Retrofitting and Rehabilitation of Civil Infrastructure
Professor. Swati Maitra
Ranbir and Chitra Gupta School of Infrastructure Design and Management
Indian Institute of Technology, Kharagpur
Lecture 08
Semi-Destructive Testing

Hello friends, welcome to the NPTEL online certification course on Retrofitting and Rehabilitation of Civil Infrastructure. Today, we will discuss Module B, the topic for Module B is condition evaluation and testing.

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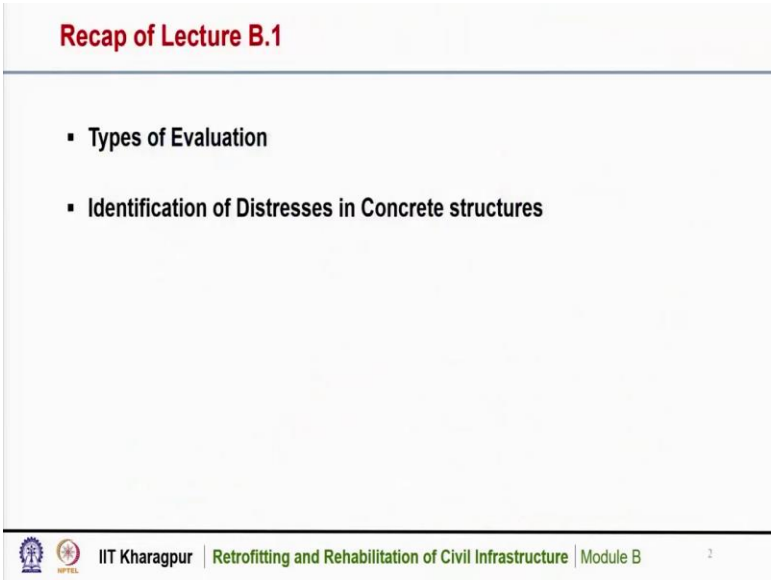

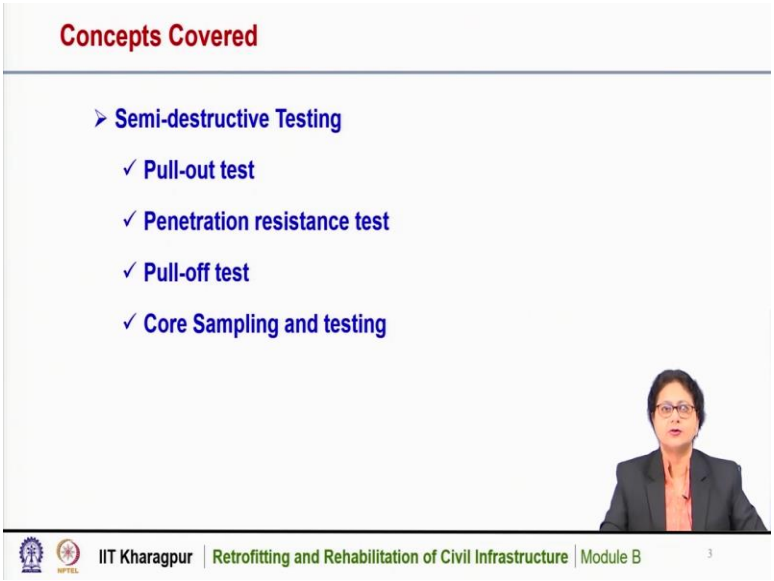

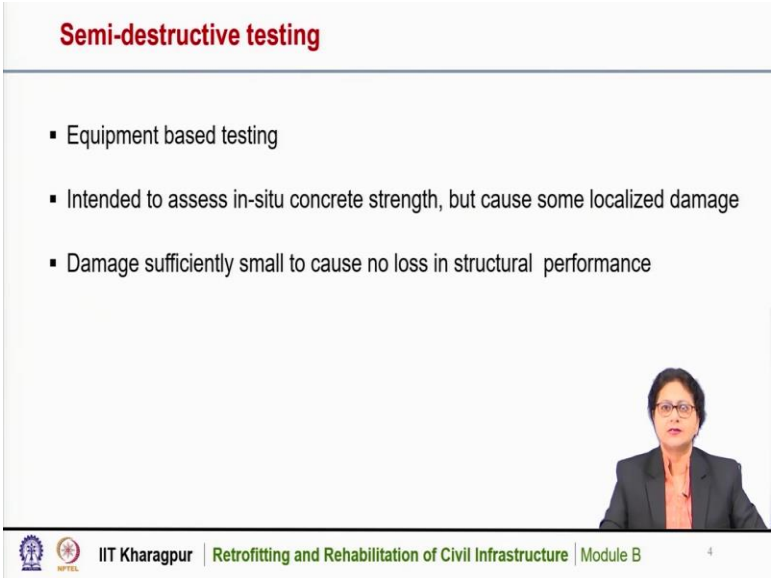

In previous lecture, we have discussed what are the different types of evaluation for condition assessment of existing infrastructure. We have also discussed what are the different types of distresses and how we can identify those distresses in existing structures. In the evaluation, we have discussed that we could do visual inspection, we could also do semi destructive testing and non-destructive testing of evaluation also structural health monitoring can also be done.

Today, we will discuss some of the semi destructive testing that are used for condition assessment of existing structures. We will discuss pull out test, penetration resistance test, pull off test and core sampling and testing.

Semi destructive type of testing is equipment based. We require a specialized apparatus or equipment for carrying out this type of testing. It is intended to assess the in-situ strength of the member and with that, we can correlate it with some other test results. When the semi destructive testing, there may be some localized damage to the structure, however, the damages are not large and these damages do not cause any loss of strength or in the loss of structural performance or durability of the member.

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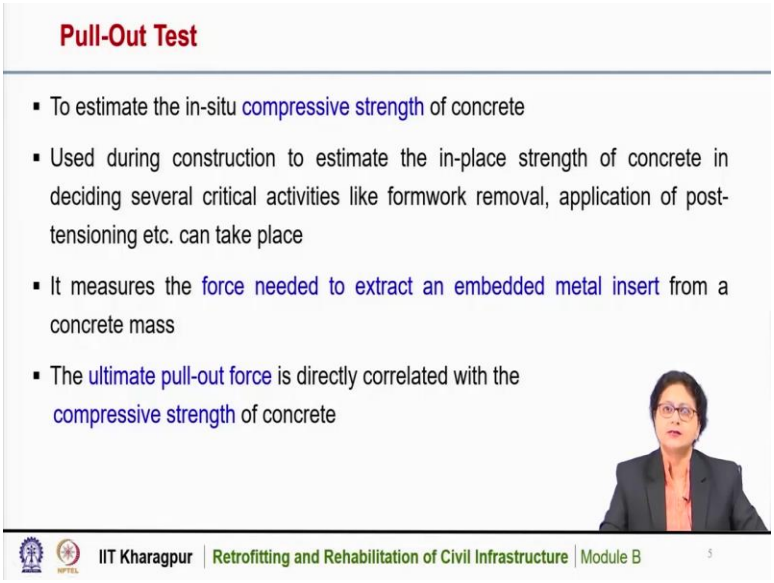

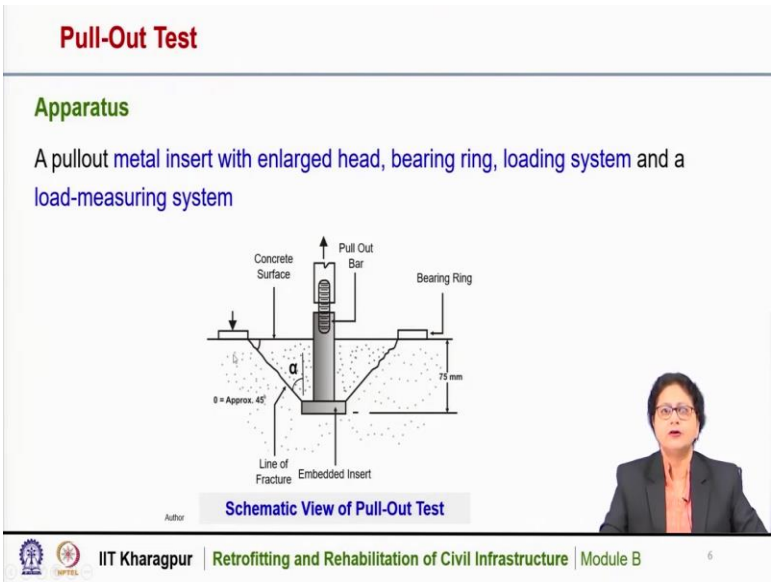

Pullout test is a type of semi destructive testing. It is widely used to assess the in situ compressive strength of concrete. The test is used during the construction to estimate the in-place strength of concrete, in deciding several critical activities like, to determine the strength of concrete for formwork removal or application of post tensioning work etcetera. The test measures the force required to extract an embedded metal insert from a concrete mass.

The ultimate pullout force is then related to the compressive strength of concrete. Pull out, this is a widely used semi destructive test for condition assessment of existing structures. The apparatus that is required to carry out a pullout test consists of a metal insert with enlarged head, a bearing

ring, a loading system, and a load measuring unit. We can see here in this schematic view of the pullout test, this is the insert, metal insert with enlarged head. And this is the bearing ring.

This is the loading system by which we can apply the pullout load. And it also has a load measuring unit by which we can record that how much load is applied. And this is the possible line of fracture of the concrete with the application of the load.

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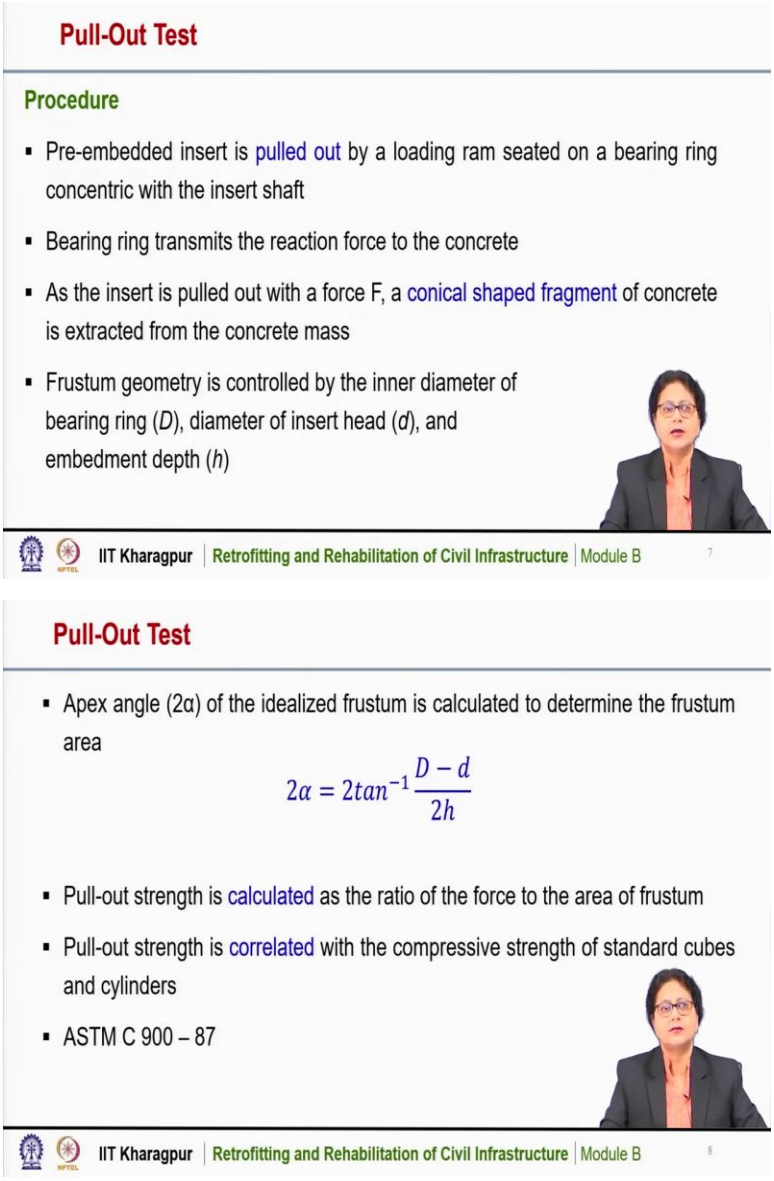

In order to carry out the pullout test, a pre-embedded insert is pulled out by a loading ram which is seated on a bearing ring concentric with the insert shaft. The insert is pre embedded and we apply a pullout load so that the insert can be pulled out. The bearing ring transmits the reaction

force to the concrete. As the insert is pulled out with the force, a conical shaped fragment of concrete is extracted from the concrete mass. This conical shaped fragment or the frustum geometry is controlled by the inner diameter of the bearing ring, the diameter of the insert head and also on the embedment length of the insert.

In the frustum of concrete, the apex angle can be calculated using this relationship. If we know the diameter of the bearing ring, the diameter of the insert head and the depth of embedment, we can find out the apex angle. This is required to calculate the frustum area. The pullout strength is estimated as the ratio of the pullout force to the area of the frustum. The pullout strength is then correlated with the compressive strength of standard cubes or cylinders. There is an ASTM guideline C 900. That gives us the steps for carrying out pullout test on existing structures.

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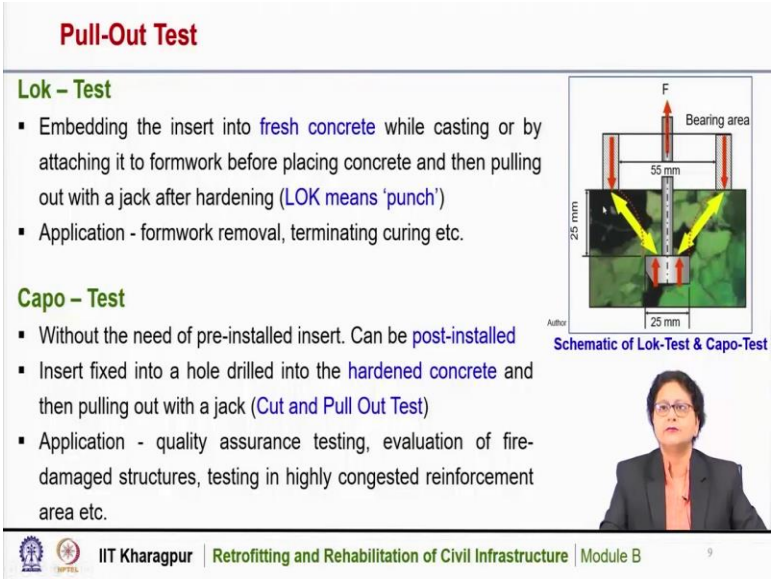

Pullout tests can be of different types. Several researchers have carried out pullout test considering different specifications. Of them Lok-test and Capo-test are quite popular. In Lok-test, the insert is embedded into fresh concrete during the time of casting or by attaching it to the formwork before the placing of concrete. And then the insert is pulled out with the jack after the concrete is hardened.

The application of Lok-test is that to estimate the strength of concrete for formwork removal or for the termination of curing, etcetera. In case of Capo-test, there is no need of pre-installed insert. The insert can be post installed. Here the insert is fixed into a hole, that is drilled into the hardened concrete and then pulled out with a jack. So, a hole is drilled and then the insert is fixed into it and then it is pulled out.

It is also called Cut and Pull Out Test. That means the hole is cut and then the insert is pulled out. The application of Capo test is for quality assurance testing, evaluation of concrete of fire damaged structures, evaluation of concrete for the area in highly congested reinforcement etcetera. Here is the schematic diagram of Lok-test and Capo-test.

In both these tests, the specifications are kept constant. That is, the diameter of the insert head is kept as 25 millimeter, the diameter of the bearing ring is also kept as 55 millimeter in both the tests. And the embedment depth remains as 25 millimeter. So, this is the typical dimensions that is followed in Lok-test and Capo-test. When the load is applied, this is the pullout load which is

applied the concrete is extracted. And approximately it follows this path. So, this is the approximate failure path of the concrete when it is pulled out.

These are some of the pictures of Lok-testing and Capo-testing. Here we can see that lok-testing is being carried out, the insert is embedded and the force is applied, so that the concrete can come out. The maximum load that is required to pull out the insert and the frustum of concrete is displayed here in this display unit.

This is the setup for Capo-test. Here the insert is post installed and by making a hole and we can see here then it is fixed on the existing surface. And this is the Capo-testing being carried out on an existing surface. We can see here that the setup is being fixed and then the load is applied for the test.

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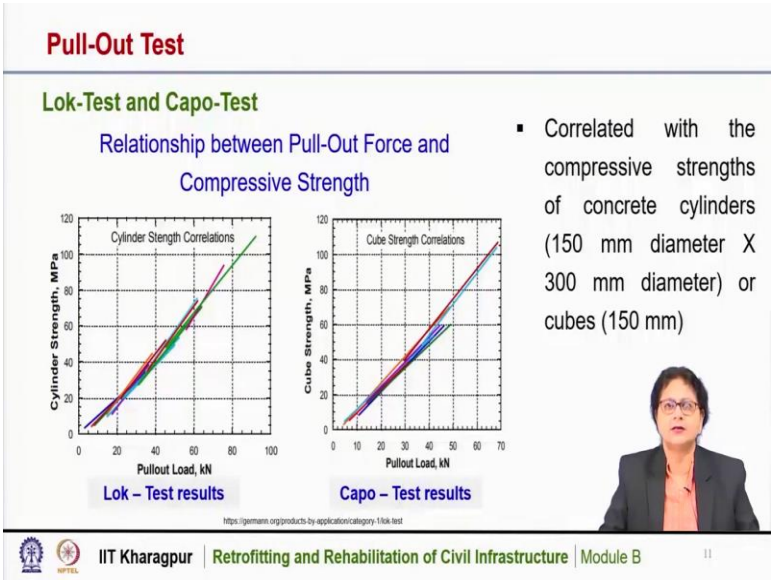

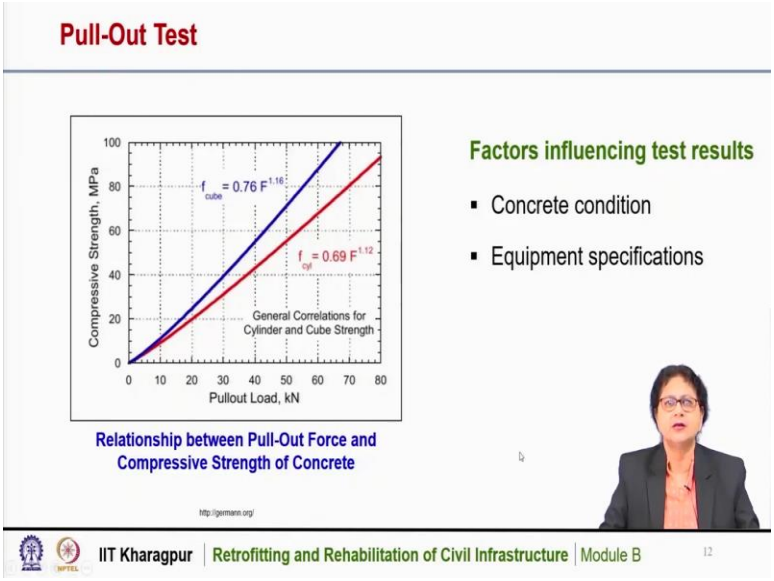

These figures show the typical relationships between the pullout force and the compressive strength of concrete. The correlations have been developed between the compressive strength of concrete cylinders or concrete cubes of standard dimensions. The relationships are shown for both lok-test as well as Capo-test. Here it is shown that if the pullout load is high, this indicates that the strength of concrete is also high.

Here, this figure shows that the relationship is nearly a linear relationship, as the pullout load increases, the strength of concrete also increases. Here in case of Capo-test, the pullout load is plotted against the cube compressive strength of concrete. As the pullout load increases, this indicates that the strength of concrete is also high. So, almost a linear relationship is obtained between the compressive strength of concrete and the pullout force.

This is a general relationship between the pullout force and the compressive strength of concrete. Here the relationship is shown between the pullout load and the compressive strength both cube compressive strength and the cylinder compressive strength. And regression equations have been developed. Generally, in the cube compressive strength is higher as compared to cylinder compressive strength of the same material because of the end restraints. So, that is also depicted in this figure.

Here this figure indicates that if the pullout load is high, this indicates that the strength of concrete is also high. The factors that may influence the pullout test results are concrete

condition and the equipment specifications. Equipment specifications include the diameter of the insert head or the diameter of the bearing ring as well as the depth of embedment of insert.

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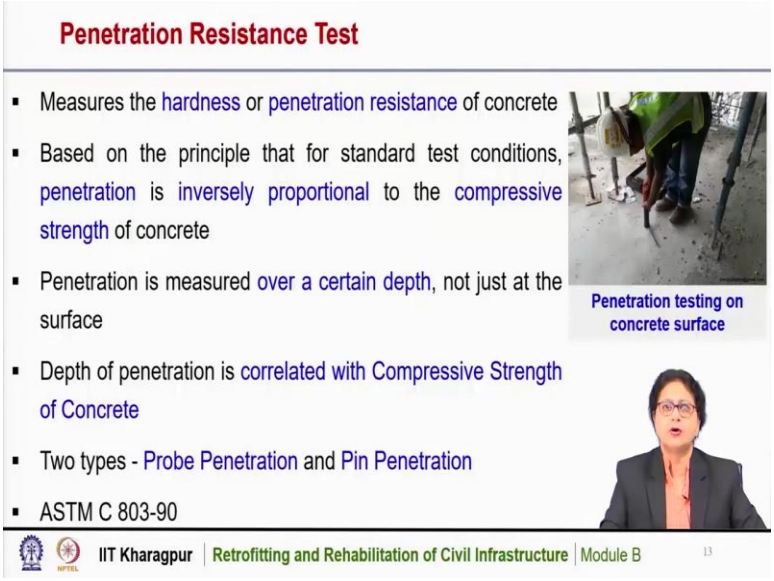

Penetration resistance test is another type of semi destructive testing. The test measures the hardness or penetration resistance of concrete. The test is based on the principle that for standard test conditions, penetration is inversely proportional to the compressive strength of concrete. The penetration is measured over a certain depth not just at the surface, but at a certain depth of the material.

The depth of penetration is correlated with the compressive strength of concrete. Here, we can see a picture of penetration testing being carried out on an existing concrete surface. Penetration resistance test is of two types, probe penetration test and pin penetration test. There is an ASTM guideline C 803 is available, which tells us the steps to be followed for carrying out penetration resistance test in estimating the strength of existing concrete.

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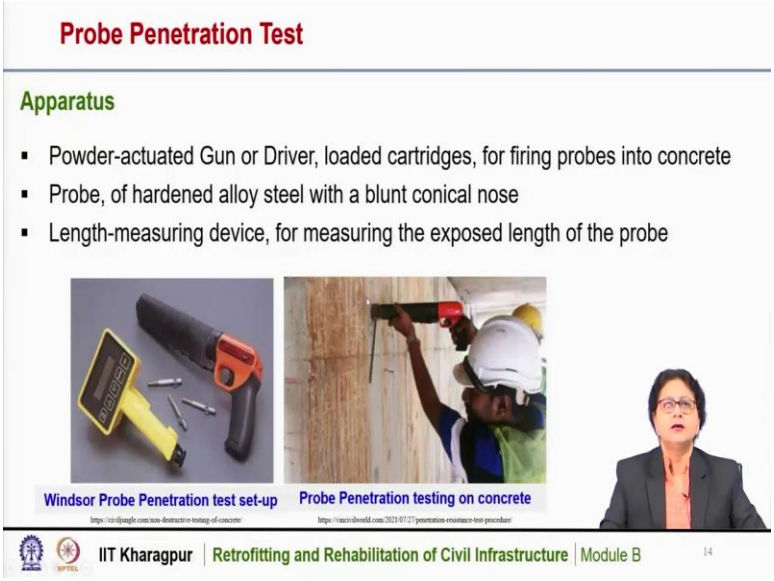

In probe penetration test, the apparatus that are used is composed of a powder actuated gun or driver with loaded cartridges for firing the probes into concrete. The probes which are made of hardened alloy steel metal as a blunt, conical nose, it also has a length measuring device for measuring the exposed length of the probe.

We can see here in these pictures, a typical Windsor probe penetration test setup. This is the gun or driver by which it can fire the probes into the existing concrete and these are the metal probes that needs to be penetrated into the material. This picture shows, the penetration testing is going on an existing concrete surface. This is the gun that is used for the testing.

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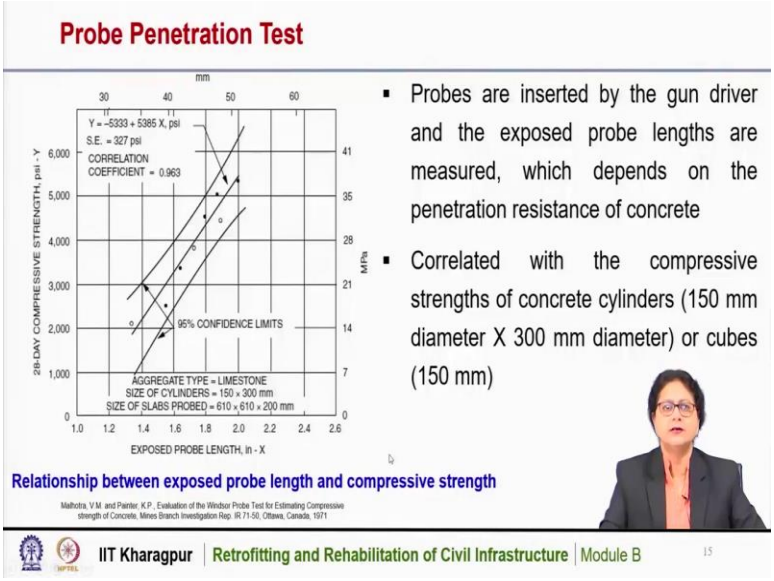

Probes are inserted by the gun driver and the exposed probe lengths are measured, which depends on the penetration resistance of the concrete. So, if the depth of penetration is more, that indicates the strength of concrete is less. The strength of concrete and probe penetration depth is correlated with the compressive strength of concrete cylinders or cubes of standard dimension. Here this graph shows a relationship between the exposed probe length and the compressive strength.

Here, in this test we are measuring how much is the exposed length of the probe. When the probes are inserted into the existing member, how much is the exposed length that is measured. So, if the exposed probe length is high, that indicates the strength of concrete is also high. So, here this relationship shows that with increase in exposed probe length, the compressive strength of concrete also increasing. So, this is almost a linear relationship we can see here that has been developed.

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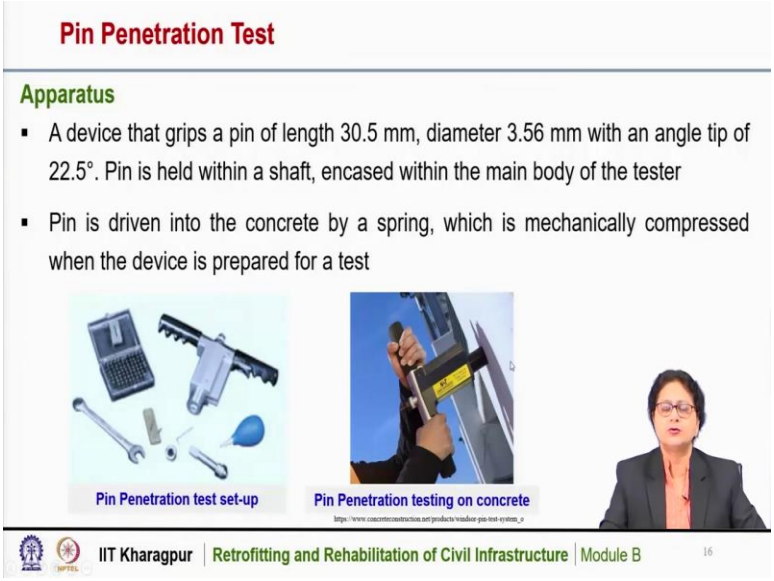

In pin penetration test, the apparatus consists of a device that clips a pin of length 30.5 millimeter with a specific diameter and an angle tip. The pin is held within the shaft which is encased within the main body of the tester. The pin is driven into the concrete by a spring which is mechanically compressed when the device is prepared for a test.

Here in these pictures, we can see that a typical pin penetration test setup. This is the main device, which has the pin that needs to be penetrated into the material. This picture shows that when pin penetration testing is carried out on an existing concrete surface. It is pressed and the pin is penetrated into the member and that we can measure there.

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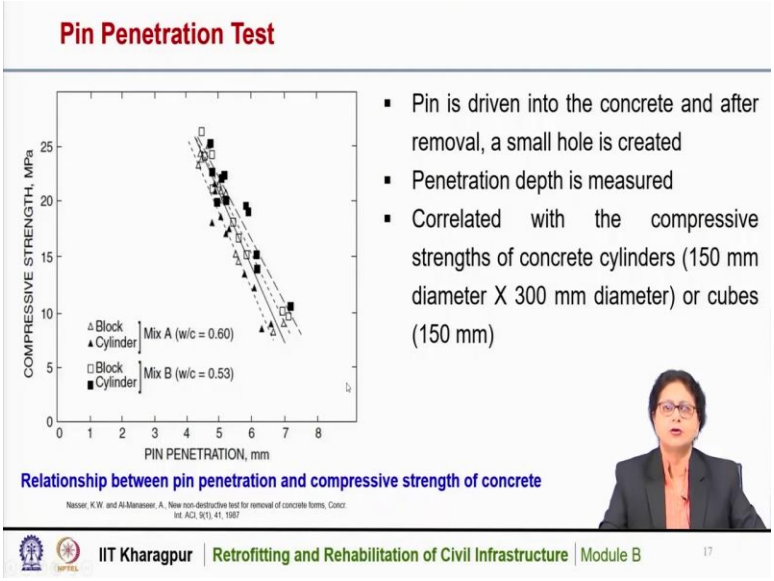

The pin is driven into the concrete and after removal a small hole is created. The penetration depth is measured within that hole. So, we are measuring the penetration depth, that has been created by the pin which is driven into the concrete. So, higher is the penetration depth, this indicates that lower is the strength of concrete. So, here we are measuring the depth of penetration within the material.

So, this relationship you can see here that this is the relationship between the pin penetration depth and the compressive strength of concrete; higher is the penetration depth, lower is the compressive strength of concrete. The correlation can be drawn with compressive strength of concrete cylinders or cubes of standard dimensions.

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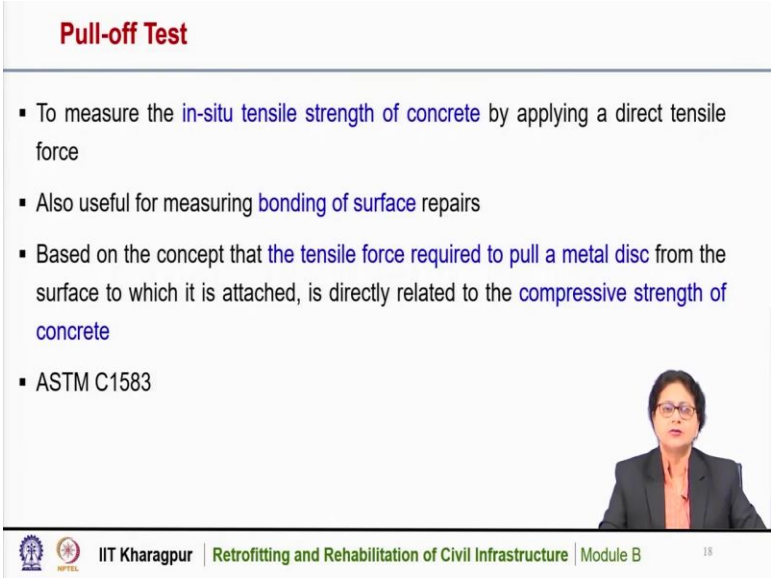

Another semi destructive testing is pull-off test. Pull off test is used to measure the in-situ tensile strength of concrete by applying a direct tensile force. The test is also useful for measuring the bonding between the two surfaces. For example, if a new concrete layer is placed on an existing surface, say for repair purpose. Then to find out the bond between the new and the existing layers, we can perform pull-off test.

The pull-off test is based on the concept that the tensile force required to pull a metal disk from the surface to which it is attached is directly related to the compressive strength of concrete. The ASTM guidelines C 1583 is available, which tells us the steps to be followed for carrying out pull-off test in the concrete material.

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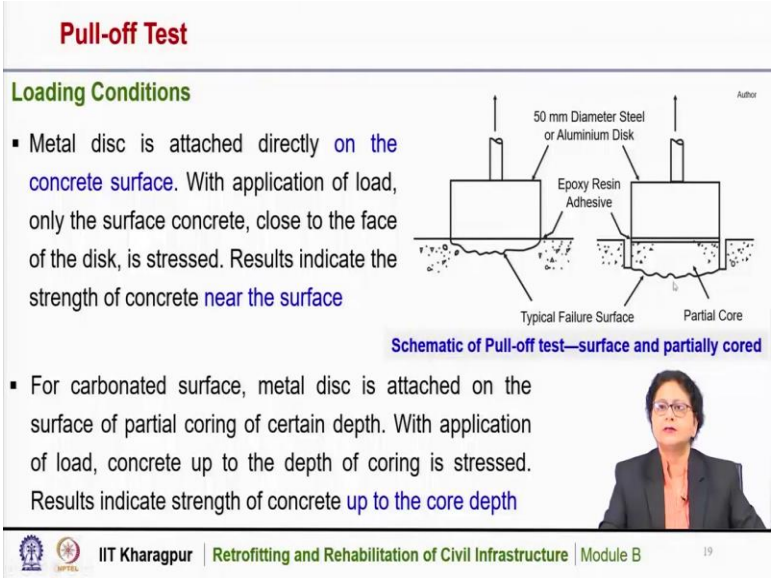

In pull off test, the loading conditions may be of two types. When the concrete surface is good and uniform, the metal disc is attached directly on the concrete surface. This metal disc is a 50 millimeter diameter steel or aluminum disk and that can be attached to the concrete surface with epoxy resin adhesive. Now, when the load is applied, the pull off load is applied, then only the surface concrete which is close to the face of the disk is stressed.

So, the results indicate the strength of the concrete near the surface only. So, here in this schematic diagram, we can see that this is the existing concrete surface and the metal disc is attached to this concrete with the epoxy resin adhesive. When the load is applied, the concrete surface near the top surface or near the disk is stressed and so, it fails and this is the typical failure surface which is close to the surface of the member.

So, here we can see that the typical failure surface, which is close to the top surface of the concrete member. Sometimes the concrete surface is not that good, it may not be uniform due to the effect of carbonation or other effects. So, in that case, the metal disc is attached on the surface of partial coring of certain depth. So, in that case of the existing concrete member, we can develop a partial coring on that and on the top surface of the partial coring, the metal disc is attached.

So, the metal disc is attached with epoxy resin adhesive and the pullout load is applied. So, the metal disc is attached on the surface of the partial coring of certain depth and with application of

the load, concrete up to the depth of the coring is stressed. So, here when we apply the load the concrete which is stressed that is not very near to the surface, but up to the depth of the coring. So, the results indicate the strength of concrete up to the core depth.

So, here in this schematic diagram. We can see that, this is the partial core that has been made on the existing concrete member. And the metal disc is attached to it. When the load is applied, the concrete is stressed up to the depth of the partial core. So, this is the typical failure surface which is not very close to the surface, but near the depth of the core.

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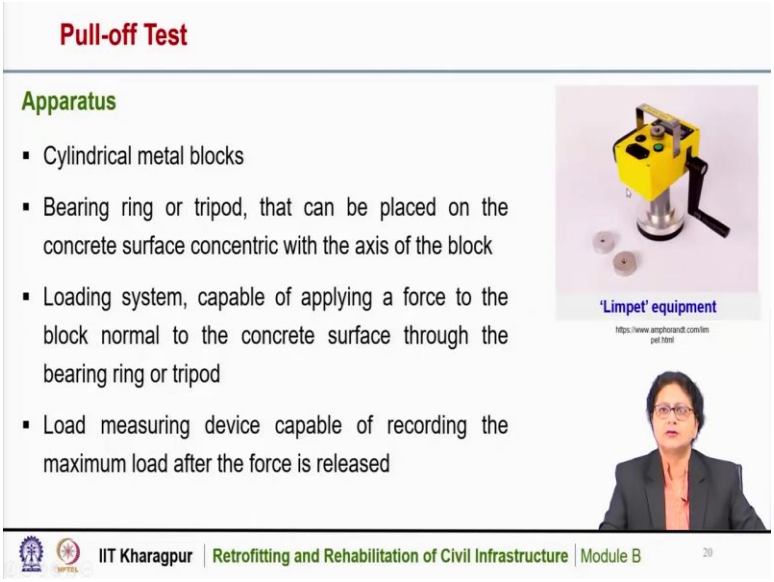

The apparatus that is used for carrying out pull off test consists of cylindrical metal blocks. It also has bearing ring or tripod, that can be placed on the concrete surface. Concentrate with the axis of the block, we can see here these are the metal blocks and this is the bearing ring.

A loading system which is capable of applying a force to the block, normal to the concrete surface through the bearing ring or tripod and a load measuring device which records the maximum load when the load is applied. So, this is the typical pull-off test apparatus it is called limpet, which is used to perform the pull-off test on existing concrete members.

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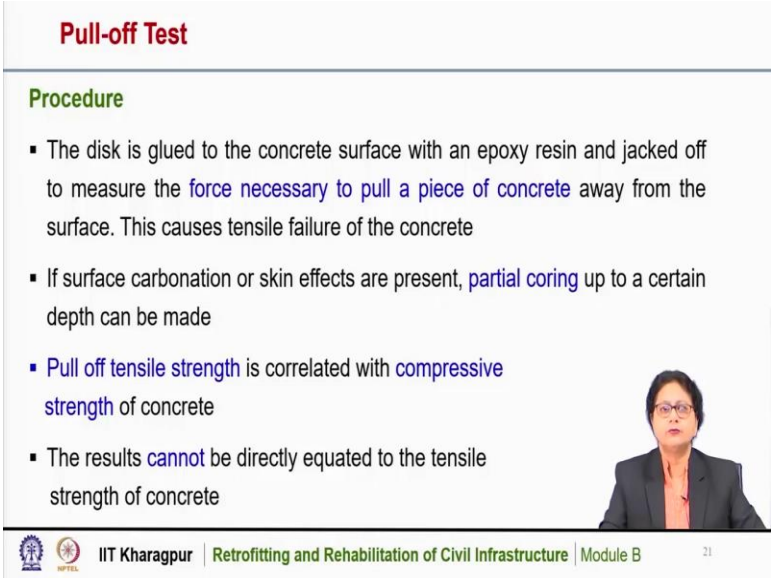

In carrying out the pull off test, the disk is glued to the surface with an epoxy resin and jacked off to measure the force necessary to pull a piece of concrete away from the surface. This causes tensile failure of the concrete and if there is carbonation effect, the surface concrete or skin effect is there, then a partial coating can be made up to a certain depth.

Pull off tensile strength is then correlated with the compressive strength of concrete. So, when we apply the load, that load is then correlated with the compressive strength of concrete; higher is the pull off strength higher is the compressive strength of concrete. However, the results cannot be directly equated to the tensile strength of concrete.

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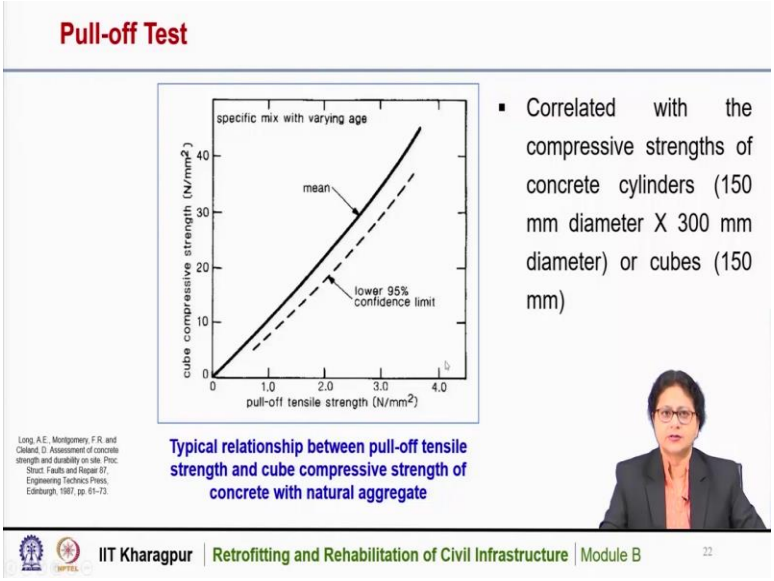

Here this diagram shows a typical relationship between the pull off tensile strength and the cube compressive strength of concrete with natural aggregates. Here it shows that, if the pull off strength is higher, this indicates that the compressive strength of concrete is also higher. So, this relationship is shown here. It is nearly a linear relationship. And that relationship can be developed by correlating with the compressive strength of concrete cylinders or cubes of standard dimensions.

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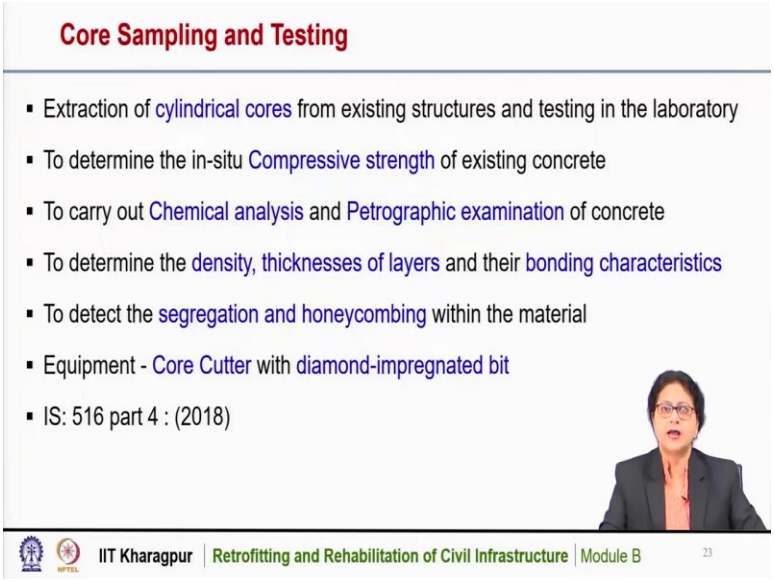

Core sampling and testing is another semi destructive type of testing. Core testing is used widely to determine various properties of the existing members. In this method, the extraction of cylindrical cores is done from existing structures and then the cores are tested in the laboratory. It is intended to determine the in-situ compressive strength of existing concrete and in majority of the cases the compressive strength is determined from the cores.

From the cores, we can also determine the density, thickness of layers and their bonding characteristics. We can detect any segregation or honeycombing if it is present within the material, that also can be identified from core extraction. We can carry out chemical analysis and petrographic examination of concrete by examining the cores.

The equipment that is required for core extraction is termed as core cutter, which has diamond impregnated bit. Indian standard guidelines IS 516 Part 4 is available, which tells us the steps for extraction of cores and testing it in the laboratory.

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These are some of the pictures of the equipment and the testing. Here we can see a typical core cutter used for the extraction of cores from existing members. This equipment is available in our laboratory. This picture shows the extraction of concrete core using the core cutter. This is the existing concrete member and this is the core cutter that is placed firmly against the surface of the member.

And the extraction of core is being done. After extraction of the cores, the cores are to be taken to the laboratory. They were processed and these are the typical cores which are ready for testing.

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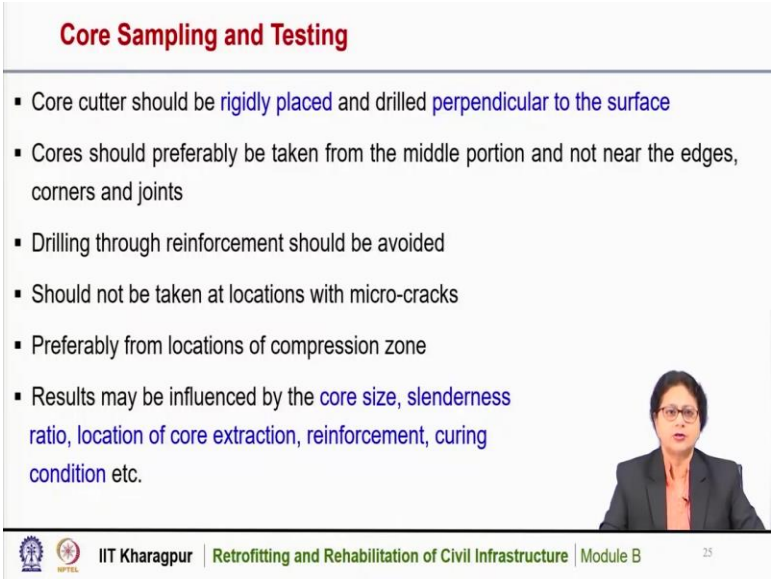

While extraction of core, the core cutters should be rigidly placed and firmly fixed on the existing surface. And drilling should be done perpendicular to the surface. Cores should preferably be taken from the middle portion and not near the ages, corners, or joints. Because if we take the cores from the edges or corners, then the member may get damaged. So, it is preferable to take the core from the middle part of any member.

Drilling through the reinforcement should be avoided. It is desirable to avoid the reinforcement area for taking the cores. Because, when we take the cores, if we use that area with reinforcement, the reinforcement may also get cut. So, it is not desirable that we can do the coring through reinforcement.

Core should not be taken at locations with micro-cracks. If in a member at some pockets, there are micro-cracks or honeycombing present, then we can avoid those locations because those are only distresses locally. So, that may not reflect the strength of the remaining member. So, we can avoid those locations for extraction of cores.

Core should be taken preferably from locations of compression zone. Because in majority of the cases, it is the compressive strength that is to be determined from the cores. So, it is preferred

that we can take the cores from compression zones. Results of core testing may be influenced by several factors, the size of the cores, the slenderness ratio of the course, the location of core extraction, the presence of reinforcement, the curing condition of the concrete etcetera.

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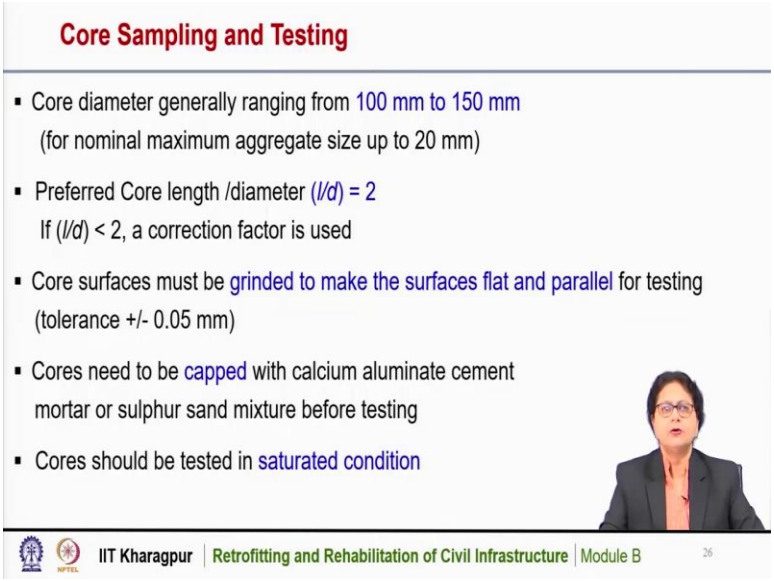

While extracting a core from an existing member, we have to follow certain specifications. Generally, the core diameter is in the range of 100 to 150 millimeter. Particularly for nominal maximum size of aggregates up to 20 millimeter. In that case, we can have the core diameter in the range of 100 to 150 millimeter. The preferred core length to diameter ratio is 2. If the length by diameter ratio is less than 2, a correction factor is needed.

Core surfaces need to be grinded properly. Because when we extract core from an existing structure, the surfaces are not uniform. There may be irregularities at the two ends. So, for testing the core in the laboratory, we need to grind it properly so that the surface becomes flat and parallel to edge. In addition to that, cores need to be capped with calcium aluminate cement mortar or sulfur sand mixture before the testing. Cores should be tested in saturated condition.

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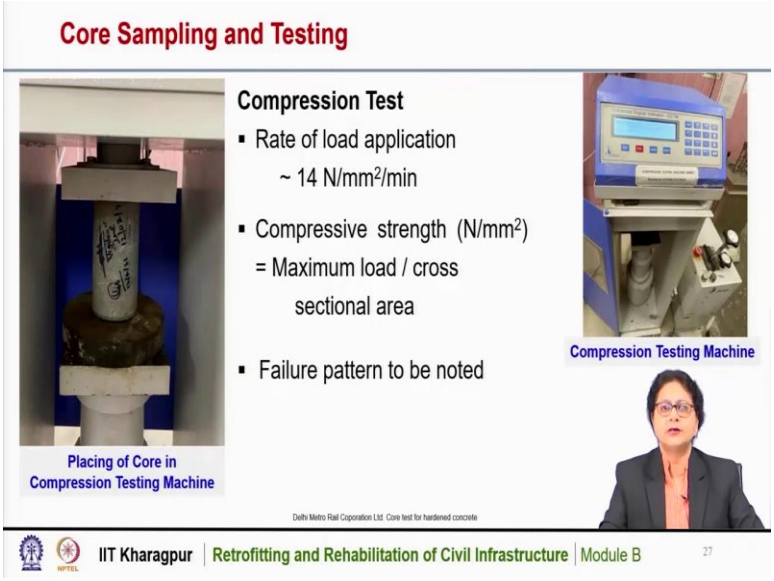

These are some of the pictures of cores testing. Here we can see a typical compression testing machine used for core testing. And this is the picture of a core which is placed in a compression testing machine. This is the core extracted from the field and then it is placed in a compression testing machine after grinding and capping. So, these are the loading platens, we can see here these are the loading platens through which the load is applied.

The rate of load application should be uniform and it is in the range of 14 N/mm^2/min. When the load is applied, it is required to note down the load and the maximum load is to be noted. The compressive strength is estimated as the maximum load divided by the cross sectional area of the core. Along with the maximum load, we also need to observe the failure pattern of the cores.

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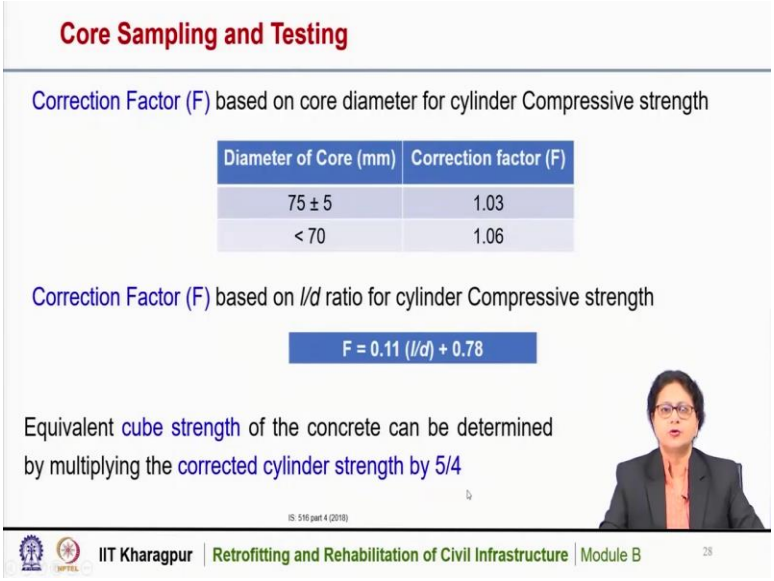

There are several correction factors that need to be used for estimating the actual compressive strength for the Cores. The correction factors are based on core diameter and core length. When the diameter of the cores are not in the range of 100 to 150 millimeter, which is the standard diameter, we have to use a correction factor. For 75 millimeter diameter of core, a correction factor of 1.03 is to be used and when the diameter of core is less than 70 millimeter, a correction factor of 1.06 is to be used.

This correction factor is to be multiplied with the obtained compressive strength to find out the actual strength of the member. The correction factor for length by diameter ratio is estimated with this equation. **$F = 0.11 (l/d) + 0.78$**

The ideal length by diameter ratio is 2. When l by d ratio is 2, then this factor becomes 1 for; other l by d ratios, we have to calculate the correction factor and that needs to be multiplied with the compressive strength to get the actual strength.

To find out the equivalent cube strength of concrete, we need to multiply another factor that is 5/4. That can be multiplied with the cylinders strength to obtain the cube strength. Generally, the cube strength is higher as compared to cylinder strength of the same material because of the end restraints. So, the compressive strength obtained from the cores is the cylinder strength.

So, if we want to find out what is the equivalent cube strength, we need to multiply a factor 5/4, that is mentioned in IS code. So, to find out the equivalent cube strength this factor is to be used.

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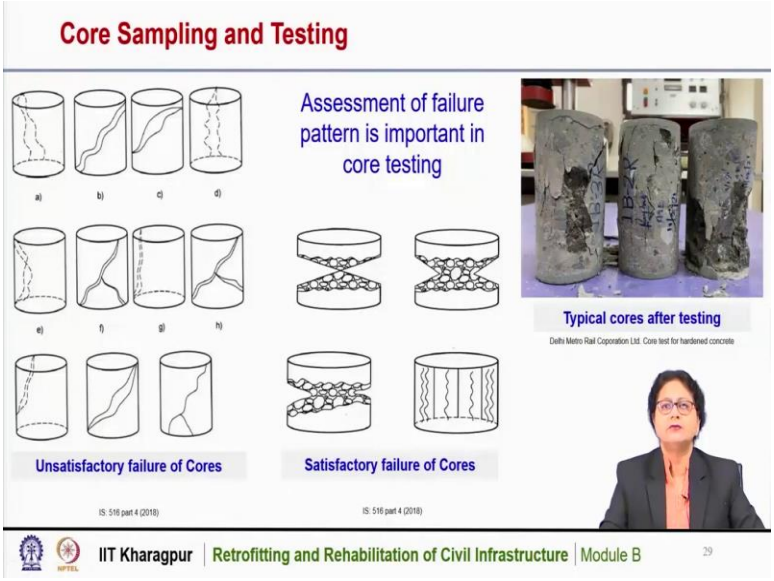

While testing the cores in the laboratory, it is important to assess the failure patterns of the core. The failure pattern should be satisfactory to accept the test results. We can see here, that some of the satisfactory failure patterns of the cores. The cracks may appear along the length of the member or there may be a wedge like formation. So, these are all failure patterns which can be considered as satisfactory.

This is a picture which shows that the cores after testing the failure pattern is satisfactory. However, sometimes the failure pattern is not satisfactory. Based on the failure pattern, the test results can be considered as accepted or rejected. Now, sometimes the failure pattern is not satisfactory. We can see here several unsatisfactory failure pattern of the cores under loading. If the two surfaces are not uniform or not parallel to each other or the load is applied eccentrically, then the failure pattern may be unsatisfactory.

So, there may be random cracks along the length or diagonally or along the width of the core. So, all these random failures may occur. So, these are not desirable pattern of failure. So, if this type of failure occurs the test result should be discarded. So, it is very important to observe the failure patterns of the cores. And if the failure pattern is not satisfactory, we should not consider the test results.

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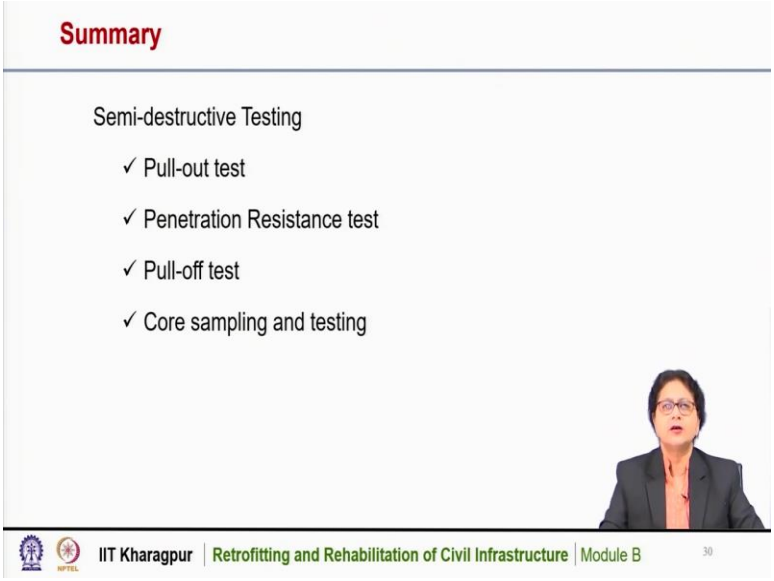

So, to summarize we have discussed several semi destructive testings that can be used to assess the in-situ strength of concrete members. We have discussed pull out test, penetration resistance test, pull off test and core sampling and testing. Thank you.