Retrofitting and Rehabilitation of Civil Infrastructure
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Lecture 09
Non- destructive Tests

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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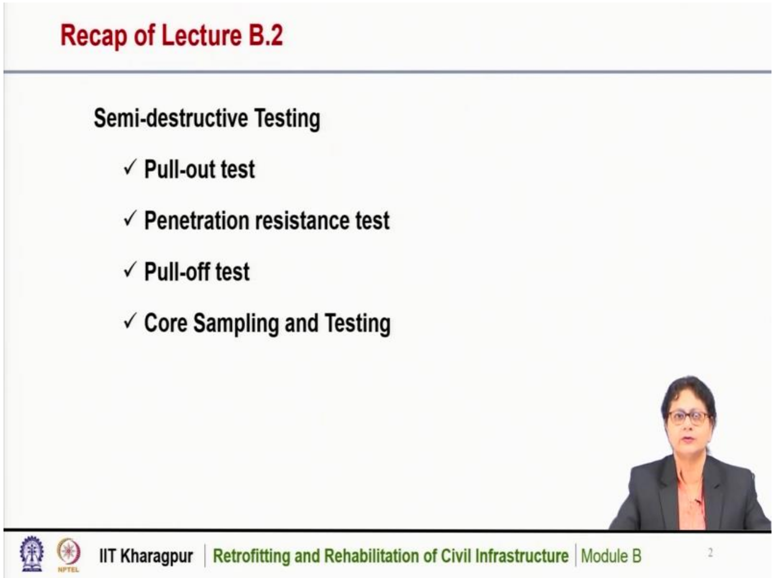

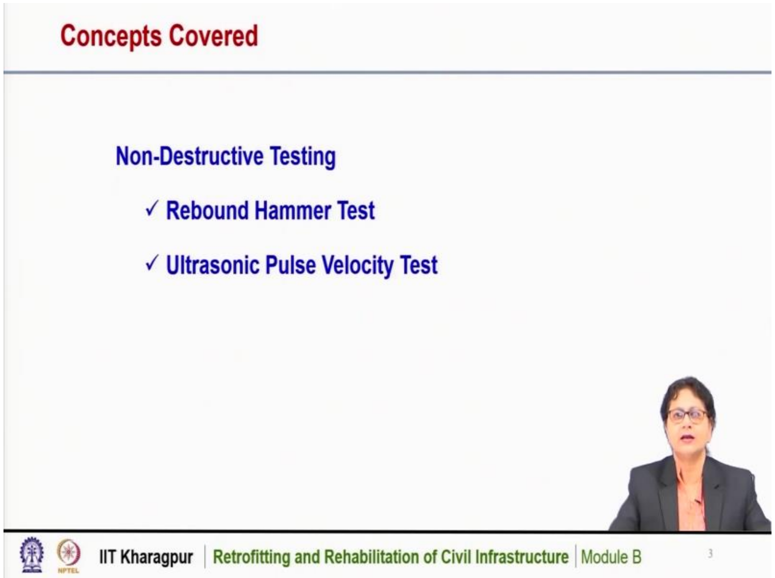

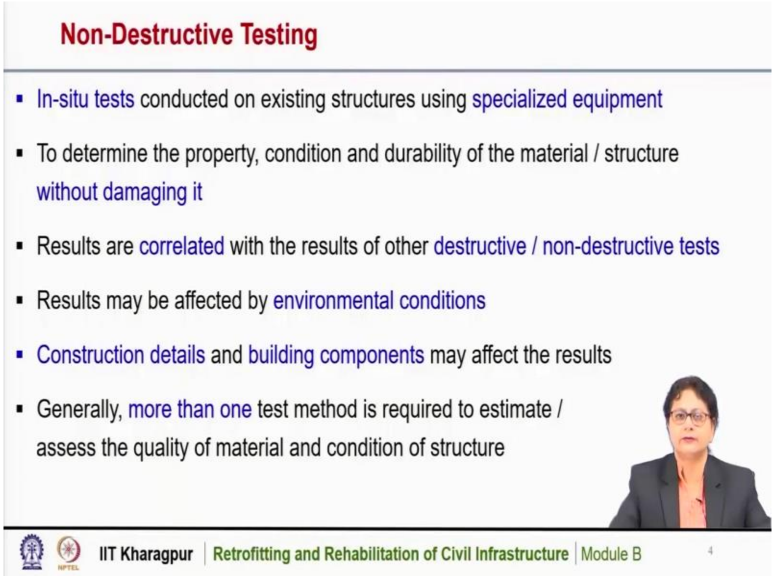

In the previous lecture, we have discussed several semi destructive testings. We discussed pullout test penetration resistance test, pull off test and core sampling and testing. In semi destructive testing, there may be a localized damage on the structural member. But these localized damages are not big enough to cause the reduction in strength or performance of the member. In non-destructive testing, there is no damage on the structural member.

We will discuss today some of the non-destructive testing that can be carried out on existing structure to determine its properties. Today, we will discuss rebound hammer test and ultrasonic pulse velocity test. Non-destructive testing is carried out on existing structures using specialized equipment. The tests are carried out to determine several properties of the existing member to determine the condition and durability of the material without damaging it. The results of non-destructive testing are correlated with the results of other destructive or other non-destructive tests.

Here in non-destructive testing, we are not estimating the properties of the member directly. So, it is to be correlated with the results of other destructive or semi destructive or non-destructive tests. Results may be affected by several environmental conditions. For example, temperature or relative humidity. The construction details and building components may also affect the results of NDT testing.

Generally, more than one test method is required to estimate or assess the quality of material and condition of structure. This is important because, in NDT testing, we are not directly measuring the strength or other properties. So, it is always desirable to carry out more than one test methods for getting a clearer picture of the in-situ condition of the structure.

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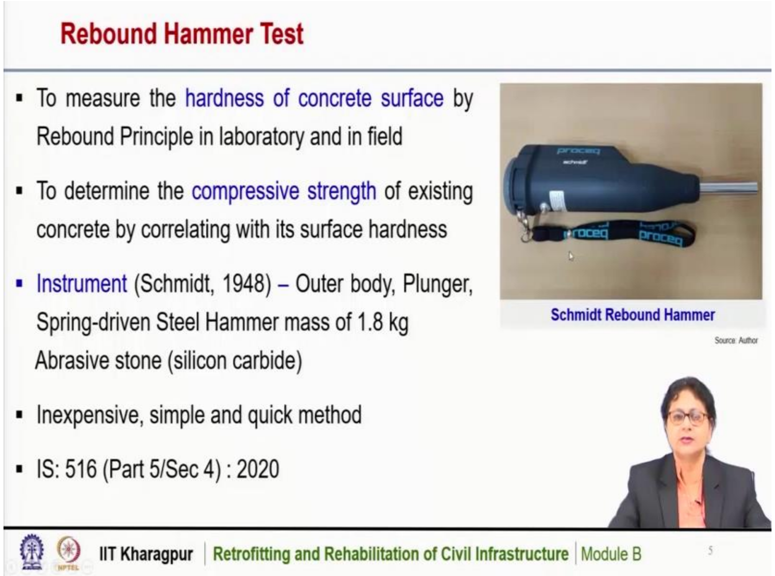

Rebound hammer test is a widely used non-destructive test to determine the in-situ strength of the material. The test is used to measure the hardness of concrete surface by rebound principle. It is to determine the compressive strength of existing concrete by correlating with its surface hardness. The test can be carried out in laboratory also in the field. The instrument that is used for carrying out rebound hammer test is the rebound hammer.

The Schmidt rebound hammer is the most common. Here is a picture of this Schmidt rebound hammer, which is used for conducting the rebound hammer test. The apparatus is available in our laboratory. The apparatus consists of outer body, we can see here. This is the outer body a plunger, this is the plunger. A spring driven steel hammer mass of 1.8 kg, which is placed inside this outer body and it also has a silicon carbide abrasive stone for smoothing the surface.

The test is very simple and quick and also inexpensive and it can be carried out in field very quickly. Indian standard code IS 516 Part 5 section 4 is available, which tells us the steps for carrying out rebound hammer test in field and also in the laboratory.

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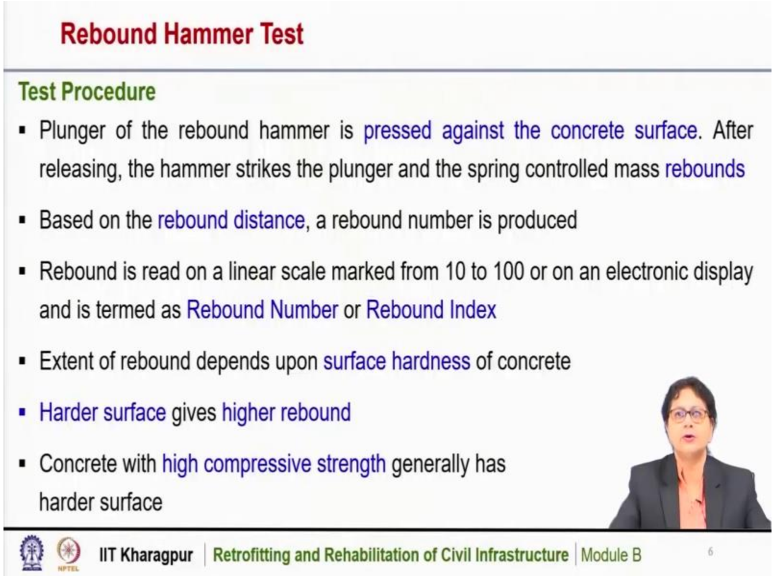

The test procedure is that, the plunger of the rebound hammer is pressed against the concrete surface. When it is pressed, the spring inside the outer body is stretched and after releasing the hammer strikes the plunger and the spring control mass is then rebounds. Based on the rebound distance a rebound number is produced. Rebound is read on a linear scale, marked from 10 to 100 or on an electronic display. And this is termed as rebound number or rebound index.

This rebound number depends on the surface hardness of the material. Higher is the surface hardness, higher is the rebound number. So, we can see that for a concrete which has high compressive strength generally has harder surface. So, for that case, the rebound number will also be higher.

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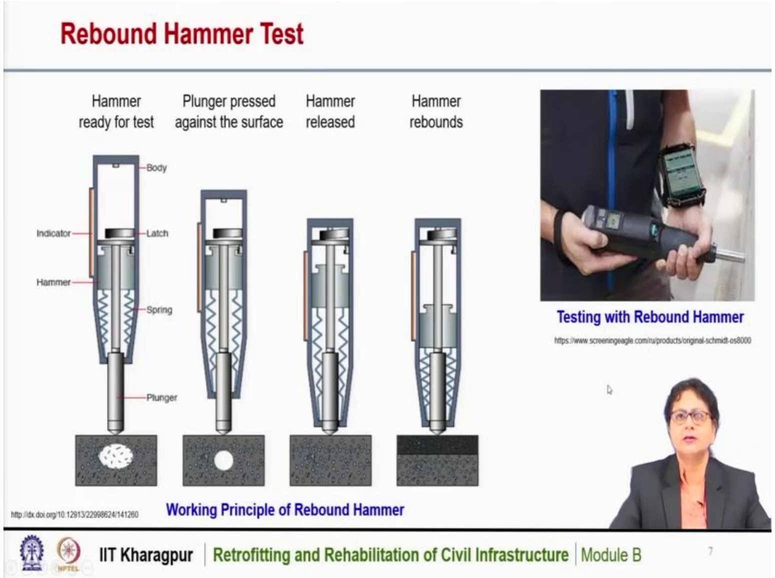

Here it is showing schematically, the working principle of rebound hammer. We can see here that this is the schematic diagram of the rebound hammer. The hammer is placed on the concrete surface, the hammer is now ready for the test. This is the plunger, this is the spring and this is the hammer attached to it and this is the entire body of the hammer and this is the indicator where the rebound number is displayed.

So, the hammer is ready for the test now, it has to be pressed against the concrete surface. When it is pressed the spring is stretched, the plunger is pressed and further the spring is further stretched. And when it is stretched up to this position we can see here, the hammer is not released. After that the hammer rebounds. You can see here the hammer rebounds and this rebound distance is displayed on the indicator.

Here is the picture of rebound hammer test being carried out on a concrete surface. When the hammer is pressed against the surface and then it is released the hammer rebounds. So, the rebound number is indicated here and from the round number we can correlate the compressive strength of concrete.

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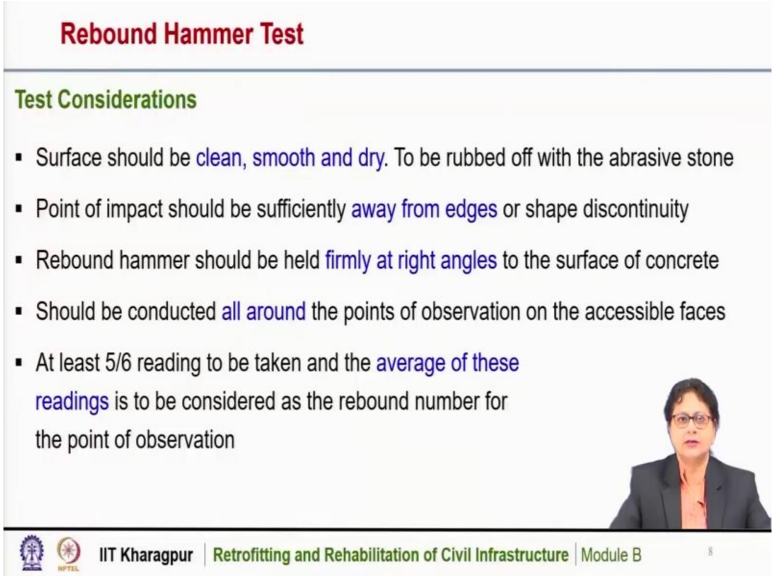

Test considerations we have to follow. Certain guidelines for carrying out the test. The surface should be clean, smooth and dry. If it is not so smooth, we can rub it to make it smooth using the abrasive stone. The point of impact should be sufficiently away from the edges or shape discontinuity. We should not carry out the test near the corner or edges because that may damage the member. The rebound hammer should be held firmly at the right angle to the surface of concrete.

This is important, the hammer should be placed properly and very rigidly against the surface at right angle to it. Should be conducted all around the points of observation on the accessible faces. We should not take only one reading but at least 5 or 6 readings to be taken around the point of observation and then the average of these readings will give us the rebound number for that point of observation.

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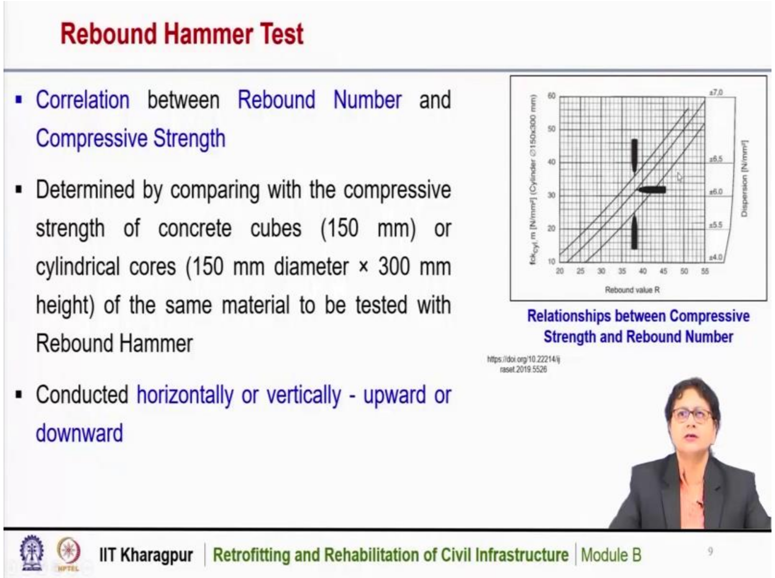

Then correlation can be drawn between the rebound number and the compressive strength of concrete. That correlation can be done with the concrete cubes or concrete cylinders of standard dimensions. For concrete cubes we can use 150-millimeter cube or for concrete cylinders we can use the size as 150-millimeter diameter × 300-millimeter height. So, we can prepare concrete cubes or cylinders with different strengths and carry out the rebound hammer test on those.

And from the rebound number we can find out the correlation. So, this is a typical relationship showing the compressive strength and rebound number. The relationship shows that, higher is the rebound number, higher is the compressive strength of concrete. Three different lines have been drawn denoting the three different positions of the hammer. The rebound hammer test can be conducted horizontally or vertically upward or vertically downward.

When the concrete surface is vertical, we can put the hammer horizontally against the surface and this correlation graph is for that. When the surface is horizontal, and we can carry out the test with the plunger pointing downward then this is the correlation graph. When the test can be conducted on a horizontal surface with plunger pointing upward, this is the correlation graph. Depending on the gravity effect on the different positions of the hammer, whether it is vertical or horizontal, different relationships are developed.

So, these are the different relationships, based on the different positions of the rebound hammer. The relationships show that higher is the rebound number, higher is the compressive strength of concrete. There are several factors that may influence the test results that we have to consider while analyzing the rebound number values for estimating the in-situ strength of concrete.

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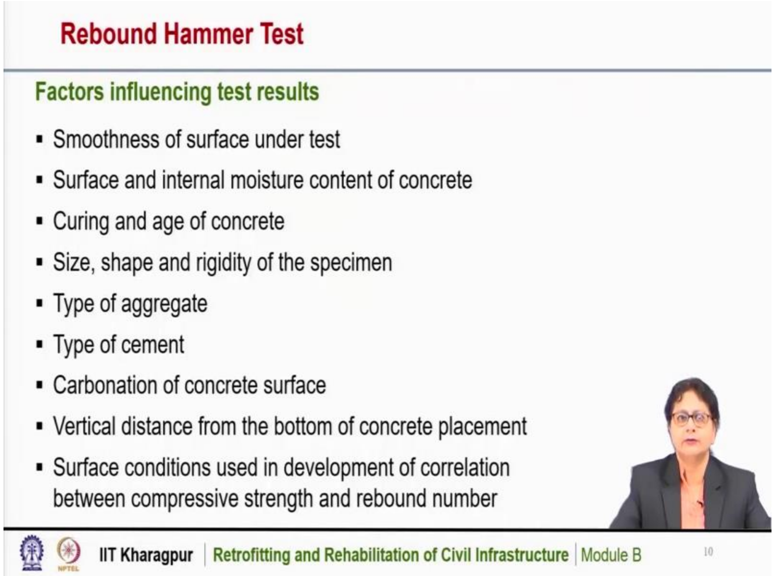

The smoothness of surface under test, it is important to have the surface properly smooth to carry out the test. If it is not so, then the aggregates may come out and if the plunger hits on the aggregate, the aggregate may crash and we may get a lower hammer value. Surface and internal moisture content of concrete, if the internal moisture concrete is higher, than the rebound value will be lower.

Curing and age of concrete also influences the rebound value. With proper curing and with increasing age of concrete generally the surface hardness improves. So, a higher rebound value will be obtained. Size, shape and rigidity of the specimen may also affect the rebound number value. It is important to have the surface properly rigid for carrying out the test. Sometimes, if the specimen is smaller, then while carrying out the test there may be some movement. So, in that case, we can get a lower hammer value or lower rebound value.

Type of aggregate and type of cement may also influence the rebound hammer value. For the same strength of concrete, if we have a concrete with aggregates is gravel and in another aggregate is limestone, we may get a higher rebound value for the concrete with gravel aggregates. Type of cement may also influence the rebound value; sometimes high alumina cement may give a higher rebound value as compared to the concrete with OPC.

The carbonation of concrete surface is an important component or important consideration for rebound hammer test. Because if the concrete surface is carbonated, then it becomes very hard. So, in that case we may get a high rebound value. However, the inner concrete may not be that strong, the quality may not be good, it may have cracks or voids, but that is not reflected from the surface hardness.

So, a carbonated concrete surface may give a higher rebound value. The vertical distance from the bottom of concrete placement may also sometimes give a higher rebound value. If the distance between the bottom surface and the rebound surface is less than we may get higher rebound value because sometimes the bottom of the surface may get well compacted. So, we may get a higher rebound value.

The surface condition used in development of correlation between the compressive strength and rebound number may also influence the rebound value.

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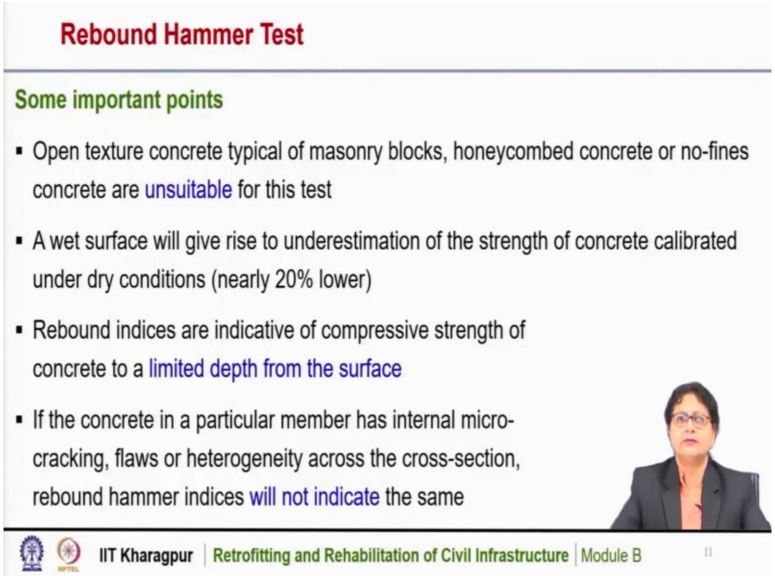

Some other important points for carrying out the rebound hammer test is that open textured concrete typical of masonry blocks, honeycomb structure, or no fines concrete are unsuitable for this test. So, it is important to have a smooth surface for carrying out rebound hammer test. If the surface has honeycombing in it, so the aggregates are exposed. So, we may not get a correct strength for that type of structure.

A wet surface will give rise to underestimation of the strength of concrete calibrated under dry condition. Rebound indices are indicative of compressive strength of concrete to a limited depth from the surface. The test gives a measure of surface hardness of the member. So, it is an indicative of the compressive strength of concrete up to a limited depth of the member not at a deeper depth.

If the concrete in a particular member has internal micro-cracking, flaws or heterogeneity, across the cross section, rebound hammer indices will not indicate the same. So, since rebound hammer gives the surface hardness and from the surface hardness we can correlate the compressive strength. So, it does not give the strength or quality of the concrete which is at a larger depth. So, the presence of cracks or flaws cannot be identified with this type of test.

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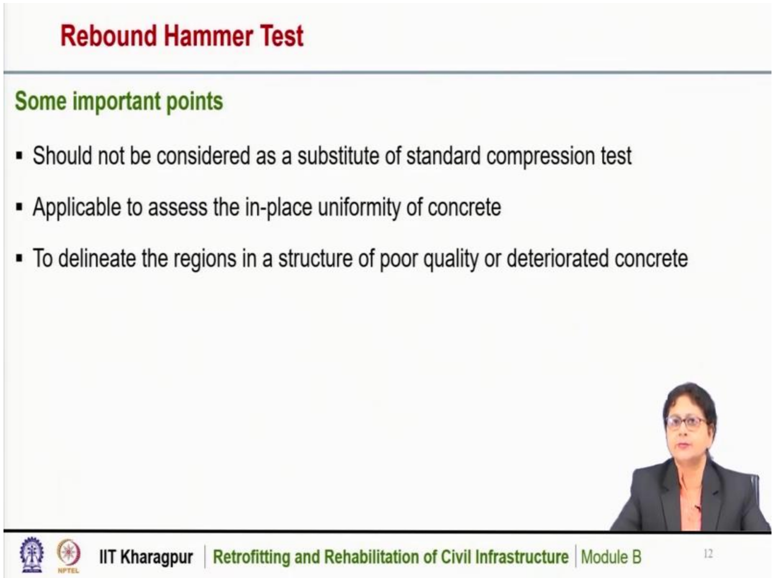

The test should not be considered as a substitute or standard compression test from the rebound hammer test, we correlate from the surface hardness, the compressive strength of concrete. But it should not be considered as a substitute of standard compression test. For compression test, we have to do it to find out the exact compressive strength of concrete.

The test is applicable to assess the in place in uniformity of concrete and also to delineate the region in a structure of poor quality or deteriorated concrete. Sometimes some portions may be not of higher strength. So, that can be identified with this type of rebound hammer test.

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Here are some pictures of the rebound hammer test being carried out on a ROB, a road over bridge. This is the longitudinal girder, we can see here and this is the cross beam. So, the rebound hammer test is carried out and the hammer is placed horizontally for the test. Here the rebound hammer test is carried out on the crossbeam and the rebound hammer is placed vertically upward.

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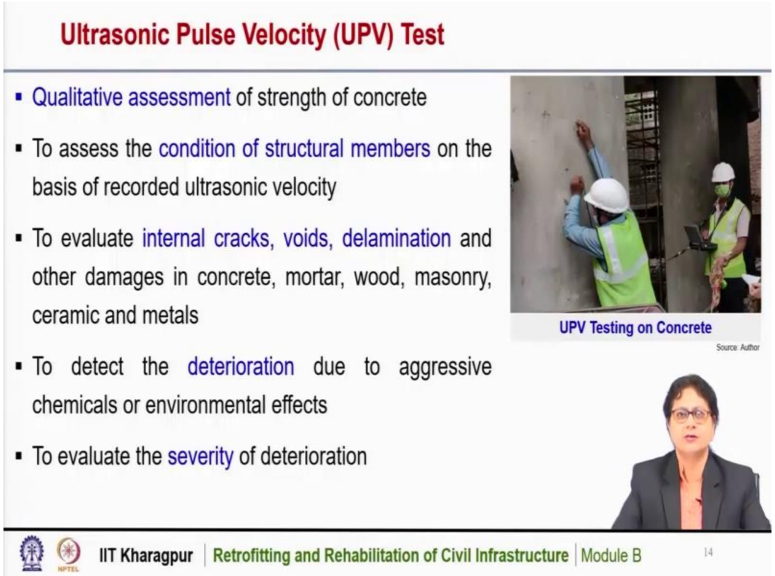

Ultrasonic pulse velocity test is another widely used nondestructive test. The test is used for the qualitative assessment of strength of concrete. The test is used to determine the in-situ strength of concrete qualitatively and also to assess the condition of structural members on the basis of recorded ultrasonic velocity. To evaluate the presence of internal cracks, voids or delamination and any other damages within the material can be detected by UPV testing.

The test can be conducted on concrete, mortar, wood, masonry, ceramic, or on metals. The test is used to detect the deterioration due to aggressive chemicals or environmental effects and also to evaluate the severity of deterioration. Here is one picture of the UPV testing carried out on a concrete pier. Here we can see that the test is done on the pier of road over bridge with the UPV test setup.

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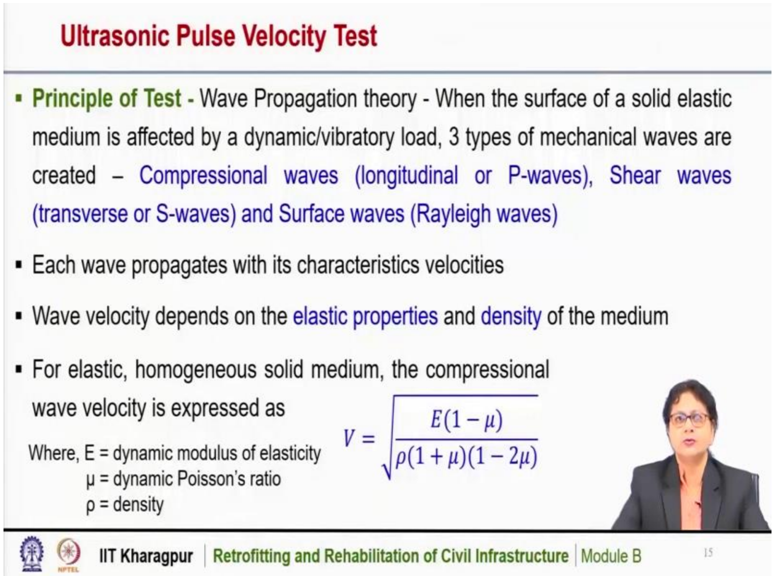

Ultrasonic pulse velocity test is based on the wave propagation theory. When the surface of a solid elastic medium is affected by dynamic or vibratory load. Three types of mechanical waves are created. Compressional waves or longitudinal waves or P waves, shear waves or transverse or S-wave, and surface wave, or Rayleigh waves. Of the three types the compressional waves have the highest velocity and the surface waves have the least.

Each wave propagates with its characteristic's velocity, the wave velocity depends on the elastic properties and density of the medium. For an elastic, homogeneous and solid medium, the compressional wave velocity can be expressed using this equation.

$V=\sqrt{((E(1-\mu))/(\rho(1+\mu)(1-2\mu)))}$

Where E is the dynamic modulus of elasticity of the medium. μ is the dynamic portions ratio of the medium. And ρ is the density of the medium.

So, with this equation we can understand that the velocity of the wave depends significantly on the dynamic modulus of elasticity, on the density and on the poisons ratio of the medium. However, the influence of poisons ratio is much less as compared to the elastic modulus of the medium. Higher is the elastic modulus, higher is the velocity. So, this principle is used in the UPV testing.

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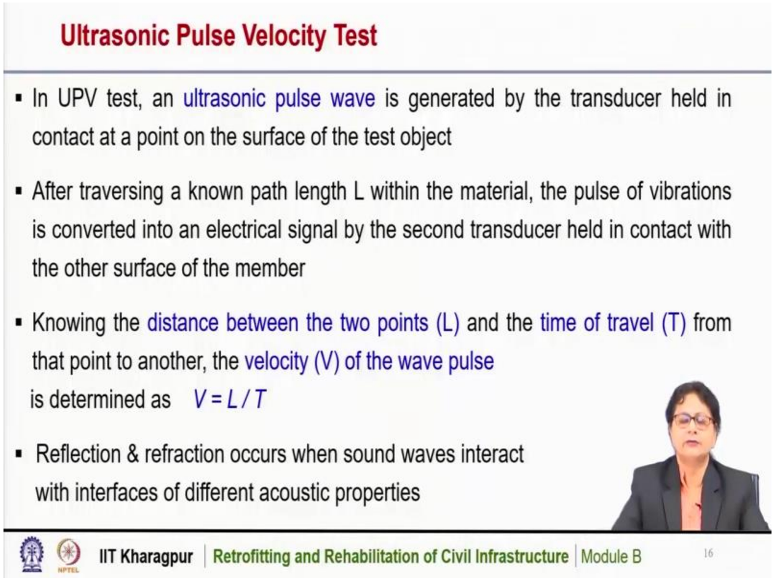

In UPV testing, an ultrasonic pulse wave is generated by the transducer, held in contact at a point on the surface of the test object. After traversing a known path length within the material, the pulse which is generated is converted into an electrical signal by the second transducer held in contact with the other surface of the membrane. Knowing the distance between the two points from the generation to the receiver and the time of travel from the point to the another, the velocity of the wave pulse can be determined.

As, V = L / T, that is the length between the two points divided by the time of travel. The reflection and refraction occur when the sound waves interact with interfaces of different acoustic properties. Then the sound wave is generated and it is moving, that may experience some scattering due to the different interfaces that it may face. The interfaces may be due to the concrete and cement sand matrix interface and that interface may cause that reflection or refraction of the waves.

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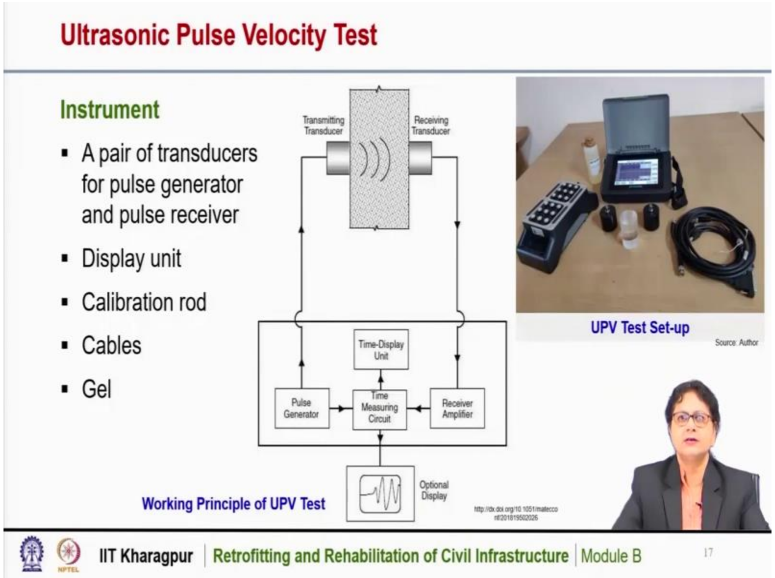

Here is a typical UPV test setup. This is the typical ultrasonic pulse velocity test setup available in our laboratory. The instrument consists of a pair of transducers, these are the two transducers, one is for pulse generator and the other for pulse receiver. Either of the two can be used as a generator and receiver. The display unit, where we can see the velocity. The calibration rod, this is the calibration rod, every instrument requires calibration before testing.

So, it has to be calibrated also. Cables, the transducers need to be connected to the display unit and it has to be placed on the surface. So, these are the cables for that purpose. And a gel is required for fixing the transducers on the concrete surface. This is the schematic diagram of the working principle of UPV test. This is the object and these are the two transducers, one is the transmitting transducer and the other is the receiving transducer.

When the pulse is generated, it goes here and moves through the medium and the receiving transducer receives this pulse and the time of travel is noted. And the distance also is noted and from that we can find out the velocity which can be displayed here. So, this is the working principle of UPV testing on existing concrete structures.

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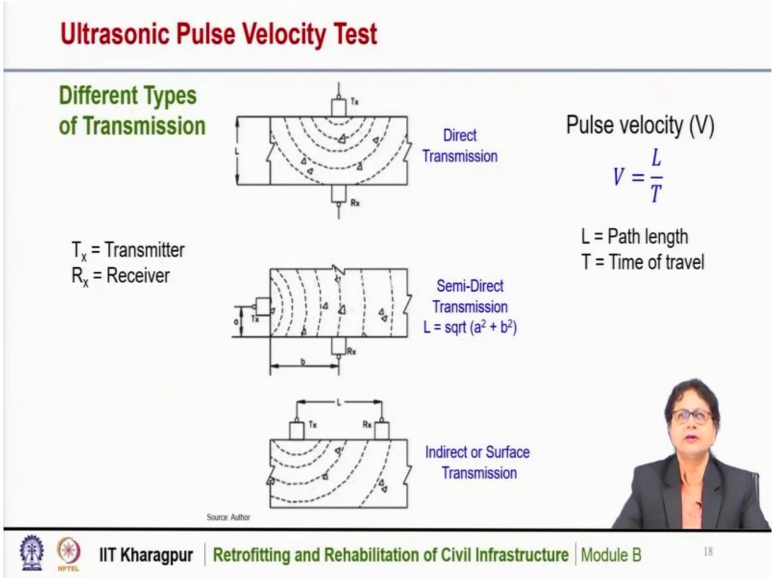

The ultrasonic pulse velocity test can be carried out with different types of transmission. One is direct transmission and other is semi direct transmission and the other one is indirect or surface transmission. This is the object when the two transducers are placed just opposite to each other, then we call it direct transmission. Here is the length to be traveled by the wave paths. And these are the waves generated by this transducer and it is received here. This is the most effective one, sometimes the access is not available for direct transmission.

So, in that case the two transducers can be placed right angle to each other. So, this we call it semi direct transmission. So, here in this case, the length of travel can be estimated as $L=\sqrt{(a^2+b^2)}$. sometimes it is difficult to get access from the other three sides. So, in that case the two transducers can be placed on the same surface with a known distance and the time of travel of the wave pulse is noted. This is called indirect or surface transmission. The velocity of the pulse can be estimated by knowing the length of travel divided by the time of travel.

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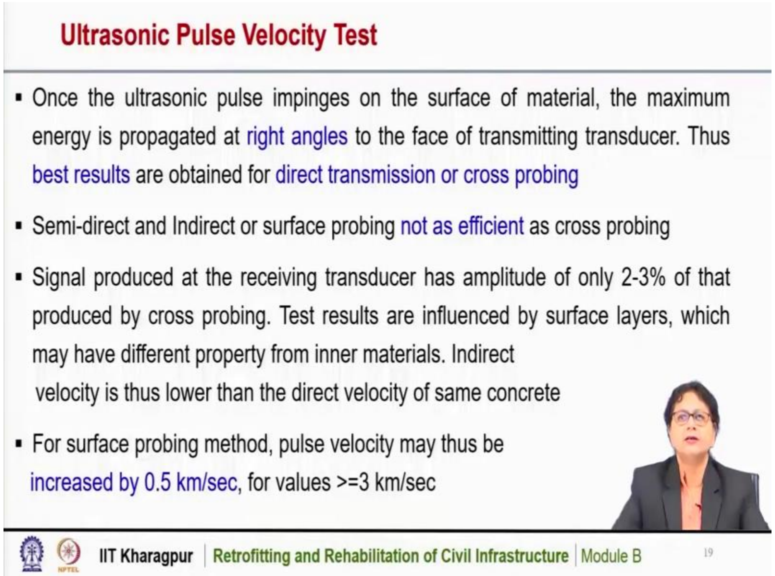

Once the ultrasonic pulse impinges on the surface of material, the maximum energy is propagated at right angles to the face of the transmitting transducers. And that is why we can get the best results for direct transmission or cross probing. So, direct transmission gives the best results and it is preferable to use direct transmission for the UPV testing, if the access of the sites are available.

Semi direct or indirect probing are not as efficient as cross probing. Here in these cases, the signal produced in the receiving transducer has amplitude of only 2 to 3% of that produced by cross probing. So, the test results may be influenced by surface layers, which may have different property from the inner materials. That is why the indirect transmission or semi direct transmission are less effective as compared to the cross probing.

So, the velocity here in these cases are lower than the direct velocity of the same material. For surface probing method, when the concrete is found to be quite good, the pulse velocity may be increased by some amount, maybe 0.5 kilometer per second. If the pulse velocity we are getting from indirect method is more than 3 kilometers per second, we can increase the pulse velocity by 0.5 kilometer per second.

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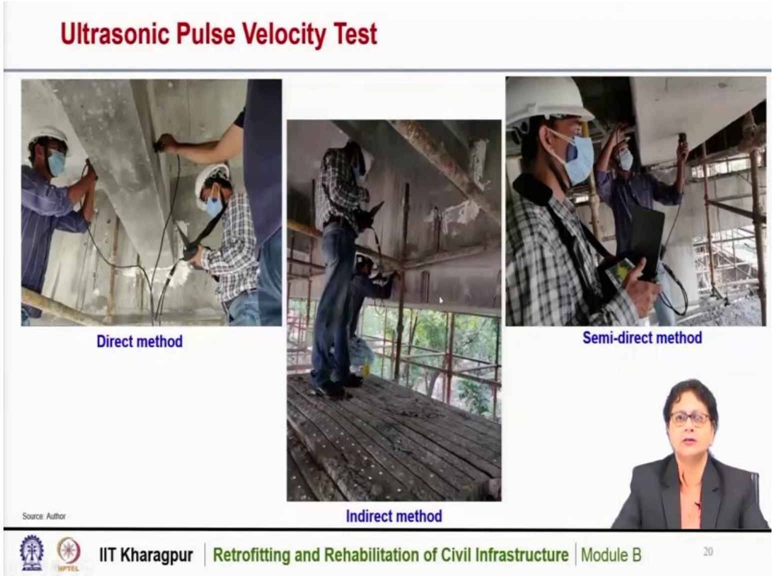

Here are some pictures of the ultrasonic pulse velocity testing being carried out on the longitudinal girder of the ROB, which is now being repaired and retrofitted, the UPV tests are carried out by direct method, indirect method as well as by semi direct method. Here we can see that the access is available.

So, the direct transmission method has been followed. Here semi direct transmission method is followed. The two perpendicular faces are seen. And the two transducers are placed on the two perpendicular faces and the test is being carried out. Here in indirect method, the two transducers are placed on the same surface of the girder and the test is being carried out.

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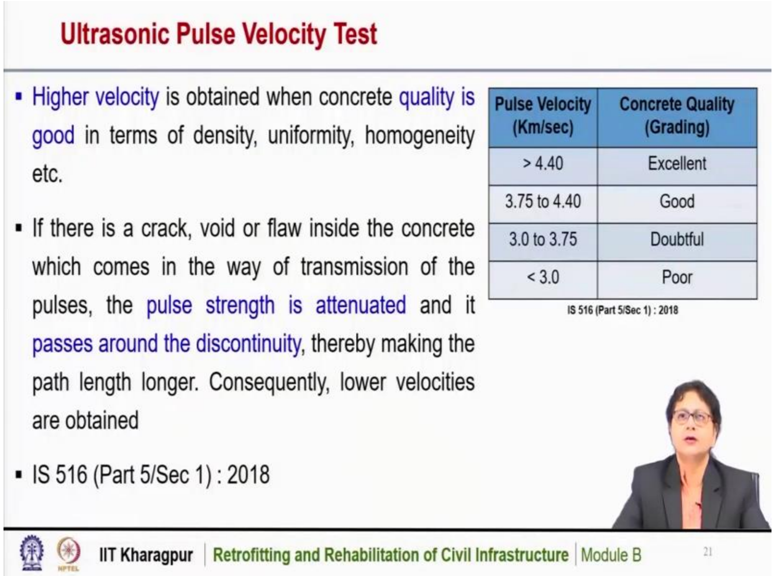

In UPV testing the higher velocity is obtained when the concrete quality is good in terms of density, uniformity, homogeneity etcetera. If there is a crack or void or some discontinuity within the material, and which comes in the way of transmission of the pulse, the pulse strength is attenuated. And it passes around that discontinuity, thereby making the path length longer. Consequently, we will get a lower velocity within the material.

So, this test tells us that if there is a crack or void, by observing the pulse velocity, we can detect that whether the concrete has any defect within it or not. The Indian standard guideline IS 516 is available, which tells us the steps for carrying out the ultrasonic pulse velocity test. This table shows the threshold values of pulse velocity. And with those values we can estimate the quality of concrete.

When the pulse velocity is more than 4.4 kilometers per second, the concrete quality can be considered as excellent. When the pulse velocity is in the range of 3.75 to 4.4 kilometer per second, the concrete quality is good. When the pulse velocity is in the range of 3 to 3.75 kilometer per second, the concrete quality can be considered as doubtful. And when the value is less than 3 kilometer per second, the concrete quality is considered as poor.

So, these are the threshold values as given in the IS code and that tells us the quality of concrete, based on this pulse velocity.

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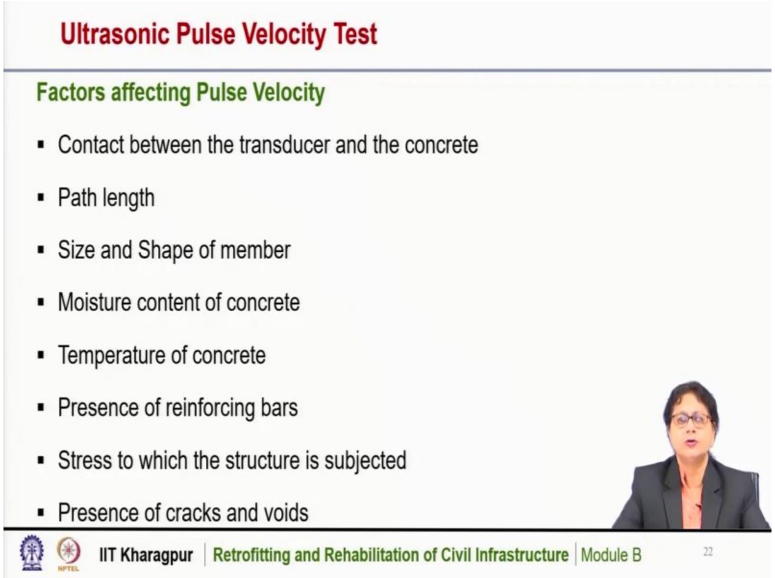

There are several factors which may influence the pulse velocity. Contract between the transducer and the concrete. It is important that the two transducers should be placed firmly on the concrete surface and there should not be any air gap in between. If there is any air gap, then the pulse will not propagate and we can get a lower UPV value. The path length, generally path length does not have any significant influence on the UPV value.

However, if the path length is too small, particularly in case of concrete, then due to the inherent inhomogeneity of the material, we may get a higher UPV value. The size and shape of member may also influence the UPV value. Generally, there is no significant influence, but when we will consider the equation for estimating the pulse velocity, that equation is valid when the member is infinite in extent.

However, this condition can be achieved for any other member if the least lateral dimension of the member is more than the wavelength. Now, the moisture content of concrete may influence the UPV value. If the concrete is saturated, we can get a higher UPV value. The temperature of concrete may have some influence on the UPV value. If the range of concrete is in from 5 degrees to 30 degree centigrade, then there is no significant influence on the UPV value.

However, if the temperature is beyond this range, a correction factor needs to be used. Presence of reinforcing bars, it is generally desirable to avoid the reinforcement area because the pulse velocity is higher in metals. So, if we do the testing near the reinforcement area, we may get a higher UPV value. Stress to which the structure is subjected, normally, there is no such effect, but if the structure is subjected with high static loading or repeated loading.

And because of that, if there are micro cracks within the material, then we may get a lower UPV value. Presence of cracks and voids may affect the UPV value. We may get a lower in value due to the presence of cracks or voids within the material.

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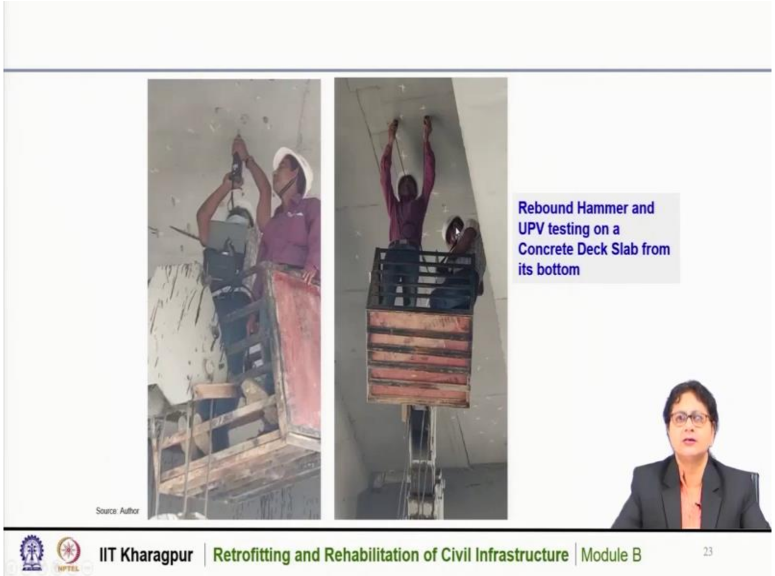

Rebound hammer test and UPV tests are generally carried out together to get a better picture of the condition of the insitu structure or the existing structure. So, here are some pictures of the UPV test and the rebound hammer test being carried out on a deck slab. We can see here that this is the deck slab. So, the access is available only from the bottom. So, the rebound hammer test is being carried out with the plunger pointing upward.

And the UPV test is carried out with indirect transmission. The two transducers are placed on the same surface and the test is being carried out. And by analyzing the two results, we can estimate the condition of the structure or the quality of the material.

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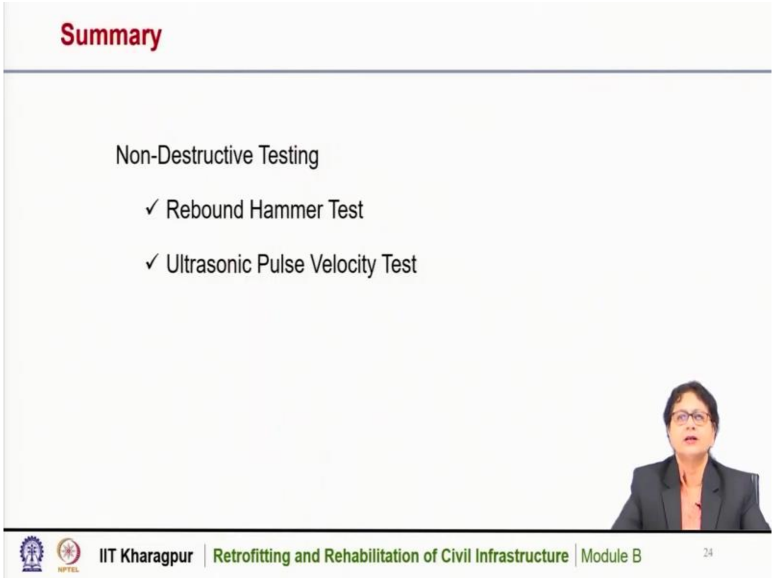

So, to summarize, we have discussed two non-destructive testing for assessing the strength and quality of concrete. One is rebound hammer test and the another is ultrasonic pulse velocity test. The two tests are used widely in field for assessing the strength and quality of concrete. Thank you.