Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 17
Strengthening of Structural Components (Contd.)

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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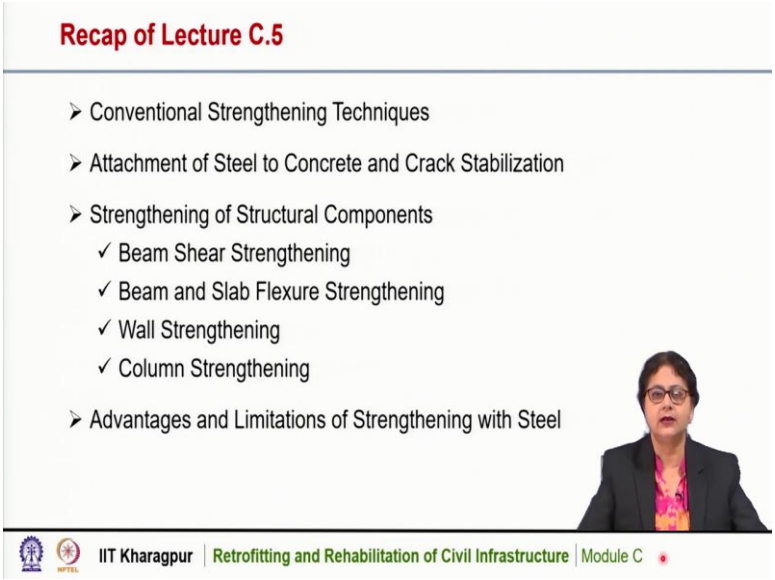

In the previous lecture, we have discussed the conventional strengthening techniques of various civil structures. We have discussed the attachment of steel to concrete and crack stabilization, steel is used widely for the repair and strengthening of existing structures. So, what attachment can be done for the steel in repair and retrofitting that we have discussed and also the crack stabilization; how to stabilize the crack in existing member?

We have discussed the strengthening of various structural components, the beam shear strengthening, we have discussed the flexural strengthening of beams and slabs, wall strengthening and column strengthening. Advantages and limitations of strengthening with steel in existing structures have also been discussed in the previous lecture.

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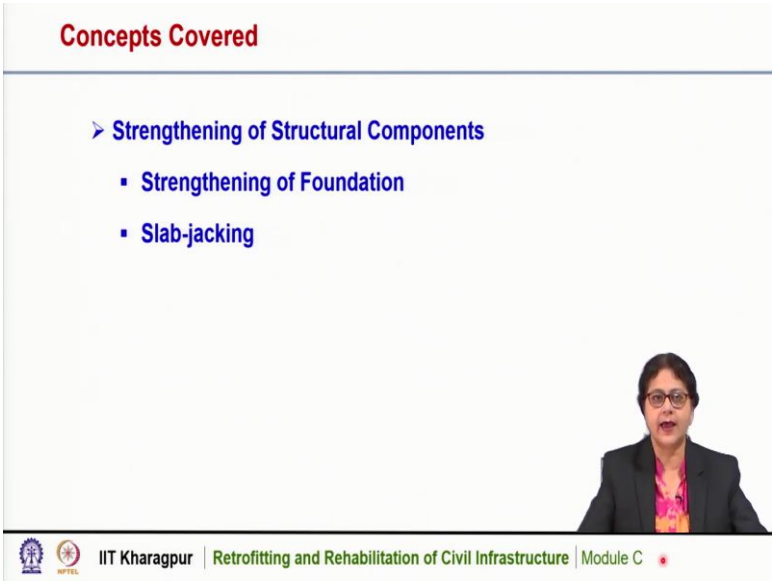

In today's lecture we will continue the strengthening of structural components, we will discuss strengthening of foundation and slag-jacking.

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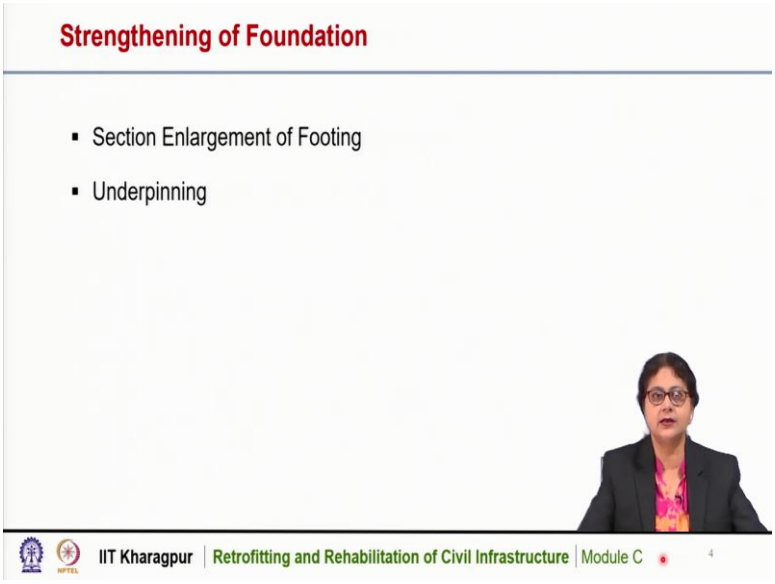

In strengthening of foundation, there are two major techniques, one is section enlargement of footing and the other is underpinning.

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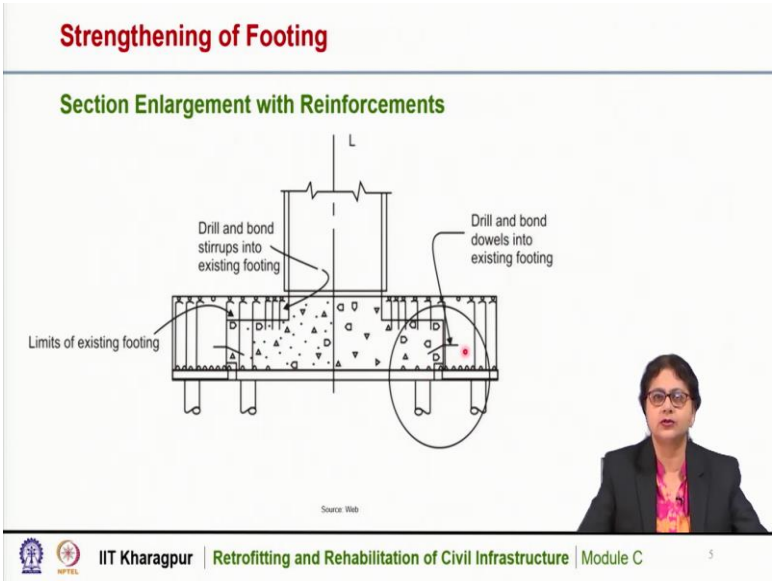

In section enlargement of footing the existing footing is enlarged in its section, as we have seen in case of beams or slabs or columns. The section enlargement is an effective technique for improving the capacity of the member. So, in case of footing also the section enlargement is an effective technique to improve its capacity. So here it is shown schematically that this is the existing footing.

And by additional concreting with steel reinforcement, the footing area is enlarged and thus, the capacity of the footing is also enhanced. In this case, drill holes are made and we can see here through these holes dowel bars are inserted, so that there is proper anchoring between the existing member and the new concrete. This is the dowels, which is inserted into the existing member for proper bonding.

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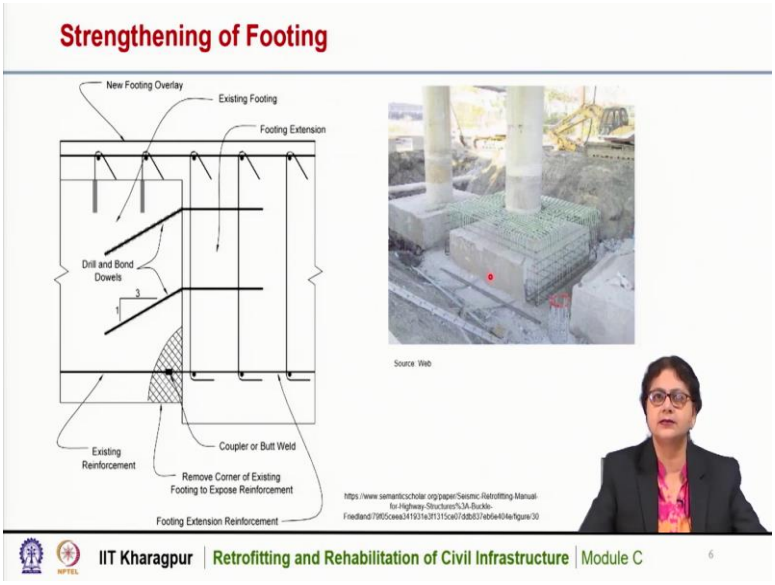

This is the enlarged view of the extended portion of the footing, as you can see this is the existing part and this is the enlarged part. We need to have reinforcement for that and these are the dowel bars which is to be inserted into the existing member and to the new member for proper anchorage and connection.

We can also use, like this that some portion at the corner may be removed; we can see here that concrete is removed in this portion and the reinforcements are attached by welding. So here the continuity of the reinforcement can be maintained in this way. So, with this the section enlargement the capacity of the footing is enhanced. So, this is also a view of the reinforcements which are to be added on the existing footing to increase its capacity.

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These are some of the pictures of strengthening of footing with enlarged section. We can see here that in this case the existing footing there are holes drilled through the member and through that whole, dowel bars are inserted. So, we can use also a smaller number of bars as per the requirement and then the reinforcement to be arranged.

So, this is the arrangement of the reinforcement for the enlarged part and after placing the reinforcement concreting can be done. So, this is the section enlargement of the footing and with this the capacity of the footing is enhanced.

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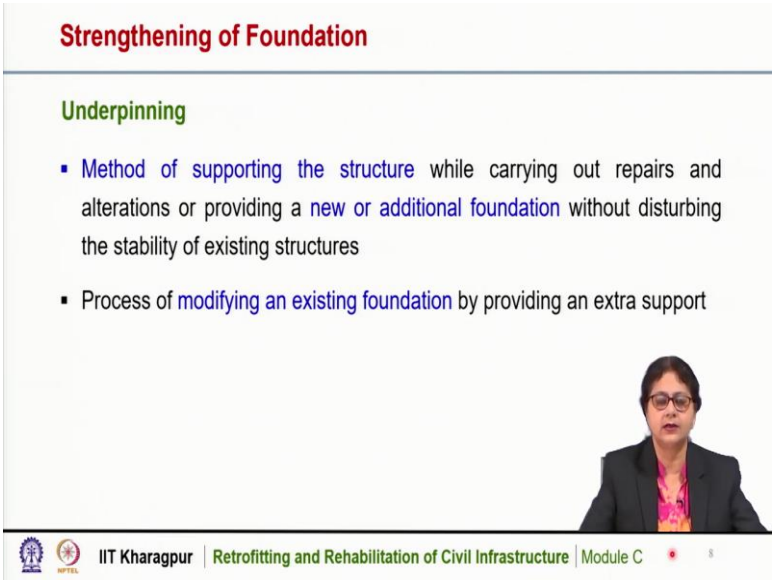

Another technique of strengthening of foundation is underpinning. Underpinning is the method of supporting the structure while carrying out repairs and alterations or providing a new or additional foundation without disturbing the stability of the existing structure. It is the process of modifying an existing foundation by providing an extra support.

So underpinning is a technique of strengthening of foundation and it is a method of supporting the structure so that it can carry additional loads and a new foundation is also added without disturbing the stability of the existing one.

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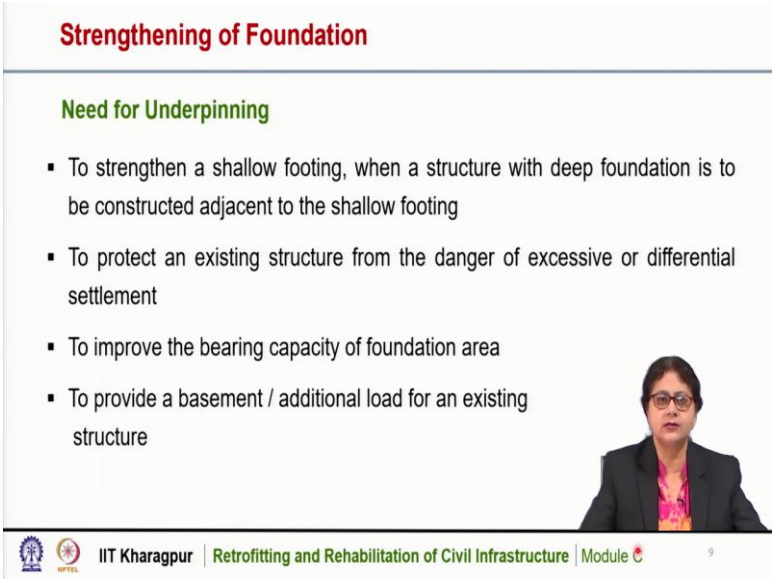

The need for underpining is that to strengthen a shallow footing when a structure with deep foundation is to be constructed adjacent to the shallow footing. For example, a shallow footing is there for an existing structure and adjacent to it a large structure is coming up and for that the foundation may be deeper, so to support or to strengthen the existing shallow for foundation we can do underpinning.

To protect an existing structure from the danger of excessive or differential settlement, if the structure is undergoing excessive settlement, so to protect the existing structure we can strengthen the foundation by underpinning. To improve the bearing capacity of the foundation area, that is also another reason for underpinning, and to provide a basement or additional load for an existing structure. So, for these reasons we can do underpining on an existing structure.

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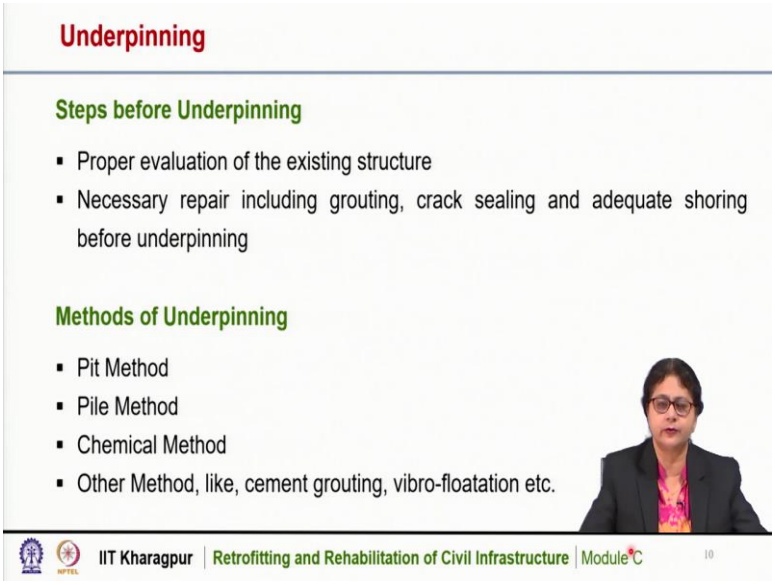

We have to follow certain steps before carrying out underpinning. It is important to properly evaluate the existing structure. What is the strength of the existing structure? What is the condition of the soil? That we need to estimate properly and with that it is also important to do necessary repair on the existing structure if some cracks are there and there is some damage. So, in that case we have to do necessary repair that includes grouting or crack sealing or adequate shoring to support the structure before carrying out the underpinning.

Before carrying out the underpinning we need to properly evaluate the existing structure. We need to know the strength of the existing soil and need to carry out several repair measures if it is required. There are several methods for underpinning, one is pit method, another is pile method or chemical method and there may be some other method like cement grouting or vibro-floatation, etc. We will discuss this in the next few minutes.

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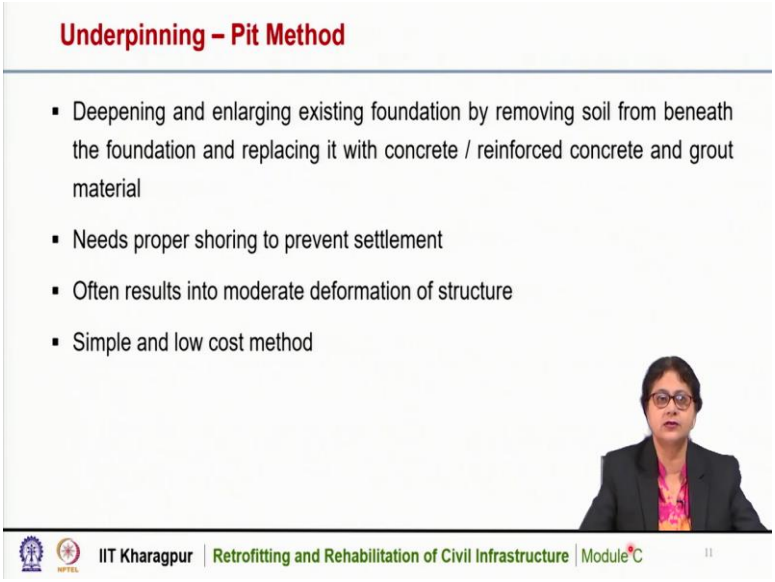

Underpinning using pit method is quite popular and it is used also for strengthening of foundation. Deepening and enlarging an existing foundation by removing soil from beneath the foundation and replacing it with concrete or reinforced concrete and grout material. So here we need to remove the soil beneath the existing foundation and then replace it with a new foundation.

It needs proper shoring to prevent settlement, because we need to support the existing foundation and the existing structure. It may often result into moderate deformation of the structure, so that is one limitation of this method and it is a simple and low-cost method.

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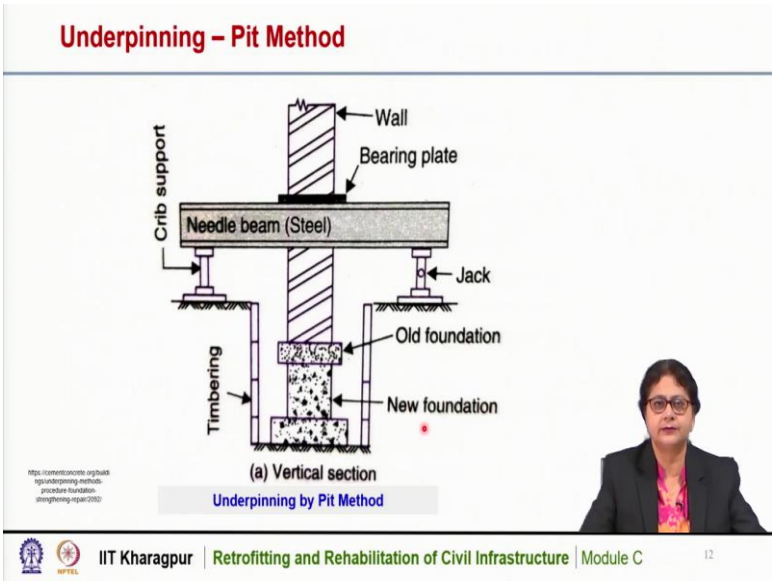

This is a schematic diagram of underpinning by pit method, we can see here this is the wall of an existing structure and this is the existing foundation. In pit method of underpinning, we need to prepare a pit below the existing foundation and it needs to be properly supported by timbering at its sides and now we need to support the wall and we will prepare a new foundation below it.

To support the existing wall, a needle beam is to be installed and that needle beam is to be supported at its two ends by this crib support and a hydraulic jack and then the wall is supported. After that we can cast a new foundation just below the existing foundation. So, after proper curing, we can remove the needle beam and the foundation is ready for taking up the additional load coming on it. So, this is underpinning by pit method.

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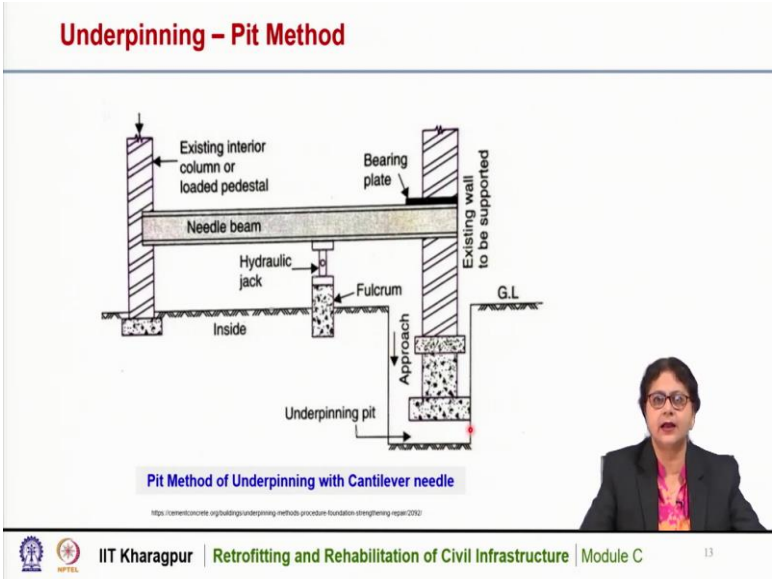

This is also a schematic diagram of underpinning by pit method. Here if the axis is not available on both sides of the existing wall to be supported, then we can do underpining by taking it on the one side only. So here, pit is to be dug, you can see here this is the pit that needs to be prepared below the existing foundation.

And a needle beam is to be placed and that is a cantilever type of needle beam. Because it is supported here and this is the jack and this part it is supporting the existing wall. So, this existing wall is to be supported on the cantilever needle beam and after supporting it, we can prepare the new foundation and when the new foundation is prepared and cast, then we can put some soils so that it is filled up and after proper curing the structure is ready for taking the additional loading.

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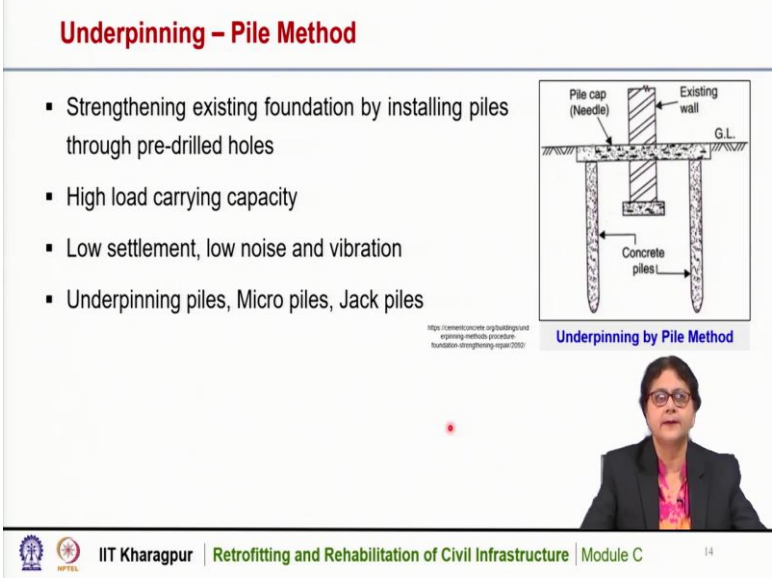

Underpinning by pile method is also quite effective. It is the strengthening technique of an existing foundation by installing piles through pre-drilled holes. The piles have high load carrying capacity and this is an effective method as it causes low settlement, low noise and vibration. So, underpinning by pile method is we can see here in this schematic diagram these are the concrete piles and this is the pile cap and this is the existing wall with its foundation.

So, under panning by pile foundation method, we can increase the strength of the existing foundation. Piles could be of different types underpinning piles, micro piles or jack piles that are used for this method.

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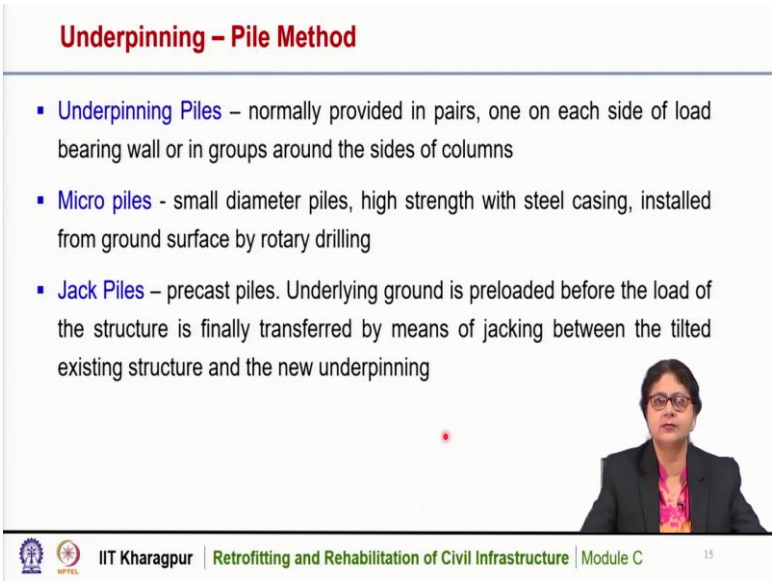

Underpinning piles are normally provided in pairs, one on each side of the load bearing wall or in groups around the side of the column. So, this is underpining piles. Micropiles are small diameter pipes having high strength with steel casing and installed from ground surface by rotary drilling.

Jack piles are generally precast piles and this is used when the underlying ground is pre-loaded before the load of the structure is finally transferred by means of jacking between the tilted existing structure and the new underpinning. So, three types of piles are used underpining piles, micro piles and jack piles depending on the type of structure and the loading to be carried by them.

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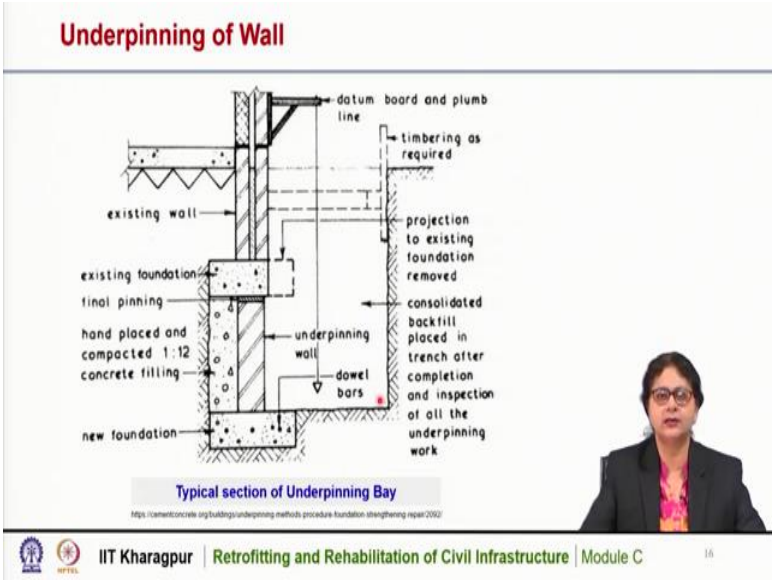

This is a schematic diagram of underpinning of wall. This is a typical section of the under pining bay, we can see here this is the existing wall and this is the existing foundation. Now to support the existing wall, we can cast a new foundation here, but before that the extended portion of the existing foundation need to be removed and before that, pit is to be dug and the existing wall needs to be supported with proper shoring.

Now hand placed concrete is to be placed on this side and then this is the underpinning wall and this is the new foundation. So, the consolidated backfill is placed in the trench after completion and inspection of all the underpinning work.

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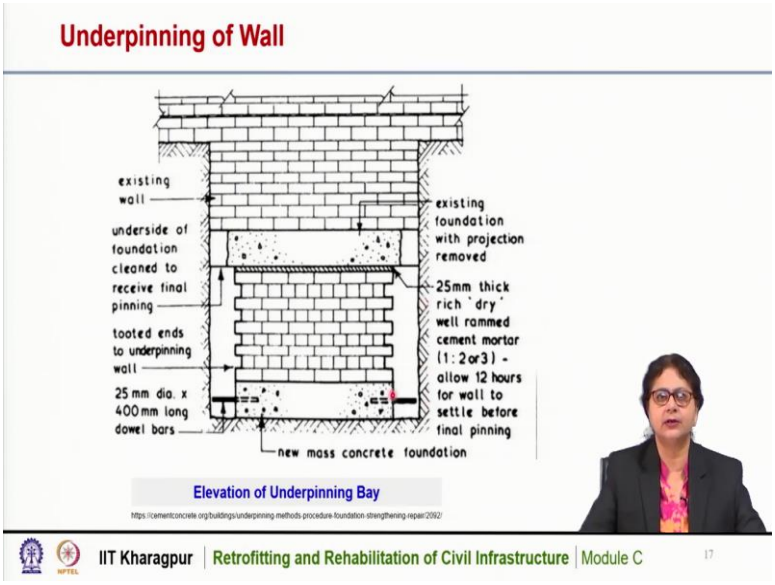

This is the elevation of the underpinning bay. We can see here that this is the existing wall and this is the existing foundation with the projected portion removed. Now this is the underpining wall and this is the new mass concrete foundation within this pit. Now after that the underpinning work this has to be filled up and then it can be ready for taking up the extra load.

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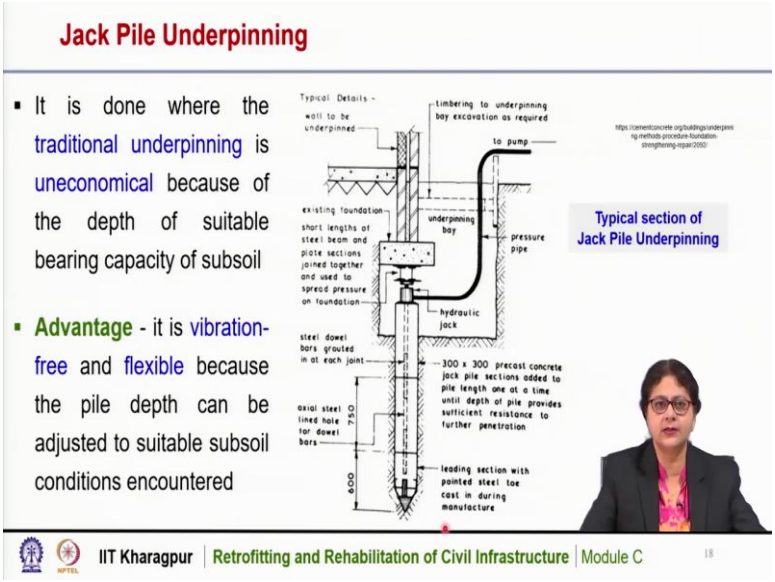

Now jack piling is also used for strengthening purpose. It is done where the traditional underpinning is uneconomical, because of the depth of suitable bearing capacity of subsoil. Sometimes we do not estimate that where is the soil which has sufficient bearing capacity.

So, in that case jack piling method is quite effective. So here what is done that the jack piles which are precast piles are inserted till we reach the soil strata, which have sufficient strength. So, this is the existing wall and this is the existing foundation of that wall.

The existing structure needs to be supported with proper shoring and then below the foundation a hydraulic jack is to be placed and a steel frame is to be placed so that the load of the foundation is properly distributed and with this jack we can insert the jack piles. Now depending on the length or depending on the depth of the soil strata which is having sufficient bearing capacity we can extend the number of piles also.

Here you can see this part is, the first part where it has a steel casing at its tip and then if the depth of the soil strata of sufficient strength is not reached, we can add one more pile and then again one more pile till we reach the soil strata of sufficient strength. And between these precast piles, there are slots and in that slot dowel bars can be inserted and after inserting the dowel bars it is to be grouted and filled up.

So, this is an effective method of strengthening of foundation. The advantage is that it is vibration free and flexible because the pile depth can be adjusted to suitable subsoil conditions in and encountered. So, this is the advantage of jack pile, if we cannot estimate that how deep is the soil strata of sufficient strength, jack piling method is quite effective for that.

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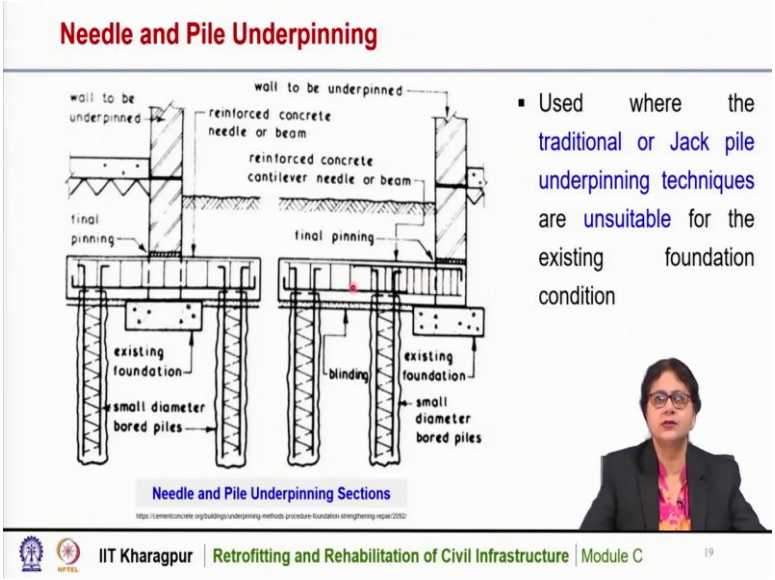

This is needle and pile underpinning. This is used where the traditional or jack piling underpinning method are unsuitable for the existing foundation. So here it is actually the combination of needle beam and the piling method. Here we can see that this is the existing wall and this is the existing foundation. Here we can prepare a needle beam and that is a concrete beam we can prepare and we can also insert piles.

So, these are the small diameter bored piles on both sides of the wall and it is connected to this concrete needle beam and the existing foundation is supported. If we cannot get access on both sides, we can do it on one side with cantilever needle beam. So, this is cantilever needle beam and a pile method of underpinning.

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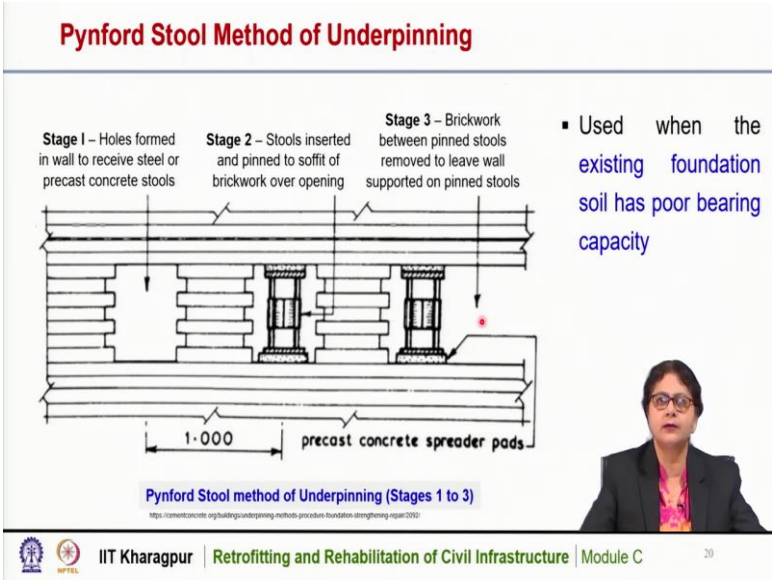

This is another method, Pynford Stool method of underpinning. This is used when the existing foundation soil has poor bearing capacity. So here we can see that this is a schematic diagram of the pynford stool method of underpinning, this is the wall at its elevation we can see the existing wall. So here in this method, several steps need to be followed. In stage one, a hole is formed in the wall to receive the steel or precast concrete stools.

First, we need to prepare a hole within the wall, then in the second stage a steel stool is to be inserted and pinned to soffit of brickwork over the opening. So, this stool is inserted and it is placed and fixed or pinned to the soffit of the brickwork. After placing this tool, in the next stage we need to remove the brickwork adjacent to this stool. So, brickwork between the pinned stools removed to leave wall supported on pinned stools only, so this portion the brickwork needs to be removed.

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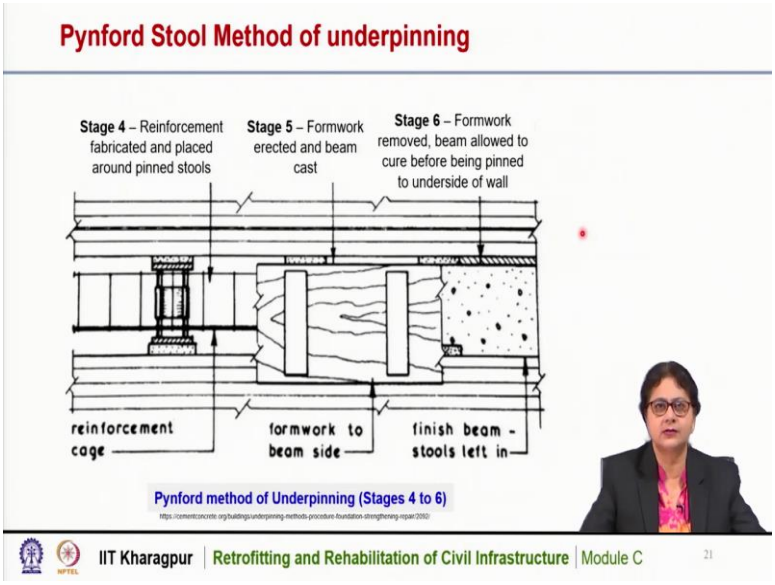

Then in stage four, the reinforcement fabricated and placed around the pinned stool. So, we have a reinforcement cage and that reinforcement is to be placed around this stool. So here we can see that this is the main reinforcement and this reinforcement cage is to be placed within that portion. And in the next stage, a formwork is to be erected.

You can see here this is the formwork is to be erected on both sides of the wall and concrete is to be poured. So, a concrete beam is cast here within the formwork, and in the next stage formwork is to be removed. The beam is allowed to cure before being pinned to underside of wall. So, after proper curing the formwork need to be removed and the beam is kept as it is.

So, this is the finished beam, stools left in, so this way we can strengthen the existing wall of an existing structure. So, this is pynford method of underpinning and this method is also used effectively for strengthening purpose.

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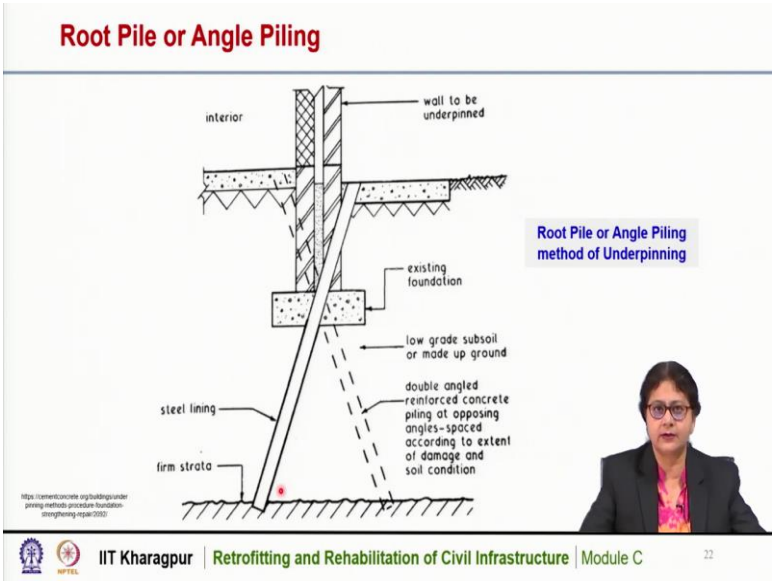

This is another a simple technique of strengthening of foundation. This is root pile or angle piling method. This method involves inserting of the steel linings on both sides of the existing foundation and it is to be done in cross way as we can see here. So, one steel lining is here and the other is here, so in staggered way it can be given.

This is the existing foundation and this is the double angle reinforced concrete piling at opposing angles, spaced according to the extent of damage and the soil condition. So, till we get a firm stratum we can insert it and then it is placed firmly on the soil strata. So, this is a simple technique but effective and with this we can improve the existing foundation and can strengthen it.

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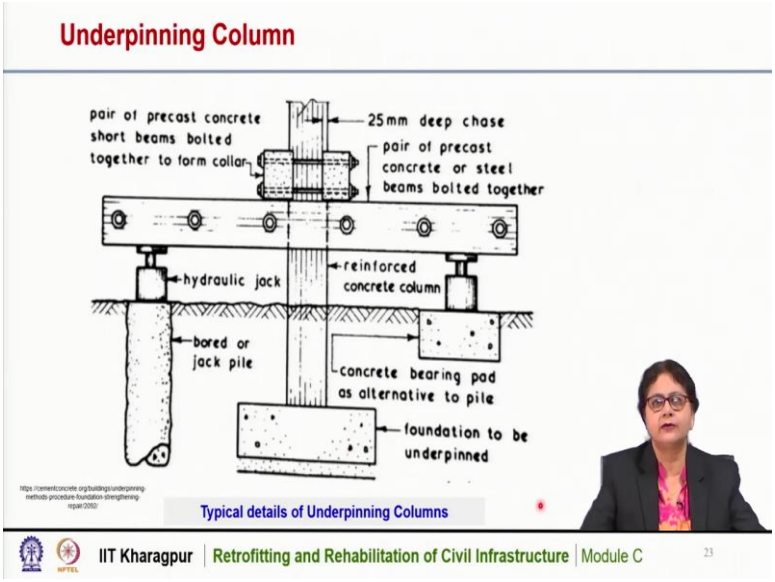

Underpinning column – Sometimes we need to strengthen the existing foundation and the column is reinforced concrete column. So here in this case to strengthen the existing foundation we need to support the reinforced concrete column. Here we can see that this is the RC column, reinforced concrete column and this is the existing foundation.

So, we need to do pit method or pile method for strengthening the existing foundation, but before that we need to support the existing column as well. So, to support the existing column this type of structure can be made, we can see here this is a pair of precast concrete or steel beams bolted together and over it a pair of precast concrete short beams bolted together to form a collar.

So here you can see that, this is a pair of precast concrete short beams and they are bolted together and this is the pair of precast concrete or steel beam which is also bolted and this is supported by these two systems. So, on one side there is a bored or jack pile over it, it is the hydraulic jack and the other side we can also have a bored or jack pile or we can also use a bearing pad to support this beam.

So, this way the precast concrete or steel beam can be supported from the ground and this structure, this beam, this precast concrete short beam also is bolted. So with this the column is tightened and it is not deflected or it is placed in its position and then we can strengthen the foundation. And for strengthening the foundation we can use pit method or pile method.

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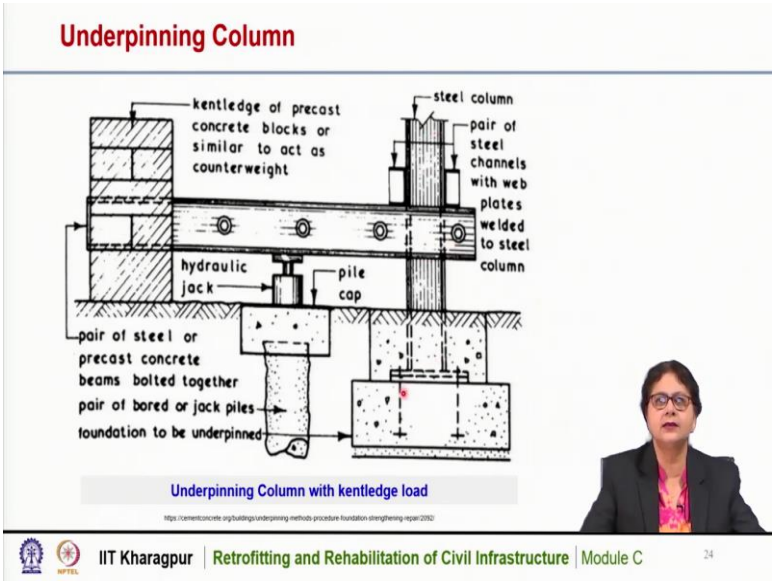

This is also another picture of underpinning column with kentledge load. It is a similar way if we can have only one side accessible then we can use the hydraulic jack here on the bored pile and another one is the pair of steel or precast concrete beams bolted together and this is the kentledge or precast concrete block or similar to act as counterweight.

So, the needle beam is to be supported one at this point and by this counter weight. So, this way also we can support the existing column and then the existing foundation can be strengthened by pit method or pile method of underpinning.

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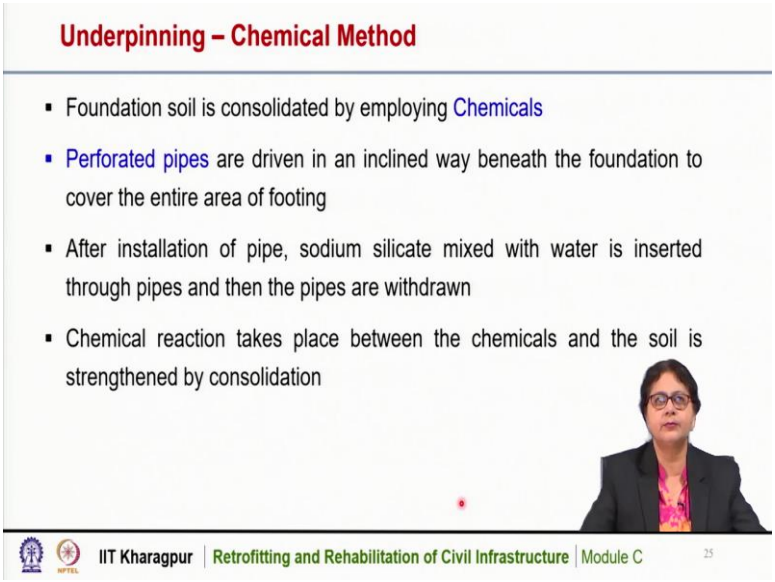

Underpinning can also be done by chemical method. Here the foundation soil is consolidated by employing some chemicals. Perforated pipes are used and the pipes are driven in an inclined way beneath the foundation to cover the entire area of footing. Now after installing the pipe sodium silicate mixed with water is inserted through the pipes and then the pipes are withdrawn.

Since the pipes are perforated, so when the sodium silicate solution is inserted, it is going into the soil. Now when the pipes are withdrawn, the mixture is mixed with the soil, chemical reactions are taking place between the chemicals and the soil is strengthened by consolidation. So, this is the underpinning or strengthening of the foundation soil by chemical method.

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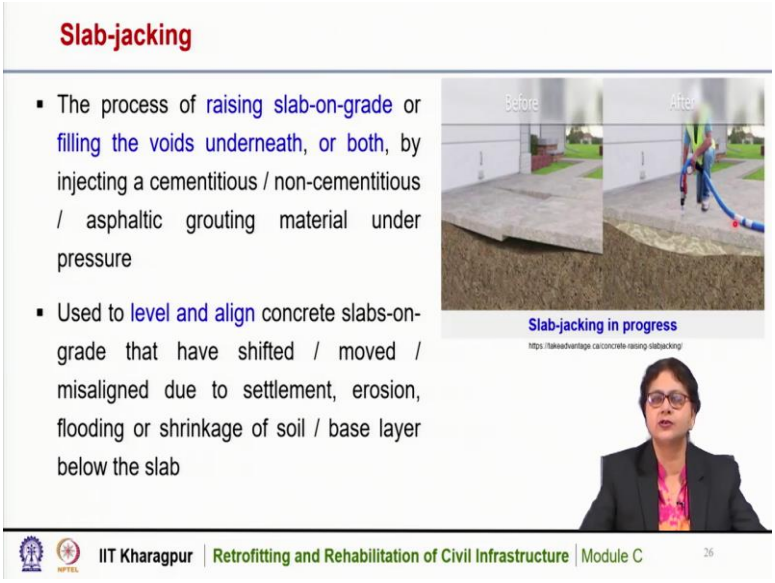

Now, we will discuss slab jacking. Slab jacking is the process of raising slab on grade or filling the voids underneath or both by injecting a cementitious or non-cementitious or asphaltic grouting material under pressure. It is used to level and align concrete slab on grades that have shifted or moved or misaligned due to settlement, erosion or flooding or shrinkage of soil or base layer below the slab.

So, slab jacking is the process by which we can raise the slab on grade at its original position and by filling the voids below the slab or there may be some settlement of the slab and that we can do by injecting some cementitious grout or asphaltic grouting material with some pressure. So that, the deflected slab or settled slab is coming to its original position.

So, this is slab jacking and this is a picture of slab jacking in progress as you can see here the two slabs are placed side by side, but one slab has moved up as you can see and with slab jacking, we can make the two slabs in their original position.

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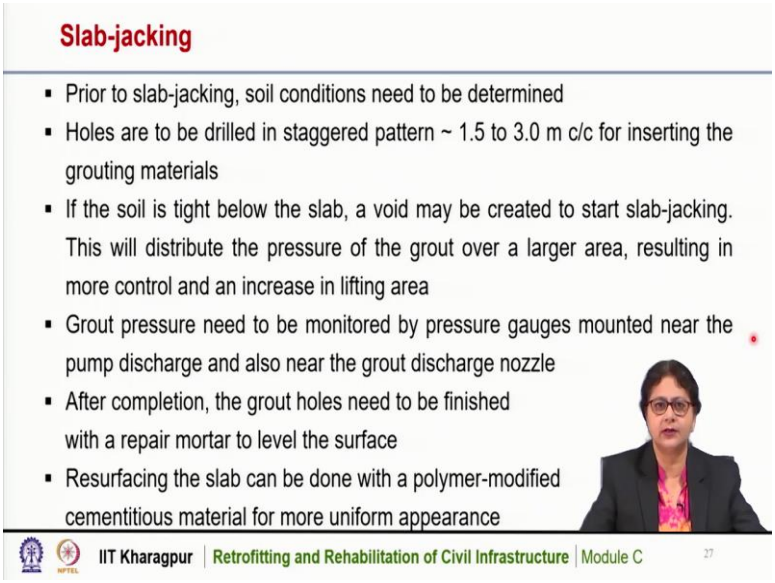

Now there are several steps for slab jacking and we have to follow those steps for this procedure. Prior to slab jacking it is important that soil conditions need to be determined, because we are inserting some grouting materials so we need to know the condition of the existing soil. So, soil conditions need to be determined.

Then holes are to be drilled in staggered pattern approximately 1.5-to-3-meter center to center for inserting the grouting materials. If the soil is tight below the slab, a void may be created to start the slab jacking procedure. This will distribute the pressure of the grout over a larger area resulting in more control and an increase in the lifting area.

So, if the soil is good, it is tight, but in due to some other reason there may be some shifting of the slab, so in that case we can create a void so that we will get an extra area, larger area and the grout can be distributed on the larger area which gives us more control in the process. The grout pressure needs to be monitored by pressure gauges mounted near the pump discharge and also near the grout discharge nozzle.

Because we are injecting the grouting material with some pressure and that is why it is important to monitor that pressure. So, by inserting or by installing pressure gauges we can

monitor the pressure on the pipes. After completion the grout holes need to be finished with the repair material and the surface can be levelled.

Resurfacing the slab can be done with the polymer modified cementitious material for more uniform appearance. If the appearance is important, we can resurface with the polymer modified material or cementitious material and the grout holes will disappear or will be covered by those material.

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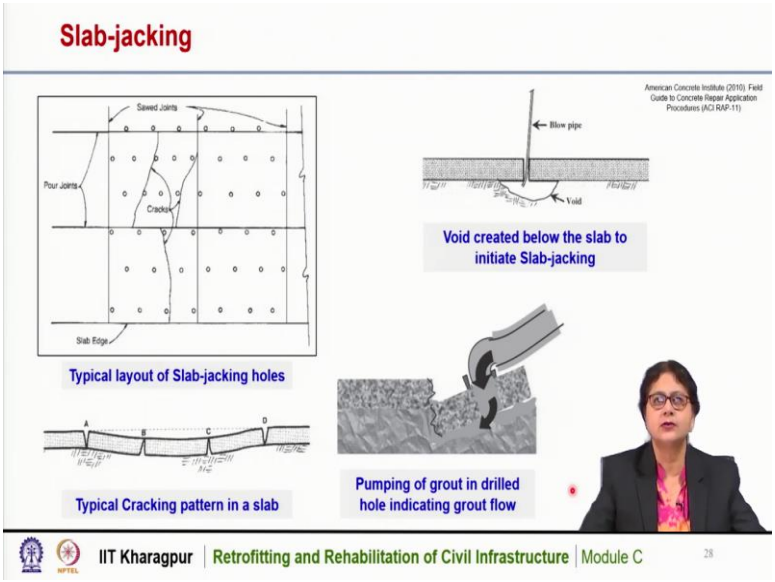

These are the schematic diagrams of slab jacking procedure, you can see here if this is a concrete slab with joints, transverse and longitudinal joints are there and the slab is cracked randomly. As you can see here these are the cracks on the slab. Now for slab jacking purpose, we need to drill a number of holes and these are the holes to be drilled staggered way throughout the slab.

The cracks on the slab may be wider at its top or wider at its bottom. So, this is schematically shown, the typical cracking pattern in a slab and if it is required, we can create a void below the slab to initiate slab jacking. So, this is the void that has been created for initiating the slab jacking procedure.

So, after preparing the holes, now the grouting material need to be inserted and this is the pumping of the grouting material in the drilled holes and this shows that how the grouting material flows below the slab. So, by flowing of this grout through the slab below it, the

voids below the slab are filled up and the slab can come to its original position. So, this is the procedure for slab jacking.

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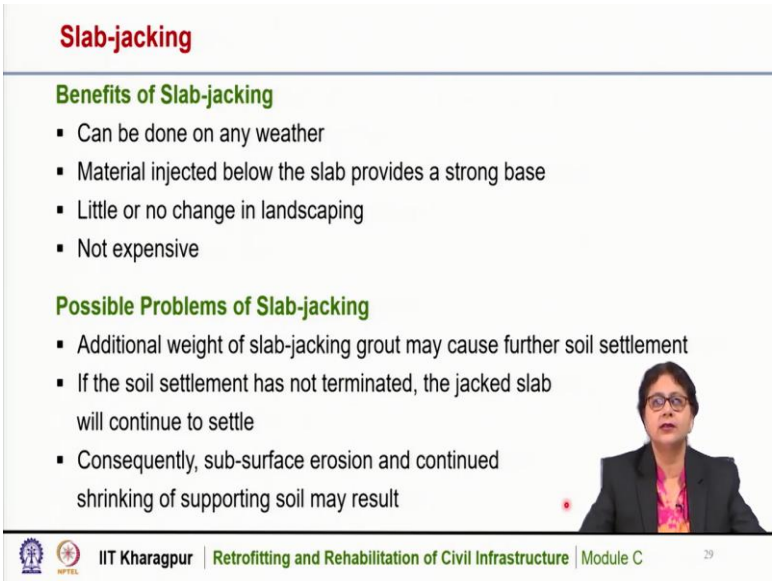

There are several benefits of slab jacking. It can be done on any weather. It does not depend whether it is summer time or winter time, so it can be done on any time. The material injected below the slab, provides a strong base, because we are inserting some grouting material; that is most of the cases it is the cementitious material or some asphalting material and that provides a strong base to the slab.

There is little or no change in landscaping, because we are inserting the grouting material below the slab, so no change in landscaping, only the holes may be visible but that also can be rectified by placing an overlay type of thing, a thin overlay or polymer modified material. So, no change inpractically in landscaping and it is not an expensive technique and quite a simple technique of slab jacking.

However, there are several possibilities of some problems in slab jacking. The possible problems of slab jacking are that an additional weight of slab jacking grout may cause further soil settlement. If the soil settlement has not terminated, the jacked slab will continue to settle, therefore, it is important to know the present condition of the soil. So, before slab jacking that is why it is important that we need to estimate the soil strength.

If the soil settlement is not terminated, then the jacked slab may again settle and that may lead to subsurface erosion and continue shrinking of the supporting soil. So, these are some

of the problems that may arise that additional weight of slab jacking grout may cause further soil settlement. If the soil settlement has not terminated then the jack slab will continue to settle and we may again do the slab jacking procedure. And if the soil settlement continues then that may lead to subsurface erosion and continuous shrinking of the supporting soil.

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These are some of the pictures of slab jacking, you can see here this is a driveway and the slab is cracked very badly and one portion is settled down, so here this portion is settled down and with slab jacking it is restored, we can see here the portion is restored and they are in one level now. This is also another picture of sinking walkway we can see here; the the slabs are at different levels and by slab jacking procedure the slabs are now in leveled position.

So, this is a slab jacking and it is an effective technique by which we can improve the slab position and we can strengthen also.

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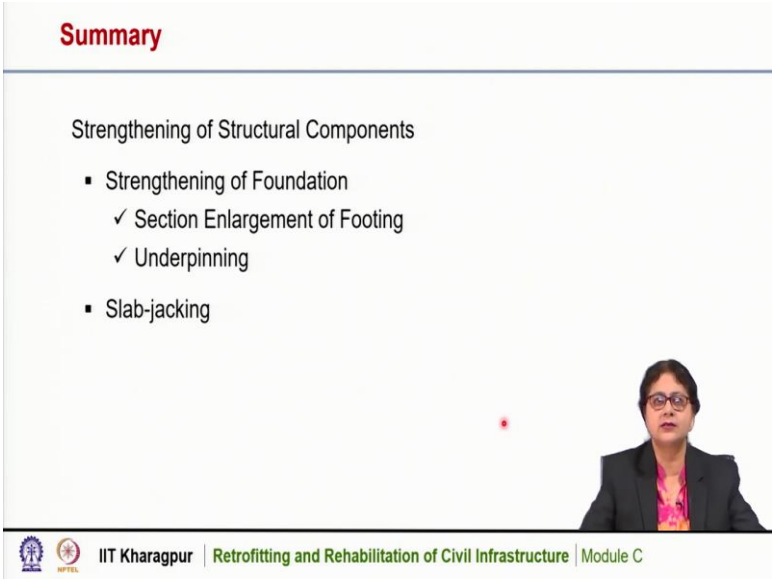

To summarize we have discussed the strengthening of structural components, we have discussed the strengthening of foundation using section enlargement of footing and also underpinning. We have discussed different methods of underpinning using pit method or pile method and we have also discussed slab jacking.

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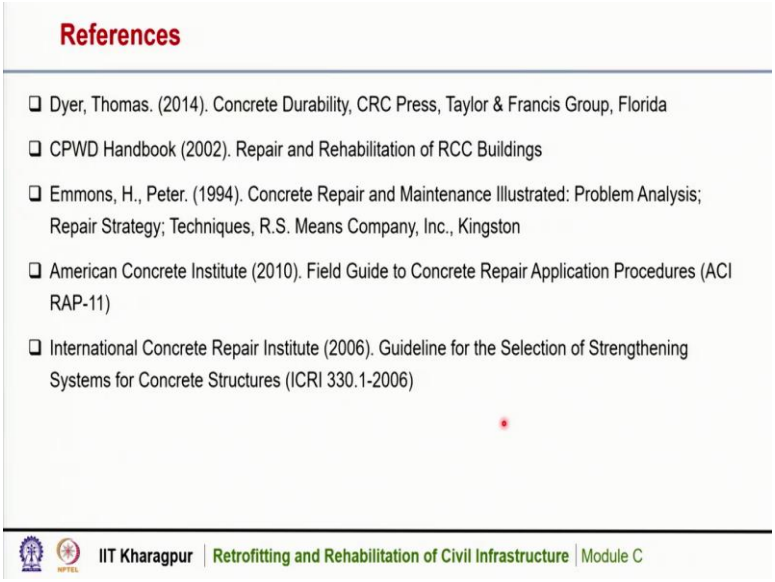

These are the references of module C. Thank you.