Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 13
Repair Techniques

Hello friends welcome to the NPTEL online certification course on 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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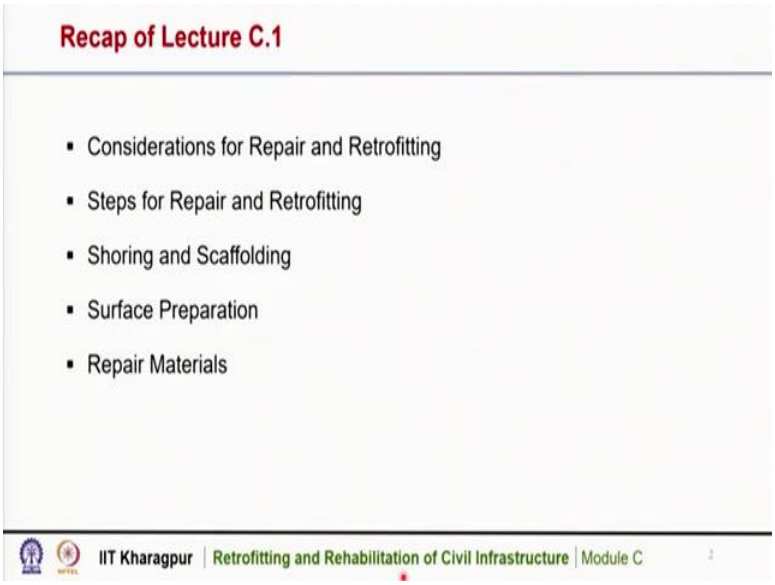

In the previous lecture, we have discussed what are the considerations for repair and retrofitting of existing structures? What are the steps for carrying out any repair and retrofitting work in a structure? The shoring and scaffolding that are necessary for carrying out the repair works. We have also discussed, the several surface preparation techniques and also about the repair materials.

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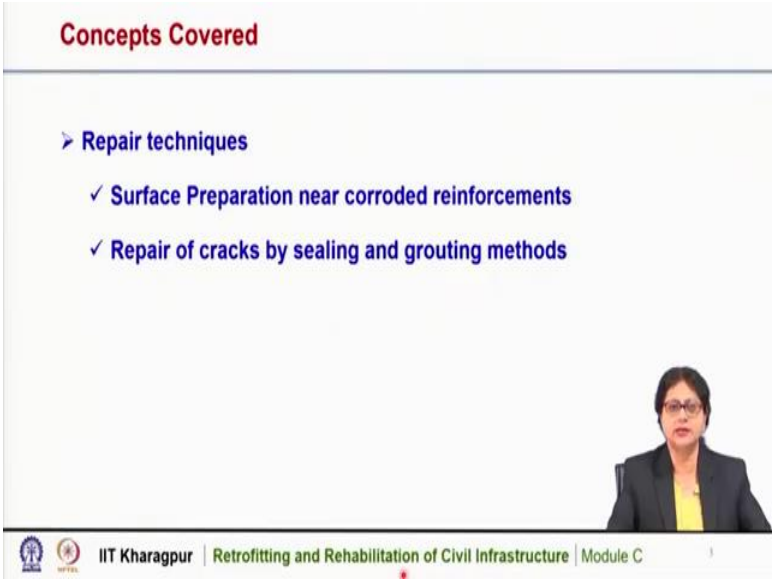

Today we will discuss the surface preparation particularly near the corroded reinforcement of an existing structure. And also, we will discuss the repair of cracks by several sealing and grouting methods.

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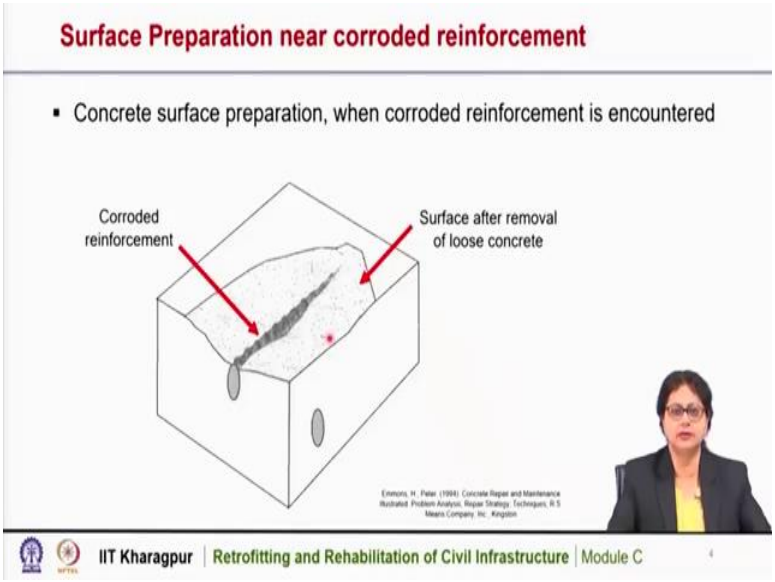

We have discussed that, before carrying out any repair and retrofitting work, surface preparation is necessary. For an existing structure, surface preparation is important so that the repair material can be placed on it. When the surface is distressed due to the corrosion of reinforcement, that area we need to clean. So, here in this schematic diagram, we can see that this is a diagram of an existing structure with reinforcement, the reinforcement is corroded.

And because of the corrosion of reinforcement, there may be cracks on the surface and delamination of the material. So, first it is important to remove all the loose materials near the corroded reinforcement. So, here we can see that, the loose materials are removed and the reinforcement, which is corroded is exposed.

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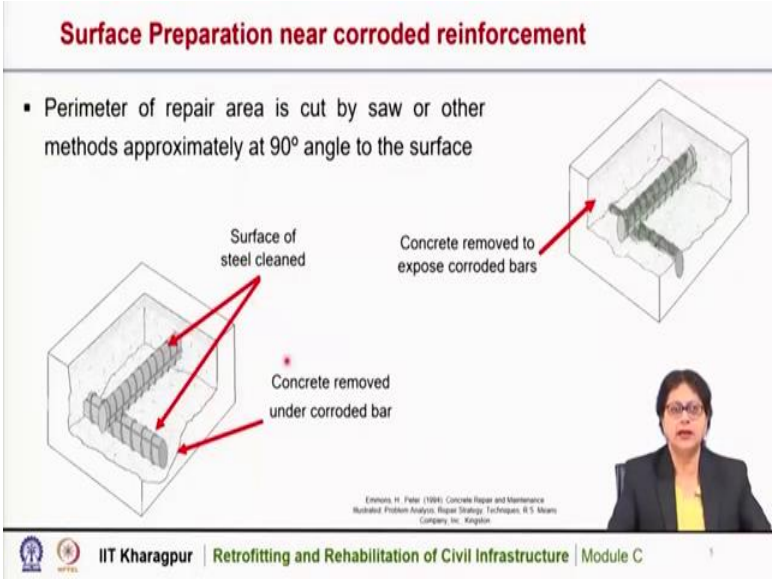

After exposing the corroded reinforcement, it is important to have a clear area for the repair work. So, the perimeter of the repair area needs to be cut by saw cutting or by any other means, approximately a rectangular shape. And that we can do it by saw cutting at approximately 90 degrees.

You can see here in this schematic diagram, the area is removed near the corroded reinforcement by saw cutting or any other means and the exposed reinforcement we can see here. Now, it is important to remove the rust over the corroded reinforcement.

And we also need to remove some portion of the concrete near the corroded reinforcement, particularly below the corroded reinforcement. So, here it is seen that the concrete is removed under the corroded bar and here in this place now the repair material is to be placed. So, we should have a proper area, so that the repair material can be placed on it.

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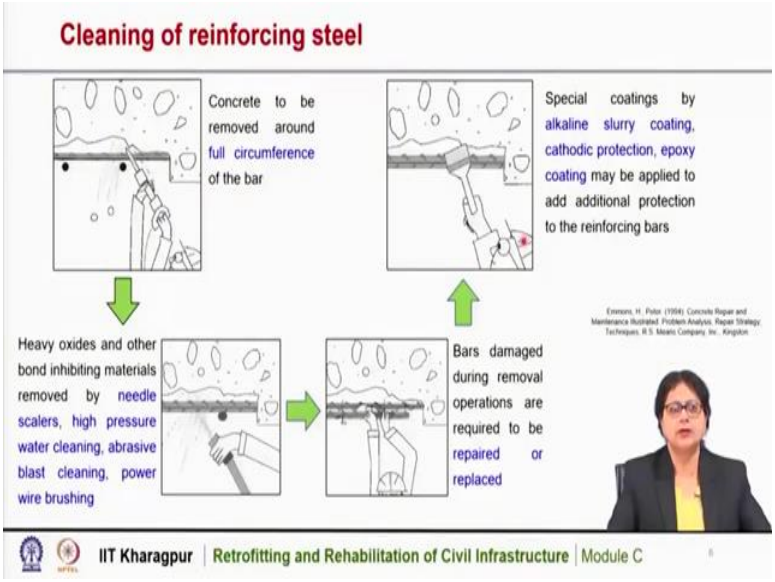

Now, it is to be cleaned, the corroded reinforcement, we have seen that once we remove the loose materials and by saw cutting we can have a clear surface for the repair work. Now we need to clean the corroded reinforcement. So, here are some steps shown schematically, the concrete is to be removed around the full circumference of the bar. We can see here the concrete is to be removed and we can get a rectangular shaped area.

Now, the heavy oxides and other bond inhibiting materials are to be removed by needle scalers, or high-pressure water cleaning, or abrasive blast cleaning, or power brushing, and with these methods any of the methods can be used the reinforcement is cleaned the corroded portion is removed, you can see here all the loose oxides over the reinforcement is removed.

Now, the bars damaged during removal operations are required to be repaired, or replaced, we will discuss next. And then special coating by alkaline slurry coating, or cathodic protection, or epoxy coating, may be applied to add additional protection to the reinforcement bars. So, it is important to clean the reinforcement steel. Once it is corroded and when we will use the repair material over it, we need to clean all the loose oxides over it. And we can use several techniques for the removal of these materials.

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So, the cleaning of reinforcement steel can be done by needle scalers, or high-pressure water cleaning, as we have just mentioned. So, this is a picture of a typical needle scalers, needle scalers are pneumatic tools, which are utilized for the cleaning of reinforcement bars. And they have small diameter steel rods powered by an internal piston.

The steel rods hit the intended surface, you can see here it is applied on the corroded surface and that removes the surface material. We can also use high pressure water cleaning with which we can remove the corroded portions. The water is mixed with sand that cleans the concrete and steel surface.

And the removal of the unsound materials, that results in a roughened surface, roughened surface is actually beneficial, which promotes a better bond with the repair materials of the existing surface. So, we can clean the reinforcement steel, which is already corroded by needle scalers or high-pressure water cleaning.

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We can also use abrasive blast cleaning technique, or power brushing, by which we can remove the rust over a reinforcement steel. Now, in abrasive blast cleaning the abrasives are mixed with pressurized air and are projected through a nozzle to clean the surface. You can see here the it is applied through a nozzle with high pressure and the surface is cleaned.

Power brushing can also be used to remove the rust over a steel bar, power brush finishing employs wires, or elastomer bonded wires, or non-metallic wires, brushing wheels in automatic, or semi-automatic mechanism. And portable air tools to smooth, or roughen, the surface, remove the surface oxidation and the weld scale.

So, these are several techniques by which we can clean the reinforcement steel, which has corrosion over it. And that is important to remove, otherwise there will not be proper bonding to the repair material with the existing member.

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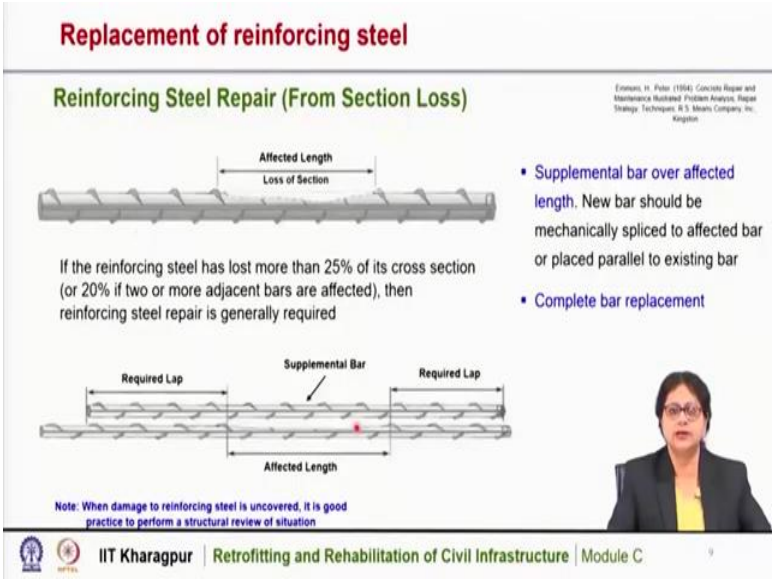

If the reinforcement steel is damaged with loss of surface area, then we have to take some more actions. Here you can see that, the reinforcement steel is shown here and there is a loss of section at some part of it. So, this is the affected portion of the reinforcement steel and due to corrosion, there is a loss of material at some portion on the bar.

Now, if the reinforcement steel has lost significant amount of its cross section, which is about say 25 percent of its cross section, or 20 percent if two or more adjacent bars are affected, then the reinforcing steel repair is generally required.

So, we have to take some actions for the repair of the reinforcing steel. And for that supplemental bar are needed over affected length. And the new bar should be mechanically spliced, or to be placed parallel to the existing bar. So, here is the affected bar with some portion is lost due to corrosion.

And here is the supplemental bar, which is to be placed over the affected reinforcement. And with sufficient lap length on both sides of the bar, you can see here on both sides of the affected area, we can place the supplemental bar. And when the damage is significant, then it is a good practice to perform a structural review of the section. So, if the reinforcement bar is significantly damaged, then we can also replace it at least full length, or a part length.

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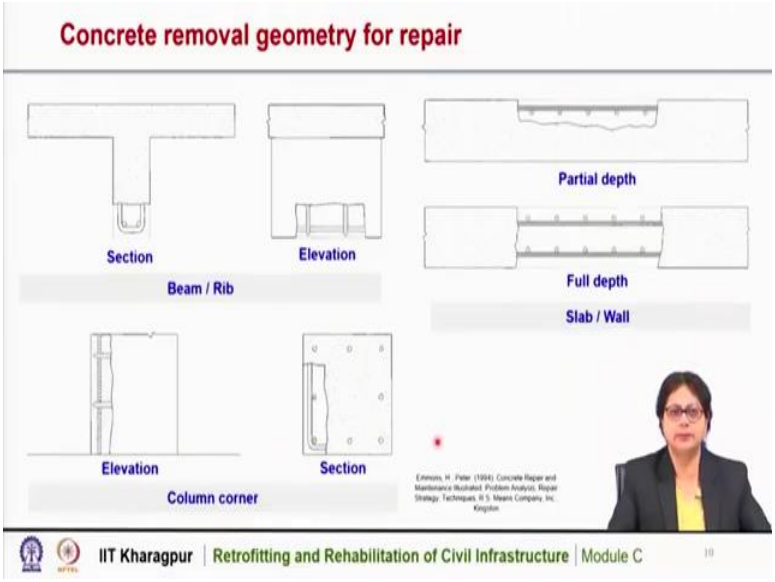

Now, after cleaning the reinforcement, we have seen earlier that the concrete also need to be removed and it has to be done in a proper way. We should have a proper rectangular area for the concrete so that the repair material can be applied on it. So, in case of a beam, say if this portion is damaged, we have to clean this portion and a rectangular section is seen here and the reinforcements are exposed. So, this is the sectional view and this is the elevation.

So, these are the portions, which needs repair. So, here in these portions, we have to put the repair materials. In case of a slab, it may be partial depth repair, or a full depth repair. So, in case of a partial depth, some portion of the slab is here you can see the reinforcement bar is exposed in the some part of the slab, and up to a certain depth. So, this portion we have to place the repair material.

In case of a full depth repair, the entire depth of the affected portion is to be replaced by a new material. In case of a column, you can see here this is the elevation and this is the sectional view of the column at its corner. So, this portion is damaged, so concrete is removed at this portion, the loose concrete has to be removed, and the reinforcement bar is exposed, it needs to be cleaned, if it is corroded.

And then a new material to be applied. So this is the portion, that is to be repaired. So, this is the elevation and this is the sectional view of the column. So, we have to follow the proper geometry, so that the repair material can be applied on the affected area.

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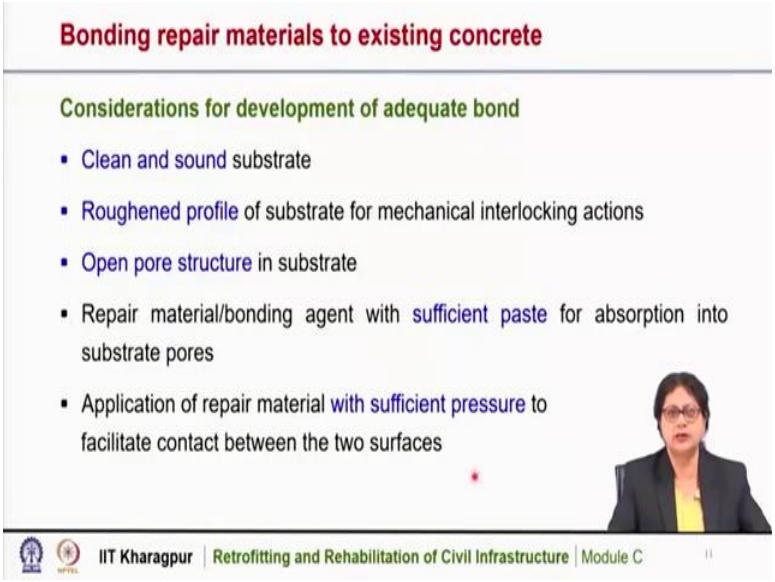

Now, bonding repair materials to existing concrete, it is important that the new material should be properly bonded to the existing surface. And for that there are certain considerations and while doing the repair work, we have to follow certain considerations.

The considerations for development of adequate bond are that the substrate or the existing surface should be clean and sound. So, that there should not be any loose material on it, otherwise the bond will not be proper. Roughened profile of the substrate for mechanical interlocking actions, the existing surface should have a rough profile.

It should be uniform, but not very smooth, because if the surface is smooth, then the bonding will not be proper. So, a roughened profile is actually beneficial, so that the mechanical interlocking, or aggregate interlocking action can take place between the existing surface and the new material.

The existing substrate should have open pore structures and the repair material, or bonding agent with sufficient paste should go through that open structure, for absorption into the substrate pores. And application of the repair material with sufficient pressure is necessary to facilitate the contact between the two surfaces.

So, it is to be considered that the substrate should be clean and sound, it should be uniform, it should have a rough surface a rough profile, so that the aggregate interlocking action can take place and the bond is achieved. The existing substrate should have open porous structure, so

that the repair material, which is of sufficient paste, that can enter into those open pores and can achieve the necessary bonding.

And the application of the repair material also should preferably be done with sufficient pressure. So, that it facilitates the contact between the two surfaces. So, these are the considerations for the development of adequate bond and this we have to consider while carrying out any repair work.

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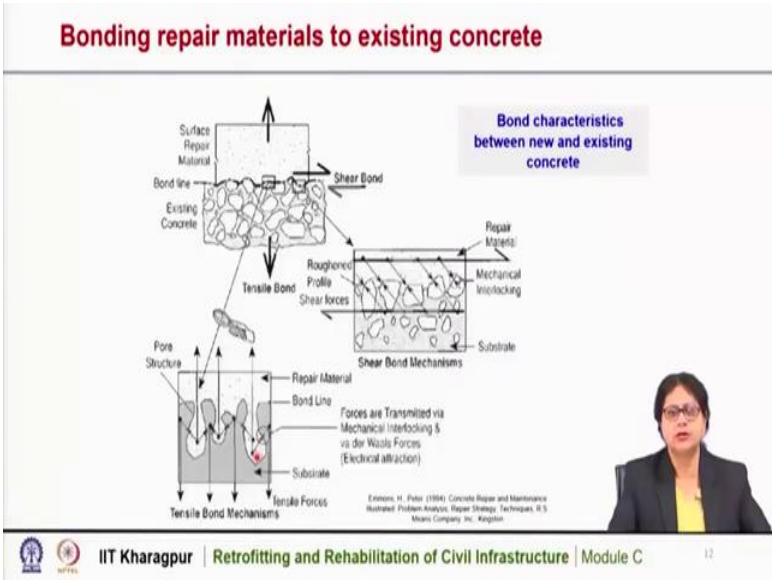

These are the schematic diagrams of the bond characteristics between the new and the existing concrete. We can see here in this diagram, that this is the existing concrete, these are the aggregates and this is the surface of the existing member and this is the new material. So, this is the repair material, which is to be applied on the existing surface. The existing surface has pores on it, and it is not very smooth, it is roughened surface.

The bond surface may experience the shear stress, as you can see here and also the tensile stress. So, it should be capable of taking the shear stress coming on it and the tensile stress. Here you can see that, the repair material is applied and the repair material goes through the pores of the existing substrate so that the aggregate interlocking action can take place to resist the shear stress as well as the tensile stress.

So, here is also the, this is the pore structures and the repair material, which is sufficiently soft and have sufficient paste can enter through these pores, so that the adequate bond can be achieved.

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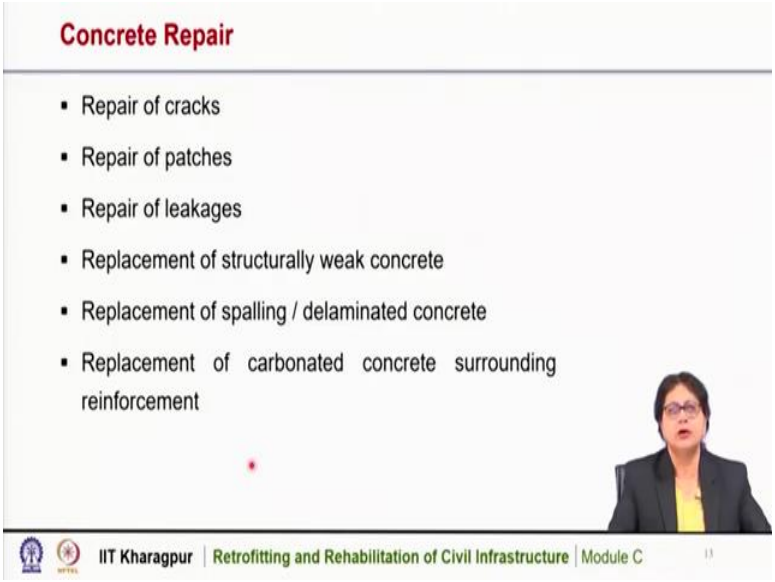

The repair may be of different types, we can repair the existing member by repairing the cracks on it, by repairing the patches on the surface. We can also repair the leakage on the existing surface. The replacement of structurally weak concrete, or replacement of spalling, or delaminated concrete and replacement of carbonated concrete surrounding the reinforcement.

So, while considering the repair of an existing substrate, the repair can be of different types, which are repair of cracks, repair of patches, repair of leakages, and replacement of structurally weak concrete, or carbonated concrete, or delaminated concrete. So, now we will discuss the different techniques of this repair.

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There are several techniques by which we can repair an existing structure, or existing substrate. We can do it by sealing the cracks, surface coating, dry packing, grouting, there are several methods of grouting, or gravity filling, surface impregnation, drilling and plugging, pre-placed aggregate concrete, routing and sealing, stitching and stapling etcetera. So, we will discuss these techniques in detail in the subsequent lectures also.

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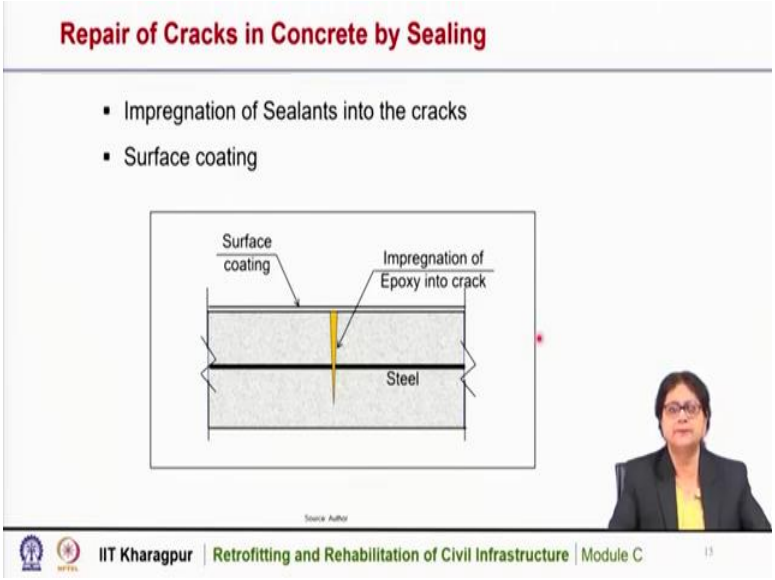

Now, repair of cracks in concrete by sealing. If a crack is there on an existing member and the crack is extended beyond the reinforcement, but it is very fine. So, here you can see schematically, it is shown that this is the existing concrete member and this is the crack on

the surface. And that is very fine crack and it is extending up to a certain depth. So, in this case, what we can do?

One method is to seal the cracks by impregnation of sealants into the crack, that material may be epoxy. And then a surface coating may be applied. So, if a crack is very fine, we can fill up the crack by some repair material. It may be an epoxy resin, which is very commonly used for sealing of cracks. And then a thin surface coating is to be applied. So, by which we can seal the cracks and the integrity of the structure can be maintained.

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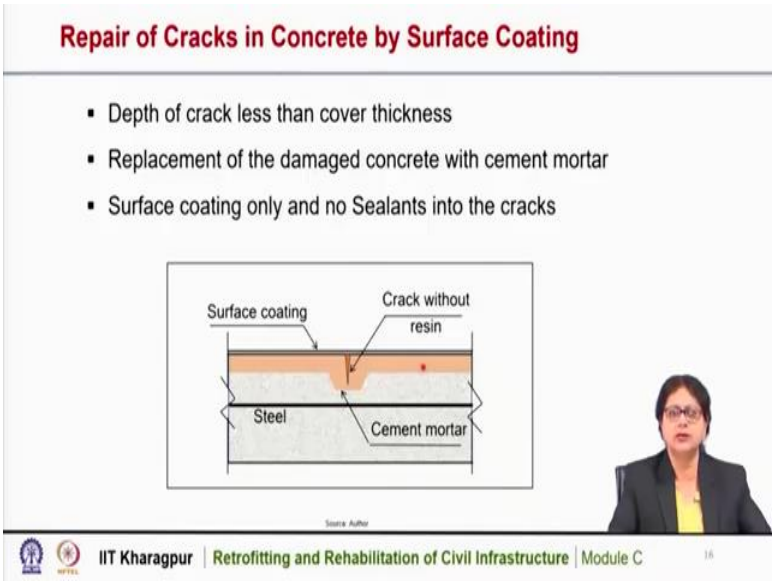

Repair of cracks by surface coating, you can see here in this schematic diagram, this is the existing member and there is a crack at the surface. The surface is also damaged at some portion and the depth of crack is however not much and less than the cover thickness. So, it is shown schematically, that this is the crack and it has not reached up to the reinforcement. So, the cover depth is this, so it is not reaching up to the reinforcement.

However, some portion of the concrete at its surface is damaged. So, in that case we can treat this by replacement of the damaged concrete with cement mortar and then a thin layer of surface coating on the surface on the on the surface. So, here we can do, we can seal the in repair of cracks in concrete by surface coating, sometimes the cracks are thin, but may not reach up to the depth of the reinforcement.

So, in that case what we can do? We can repair the cracks and if the surface is also damaged, we can remove the damaged portion on the surface and replace the damaged concrete with

cement mortar. So, here we can see that, this is the repair material, this is the cement mortar, which is to be placed on the surface, after removing of the damaged material. The crack is also removed, when we remove the loose concrete, the damaged concrete and then a thin layer of surface coating may be applied. So, that the integrity of the member is maintained.

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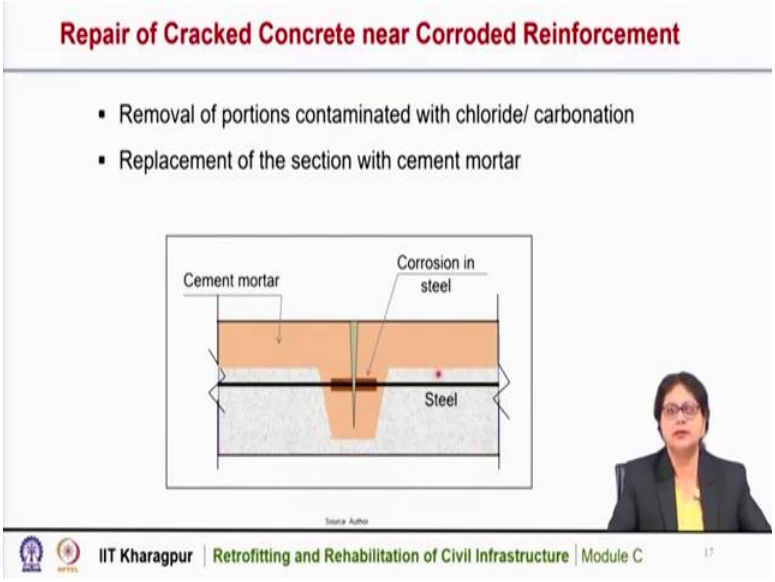

Repair of cracks near the corroded reinforcement, so if the crack is fine and it reaches up to the reinforcement or beyond, and also the area near the corroded reinforcement is distressed, so in that case, we can first remove the distressed material, you can see here, this portion the material is distressed. So, we can remove the distress material and beyond the corroded reinforcement also, so that the crack is also removed.

And then we can replace that portion by cement mortar. So, here you can see that, this is the cement motor, which is to be placed on the surface, after removal of the distressed concrete. And also, the crack is removed, which was extended beyond the reinforcement. So, this way we can also treat the surface distress by placing cement mortar near the corroded reinforcement.

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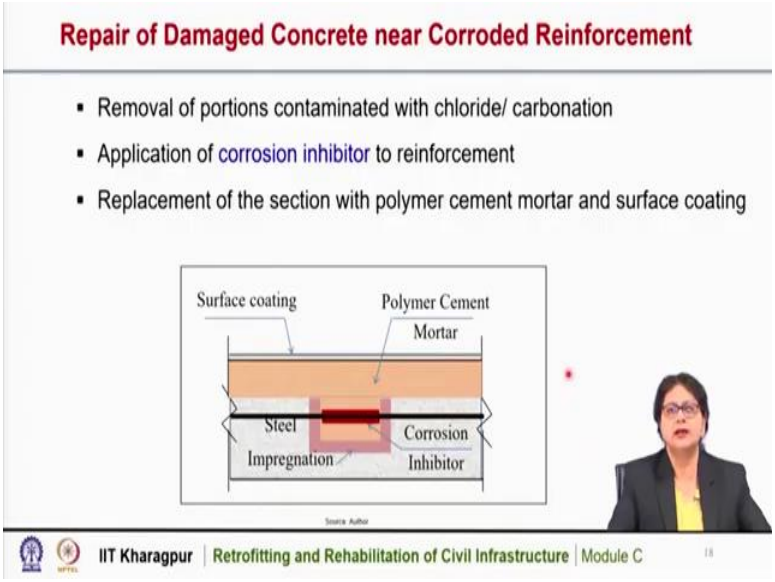

Repair of damaged concrete near corroded reinforcement, it is another way of repair. The removal of the portions, which is contaminated with chloride, or carbonation. So, here also the reinforcement bar is corroded you can see this portion, the bar is corroded and some portion of the concrete, which is also distressed due to delamination, or so. So, what we can do here?

We can also put some corrosion inhibitor over the affected area after cleaning the reinforcement. And then the polymer cement mortar can be applied on the portion, which is where the distressed concrete was there. So, polymer cement mortar can be placed on the portion of the member and then a surface coating can be applied. So, this is a repair technique of damaged concrete near the corroded reinforcement.

If significant amount of the reinforcement bar is corroded, we can use a corrosion inhibitor. And after that we can place the polymer cement mortar, or cement mortar and also around the reinforcement area. So, the distressed concrete is to be removed and then we can place the cement mortar, or polymer cement mortar, on the surface. And a surface coating may also be applied.

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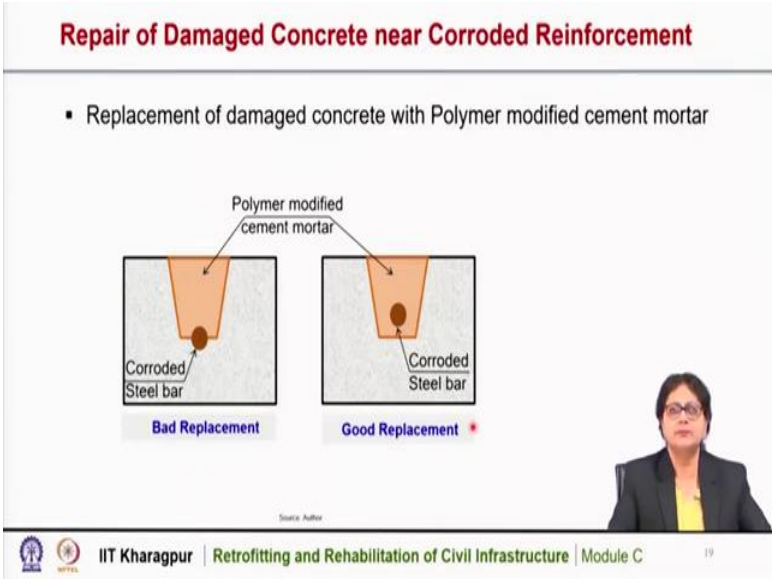

So, as we have shown in the earlier sketches, that if the concrete is distressed near the corroded reinforcement. So, it is a good practice, that we should remove the concrete below the reinforcement also, below the corroded reinforcement. So, this is the good practice of removal of distressed concrete.

And this is not a good practice, because in that case, the area the reinforcement may be subjected to more stress. So, it is not a good practice of removing of the distressed material. So, concrete should be removed below the reinforcement as well. So, this we have to keep in mind, while removing the distressed material near the corroded reinforcement.

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Now, there are several methods of crack repair, we can use dry pack, or epoxy bonded dry pack, for crack repair. Dry pack is a dry cements and mortar, generally, 1 is to 2.5 is the ratio of cements and mortar with little water in it, and that is why it is called dry pack.

And with that dry pack we form a ball type of formation, you can see here. This is the dry pack and that is used for sealing of cracks. The dry pack is made and immediately packed and placed in thin layers and compacted with hammer. Since the material is very dry. And so, it is to be compacted with hammer. And sometimes epoxies are also used as a binder.

So, then it is called epoxy bonded dry pack. And dry pack, or epoxy bonded dry pack, is suitable for small areas, for fine cracks, and particularly it is suitable, when the access is difficult and conventional concreting, or repairing is difficult. So, in those cases dry pack, or epoxy bonded dry pack is a convenient way of crack repair.

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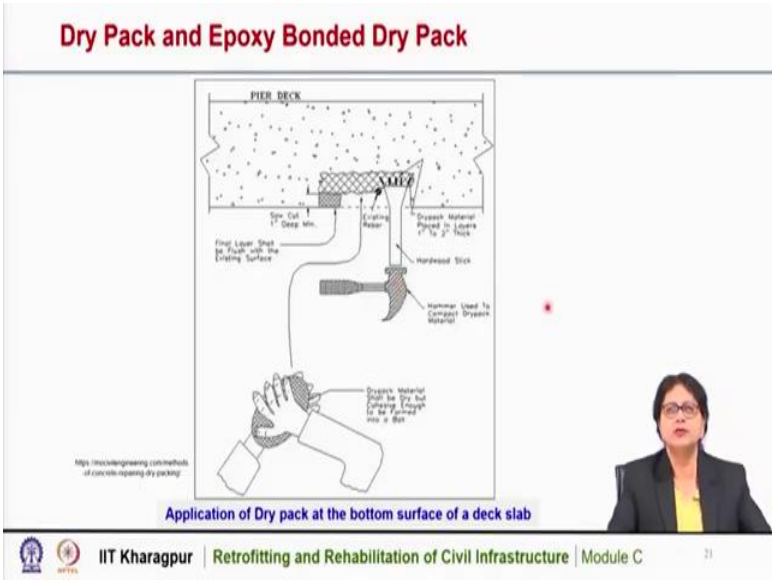

This is a schematic diagram of the application of dry pack, at the bottom surface of a deck slab. So, this is the schematic diagram of a deck slab, the bottom surface may have several cracks, and these are fine cracks. So, in that case dry pack is a suitable method for crack repair. So, dry pack is prepared with little water, or sometimes epoxy can also be used. And then it is to be placed on the cracked area and then a hammering is to be done. So, that the dry pack is filled up through the cracked area. So, by which we can seal the cracks on the surface.

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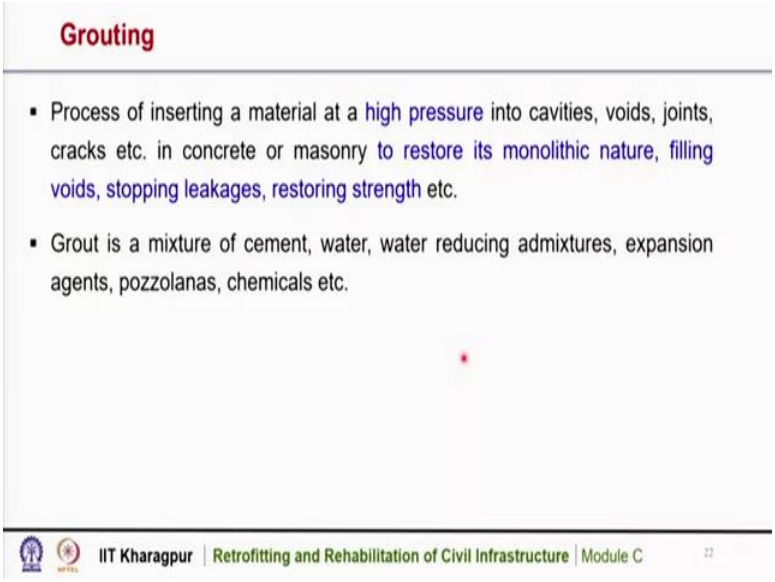

Grouting is a method used for crack repairing. It is a process of inserting a material at a high pressure into the cavities, or cracks, voids, joints, etcetera, on concrete surface, or masonry surface to restore its monolithic nature, to fill up the voids, to stop the leakages, and to restore the strength of the member.

So, grouting is a popular technique for repair of the existing structure and by which we can insert the grouting material at high pressure to fill up the voids, or cracks. Grout is a mixture of cement, water, water reducing admixtures, expansion agents, and sometimes pozzolanas and chemicals are also there.

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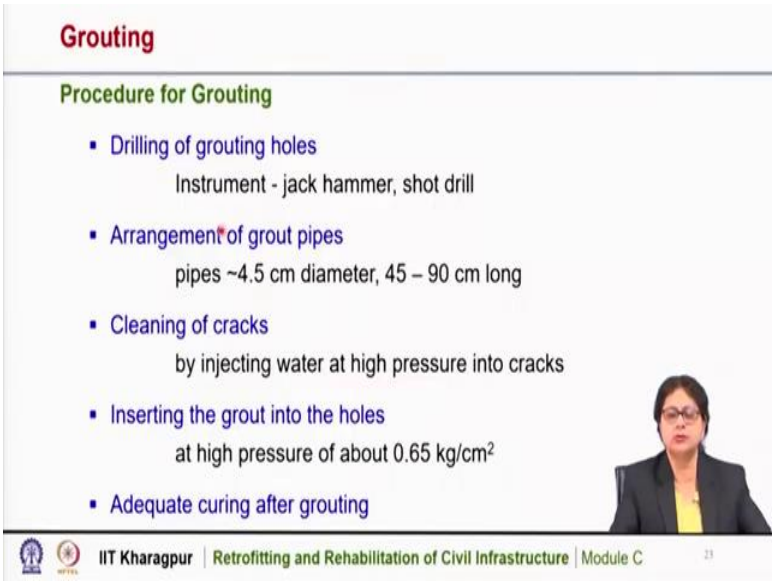

There are several procedures for grouting. Procedure for grouting is that, we have to drill grouting holes, a number of grouting holes to be drilled on the surface. The instrument that is used for drilling holes are jack hammer or short drill, by which we can drill holes of different diameters. Then we have to arrange some grouting pipe, the pipes are of diameter in the range of 4.5 centimeter, or so.

And it is of length 45 to 90 centimeter, depending on the type of structure and the type of repair. Then we have to clean the cracks by injecting water at high pressure into the cracks. After cleaning the cracks, the grouting material is to be inserted, through these holes. And the grouting material is to be inserted at high pressure of about 0.65 kg/cm^2 approximately.

And after filling up the voids, when the grouting material will come from other holes, we can ensure that the all the voids are filled up. And then it is to be cured, adequate curing is necessary after the grouting. So, for carrying out the grouting operation, several holes to be drilled and through those holes grouting pipes are to be placed, after cleaning the cracks we have to insert the grouting material through the holes with high pressure. And after curing the surface is ready.

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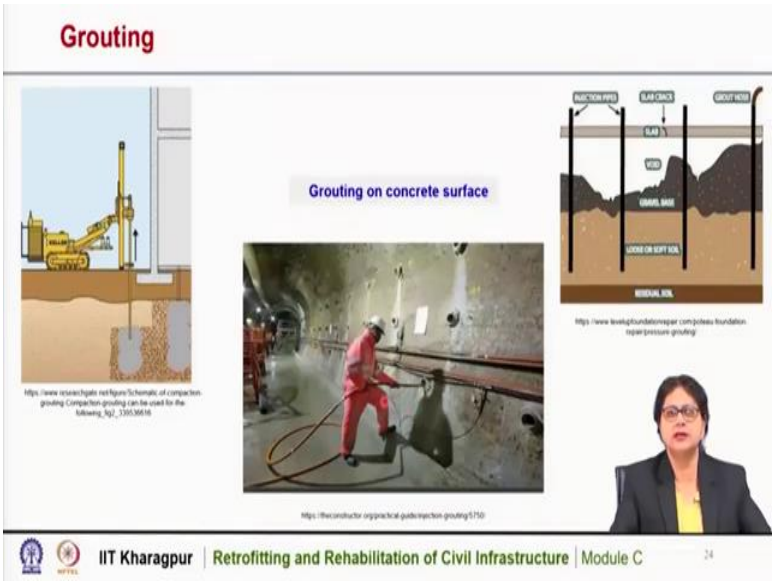

Here are some pictures of grouting, we can see here that, the grouting hole is prepared and through this the grouting material can be injected. So, these are some of the grouting pipes, which are inserted through the holes of the structure, and the grouting material is to be inserted into this.

So, this may be a soil and grouting material can be injected through these pipes into the soil. And this is the grouting on concrete surface, we can see here that the grouting material is inserted through the pipes, grouting pipes on this surface.

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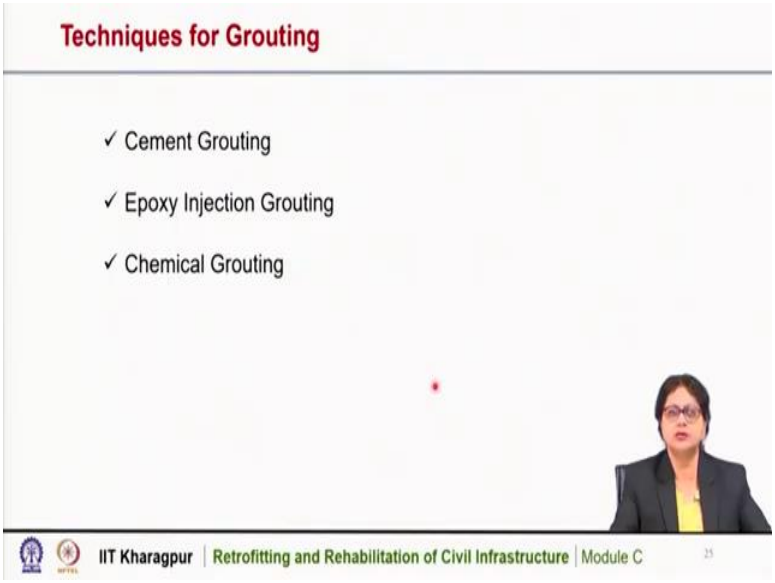

There are several techniques of grouting, we could use cement grouting, or epoxy injection grouting, or chemical grouting.

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Cement grouting is a composite material, generally consisting of water, cement and sand. We can see here in this picture, it is the cement grout, or sometimes calling at slurry grout, and

this is used for cement grouting. The cement grouting is used to fill the underground voids, or underpin foundations to strengthen the soil or structure or material.

Here in this picture you can see that, the grouting pipes are placed, these are the grouting pipes, which are placed and through which the grouting materials can be inserted with high pressure so that the soil can be strengthened.

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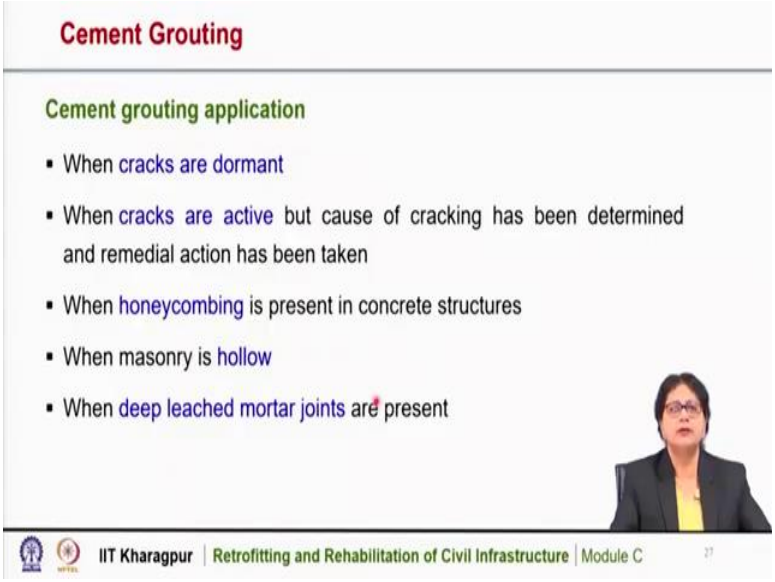

Cement grouting application. When the cracks are dormant, we can use cement grouting, we can also use when the cracks are active, but the causes of cracking have been determined. And also, some remedial actions were taken. So, in that case when the cracks are active, we can also use the grouting. When there is honeycombing present in the concrete structure there also, we can use cement grouting to fill up the voids.

We can also use it in masonry structure, when the masonry becomes hollow. So, we can use cement grouting to fill up the voids. And when deep leached mortar joints are present so in that case also cement grouting can be applied.

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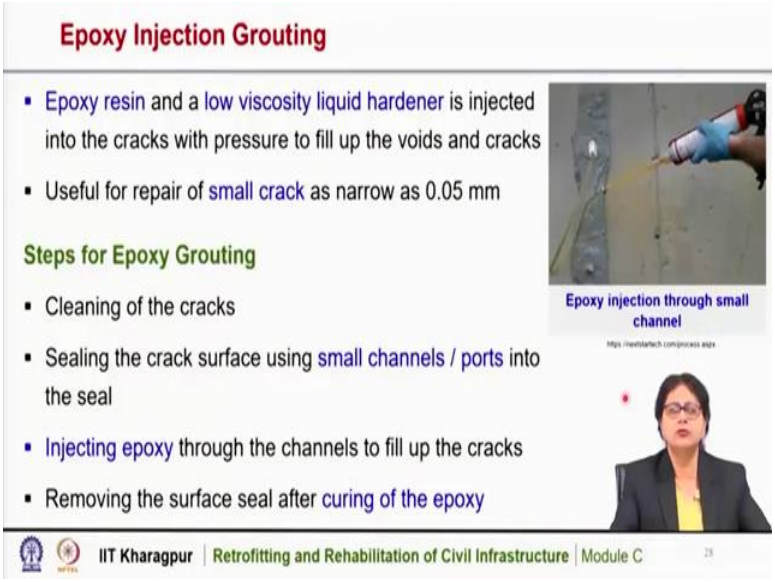

Epoxy injection grouting is also another effective technique of crack sealing. In this technique, the epoxy resin with a low viscosity liquid hardener is injected into the cracks with high pressure to fill up the voids, or cracks. And it is useful for repair of small cracks as narrow as a 0.05 millimeter, particularly for very fine cracks, we can use epoxy grouting injection technique. And the cracks, or voids within the material is filled up.

Here is a picture you can see that epoxy injection through small channels, and with this the cracks are filled up. The steps for epoxy grouting are that we have to first clean the cracks, then the sealing of crack surface using small channels, or ports into the seal. So, this is a small channel, which is to be placed on the surface for the epoxy grouting.

Then the epoxy is to be injected through the channels to fill up the cracks. Then the removal of the surface seal after the curing of the epoxy. So, with this we have to put some small channels, or ports, on the surface and through which the epoxy is to be ejected with high pressure to fill up the cracks.

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Here are some pictures of the epoxy grouting injection. We can see here, that this is a road over bridge, which is under retrofitting and the deck slab has several cracks on it. And these are the portions, which is to be grouted with epoxy injection. Small ports, or channels, are placed on the surface and through which the epoxy grouting can be done.

So, here is the enlarged view of that deck slab, you can see here, the ports are placed through which the epoxy can be injected with high pressure. Here is the picture the channels are fixed for the epoxy grouting. So, this is an effective method of crack sealing with high pressure epoxy can be injected through these small holes, or channels, or ports, and by which the integrity of the member can be restored.

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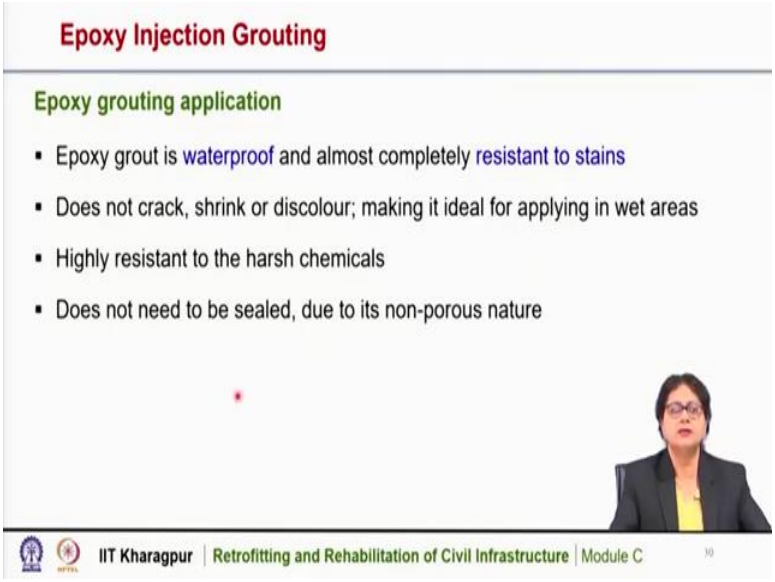

Epoxy grouting application is for integrity of the structure and also for waterproofing. It is quite effective, because it does not crack, shrink, or discolour, making it ideal even for wet surfaces. It is resistant to harsh chemicals and after sealing with epoxy, it most of the time it does not require any other sealing.

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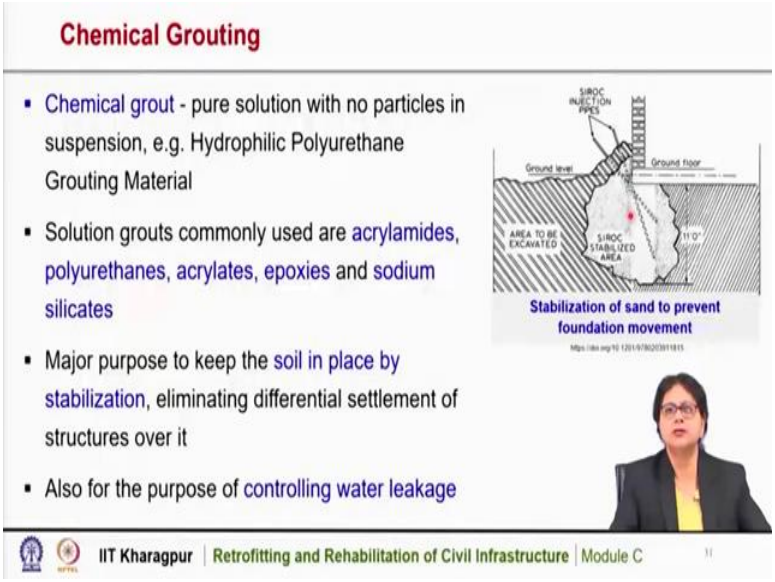

Chemical grouting is also done and chemical grout is a pure solution with no particles in the suspension, for example hydrophilic, polyurethane, grouting material. The solution grouts commonly used are acrylamides, polyurethanes, acrylates, epoxies, sodium silicates, etcetera. So, these are the materials, which are generally used as chemical grouts.

The major purpose is to keep the soil in place by stabilization, eliminating differential settlement of the structures over it. Chemical grouting is mostly done to consolidate the soil, or to stabilize the soil. So, that the differential settlement of the structure over the soil is reduced, or eliminated. It is also used for the purpose of controlling water leakage.

So, to control the water leakage, we can also use chemical grouting. So, here is a schematic diagram, you can see the stabilization of soil to prevent the foundation movement. The chemical grouting is applied, so that the foundation movement is reduced, or eliminated.

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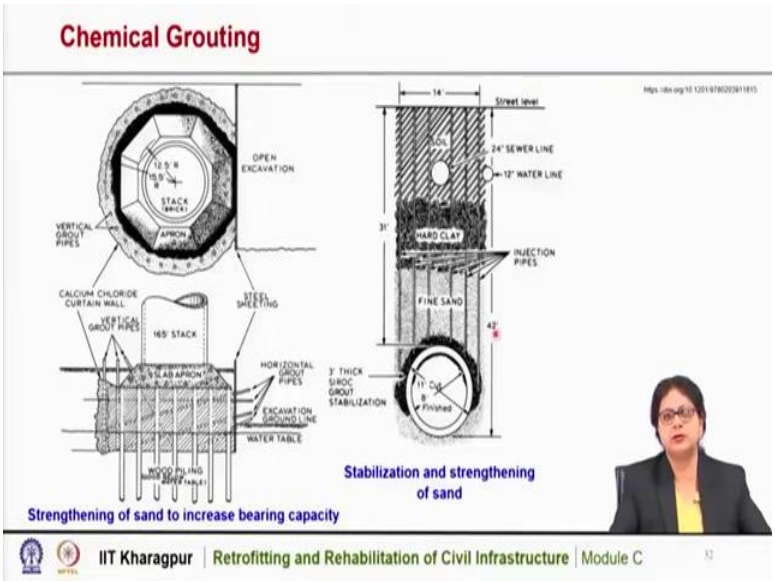

These are the schematic diagrams of the chemical grouting, strengthening of sand to increase the bearing capacity. So, these are the grout pipes, we can see here. So, through this grout pipes, chemical grouts are inserted with high pressure and the sand below it is stabilized and strengthened. So, this is also another picture, or with stabilization and strengthening of sand through chemical grounding.

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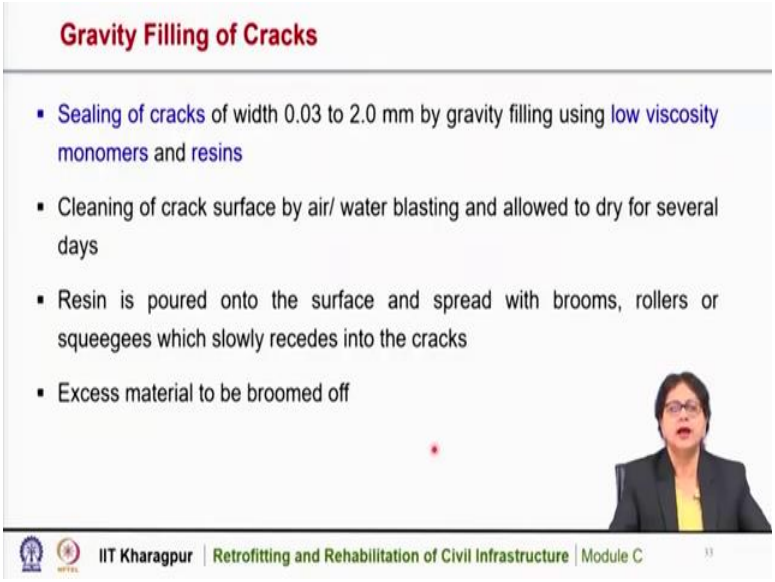

Cracks can also be filled up by gravity filling. So far we have discussed that, either injection grouting, or chemical grouting, or cement mortar grouting, we have to inject the grout through high pressure. However, sometimes gravity filling is also done and in this technique the sealing of cracks can be done by low viscosity monomers and resins.

So, by gravity filling, the cracks of weight say up to 2 millimeter, or so, can be filled up by several resins, or monomers. First, it is to be cleaned, the crack surface need to be cleaned by air, or water blasting, and then it is allowed to dry for several days, after that the resin is poured into the surface and spread with brooms, rollers, or squeezes, which slowly recedes into the cracks.

So, it takes some time for the material to go into the cracks and then after doing it the excess material need to be broomed off. So, the cracks can also be filled up by gravity filling and depending on the type of distress and the type of structure, we can use gravity filling type of technique for crack sealing. And for this particularly we use low viscosity resins as a repair material.

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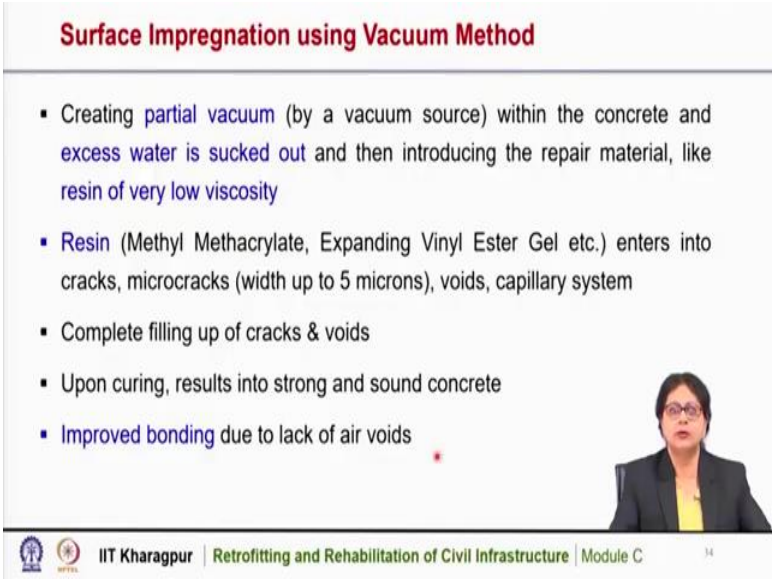

Cracks can also be repaired by surface impregnation using vacuum method. In this method a partial vacuum is created within the concrete and excess water is sucked out and then introducing the repair material. So, here we can remove the water by creating partial vacuum and then the repair material is introduced. And the repair material is mostly resin of very low viscosity.

The resin, which is of different types may be methyl, methacrylate, expanding vinyl ester gel, etcetera, may enter into the cracks, or voids, or capillary pores and then completely filled up the cracks and voids. Now, after curing, it results into a strong and sound concrete surface. So, this is also quite effective method of crack repairing. And the bond that is created is also quite effective due to the lack of air voids. So, crack can also be repaired by surface impregnation using vacuum method.

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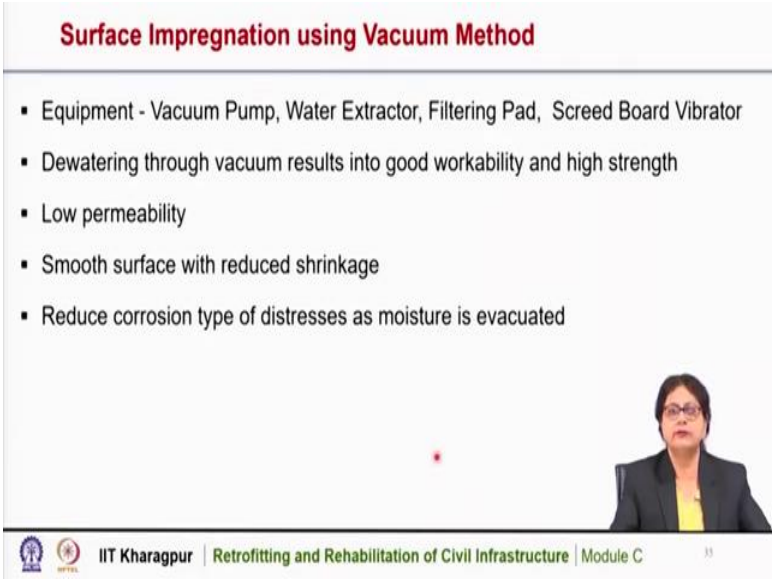

The equipment required for surface impregnation is vacuum pump, water extractor, filtering pad, screed board vibrator, etcetera. Dewatering through vacuum results into good workability and high strength. It results into low permeability of the structure, the smooth surface with reduced shrinkage and reduce the corrosion type of distresses as moisture is evacuated.

In surface impregnation, we are extracting the water. So, the chances of corrosion are also reduced in that area.

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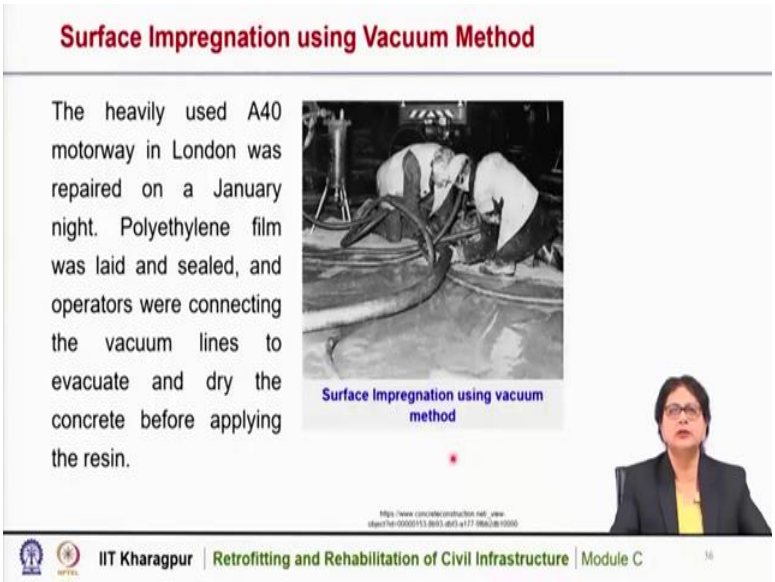

This is a picture of surface impregnation being carried out using vacuum method. This is a picture of a heavily used A40 motorway in London, which was repaired using vacuum method, using surface impregnation. Polyethylene film was laid and sealed and the operators were connecting the vacuum lines to evacuate and dry the concrete before applying the resin.

So, these are the vacuum pipes and the operation is carried out with vacuum method so that the cracks on the motorway can be sealed. So, surface impregnation using vacuum method is also quite effective technique for crack repairing on existing surface.

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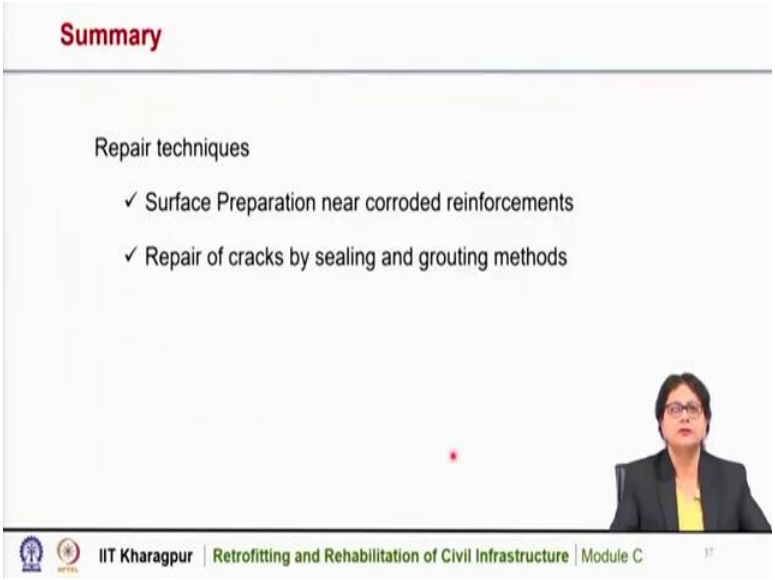

So, to summarize, we have discussed the surface preparation particularly near the corroded reinforcement area. And we have discussed the repair of cracks by several sealing and grouting methods. We have discussed the dry pack, or epoxy bonded dry pack. And we have discussed the surface impregnation using vacuum method. And we have discussed the grouting methods. So, these are the several techniques and we will discuss some more techniques in the next class. Thank you.