Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 38
Design of Axial Strengthening

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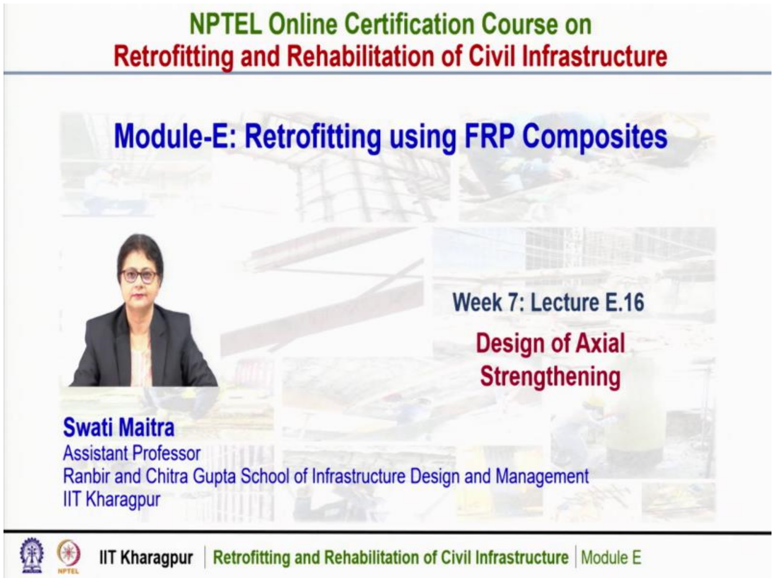

Hello friends, welcome to the NPTEL online certification course Retrofitting and Rehabilitation of Civil Infrastructure. Today, we will discuss module E, the topic for module E is retrofitting using fiber reinforced polymer composites.

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In the previous lecture we have discussed the design approaches for axial strengthening of structural members using FRP composites.

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Today we will discuss the design example of an axial strengthening of structural member using fiber reinforced polymer composites based on the design approaches that we have discussed in the previous lecture.

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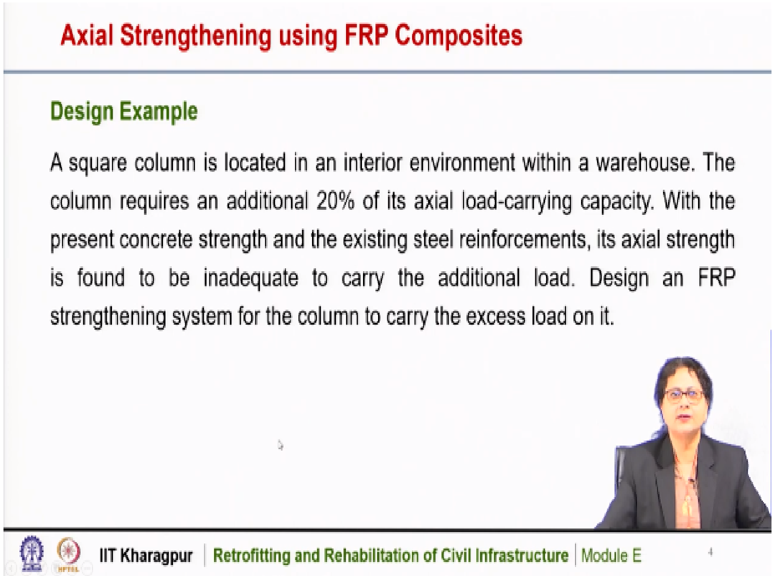

So, let us discuss the design example for axial strengthening using fiber reinforced polymer composites. The design example, the design problem states that a square column is located in an interior environment within a warehouse. The column requires an additional 20 percent of its axial load-carrying capacity. With the present concrete strength and the existing steel reinforcements, its axial strength is found to be inadequate to carry the additional load. Design an FRP strengthening system for the column to carry the excess load on it.

So, as we have discussed in case of flexural strengthening or shear strengthening examples here also the existing column is subjected to an increase in its axial load 20 percent more axial load. So, we have to design the system of confined concrete column using FRP, so that the column is able to carry the excess load on it.

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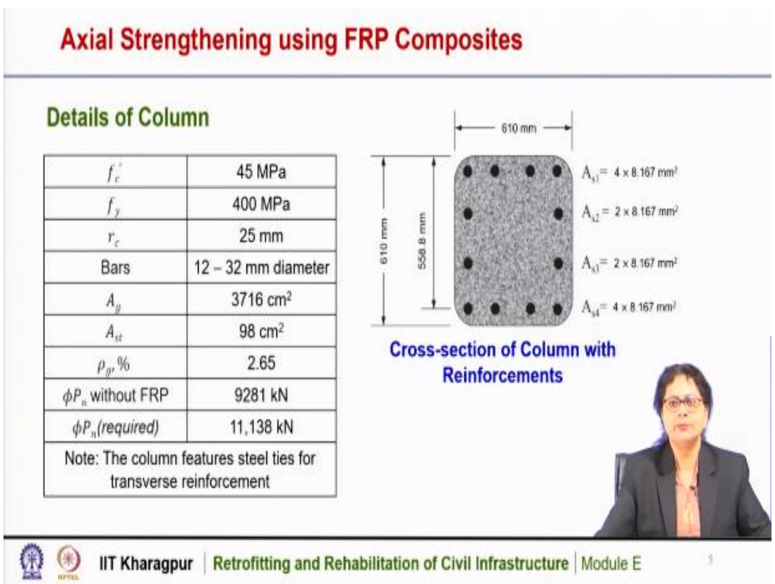

So, these are the details of the existing column, we can see here that this is the cross section of the column with reinforcement, lateral ties are not shown here but the column has lateral ties. It has 12 number of 32 millimeter diameter bars as longitudinal reinforcement as we can see here. The dimensions are given here 610 × 610 this is square column. The concrete compressive strength is 45 MPa, the steel strength is 400 MPa, the column generally is perfect square or rectangular, but if it requires retrofitting with FRP we need to round off its corner to avoid the stress concentration.

So, here also the corners are rounded off with grinding or so and for that the corner radius that is used here in this case is 25 millimeter. So, this is the corner radius 25 millimeter for the column, the gross area has been calculated as 3716 centimeter square, the Ast that is the total steel area is also estimated, percentage of steel area and this is the load on the column without FRP, that is 9281 kilo Newton, this is the existing load on the member.

Now, it requires 20 percent more it has to carry, so the required load on the column is 11,138 kilo Newton. So, these are the details of the column and this is the cross section of the column with reinforcement and it has lateral ties.

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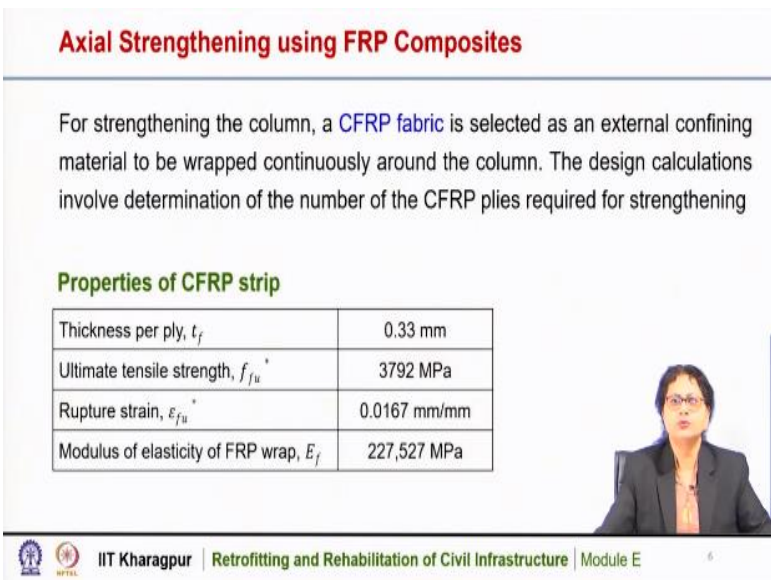

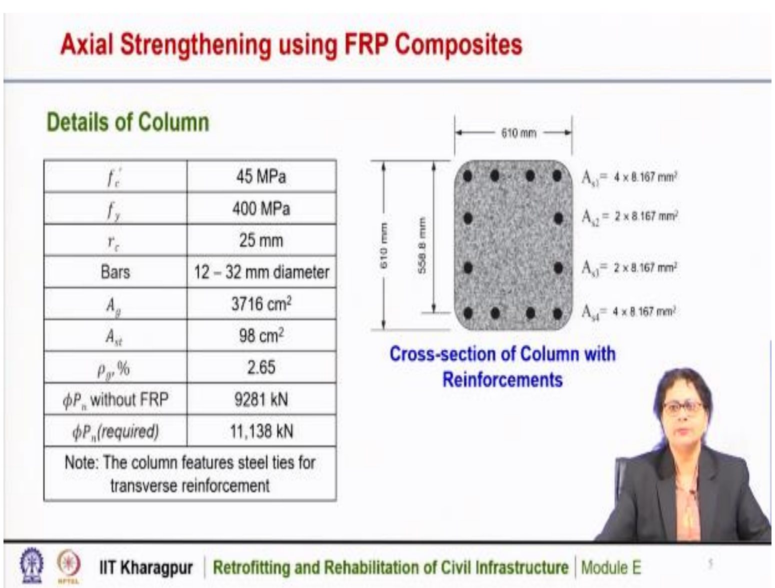

Now, we need to strengthen the column because there is an increase in the strength or increase in the load on the column, so we need to retrofit the column. So, for strengthening the column a CFRP fabric is selected as an external confining material to be wrapped continuously around the column.

So, let us take a CFRP fabric for strengthening the column and the confinement will be complete wrapping around it, the properties of the CFRP is as given from the manufacturer are shown here, the thickness per ply is 0.33 mm, the ultimate tensile strength, the ruptured strain, the modulus of elasticity all are given here in this table.

Now, we need to design the member for this CFRP composite, so how many plies will be required to carry that amount of axial loading. So, the design calculations involve determination of the number of CFRP plies required for strengthening. So, we have to see that whether this CFRP strip is able to take up the additional load and how many number of layers are required for carrying out that extra load on the column.

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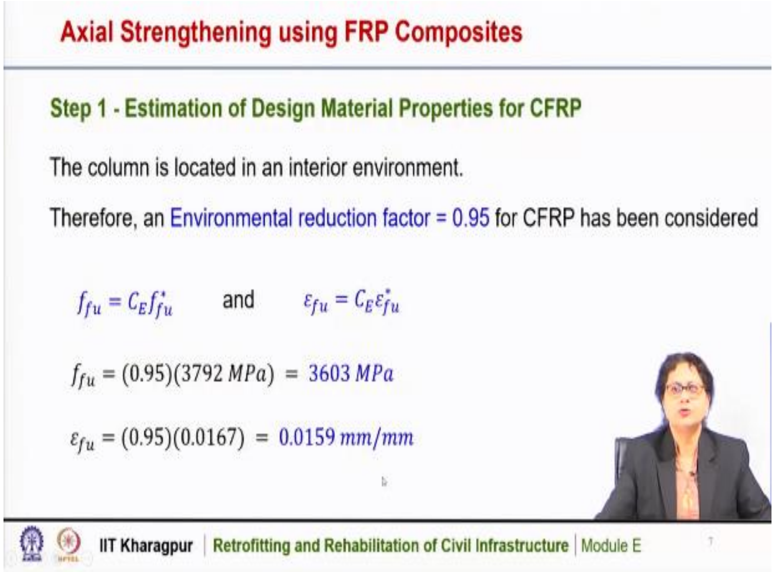

So, as we have discussed in the design approaches we have to follow certain steps based on that design approach. So, first step is the estimation of the design material properties for the CFRP composite. The column is located in an interior environment, so we have to consider an environmental reduction factor and for CFRP and with interior exposure it is

0.95. So, we have to multiply the ultimate strength and the strain value with this environmental reduction factor to obtain the design material properties.

So, the design material properties that is f_{fu} that is the design strength of the FRP is 0.95 times f_{fu}^*, that is the ultimate strength of the FRP and that comes out as 3603 MPa. Similarly, the design strain in the FRP is 0.95 × the ultimate strain of the FRP and that comes out as 0.0159 is the design strain. So, we have estimated the design material properties for the CFRP considering the exposure condition for the column member by considering the environmental reduction factor as 0.95.

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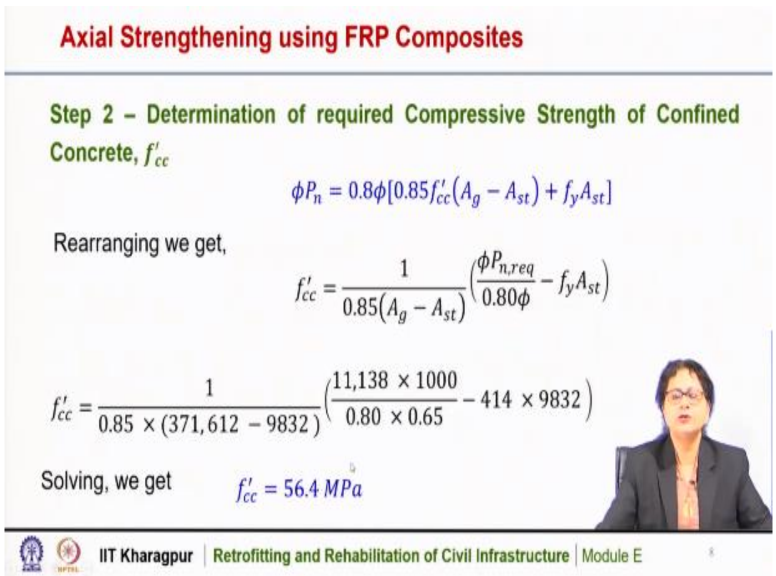

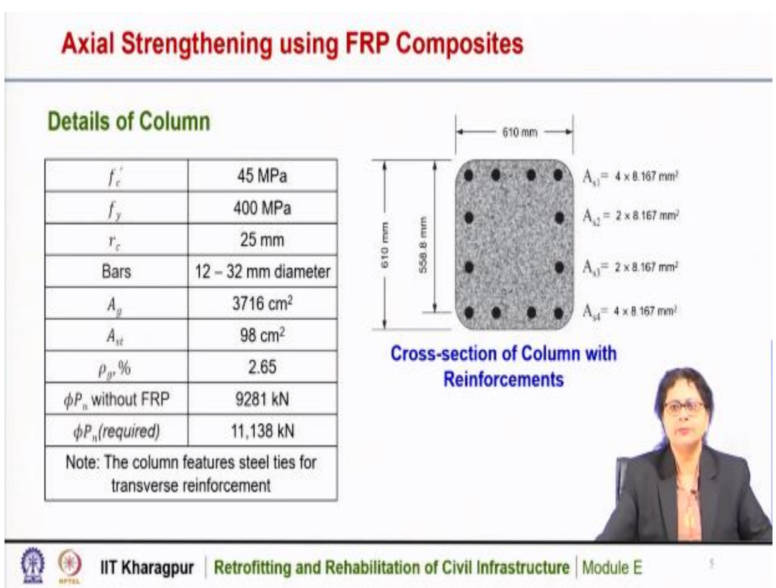

Now, we need to determine the required compressive strength of confined concrete. So, we have seen that how much is the increase in load the column has to carry that has been given and that is this 11,138 kilo Newton, which is 20 percent more than its existing load. So, what is the required compressive strength of confined concrete if that load is to carry?

So, we have to use this equation that is the design strength for the confined concrete column. This is the design load that is to be carried and these are the notations that are used, this is for the steel and this is for the confined concrete.

So, we know that what is the ϕP_n that is by considering 20 percent more than the present load, that load is given as 11,138 kilo Newton, so by rearranging we can find out what is f_{cc}', that is what is the required compressive strength of the confined concrete column.

So, by rearranging we can get what is f_{cc}' and by putting these values we get that the confined concrete strength should be 56.4 MPa and the present strength of the column is 45 MPa as given here, the present strength or the present compressive strength of concrete is 45 MPa and the confined concrete strength is to be this is the required compressive strength of the confined concrete and it is coming out as 56 MPa.

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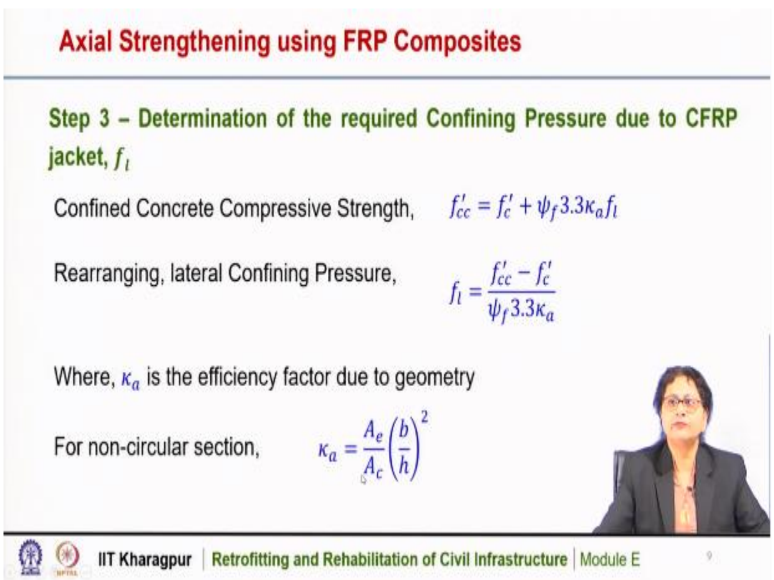

Now, we need to determine the confining pressure due to the CFRP jacket and these equations have been used the confined concrete compressive strength can be estimated using this equation, we have discussed earlier that $f_{cc}' = f_c' + \psi_f 3.3\kappa_a f_l$, where f_l is the lateral confining pressure and κ_a is the reduction factor or modification factor and ψ_f is the reduction factor for FRP and f_c' is the existing concrete strength.

So, by rearranging we can write the lateral confining pressure as per this equation f_l is equal to this and we have to calculate this κ_a, this is the efficiency factor due to geometry and we have discussed that for circular section the value of κ_a is 1, whereas for non-circular section we have to calculate the value of κ_a, which is dependent on the lateral dimension of the column.

So, the κ_a can be expressed by this equation and these equations have been developed based on several research works, experimental works on non-circular columns.

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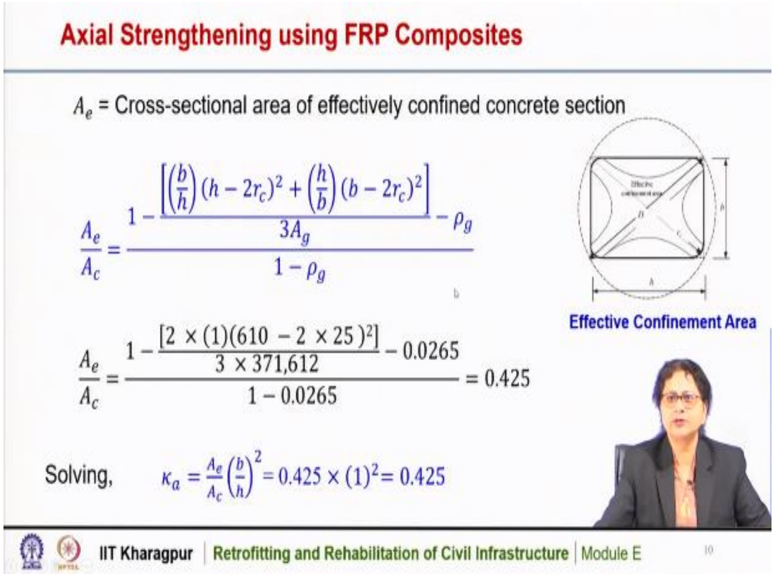

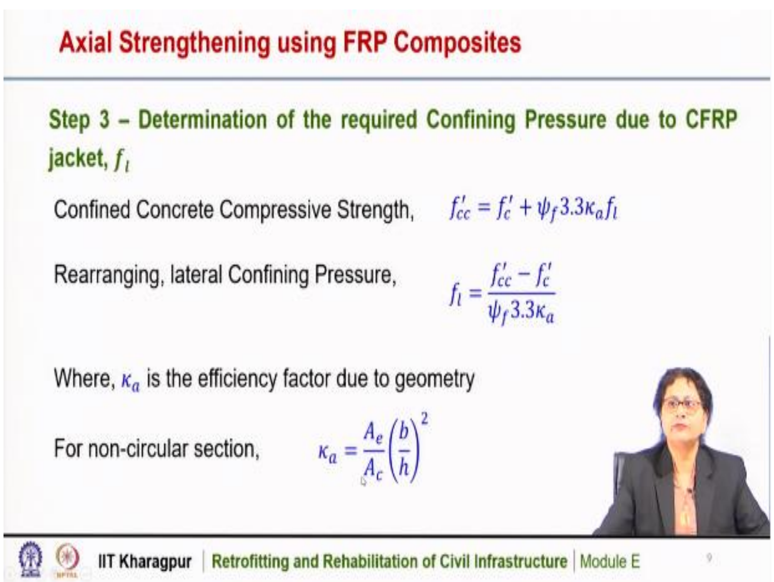

So, A_e / A_c is the ratio that can be expressed by this equation and by knowing the lateral dimension that is b and h, the two-lateral dimension of the non-circular column r_c is the corner radius, A_g is the gross area and this is the percentage of reinforcement. So, from these factors we can find out the ratio A_e / A_c and that comes out to be 0.425.

So, we can obtain the A_e / A_c ratio, so we can determine the value of κ_a as well. So, κ_a is the efficiency factor for the non-circular section and that comes out to be 0.425 because b and h are same because it is a square column. So, we can determine the value of κ_a from these values, so this is the efficiency factor due to geometry. So, this we have to use here to determine the lateral confining pressure.

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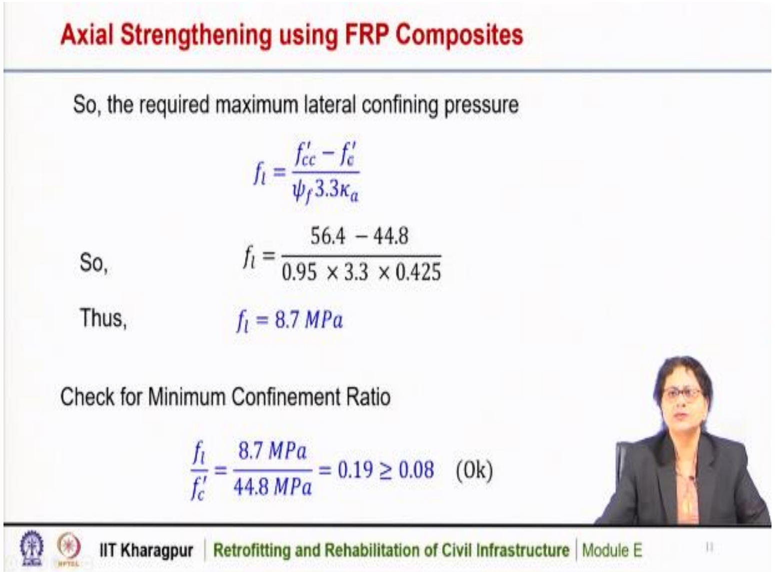

So, the required maximum lateral confining pressure can be obtained by rearranging that equation for f_{cc}'. So, by putting the values of f_{cc}' that is the required confined concrete strength, f_c' is the original strength, 0.95 is the ψ_f value strength reduction factor, κ_a we have obtained.

So, we can get the maximum required lateral confining pressure by the FRP is 8.7 MPa. So, this is the maximum required lateral confining pressure on the concrete by the FRP. Now, we have to check the minimum confinement ratio because the confinement ratio should have a limit, it should not be very less otherwise there will be no effect of confinement.

So, f_l/f_c' should not be less than 0.08 and that we can check f_l we have obtained, f_c' is given. So, this ratio comes out as 0.19 which is more than 0.08, so the effect of confinement will be there on the column.

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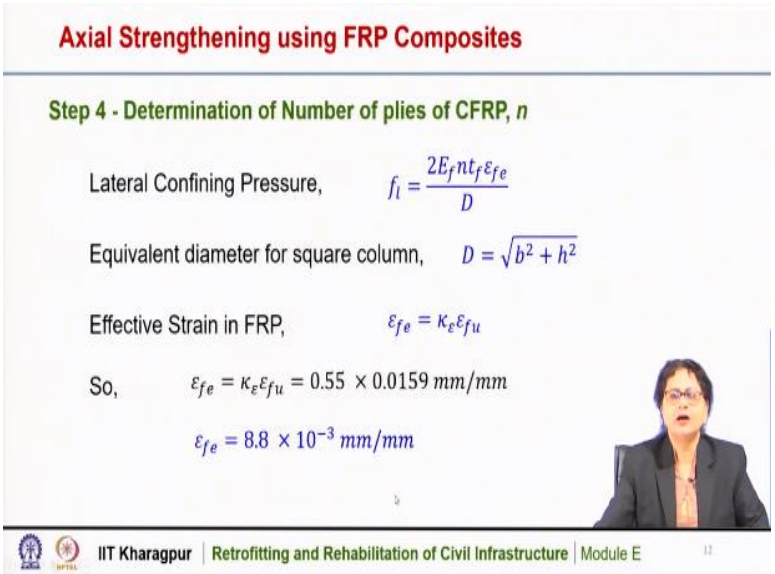

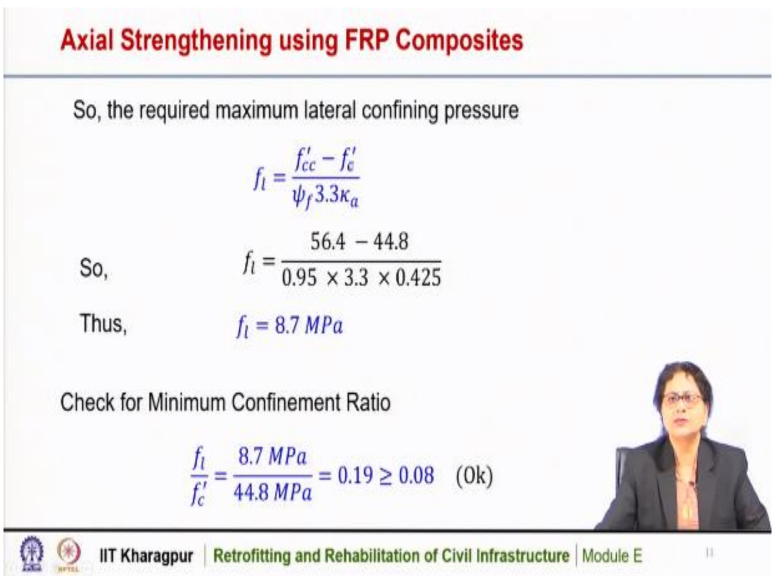

Now, the next step is the determination of the number of plies of CFRP. Now, we have seen earlier that the lateral confining pressure can be expressed as this equation and the lateral confining pressure depends on the stiffness of the confining material and it also depends on the dimension of the column.

So, this we have discussed in the previous lecture that the lateral confining pressure can be expressed as $f_l = 2E_f n t_f \varepsilon_{fe}/D$, where E_f is the elastic modulus of the FRP, n is the number of plies, t_f is the thickness of the FRP, ε_{fe} is the strain level in the FRP and D is the lateral dimension.

For circular column it is the diameter, for non-circular column we have to consider an equivalent diameter. So, for the square column for this problem we can use this equation b and h are equal for square column, so $D = \sqrt{(b^2+h^2)}$ and from that we can find out the lateral confining pressure.

So, the effective strain in FRP can also be obtained by using this equation $\varepsilon_{fe} = \kappa_\varepsilon \varepsilon_{fu}$. κ_ε is the strain factor, so that has been obtained as 0.55 and this value of κ_ε is ranging from 0.55 to 0.61 as from different experimental work these values have been considered, this is the strain efficiency factor for the FRP.

So, to determine the effective strain level in the FRP we have to consider this strain efficiency factor κ_ε and the value ranging from 0.55 to 0.61. So, here we are considering the value of 0.55 and that should be multiplied with the design strain of the FRP which is 0.159, so we can get the effective strain level in the FRP as 8.8×10^{-3}.

So, this is the effective strain level in the FRP and this strain level we can use it here and from the previous step we have obtained that what will be the maximum f_l. So, what will be the required f_l that is the lateral confining pressure that we have obtained from the previous step, so that is 8.7 MPa. So, this is the required maximum lateral confining pressure that is to be provided by the confining material.

So here in this step we need to find out what will be the number of plies if the required lateral pressure is 8.7 as we have obtained from the previous step. The lateral dimension can be written here because we know the dimension of the column, we know the E_f that we have selected a CFRP system. So, the t_f and E_f are known to us and we have also estimated the effective strain level in the FRP using this equation.

So, this effective strain level is coming out as 8.8×10^{-3}. So, by putting these values and by rearranging this equation we can find out the number of plies of CFRP that is required.

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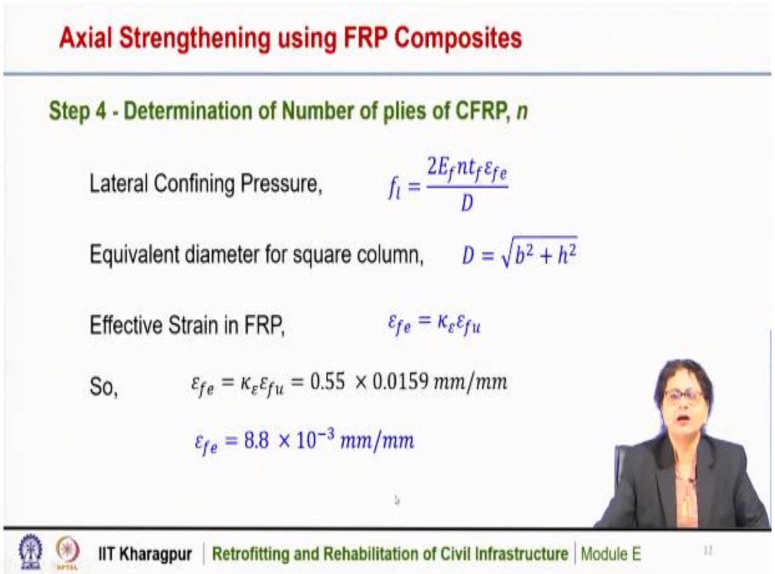

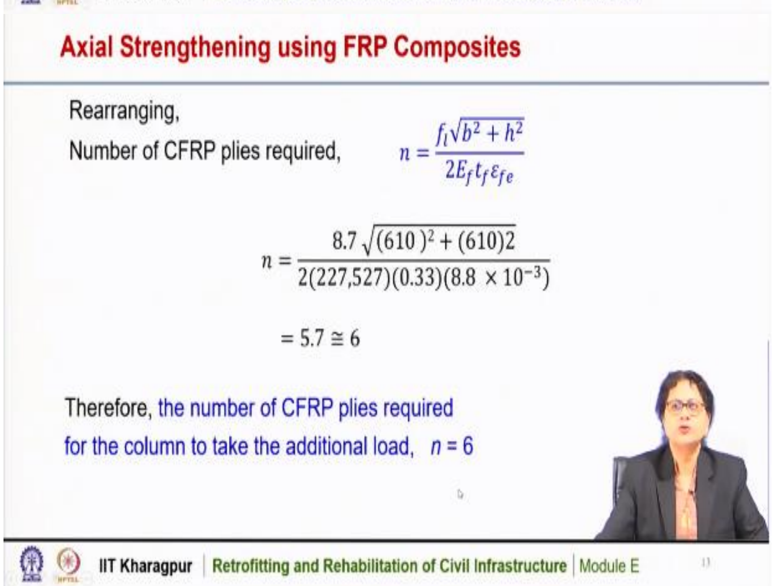

So, here by rearranging we can write the number of plies for the confined concrete column is n is equal to $n = [f_l\sqrt{(b^2+h^2)}]/(2E_f t_f \varepsilon_{fe})$. So, here this equation for lateral confining pressure we are just rearranging it to find out what is n.

We have obtained what should be the required lateral confining pressure because we know that what is the required confined concrete strength from that we have obtained what is the required lateral confining pressure and, in this equation, we have put that required f_l value to find out the n value, so that has been done here.

So, we have rearranged that equation and putting the values of f_l which is 8.7 and this is the equivalent diameter for the square section that is equal to $D = \sqrt{(b^2+h^2)}$, b and h are same and E_f is known to us, it is the elastic modulus of the FRP, t_f is the thickness of the FRP and ε_{fe} is the strain level in the FRP. So, we are getting 5.6 as n. So, to make it round off we are getting n is equal to 6.

Therefore, the number of CFRP plies required for the column to take the additional load is 6. So, if we provide the CFRP system and the properties we have selected also from the manufacturers data. So, the existing column if it is retrofitted with 6 number of plies of the CFRP then the confined column will be able to take up the additional load.

So, we can see that our CFRP system what we have selected is capable of taking the additional load coming on the column if we provide 6 number of layers of CFRP around the column continuously along its length.

So, by this way we can find out what is the required number of plies for strengthening the existing column to take up the additional load. So, we need to know that what is our required strength, how much additional load the column needs to carry and from that we can find out that what will be the confined concrete strength or what is the fcc dashed because we know that what is the design strength. So, what will be the confined concrete strength.

So, if the confined concrete strength is known to us by rearranging, we can find that what will be the required f_l or what is the required lateral confining pressure because we know the equations for that, the equations have been developed based on several experimental works. So, what is the required f_l for the confined concrete system?

So, how much amount of FRP reinforcement is required to produce that amount of lateral confining pressure that needs to be found out. So, if we have selected one CFRP or any other FRP composite strips how much is the total reinforcement that is how much, how many numbers of plies are required so that it can produce that amount of lateral confining pressure.

So, from that we can find what is the required lateral confining pressure and then we need to calculate also the strain levels and from that by using the equation that has been developed for lateral confining pressure we can find out the number of plies required because the lateral confining pressure depends on the stiffness of the confining material, the thickness and number of plies.

So, it requires this information, so from that and from the required f_l value we can find out the number of CFRP plies required for the column. So, here in this case we are getting n is equal to 6, that means 6 number of plies are required for the column to take up the additional load coming on it.

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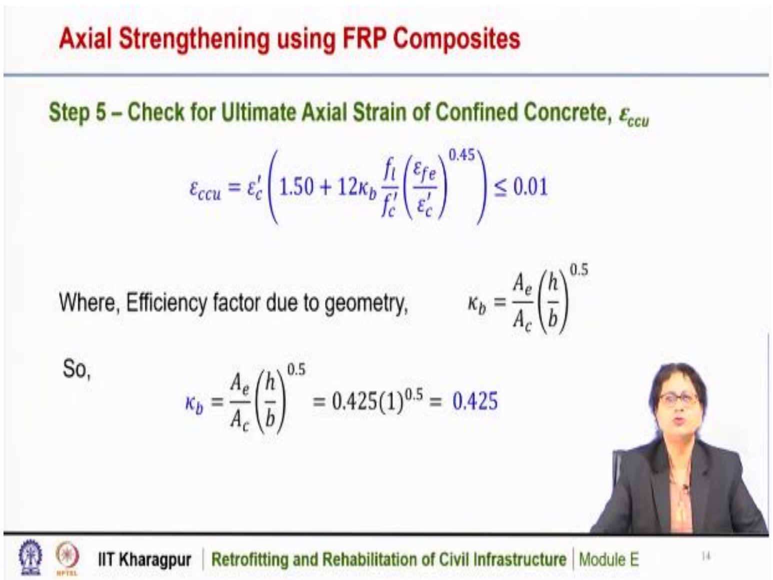

Now, we need to check the ultimate axial strain because that ultimate axial strain that is ε_{ccu} should be less than 0.01 to restrict the failure of the concrete. So, this ultimate strain in the confined concrete should be less than 0.01. So, this equation has been used to determine the ε_{ccu} and for that also we have another parameter efficiency factor due to geometry that is κ_b.

So, here also this another factor is there κ_b and this is expressed by this equation. So, here also we can find out this value of κ_b, we have already determined the ratio A_e / A_c and we know h and b for the square column it is the same. So, we can find out κ_b is equal to 0.425.

Now, we can use this value of κ_b and we know that what is the required f_l, what is the f_c' that is original concrete compressive strength, the ε_{fe} is the strain level in the FRP, ε_c' is the strain in the concrete. So, we can find out the ε_{ccu}.

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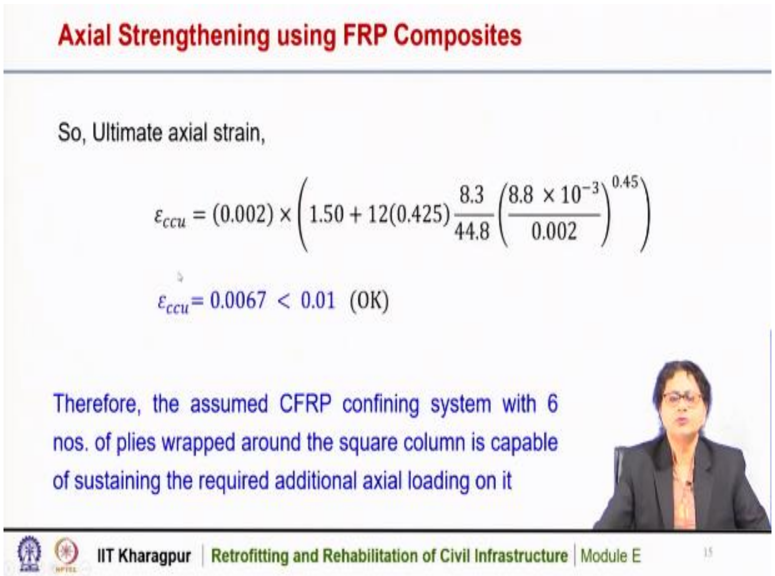

So, the ε_{ccu} is obtained from this equation and the strain level in the concrete before strengthening we are taking 0.002 that we have mentioned earlier. So, that value of epsilon c dash has been used here and using the values for these different parameters we can find that ε_{ccu} is coming out as 0.0067, which is less than 0.01. So, it satisfies the condition of the ultimate axial strain of the confined concrete and the value coming out is less than 0.1.

Therefore, the assumed CFRP confining system with 6 number of plies wrapped around the square column is capable of sustaining the required additional axial loading on it. If the value we are getting for ε_{ccu} is more than 0.01 then we have to check the system, if from our design we get the value of ε_{ccu} is more than 0.01 then we need to change some of the parameters, we may use a different CFRP system with different properties so that the strain level of the FRP confined concrete column is less than 0.01.

So, for the present case we have used the CFRP system with the given properties as mentioned earlier and for that the strain level is also within the limit of 0.01. So, the assumed CFRP confining system with 6 number of plies wrapped around the square column is capable of sustaining the required additional axial loading on it.

So, we can consider that our assumed CFRP confining system with 6 number of plies is safe to take up the additional load for the column and by confining the column with this CFRP strip with 6 plies on it completely wrapped around it, the column is capable of taking the additional load coming on it.

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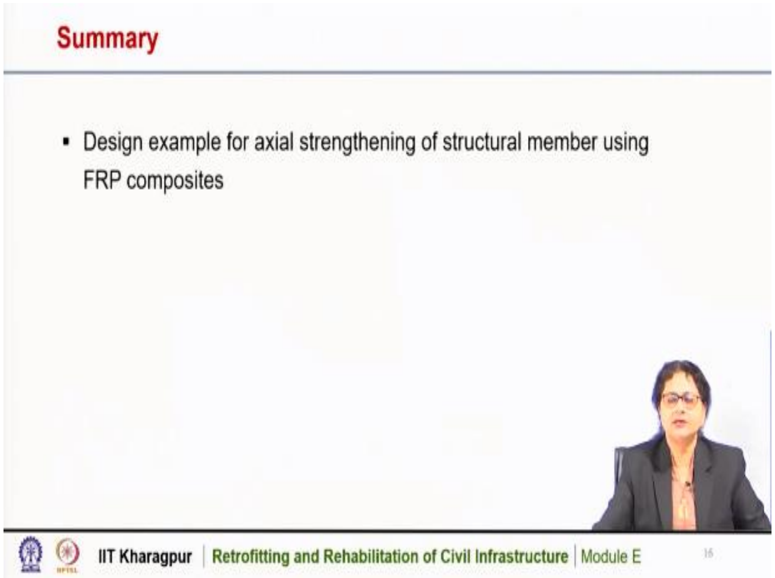

So, to summarize we have discussed a design example for axial strengthening of structural member using fiber reinforced polymer composites.

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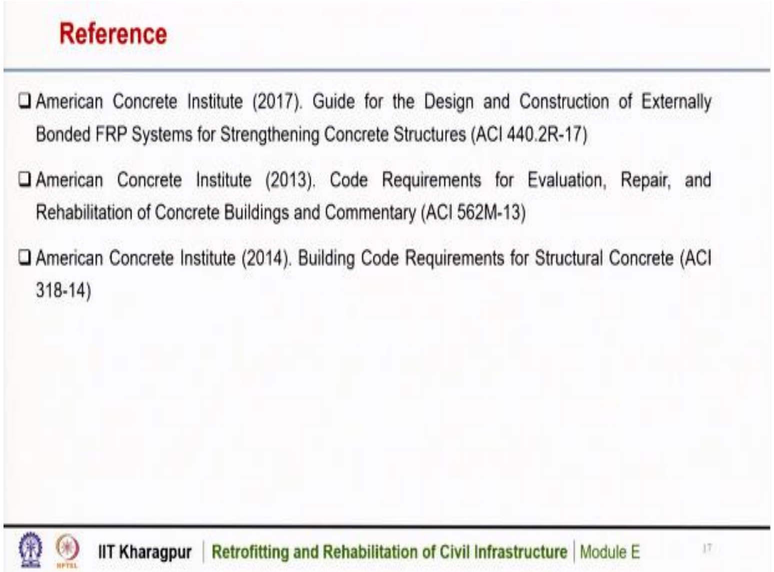

These are the references for these lectures. Thank you.