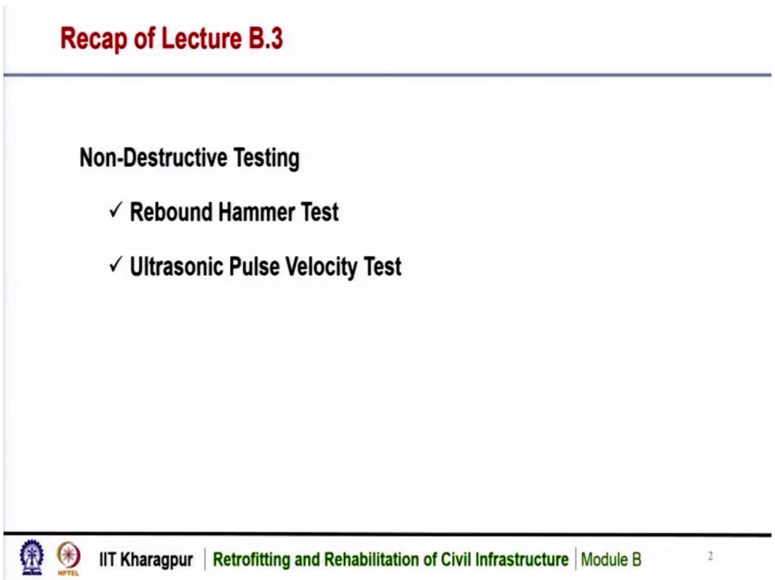
Retrofitting and Rehabilitation of Civil Infrastructure
Professor. Swati Maitra
Ranbir and Chitra Gupta School of Infrastructure Design and Management
Indian Institute of Technology, Kharagpur
Lecture 10
Non-destructive Tests (Contd.)

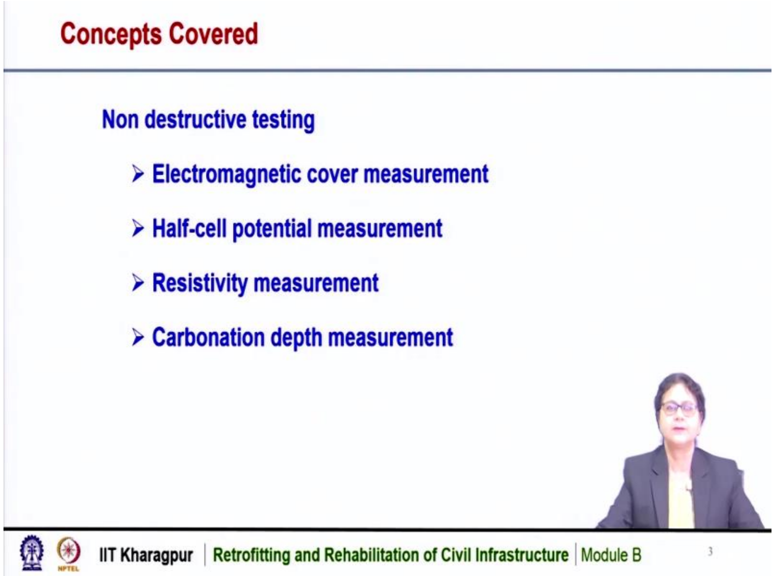
Hello friends, welcome to the NPTEL online certification course on Retrofitting and Rehabilitation of Civil Infrastructure. Today we will discuss Module B. The topic for Module B is conditioned evaluation and testing.

(Refer Slide Time: 0:44)



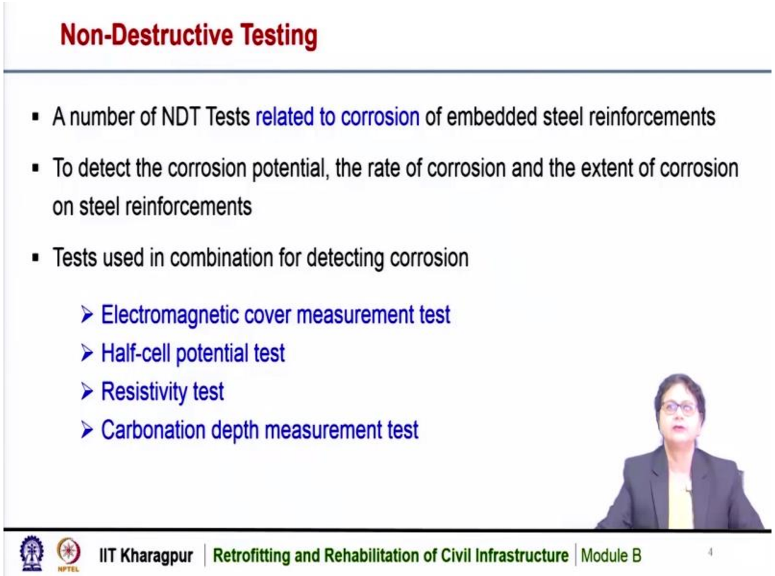
In the previous lecture, we have discussed non-destructive testing, the non-destructive testing are used to assess the strength and other properties of structural members without damaging the members. We have discussed rebound hammer test and ultrasonic pulse velocity test. These tests are widely used to assess the in-situ strength properties of structural member from surface hardness, and also the quality of concrete using ultrasonic pulse velocity. The tests are widely used in existing structure to assess their strength and quality of the material.

(Refer Slide Time: 1:28)



Today, we will discuss several other non-destructive tests that are carried out on existing reinforced concrete structures. We will discuss electromagnetic cover measurement test, half-cell potential measurement test, resistivity measurement test and carbonation depth measurement test.

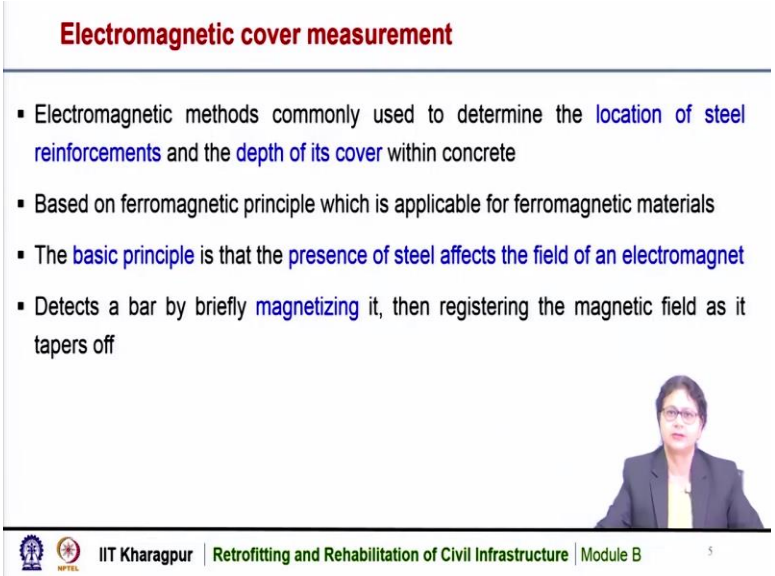
(Refer Slide Time: 1:54)



There are a number of non-destructive tests that can be carried out on existing reinforced concrete structures related to corrosion activities. These tests are carried out to detect the corrosion potential of the reinforcement, the rate of corrosion in the member and the extent of corrosion on steel reinforcement. And all these tests can be carried out in conjunction with each other. And based on those tests, we can detect the rate of corrosion or the risk of corrosion and how much corrosion has been taken place in that steel member that can be found out.

So, we will discuss today the electromagnetic cover measurement test, half-cell potential test, resistivity tests, and carbonation depth measurement tests and these tests are generally used in combination for detecting the corrosion activity in steel members.

(Refer Slide Time: 2:56)

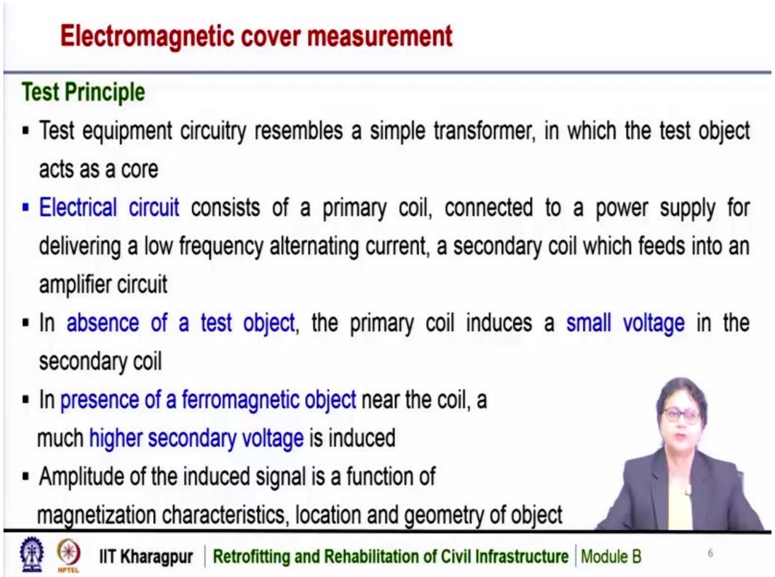


Electromagnetic cover measurement test is commonly carried out to determine the location of steel reinforcement and the depth of its cover within the concrete member. Cover is an important component for all reinforced concrete structures. Cover protects the steel members from the effects of environmental activities and also from the chemical attacks. So, adequate cover is important for the reinforcement. So, that they can work effectively.

Now, for an existing structure, due to several reasons due to weathering actions or aging, the cover may reduce over time. Therefore, it is important for the existing members to determine the available cover for the reinforcement to estimate the chances of corrosion in the reinforcement. The electromagnetic cover measurement test is based on ferromagnetic principle and thus it is applicable for ferromagnetic materials like steel.

The basic principle is that the presence of steel affects the field of an electromagnet. And by magnetizing the steel member, we can estimate the location and the size of the member. So, the principle is based on ferromagnetic principle and with that we can find out the available cover to the existing member.

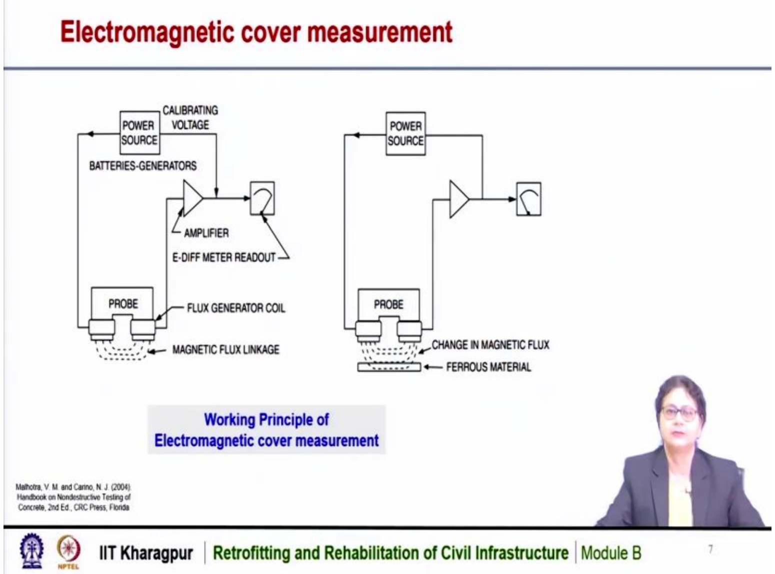
(Refer Slide Time: 4:31)



The test principle resembles an electrical circuit, which consists of a simple transformer where the test object acts as a core. The electrical circuit consists of a primary coil which is connected to a power supply for delivering a low frequency alternating current and a secondary coil which is connected to an amplifier circuit. When there is no test object, the primary coil induces a small voltage in the secondary coil, when there is a flow of current. When there is a ferromagnetic material near the coil, the induced voltage is much higher.

So, when we can measure the induced voltage, we can find out the presence of the material, which is a ferromagnetic material, its location and the geometry that its diameter can also be found out from the magnitude of the voltage.

(Refer Slide Time: 5:26)



This is the schematic diagram of the working principle of the electromagnetic cover measurement. We can see here; this is the electrical circuit. And this is the power source and through which the alternating current can flow. And this is the amplifier and this is the magnetic probe. And when there is flow of current, there is a magnetic flux that is generated.

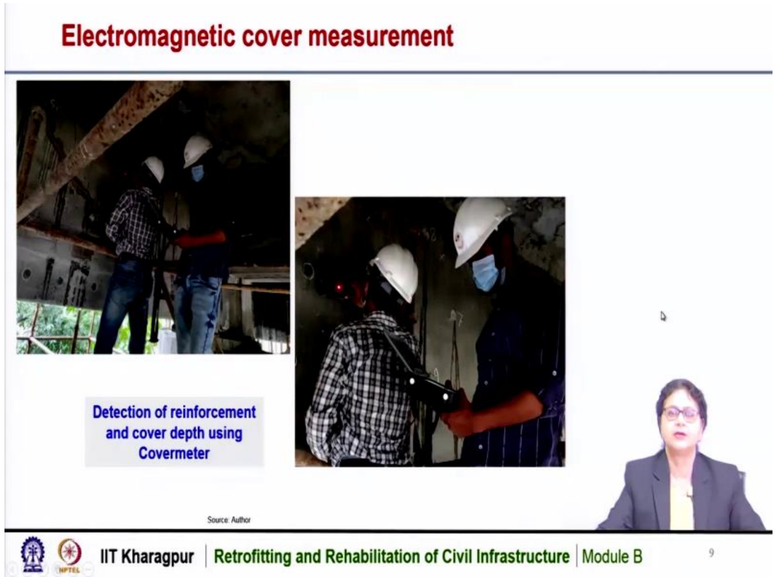
Now, when there is no reinforcement or no ferromagnetic material near it, then the voltage is much lower. But when there is a ferrous material near the coil, the voltage is much higher. So, by seeing the voltages, we can find out its location and its dimension also. So, this way we can identify the available cover in an existing reinforced concrete member.

(Refer Slide Time: 6:30)

The instrument is based on the ferromagnetic principle and is commonly known as cover meters. It is a battery-operated device that utilizes the eddy current method of magnetic testing. The method induces eddy current to flow around the circumference of the bar when it is placed near the equipment, which produces a magnetic field.

The head of the device picks up the magnetic signal. Here we can see a typical cover meter, this is the display unit and when it is placed on an existing surface, we can see here it is just placed on the existing surface. And when it detects reinforcement, there is a signal and through which we can identify that there is a reinforcement bar, the diameter is also identified and displayed here.

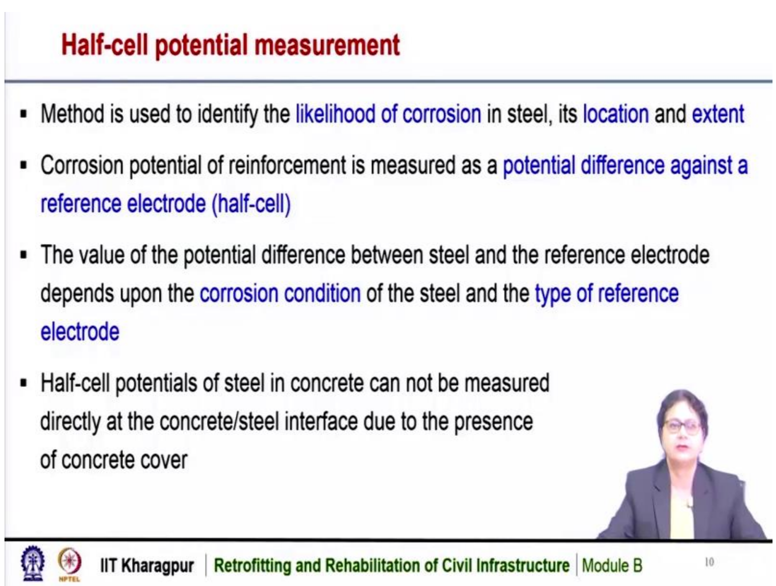
(Refer Slide Time: 7:25)



These are some of the pictures of cover meter test. We can see here that the cover meter test is carried out on a longitudinal girder of a road over bridge, which is under retrofitting presently. And we can see that the cover meter is used to detect the reinforcement and its cover. And when it detects a reinforcement, a red signal appears on it.

And the presence and diameter of the member is also displayed. There is a separate display unit for this equipment. So, that is displayed here, the diameter and the presence of the bar. So, these are the pictures for the test being carried out on a longitudinal girder of an ROB.

(Refer Slide Time: 8:19)

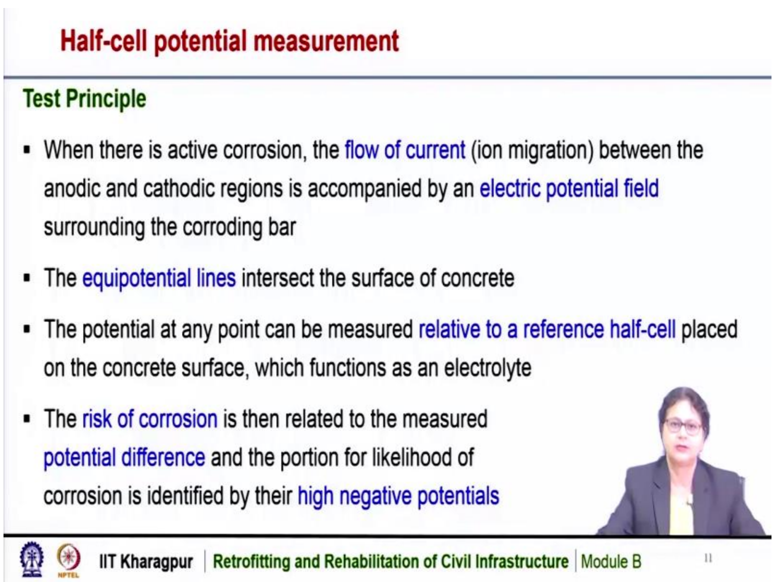


A half-cell potential measurement is used to identify the likelihood of corrosion in steel its location and extent. Corrosion potential is measured as a potential difference against a reference electrode or half-cell. Half-cell potential test is also widely used to detect the corrosion activity in reinforced concrete members.

In this test, the corrosion potential is measured as a potential difference against a reference electrode and that reference electrode is called the half-cell. The based on this potential difference, we can identify the extent of corrosion, the location of corrosion on that steel member. The value of this potential difference between the steel and the reference electrode depends on the amount of corrosion or the extent of corrosion in that steel member.

And also on the type of the reference electrode. There may be different types of reference electrode and based on that we can carry out the test. The half-cell potential of steel in concrete cannot be measured directly at the concrete steel interface due to the presence of concrete cover. So, we require the exposure of the steel reinforcement for carrying out the half-cell potential test.

(Refer Slide Time: 9:38)

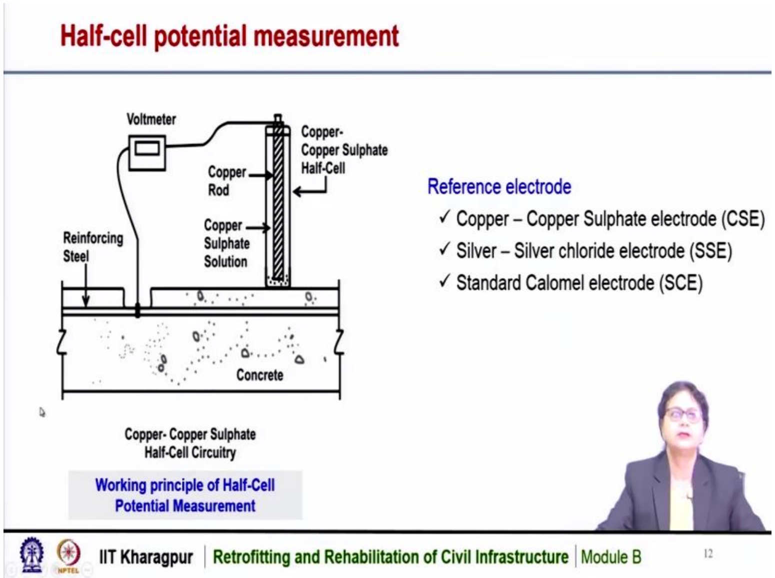


The test principle is that, when there is active corrosion, there is flow of current. That is the migration of ions taking place from the anodic to the cathodic region as we have discussed earlier. And that flow of current is accompanied by an electric potential field surrounding the corroding bar.

The equipotential lines intersect the surface of the concrete. The potential at any point can then be measured relative to the reference electrode or reference half-cell, which needs to be placed on the concrete surface and this concrete now functions as an electrolyte. And for that, the risk of corrosion is then related to the measured potential difference and the portion for likelihood of corrosion is identified by their high negative potential.

So, when the electrode is placed on the concrete surface, there is an electric circuit and the difference in potential we can measure and higher is the negative potential, higher is the likelihood of corrosion in the reinforcement.

(Refer Slide Time: 10:53)

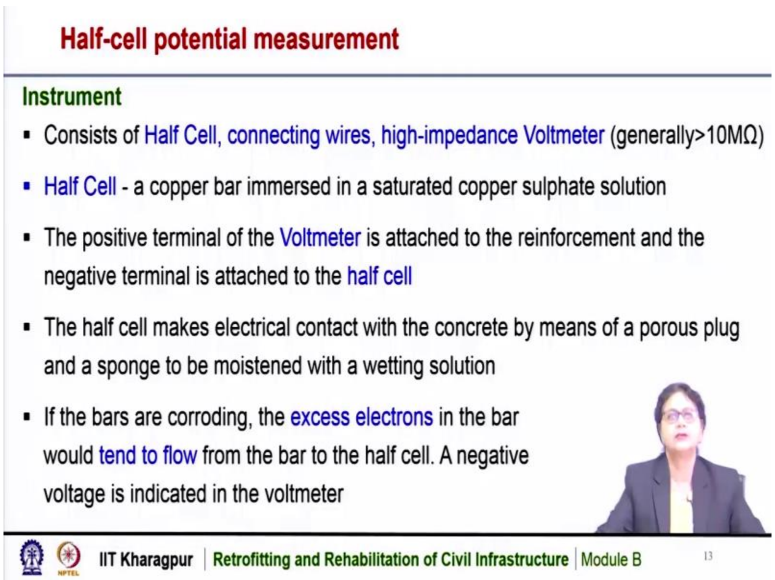


This is the schematic diagram of the working principle of half-cell potential measurement. Here is the concrete member and this is the reinforcement we can see here; this is the reinforcement. The reinforcement needs to be exposed for carrying out half-cell potential test. This is the half-cell or the reference electrode. The reference electrode could be of different types. We can use copper-copper sulphate electrode or silver-silver chloride electrode or standard calomel electrode. Copper-copper sulphate electrode is the most common used electrode in half-cell potential test.

And you can see here that this half-cell is a hollow cylinder and a copper rod is inserted into it and a copper sulphate solution is then poured into the cylinder. So, it becomes the copper-copper sulphate half-cell. And that needs to be placed on the concrete surface. It has a porous sponge at its bottom, so that the concrete surface is moistened and the circuit completes. So, there is a voltmeter you can see here this is a schematic diagram of a voltmeter. The positive end is connected to the reinforcement and the negative end is connected to the half-cell.

Now, when there is electrical connection, that is flow of iron and the reinforcement is also corroded, then there will be a flow of ion from the reinforcement to the half-cell. So, more is the flow of ion, that indicates the more is the corrosion taking place in that reinforcement.

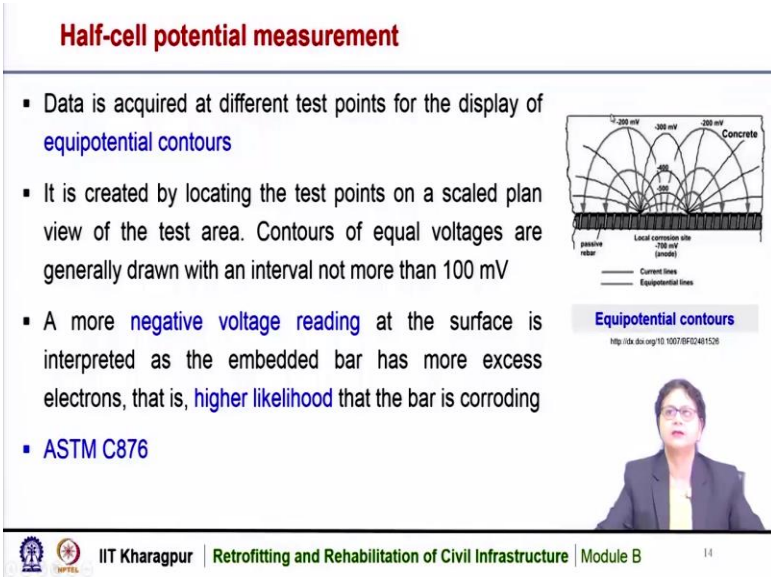
(Refer Slide Time: 12:40)



So, the instrument which is used for carrying out the half-cell potential test consists of a half-cell, a connecting wires, high impedance voltmeter. The half-cell as we have mentioned a copper bar immersed in a saturated copper sulphate solution. There is a voltmeter, the positive terminal of which is connected to the reinforcement and the negative terminal is connected to the half-cell.

The half-cell makes the electrical contact with the concrete by means of a porous plug and sponge to be moistened with a wetting solution and that need to be placed on the concrete surface which is to be tested. If the bars are corroding, the excess electron in the bar would tend to flow from the bar to the half-cell and a negative voltage indicated. So, higher is the negative voltage, higher is the corrosion in that reinforcement. So, by measuring the negative voltage, we can identify the extent of corrosion in that reinforcement.

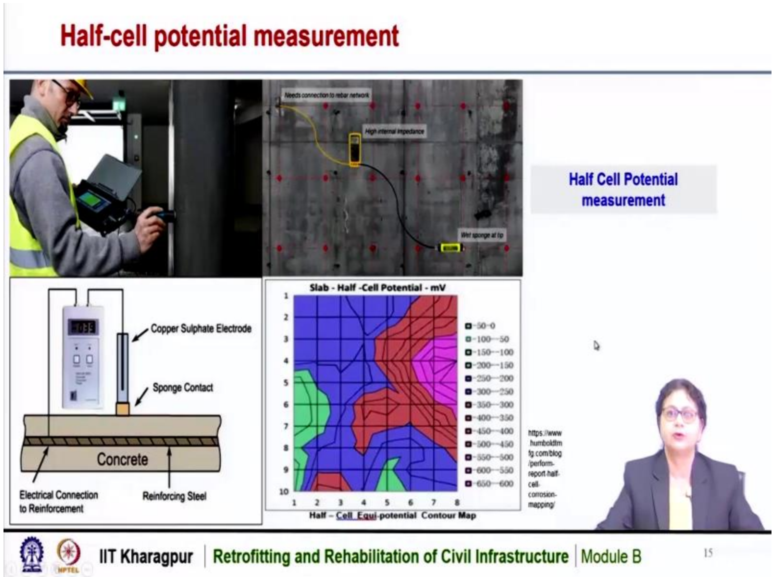
(Refer Slide Time: 13:40)



We can see here that a schematic diagram of a reinforcement. These are the lines for the current and these are the equipotential lines. You can see here, these are the equipotential lines and the test is done at different places on the reinforcement to find out the potential difference at different locations. So, data is acquired at different test points for the display of the equipotential contours. So, we need to identify the potential difference. And we also want to develop a equipotential contour.

It is created by locating the test point on a scaled plan view of the test area. Generally, we are doing it at different points on the reinforcement area and contours of equal voltages are generally drawn with an interval of 50 to 100 millivolt. A more negative voltage reading indicates that there is more likelihood of corrosion in the reinforcement. There is an ASTM guideline, ASTM C876, which gives us the steps for carrying out half-cell potential measurement on existing reinforced concrete members.

(Refer Slide Time: 14:57)

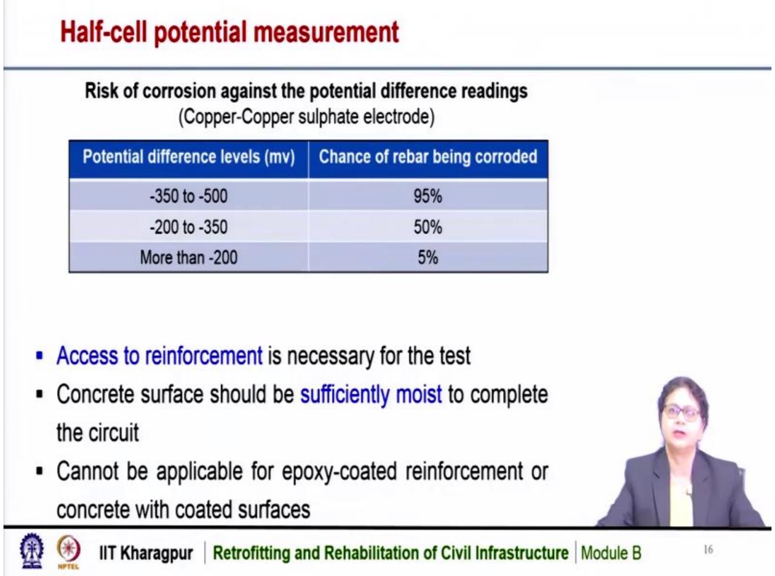


These are some of the diagrams and pictures of half-cell potential test carried out on an existing structure. You can see here that this is an existing structure and this is the half-cell which needs to be placed on the existing surface and need to be moistened also. This is the display unit where the voltmeter is also there and one end is connected to the reinforcement. So, here you can see that this is the existing concrete surface.

And this is the voltmeter and one end is connected to the reinforcement. The reinforcement needs to be exposed and this type of grid can be drawn on the existing surface, so that we can take the readings at those points. And at those points, we need to place this half-cell, so that there is a circuit and we can take the readings.

So, this is the schematic diagram and from the test we can get these types of contours. So, this is a typical half-cell equipotential contour map for the test. You can see here that these different lines shows the equipotential lines and this is the entire map of that region. So, with that we can find out the extent of corrosion in the reinforcement.

(Refer Slide Time: 16:25)



Based on the different values of potential difference, we can identify the chances of corrosion in the reinforcement based on previous studies. Several values have been suggested in the ASTM code. When the potential difference is in the range of minus 350 to minus 500 millivolt, the chance of rebar being corroded is 95 percent. So, as the value of the potential difference is in this range, so, we can say that 95 percent probability that the reinforcement is getting corroded.

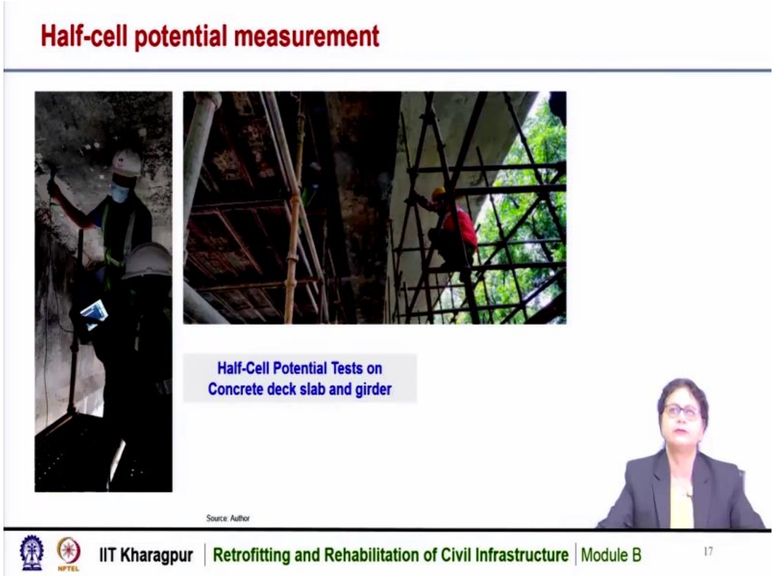
When the potential difference is in the range of minus 200 to minus 350 millivolt, there is a 50 percent chance that the rebar is corroded. And when the value is more than minus 200 millivolt, there is a negligible chance of corrosion in the reinforcement, at least 5 percent chance of corrosion. So, by measuring the potential difference from the test, we can identify that the risk of corrosion in the existing reinforcement member.

Now, for carrying out the test, we have to remember several points that access to reinforcement is a must for carrying out the test, because one end of the voltmeter need to be connected to the reinforcement. And that is why it is important to have the access of the reinforcement. Concrete surface should be sufficiently moist to complete the circuit. And that is why this porous sponge is required at the bottom of the half-cell.

And unless it is moistened sufficiently, the surface there is the circuit will not be completed. So, we cannot get the required results. So, it is important that the surface should be sufficiently moist and we should have access to the reinforcement. The test cannot be applicable for epoxy coated reinforcement or concrete with coated surfaces. Because when the reinforcement is epoxy coated then we cannot have a complete circuit. So, it is difficult to carry out the test.

So, the reinforcement should be of no coating and also for the concrete surface and then only we can carry out the half-cell potential test. Half-cell potential test is widely used to assess the corrosion potential of the existing reinforcement.

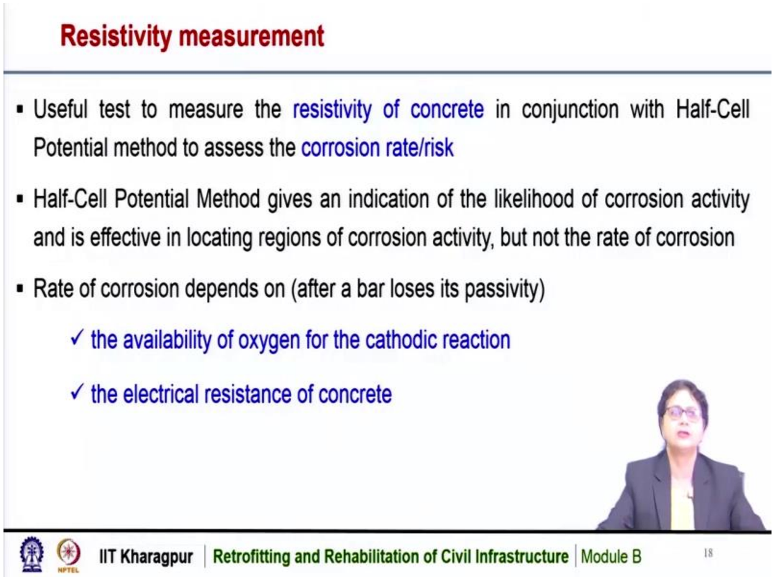
(Refer Slide Time: 18:58)



Here are some pictures of the half-cell potential test carried out on the ROB, which is being retrofitted now. We can see here that the test is carried out on the deck slab of the ROB. The reinforcement is exposed here and one end is connected to this expose reinforcement, the other end is to the half-cell. So, this is the half-cell, which is placed on the bottom surface of the deck slab and the readings are displayed here.

Here is also another picture of that ROB you can see here that the reinforcement is exposed and the other end is connected to the half-cell and the readings are being taken. So, these are some of the pictures of half-cell potential test carried out on a concrete deck slab and along longitudinal girder of an ROB. And this test can tell us the corrosion potential of the reinforcement of the members.

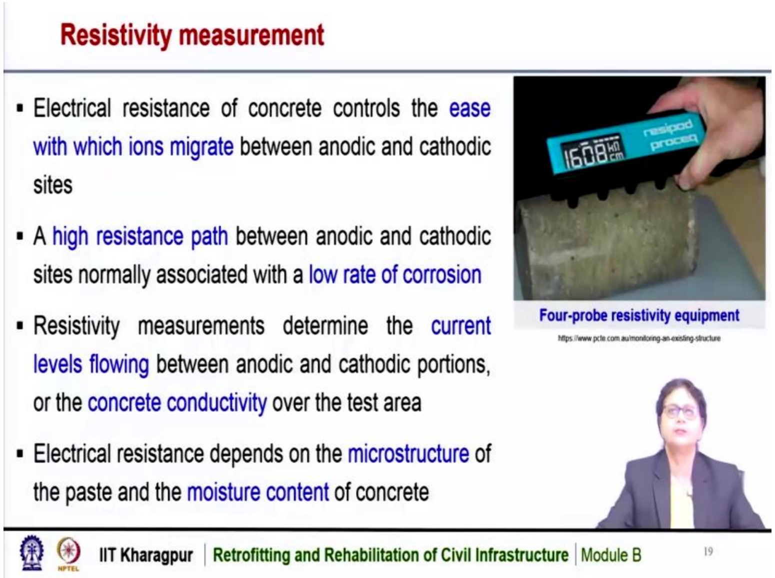
(Refer Slide Time: 20:09)



We will discuss a resistivity measurement test. This test is useful to measure the resistivity of concrete. And the test is done in conjunction with half shell potential method to assess the corrosion rate or corrosion risk. Half-cell potential method gives us an indication of the likelihood of corrosion activity, the potential of corrosion in reinforcement and is effective in locating the regions of corrosion activity.

But how much is the rate of corrosion, that we cannot get from half-cell potential test. So, for that we can perform the resistivity test, which can give us an indication of the rate of corrosion. The rate of corrosion in a reinforced concrete member depends on the availability of oxygen for the cathodic reaction to take place and also on the electrical resistance of concrete. So, by measuring these things, we can get indirectly the rate of corrosion in the member. So, here in the resistivity test, we measure the electrical resistance of concrete and that gives us an indication of the rate of corrosion in the reinforcement.

(Refer Slide Time: 21:24)

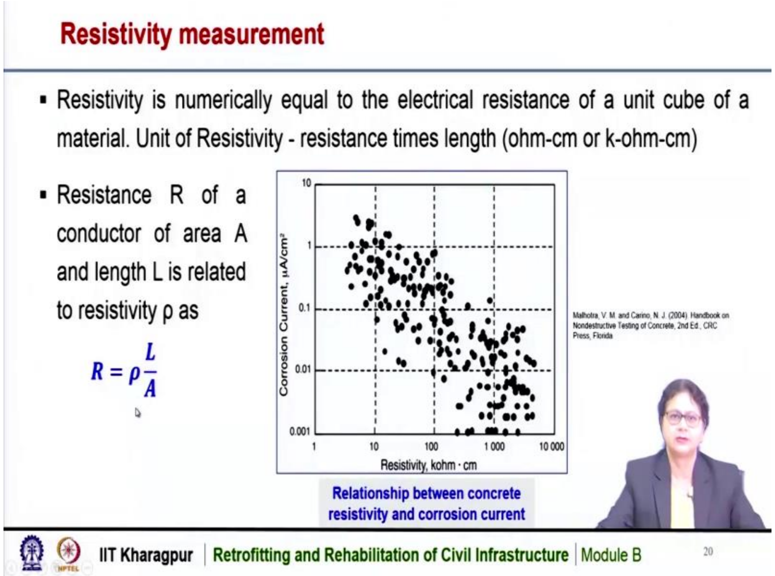


Electrical resistance of concrete controls the ease with which the ions migrate from the anodic to the cathodic region. So, a high resistance path between anodic and cathodic region normally associated with a lower rate of corrosion. If concrete has high resistivity, then there is less flow of ions due to corrosion activity. So, a high resistant path is beneficial for resisting the corrosion.

So, resistivity measurements determine the current level flowing between the anodic and cathodic portions or the concrete conductivity over the test area. So, by measuring the resistivity we can find out that what could be the rate of corrosion in that member. The electrical resistance depends on the microstructure of the paste and also on the moisture content of concrete.

So, here is a picture showing the resistivity test carried out on a concrete cylinder. You can see here this is the equipment used for that and this is the concrete member and the test is carried out to determine the resistivity of concrete. And resistivity of concrete indicates the flow of ion within that member. So, if the concrete has high resistivity, then it can resist the flow of corrosion current.

(Refer Slide Time: 22:55)

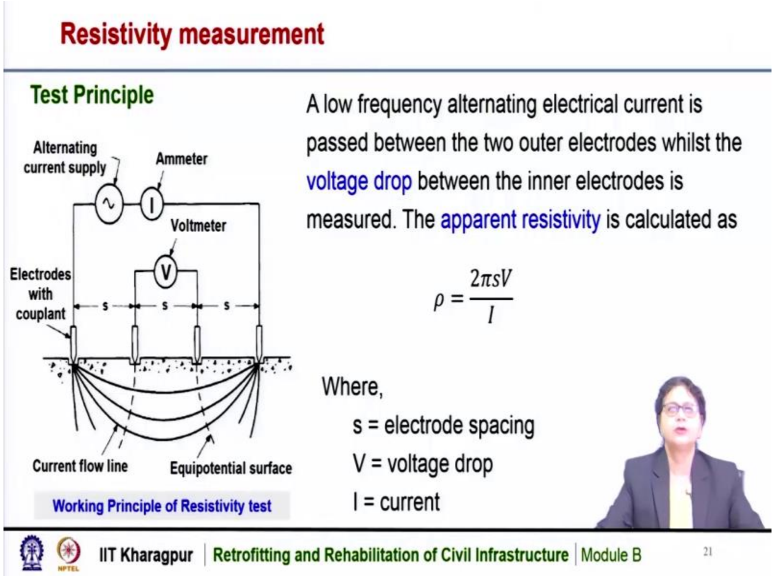


So, here in this diagram, we can see the relationship between the concrete resistivity and the corrosion current. We can see that higher is the resistivity, lower is the corrosion current. That means, if a concrete has high resistivity even if the reinforcement has lost its passivity, then the corrosion current flow is much less. So, this is an inverse relationship between the two.

So, we can say that when the resistivity of concrete is high, the corrosion current flow is less. So, here in this test we are measuring the concrete resistivity and that gives us an indication of the rate of corrosion in the member. The resistivity is numerically equal to the electrical resistance of a unit cube of a material. The unit of resistivity is ohms centimeter or kilo ohms centimeter.

So, the resistance R of a conductor of area A and length if it is known, we can find out the resistivity using this relationship R is the resistance of the conductor L is the length and A is the area. So, we can find out the resistivity with this relationship.

(Refer Slide Time: 24:15)

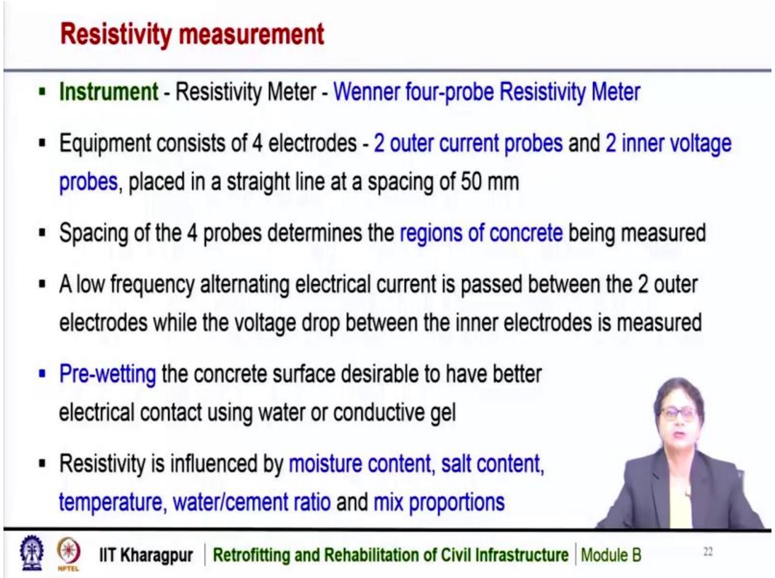


This is the schematic diagram of the working principle of the resistivity measurement. Here are several electrodes. We can see here two electrodes are there for the flow of current and two are there to measure the voltage drop. So, a low frequency alternating current is passed between the two outer electrodes, you can see here, these are the two outer electrodes and the flow of current is there through these two electrodes. These are the current flow lines and the inner two electrodes are there to measure the voltage drop. So, we can see here that these are the two electrodes in our electrodes and we can measure the voltage drop.

Now, the resistivity can be estimated using this relationship. $\rho = 2\pi sV/I$

So, higher is the voltage drop, that indicates higher is the resistivity. So, with this relationship we can find out what is the resistivity in that concrete member. So, when there is higher voltage drop that means, concrete has high resistivity. So, it indicates that the flow of current through the member is less. So this principle is used in the resistivity meter to estimate the resistivity of concrete.

(Refer Slide Time: 25:52)

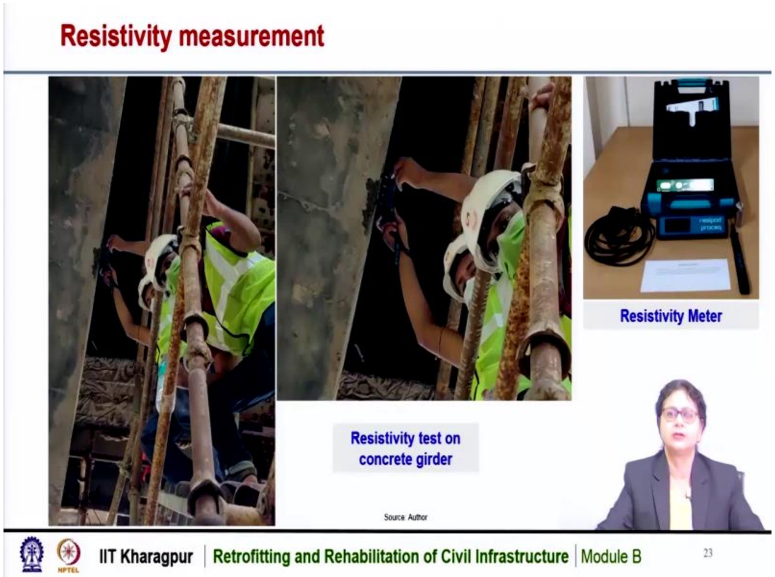


The instrument is called resistivity meter. Wenner four-probe resistivity meter is the commonly used commercial resistivity meter. The equipment consists of 4 electrodes, 2 outer current probes through which the power is flowing and the 2 inner voltage probes placed in a straight line at a spacing of 50 millimeters. Generally, the spacing between the electrodes are kept the same and for this Wenner four probe a resistivity meter 50 millimeter spacing is maintained.

The spacing of the 4 probes determines the region of concrete being measured. The distance between the 4 probes actually is the distance of concrete or the depth of concrete being measured for its resistivity. A low frequency alternating electrical current is passed between the 2 outer electrodes while the voltage drop between the inner electrode is measured.

And it is important that the concrete surface should be pre-wetted, so that there is a proper electrical contact. The resistivity is influenced by moisture content, salt content, temperature, water cement ratio and mix proportion of the material.

(Refer Slide Time: 27:15)

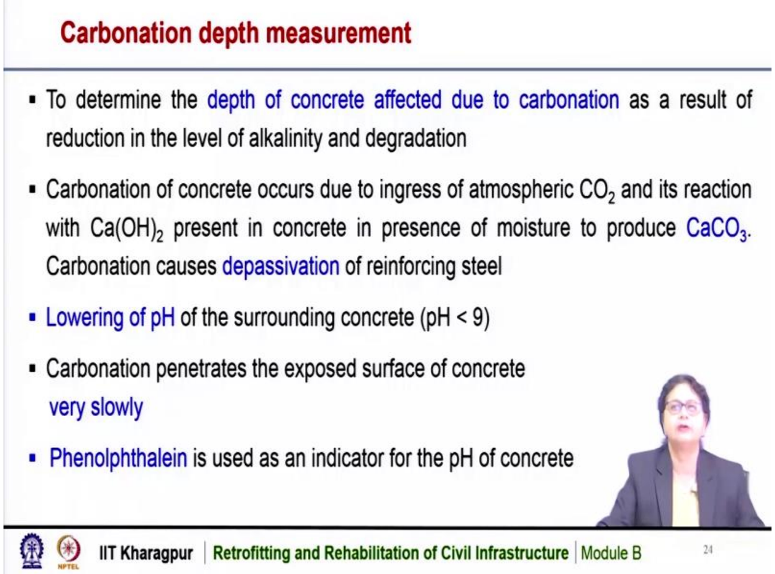


These are some of the pictures of the instrument and the resistivity test carried out on existing structure. You can see here; this is the picture of a resistivity meter. This is the four-probe resistivity meter and these are the connecting wires and this is the plate for the calibration of the instrument. And these are the pictures of the resistivity test carried out on the ROB.

You can see here the Wenner four probe is placed on the longitudinal girder and the test is being carried out. You can see here the surface is moistened for carrying out the test and the readings are displayed here. So, we can find out the resistivity of the concrete member and which gives us an indication of the rate of corrosion in the member.

So, by measuring the resistivity, we can find out that how much is the rate of corrosion in that member or how much is the deterioration rate in that member. If the reinforcement is already corroded or lost its passivation, then also if the concrete has high resistivity the rate of corrosion may be less. So, this test gives us an indication of the rate of corrosion by measuring the concrete resistivity.

(Refer Slide Time: 28:45)



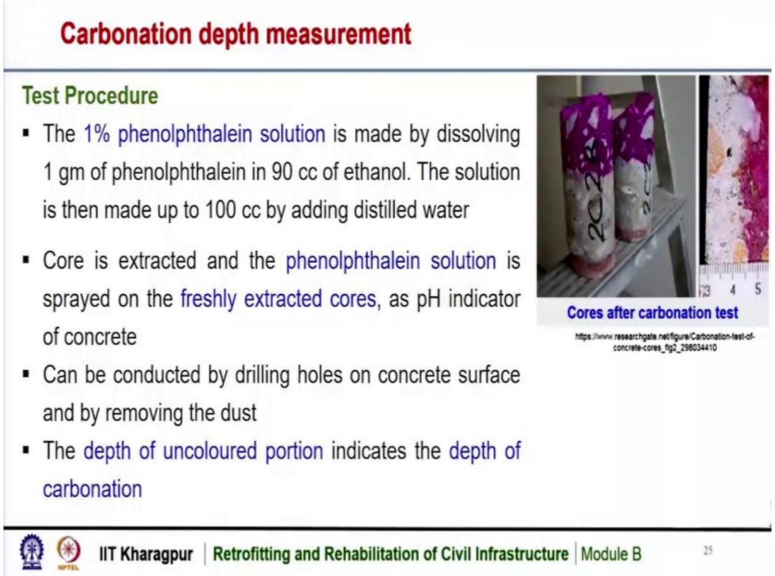
Another non-destructive test carried out on existing reinforced concrete structures is the carbonation depth measurement test. The test is carried out to determine the depth of concrete affected due to carbonation. And this is as a result of the reduction in the alkalinity level of the concrete. Concrete is generally alkaline in nature. However, over a period of time, it may get affected and the alkalinity level may reduce.

And it may be affected due to carbonation type of distress. Carbonation occurs due to the ingress of atmospheric carbon dioxide into the concrete member and its reaction with calcium hydroxide, which is present in concrete in presence of moisture to produce calcium carbonate. The carbonation causes depassivation of the reinforcing steel. When there is a lowering of the pH in the surrounding concrete, the pH level may be less than 9 or so.

And there are cracks on the surface of concrete. In that case, atmospheric carbon dioxide may enter into the member and reach to the level of reinforcement. That causes distress to the reinforcement. This carbonation penetrates the exposed surface of concrete very slowly. And how much is the depth of a concrete which is affected due to carbonation, that can be tested by this carbonation depth measurement test.

For carrying out the carbonation depth measurement test, phenolphthalein can be used as an indicator for the pH of concrete. A phenolphthalein is a common indicator that is used to identify the basicity or alkalinity of a material and this phenolphthalein is also used here for identifying the level of pH in the member.

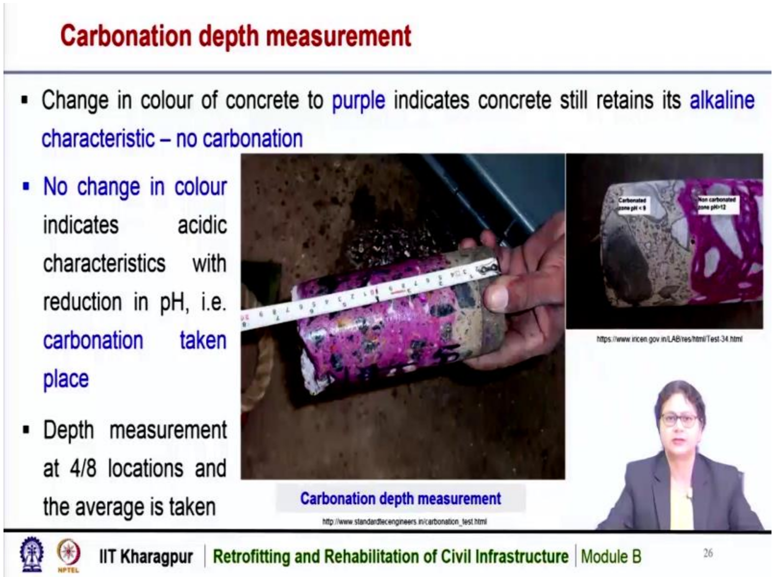
(Refer Slide Time: 30:54)



The test procedure is that 1 percent phenolphthalein solution is made by dissolving 1 gram of phenolphthalein in 90 cc of ethanol. The solution is then made up of 100 CC by adding distilled water. Generally, for performing the carbonation depth measurement test, we extract cores from existing member. And the phenolphthalein solution is sprayed on the freshly extracted core. Sometimes, cores are not extracted or the test can also be done by drilling holes on the existing concrete member. And by removing the dust and then we can spray the phenolphthalein solution.

When we spray the phenolphthalein solution on the core or into the drilled hole on the member, then some portion may get discolored. The depth of the uncolored portion indicates the depth of carbonation. So, here you can see that a cores have been extracted from an existing member. Some portion is colored due to the effect of the phenolphthalein solution and some portion not.

(Refer Slide Time: 32:06)

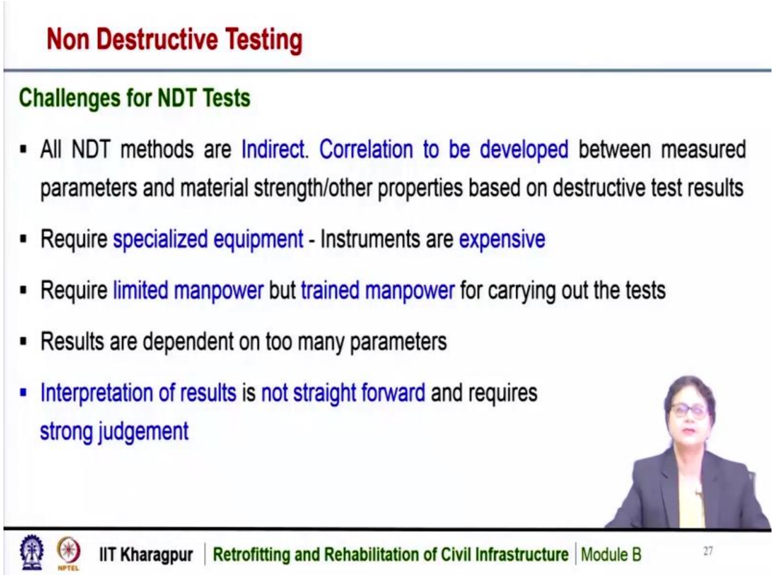


Changing color of concrete to purple indicates that concrete still retains its alkaline characteristics. When the phenolphthalein solution is added alkaline solution turns into purple. So, if there is a change in color to purple, that indicates that concrete still retains its alkaline nature. So, it is an indication that there is no carbonation taking place on the member. When there is no change in color, that indicates that portion becomes acidic. That means the pH is less in that region. So, this indicates carbonation has taken place in that part.

So, you can see here in this picture, that cores have been extracted and phenolphthalein solution is sprayed and after that this portion is turned purple, whereas this portion remains as it is. So, this indicates that in this portion, the pH level is lower. So, which is an indication of the carbonation type of distress. So, this indicates that carbonation has taken place up to this depth. So, we can measure the depth around this on this score and we can take 4 to 8 readings and the average of that readings will give us the depth of carbonation.

So, by this we can find out that how much depth of concrete is affected due to carbonation. So, this tells us that the extent of carbonation type of distress on an existing member. And this is an effective test and widely used test for finding out the carbonation type of distress in existing reinforced concrete members.

(Refer Slide Time: 34:03)



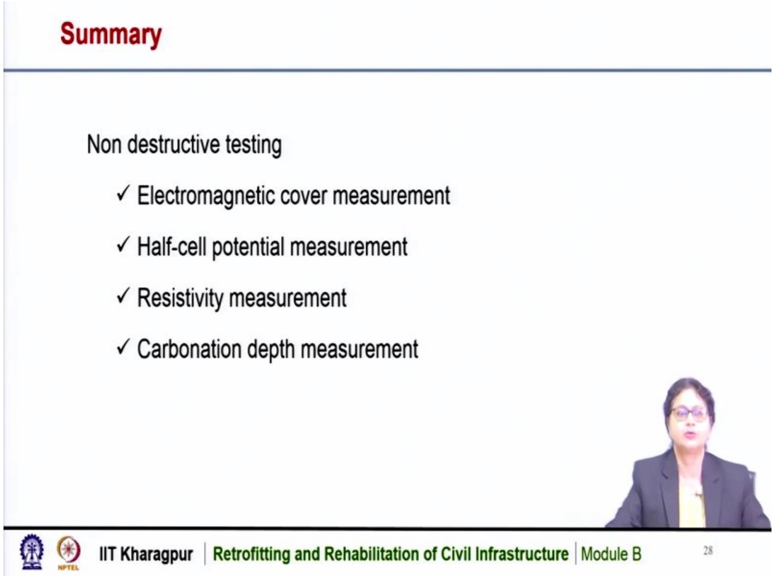
We have discussed several non-destructive testing that can be carried out on existing structures to determine the strength and other properties. But there are several challenges for NDT tests. All NDT tests are indirect. We are not doing any direct measurement of the properties of the member. So, correlations need to be developed between measured parameters and the material strength or other parameters based on some destructive test results.

The NDT test requires specialized equipment and these instruments are generally expensive. So, this is one limitation for the NDT tests. It requires limited manpower, it do not require heavy manpower like construction activities or so, but limited and manpower is required. But this manpower should be trained. So, trained manpower is required for carrying out the test and results are dependent on too many parameters.

Because we are doing indirect measurements of the material properties and that is why there may be several parameters which may influence the test results. So, may not be exact value we are getting but some near exact values we are getting from the test results. Interpretation of results is not straightforward in non-destructive tests. And it requires strong judgment.

It is not that what we are getting is what we can report it, but it is important to properly interpret the test results. And proper understanding of the structure, the other conditions and other test results also should be considered while giving the proper judgment regarding the material properties. So, interpretation of results is important for all non-destructive tests. And generally, more than one tests are used to assess the condition of the existing structures. And which can give us then the clear picture of the existing structure.

(Refer Slide Time: 36:25)



So, to summarize, we have discussed today several non-destructive tests related to corrosion activity of reinforcement. We have discussed electromagnetic cover measurement that gives us the depth of available cover for reinforcement in an existing structure. We have discussed half-cell potential method that gives us the corrosion potential of reinforcement.

The resistivity measurement test gives us the resistivity of concrete. And from that we can find out the rate of corrosion in reinforcement. The carbonation depth measurement gives us the depth of concrete affected due to carbonation type of distress. Thank you.