there is a multi axial state of stress.

So, the concrete experiences a multi axial state of stress due to the effect of the confining material and with this multiaxial state of stress, there is an increase in the axial strength and the axial strain of the member. So, when concrete achieves a multiaxial state of stress due to the confinement, the strength of the member increases and also its strain. When the concrete is under multiaxial state of stress due to the confinement by the FRP members, then the stress strain response is bilinear in nature.

So, as we can see here that, this is the stress strain response of concrete under confinement. With more levels of confinement, there is more increase in the strength of the concrete. This bilinear response is due to the confinement of the concrete members and we can see here that there is not only increase in the axial strength, but also the axial strain increases. So, if the concrete is confined, then there is a multiaxial state of stress and due to the effect of this multiaxial state of stress, the concrete axial strength increases and also its axial strain. With further increase in the confinement level, the increase in axial strength is also more.

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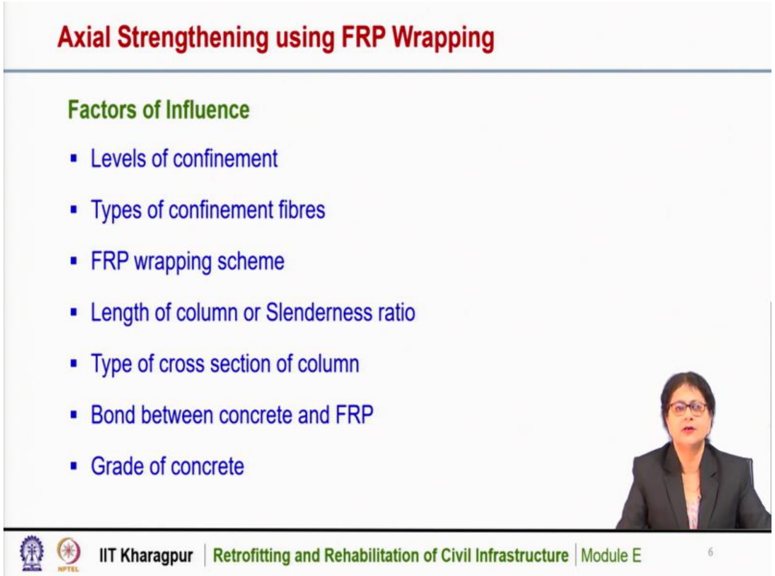

Now, we will discuss that the axial strengthening of concrete columns using FRP wraps. There are several factors that may influence the behaviour of FRP confined concrete columns. The different factors that may influence the behaviour are the levels of confinement, types of confinement fibres, FRP wrapping scheme, length of column or slenderness ratio, types of cross section of column, bond between concrete and FRP and grade of concrete. All these parameters influence the behaviour of FRP confined concrete columns.

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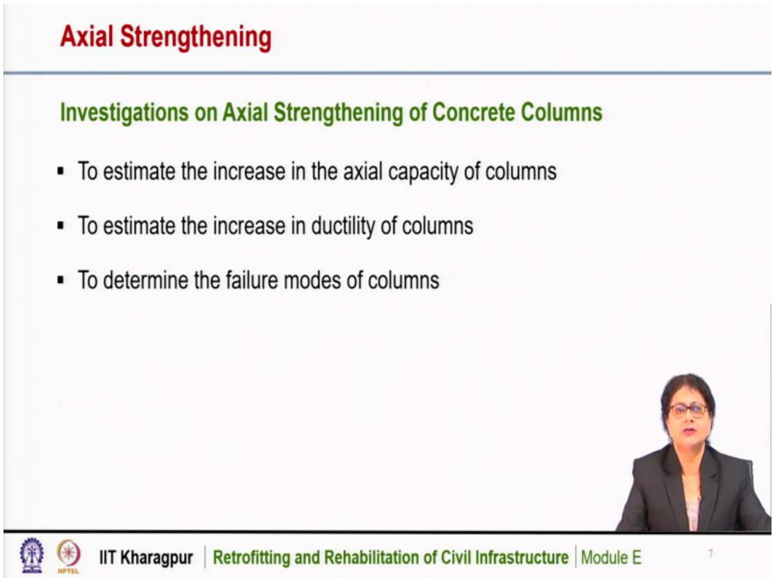

Several research works have been carried out to understand the complex behaviour of FRP confined concrete columns under the influence of these parameters, and the investigations were carried out to estimate the increase in the axial capacity of the columns, how much increase is possible due to the effect of these parameters, how much increase is possible in the ductility of the columns when these parameters are there.

And what are the failure modes of the FRP confined columns, if those influencing parameters are there. So, to investigate the behaviour of FRP confined concrete columns, several investigations were carried out to estimate the increase in the axial capacity of the columns to estimate the increase in the ductility of the columns and also to determine the failure modes of the columns.

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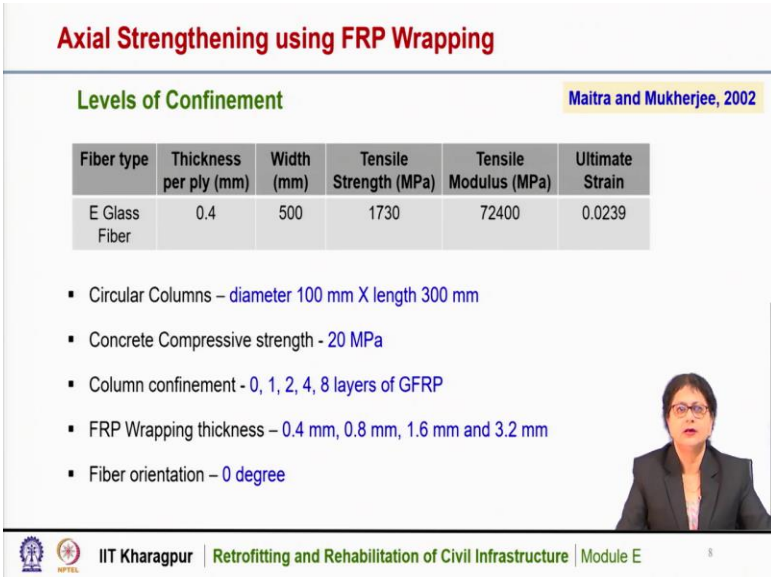

In experimental research by Maitra and Mukherjee in 2002, the different levels of confinement were studied. FRP confined columns were prepared and the columns were confined with E glass fibre composites. Circular columns were used having diameter 100 millimetre and length 300 millimetre with compressive strength of 20 MPa. The columns were confined with E glass fibre of 1 layer thickness, 2-layer thickness, 4-layer thickness and 8 layers of GFRP confinement.

FRP wrapping thickness for each layer was 0.4 millimetre. So, with different confinement levels, that means different layers of FRP, different thicknesses were used and in this E glass fibre the fibre orientation was 0º. That means all the fibres were oriented in one direction and the FRP sheet were placed around the column when the fibres are oriented at 0º. The properties of the E glass fibres are mentioned here. The tensile strength was 1730 MPa and tensile modulus was 72400 MPa with ultimate strain as 0.0239.

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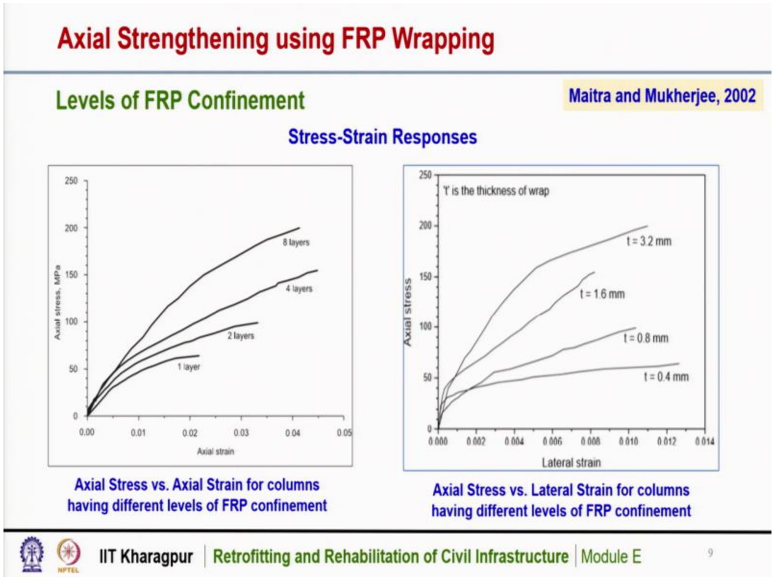

Now, the columns were tested under axial loading, and the stress strain responses were recorded. These are the stress strain responses of the confined concrete columns. We can see here that for all the columns, there is a significant improvement in the axial strength. Along with the improvement in the axial strength, there is improvement in the axial strain of the columns.

And here we can see that with increase in the level of confinement, the axial strength increases. So, the strength is maximum when the column is confined with 8 layers of GFRP. Next is when the column is wrapped with 4 layers of GFRP, then with 2 layers of GFRP and then with 1 layer of GFRP.

So, now, when the levels of confinement increases, there is increase in the axial strength of the column and also there is increase in the axial strain of the columns. These are the plots of the axial stress versus lateral strain for the columns having different levels of FRP confinement. Here we can see that, when the columns are confined with different levels of confinement, there is improvement in the lateral strain. That means, the ductility of the columns increases for all levels of confinement.

However, with increase in the level of confinement, the ductility reduces. So, maximum level of lateral strain was achieved when it is wrapped with 1 layer of GFRP. Next, when it is 2 layers of GFRP, next, it is 4 layers of GFRP and this column actually did not fail. So, it shows a significant improvement in the axial strength and axial strain as well as lateral strain. So, this shows that there is a significant improvement in the lateral strain that is the ductility also of the column. However, with increase in the level of confinement, the ductility reduces.

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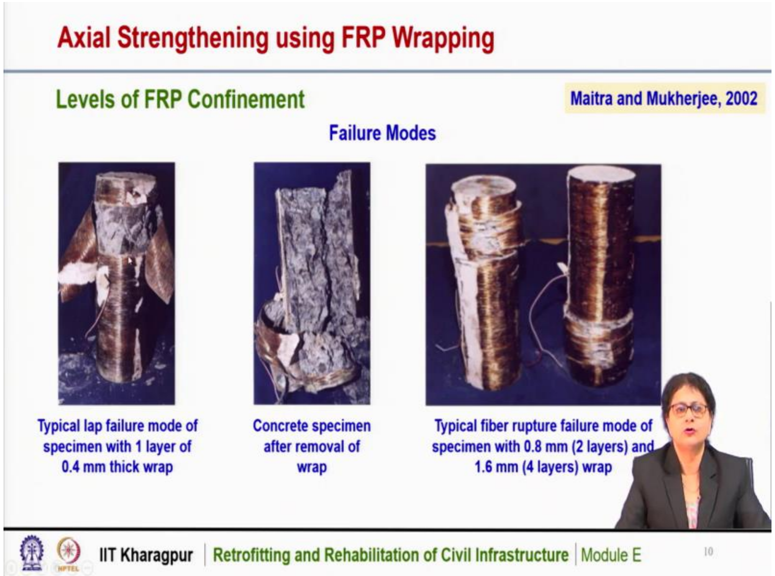

These are the failure modes of the columns confined with different levels of FRP sheets. This picture shows that the failure mode of column having one layer of GFRP sheet. The column fails due to lap failure, the lap length was 100 millimetres, and this column failed due to the opening of the lap.

This is the picture of the concrete specimen after removal of the wrap. When the wrap was cut, after the testing, the concrete busted out. This is a picture of the failure modes of the columns with 2 layers of wrapping and 4 layers of wrapping. So, here in this case, the columns fail due to rupture of the fibres.

So, here we can see that the fibre ruptured and here also the fibres ruptured. So, in both cases the failure of the column was due to the rupture of the fibre. The strain attained here in this cases were significantly high and it is more than its ultimate strain, so, the fibres break at these locations.

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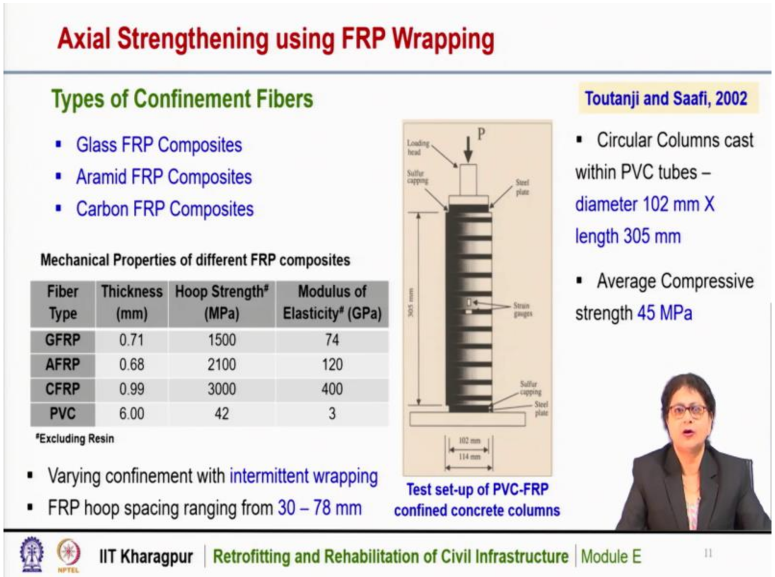

These are the experimental details of FRP confined concrete columns and the columns were confined with different types of fibres. Different types of FRP composites, glass FRP composite were used, araimd meeting FRP composite was used and carbon FRP composite were used, and these are the properties of the different types of composites.

Here in this case, PVC pipes were used or PVC tubes were used for casting of the concrete columns. So, here circular concrete columns were cast within PVC tubes, the diameter was 102 mm × 305 mm in length and the concrete strength was 45 MPa. This is a schematic diagram of the concrete column.

And here, it is confined with different types of FRP composites. The FRP was not continuous, but it is intermittently wrapped. The spacing was varied and the spacing range it from 30 to 78 millimetre. So, the levels of confinement were also varying because of the different spacing of the FRP composites. So, the levels of confinement were also varying in this case along with different types of fibres.

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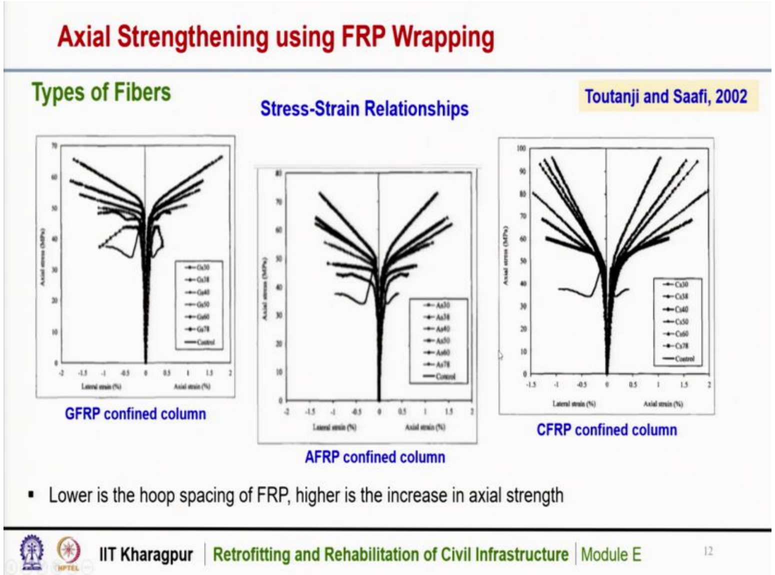

These are the responses of the FRP confined concrete columns. This is the stress strain response of the GFRP confined concrete columns. These plots are for the axial stress versus axial strain and these plots are for axial stress versus lateral strain. So, we can see here that in this case, all the columns showed significant improvement in the axial capacity when it is confined with GFRP sheets.

So, here this is the response of the control column with no FRP and these are the responses of the FRP confined concrete columns. As the confinement level increases, that is lesser is the spacing of the FRP strips, higher is the increase in the strength. The increase in the axial strain is also more, when the levels of confinement is more.

Whereas, in case of lateral strain, the increase in lateral strain is not similar with the axial strain. So, higher is the axial stress, lesser is the lateral strain. This is the response of the AFRP confined concrete columns. Here also we can see that, as the level of confinement increases, the there is significant increase in the axial capacity of the members, the axial strain also increases. However, the lateral strain increase is not that much, but there is improvement in the lateral strain as well as compared to the control column.

These are the responses of the CFRP confined concrete columns. This also shows that, as the level of confinement increases that is lesser is the spacing of the FRP strips, higher is the increase in the axial strength. So, higher is the increase in the axial strain. But, with increase in the level of confinement the increase in axial strain is not much and similarly, the increase in the lateral strain also is not much for the CFRP confined concrete columns.

Another interesting thing is that the increase in the axial strength is maximum when it is confined with CFRP composite. And least is for the GFRP composite confined columns. The strength of CFRP is the highest among the three. So, the increase in the strength is also maximum in case of CFRP confined concrete columns. However, the strain at failure for the GFRP composites are maximum as compared to AFRP and CFRP composites. So, the increase in the ductility or strain in case of GFRP confined column is much more as compared to AFRP confined column and CFRP confined columns.

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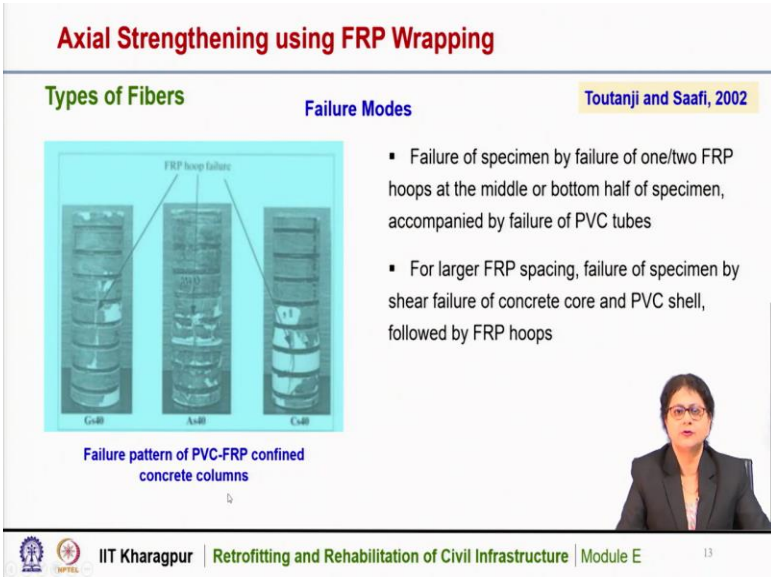

These are the failure modes of the three different types of concrete columns. This is the failure mode of GFRP confined column, this is the failure mode for AFRP confined column and this is for the CFRP confined column. The columns failed due to 1 or 2 FRP strips at the middle or the bottom half of the specimen accompanied by failure of the PVC tubes.

When the spacing is smaller, it failed due to rupture of the FRP strips at the middle or bottom half of the specimen. However, if the spacing of the FRP strips are larger, then the failure of the specimen was due to the shear failure of the concrete core in between the strips and the PVC shell followed by FRP hoops. So, it depends significantly on the FRP wrapping pattern. If the spacing is more than the failure mode is also different, it is due to shear failure of concrete. When the spacing is less than it is due to the rupture of the FRP strips.

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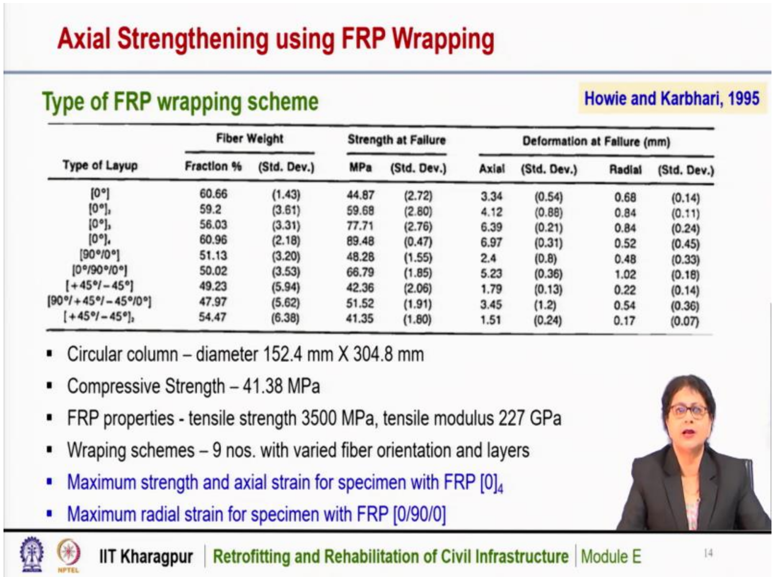

These are some of the results of experiments when the FRP wrapping scheme was investigated. The influence of different FRP wrapping scheme was investigated on the behaviour of FRP confined concrete columns. Here circular columns were used of diameter 152 millimetre × 305 millimetre in length and the strength of column was 41 MPa.

CFRP was used having tensile strength 3500 MPa and tensile modulus 227 GPa. 9 different rapping scheme was used with varied fibre orientation and layers. So, these are the 9-wrapping scheme. The fibres were oriented either 0º or 90º or in combination of 90 0, 0 90 0, +45 -45, 90 +45 -45 0, +45 -45 et cetera.

So, these are the nine schemes of rapping that were used on concrete columns and the columns were tested under loading. So, here are the test results, it has been seen that the maximum strength and axial strain was obtained when the specimen were wrapped with FRP and the fibres were oriented at 0º and with 4 layers of FRP composites.

So, here in this case, we have seen that, this is the case when the fibres were oriented at 0º and 4 layers of FRP composite were used. So, in that case the maximum increase in strength was achieved. So, this is the maximum strength that has been achieved here for this case, and maximum axial strain also is achieved in that case.

The fibres when it is oriented along the 0º, in that case the strength is maximum. So, the increase in strength of the FRP confined column is also maximum, when the fibres are oriented in 0º. However, the maximum radial strain is not. For this case, it is maximum radial strain is achieved when the specimen is wrapped with FRP with the wrapping scheme of 0, 90, 0º.

So, here it is seen that the radial strain is maximum when it is wrapped with fibres oriented as 0 90 0º. So, wrapping scheme also influences significantly the behaviour of FRP confined to concrete columns. Maximum strength is achieved when the fibres are oriented 0º.

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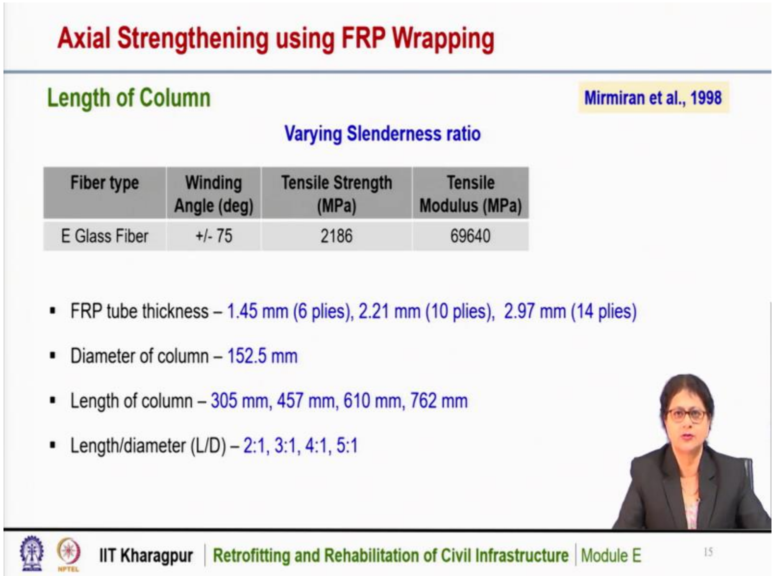

Length of column is also another important parameter that influences the behaviour of FRP confined concrete columns. Mirmiran et al. has investigated the length of column and they have used E glass fibre as confining material. The properties are shown here and here in this case the fibres were oriented +/- 75º.

FRP tubes were used of different thicknesses with different number of plies and the diameter of column was 152 millimetres. The length of column varies and 4 different lengths were used 305-millimetre, 457-millimetre, 610-millimetre and 762-millimetre. So, the 4 different L/D ratios were used for the experiment.

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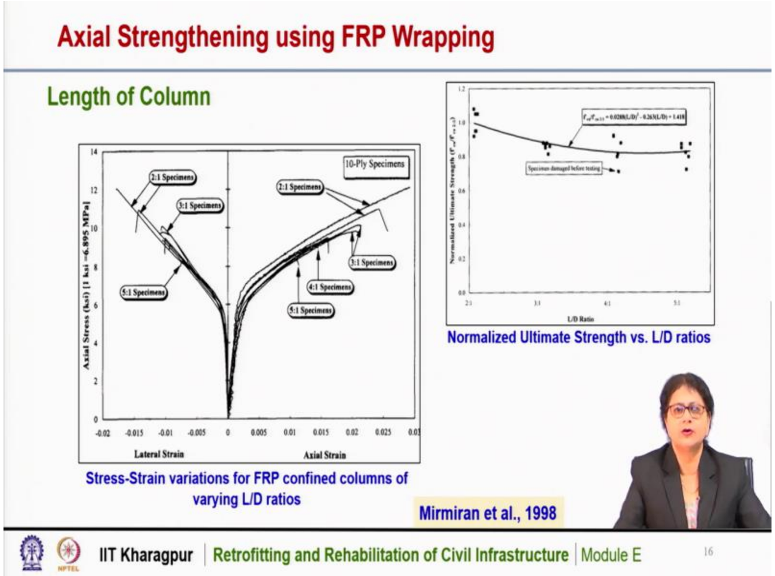

Here are the stress strain responses of the FRP confined columns of varying L/D ratios. We can see here that, when the L/D ratio increases, that means, these are the responses of the column the axial stress versus axial strain. So, as the L/D ratio increases, the increase the axial strength is less.

So, maximum stress is achieved when the L/D ratio is 2:1 and minimum when it is 5:1. Similarly, for the axial stress versus lateral strain plots. So, here it shows that as the length of the column increases, the effectiveness of confinement actually reduces. This is the plot of normalised ultimate strength versus L/D ratio, it shows that as the L/D ratio increases, there is a there is a decrease in the ultimate strength of the confined columns.

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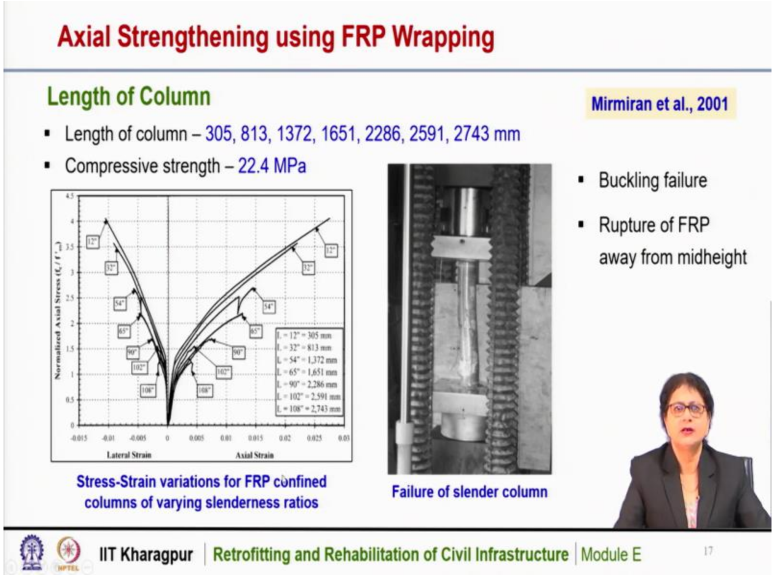

These are another set of experiments by the same researchers here different lengths of columns were used. 7 different lengths of columns were used of compressive strength 22.4 MPa and these are the stress strain responses of the FRP confined columns of varying slenderness ratios. So, here also similar observations, higher is the L/D ratio lower is the increase in axial strength. This is the typical failure pattern of slender column.

Here we see that the column fails due to buckling. Clearly it is observed that there is buckling of the column and along with this, there is a rupture of FRP away from the mid height. So, the rupture of FRP occurs near this region and along with the buckling, the FRP also ruptured.

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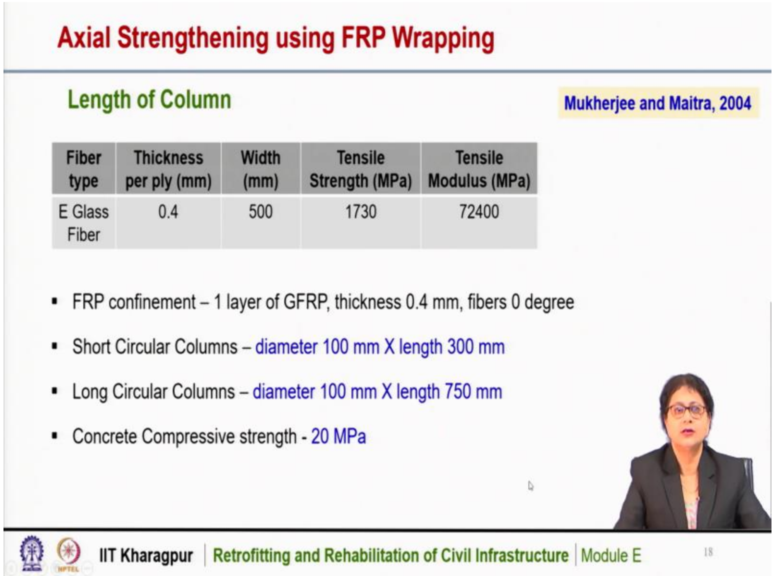

In this experiment by Mukherjee and Maitra in 2004 E glass fibres were used as confining material and the length of column effect was investigated. Here, 2 types of columns were used, one is short circular columns and another is long circular columns. The short columns have length 300 millimetre and diameter 100 millimetre, whereas, the long columns have length 750 millimetre and diameter 100 millimetre.

Both columns have compressive strength 20 MPa. All the columns were confined with 1 layer of GFRP. The properties are given here and 1 layer of GFRP having thickness 0.4 millimetre and the fibres were oriented 0º.

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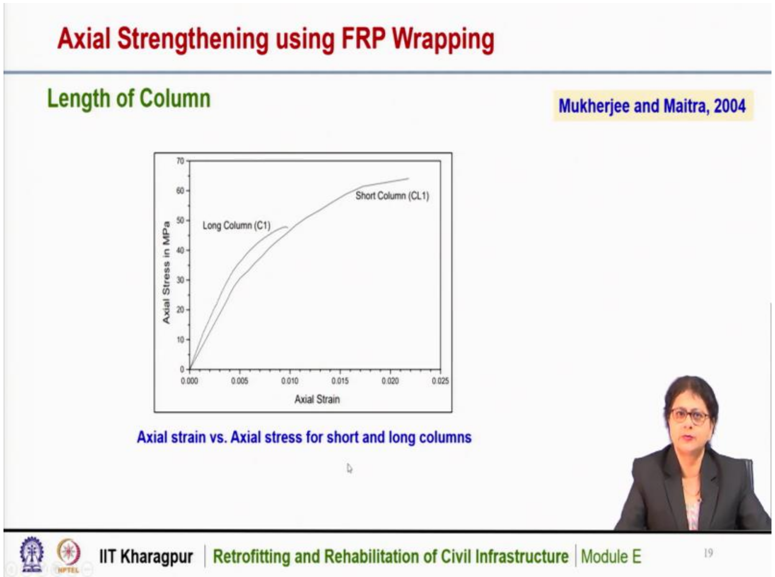

Here is the response of the short column and long column confined with glass fibre reinforced polymer composites. This is the axial stress versus axial strain plots of long column and short column. So, the response shows that the behaviour of long column and short column are similar, initially the stiffness's are similar.

However, the short column has much higher strength as compared to the long column. This is due to the effect of slenderness of the columns. So, higher is the slenderness, lower is the strength gain in case of FRP retrofitted columns. So, this shows that if the length of the column increases, the axial strength actually decreases as compared to the short column.

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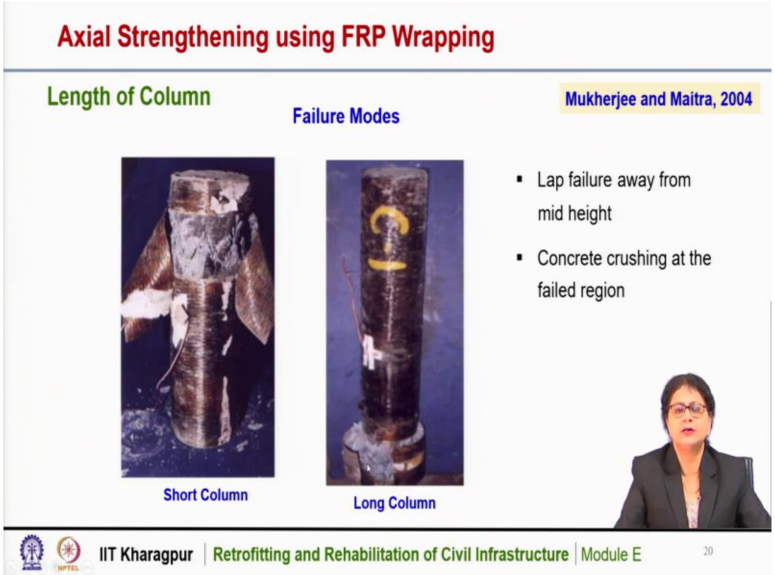

These are the failure modes of the two different columns having different lens, this is the failure mode of the short column and this is the failure mode of the long column. In both cases, the columns failed due to lap failure. In both cases the lap length was 100 millimetres. So, the columns failed due to lab failure. However, near the failure region there were concrete crushing. So, this were observed here as well as here, concrete crushed in the failure region, here also concrete crushed at the failure region.

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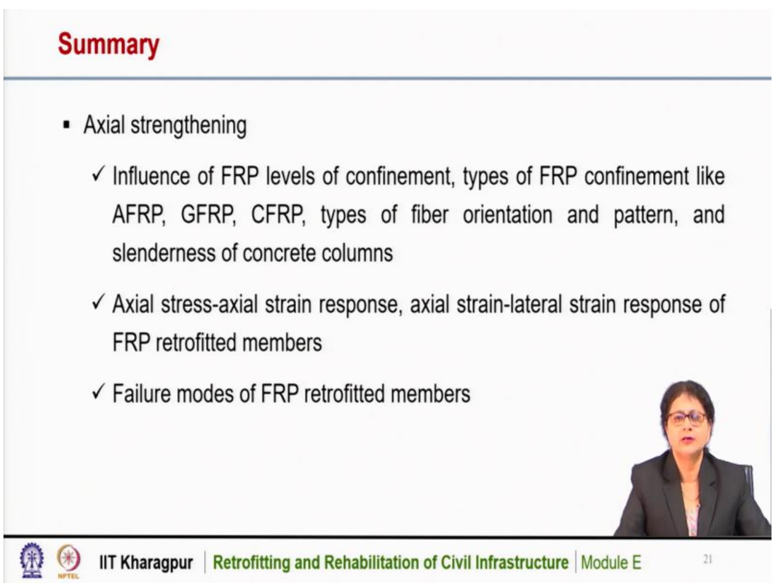

So, to summarise, we have discussed the behaviour of FRP confined to concrete columns and the influence of several parameters on the stress strain responses. We have discussed the influence of different levels of FRP confinement, different types of FRP confinement like AFRP, GFRP and CFRP on the stress strain response of the confined columns, the different fibre orientation, different pattern of FRP schemes and the slenderness ratio of concrete columns.

So, these influencing factors significantly affect the stress strain response of columns. The responses were discussed in terms of axial stress versus axial strain plots axial stress versus lateral strain plots. We have also discussed the failure modes of FRP retrofitted members. We will continue our discussion on FRP retrofitted concrete columns. Thank you.