Concrete Engineering and Technology
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Lecture - 34
Basic non-destructive testing for concrete structures

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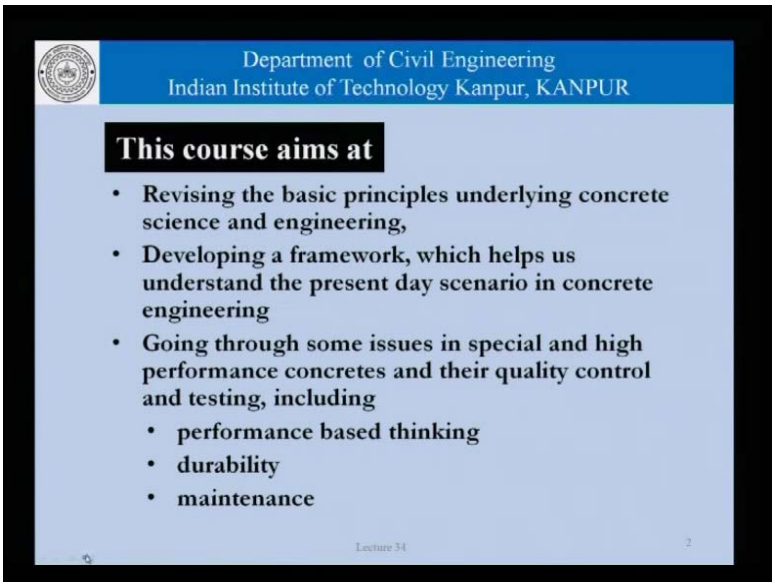

[FL] and welcome to this lecture in concrete engineering and technology. In this course we have been trying to revise some basic principles to develop framework which helps us to understand the basic or the present day scenario in concrete engineering and go through some special issues in high performance and special concretes especially with the view of performance based thinking durability and maintenance.

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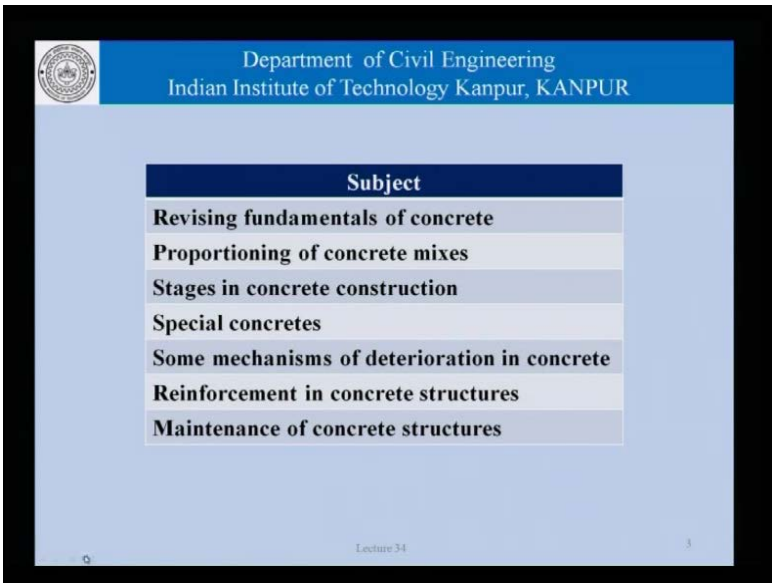

Now, in this connection we have tried to divide our course or the subjects in these key words fundamentals, proportioning, stages in concrete constructions, special concretes mechanisms of deterioration, reinforcement in concrete structures and maintenance.

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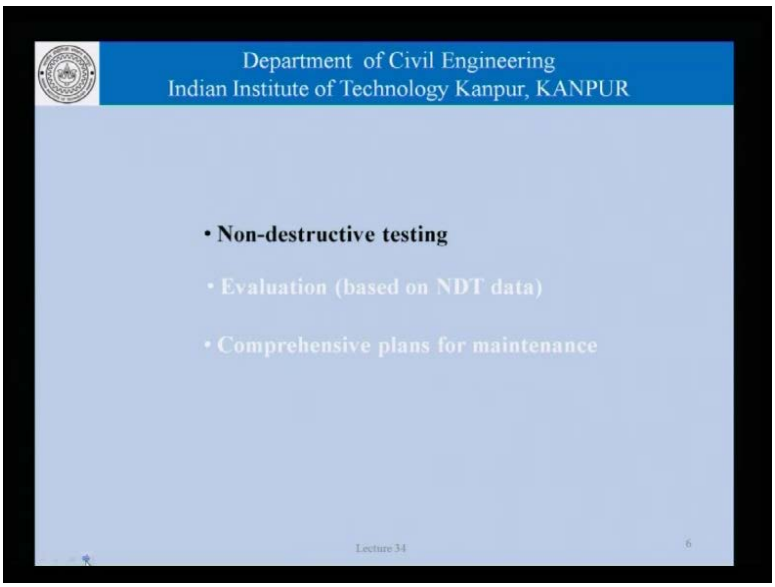

Now, as far as maintenance of concrete structure is concerned that is what we are talking about now and we have said that we will try to divide this discussion into 3 parts non-destructive testing, evaluation which is based on non-destructive testing and a comprehensive plan for maintenance.

Now, let us start our discussion on non-destructive testing of reinforced concrete structures. So, in the discussion today we will focus on some basic techniques which we use, go through their applications the principles involved and so on.

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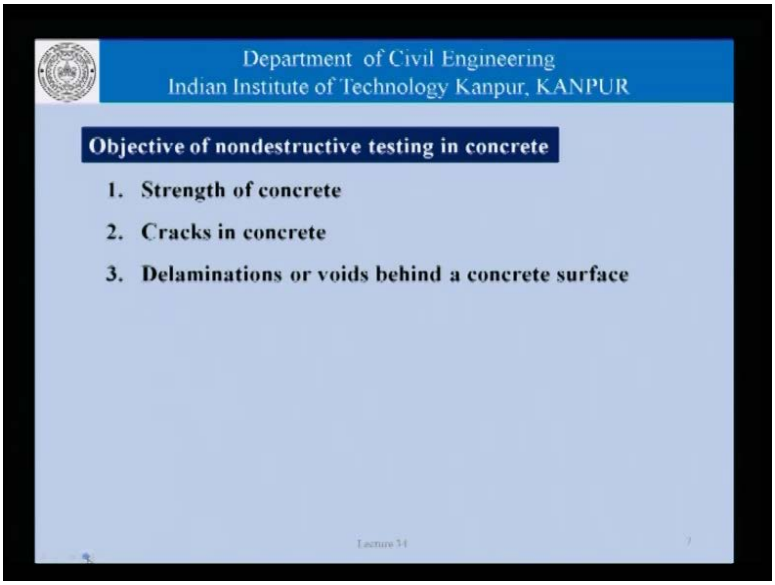

Now, first of all we must understand as to why we are carrying out the non-destructive testing. In any concrete structure one of the time reasons we carry this exercise out is to estimate the strength of concrete. We must remember that the strength of concrete in a structure is not the same as that of the cubes which we use as a measure of quality control. The cubes are taken cured in water for 28 days most of the time and then tested.

Now, neither the placing conditions nor the curing conditions of the cubes are the same as the conditions in which the concrete is exposed in the actual structure its stands reason. Therefore, that we make efforts to get an estimate of the actual strength of concrete in a structure this strength may be higher or lower than the cube strength. The cube strength is a measure of the quality control itself. Whereas, though it represents the strength of the concrete in the actual structure it is not really the same thing.

We have seen so many reasons because of which cracks may develop in a concrete structure. There may be flexural cracks which are expected for example, in a reinforcement concrete beam or sometimes a slab there may be cracks on account of shrinkage and other reasons in concrete. We have also seen the situation where cracks

can be formed along the reinforcing bars in the case of reinforced concrete in the case of reinforcement corrosion.

We have seen evidence of cracking on account of alkali aggregate reaction and so on. So, basically there could be a need or a reason to try to ascertain through nondestructive testing the extent of cracking in concrete. There is a possibility that there can be a void behind a concrete structure. There is possibility that the concrete structure may have some delamination or a void behind the concrete surface.

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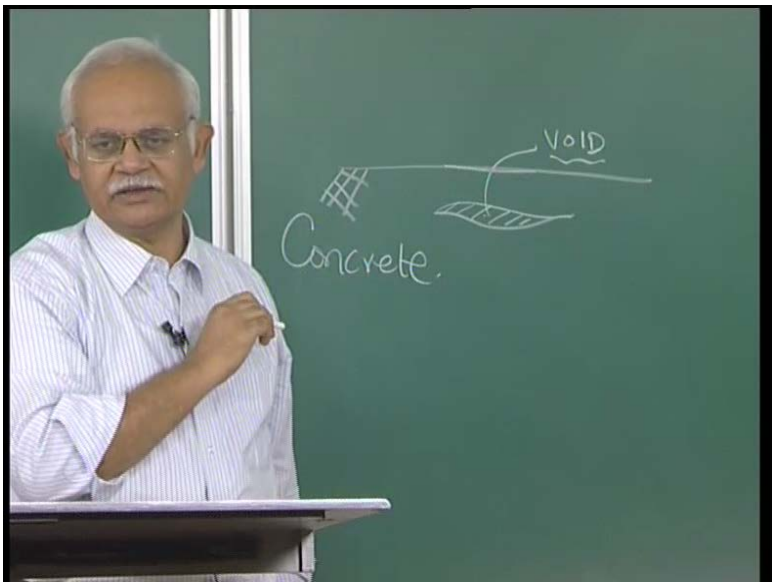

If we look at a concrete structure and we have placed concrete like this, if this side is concrete it is likely that sometimes for whatever reason, lack of compaction having some difficulties in placing the concrete and so on. This void may remain within the concrete surface or within the concrete main body. It will not be apparent on the surface because a surface appears to be integral but, we are interested to know if such a delamination or a void exists below the surface of concrete.

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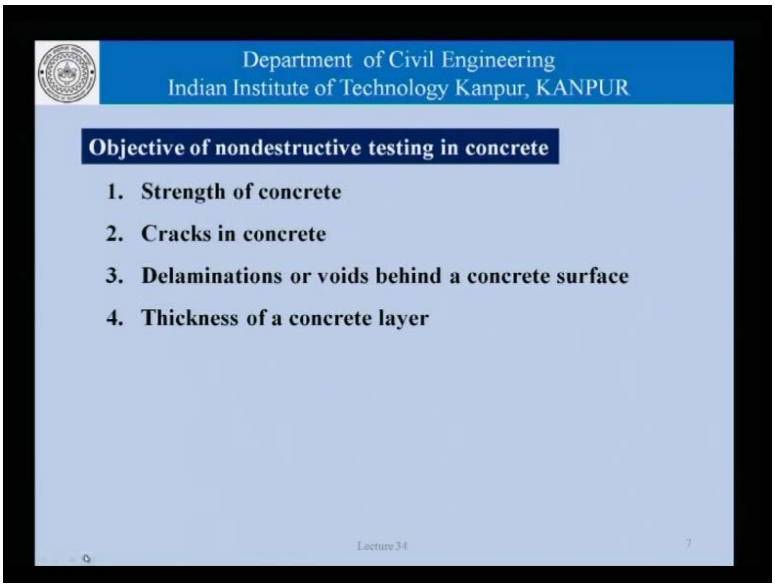

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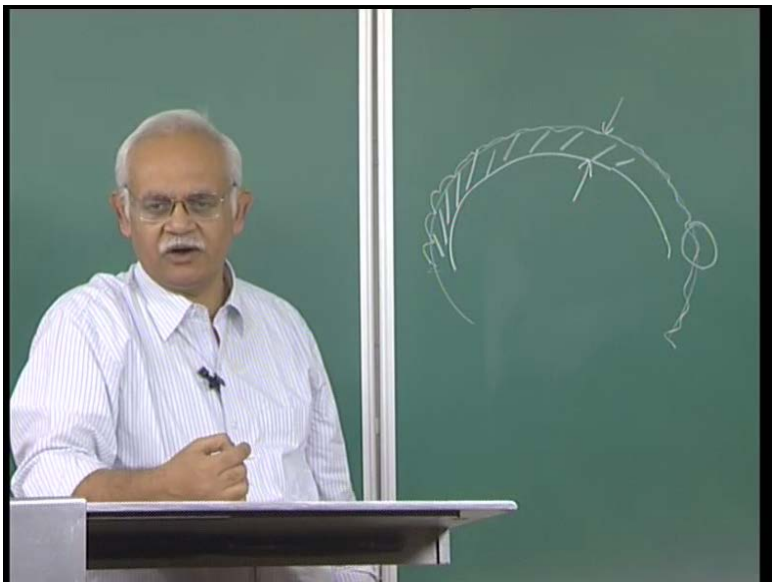

We could be interested in finding out what is the thickness of a concrete layer. I can give 2 examples where this is something of importance to an engineer. For example, in a tunnel lining if this is the space of the tunnel which we have excavated and we have shotcreted concrete like this, it is not necessary that this thickness of the concrete layer is actually uniform throughout the tunnel surface. There may be possibilities that due to some irregularities here the thickness may be smaller or larger.

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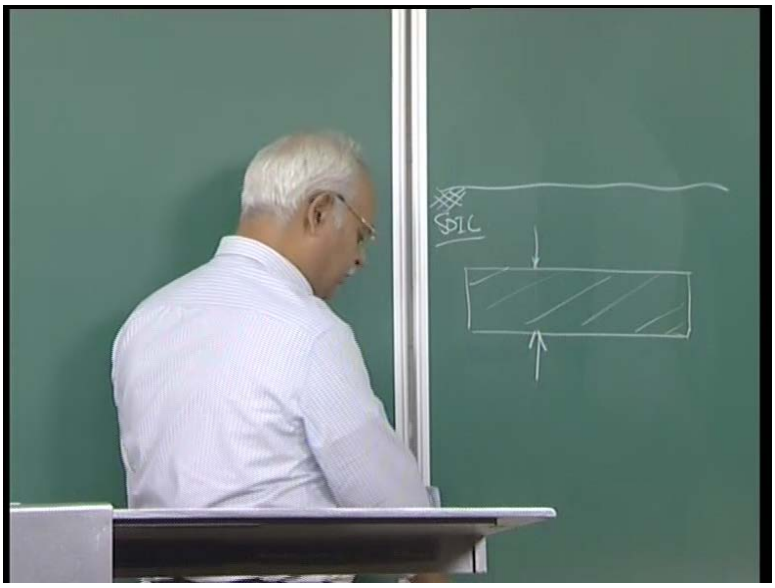

And we would be interested to know through nondestructive methods as to what is the actual thickness of the concrete in that layer. Another example is in the case of foundations, where we would like to know what is the thickness of this concrete block or concrete layer which is lying below the surface.

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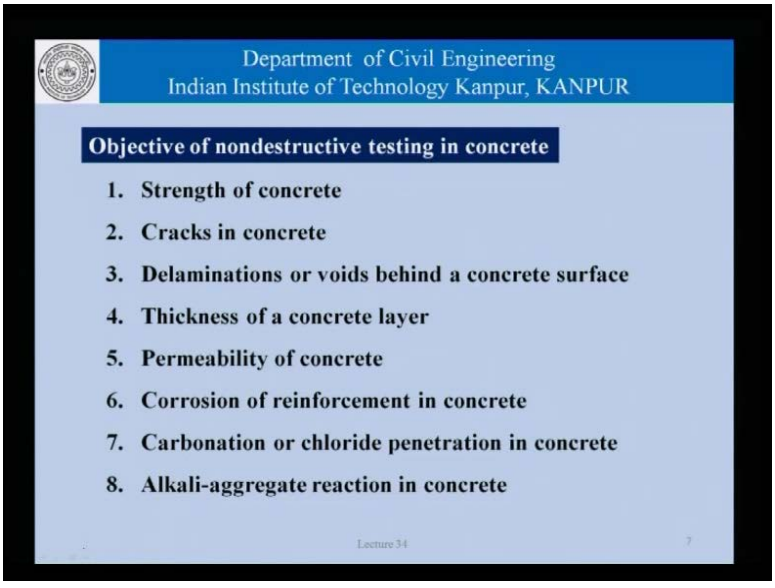

So, we are interested to find out this thickness. There are different methods which are available and we could be talking about those we could be interested in finding out the permeability of concrete. Permeability is related to strength because it is related to

porosity and porosity is related to strength but, there are circumstances, there are possibilities, there are cases when we are when we are interested to measure the permeability concrete parse either quantitatively, as in absolute measure, or compare the permeability's of 2 concrete.

We could be interested in finding out the corrosion of reinforcement in concrete. Now as far as corrosion is concerned we have seen the mechanism, we have seen the implications and now we could be interested to find out whether or not corrosion is taking place in the concrete structure or we could be interested to find out if corrosion is occurring. Then what is the rate of the instantaneous corrosion in the concrete structure?

We could be interested to find out carbonation or chloride penetration in concrete because this is something which is related to corrosion even if corrosion is not taking place. We may like to know what is the extent of carbonation. We may like to know what is the extent of chloride penetration? And we have seen the importance of these parameters when we were talking of chloride induced corrosion or carbonation induced corrosion in concrete structures.

We could be interested to find out the damage on account of alkali aggregate reaction in concrete. We know that alkali aggregate reaction does not continue forever. There is of ultimate level beyond which the reaction really ceases and therefore, one may be interested to know if in a structures, which is afflicted with alkali aggregate reaction, the extent of deterioration which is observed, is it really the ultimate level or there is a potential for the alkali aggregate reaction to continue further.

Now we must remember that nondestructive testing is similar to that of health check, much like we go to a doctor and try to ascertain how healthy the different parts of our body whether it is kidneys or the liver or the heart, how healthy these parts are and there are tests by which their health can be determined, that performance of these parts can be determined, whether they are performing the way they are supposed to much in the same manner. Those nondestructive tests are designed to give us an idea as to what is the performance of the concrete structure.

The performance we measured in terms of strength cracking, delamination thickness of the concrete layer. Performance here includes the quality of the concrete as well, which

is an important parameter as far as the susceptibility of a concrete structure to premature deterioration is concerned.

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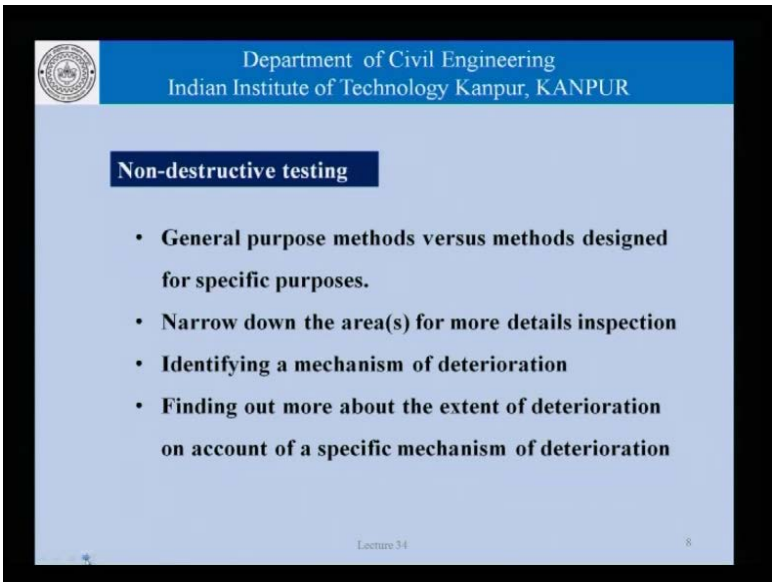

Another thing which we must remember for non-destructive testing is whether the method that we are looking for or the method that we use is a general purpose method or it is a method which is designed for a specific purpose. You must remember that concrete structures are often very large structures and it is physically impossible to actually ascertain or actually monitor the performance of this structure as a whole. We need to identify smaller areas and carry out a greater in depth analysis in those areas.

There are methods which help us narrow down the areas for more detailed examination. If we look at a bridge for example, it could have several pears. It has a deck slab; it has the beams, now all those elements cannot be examined for shear economy, from the shear point of view of ease of carrying out the tests and therefore, there are methods which we need which will enable us to narrow down our choice to specific areas. So, that is what I mean when I say narrowing down of areas for more detailed inspection.

We could be interested to find out through nondestructive test, what exactly is the mechanism that is operating? As far as deterioration is concerned is the cracking. For example, due to alkali aggregate reaction or corrosion induced or shrinkage and so on.

So, we need to carry out the forensic kind of an exercise to understand whatever is going on in the structure and causing changes in the performance. We may like to find out through nondestructive test more about the extent of deterioration an account of a specific mechanism of deterioration. That is the kind of example which I gave when we talked about reinforcement corrosion.

The extent of reinforcement corrosion that has occurred till date is 1 part of the discussion and instantaneous rate of corrosion is another part. Its slightly the substantial amount of corrosion has occurred in reinforce concrete structure but, the instantaneous rate is quite low. Conversely it is possible that though very little corrosion has really taken place but, the instantaneous rate rate of corrosion is very high, that is, the corrosion currents are very high and so on.

So, we have to keep in mind when we use a particular method of non-destructive testing as to what we are looking for from that method. Most method will give us a value, they will give us a parameter but, it is up to us to interpret those results, not necessarily only from the point of view of that particular result but, also look at it comprehensively in conjunction with the results from other tests.

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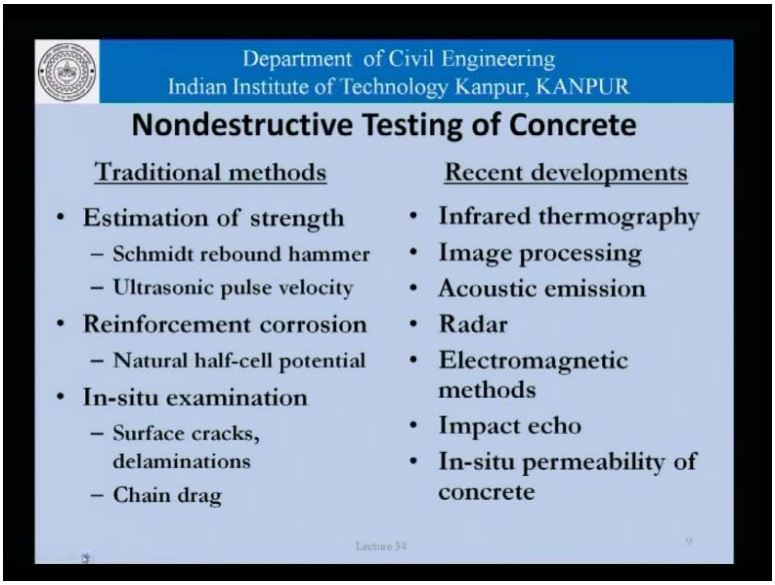

Now, coming to the method that are available to us, as far as non-destructive testing of concrete is concerned there are traditional methods, the Schmidt rebound hammer, the ultrasonic pulse velocity, are 2 of those which help us determining or estimate the

strength of concrete. As far as reinforcement corrosion is concerned natural half-cell potential measurements are a standard method once again.

As far as other in situ examinations are concerned we could be looking at surface cracks, delamination chain drag and so on, and, as far as recent developments are concerned in this filed we have infrared thermography image processing, acoustic emission radars, electromagnetic methods, impact echo and in situ permeability determination as some of the methods which have been used and their use in the field varies depending on the extent of specialties available, the funds available and so on. So, in this discussion from this point onwards we will look at some of these methods and understand the principles underlying them and the results that we get.

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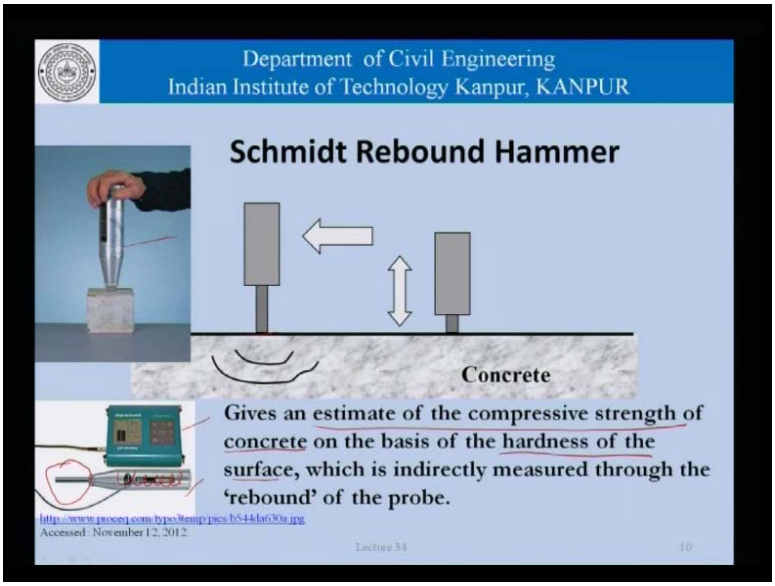

The first thing that we want to talk about let us say, is the Schmidt rebound hammer. Now, this picture here shows the Schmidt hammer which is very commonly available for non-destructive testing test in estimation of concrete strength. This here is the same Schmidt hammer except that now we have devices such as this which enable us to actually date alarm the number that we get.

Basically the method is based on the hardness of the surface and what we do is that this plunger of the Schmidt hammer strikes the surface of concrete here with a certain predetermined energy, which is governed by the spring, which is sitting inside the Schmidt hammer and once the plunger strikes the surface of concrete with the certain

amount of energy then, that energy is dissipated either by breaking the concrete in the immediate neighborhood and so on, or it is used for the rebound of the probe.

Now the extent of rebound gives us a measure of the hardness of the surface and is correlated with the strength of the concrete. We must remember that this method gives us an estimate of the compressive strength of the concrete. It's really that is the surface concrete it does not give us the estimate of the concrete deep inside the structure if we are talking of a large structure strength of the surface concrete on the basis of the hardness of the surface which is an indirect measure of the strength and the hardness is what determines or is responsible for the rebound of the probe.

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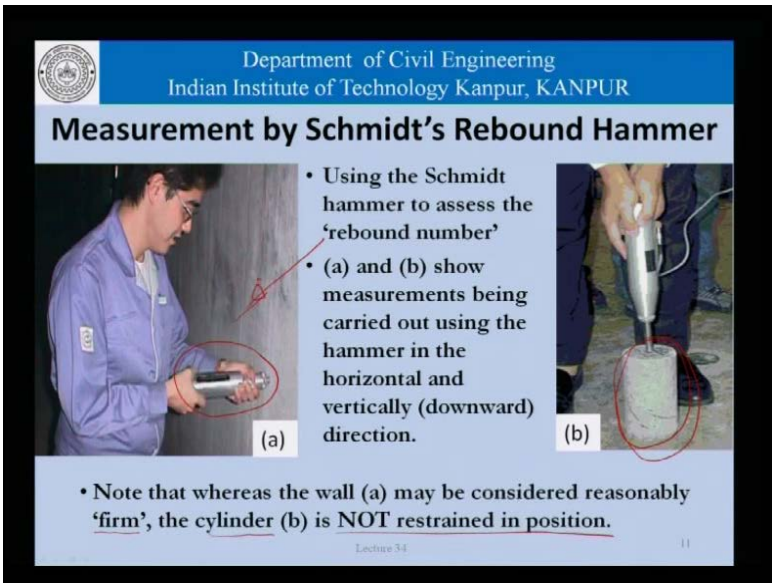

If we look at these 2 pictures we see here the Schmidt in this picture we see the Schmidt hammer being used to estimate the strength of a wall, that is, the Schmidt hammer is being held horizontally whereas, in this case the effort is being made to estimate the strength of a concrete cylinder which is just held or kept on the ground and the Schmidt hammer is vertical.

Now if we look or take look at these 1 cases what we realize is that whereas, the wall may be reasonably firm or fixed, the cylinder is not restrained in position. Now if the concrete in the 2 cases was really the same, then the energy dissipation on account of the non-fixity of techniques cylinder would give us a lower rebound.

Similarly if the wall thickness that we have is very small then striking that wall with the Schmidt hammer will cause a wall to start vibrating and that again will lower the rebound of the Schmidt hammer, that again will lower the rebound that we observe in the Schmidt hammer. These are the kind of things that we must watch out against when we try to standardize the test and try to carry out the actual estimate of strength of concrete in an existing structure.

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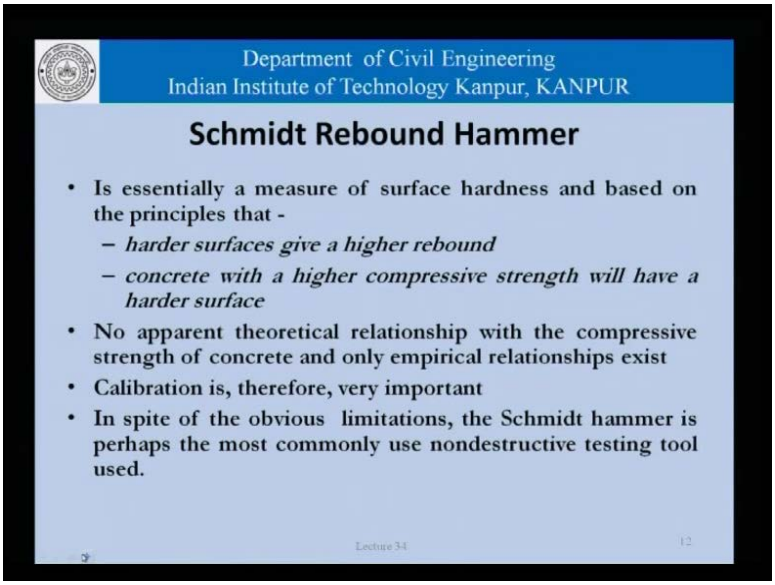

Continuing our discussion with the Schmidt hammer it is essentially a measure of surface hardness and is based on the principles that, harder surface give a higher rebound and concrete with a higher compressive strength will have a harder surface. There is no apparent theoretical relationship between the compressive strength of concrete and only empirical relationships exists, in fact most of the time the manufacturer of the Schmidt hammer provides along with Schmidt hammer the actual device, a calibration curve which enables us to estimate or determine the compressive strength of concrete based on the rebound number or the rebound that we get from that particular hammer. It is very important therefore, that each instrument is actually calibrated very properly and it is not only done once but, it is periodically calibrated to make sure that the hammer continuous to give consistence results. It is slightly that over period of time the spring stiffness, which is the key parameter to giving consistence and accurate results from the Schmidt hammer, changes and therefore, we must recall these changes and modify the calibration curve at different points and time. Of course, in spite of the obvious limitations the

Schmidt hammer is perhaps the most commonly used nondestructive tool as far as estimation of strength of concrete is concerned.

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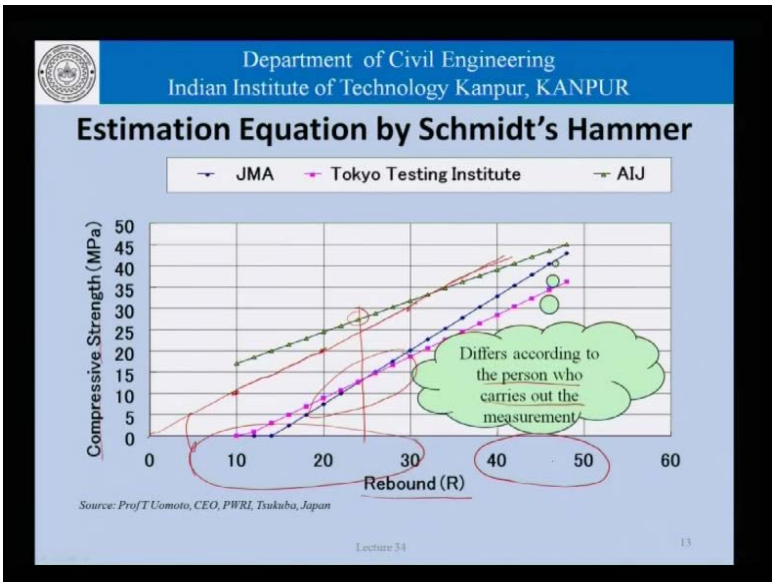

If we look at the estimates of strength from the Schmidt hammer this is the representative data and if we have the compressive strength plotted on the y axis and the rebound numbers plotted on the x axis, we find that the numbers are not necessarily same, for example, the actual line if we look at the calibration equations or the calibration graphs of estimating the strength based on rebound hammers. This here represents the line of equality drawn very roughly and we see that depending on the test which have been carried out these numbers could be lower than the actual strength or higher than the actual strength, depending on where the test is been carried out, who has carried out the test and so on. Also there is this issue as to what strength levels we are talking about if we are talking at, let's say, 10 15 20 MPa or very normal or nominal kind of strength or we are going into slightly higher levels of strength the calibration equations or the calibration estimating.

At higher levels of strength the same equations need not hold and therefore, we need to calibrate our hammer for different levels of strength. We should be very careful about doing this in order that the results that we get are accurate consistent and repeatable.

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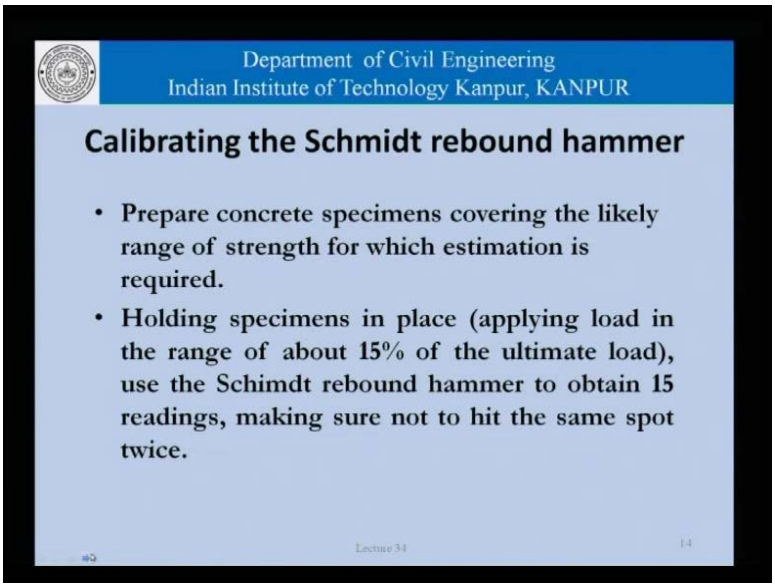

As far as calibrating this Schmidt hammer is concerned, let us carry out by preparing concrete specimens covering the lightly range of strength for which the estimation is required and then holding the specimens in place by applying a load in the range of about 15 percent of the ultimate load used by the Schmidt rebound hammer. To obtain 15 readings making sure not to hit the same spot twice and then once we load this specimen to failure then we have the actual value of the failure load or the actual strength of concrete and also the estimated strength from the 15 readings. It's slightly that they will be lot of variation in the 15 readings and the test methods specify or lay down procedures by which this data 15 readings is to handle and how the extreme values are to be treated in terms of whether they are accounted, whether they are counted, when taking the average or discarded as outliers.

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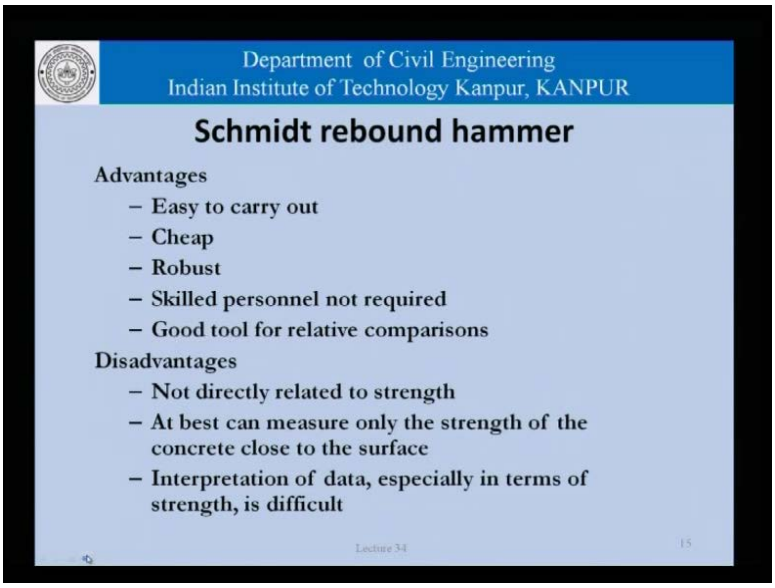

Of course, the advantages to summarize the advantages of Schmidt rebound hammer are that it is easy to carry out, it is cheap, the method is basically very robust, it does not require very high degree of skill in the personal what actually carrying out the tests and is a good tool for carrying out relative comparisons between different part of a concrete structure, where the concrete is supposed to have the same strength and so on.

It suffers of course, from disadvantages that it does not give a direct measure of the strength, it only gives an indirect measure, it is a rebound number strength or the rebound strength as difference specifications call it. At best we can measure only the strength of the concrete close to the surface and the interpretation of the data especially directs strength is very very difficult. Now, this brings me to a close of the discussion on Schmidt hammer.

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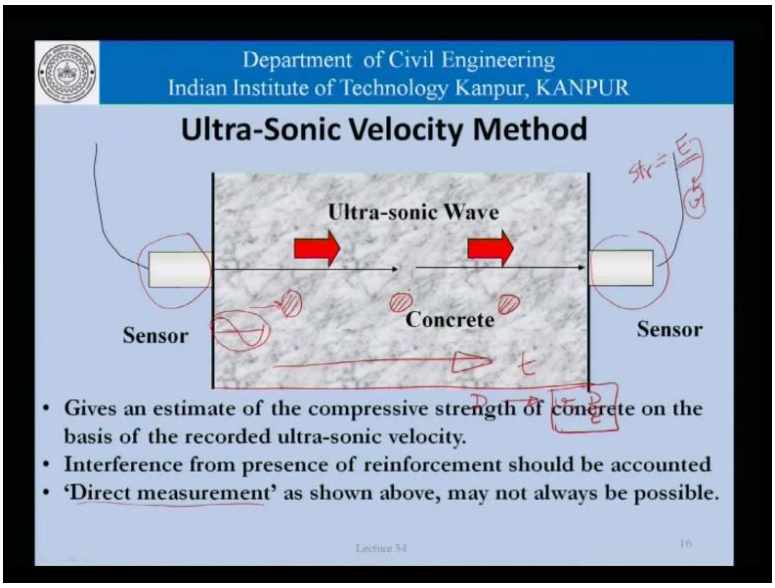

And let us try to now work on another method which is commonly used, that is, the ultrasonic velocity method. In this case using sensors as shown here an ultrasonic wave is passed through the concrete surface and the time it takes to pass through this distance, let us say, d, this gives some velocity which is d by t and this velocity is a measure of the quality of concrete or the strength of concrete.

Now in this case we should remember that strength of the concrete in this case we should remember that the strength of the concrete is also related to the modulus of elasticity of the concrete and this modulus of elasticity of the concrete is very much related to the velocity of the ultrasonic pulse velocity is very much related to the velocity of an ultrasonic pulse which traverse as the concrete or traverse this medium that is concrete.

Now this method as can be seen now, gives an estimate of the compressive strength of concrete on the basis of the recorded ultrasonic pulse velocity and of course, the methods suffers from the drawback that presence of reinforcement within the bar the presence of reinforcement bars within the concrete which is very likely in the case of reinforce concrete structures in fact most concrete structures is likely to affect the passage of these waves and that should be accounted for when we estimate the velocity or interpret the results based on the velocity.

Further direct measurements or a direct measurement of pulse velocity, the weight is shown here may not always be possible, because both the surfaces of concrete may not

really be accessible to us. Only in certain very limited cases both sides of the concrete surface or a concrete structure are equally accessible to us and therefore, what we need to make do is with not necessarily what is called direct method but, indirect methods as we shall see.

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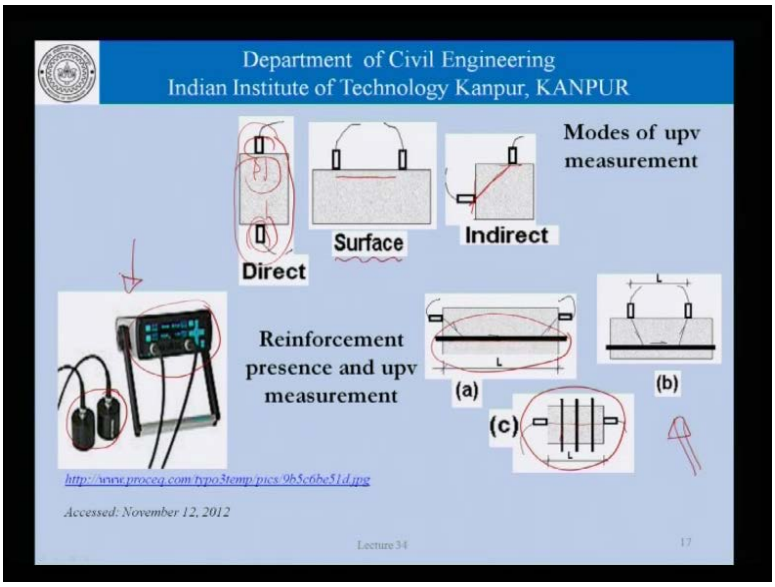

Here is what the indirect method is. What we saw was a direct method, where the transducers which sent in the wave as well as the transducer which receive the wave were opposite each other. Now in this case what is written as surface, both these transducers are on the same side of the concrete structure and the wave is really just passing through this distance, not necessarily in the same way as it was passing through this distance.

Similarly in the case of a column for example, it may be possible that we can put or we need to put sensors on 2 adjacent faces of a concrete structure and then the distance involved is something like this. These are the kind of things which we need to account for, when we are talking in terms of interpretation of data based on the ultrasonic pulse velocity measurements. This set of pictures here shows how the presence of reinforcing bars can interfere with the upv measurement or the ultrasonic pulse velocity measurements.

In this case the reinforcing bar is parallel to the direction in which the ultrasonic pulse wave or the ultrasonic pulse is moving. In this case however, the reinforcement is

arranged in a manner that it is perpendicular and there are multiple reinforcing bars in the path of the ultrasonic pulse. These things we really need to account for when we are talking of evaluating the results or interpreting the results based on ultrasonic pulse measure. Based on ultrasonic pulse velocity measurements this here is standard equipment which is often available and sometimes used. These are the sensors which are fixed at the different or 2 ends of the concrete and this device. Here is what gives us the measurement or which helps us measure either the time of traverse for the pulse or the velocity directly. If the distance is already been fed in this system does not have any mechanism as of now so far to account for the presence of reinforcement and so on in the path of the wave that part has to be taken into account at a later stage when we are trying to correct the raw data for interpretation.

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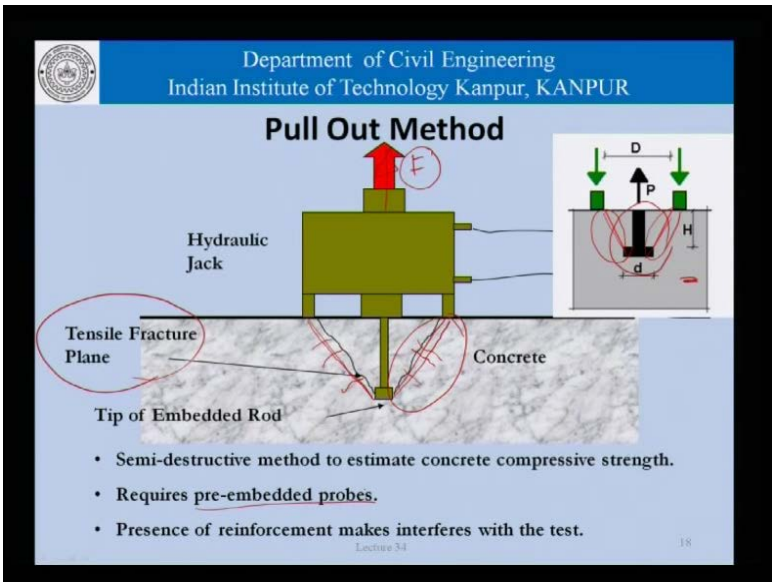

Now, let us come to some other methods, still continuing with the basic objective of determining or estimating the strength of concrete in situ or in an actual structure. Now this method which is the pull out method requires that an insert is placed within the concrete and at a given point and time. After this concrete here has hardened we have a mechanism by which we try to pull this insert out.

Now as we pull the insert out, it will induce a failure which is shown here, along this coal as here now depending on the force required to induce this failure we can estimate the strength of concrete as it causes a rapture surface to be formed along this coal. This

method is more amenable to analytical treatment where we try to figure out what really is happening as far as the concrete is concerned when it is under the action of these forces and at the time it fails.

So, we are really measuring the tensile fracture, along the tensile fracture plane the stress at which the concrete has failed. This of course, is not a truly nondestructive method. It is semi destructive to estimate the concrete compressive strength but, it requires is pre-embedded probes and of course, once the reinforcement is present in the concrete then that present then that will interfere with the test.

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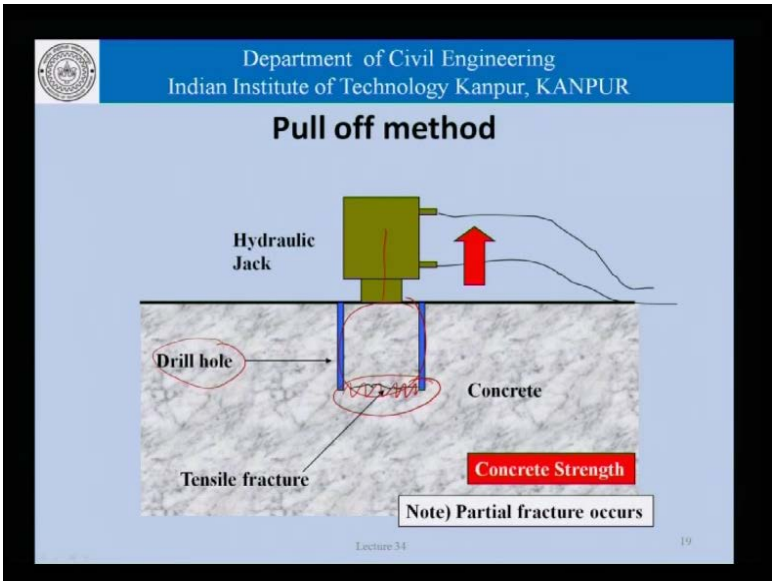

Once we take these things into account then of course, we can use the pullout method to actually determine the strength of concrete in situ. This is the very good method provided we can take care of pre-embedded probes, that is, we have planned for a certain testing protocol. The method is very useful to actually determine the strength of concrete at a given point and time which may be required for example, for deshuttering removal of formwork transfer of pre-stress and so on. Those are very useful method from that point of view, as it gives us an actual estimate of this strength of concrete. In the structure this here is another method which is slightly different and is called the pull off method.

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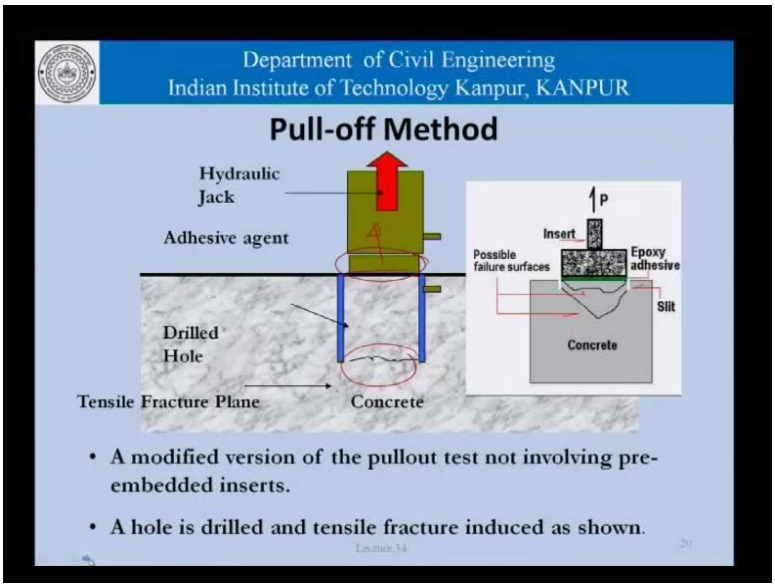

In this case what we do is to drill a hole here and then try to pull this concrete of from within the hole, thereby, trying to induce direct tensile failure in this flame this is accomplished by gluing a plate to the surface and trying to pull the plate off assuming that the plate and the concrete surface are properly bounded.

Now once that is accomplished we induce direct tensile failure in a plane which is shown here and we can get a direct measure of the tensile strength. In this case again we are not getting compressive strength that we get from the cubes normally tested but, we get a measure of the tensile strength, which again, is related to the compressive strength.

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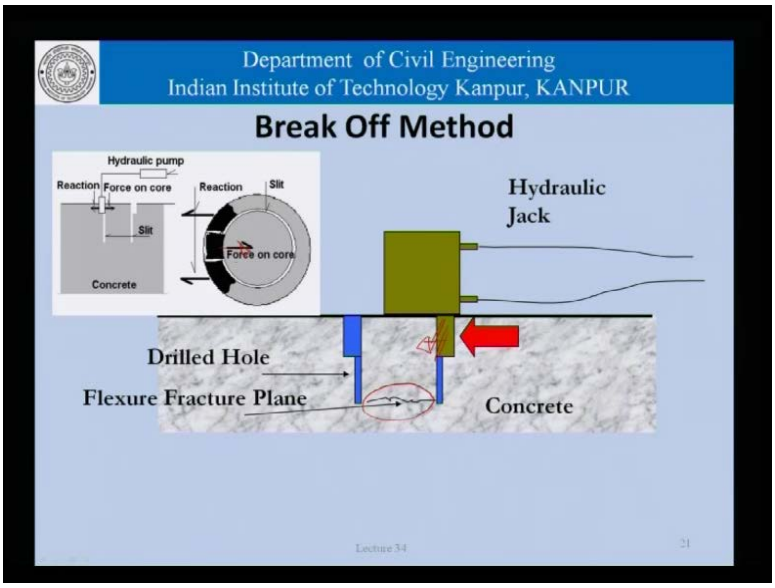

Continuing with the discussion once again there is no break off method. Now in this case what is done is that after the hole has been drilled instead of trying to pull the concrete off and in and inducing a tensile failure in this portion what we try to do is to apply a horizontal force here the weight is shown in this diagram here.

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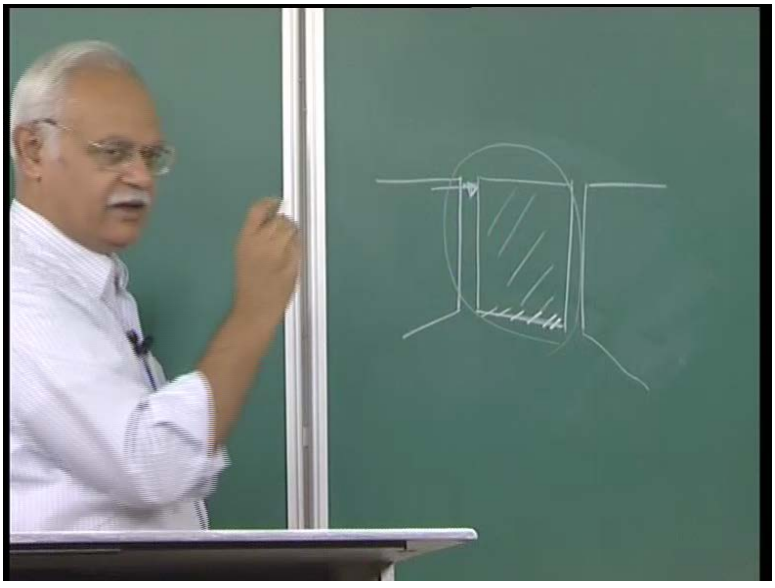

The way this method works if we look at a diagram, which shows, this test what happens is that we have this concrete core or a part of a concrete which has been isolated from the main concrete here, and if we apply a force here, this amounts to this part of the concrete

block behaving as a cantilever and breaking off at this surface and that is really a flexural failure of the concrete block.

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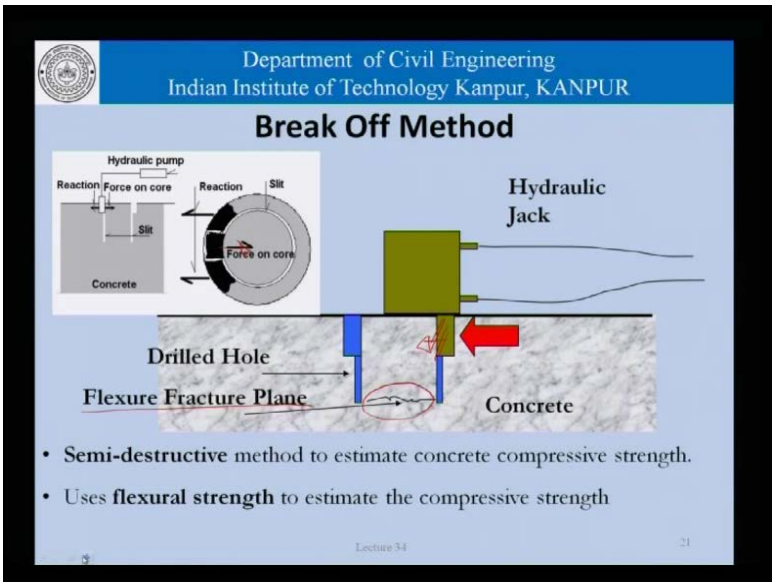

As shown here, it is a flexural fracture plane induced and instead of that in this method what we do is get a flexure fracture plane and not a tensile fracture plane, as we got in the pull of method. This too is a semi destructive method to estimate the concrete compressive strength and then what we need to do is to estimate the compressive strength from the flexural strength that we get from the test.

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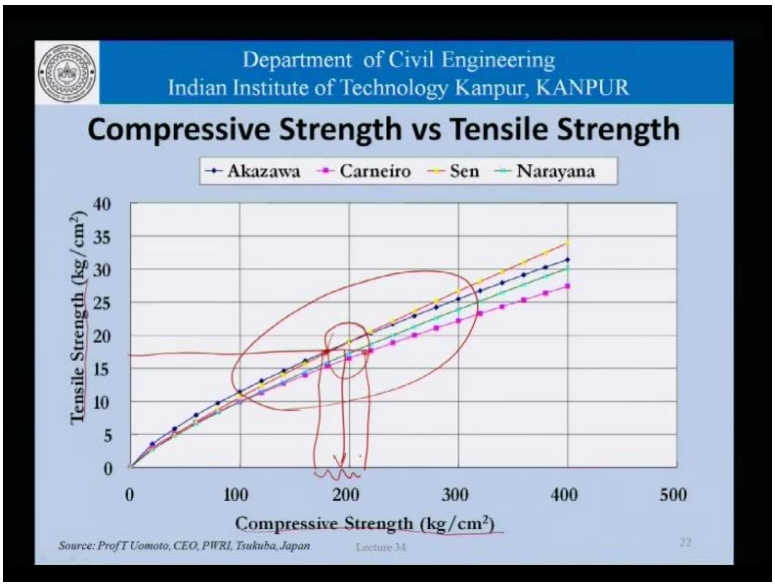

Now if you look at some of the correlations which are available, we see that the compressive strength and tensile strength are indeed related to each other in a certain manner. This here is compressive strength and this tensile strength of course, the units are in kg per centimeter square and we need to convert them to the SI units but, the principle is very clear that once we have these values and these kind of a correlation we look at it 2 ways, 1 is that yes if we are able to get an estimate of the tensile strength we will be able to get an estimate of the compressive strength that is point number 1. The second point is depending on the accuracy of this calibration curve we may get values which are ranging. For example, in this case from this point to this point.

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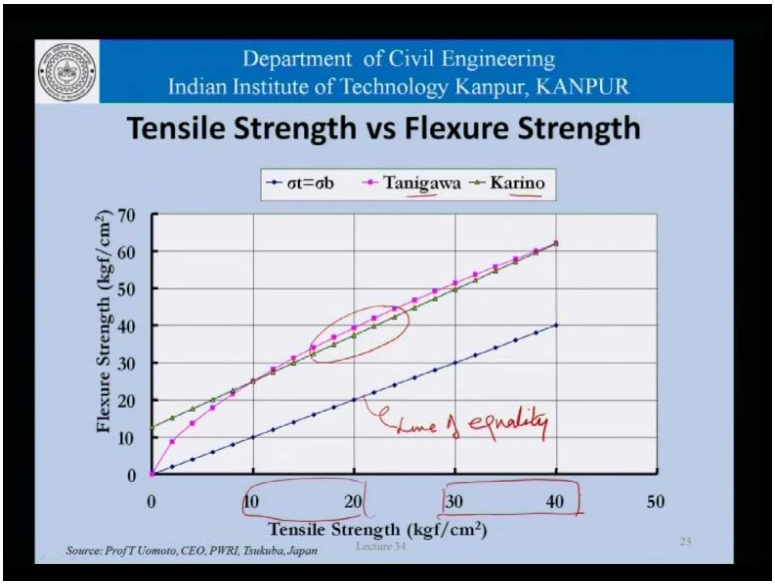

Now, if you look at the correlation between tensile strength and flexural strength this is the line of a quality and what it shows here is deepening on whatever is the data that we take. These data need not be really exactly identical and therefore, we need to establish correlations for the range in which we are working whether we have working in this range here or we are working in this range here, the relationships could be different and once we have this relationships with us then of course, it is not so difficult to have a calibration curve, which helps us estimate the actual compressive strength of concrete, based on the tensile strength or the flexural strength that we measure or determine using the pull out test or the pull off test or the break off test.

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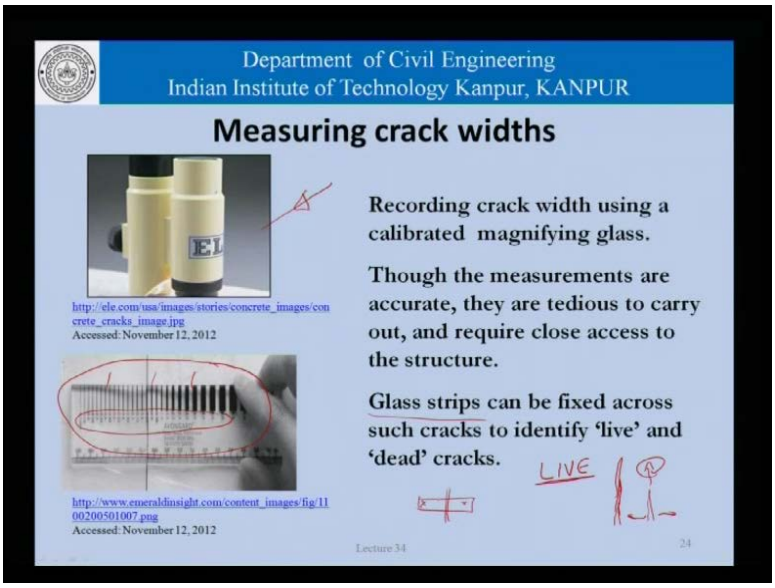

Now, let us come to something else measurement of crack widths. Now, this here is a simple optical device which helps us measure the width of these cracks. It is like using a magnifying glass and recording the crack width. This here is another very common and very interesting device which has the thicknesses of lines for example, this line and this line and so on. All these lines the thickness or the widths are given and what the investigator or the inspector does is to align this crack gauge along the crack in the concrete surface and sees which of these lines best represent the width of the crack being measured and that is what is recorded. As far as cracking is concerned one also needs to determine sometimes whether the crack is live.

Now what is the live crack? Live crack is 1 that is growing either in width or in length. We might find a crack which are some point in time was only this much but, over a period of time it continues to grow inside of within and over a period of time it grows within the concrete or grows into the concrete. It may happen that the crack does not necessarily grow inside the structure but, grows as far as the width is concerned and these kind of things can be determined using a glass strip which is fixed across the crack. If we have a crack like this we fix a glass strip across a glass and then over a period of time we monitor whether or not the glass is strip breaks and if the glass strip breaks it is an indicator that the crack is live and that is the movement along the crack surface is causes this glass strip to break.

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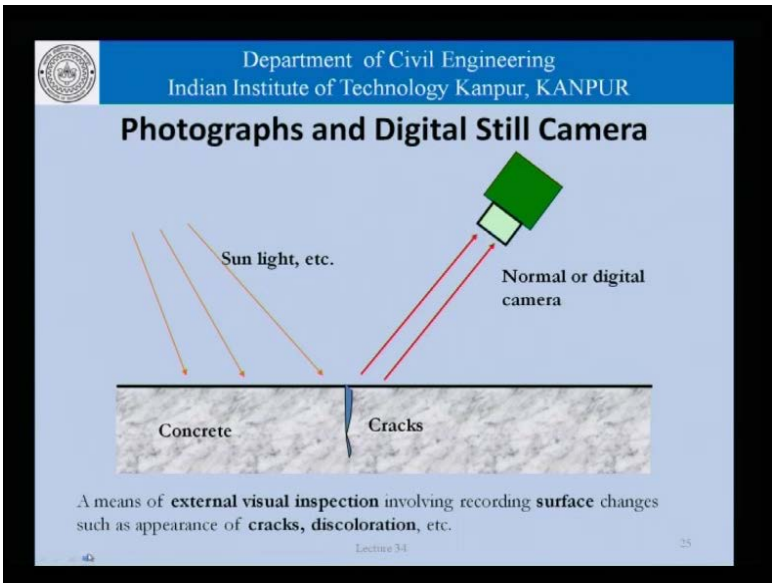

Modern technology has enabled the use of photographs and digital stills as a very very important tool for keeping records of concrete surfaces and monitoring their changes over a period of time, in terms of appearance of cracks the surface becoming rougher discoloration and so on.

So, what we need to do is to consciously and meticulously take a photograph of concrete surface and compare it with another photograph taken after period of time and see what are the kinds of changes that we see on the surface. This is a means of external visual inspection and involves recording surface changes such as appearance of cracks discoloration etcetera and removes the subjectivity that may be there if the inspector was only using his own subjective judgment. As far as vision is concerned what that means is that an inspector when he looks at a concrete surface he may not record something or he one inspector may record differently than another. Photographs remove this subjectivity in the records.

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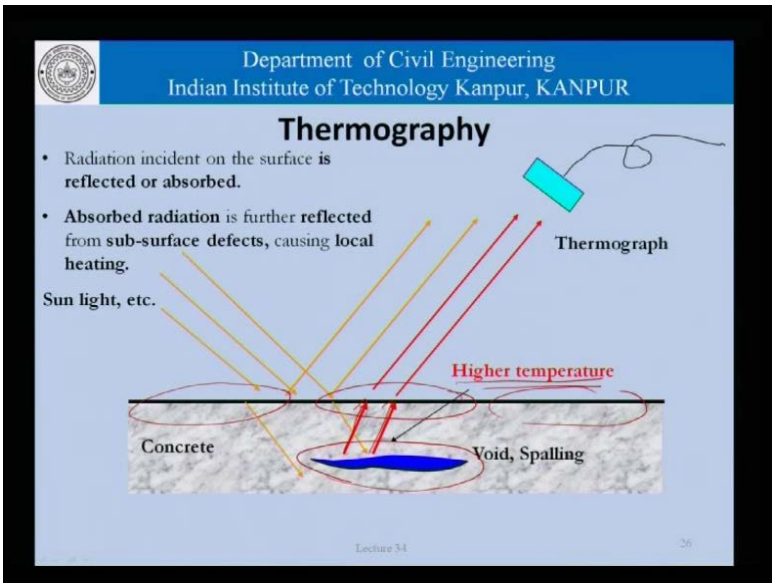

Thermography is a slightly different form of the same process what we have. As far as concrete structures is concerned that, radiation is incident on the surface and that is radiation is reflected or absorbed absorbed radiation is for the reflected from the sub-surface defect leading to local heating as is shown here. If this radiation falls on a concrete surface like this, then if this delaminations or the void was not there, then lot of this radiation will simply get into the concrete, get absorbed and so on. Whereas, on account of this void or a delamination present within the concrete surface this radiation gets reflected back to the concrete surface and we have a patch here which has higher temperature than the neighboring patches. This difference in temperature observed on a concrete surface can lead us to think as to what is going on within the concrete surface to cause that difference.

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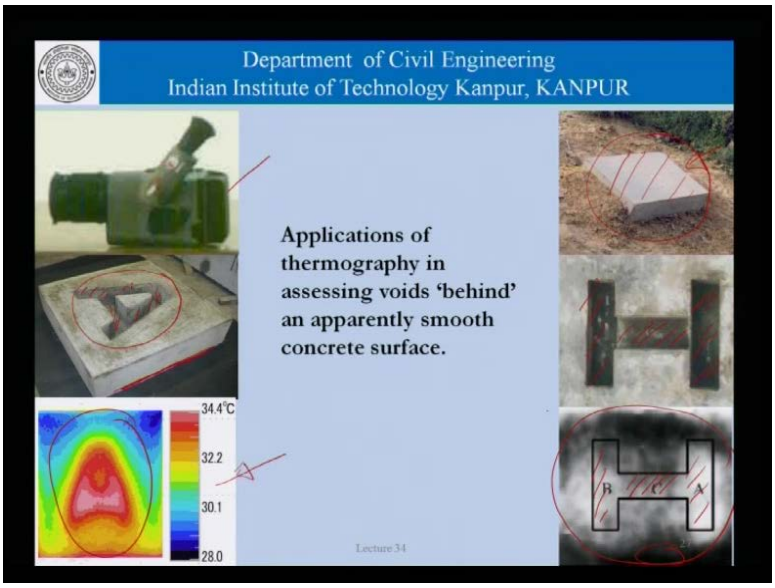

To take an example, if we have a concrete surface where this letter is embedded there is a lot of thickness variation here, we have removed the concrete from here. Now, if you look at the laboratory measurement or records using thermography which is down using commercial available thermography camera, this here is the record that is observed from the surface of the concrete, on this side where the thickness of the concrete is reduced at different places to the extent that the concrete has been taken out from this side in the shape.

So, this shape here gives us an example shows an example that something is on this surface and that is needs to be investigated similarly, if you look at this concrete block here which is just appearing to be plane concrete block and we take a thermograph, we get an image which is something like this and we can see that these patches here are different. As far as temperature is concerned from these patches here and this patches again slightly different because the depth of the concrete which is been removed on the 2 edges, on this edge and the inside is different.

So, what we have it is a method by which looking at the thermograph or the surface image of concrete we have an idea or we can get we can get some information as to what is happening behind the concrete surface or within the concrete surface.

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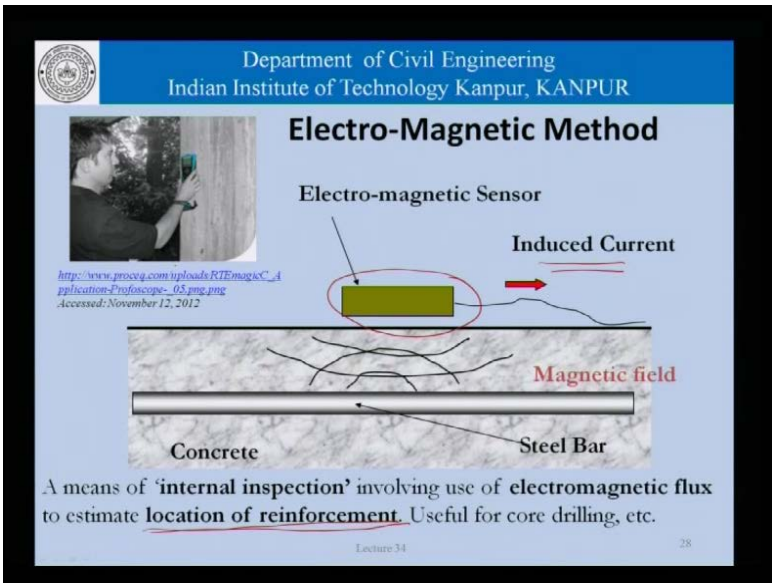

Now, let us look at electromagnetic methods which help us locate the reinforcement within the concrete and why do we need to determine the exact location of reinforcing bars? There are two reasons. 1 is in when there are two reasons. 1 is when we are trying to test reinforcing bars themselves for corrosion and so on. We need to know the exact location and the second is when we are trying to take course out of the concrete structure. Then we would not like to damage the reinforcement and take the core from areas avoiding the reinforcing bars.

How this methods works is that there is a electromagnetic sensor. There is an induced current involved and in portions where the probe passes directly over the reinforcing bar response is different compared to cases when the underlying surface is steel free. This here is a commercially available device for the same purpose and we can see that we can make an effort to locate the reinforcement in the concrete structure using this hand held device.

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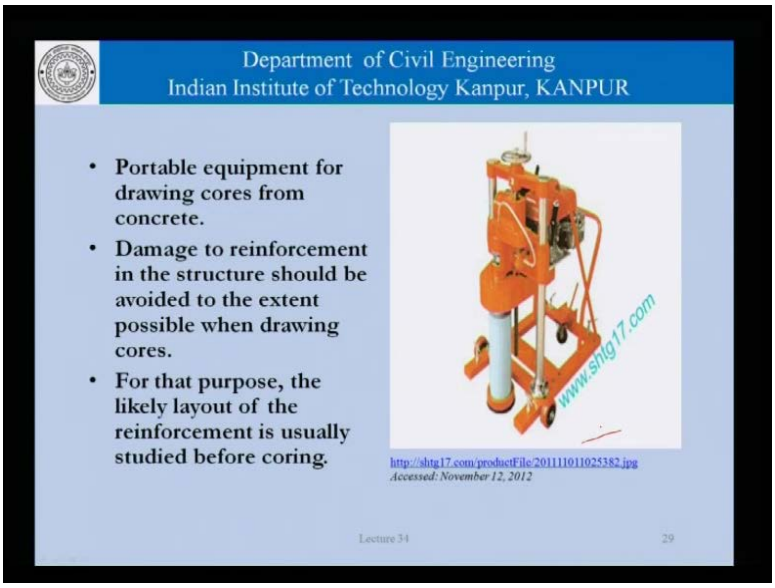

This here shows the portable equipment for drawing cores for concrete and cores are very very useful tool. As far as getting information about the exact nature of concrete in terms of its composition, in terms of its strength, in terms of deterioration and so on, except that it is a destructive test to some extent it involves removal of the concrete core from the concrete structure and that may not be always so easily allowed. When taking a core we should make sure that the damage to the reinforcement in the structure is avoided to the extent possible and for that purpose we need to have a layout of the reinforcement in the concrete structure. There are different devices such as the one shown here which are available for drawing course from a concrete structure, either it from horizontal position or from a vertical position.

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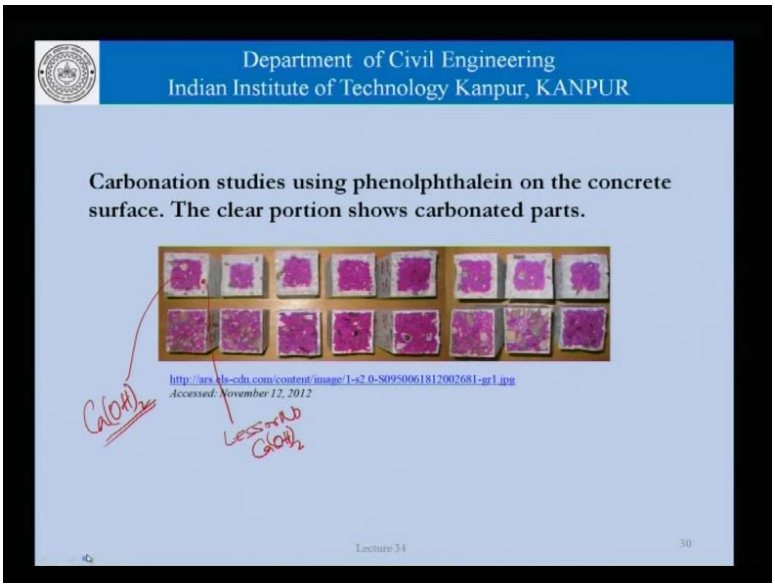

Now continuing a little bit more into more specialized test this I showed picture from a study where carbonation was being studied for different concretes and we can see that the depth of carbonation in the different specimens is different and is measured by way of the clear thickness of the concrete, that is, the non-coloured part. The clear portion actually shows the carbonated part.

The color portion shows the noncarbonated part because it is in the colored portion that we still have a lot of calcium hydroxide available and this calcium hydroxide turns the phenolphthalein pink in these portions which are on the outside. There is less or no calcium oxide and therefore, we have phenolphthalein in its original color that is more or less white or colorless.

So, this is a picture showing how the carbonation depth of a structure can be measured using a phenolphthalein solution. It takes a core and then try to estimate or determine the carbonation thickness which can be part of an inspection procedure for carbonation induced reinforcement corrosion and the structure susceptible to that.

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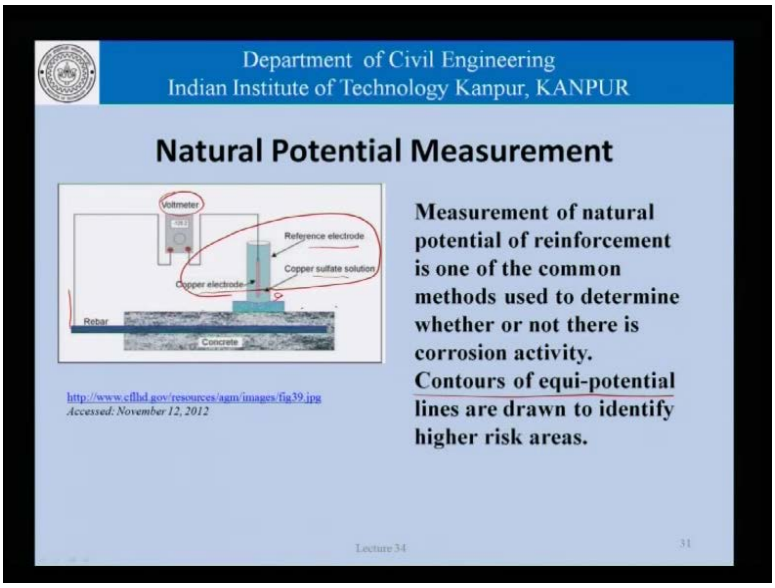

Now this is a picture of how the reinforcement corrosion itself is monitored. From the point of view of reinforcement corrosion we have natural potential measurements as a very standard method of carrying out the test. It consist of a voltmeter connected to the rebarat, the one side to a copper copper sulfate electrode at the other and this electrode is moved around from 1 place to another to get the half-cell natural potential of the reinforcement at that location. Finally what we do is to draw contours of equipotential lines and identify areas of higher risk of corrosion depending on the actual value of the half-cell potential that is recorded.

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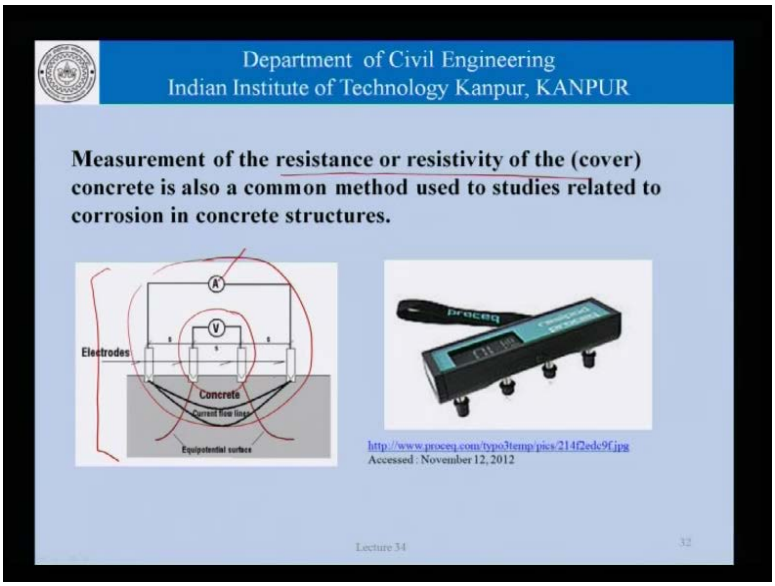

This is another slightly more specialized device or method used in corrosion studies at involves the resistance and or resistivity of concrete which is basically the cover concrete. Recall from a discussion on reinforcement corrosion and the mechanism involve that corrosion is an electrochemical process where concrete place the role of the electrolyte and this electrolyte, if it has a high resistance or resistivity then a possibility of corrosion is so much lower and this method here helps us to estimate or determine the actual resistance or resistivity of the thermo concrete based on the principle as in strained or the based on the principle given here, where the in situ electrodes we try to measure the voltage against the current at the outer heads.

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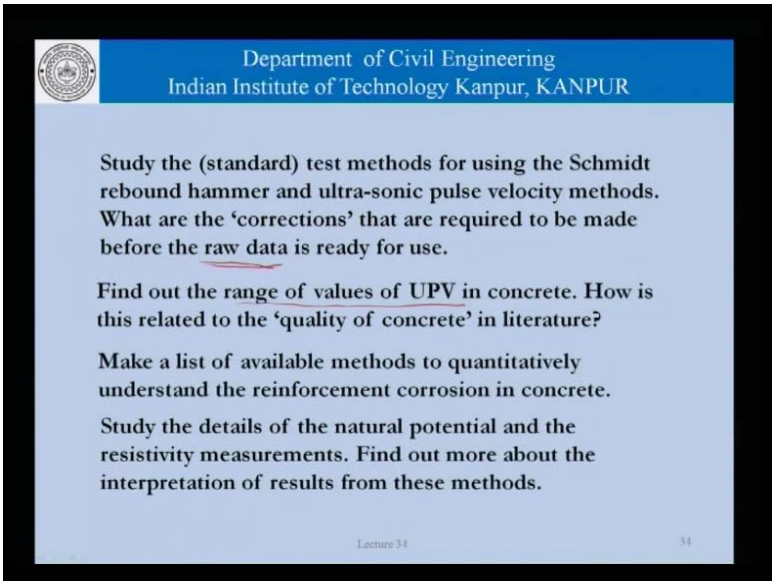

Before we close the discussion today let us try to go through some questions which will help us better understand. What we talked about one can study the standard test methods for using the Schmidt rebound hammer in the ultrasonic pulse velocity methods. These methods have standards which require the engineer to carry out the test in the certain manner and then correct the data, modify the data or modify the raw data before the exercise of evaluation is carried out. Those standards also give us a range of the values of the pulse velocity and relate that range to the quality of concrete. It is must that we must remember that ultrasonic pulse velocity again, does not often give us a direct measure of the compressive strength itself. What it just gives us, as far as the standards are concerned, is a measure of the quality of concrete in terms of excellent, good and so on.

If you make a list of available methods to quantitatively study reinforcement corrosion in concrete that will help you get better in site on non-destructive testing in that particular area and that is what we talked about when we said that we need to know more about the total amount corrosion that has occurred till a certain point or the instantaneous rate of corrosion, as is occurring at that point and time. If you study the details of the natural potential measurements and the resistivity measurements and find out more about the interpretation of the result from these methods that will help you understand the method as well as the method and also the application and the limitations of these tools.

Thank you.