Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 12
Considerations for Repair and Retrofitting

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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The concepts that will be covered today are considerations for repair and retrofitting, the steps for repair and retrofitting. The shoring and scaffolding, that is necessary for repair and retrofitting. Surface preparation and repair materials.

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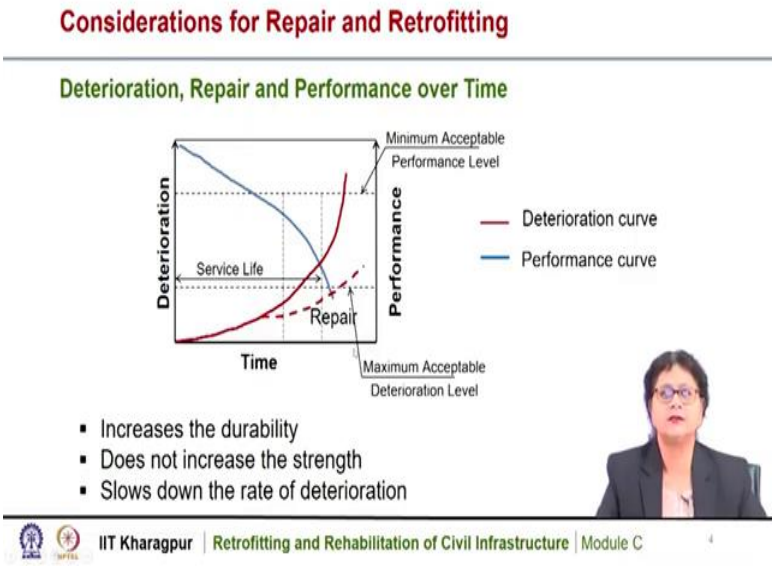

All structures are deteriorated over time. The deterioration may be due to the material degradation, or due to aging, or due to the effect of earthquake type of natural calamities and weathering actions. As the structure is deteriorated its performance is decreased. The rate of deterioration is increasing over time.

If we see the deterioration curve and the performance curve of structures, we will see that initially the rate of deterioration is much less, but after some time the rate of deterioration increases and afterwards there is a significant increase in the rate of deterioration. Consequently, the performance is also decreasing.

As a result, there is a decrease in the strength of the structure, there is decrease in the durability of the structure, and it may result into the lesser service life of the structure as compared to its design life. So, the structure may fail also early, because of this deterioration. So, for an existing structure, it is important to have repair and retrofitting at a timely manner.

For an existing structure, it is required to have adequate repairing and that repairing increases its service life. If we see the deterioration and performance curve along with its repair, so we can see that, if we do the repair it slows down the rate of deterioration of the structure. We can see here that if we repair after certain time, the rate of deterioration actually decreases.

However, with repair there is no increase in the strength of the structure, but the durability of the structure increases significantly. So, a repair is quite effective in increasing the service life of the structure and that is an important consideration for any existing structure.

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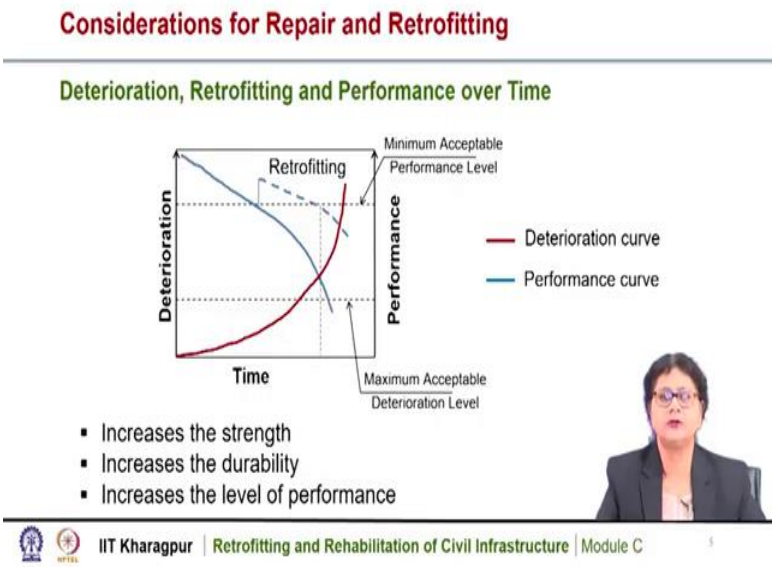

Now, if strengthening is required and that increases the level of performance of an existing structure. So, we can see here in this deterioration curve and performance curve, that retrofitting has been done in this time. So, that retrofitting causes the improvement of the performance level of the structure. So, not only the performance level, it increases the strength of the overall structure and also the durability of the structure.

So, retrofitting causes the improvement in the strength of the overall structure, increases the service life or the durability of the structure and the overall level of performance of the structure. So, for an existing structure, it is important to have timely repair and retrofitting to improve its performance and to increase its service life. So, that it can serve in a better way.

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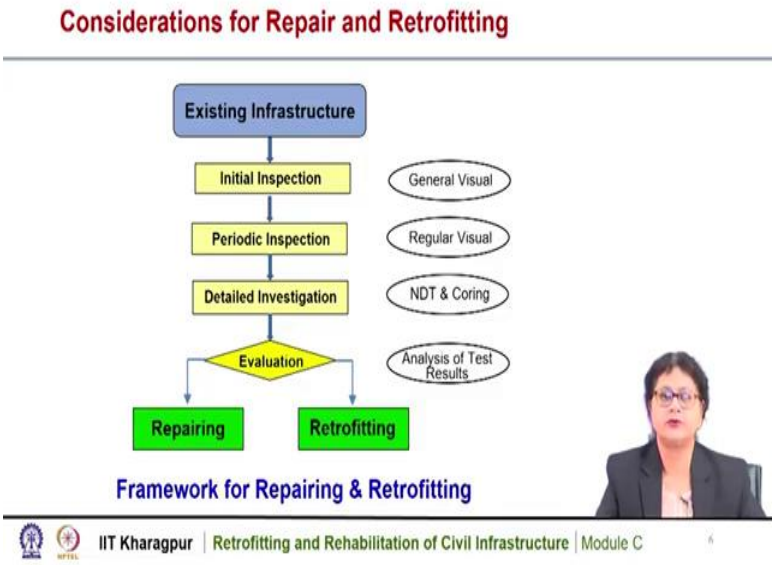

Therefore, for an existing structure, if we can write down the framework for repair and retrofitting, it is important to follow certain steps, an initial inspection is necessary and that initial inspection may be done at some time after the structure has been constructed. And that initial inspection includes a general or visual inspection.

After that, a periodic inspection is necessary. That periodic inspection is a regular interval, that has to be done and that is also visual, but more detailed visual inspection need to be done for an existing structure. After the regular visual inspection, if it is found that there are certain distresses, which are visible, like spalling or cracking on the structure, then a more detailed investigation is necessary.

And that detailed investigation has to be done using several semi-destructive or non-destructive testing, including the extraction of course and testing it in the laboratory. So, a detailed investigation is necessary for existing infrastructure, if visually it is found that there are certain distresses on the structure.

Now, the test results of the semi-destructive or non-destructive testing need to be analysed and the analysis of those test results will tell us the next step. So, based on the test results of the NDT and other semi destructive test, we need to evaluate the current condition of the structure, and based on that evaluation it is to be decided that whether a repairing work or a retrofitting work is necessary for the structure.

So, if there is not much decrease in the overall strength of the structure, then repair measure may be sufficient. However, if the strength of the structure is reduced significantly, then a retrofitting measure need to be taken. So, based on the evaluation or the current condition of the structure, a repair and retrofitting measures need to be taken.

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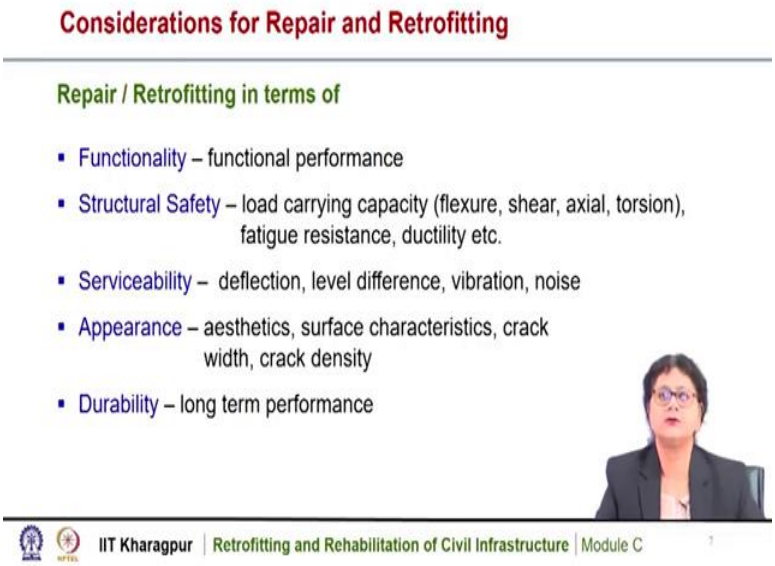

Now, the repair or retrofitting of an existing infrastructure may be done to fulfil certain criteria. The first thing is that the functionality, that is the functional performance of the structure need to be fulfilled. For example, if there is a road and the road may be sound otherwise structurally okay, but functionally it is not proper, that means the riding quality is not good, it may have several potholes or cracks or undulations and that causes uncomfortable journey to the road users, which may also affect the safety.

So, the functional performance; so, the function of the road is not satisfying, so when we will go for repair, or retrofitting we have to consider that the purpose of the infrastructure for which it is built has to satisfy. So, the functionality is one of the main reasons for going to a repair, or retrofitting work.

Then comes the structural safety. All infrastructures must be structurally sound to carry the load, it is subjected to and the load carrying capacity should be sufficient in terms of flexure, shear, axial, torsion, fatigue and ductility, considerations. So, the structural safety needs to be considered, while carrying out any repair, or retrofitting work.

The serviceability also needs to be checked, while carrying out repair and retrofitting work. Serviceability means we have to see the deflection, if there is any large deflection or not, or there is any level difference, or there may be any vibration on the structure, or noise and that also need to be considered. In those cases, sometimes the functional performance and the structural performance may be fine.

But the serviceability consideration, there may be some defects. So, we need to take care of those issues. Appearance is also another factor, that also need to be considered, like the aesthetics of the structure. For example, some concrete structures may have several cracks on it and those cracks may be non-structural, may not affect the structural integrity of the member, or they are not also causing any functional problem.

But aesthetically they may not be so good. So, we have to consider that as well. The other surface characteristics also we need to consider, when we will go for repair and retrofitting of any infrastructure. And the overall durability. For any repair and retrofitting, it is important to have sufficient service life of the structure; the structure should perform in a longer duration, so that its durability is enhanced.

So, these are the major considerations for any repair and retrofitting work of an existing infrastructure. It should satisfy the functional performance, the structural safety should be maintained, the serviceability also needs to be considered and appearance as well as the durability of the structure should be enhanced when we will go for repair and retrofitting of any existing infrastructure.

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There are several important stages for repair and retrofitting and we need to follow those steps, while carrying out any repair, or retrofitting works. The first thing is that we need to identify the cause or reason for the damage. An existing infrastructure may have developed several distresses. So, it is important to find out the reasons for the damage.

Why the structure has been deteriorated? Whether it is due to the material degradation or due to the overloading, or due to any other construction difficulties; that need to be identified and based on that we will find out the solution. Now, after determining the reasons of distresses, we need to find out how much damage has been occurred on the structure.

So, the extent of damage also needs to be find out and that we can find out from carrying out several non-destructive or semi destructive tests. So, the analysis of those test result will tell us the in-situ condition of the structure and the extent of damage. Then we need to evaluate, the need for repair and retrofitting, that need is whether a structure which may be damaged, but how much is the requirement of the repair or retrofitting based on the type of structure and its usage, we have to find out the need for repair and retrofitting.

After finding out the need or necessity for repair and retrofitting, we have to select what are the repair or retrofitting methods, that can be applied to the structure to improve its performance and durability. And what will be the corresponding material for that? There may be several alternatives for repair and retrofitting. There will be several materials also.

So, we have to select one particular method for the appropriate repair and retrofitting work and also the material. Depending on the type of structure, the exposure condition and also the condition of the structure we have to select a suitable repair and retrofitting measure and a corresponding repair material.

Then we need to prepare the existing structure suitable for repair and retrofitting work, because the structure needs to be properly prepared and ready for taking up the retrofitting work. So, we need to prepare the surface condition and other parts of the structure ready for taking up the repair and retrofitting work. Then we have to implement the repair and retrofitting measures.

And then after completing the retrofitting work, it needs to be cured and finished, so that the process of retrofitting is over. And after the retrofitting, it is also important to evaluate the structure, whether it has attained the necessary strength gain or not, that needs to also be checked. So, a structure after retrofitting also needs to be evaluated properly to check that whether it has attained sufficient strength to sustain the loading it is subjected to.

So, these are the important stages of repair and retrofitting. We need to identify the causes of damage; we need to identify how much damage has been taken place. And also find out the actual need for retrofitting. And then based on several alternatives, we have to select one appropriate repair or retrofitting method and a suitable repair material.

Then we need to prepare the surface for carrying out the retrofitting work and then implement the measure, cure it and finish it. And after retrofitting, it is important also to check, whether the structure has attained its required strength or not after the retrofitting work is over. So, this has to be followed for carrying out any repair and retrofitting work for an existing infrastructure.

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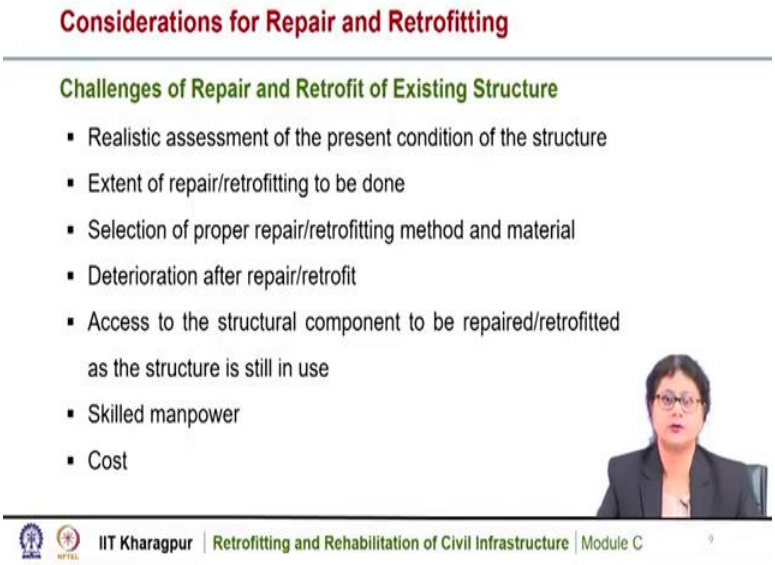

However, there are several challenges of repair and retrofitting of existing structure. Repair and retrofitting is more challenging as compared to a new construction. There are several reasons for this. It is important to realistically assess the present condition of the existing structure. Because when we will go for a repair and retrofit, we need to find out that how much damage has been occurred or not, on the existing structure.

So, it is important to realistically estimate the present condition of the structure. Also, how much damage has been done and based on that how much repair or retrofitting need to be done. So, that need to be assessed in a proper way. Then we have to select a proper repair and retrofitting measures and that also is quite challenging, because there may be several methods, there may be several materials available.

So, how much we can retrofit it? And how what is the appropriate material for that? What is the appropriate measure for retrofitting from several alternatives that we need to select? So, these are the challenges for repair and retrofitting. There may be also that the existing structure after retrofit, there may be deterioration. So, deterioration may also occur and that also we have to consider, while selecting a proper measure of retrofitting.

So, that is also quite challenging, that after the retrofitting also we need to assess that what kind of deterioration the structure may have. And access to the structural component to be repaired or retrofitted as the structure is still in use. This is a very important challenge and

often it is causing difficulties in carrying out the retrofitting work, because in most of the cases the existing structure is still in use.

So, if it is a building, people are staying in it, if it is a bridge, there are vehicles moving, of course, we can restrict some of the things, that we can restrict heavy vehicles on a bridge, or in buildings we can also say that, ok, there may be limited usage on that particular area. So, that can be done, but it is very, very challenging to get access to the proper location of damage without disturbing the other portion, without damaging the other portion.

So, this is a real challenge of retrofit of an existing structure. Skilled manpower is also important. For new construction, masons are available or the manpower is available, but a proper retrofitting work, we need a skilled manpower and many a times skilled manpower is not available. So, that is also a challenge for a proper retrofitting work of an existing infrastructure. And of course, the cost we need to consider the cost of retrofitting, considering the method and the material. So, that is also an important consideration.

So, these are the challenges of repair and retrofitting and as compared to new construction, this is more challenging, because of this issue. We need to identify properly that what is the damage and how much retrofit we can do for that structure, and what is the most optimum method and material for that.

And what could be the deterioration after the retrofit, or whether any other type of distresses may appear, or not that also we need to consider. And access to the structural component is important, because most of the cases the structures are in use. So, we have to do the repair and retrofitting work without damaging the other part. And skilled manpower and cost also are to be considered for repair and retrofitting of an existing structure.

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Now, there are several steps for carrying out repair and retrofitting work of an existing infrastructure. The first thing is that, fixing suitable support and form work for the structure, it is necessary for the application of the selected repair and retrofitting measures, because we need to have sufficient arrangement for carrying out the repair and retrofitting work.

And the structure which is already in distress needs to be properly supported, so that the retrofitting work can be done properly. The surface preparation – The surface of the distress structure needs to be prepared using sand blasting, or water blasting, and with that the removal of dust and debris can be done. So, that the structure is uniform and clean to have the repair materials on it.

Application of the appropriate measure – After cleaning the surface the surface is prepared and now, we can apply the appropriate measure for repair and retrofitting with the selected material. So, this we have to follow, we have to first fix up some support to the structure and form work for carrying out the retrofitting work.

The surface of the existing structure needs to be prepared, clean and uniform so that the repair material and other retrofitting measures can be applied on it. And then we can apply the appropriate retrofitting measure.

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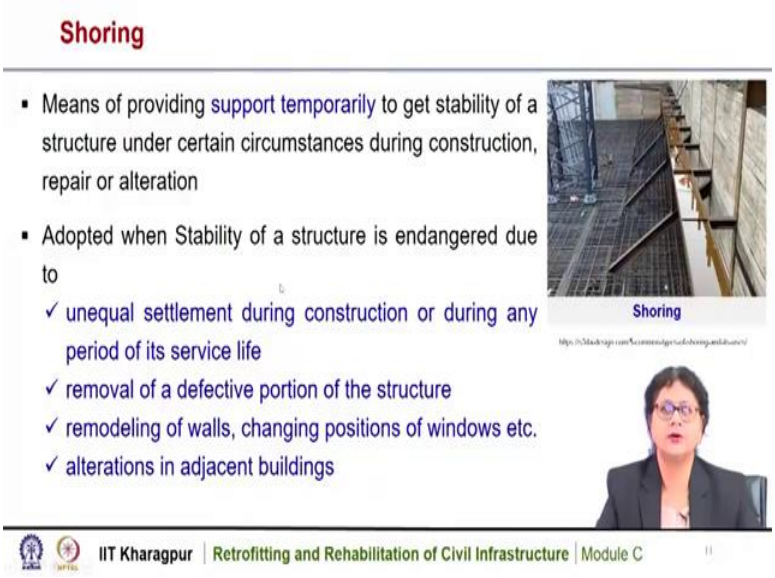

Shoring is a temporary support that is provided to an existing structure, which needs repair and retrofitting. And this shoring gives the structure a stability under certain circumstances during construction, repair, or any alteration. So, shoring is a type of temporary support to an existing infrastructure, which needs to be repaired, retrofitted or any alteration.

The shoring is adopted, when the stability of the structure is in danger, due to several reasons the structure may be in danger due to unequal settlement during the construction time, or during any period of its service life, or during retrofitting work. So, we need to support the structure and that support is a temporary support.

The stability of the structure may also get affected due to the removal of a defective portion of the structure and for that we need to support that portion of the structure, which is removed. Remodelling of walls, changing position of windows etcetera, that also requires an additional support to the nearby areas.

And with shoring we can do that and alteration in the adjacent buildings. So, if there is a building, which is very next to it and that requires major retrofitting, or a construction is going on like a large multi store is coming up on a small near a small building, then the adjacent building may require an additional support.

So, alteration in the adjacent building may also require an additional temporary support to the building nearby. So, this picture shows a typical temporary support, or shoring of an existing building, which is undergoing retrofitting.

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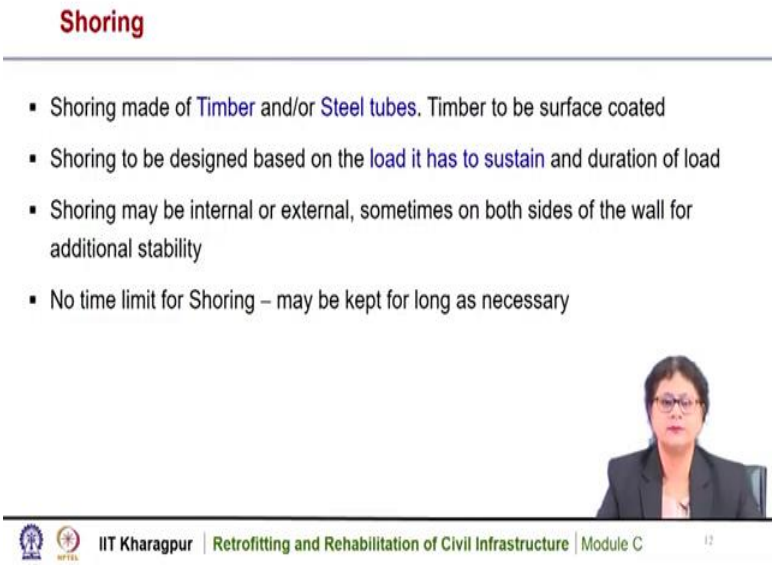

Shoring is generally made of timber, or steel tubes. And if we use timber, that needs to be surface coated. Shoring needs to be designed based on the load it has to sustain, because it is supporting the structure, though it is temporary, but it is supporting the structure.

So, it needs to be designed properly based on the load it has to sustain and also on based on the duration of the load. The showing may be internal or external and sometimes it may be on both sides of the wall for additional stability. And there is no time limit for shoring; it may be kept for long time as per the requirement of the structure.

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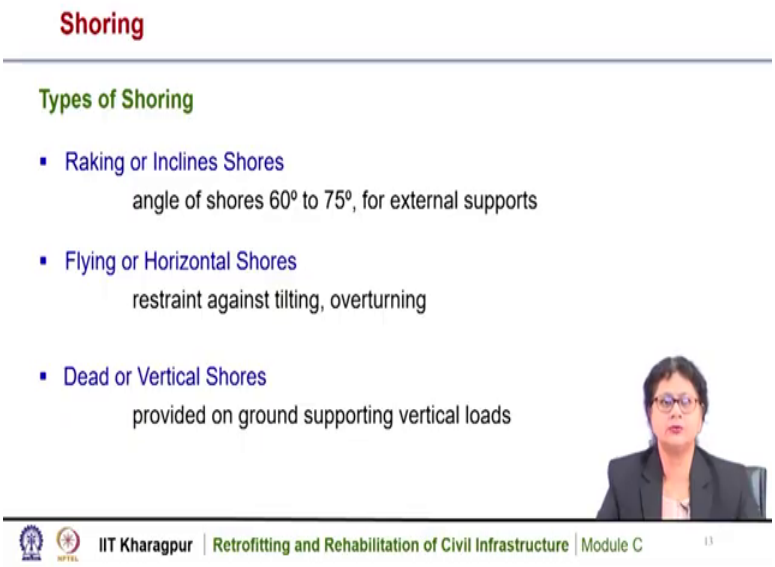

There are several types of shoring, one is raking or incline shoring. Another one is flying or horizontal shoring. And the other one is dead or vertical shoring. In incline shoring the angle of shore is generally kept in the range of 60 degree to 75 degree.

In case of flying or horizontal shoring, it is placed horizontal to the member to restrict against tilting, or overturning of the structural member. And dead or vertical shoring is provided on the ground generally to support any vertical load coming on that. So, these are the different types of shoring and generally all are used to support the structure on a temporary basis.

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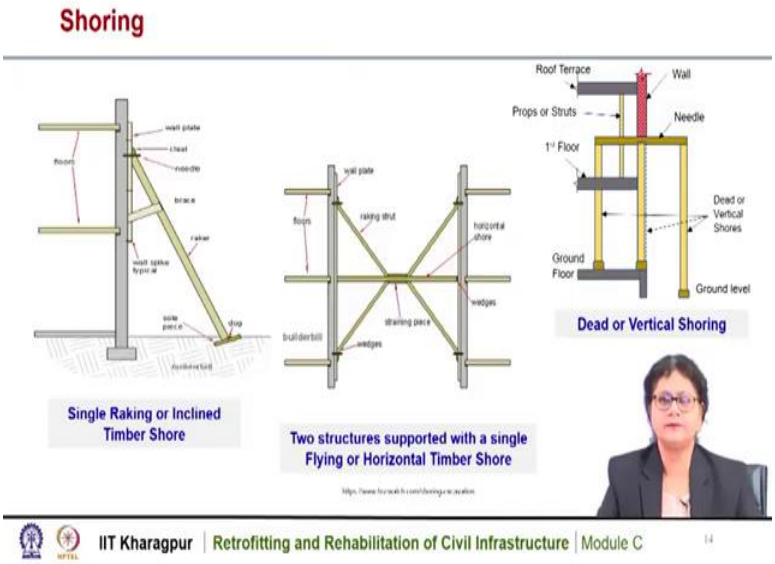

These are some of the pictures of the different types of shoring; we can see here this is an inclined shoring. And you can see here, this is the incline shoring supported and this supports the structure. This is a horizontal shoring you can see here, these are the two adjacent structures and with single horizontal shoring, it is supported along with some inclined shoring. So, this is an example of horizontal shoring.

And this is an example of vertical shoring, you can see here, that these are the vertical shoring, which is supported here and it supports the floors of the building. So, these are the types of shoring, the inclined shoring, the horizontal shoring and the vertical shoring to support the existing structure during any construction work, or any alteration work, or any repair and retrofitting work. And they are used to support the structure on a temporary basis.

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These are some of the pictures of shoring, you can see here, this is vertical, hydraulic shoring, this is hydraulic shoring, supporting vertical loads and this is inclined and horizontal shoring, they support this wall. And so, these are all temporary supports to the existing structure. So, that repair work, or any alteration work can take place uninterruptedly.

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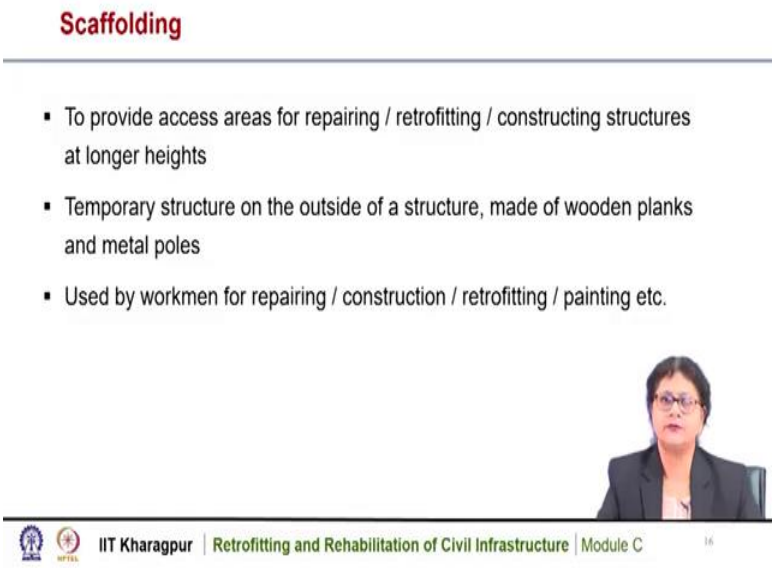

Scaffolding is also another type of support and it is provided to give access to the areas for repairing retrofitting and constructing structures at longer heights. The temporary structures on the outside of the structure, the scaffolding are generally placed outside of a structure and these are also temporary structure made of wooden planks, or metal poles, depending on the type of structure and used by workmen for repair, retrofitting and construction related works.

So, these are the temporary structures, which are built, so that the retrofitting work, or any small construction work can take place.

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These are some of the pictures of scaffolding for repair and retrofitting of structures, you can see here these are the scaffolding outside the building, and that scaffolding has been done for the repair and retrofitting of this building. This is a picture of a road over bridge, which is presently undergoing repair and retrofitting. We can see here the arrangement of scaffolding. The arrangement of scaffolding has been done below the entire deck slab of the ROB.

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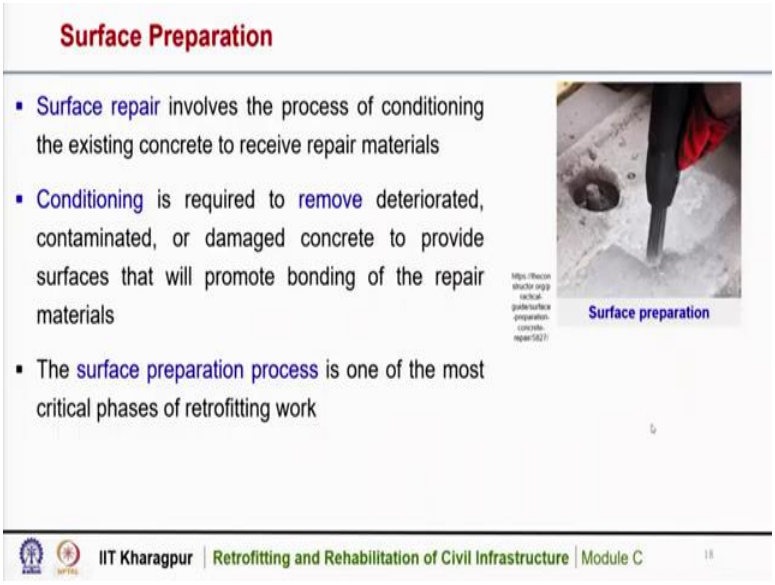

After shoring and scaffolding, the next stage is the surface preparation of the existing member. The surface preparation process is one of the most critical phase of the retrofitting work. It is important to prepare the existing surface properly so that the repair work can be carried out after that.

Surface repair involves the process of conditioning the existing concrete to receive the repair materials. Surface preparation involves removal of the loose, or deteriorated, or contaminated, or damaged material, from the existing surface to provide a uniform and rough surface for promoting the bonding of the repair materials.

It is important to have a uniform surface for carrying out the repair and retrofitting work. However, the surface needs to be rough so that the bonding can be done properly with interlocking of aggregates with the new material as well as with the existing material. So, a uniform surface is necessary for carrying out repair and retrofitting work and that is to be done with proper surface preparation.

Here is one picture, we can see that, the surface preparation is going on with this type of arrangement. These are needle, wires, with that the loose materials. or contaminated material is removed. So, this is a typical picture of surface preparation of existing structure for carrying out the repair and retrofitting work.

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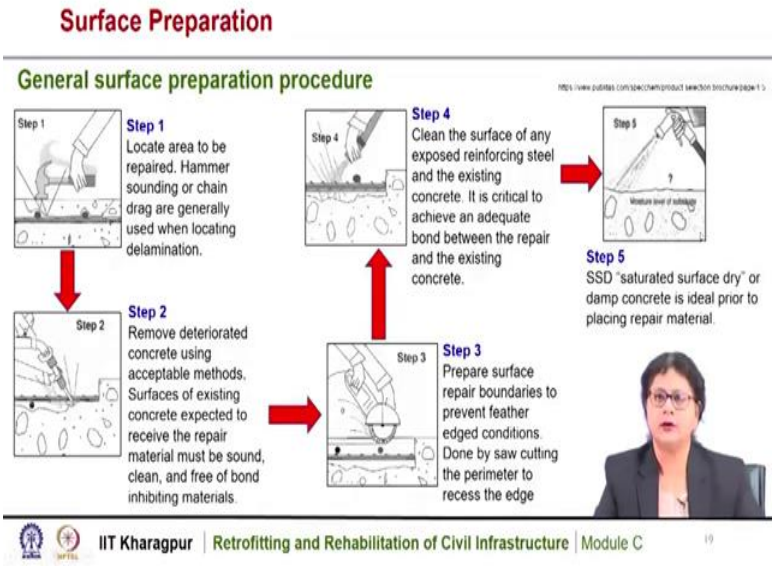

These are some of the steps for surface preparation, which is shown here schematically. In step one, it is important to locate the area to be repaired, that can be done by hammering, or chain dragging, and with that we can understand where there is any void, or delamination, into the structure and that can be identified this with this hammering, or chain dragging.

The next stage is the removal of the deteriorated concrete using acceptable methods. So, that you can see here that the distressed materials are removed and the repair material then can be poured on it. In step 3, it is required to have a proper boundary for carrying out the repair work. So, a proper boundary for repair work needs to be done and that can be done by saw cutting the area, which is to be repaired.

Next stage is the cleaning of the surface within the boundary and that can be done by air blasting or brooming. After that the surface need to be moistened and a saturated surface dry condition is always desirable for applying the repair material.

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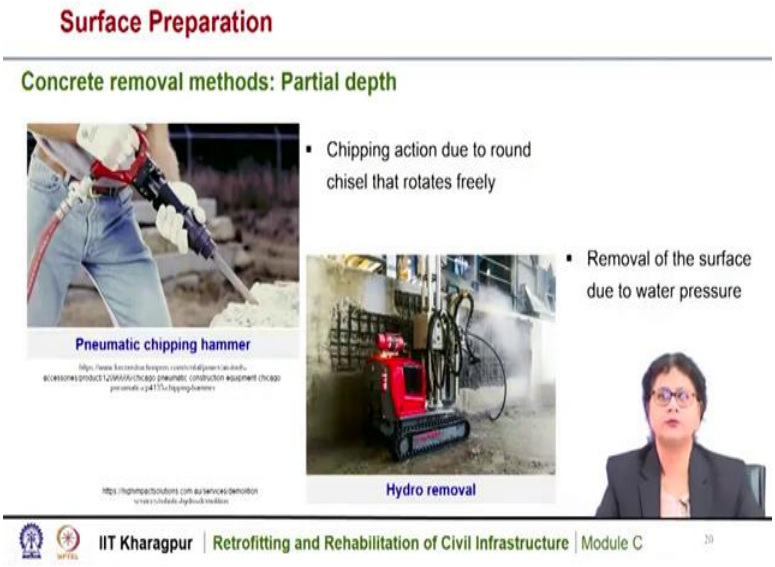

These are some of the methods of the surface preparation with the removal of the distressed material. We can see here there are several techniques of concrete removal, which are already distressed. We can use pneumatic chipping hammer, that with that the chipping action can be done due to the round chisel, that rotates freely on the on the distressed surface and the distress material can be removed.

The removal of the distress surface can also be done by this hydro removal process that is the water is applied with very high pressure. And with hydro removal the distress surface can be removed and that can be partial depth removal. So, with hydro removal technique, the distressed material can be removed.

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The partial depth of material can also be removed by milling. We can see here a typical milling machine. So, for a large structure like, a pavement that the top surface can be removed by milling, so or it can also be done by handheld device, this is a pneumatic scapular and that can be used to remove the top surface of a pavement.

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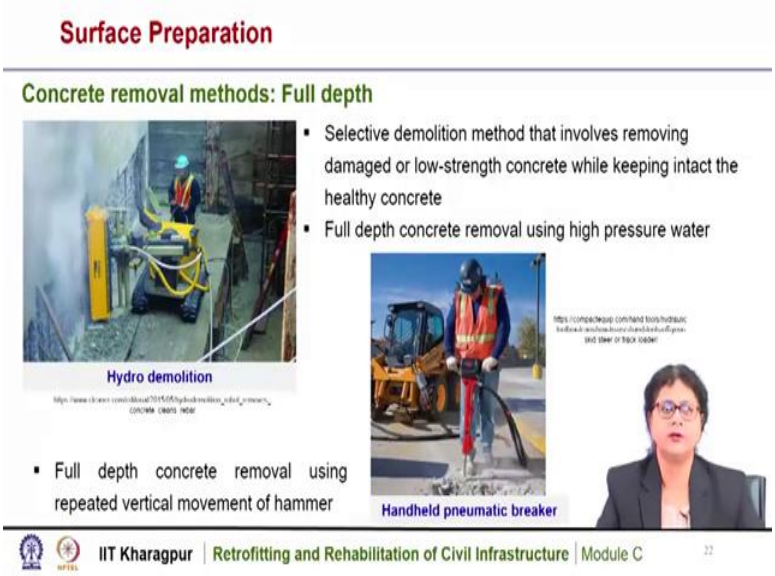

The full depth concrete removal method also. There are several methods for the full depth of concrete removal. Hydro demolition is one such method. Here also the with high water pressure, the water is injected and the damaged concrete is removed. We can also use

pneumatic breaker and that is a handheld equipment and with that with the vertical movement of the hammer, the full depth of concrete can be removed.

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Another method is by the use of splitters. This hydraulic splitter means controlled demolition. It is important that for large structures a control demolition is necessary and with this type of splitter, it eliminates the shock and vibrations associated with large impact tools.

So, splitter can also be used for the removal of distressed material. And we can also use pneumatic or hydraulic mounted breakers. Particularly in case of bridges, or roads, we can use this type of equipment for the removal of the distressed material.

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So, after the surface is prepared, it needs to be uniform and clean, so that the repair material and retrofitting work can be applied. So, there are several repair materials available, however the repair materials should have some desirable properties. The properties are for a repair material that, it should have low shrinkage, so that there should not be any shrinkage type of cracks, after the application of the material.

The repair material should be quick setting, or hardening properties. It should not take much time to harden, or cure. So, that is important, because in most of the cases, the structures need to be repaired are in use. So, a quick setting, or hardening properties of a repair material is important. It should have good bond strength with existing substrate, because in most of the cases, we are adding a new material to the existing one.

So, the two surfaces need to have a proper bonding. So, the repair material must have a good bond strength with the existing substrate. It should have sufficient strength and compatible material properties and this is important in many cases, the repair material may have a higher strength as compared to the existing material and that is required, because we are using a an additional material on the existing structure.

So, it should have a sufficient strength and compatible mechanical properties. It should have adequate workability, because there should be ease of working with that material. So, workability is important. Minimal curing requirement, it should not take much time for curing, so that it can be used quickly.

Should allow relative movement, in many cases we are using these materials to fill up the cracks or so. And if there are any thermal contraction, or expansion, that can be accommodated. So, it should allow the relative movement. Air and water permeability, it is important for the repair material to be impermeable. It should not penetrate water, or air, or any hazardous material through it.

The repair material should be non-hazardous and non-polluting, because when people are working with it, it should not cause any harm to the workmen. And the repair material also should be durable and cost effective.

So, these are the desirable properties for repair materials, it should have low shrinkage, quick setting, good bond strength, sufficient mechanical strength, workability, and impermeable and non- hazardous and also durable and cost effective. So, this we should keep in mind

while selecting a repair material for the repair and retrofitting work of a existing infrastructure.

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There are several types of repair materials, which are available and some are commercially available. And based on the requirement of the structure, the type of structure, the extent of damage, we have to select the type of repair material. The repair material has the desirable properties and based on that we are having several materials available in the market.

The repair materials may be cement mortar, or polymer modified mortar, epoxy resin, low viscosity epoxy sealing compounds, epoxy mortars, polyurethane and methacrylic acrylate resin, silane and siloxane sealing compounds etcetera.

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Cement mortar is a mixture of cement and sand, which are widely used in all repair works. And sometimes it may also contain supplementary cementitious materials like, fly ash, or blast furnace slag etcetera, or silica fume etcetera and also some chemical admixtures. And cement mortar should be consumed within 30 minutes after adding the water, otherwise it will be hardened.

Along with the cement mortars, if some polymer or latex material is mixed, then we call it polymer modified cement mortar, which is a mixture of mortar and polymer, or latex, in a dispersed form. This polymer or latexes are consisting of very small diameter particles based on elastomeric and thermoplastic materials emulsified in water.

So, we can see here, that this is a typical picture of polymer modified cement mortar, this part is the cement mortar without any polymer, and this part is the polymer modified mortar. And both are used for the repair works.

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Epoxy resin is also widely used repair materials and particularly all sorts of repair and retrofitting work epoxy resins are used. Epoxy resin is actually a mixture of epoxy resin and hardener in specified proportion, either one is to one or one is to two as specified by the manufacturer.

Epoxy resin generally created by transforming liquid polyethers into infusible solids through a special curing process. It results for chemical reaction between the epichlorohydrin and bisphenol-A. So, it is it is due to the chemical reaction of these materials and the hardener, which is actually the curing agent is the aliphatic and aromatic amines and polyamides.

So, it is the epoxy resin is coming in combination with the epoxy resin and the hardener and they have to be mixed properly. And then we can apply it as a repair, or retrofitting works. Sometimes additional diluents are added in the epoxy resin for lowering its viscosity to improve the workability. And that is also used in repair work.

So, here you can see that, this is the picture of low viscosity, epoxy sealing compounds, coal tar epoxy system, is also used or rubber modified epoxy system, where you will find that rubber granules are used as a modifier, or coal tar is used in the epoxy system. And these are all used as a sealant.

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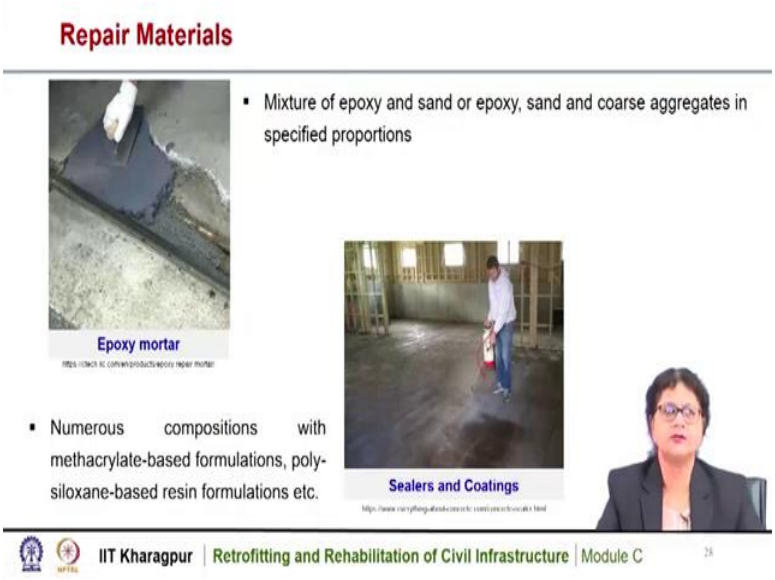

Epoxy mortar is also used as a repair material, which is actually a mixture of epoxy and sand, or epoxy sand and coarse aggregates of small sizes in specified proportion. So, we can see here a typical epoxy mortar application on a deteriorated surface for repairing. There are numerous compositions with methacrylate-based formulations, poly-siloxane-based resin formulations that are used as sealers and coatings for the repair works of several structures.

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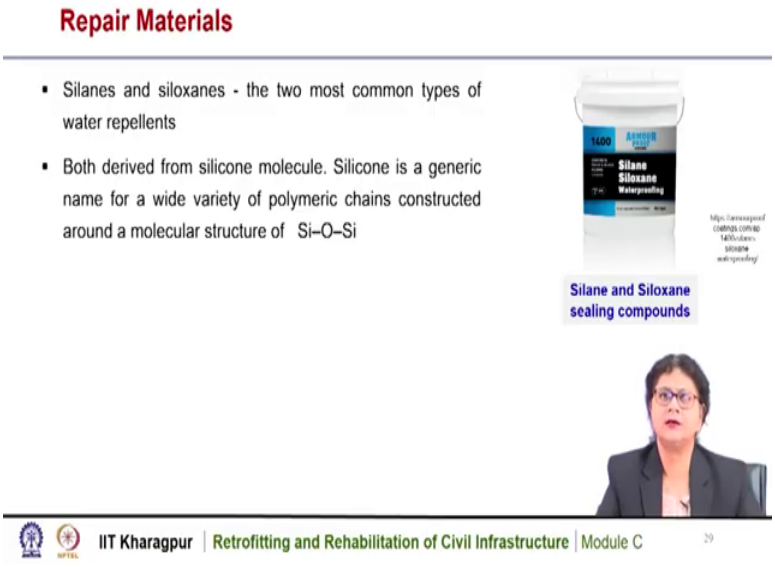

Silanes and siloxane are the two most common types of water repellents. We can see here this is a container for silane and siloxane type of water repellent or waterproofing material and which are used widely in the repair works. The materials are derived from silicone molecule.

Silicone is a generic name for a wide variety of polymeric chains constructed around a molecular structure of Si-O-Si.

So, this silane and siloxanes are used for water repellent material. And they are also used as a repair material in many repair and retrofitting works of existing structures.

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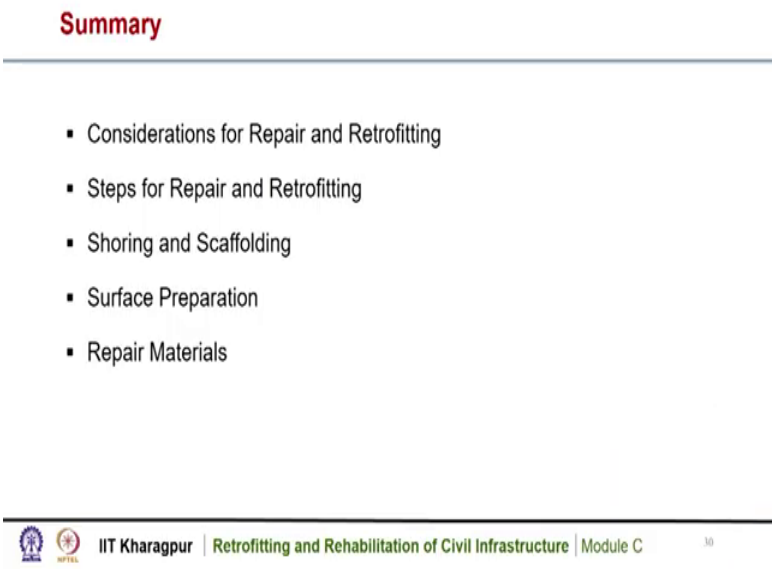

So, to summarize, we have discussed what are the considerations for repair and retrofitting of an existing infrastructure, what are the steps for repair and retrofitting. We have discussed the temporary supports that are needed to an existing structure for carrying out the repair and retrofitting. Shoring is required to support the structure temporarily, so that we can carry out the repair and retrofitting work.

And scaffolding is an external support arrangement by which the workman can work and carry out the retrofitting work. The existing structure needs proper surface preparation, the surface needs to be properly uniform and clean so that the repair material and retrofitting measures can be applied on it. And we have also discussed the common repair materials, which are widely used in repair and retrofitting of the existing structures. Thank you.