Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 16
Strengthening of Structural Components

Hello friends, welcome to the NPTEL online certification course Retrofitting and Rehabilitation of Civil Infrastructure. Today we will discuss module C. The topic for module C is General Repair and Retrofitting of Concrete Structures.

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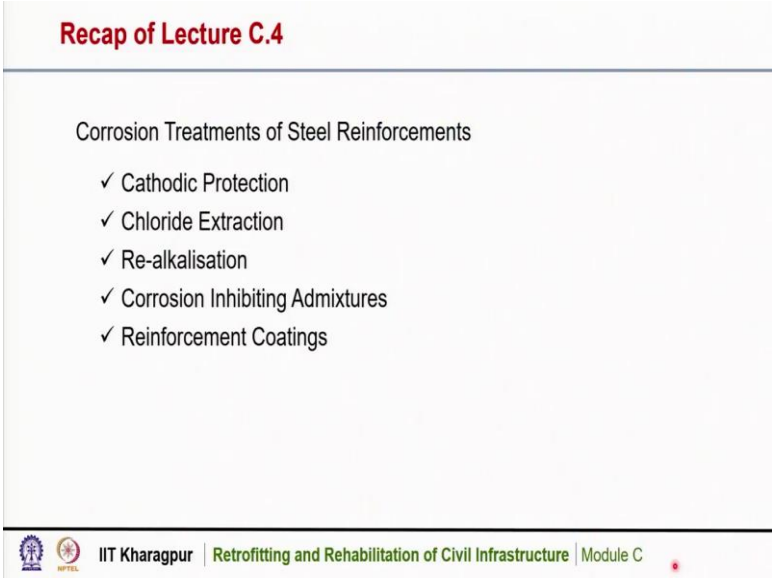

In the previous lecture, we have discussed several corrosion treatments of steel reinforcement. We have discussed cathodic protection, chloride extraction, re-alkalization for the removal of corrosion in existing steel members. We have also discussed several corrosion inhibiting admixtures and reinforcement coatings that are used to protect the steel reinforcement in existing structures.

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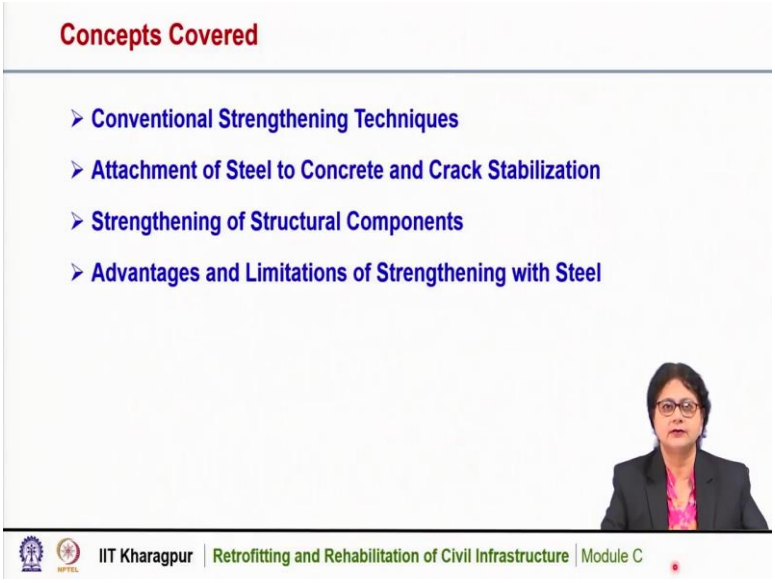

Today, we will discuss the conventional strengthening techniques of existing structures. We will discuss how we can attach the steel members to concrete and crack stabilization; we will discuss the strengthening of several structural components, typically slab, beam and columns and the advantages and limitations of strengthening with steel.

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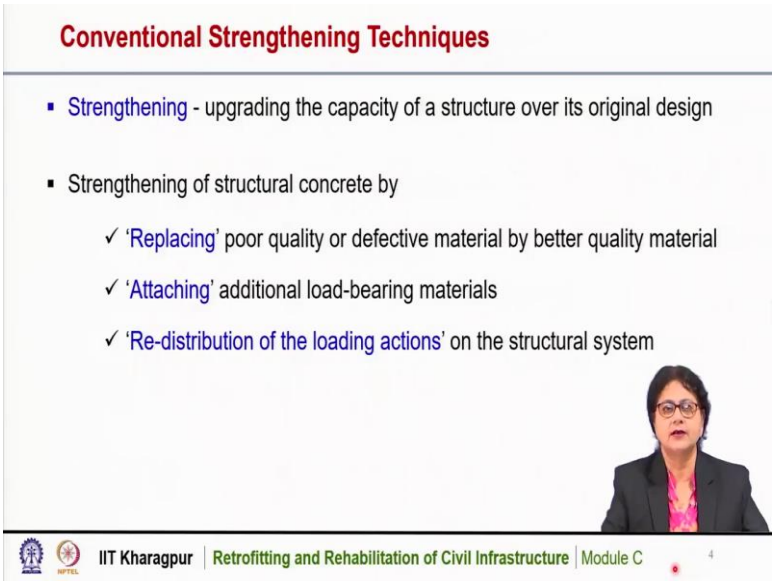

Strengthening as we have discussed earlier is the upgradation of the capacity of a structure over its original design. So, we need to upgrade the structure if it is required to improve its strength and capacity. And for that we require strengthening measures and that strengthening can be done by replacing poor quality or defective material by a better-quality material or we

can also strengthen the structural concrete by attaching an additional load bearing materials or we can also do redistribution of the loading actions on the structural system.

So, by using these techniques actually, we can strengthen an existing structure. We can replace the poor quality or defective material by a better-quality material. We can add a new material, which can take the additional load on the member and also, we can redistribute the loading action on the structural system. So, that it can take the additional load coming on it.

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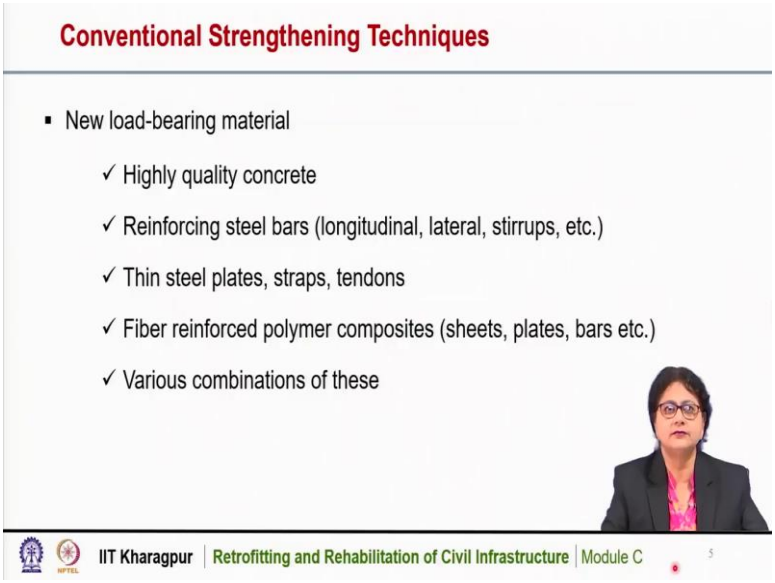

Now, the new load bearing material, it is important that it should be compatible with the existing material it should be of high strength and the rate of strength gain also should be sufficiently fast, so that it can be applied on the existing member for a strengthening purpose. It should not be susceptible to environmental actions or variations and it should be durable.

So, the new material should be compatible, should have sufficient strength gain and should be durable in nature. And for that purpose generally we use high quality concrete, reinforcing steel bars, it could be longitudinal, mean bars or stirrups. We can also use steel plates, rectangular or of any other shape, steel straps or tendons.

In recent years fiber reinforced polymer composites are also used, FRP sheets or plates or bars are also used as a new material that we will discuss later and various combinations of these materials can be used. So, we can also use concrete or steel plates or steel bars or FRP or their combinations as a new load bearing material for strengthening existing structures.

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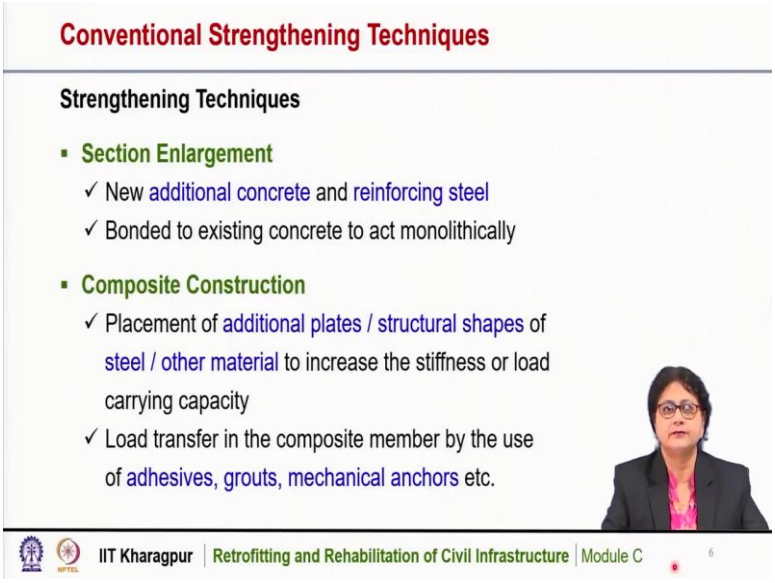

There are several strengthening techniques for existing members. And we will discuss these techniques here. The strengthening could be due to section enlargement, the existing structure is there and we can put additional concrete and reinforcing steel, so that the section of the member now retrofitted is enhanced and the new material should be bonded to the existing concrete, so that they can act monolithically.

So, a section enlargement is an effective way of strengthening an existing structure by putting additional concrete and additional reinforcing steel. The additional concrete or reinforcement steel should be bonded to the existing concrete, so that they can act as one member or monolithically. The strengthening could be also due to the composite construction.

For example, concrete structure is there and on that we can place additional steel plate or of any other material or rectangular plate or of any other shape. Structural shapes can be used to increase the stiffness of the member or its load carrying capacity. So, a concrete member can be strengthened by using steel plates or other material plates or any other shape of structural member and with that we can increase its stiffness and load carrying capacity.

And the load transfer in the composite member is done by the use of adhesives, generally epoxy adhesives, grouts or mechanical anchors. So, a composite construction can be developed and that is also a strengthening technique for existing structures.

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Post tensioning is also another strengthening technique and is widely used. In this technique, it is the placement of the tension components either internally within the member or externally to the member by jacking and the tension components that are used for this purpose are steel plates, rods or tendons or strands, etcetera.

These post tension members provide the member an active load carrying capability relieves the overstressing and reduces the deflections. So, post tensioning whether it is internally or externally post tension that improves the load carrying capacity of the existing member and releases overstressing or deflections to the member. Stress reduction can be done by altering the existing structural system.

This we can do by cutting new expansion joints on the member, by jacking displaced structure or installing isolation bearings or removal of portions of the structure. So, by these techniques we can modify the structural system a bit and with that it reduces the stress in the member. So, this method also is used and this is used for stress reduction and as a strengthening technique of the existing members.

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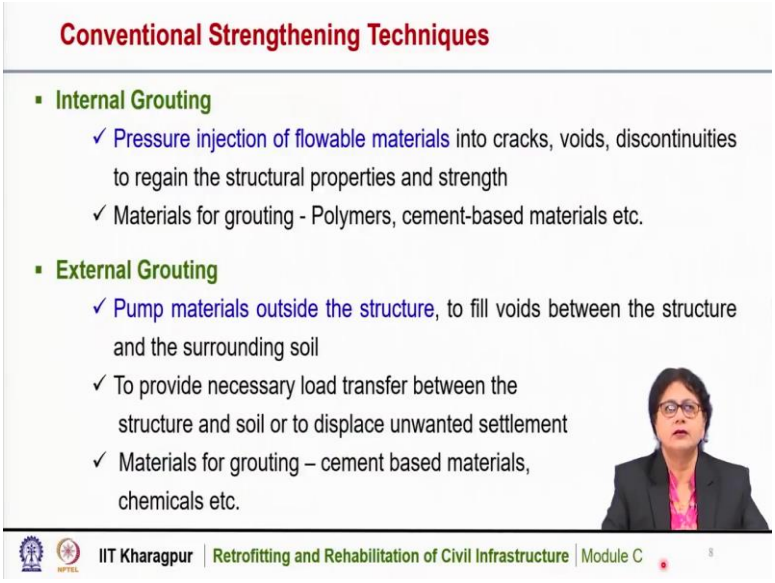

Internal grouting and external grouting are also used for strengthening purposes and they are used for existing structures. In case of internal grouting, it is the pressure injection of loadable materials into the cracks, voids or discontinuities within the member, to regain the structural properties and strength and the materials that are used for internal grouting are polymers or cement based materials or epoxy, etcetera.

And they are used widely for existing structures to repair cracks and to restore the strength and also to improve its structural capacity. In case of external grouting, it is the pumping of the materials outside the structure to fill the voids between the structure and the surrounding soil. External grouting is used to provide the necessary load transfer between the structure and the soil or to displace unwanted settlement of the structure.

So, we can use external grouting by pumping a material or grouting material and that grouting material maybe a cement based material or some chemical grout and that enhances the capacity by filling the voids between the structure and the surrounding soil. So, grouting is a technique that is used to strengthen the existing structure and internal grouting can be used or external grouting outside the structure to fill up the voids between the structure and the surrounding soil and they are used as a strengthening technique of existing structures.

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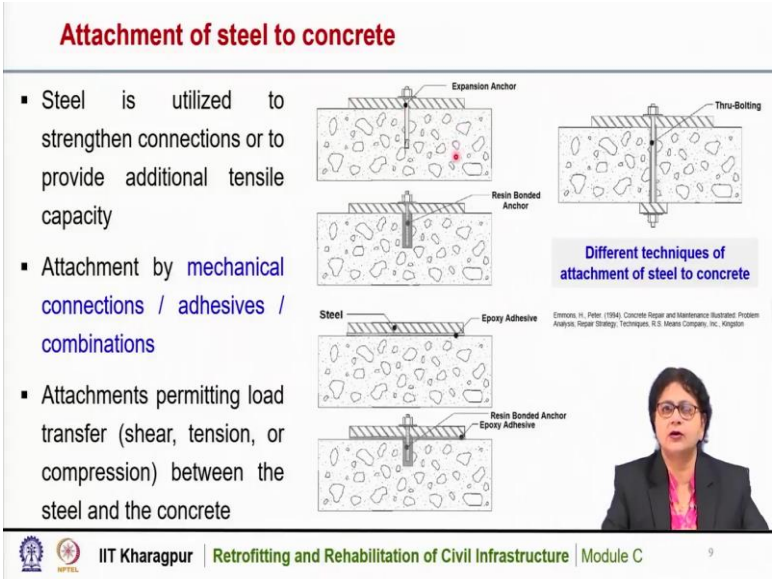

Now, these strengthening techniques we have discussed that can be done either by using new materials or grouting or by stress reduction or post tensioning, etcetera and in many of the cases we need to attach steel plates or steel members to the existing member. So, we have to follow certain, we have to follow certain guidelines for the attachment of steel to the existing structure.

Steel is used to strengthen the connections or to provide additional tensile capacity. So, sometimes we use steel rods to improve the tensile capacity or we can use steel plates also to improve the tensile capacity and that is used also to strengthen the connection.

It is the attachment is done by mechanical connections like anchor bolts or adhesives or their combinations and the attachments permitting the load transfer between the steel and the concrete. So, steel is to be attached on the existing concrete member using mechanical connectors like anchors or adhesives and their combinations.

So, here are some schematic diagrams by which we can see different techniques of attachment of steel to concrete. Look at this picture, this is the steel plate that is to be attached on the concrete, this is the existing concrete. So, here what we can do? We can insert a bolt, a mechanical anchor and with that the steel plate is attached to the existing concrete.

So, it is by this expansion anchor, we can attach the steel plate to the existing concrete member. We can also do it by drilling a hole, you can see here this is a hole is drilled and it is filled up with resin. So, mold is to be inserted through this resin filled hole and it is then fixed

up. So, it is the resin bonded anchor and this is the steel plate and with this anchoring system it is attached to the existing member.

We can use just an epoxy adhesive for anchoring the steel plate; we can see here the epoxy adhesive is used to attach the steel plate over the existing concrete member. So, this is the steel plate that is to be attached and epoxy adhesive is placed on the existing member and it is attached or we can use a combination of this that means, hole is drilled, it is filled up with resin and on the surface of the existing concrete epoxy adhesive is placed and then the steel plate is placed and it is anchored through the bolt.

So, epoxy adhesive as well as the bolts are used for attachment of the steel plate to the existing concrete. Another way is that we can make through hole by drilling and then use a through bolting on the existing member to attach the steel plate. So, a through bolt is also used to attach the steel plate onto the existing member.

So, it is in many cases strengthening is done by attaching steel plates or any steel members. And that attaching can be done by either by epoxy adhesive only or by mechanical anchors or bolts and also by the combination of epoxy adhesive and anchor bolts or it can be done through bolting.

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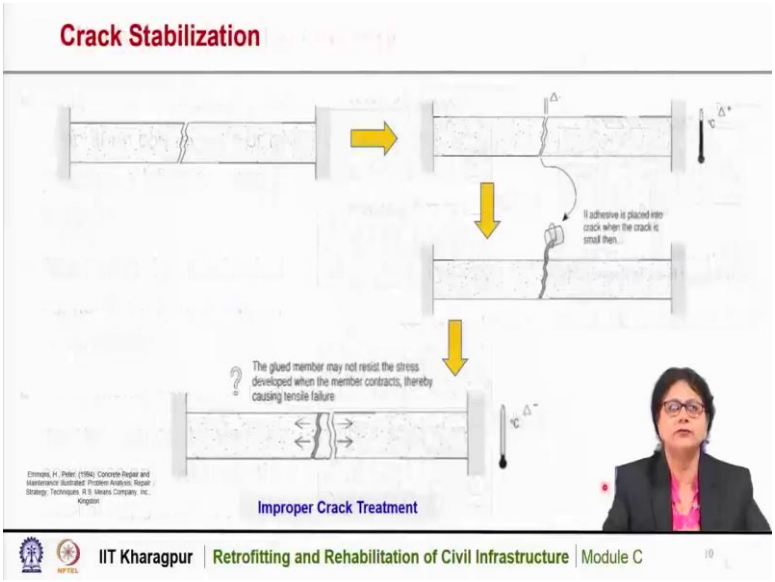

Now, we will discuss the crack stabilization, it is important to fill up the cracks present in the existing member, and for that we have to follow certain steps. If there is a crack through the entire depth of the member and it is to be filled up then we have to use in most of the cases it

is the epoxy resin that is used to for filling up the cracks. And look at these pictures, we have to fill up the cracks considering the time of repair.

In many cases the in-summer time there may be an expansion of the members and in winter time there may be contraction of the members. So, in case of summer time, if there is expansion of the 2 parts of this member, then the width of the crack becomes less, as you can see when there is increase in temperature, the crack width is less.

Now, if we can repair at this time, the crack we can fill it up with epoxy resin or so, then during the contraction period like in winter time the 2 parts may get contracted, and in that case the epoxy in the cracked portion may experience a tensile force. So, it may crack at some part. So, we can see here that there may be a crack development on the member and this is not the correct way of crack treatment.

So, we have to see that when the crack width is maximum, and during that time, it is desirable to treat the crack with proper filling.

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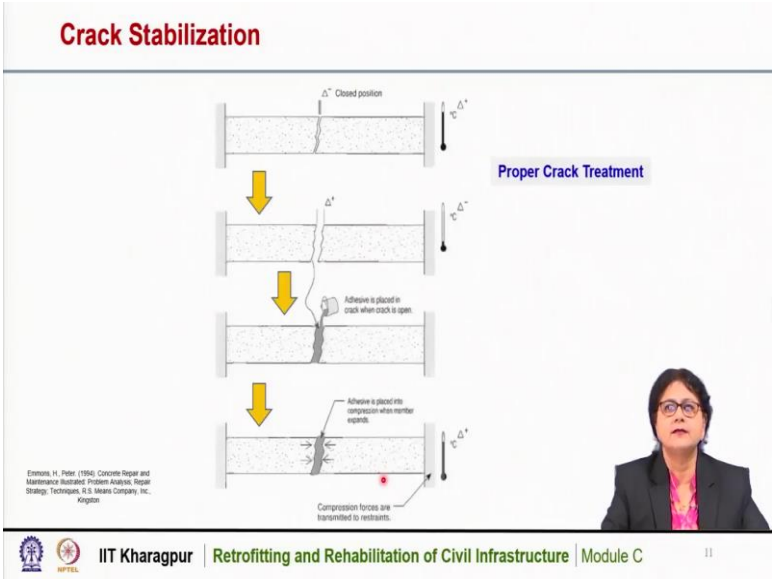

So, when the crack width is maximum, it is desirable to fill up the cracks. In the winter time, when the 2 members may get contracted, so the crack width is much more as you can see here, the crack width is much more as in case of summer time. So, that time we can fill up the crack with epoxy grout or cement grouting.

So, in that case, when there is expansion, the repaired portion may experience a compressive force and that it can sustain. So, this is the proper way of crack treatment. And whenever the crack width is much more or maximum, we can use that time for crack repairing.

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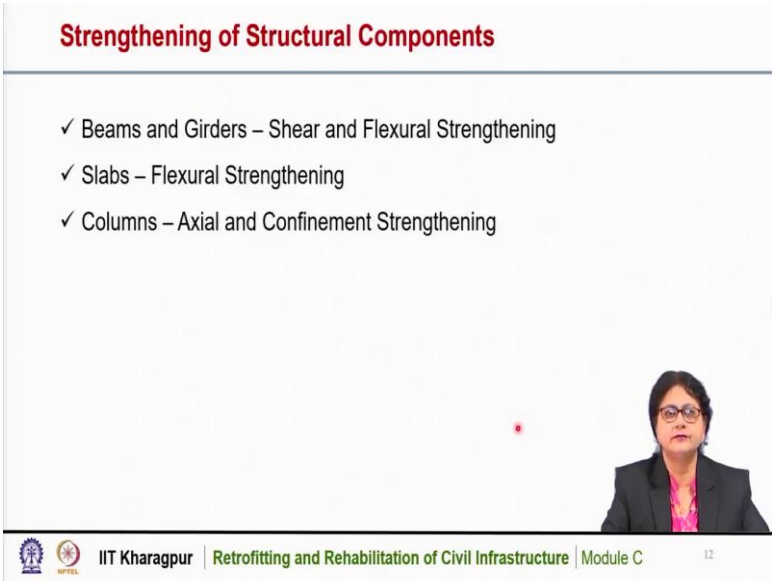

Now, we will discuss the strengthening of different structural components. We will discuss the shear and flexural strengthening of beams and girders. The flexural strengthening of slabs and for columns, we will discuss the axial and confinement strengthening.

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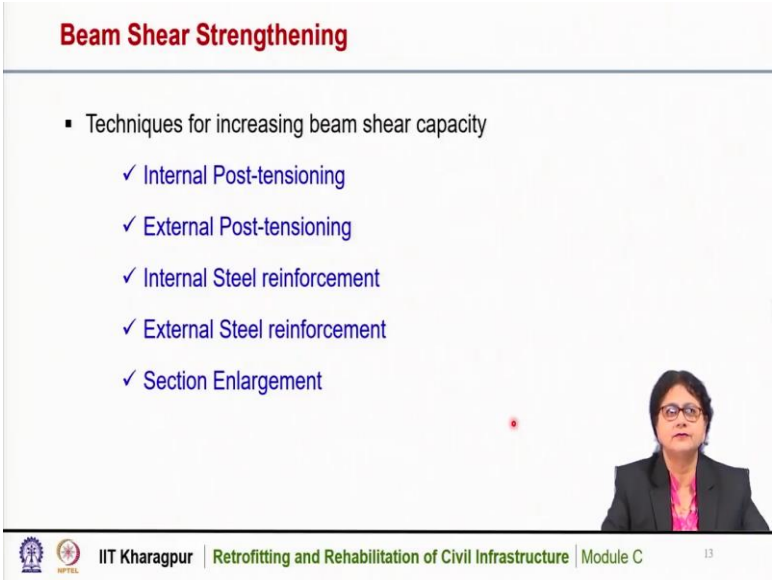

For existing beams, it is sometimes required to improve its shear capacity, there are several techniques for increasing the beam shear capacity like internal post tensioning, external post

tensioning, internal steel reinforcement, external steel reinforcement and section enlargement. So, we will discuss these techniques.

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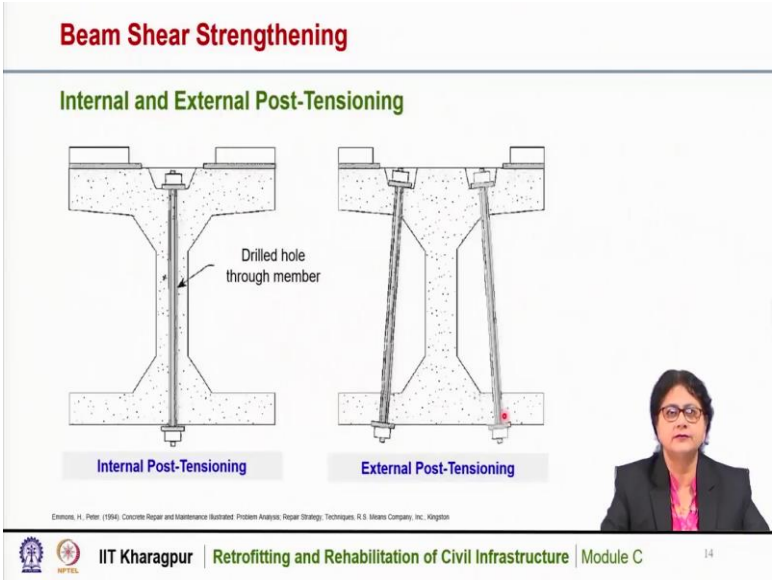

Internal and external post tensioning is done by drilling holes either through the member entirely or through some parts of the member. So, here you can see that this is a concrete girder and a hole is drilled through the member and steel bars or rods or tendons are inserted into it and then it is bolted. So, this way we can do internal post tensioning and then the hole can be filled up by epoxy resin. So, that there is no gap in it.

And in case of external post tensioning some parts of the member is to be drilled as you can see, and most of the steel rod or tendon is exposed. So, this is termed as external post tensioning and this can improve the shear capacity of the beam or girders significantly. So, this type of steel rods can be placed at suitable spacing at regular spacing throughout the length of the member, so that it can improve its shear capacity. So, this is internal post tensioning and external post tensioning.

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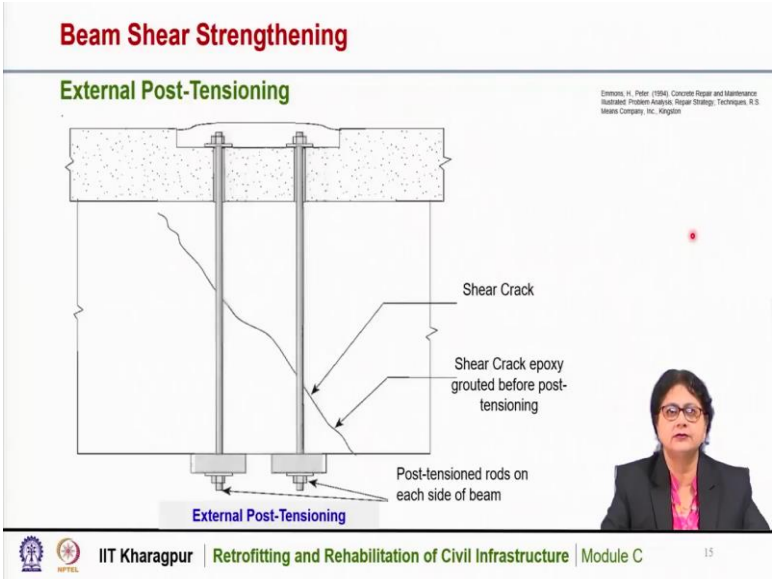

You can see here, in this schematic diagram this is a concrete member and this is a typical shear crack and this is along the length of the member these are typical shear cracks present. So, in that case, we can also do external post tensioning by drilling some part of it and by taking you can see here this part has been considered near the shear crack region and through this part, a hole is drilled and then steel bar, post tension rod is inserted and then it is fixed here.

So, these are post tension rods on each side of the beam, depending on the number of cracks, we can select the number of bars also and then the shear crack is to be filled up with epoxy grouting before post tensioning. So, cracks need to be filled up by epoxy injection and then we can place the external post tensioning to the member to improve it shear capacity.

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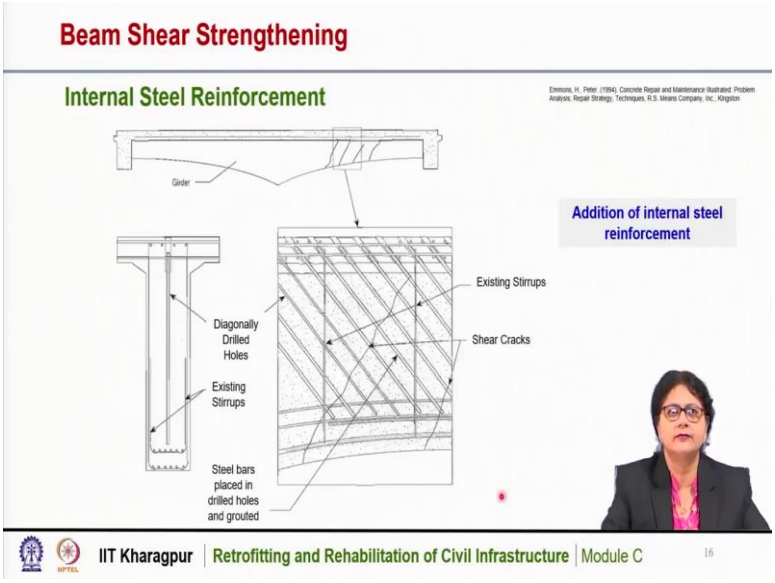

Here you can see that this is a schematic diagram of a girder and there are a number of shear cracks. So, if a more number of shear cracks are there, another technique can also be used using internal steel reinforcement insertion. So, here is what we can do these are the typical shear cracks and perpendicular to these shear cracks, we can drill a number of holes as you can see here, these are the holes to be drilled which are perpendicular to the shear cracks.

And in these holes, we have to insert steel bars. So, steel bars are placed in the drilled holes and the holes need to be grouted. Before inserting the steel bars, all the shear cracks are to be epoxy grouted or epoxy injected and they are to be filled up and then we can make the holes and insert steel bars. So that its shear capacity is improved.

So, these are the diagonally drilled holes and these are the existing stirrups, this is the existing stirrups and these holes are made perpendicular to the shear cracks and through these holes we can insert the steel bars so that its shear capacity is increased. So, this is also another technique of improving the shear strength of the existing members.

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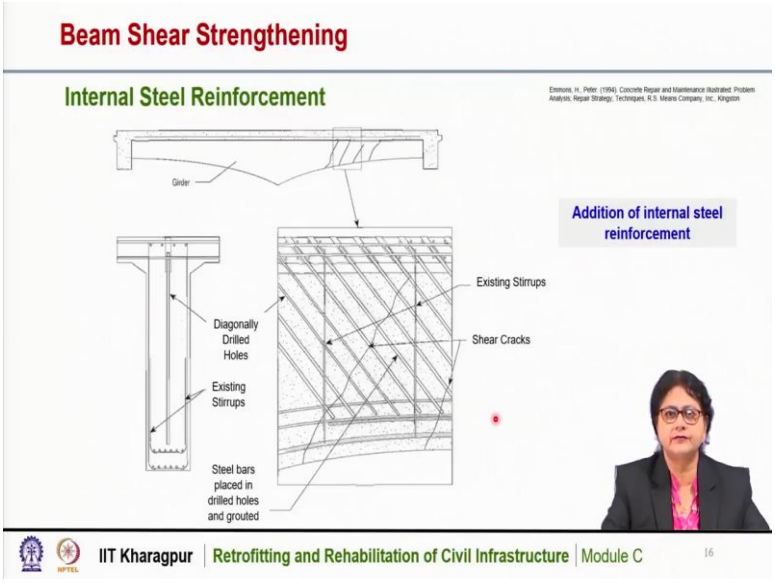

We have discussed the steel bar reinforcement, internally we can use to improve the shear capacity. We can also improve the shear capacity of the existing beam or girders by external steel reinforcement, here you can see that these are the typical shear cracks on the member.

So, by adding external steel plates, thin steel plates or strips, we can improve its shear capacity that means, it is like external stirrups we are adding to the existing member to increase its shear capacity. So, these are the typical shear cracks and those cracks need to be grouted with epoxy injection and after that the steel plates or strips are to be placed at certain spacing as external stirrups to improve it shear capacity.

So, this is a steel plate bonding this picture shows that the external steel plates are placed on the existing beam to improve its shear capacity. So, these are the techniques for improving the beam shear strength of existing members by adding steel reinforcement or steel stirrups internally or externally and also by internal post tensioning and external post tensioning.

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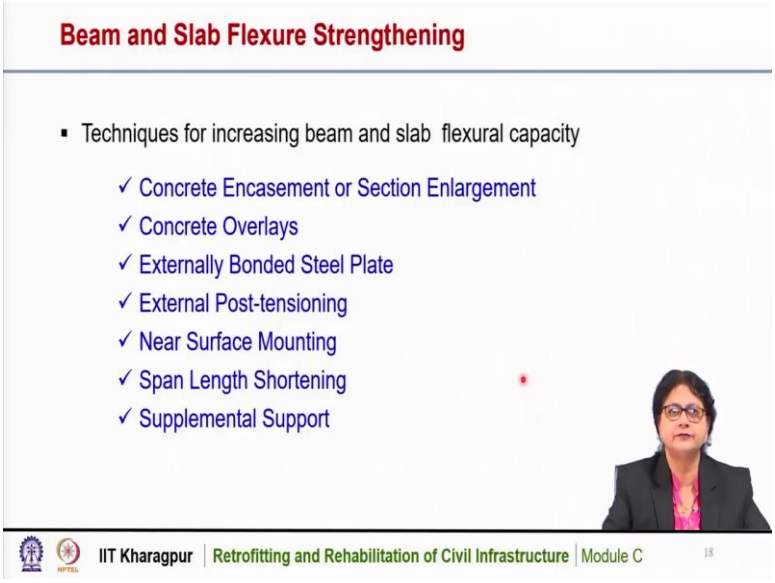

Now, we will discuss the flexural strengthening of beams and slab. There are several methods for improving the flexural capacity of beams and slabs. We can use section enlargement or concrete encasement for improving the flexural capacity of members.

We can use concrete overlays. We can also use externally bonded steel plate, external post tensioning, near surface mounting, span length shortening and supplemental support all are used to improve the flexural capacity of the beams or slabs of existing members.

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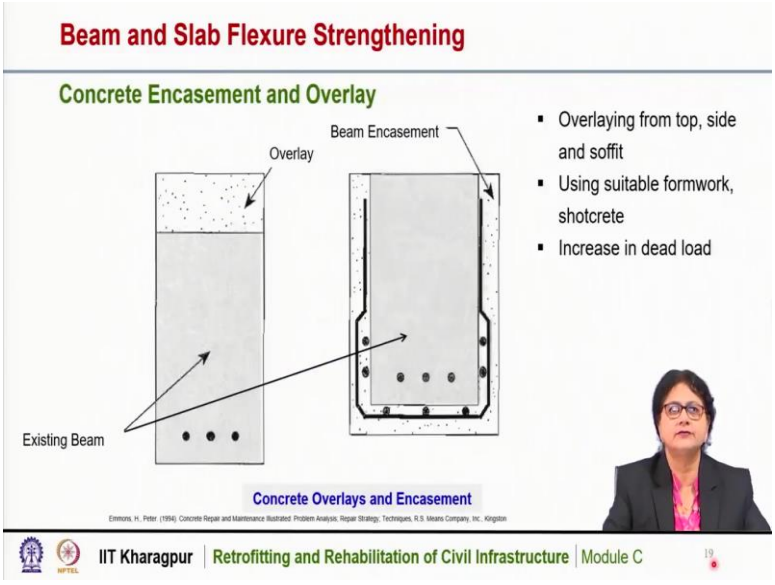

These are pictures of a concrete encasement and overlay. Overlay can be from top of the member or side or soffit or bottom. As you can see, this is an existing beam member with

existing steel reinforcement, and this is the overlay that is placed on top of the member. So, the overlay is on the top of the member or it could be at the sides or at the bottom.

Sometimes in most of the cases, we use additional reinforcement and stirrups for the encasement. And we also require suitable formwork for this. Sometimes particularly for the soffit part, we can also use shotcreting or guniting for the concreting part. And this we have to keep in mind that while doing the encasement or overlay there is an increase in the dead load of the member.

So, the member should be able to take up that additional load and for that necessary reinforcement may also be added. So, concrete encasement or overlaying is one common technique for improving the flexural capacity of the beams or slab members.

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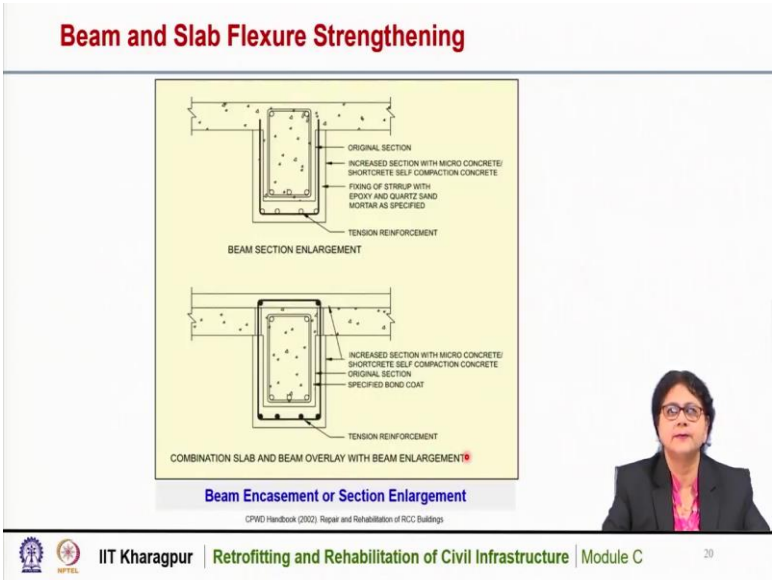

Here we can see that section enlargement or beam encasement, we can use stirrups as well as longitudinal main reinforcement. The stirrups can be 3 sided, or it could be on all 4 sides like for the existing one. So, this way we can improve the flexural capacity, the main tension reinforcement can be added and also the stirrups and with that, over it we can use the additional concreting and that could be micro concreting also, and we can use additional formwork for putting the additional concrete. So, this is a typical sketches of section enlargement or beam encasement.

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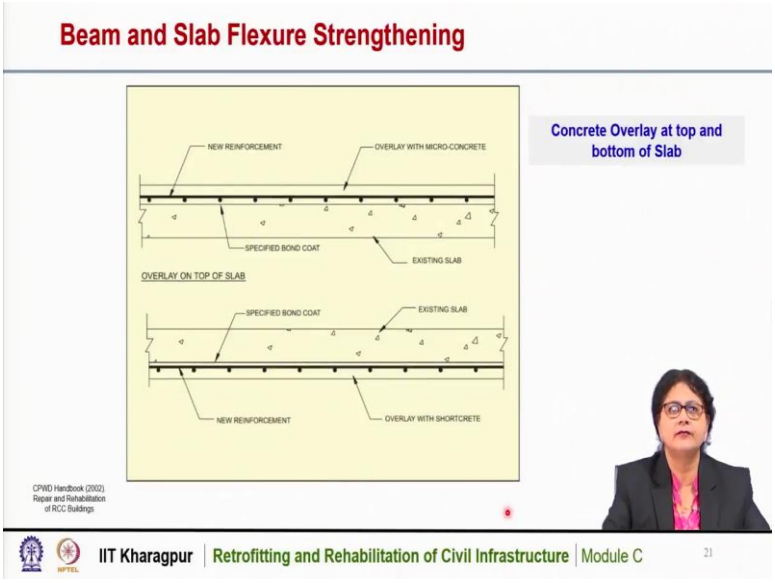

This is concrete overlay at top and bottom of slab. This is the existing slab you can see here this is the existing slab and an overlay can be laid over it with reinforcement. So, this is overlay on top of slab with additional reinforcement. Sometimes it is required to provide additional concreting below the slab. So, here you can see this is the existing slab and an additional concreting can be done below the existing slab.

So, this can be done with shotcreting or guniting and this is particularly done in case of a deck slab. So, here if the flexural strengthening is required we can use this type of additional concreting below the slab and for any other floor slab, if we want to improve its flexural capacity we can use a overlay on the top of it. So, overlay at top or bottom of slab is an effective means of improving the flexural capacity of the member.

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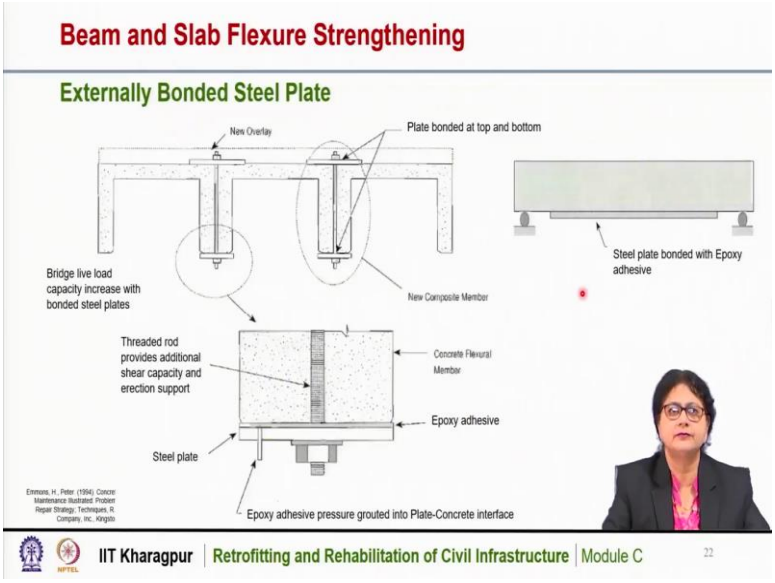

Externally bonded steel plates are effective way of improving the flexural capacity of members. We can see here this is a typical schematic diagram of girder of a bridge, you can see how these are the longitudinal girders and this is the deck slab and if we want to improve its flexural capacity, steel plates can be added at the tension face of the member. Look at this schematic diagram, this is a simply supported beam.

So, tension is at the bottom of the beam member. So, at the tension face of the member, we can add the steel plate which is attached by epoxy adhesive or by molting and this can improve its flexural capacity. In case of a continuous beam, the tension phase will be at the bottom of the slab and also at the top near the support.

So, we can add steel plates and the tension faces, you can see here, this is a steel plate attached at the bottom of the girder and also at the top of the garden; so to improve the tensile capacity of the member or improve its flexural capacity. And this is an effective way of improving the tensile capacity or flexural capacity of the member and this is the enlarged view of this part.

You can see here threaded rod provides additional shear capacity and erection support to the member and this is the steel plate and which is to be attached by epoxy adhesive and bolting. So, externally bonded steel plates are effective measures for improving the flexural capacity of beam members.

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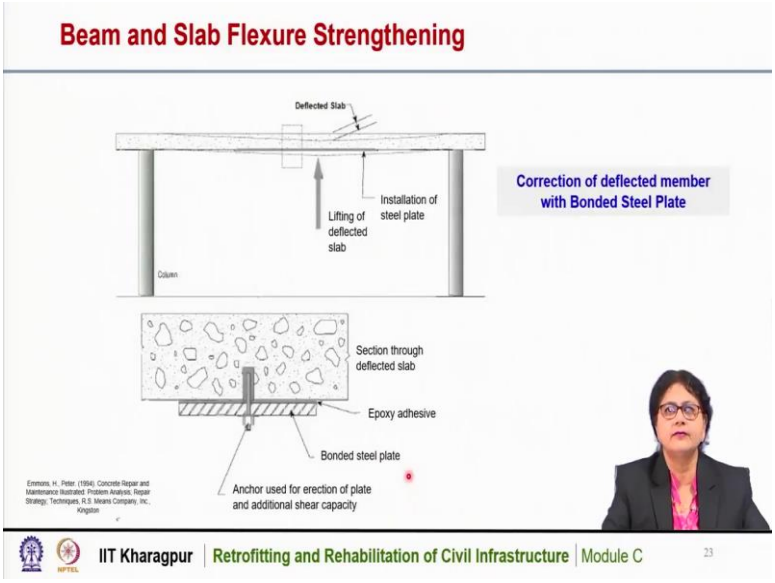

Here is also another schematic diagram to improve the deflection of the member by bonded steel plates. Look at this picture, this is a slab and the slab is deflected because of its increased loading and span length. So, the there is significant deflection at the middle of the slab and this can be corrected by attaching steel plates.

So, here first we need to lift up the deflected slab and then we can install a steel plate at the tension face of it and with that the additional deflection can be corrected. So, this is the enlarged view. You can see here, this is the existing members section through the deflected slab and this is the steel plate and it is to be bonded to the existing member by epoxy adhesive and anchor bolts.

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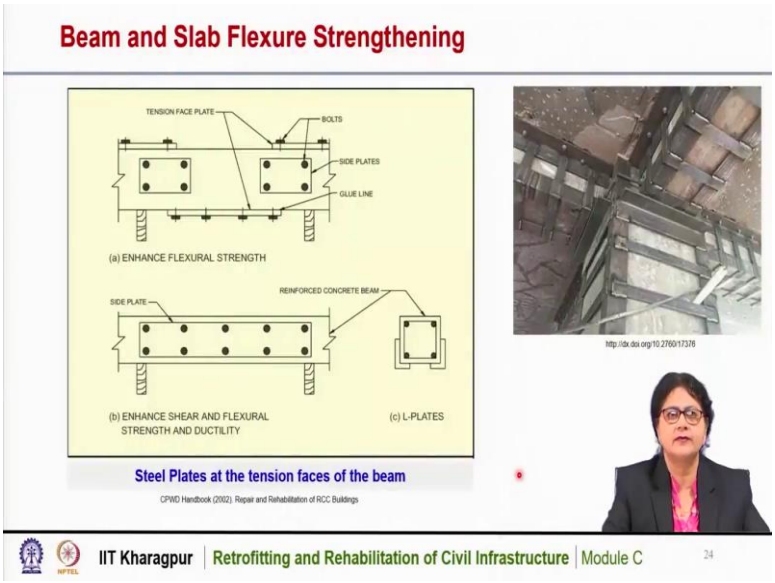

These are also some pictures of attachment of steel plates, at the tension face of the beam, we can also use the plates at the sides you can see here at the bottom or top of the member and also at the sides, we can also use L plates to improve the flexural capacity of the member.

And this picture shows that these are the steel plates to improve the shear capacity and also the L plates as you can see here, these are the L plates to improve the flexural capacity of the beam members. So, these are typical examples of improving the flexural capacity of the existing beam or slab members by attaching steel plates at the bottom or at the tension face of the members.

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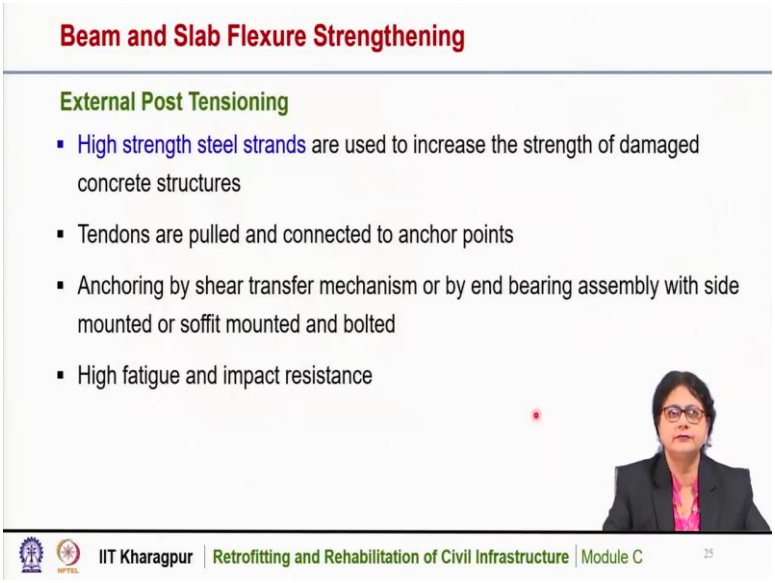

Now, we will discuss external post tensioning. External post tensioning is also used for flexural strengthening. External post tensioning are high strength steel strands which are used to increase the strength of damaged concrete structures. The tendons are pulled and connected to anchor points. The anchoring by shear transfer mechanism or by in bearing assembly with side mounted or soffit mounted and bolted. And these high strength steel strands have high fatigue and impact resistance. So, they are effective means of flexural strengthening.

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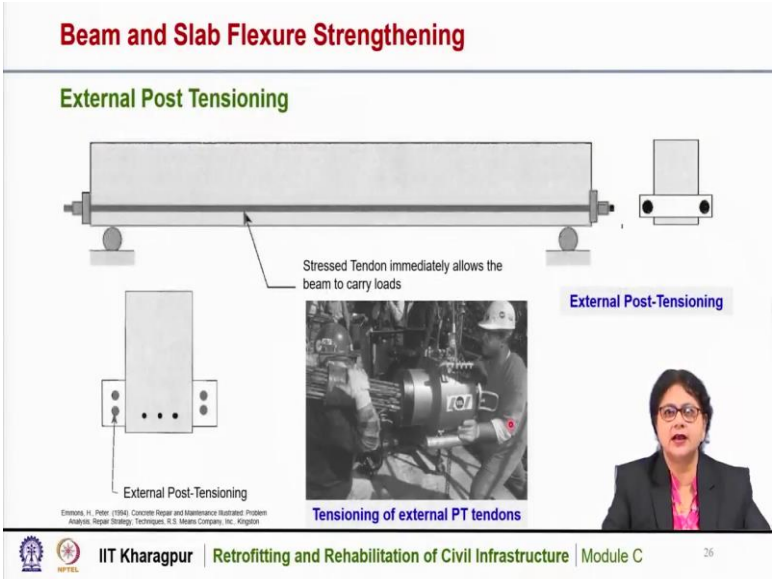

This is a schematic diagram of external post tensioning. As you can see this is the simply supported beam and this is the stress tendon which is attached to the existing beam and it allows immediately the beam to carry additional loads. These are the site views of the external post tensioning beams and this picture shows the tensioning of the external PT tendons. You can see here the post tension tendons are placed and it is tensioned so that it is anchored properly and used for improving the flexural capacity of the member.

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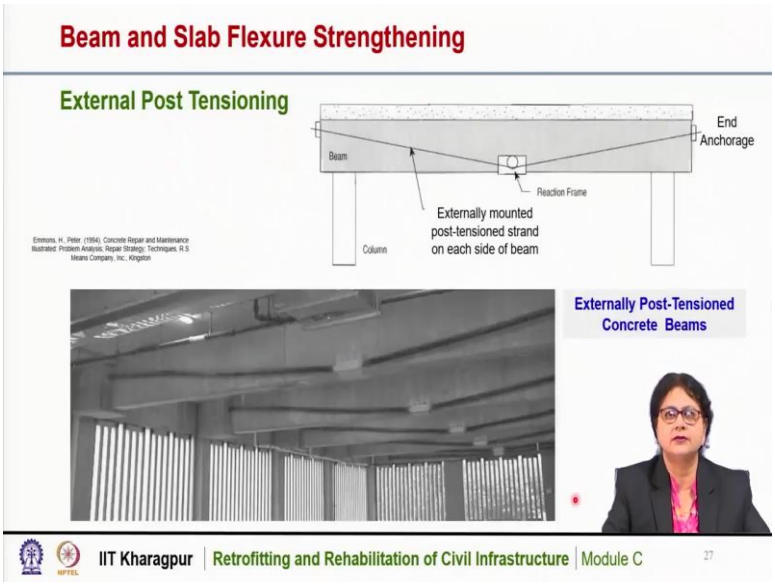

External post tensioning can also be done in this way as you can see with an additional support type of thing with a reaction frame and these are the externally mounted post

tensioned strand on each side of the beam and this is the end anchorage and with this the existing beams flexural capacity is improved.

So, here you can see that this is a typical picture of this type of external post tensioning, the beams are cracked and before the post tensioning it is important to fill up all the cracks by epoxy grouting or injection and then the post tensioning can be applied. So, this is a typical external post tensioning and on both sides of the existing beam to improve its flexural capacity.

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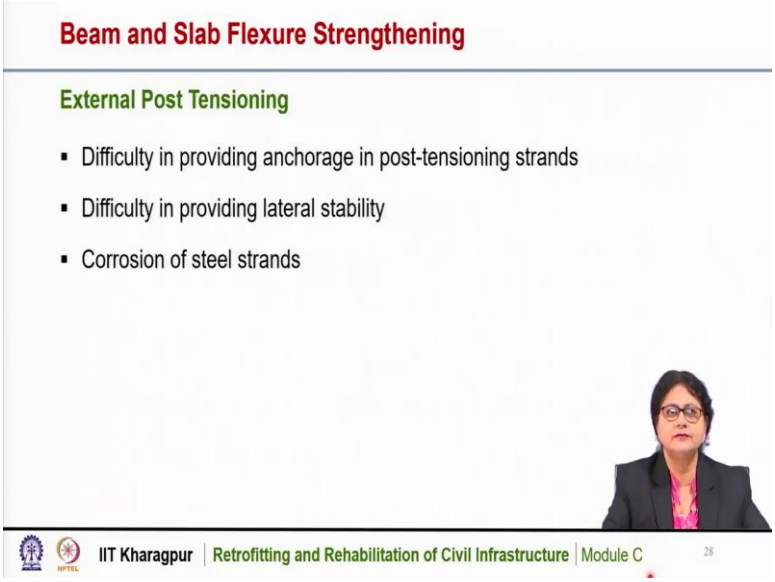

External post tensioning is quite effective and is used widely for improving the strength of existing members. However, it has some limitations; it is difficult sometimes in providing anchorage in the post tensioning strands. Sometimes it is also difficult in providing the lateral stability of the strands and since it is exposed to the environment, so corrosion of steel strands is another issue.

So, these are the limitations of post tensioning, however, they are widely used to improve the strength and capacity of existing members. But sometimes it is difficult to provide anchorage and lateral stability of the strands and corrosion may also take place because most of the cases it is the steel strands that are used for post tensioning.

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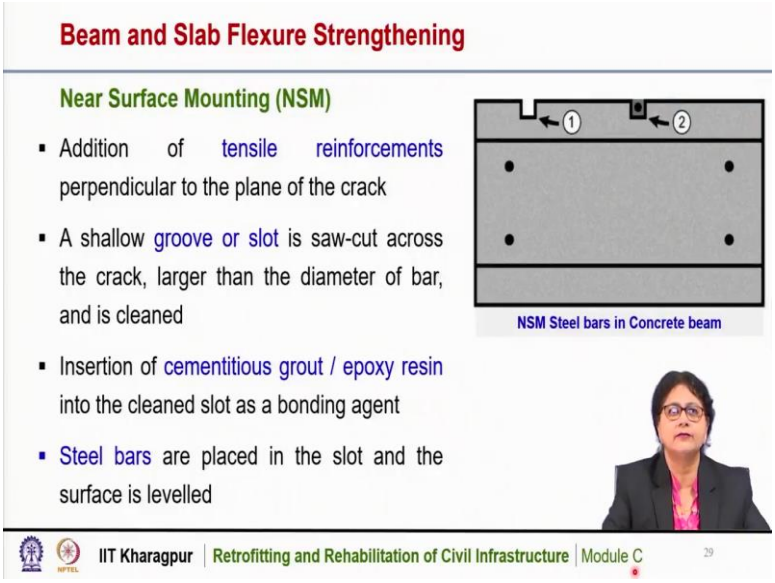

Near surface mounting is another way of improving the flexural capacity of existing members. In this technique, it is the addition of steel reinforcement particular perpendicular to the plane of the crack. So, it is the addition of tensile reinforcement perpendicular to the plane of the crack. A shallow groove or slot is saw-cut across the crack and steel bars are to be inserted into that slot.

The slot should have a dimension larger than the diameter of the bar so that the bars can be placed properly and the slot needs to be cleaned. And after placing the bar it is to be filled up with cementitious grout or epoxy resin into that slot. Steel bars are then placed in the slot and the surface is leveled.

So, this is a schematic diagram of near surface mounting or NSM steel bars in an existing member to improve its flexural capacity. We can see these are the typical slots and that slots, then we can put cementitious grout or epoxy resin and then the steel bar can be placed into these slots and then it has to be leveled.

And that indicates that this is actually an external reinforcement we are providing under tension face of the member to improve its flexural capacity. So, near surface mounting is also used to improve the flexural capacity of existing members.

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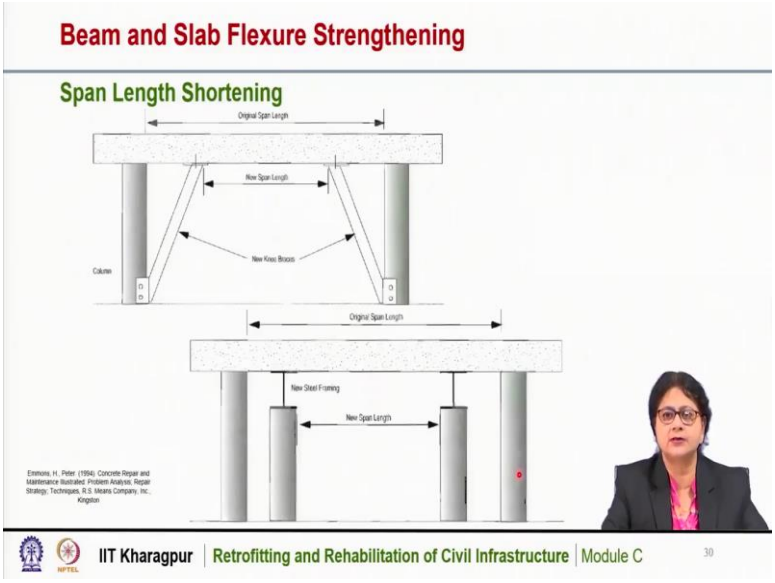

Span length shortening is also another technique, so that the moment on the existing member is reduced. We can use some steel braces, so that the effective span is reduced. And with the reduced span the moment also will be less. So, here is also another technique, you can see here the span length is shortened by placing this type of frame arrangement.

So, by shortening the span length, we can reduce the load coming on the member and with that the existing member is strengthened.

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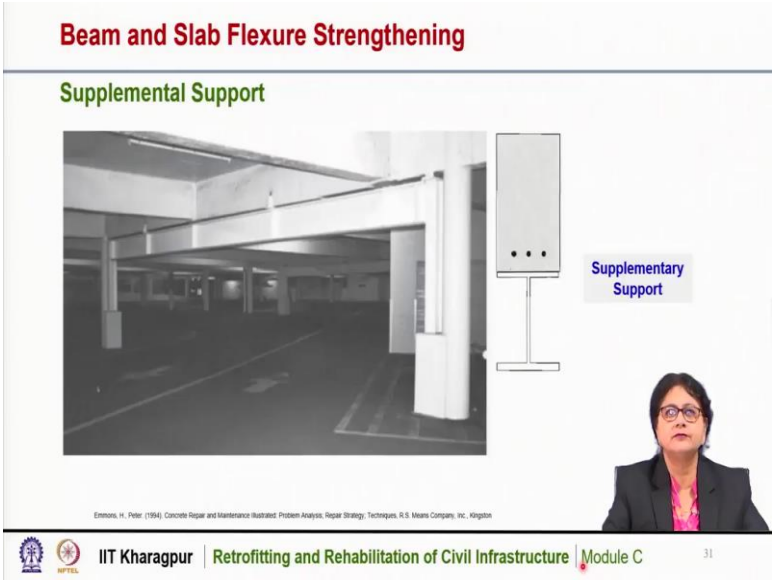

Supplemental support is also another technique for strengthening, you can see here this is the cross section of an existing beam member with existing reinforcement and a supplementary

support can be provided and this is a typical picture of the supplemental support of the existing concrete beams. So, this also can improve the existing member to take additional flexural loading.

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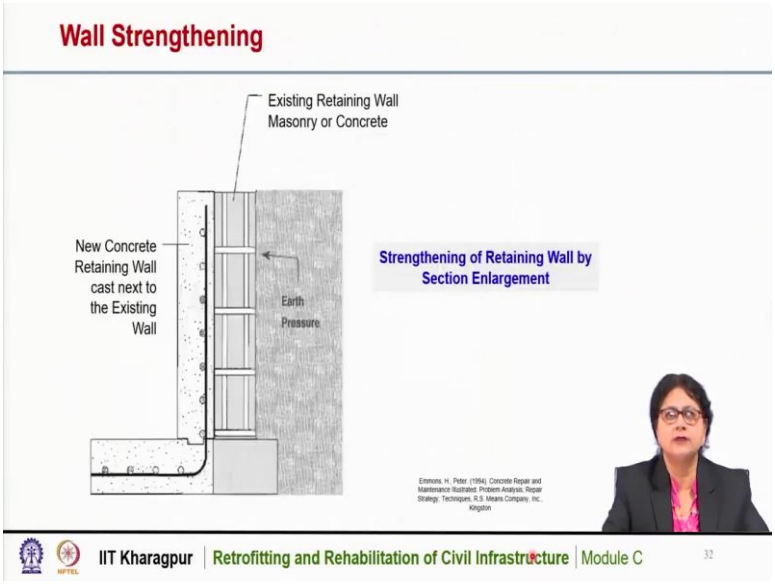

So, we have discussed the flexural strengthening of beams, girders and slabs. Now, the same way, we can improve the capacity of the walls or we can strengthen the walls particularly the retaining walls. You can see here this is a typical schematic diagram of a retaining wall which is supported here and this is the earth on it on this side. And to strengthen the retaining wall a new concrete retaining wall can be cast next to the existing wall with additional reinforcement as you can see.

So, the existing retaining wall it could be masonry or it could be concrete retaining wall and to strengthen the retaining wall we can add a new concrete retaining wall just next to it and with proper bonding and additional reinforcement can also be placed into it so that the retaining wall is strengthened by section enlargement.

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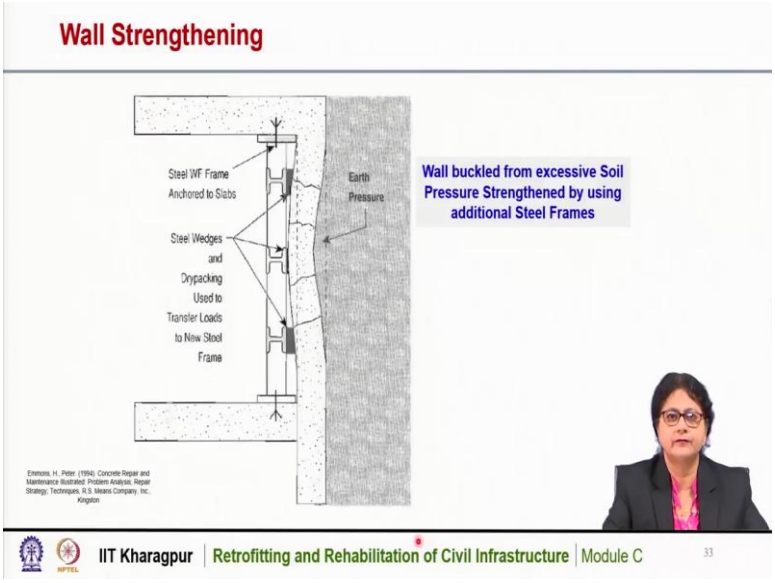

Sometimes there is high earth pressure and because of that there may be deformation on the retaining wall with lots of cracks on it. So, in that case we can strengthen the retaining wall by placing steel frame structure, as you can see here, it is an additional steel frame that has been prepared to strengthen the existing retaining wall along its length and with several joists placed on it, depending on the height of the retaining wall.

And with that proper Anchorage, the frame is attached to the existing retaining wall. So, here the wall is buckled from excessive soil pressure and it is strengthened by using additional steel frames. So, this way also we can strengthen the existing retaining wall, so that it can take the additional earth pressure coming on it.

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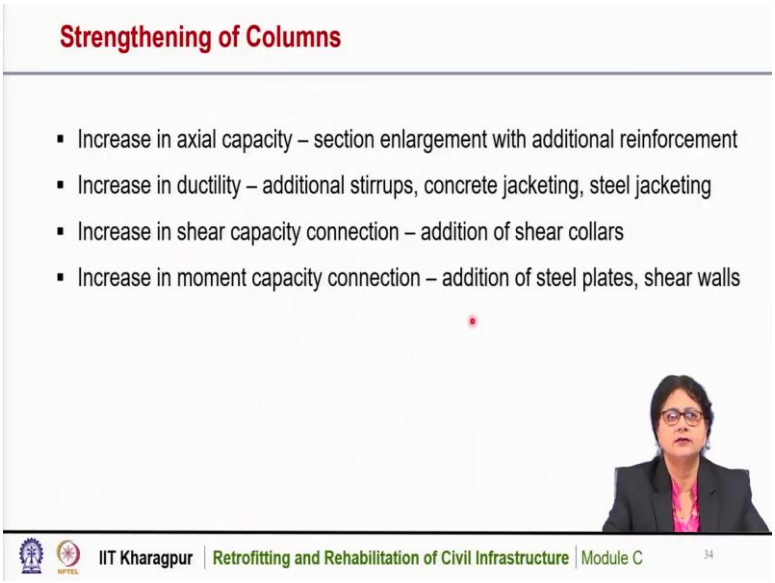

Now, we will discuss strengthening of columns. It is very important to strengthen the columns to increase its actual capacity and this we can do by section enlargement with additional reinforcement. By strengthening columns, we can increase the ductility of the column. By putting additional stirrups or concrete jacketing or steel jacketing. We can increase the shear capacity connection by the addition of shear collar.

Also, we can increase the moment capacity connection by the addition of steel plates or shear walls. So, strengthening of columns can be done to improve its axial capacity, to improve its tensile capacity and also to increase the shear capacity connection and moment capacity connection at the joints.

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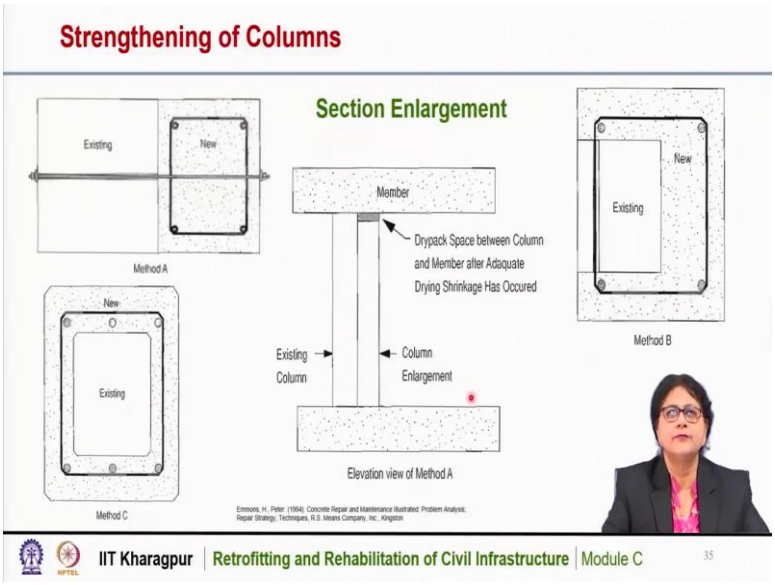

So, to improve the axial capacity of a column member, section enlargement is done. Section enlargement is a common method and it is used also for beams or slabs. And for columns also we can use the section enlargement to improve its axial capacity. So, 3 types of section enlargement can be possible. Here you can see that when the new member is cast just next to the existing member on one side of it.

So, this is the existing column and this is the new column with reinforcement and then they are tied with some anchoring system and here is the elevation of the system as you can see, this is the existing column and this is the new column and there is, some gaps may be there and that can be filled up with some epoxy grouting or dry packing and then to reduce the shrinkage type of cracks.

So, this is one method of section enlargement, on one side of the existing column a new column can be cast with this is a reinforcement and this can act as one member. We can also add the additional concreting on 3 sides of the existing member as you can see, this is the existing member and on 3 sides of it, additional concreting can be done with necessary reinforcement.

So, additional longitudinal reinforcement can be placed along with the stirrups. So, this way we can do the section enlargement to improve it axial capacity. And this is another technique of Section enlargement on all 4 sides, we can add additional concreting with reinforcement and stirrups and that can improve the axial capacity of the member. So, section enlargement can improve the axial capacity of column members effectively.

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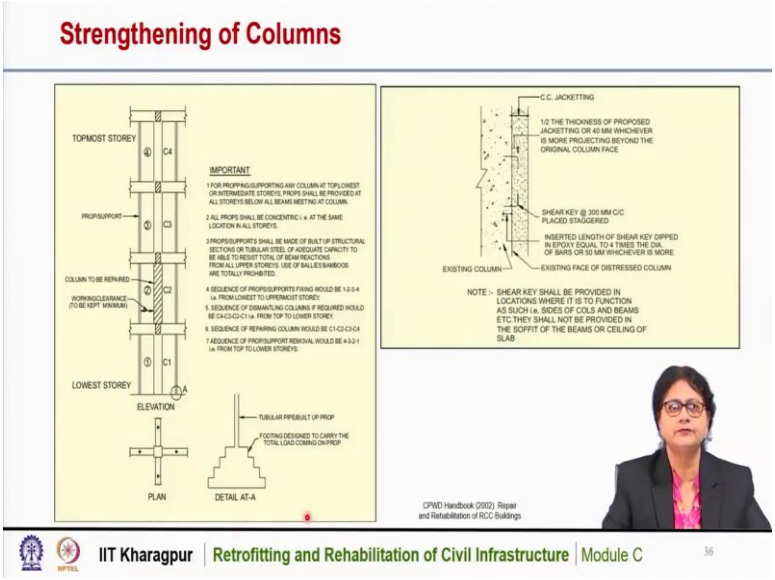

These are some of the schematic diagrams as you can see, if we required to improve the actual capacity of existing columns and all different stories as well. Then it is desirable to improve the section enlargement to start from the lowest story and then we can go upwards. Now if we want to remove the props, and that prop also has to be supported on all stories. As you can see all stories it is to be supported with props.

And if required the props also should have some footing to support the extra load. And the props also should be supported in such a way that they are concentric. And it should start from the lowest story to the topmost story. Now, while dismantling of the props, it is desirable to remove the props from the top and then we can go downstairs.

So, while installing the props or while enlarging the section of column, we should start from the bottom and while dismantling the props or removing the props, we should start from the top story to the bottom. We can also use shear keys as you can see, this is the existing column and this is the new column and they are connected by shear keys and this shear keys are to be placed staggered at regular interval around 300-millimeter center to center.

And as you can see that it has to be attached to the existing concrete to the new concrete and it is important that we should insert the shear key at a certain depth, approximately 4 times its diameter or a 50 millimeter or so. And that has to be placed properly at regular spacing so that the connection is made. So, shear key is used to connect the new concrete to the existing concrete.

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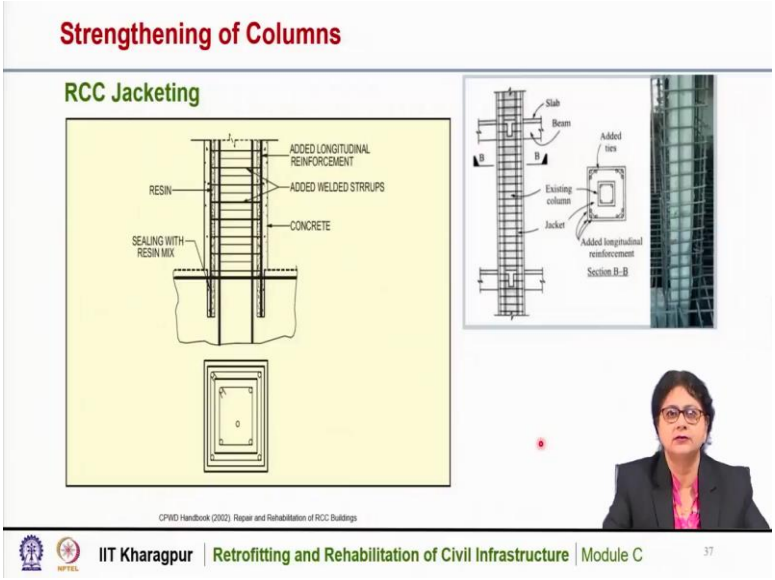

RCC jacketing is another technique of strengthening of columns to improve not only its axial capacity, but also to improve its tensile capacity. As you can see, this is the existing column and around this existing column we can use additional steel reinforcement, stirrups and then concreting. So, with that the section is enlarged and this is the new dimension of the column which gives an additional axial capacity and tensile capacity.

So, here in this picture also you can see that these are the existing reinforcement, existing longitudinal reinforcement and this is the additional new reinforcement for the jacketing part and with that the section is enlarged and its tensile capacity is enhanced due to the lateral confinement. So, this here you can see that reinforcements are placed, the longitudinal reinforcement and these are the stirrups for the enlarged portion and then concrete is poured.

So, this is called RCC jacketing or concrete jacketing and this is an effective means of improving the strength of column.

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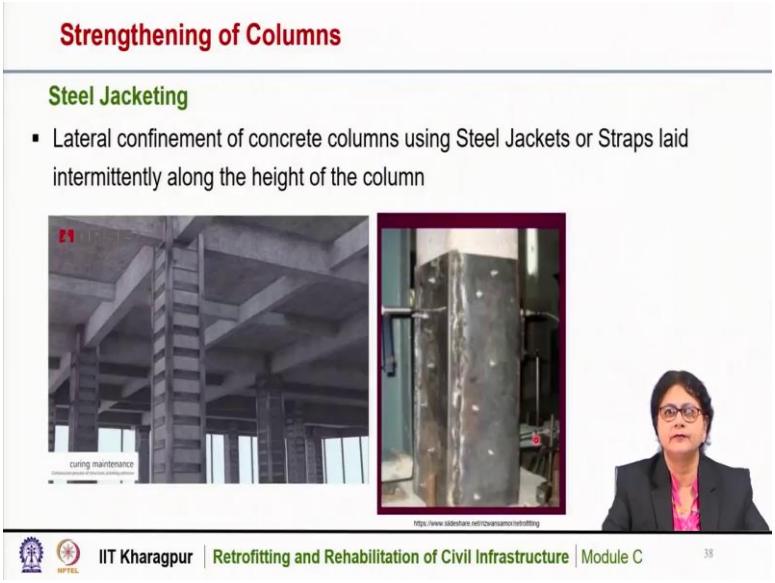

We can also use steel jacketing, concrete jacketing we have seen. A steel jacketing is also an effective means of improving the lateral confinement of concrete columns. The steel jacketing could be continuous steel plate or by steel straps laid intermittently along the height of the column. So, you can see here in this pictures that this is an existing concrete column and to improve its tensile capacity a steel plate all around the column is placed.

So, this is the steel plate and it is attached through bolts. As you can see anchor bolts are used to properly attach the steel plate onto the existing member. And instead of continuous steel plate we can also use steel straps and placed intermittently along the length of the column like an external stirrup and this improves the lateral confinement of the member. With this improvement of lateral confinement, the column is experiencing a triaxial state of stress and with that triaxial state of stress the axial capacity of the member is increased.

Along with that the tensile capacity or the ductility of the column is also enhanced significantly. So, steel jacketing or steel straps, if we can use this, improves the strength of the column significantly and is an effective means of improving the strength of existing columns.

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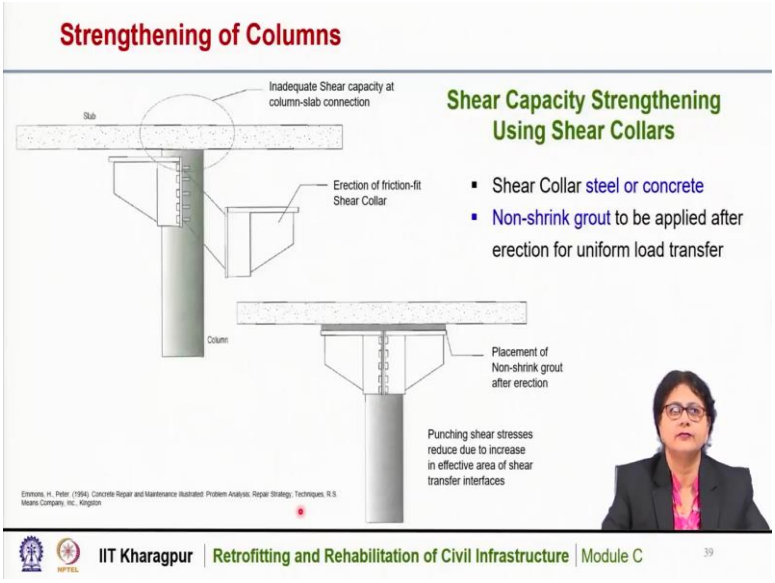

To improve the shear capacity at the of the column slab connection, we can use shear collar. To improve the shear capacity of the column slab connection, we can use shear collars, you can see here, this is a typical shear color, this is made of steel or we can also use concrete for this purpose and then non shrinking grout can be applied after the erection for uniform load transfer.

So, this is the shear collar that is to be attached near the joint and this is another view the placement of the non-shrinking grout after the erection of the shear collar. So, with this shear collar, the punching shear stress is also reduced due to increase in the effective area of the shear transfer interfaces. Now, we have the larger area at the junction.

So, the punching shear stress is also reduced. So, this is also an effective way of improving the shear capacity using shear collars.

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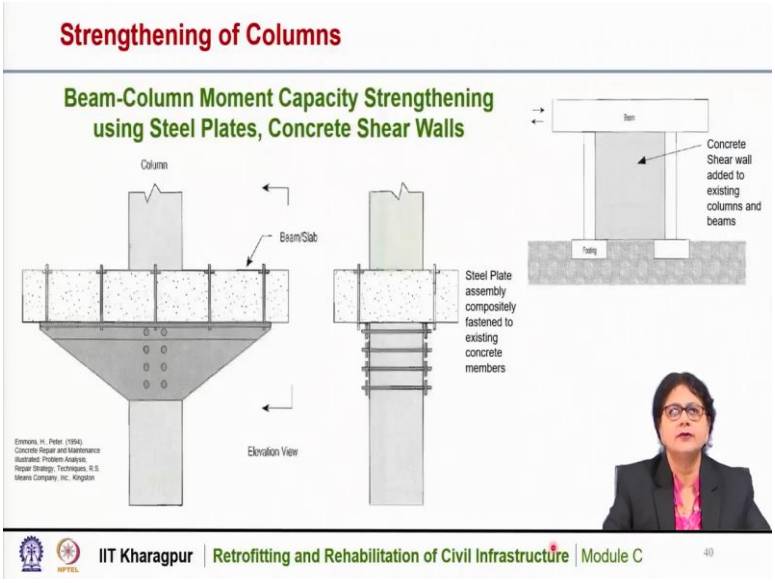

Beam column moment capacity strengthening can be done using steel plates or concrete shear walls. In this picture, these are the steel plates that are used and this is the another view and the steel plates assembly are compositely fastened to the existing concrete members to improve its moment capacity.

So, by using the steel plates, the moment capacity of the joint can be improved significantly. We can also use concrete shear walls as you can see this is a concrete shear wall added to the existing column and beams and this can improve the moment capacity of the existing member.

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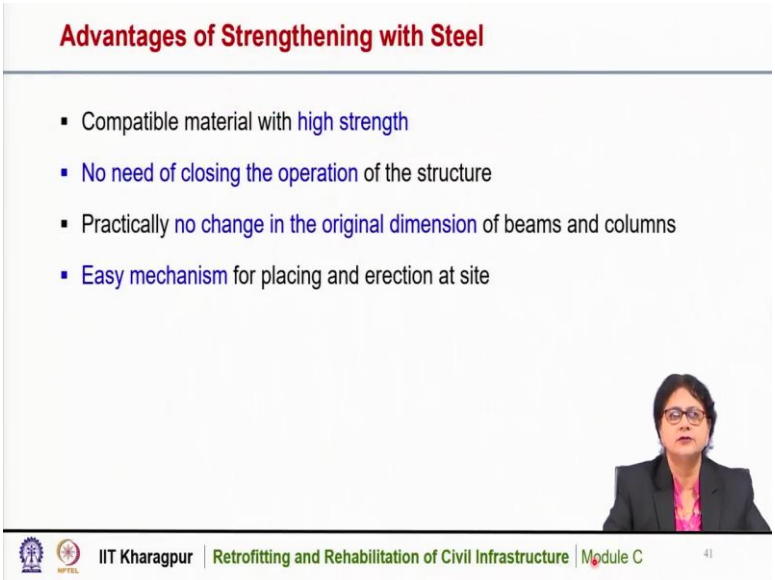

Now, we have discussed that several strengthening techniques using steel plates to improve the flexural capacity, the shear capacity as well as the axial capacity of beams, slabs and column members. So, steel is an effective and useful material for strengthening of existing concrete structures. And it has several advantages and that is why steel is used widely for strengthening and retrofitting of existing members.

The main advantages of using steel are that it is a compatible material with high strength. So, that is why it is widely used not only for new construction, but as well as for retrofitting of existing structures. So, it is a compatible material with high strength.

There is no need of closing the operation of the structure when we strengthen the existing structure with steel members. So, the structure can be in use whether it is a building or it is a bridge, if we want to enhance the capacity of a beam member or a slab member or a column, we can do it without closing the operation of that structure.

Using the steel plate practically there is no change in the original dimension of the beams or columns because it is mostly the steel plates or straps or tendons which are used and so, there is no practically change in the original dimension of the existing members. So, this is an added advantage.

And it is easy mechanism for placing an erection at site because we just require either an epoxy adhesive for attachment or molding system for anchoring. So, it is not a very difficult mechanism for placement at sight. So, these are the advantages of strengthening with steel of existing members. However, there are several limitations as well.

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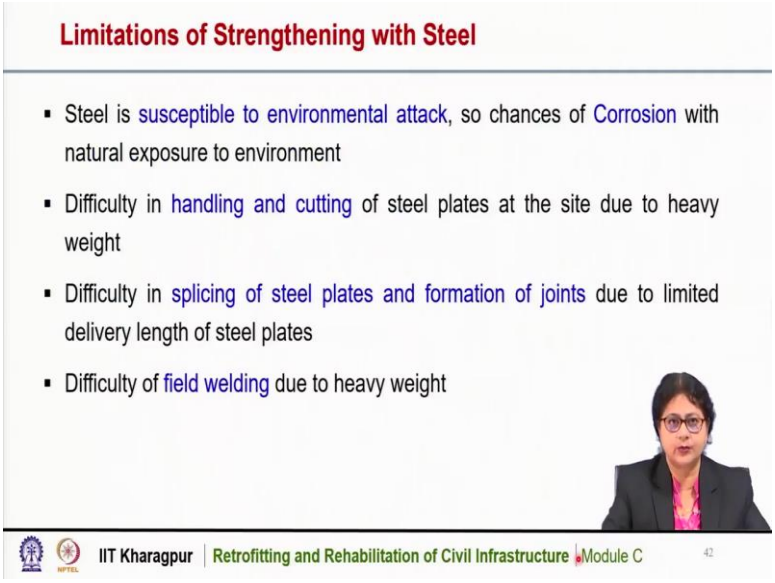

The limitations are that steel is susceptible to environmental attack, and most of the cases the steel straps or tendons or plates are exposed to environment. So, the chances of corrosion are there. And corrosion if it is there then it reduces the effectiveness of strengthening. So, corrosion is a major issue for using steel plates in strengthening of structures.

It is also difficult sometimes in handling and cutting the steel plates at site due to heavy weight and most of the cases if it is a large structure, so, we have to use a comparatively thick plate so, it is quite heavy. So, handling and cutting is difficult sometimes splicing of steel plates and formation of joints are also difficult due to limited delivery length of steel plates. So, steel is prepared in the factory.

So, we have to splice it, if it is required for longer length and formation of joint is also sometimes difficult and it is also difficult for field welding due to its heavyweight. So, though it is very effective in improving the strength of existing member but handling and cutting at site or splicing at site and formation of joints are difficult along with field welding. So, these are some of the limitations of using steel plates in strengthening.

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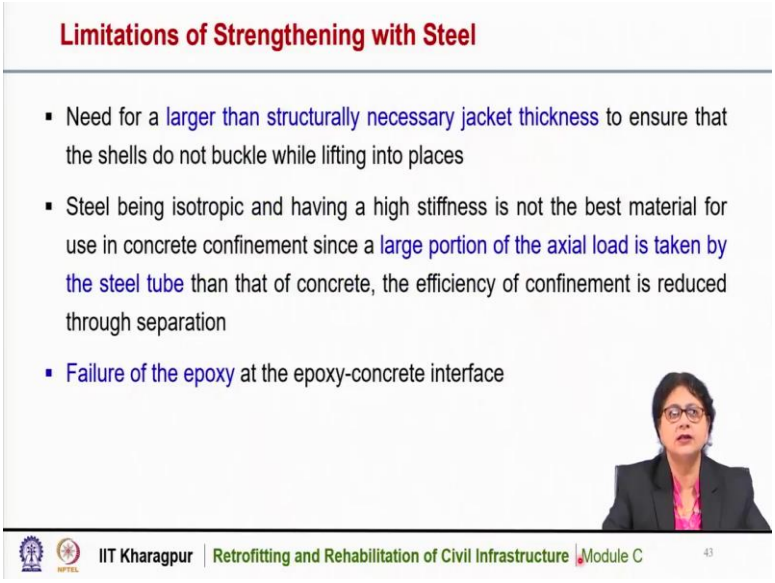

It is also important that we require to have a larger than structurally necessary jacket thickness to ensure that the shells do not buckle while lifting into places. In using steel, sometimes we require a larger than structurally necessary jacket thickness to ensure that the shells do not buckle while lifting into places.

In most of the cases while doing the steel jacketing to improve the strength of columns, we require steel plates of certain thickness but since it is manufactured in factory, so, we may require a larger than structurally necessary jacket thickness. Also, steel being isotropic in nature and having a high stiffness may not be a best material for use in concrete confinement that is required for columns, since a large portion of the axial load may be taken by the steel tubes than that of concrete.

So, if the steel tube takes a large amount of axial load, then the efficiency of confinement may reduce through separation. So, it is desirable that the concrete should take the axial loading and steel jacket is used for confinement only. But sometimes steel may take some amount of axial loading and because of taking the actual loading, the steel may buckle also.

And if it buckles then there may be a gap between the concrete and the steel plate and that may reduce the efficiency of confinement and if the efficiency of confinement is reduced, then the tensile capacity of the member and the ductility of the member is also reduced. So, we may not get the necessary improvement in its strength.

So, that is an issue for using steel jacket. Another issue is the failure of the epoxy at the epoxy concrete interface. In most of the cases, we are using the epoxy adhesive for

attachment of steel plates whether it is steel plate or steel jacketing and sometimes the steel may be okay but the epoxy may fail or the epoxy may not be that durable as steel.

So, there may be a failure at the interface of epoxy and concrete and if the interface fails, then the retrofitting system also may not be that effective. So, these are the limitations of using steel. It is quite effective material for improving the strength of the members. But it is sometimes quite heavy and that is why it is difficult to handle or cut or making splicing or welding at sight.

And sometimes we also require a structurally higher thickness jacket for the jacketing purpose and sometimes it may take axial loading also and with that the efficiency of confinement may be reduced and then maybe a chance of failure of the epoxy or the epoxy concrete interface. So, these are some of the limitations of using steel. So, researchers are studying for new materials, which can be used as a replacement of steel and that we will discuss in subsequent lectures.

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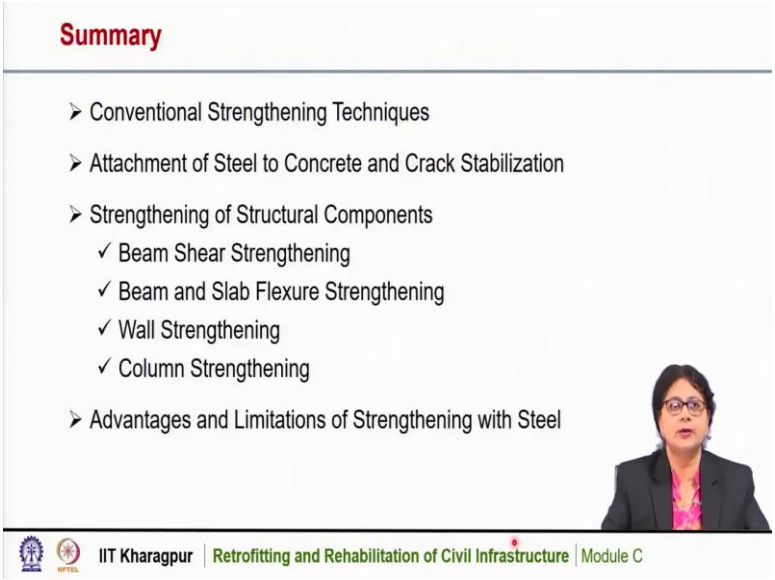

So, to summarize we have discussed the conventional strengthening techniques there are several conventional strengthening techniques like section enlargement or post tensioning etcetera. And that we have discussed today.

Attachment of steel to concrete and crack stabilization how we can do it and strengthening of several structural components like beam shear strengthening, beam and slab flexural strengthening, wall strengthening and column strengthening by jacketing or RCC jacketing or

steel jacketing etcetera or section enlargement. And we have also discussed what are the advantages and limitations of strengthening with steel.

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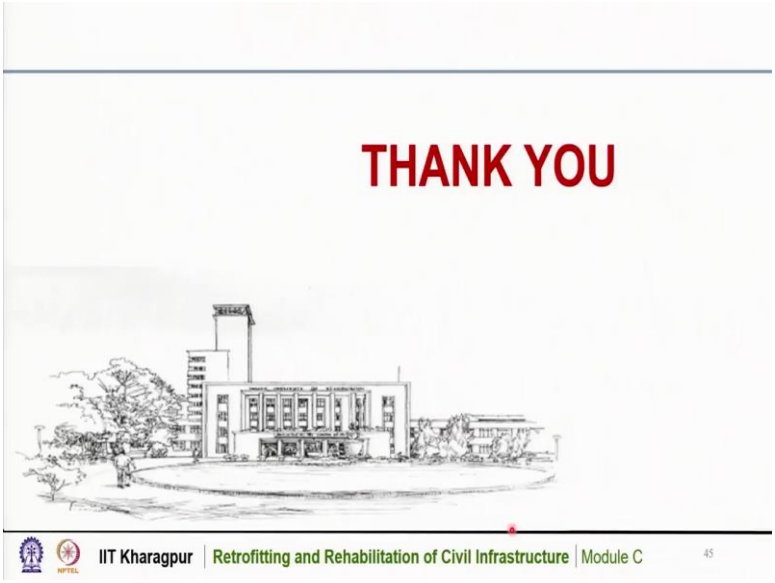

Thank you.