Maintenance and Repair of Concrete Structures
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Lecture 11
Condition Assessment of Concrete Structures (2/3)
(Evaluation of concrete in laboratory)

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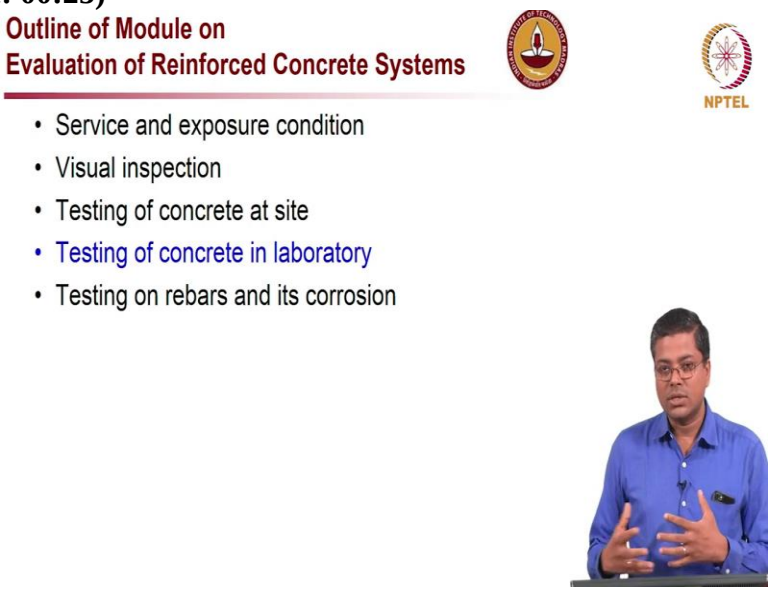

Hi, today we will have our second lecture on this module on condition assessment of concrete structures. In the first lecture we covered the service life and exposure conditions. And then visual inspection techniques, what are the things we should be worried about while going for a visual inspection and also we looked at testing of concrete at site. Today in this lecture, we will be looking at testing of concrete in laboratory. This could be on specimens that are prepared in the laboratory or also on specimens which are extracted or obtained from the field structures. But the point is that testing will be in laboratory.

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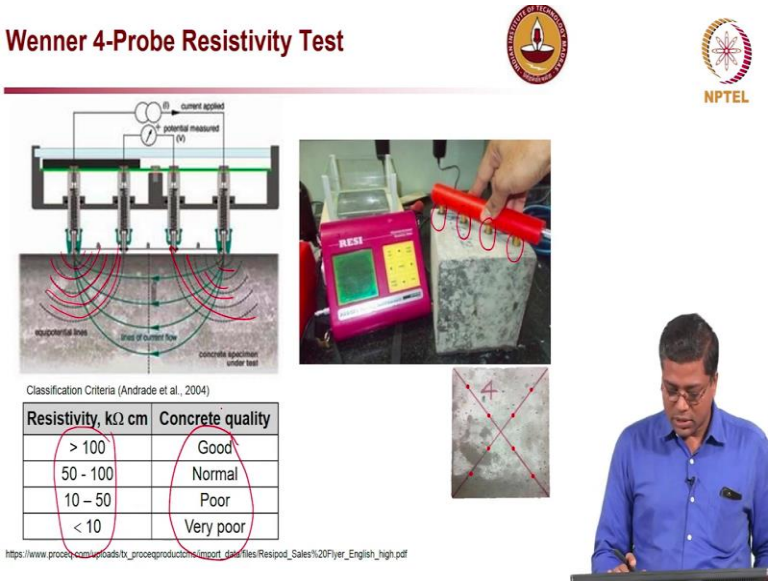

Now, first test which we are going to discuss is this resistivity test, which is a Wenner 4-probs resistivity test. As you see on the picture on top right this is the how the test is being done and you can see those 4 points which are in contact with the concrete surface. And the schematic is shown on the left side, where you can see that there are lines of current flow between the two outermost probes. And then you can see there are equipotential lines which are indicated by dotted line or curve and then, the idea is you measure the potential across the two inner probes. So, pass a correct between the two outer props and measured the voltage or potential difference across the two inner probes and that is the idea.

Now how it is helpful is, the resistivity which is measured can be related to the concrete quality or in other words, the resistivity of the concrete influences the corrosion rate which rate of corrosion which can happen in concrete structures or rate of movement of any deleterious elements into the concrete like chlorides. So, this can be a good indicator for many other potential deterioration mechanisms. So, the table is given at the bottom left on the criteria, which can be used based on the resistivity or the surface resistivity which measure we can see whether the concrete belongs to good, normal, poor or very poor quality.

But I would say one thing here, even though this specification or these criteria provides to decide whether good, normal, poor or very poor, but you have to be careful because good for a particular case could be just a normal condition quality for another case. So, that also has to be

sometimes related to the exposure condition which you have. So, an exposure condition and the desired service life. But this table here is just a rough idea for you to guide you on how to use this resistivity to assess or to define the quality of the concrete but in addition to this, you should also try to link this to the specific exposure condition to which the concrete will be exposed and also the desired service life. So, some sort of quantitative estimate is required, but still this gives a good starting point.

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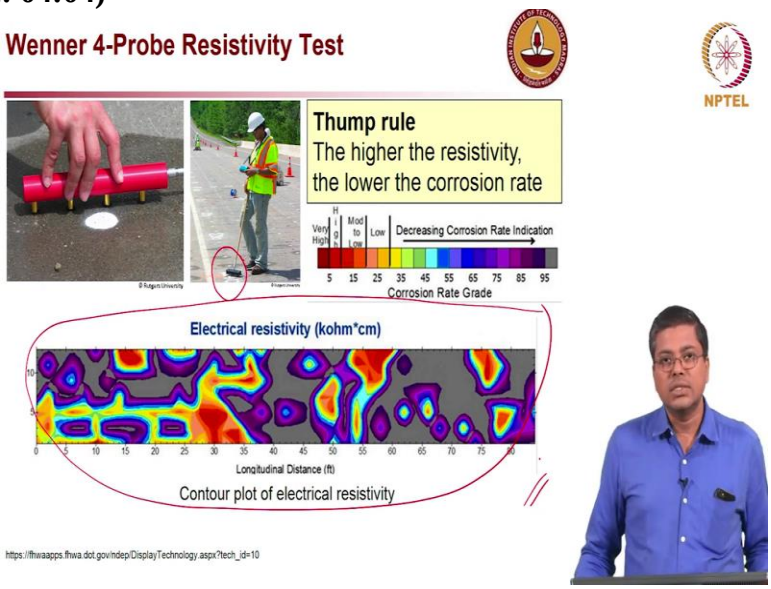

And this is some more examples to show how this resistivity test is done you can see on the left side it is done on asphalt or concrete pavement, where you can see that, even on a large area if you want to cover you can still do this the and the thump rule is the higher the resistivity the lower the corrosion rate. Now, once you do this test on a large surface area, you can actually create a contour plot of surface electrical resistivity and then we can say, okay there are some region with low resistivity and some with high resistivity and then we have to take care of the regions with low resistivity, there could be a probability of higher corrosion in those locations. So this chart which is developed by Rutgers University, you can see more details. But something like this is very useful for a quick assessment of large a surface area, if you want to see how good the quality of the concrete is.

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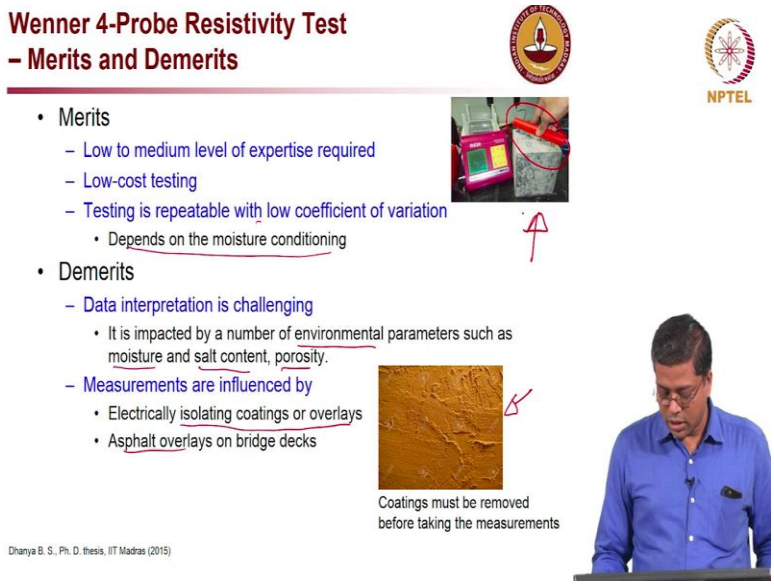

Now, what are the merits and demerits of this test? For merits we can say that this is low to medium level of expertise required because it is not really much complex to do this test, you take this concrete suffers, you put the probe on that and you take the reading directly you can get the test results. So, not much of, skill level required is not very high. Then testing is repeatable. And if we can maintain quality of the conditioning of the testing surface or the concrete, that then the test can give you good repeatability and that means the error in the test results could be much lower low or the scatter of the test results which you get could be much small.

Now, what are the demerits? Demerit is, how to interpret the data is becomes sometimes challenging because it is impacted by a number of parameters including environmental parameters for example, the moisture condition, salt content, porosity, because all these influences the electrical resistance of the concrete, if it is more porous, then the resistance will be less, if you have salt content again that means a lot of free ions present in the concrete that will also reduce the resistivity. So, all these have to be considered while interpreting the data which you get. And the measurements are influenced, if there are coatings or overlays, if you are talking about asphalt road, there could be bitumen overlays, you cannot really take the measurement concrete underneath, when you have a layer of bitumen on top. So these are the some of the challenges associated. And also if you have coating on the concrete surface like just took representative image here. If you have a paint on the concrete surface, you have to really take care because the paint will also provide some good resistance and that should not influence

the assessment of the concrete resistivity. So, you have to make sure that wherever you are placing the probe, you are placing the probe on the exposed concrete surface as it is shown in the cube over there. There cannot have any coating or an insulating layer on the concrete surface.

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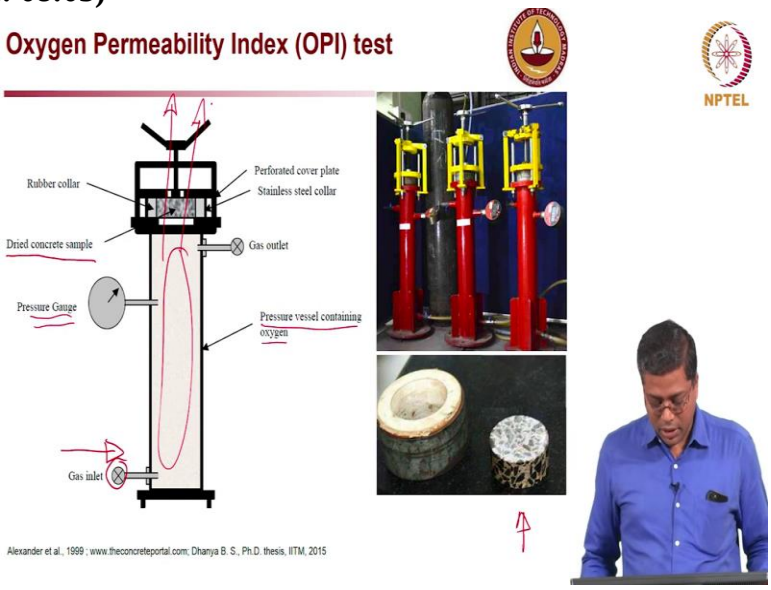

Another test which is very useful is oxygen permeability index test. Now, it is also in many of the standards including Indian standard, it is going to come very soon. What is in this test you can see on the right side there is a test cylinder and a gas cylinder which is the oxygen gas cylinder and you have the specimens like this. Essentially the idea is you have a pressure cell which is this and over here you have a dried concrete sample. Basically this disk like specimen which is shown on the bottom right, you prepare a specimen like that, and then close the pressure cylinder. That is the end pressure vessel here, you can say it is containing oxygen and then you pump in oxygen into the pressure cell, now close it and close the valve here and then you see how much air can leak through leak through the concrete cap.

So the concrete cylinder which is made is essentially used to close the pressure cell like a cap only. So if there is a release pressure release happening, this can be measured using the pressure gauge here and if the release is more that means the concrete is more porous, if the pressure release is less, the rate of pressure release is less than that means the concrete is much more compact or, more impermeable. So, that is how the oxygen permeability index can be determined.

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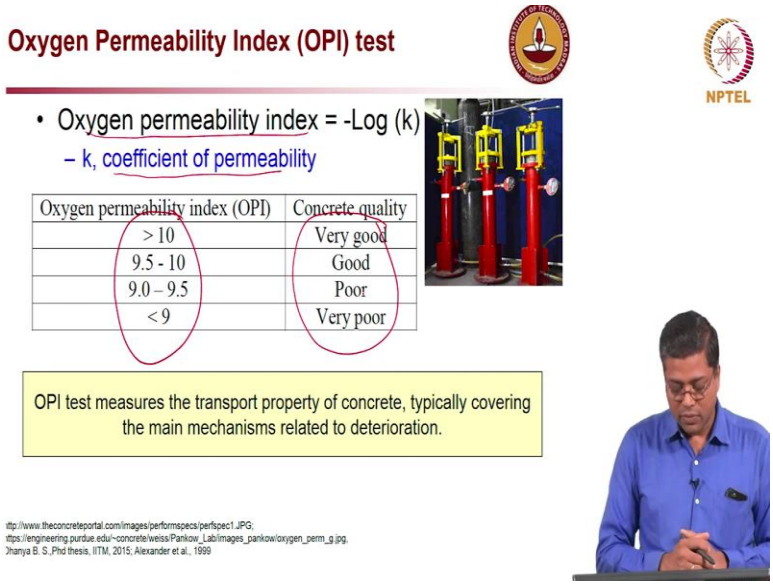

Now, based on test results which we get, we get the coefficient of permeability and then from that we get OPI or Oxygen Permeability Index. Now, once you get the oxygen permeability index this can be related again to the general quality of the concrete. You can say if the test result index is more than 10 then I can say the concrete is very good, then good, poor, or very poor. So, four different categories you can assign to the various concretes. Again this is a good test and it has been shown to be having very good correlation with carbonation rate or carbonation depth. Especially in Portland cement systems.

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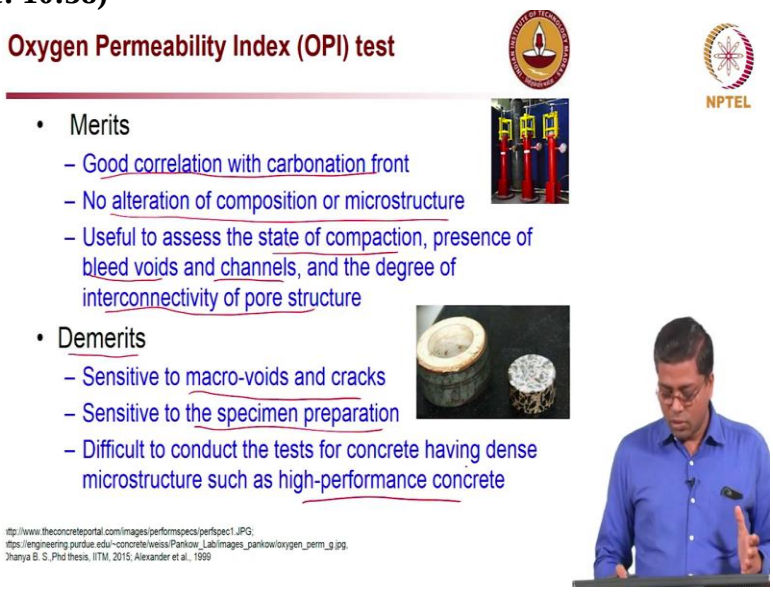

So, what are the merits and demerits? So, merit is it has good correlation with carbonation front. It does not really alter the composition or micro structure of the concrete system in other words

during the test, you do not really change the concrete or you do not really induce a micro structural changes in the concrete. And then useful to assess the state of compaction, how compact the concrete, is there any bleed voids or other channels or pathways through which air can get released, and the degree of interconnectivity of pore structure. All these can be assessed in a rough way using this particular test.

Now, what are the demerits, demerits it is very sensitive to macro words, if there is any crack in the concrete or if there are any macro void, then there will be a significant drop in the pressure and that will probably indicate that the concrete is very bad, but that bad that is mainly because that is the presence of a particular crack or a macro void. That may not be the case for the entire concrete system which you are talking because here you are essentially looking at a material property of the bulk concrete. So, this presence of such cracks and macro voids in the specimen should not be influencing the test result. So, that is one demerit or the best way to get over this is you make sure that the specimen which are preparing has no macro voids or cracks in it. And so it is sensitive to the preparation of the specimen. Now, it difficult to conduct this test for concrete having very good micro structure like high performance concrete because then you will get greater than 10 OPI, you will come into that range, the finer categorization becomes a little bit difficult but you can say all this concretes comes into that category of very good.

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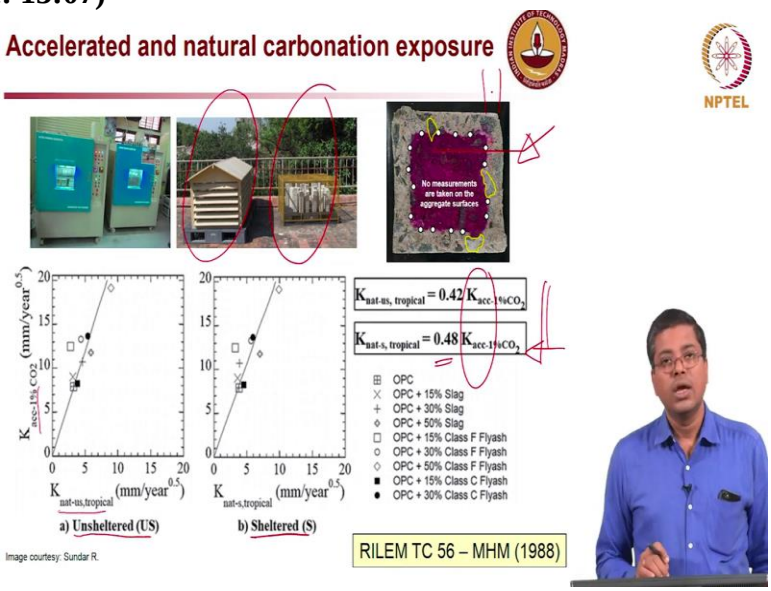

Now, another test is carbonation. Especially when we are talking about today's concrete there is a concern about concrete with supplementary cementitious materials, they might have higher

carbonation etcetera. But we have to really test them before concluding on such observations which are mostly based on a short term test results. So, here I am going to show a relationship between short terms or accelerated test and natural carbonation test.

So, it can be well, you can see here at two sets one is sheltered and unsheltered. Why it is important to show you this as you can see here, this is a sheltered, there are specimens inside this small box and then the unsheltered specimen because this creates a difference in the moisture condition and the carbonation is very much influenced by the moisture condition inside the concrete. So, in the sheltered case and unsheltered case you can really have a different rate of carbonation.

In the case sheltered case, especially in tropical environment you will see that the carbonation is much more than what you could observe in an unsheltered case where the concrete gets dried also, very fast. Now, the graphs at the bottom, it shows how we can use the accelerated test to assess the performance of concrete in long term carbonation. Now, you see here in the graphs, you can see that these are natural and then these are accelerated. If we know the accelerated test result, you can easily correlate that to a natural test result. We have two equations for unsheltered and sheltered case, the point is if you can get the accelerated test result which takes usually about, let us say 4 months and from that you can estimate how good that concrete will be if subjected to natural carbonation.

$$K_{nat\text{-}us} = 0.42\ K_{acc\text{-}1\%CO_2}$$

$$K_{nat\text{-}s} = 0.48\ K_{acc\text{-}1\%CO_2}$$

So, let us look at this example here in the bottom case, which is for natural case and sheltered case, you can say that the coefficient is almost 0.5 of the accelerated carbonation coefficient. Why this is important because if you talk about natural carbonation it takes very long time many years to do the test, nobody would want to wait for that long. So, you have to have something which is which can be which can give you results in very short term, let us say 4 months. So, it us a good test to adopt. More details are provided in this RILEM technical committee 56.

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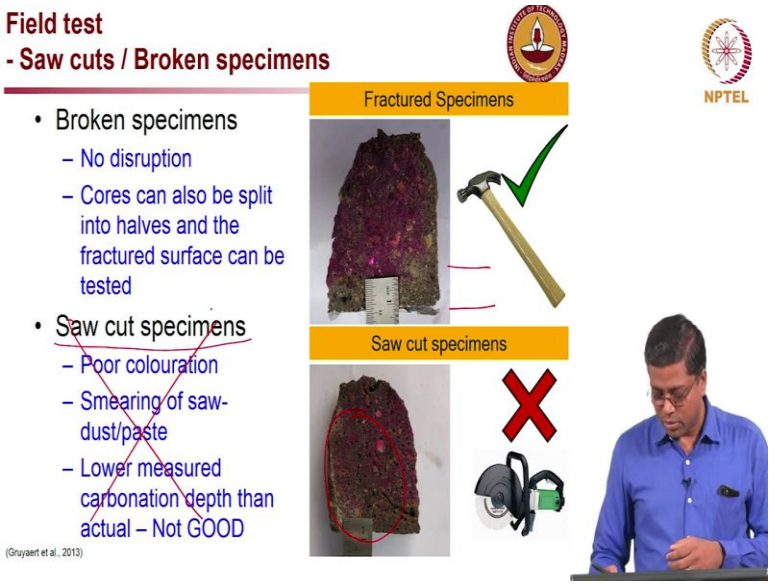

When people test carbonation on concrete, usually this phenolphthalein test is done, which is basically you spray the phenolphthalein indicator on to a fractured specimen, as you see and then a look at the pink color. In the previous slide also I showed this is basically that pink color, which I am talking about. And you see that interior of the concrete is more pink than the peripheral region that means, in this particular specimen, this much region is highly carbonated, and as you go inward there is less carbonation. So, it is a good test, phenolphthalein indicator.

And here, I am trying to show you, if you are saw cutting a specimen and if you are actually fracturing a specimen, these two will actually give you different result. So the test method or the procedure will have an influence on the test result which you get, which is not a good a good thing. So you have to know that or make sure that saw cutting is not done when you talk about carbonation testing in the field.

Now the first picture is a fractured specimen where you can see very clearly this much region is carbonated. And whereas in a saw cut specimen, as you can see here, it is not very clear on the image. So what happens when you saw cut is, the blade itself smears the powder, and it spreads this powder in the entire surface after that when you spray the phenolphthalein indicator on to it, you really cannot see because there is a lot of cross contamination from point to point happening on that specimen. So, point from this slide is that you have to fracture the specimen. You can even take a core and then do a split, take the core and split into half and then spray the

phenolphthalein indicator on the fractured surface that is also very easy to do. But in whatever be the case, you should not adopt this saw cutting of the specimen. So, this is not a good idea to practice that will give misleading information.

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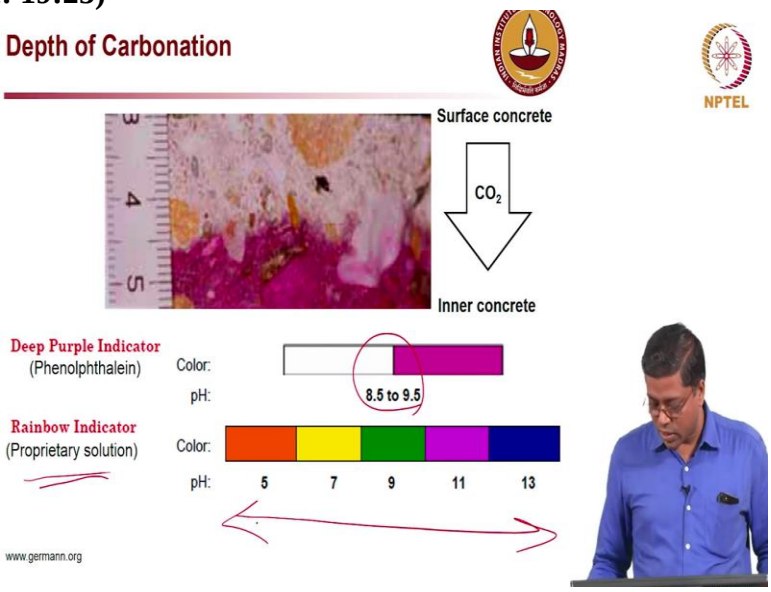

Now, there are also other indicators available like a rainbow indicator. Phenolphthalein indicator is widely used, which gives this change in color from around pH 9. But if you are talking about rainbow indicator, then you can also get a wide range, you can see whether the pH is at 13 or 11, 9, but it is not very easy to distinguish between these colors, but if some if somebody is really want to see exactly what is a pH this is one way to go for.

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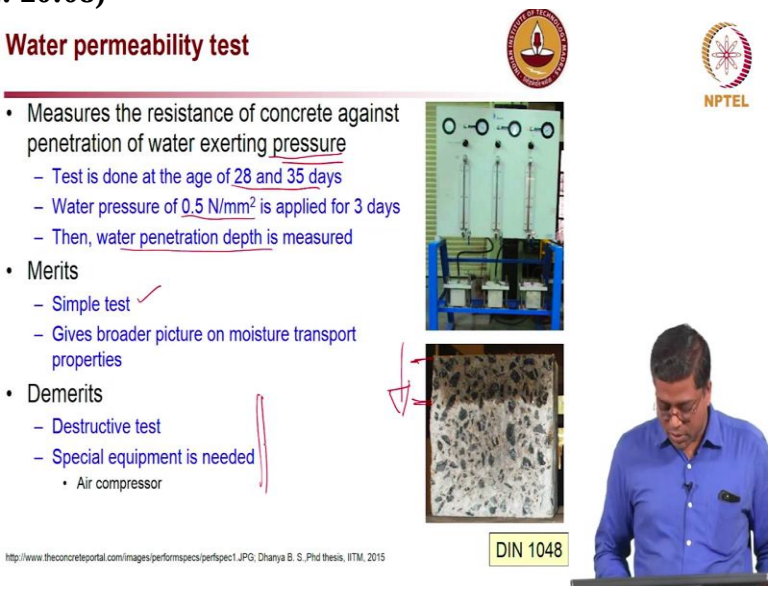

And water permeability test is another test which is widely used to assess concrete quality. Mainly, this measures the resistance of concrete against penetration of water when there is a pressure and it is looking at the permeability. Permeability is mainly with the driving force is the pressure. So, if you are talking about a dam structure or any water retaining structure, you will have a hydrostatic pressure or if you are looking at sub structure, exposed to or water table is above the concrete level, then also you might have some pressure exerted onto the concrete surface, in such cases, this is very good.

Now, test is done at about 28 and 35 days and this is the pressure which you apply and then what you look at is that what is the penetration of water into the concrete? As you see in this picture here you can see color difference in top region and that indicates the presence of water or the penetration of water and how much it has penetrated. So, if you have multiple concretes with different penetration depth, then you can say concrete A is better than concrete B something like that.

What is the merit it is very simple test, easier to do and gives broader picture of moisture transport properties. Demerit is you have to have a core specimen and also then the equipment which you need an air compressor because you are talking about pressure. But these are all, part of the facility itself. So, really there is not much of demerit, but it is a very good test to adopt for assessing the water permeability of concrete.

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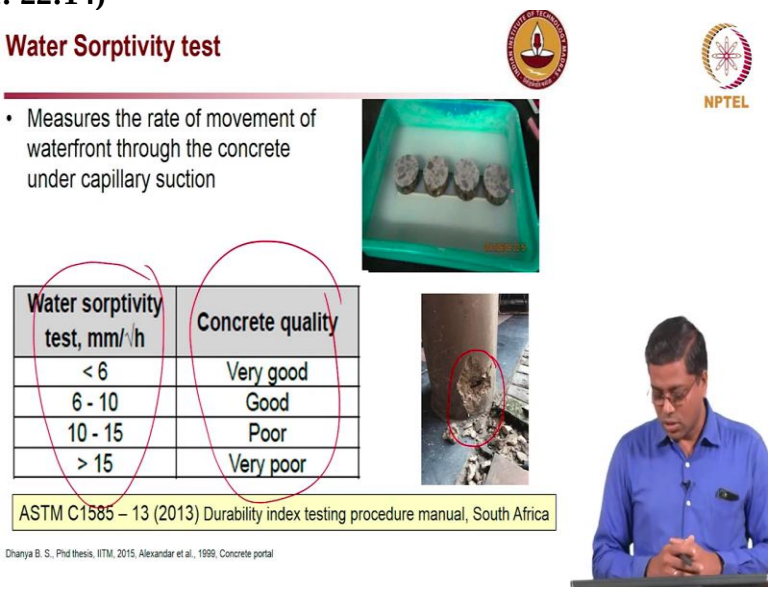

Now, another mechanism which happens when you talk about moisture is sorption. So, as you see in the picture on the bottom right, you can see that the concrete column and stirrup at the bottom of the concrete column, is actually corroding very severely, but, in this particular column, there is no other space which experience corrosion. So, very clearly this has something to do with the concrete because it just coming out of the ground and that is where you have corrosion mainly because of the capillary suction.

You know, the suction of moisture from the ground and then it keeps the moisture available for corrosion reaction to happen. This is something which needs to be addressed also. So the type of concrete which you use, if it is highly resistant against sorption then maybe that is one way to decide on the type of concrete and so, we can actually avoid these kind of problems in our structures. Now, this is classification criteria where different waters sorptivity ranges and then which is then related to the quality of the concrete.

Now, how to do this, you can take course of the specimen and then basically a small tray in which the specimens are kept with a few millimeter from the bottom which is in touch with the solution and then you see the change in the weight of the concrete slices or in are disk which you see on the picture on the top right.

And then you look at the weight change and if the change in the weight is more that means more water has been absorbed or is sucked into the concrete which is not a good idea. So, the amount of water which is sucked into the concrete should be low that means the concrete is of high quality.

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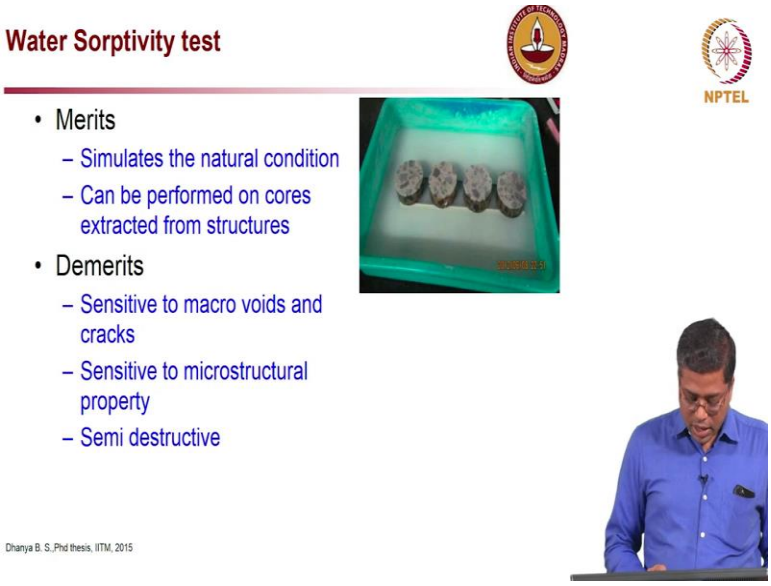

Merits are it simulates a natural condition and then can be performed on cores which are actually extracted from the structure and you can also do it on specimens before even construction if you want to assess the quality of a particular mixture proportion. And then demerits, it is against us sensitive to macro voids and cracks like we discussed in the case of oxygen permeability and it is very sensitive to the micro structural properties, pores structure, pore distribution, not only the total porosity, but the how the ports are distributed and connected. And it is a semi destructive test.

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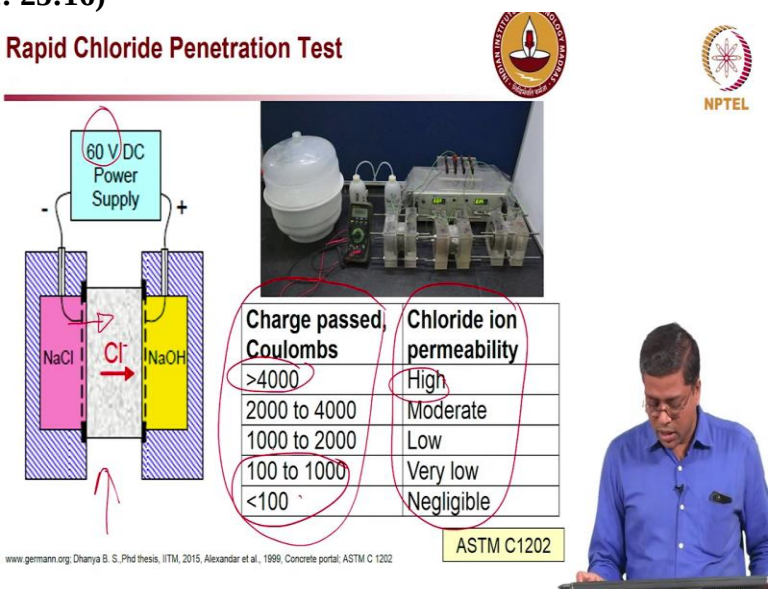

And then another test is rapid chloride penetration test, where you again take a concrete cylinder, as you see here, and then there are two cells on either side of the cylinder, one cell is with the

sodium chloride solution the other cell is with the sodium hydroxide solution, and then you connected to a power source. When you apply 60 volt, essentially what happens is, it drives the chloride ions from the left side to the right side as in the picture. The negatively charged ions in the left side cell, which is the chloride ions, it moves or gets transported into the concrete, based on that the that you actually measure is the charge passed. So, you have a power source connected, then you have this chloride movement and then you measure how much charge or electrical charge is passed during the test.

And then you apply this current for about 6 hours and then you measured the charge passed and relate that amount of charge fast to the permeability of the concrete. If it is very large number of charge passed, let us say in this case greater than 4000 then the permeability is very high that means a concrete quality is very low. So, in this table here, the higher the permeability that means the quality of concrete is not good. So, if you have a concrete which is let us say in less than 1000 or less than 100 this range then you can say the concrete quality is very good.

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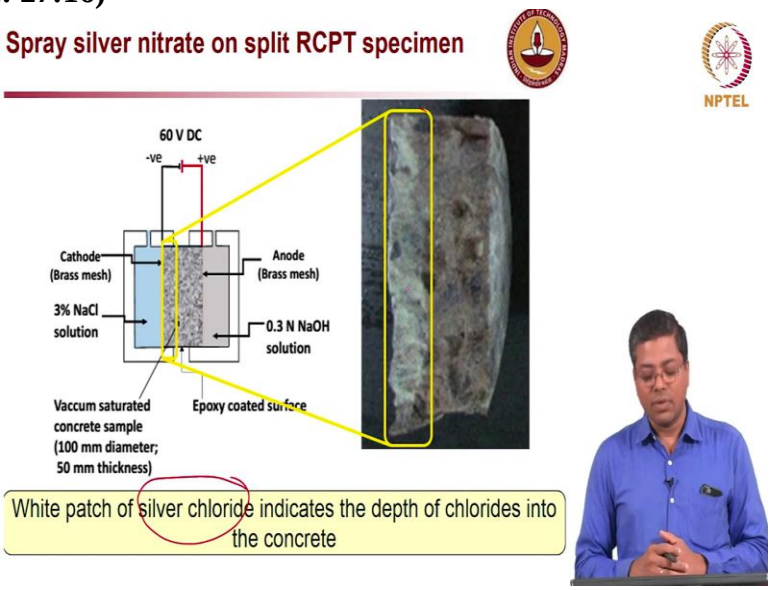

And on top of this, the same specimen after the testing you can take, the disc which is used for this RCPT (rapid chloride penetration test), same specimen can be taken after the test is done. Now you know the charge passed and on top if you want to know what is the depth of penetration of chlorides you can actually take the cylinder split into half by splitting and you can then spray silver nitrate solution on to the fractured surface and if there are chlorides it will react with the silver nitrate and then form silver chloride. So, the white patch which you see on the

cylinder indicates the presence of silver chloride that means, approximately up to about this depth in the yellow box, you have that much of chloride penetration.

So, this gives a very visual assessment of the depth of penetration of chloride or how good the concrete is resistant to the penetration of chloride. It is a very good test because there is no calculation or anything which is involved you can directly see what is happening. That is a good indicator.

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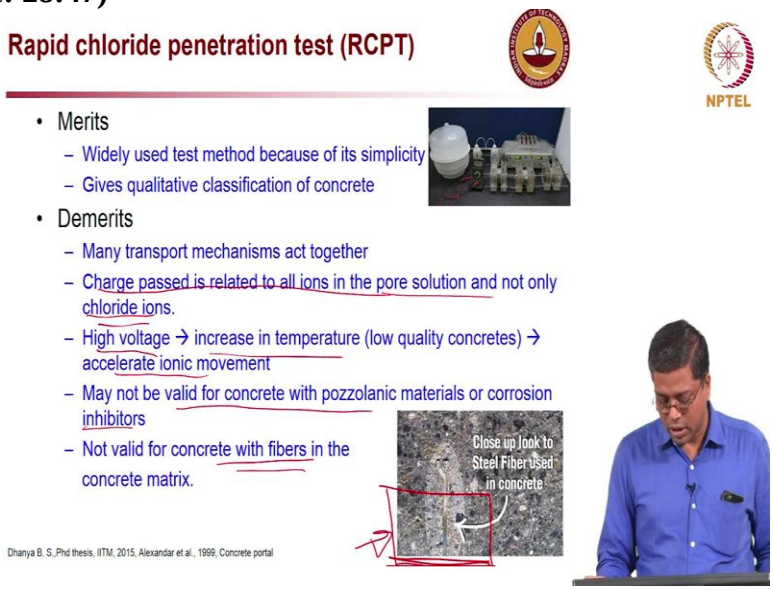

Now, what are the merits? It is a widely used test and then it gives a qualitative classification of concrete. Some demerits of this test is there are multiple mechanisms act together, and in this particular test you the migration is also there and different types of chemicals present in the concrete, then there is a problem. This is mainly on the assessment based on the charge or the coulombs, so, the charge passed is related to all the ions in the pore solution and not only the chloride ions. If you have some other negatively charged ions in the concrete that may also get transported when you apply that 60 volts and what will happen is the charge passed is based on the combined effect of all the negatively charged ions and not only the chloride ions. And also when you have high voltage 60 volts, there could be an increase in the temperature especially the quality is low and then this will also accelerate ionic movement. So, these are all other complexities are the associated with this RCPT test and if the assessment is based on purely on the coulombs, the charge pass, you have to be a little bit cautious before concluding. So, and it may not be valid for concrete with SEM or corrosion inhibitors because the chemistry is much

more complex in that case and especially if you have fibers in your concrete, we have seen test reports which shows RCPT test on fiber reinforced concrete which is not a good idea to do. I am showing a picture which shows the small fiber you can see. So, what happens is, imagine you are taking a concrete specimen and that specimen is something like this and which has a fiber, which is aligned to the axis of the cylinder or if it is reaching from one surface of the cylinder to the other surface then definitely the ions will pass through the interface between the fiber and the concrete. So, that gives an easy pathway for the chloride to penetrate. So, which is not something which is good, especially when you apply the voltage in this test, you apply the voltage but in reality you do not apply the voltage. So, and also in this test you are talking about assessment based on a small disc where in reality you are talking about large concrete the travel traveling of this chloride to a larger depth also depending on the type of structure you are talking.

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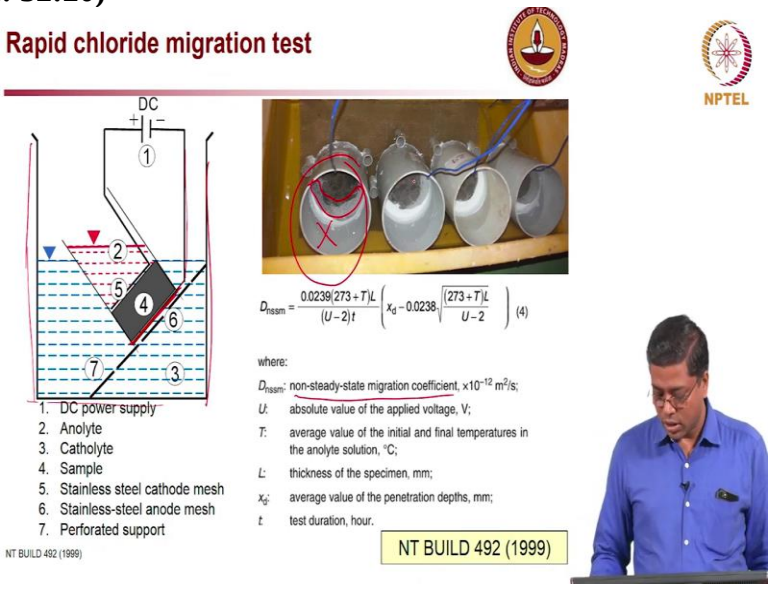

Now, rapid chloride penetration test this is also a very fast test which can be used to assess the chloride migration properties especially the known study say migration coefficient and here in this test you have invoice tank like this you can see and then you have this item number 4 in the sketch is the concrete cylinder and item number 5 is a mesh which is kept on the one on one surface of the cylinder. And then I the bottom of the cylinder you have another mesh which is connected to the power source and then you supply the current and then eventually you can measure the chloride migration coefficient. And make sure that when you this measured the bottom of the cylinder there should be sufficient liquid available or electrolyte available over

here. So that there is no air trapped and that is one reason why the cylinder is kept in an inclined form. So, that whatever there will be no air trap that the bottom of the cylinder.

So, it is a finely designed test setup and also something which you should not be doing. See the concrete Surface available for the migration to happen as to include in the calculations right. So, you can see here there is this a part of the silicon which is applied it is actually smeared on the concrete surface, which is not a good thing, it should only be sealing the gap between the mold and the cylinder, it should not be smeared on the concrete surface. So, this concrete surface should not be this portion should be free from this silicone. So, the preparation of the specimen is also very important and in all these tests, the specimen preparation plays a significant role. If you do not do a good job in specimen preparation, the results which you get might get altered because of the preparation, poor quality preparation. So, these are all very important to think when you do experiments again. Even here you can see that, only this much portion is available for the migration to happen whereas, some region here is actually covered by the silicone caulk. So, quality of specimen preparation is very important and that also places, if it is not well taken care, this will change the test results which you get and you might make wrong conclusions on your test.

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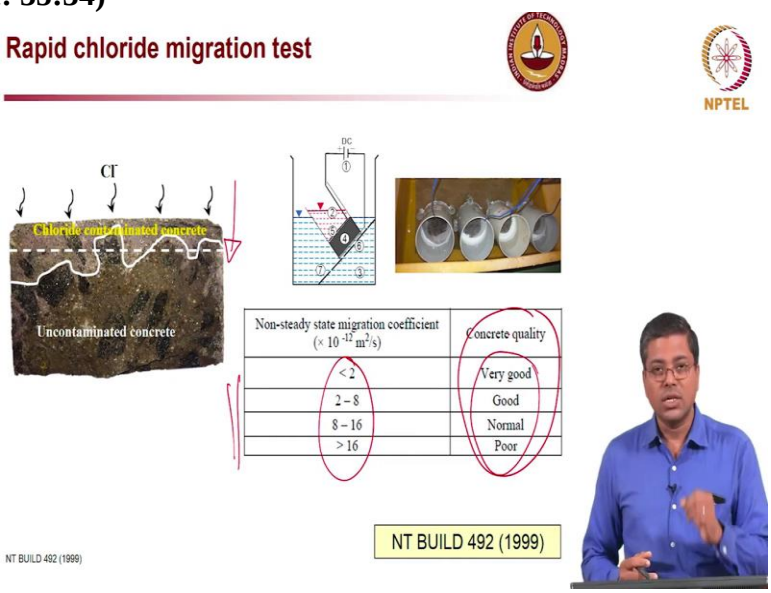

Now, here also you can see penetration of chloride into the concrete and the same silver nitrate test, which I explained earlier a few slides ago can be repeated, even on this concrete and that is what you see here. After the test, you can fracture the specimen and then spray a silver nitrate

and see what actually penetration depth of chloride is. And here is comparison where the non-steady state migration coefficient is linked to the concrete quality. Again let me emphasize, when you look at these tables which are linking a particular property, transport property to the concrete quality, make sure that the exposure condition, the specific exposure condition where the concrete will be used and the desired service life both these parameters must also be considered before giving a name like this or a category very good, good, normal, poor to the concrete. It is very important to consider the specific exposure condition and the besides service life.

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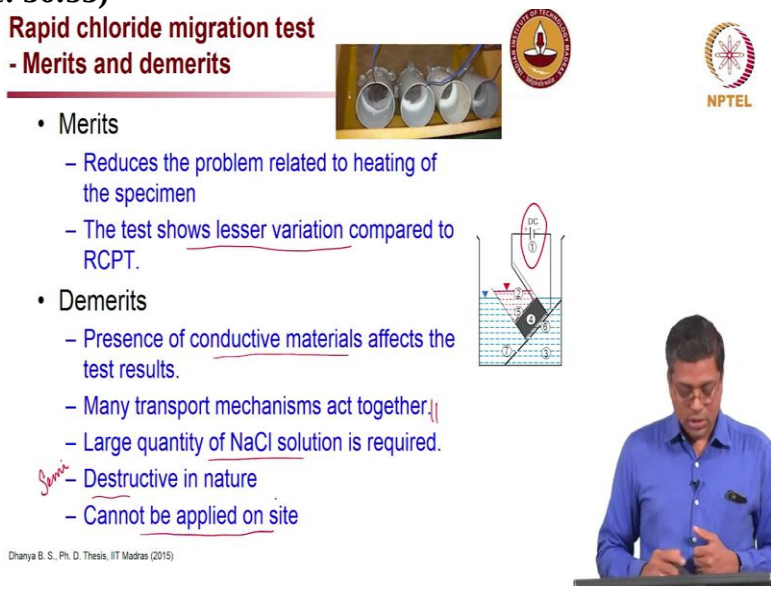

Merits of this rapid chloride migration test it reduces the problem related to the heat of specimen as you have it in the case of RCPT, because here the voltage we apply is determined based on the initial test which we do and the voltage is much lower than the 60 volt which you apply in rapid chloride permeability test. And the variation in the test result is also much less in this case as compared to RCPT.

There are of course, some demerits, if you have a conductive materials like fibers or something, it will affect the test which we should not anywhere practice and then many transport mechanisms act together like in the case of RCPT and quantity of sodium chloride solution, these are all small things, but I just wanted to mention all these also when you site the demerits. And you need to have actual cylinders to be tested. We can say it is destructive or semi destructive in nature and also you cannot reuse these concrete cylinders for any other test. For example, if you are talking about oxygen permeability test you can actually use that specimen for other tests even

after the test, but when you talk about chloride penetration test or rapid chloride migration test, you cannot reuse those specimens again for anything else. Because the test procedure itself contaminates the chloride and cannot be applied on site because you have to take the power source there, but you can always take a core from the site and bring the core specimen to the lab and then do this test.

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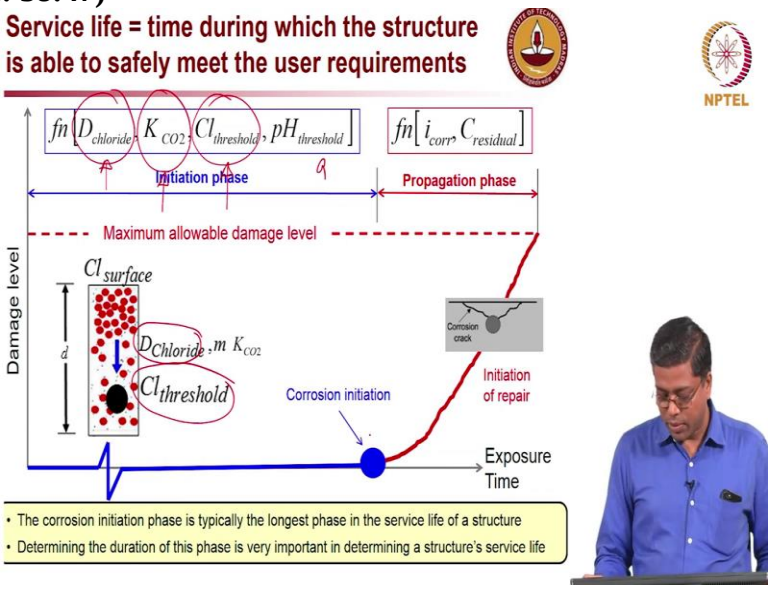

Now, service life, when you talk about service life estimation, there are different parameters diffusion coefficient of chloride, carbonation coefficient, chloride threshold, pH threshold these four things matter a lot here we are going to talk about them. If we talked about diffusion chloride, and then we talked about carbonation coefficient, we talked about chloride threshold, we did not talk about pH threshold, but we assume that it is equal to about 9 for most cases.

Now, what happens in the case of corrosion initiation or during the service life initially? So, it is during the initiation phase, you have the chloride from the surface penetrating into the concrete and it eventually reaches the steel surface and initiates corrosion. So, chloride threshold is also a very important parameter and diffusion coefficient of chloride in that particular concrete is also very important parameter to estimate when the initiation will happen or when the concrete will start corroding.

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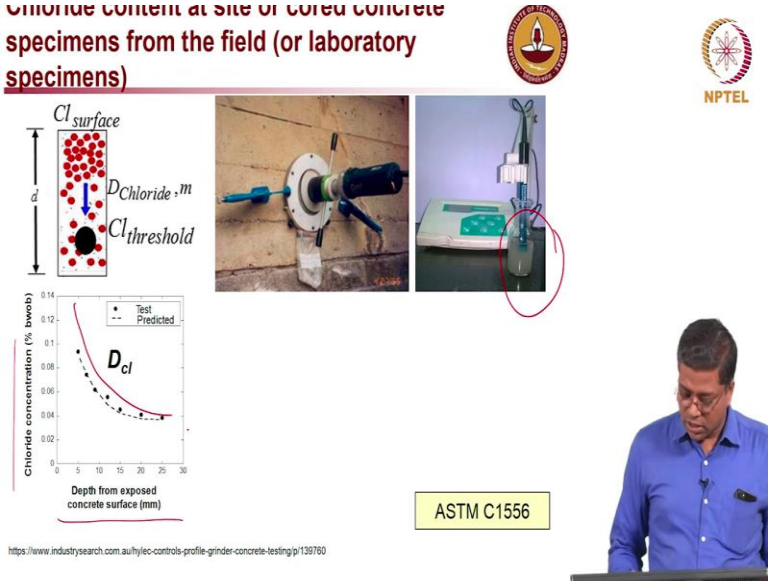

So, chloride diffusion coefficient is something very important to estimate. As you see on the picture here, you can see an instrument which is a profile grinder, which is attached to the wall surface. So, why I showed this picture is you it really tells that you can actually take powder from the concrete surface and you take the powder and then do a chemical test in the lab and then that will help you to tell how much chloride is present at different depth within the concrete.

So, as you see in the graph here, the depth from the exposure first and the chloride concentration. So, this graph will help you in determining the diffusion coefficient if you know the time of exposure and the surface conditions etcetera. So, but this graph will really help in determining the chloride diffusion coefficient of concrete.

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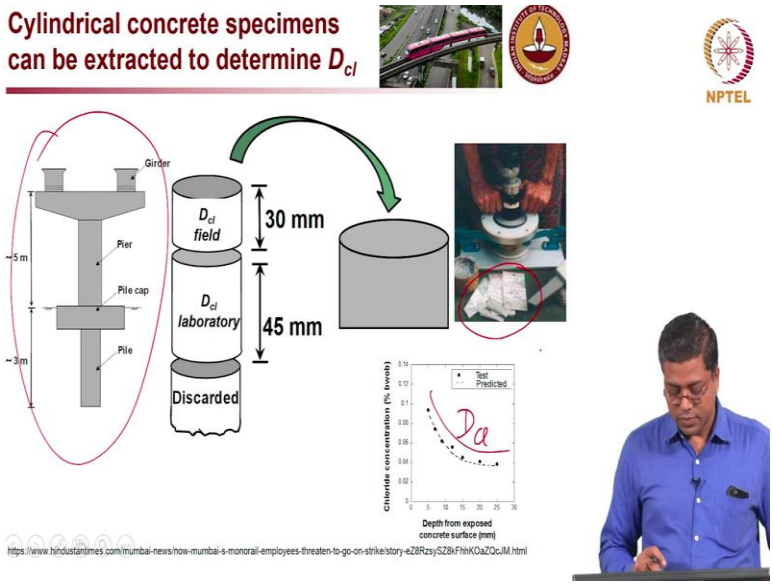

So, in fact in we can do this on specimens for any project if it is already exposed to chloride environment for some time, so, that the time and then you can extract the core specimen from the structure, this is just to show you actually a bridge monorails a bridge structure and then you get the core specimens from the structure. And then you do a test basically, you can either slice the concrete or take powder at different depths in the core specimen and then develop this profile and then from that you can determine diffusion coefficient of the concrete.

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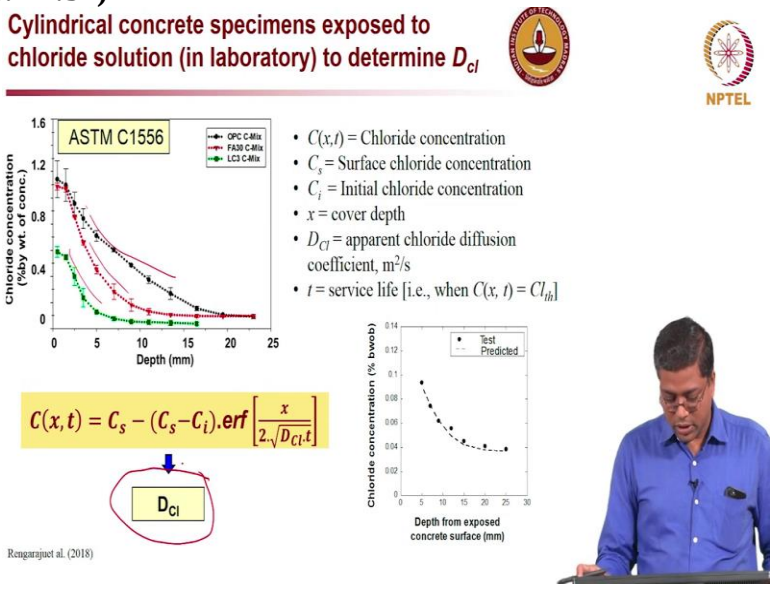

This is an example graph showing that this diffusion coefficient could be or the profile could be different depending on the type of concrete which you use. And you can see here with a black one is an OPC mix and the red one is a fly ash mix and the green one is an LC3 mix and from

this data we can use this Fick's second law of diffusion and then eventually come up with what is the diffusion coefficient of the concrete.

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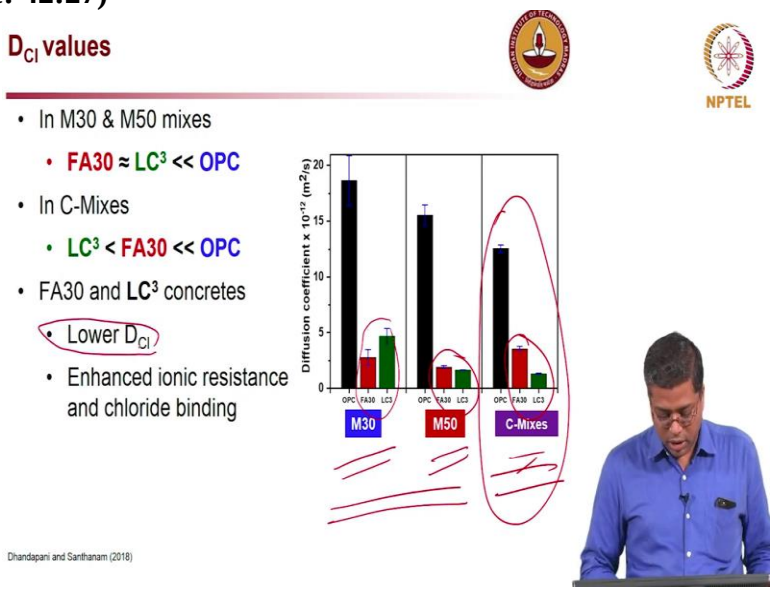

And once the diffusion coefficient, then you can really estimate the service life of concrete structure this is just to show the difference in the diffusion coefficient of different concretes. As you see here, if you are talking about an M30 concrete fly ash and LC3 systems or the systems with supplementary cementitious systems can have very low diffusion coefficient if it is properly mixed and made. And even in M50 case, you can see significant reduction in replacement mix also with the common mix design.

So, the idea of this graph is to show you that OPC mixers perform much worse than the corresponding mixes with fly ash or LC3 when I say corresponding I am talking about concrete with similar strength grade. And in the third set here, it is basically looking at concrete with similar mix design not necessarily of same strength. But if you are talking to a structural engineer, and if you are saying that, I want to use fly ash or slag or silica fume or any other concrete for that matter. They will want a concrete which will have similar strength grade, but with different materials. So that is the importance of this study here, where we looked at M30 and M50 type concrete and we clearly see that for the same strength grade you can have much better quality concrete by the use of SCMs. And when I say better quality, here I am meaning a lower diffusion coefficient. That is the key point here.

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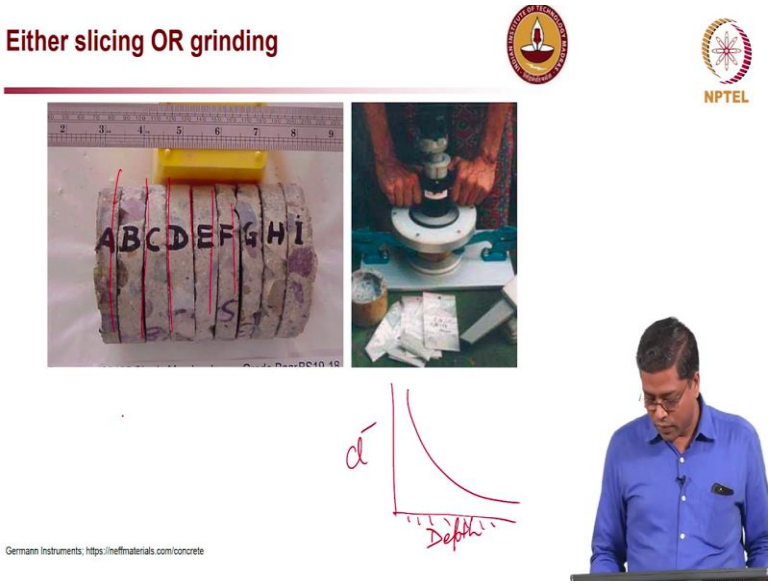

Now, in the previous slides, I showed that, you can get this profile like the we said depth and then chloride concentration and we saw a graph something like this. And this graph, at different depths on the x axis. The profile can be obtained by grinding powder from the concrete specimen and if you do not have a grinding tool, you can also take slices from the concrete specimen and then the determined the chloride concentration in each of these slices as shown here, A,B,C,D,E,F,G,H,I all the slides slices you can take and then you estimate the concentration of chloride in each of the slice. When you go for a slice, it may not be a perfect test as you compare to grinding because in the case of slice, getting the actual chloride concentration for every millimeter depth may be very difficult, but which can be easily obtainable if you are talking about a profile grinder, where you can get the powder from every millimeter if required. So, the one shown on the right side is a more sophisticated way of doing it and one shown on this left side is, less sophisticated way of getting chloride profiles.

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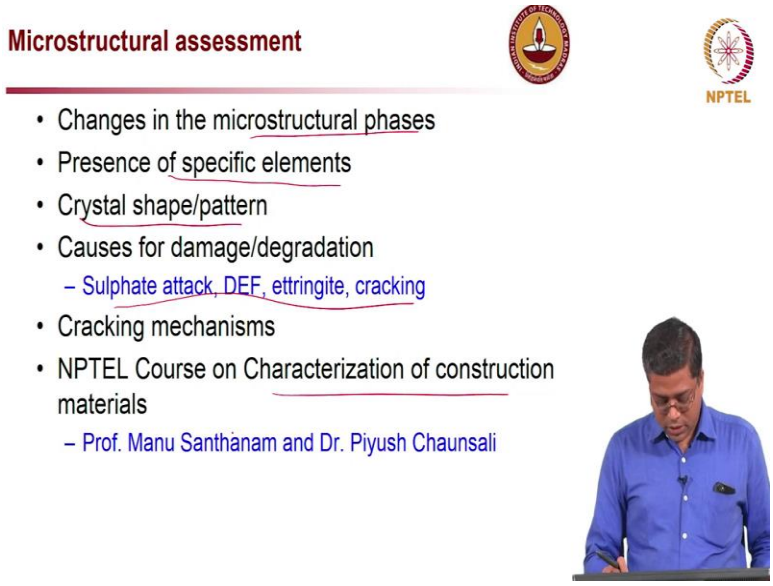

Now, we can also do micro structural assessment of concrete. Let us say you have a case where you see an unexpected cracking after some period of time in the concrete structure and then you want to know what the reason for that cracking is. So, where, if you want to really investigate, you have to look at what changes have happened in the micro structure of the concrete. And so, you have to look at phase changes in the micro structure, is there any specific elements which are present in the concrete which was probably not there in the beginning and then something from the external environment penetrated into the concrete and then, and also you can look at the crystal shape and pattern. So, you can take the core specimen and then make smaller specimens and then do a micro structural study and then which can probably tell you what type of chemicals are present in the concrete. And which can then be related to the degradation mechanism, which we already discussed in our previous module. And now, basically from those information look at it for example, one case I will tell here, if you are talking about a delayed ettringite formation DEF, we can see if there is ettringite present in the concrete and maybe that you can relate that to the DEF and the looking at the type of cracking. All these different information how to be put together and then we can conclude on what went wrong in the concrete systems. And there is a very detailed course on this how to characterize the construction materials and system, offered by Prof. Manu Santhanam and Dr. Piyush Chaunsali. So, that is something interesting, if you are more interested in microstructure assessment,

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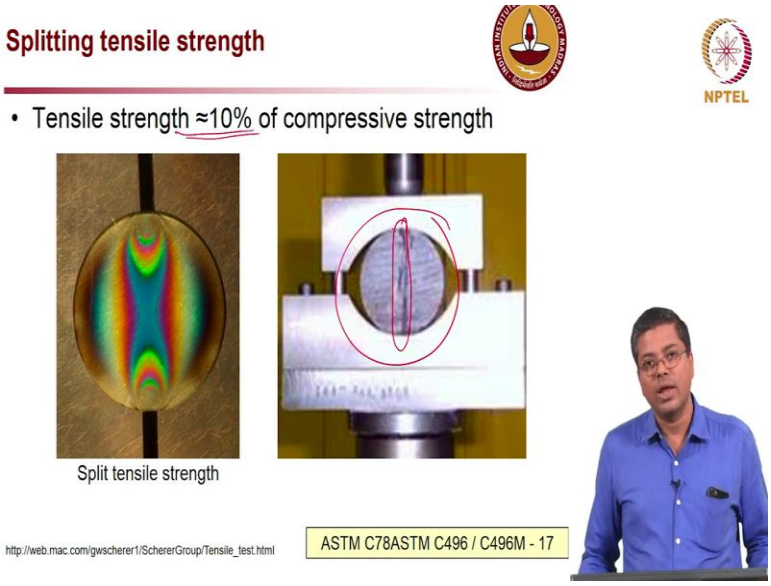

And then looking at the mechanical properties, until now we were talking about durability related test and of course, compressive strength is there I am not covering that here but, split tensile strength, typically we say that the tensile strength of split tensile strength of concrete is about 10% of the compressive strength and how do we do you take a core and then you try to split the core into half. As you see in the picture here on the right, you can see that there is a crack which is happening at the center and that splits into half and then from that you can say based on the load applied, the split tensile strength.

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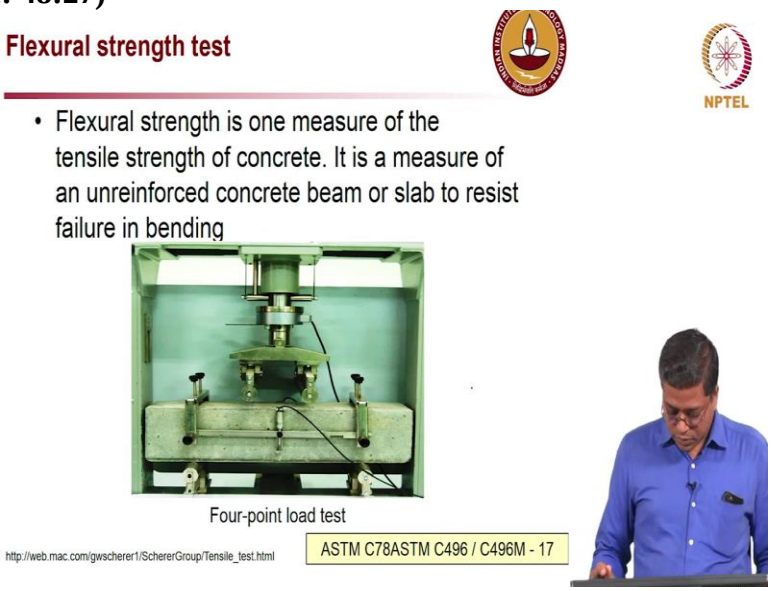

This is a flexural strength test, especially becoming more and more important when we talk about fiber reinforced concrete and things like that, where you have to get the toughness characteristics also.

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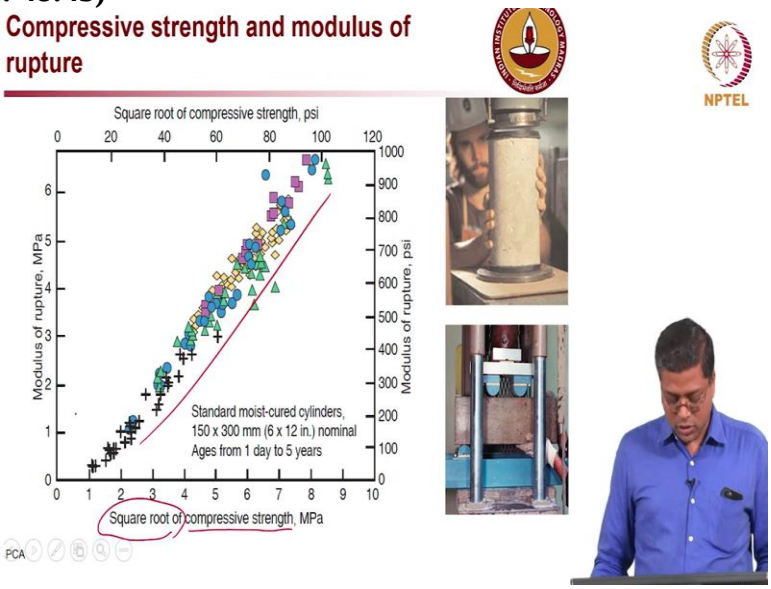

And this is an example how the flexural strength can be related to the compressive strength of concrete. As you see on this graph, this is square root of the compressive strength so you get the straight line. So, if you are actually plotting with compressive strength goes with modulus of rupture or flexural strength, then you will get square root curve.

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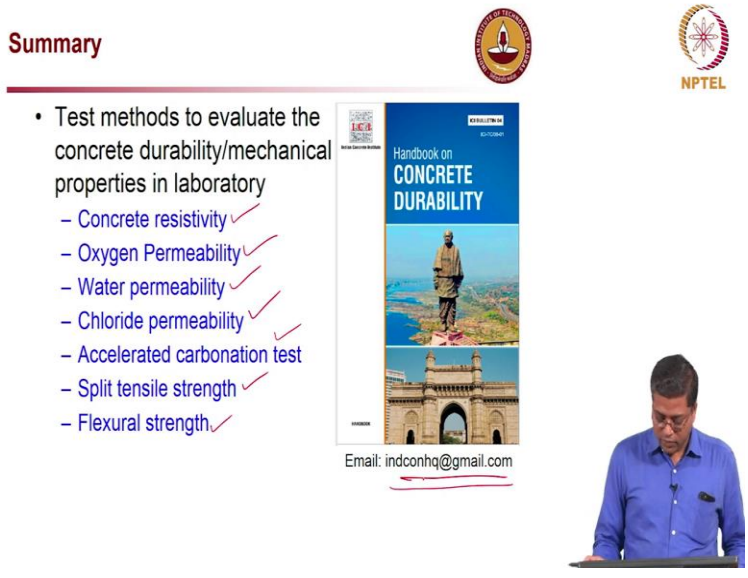

To summarize these test methods to evaluate concrete durability and mechanical properties were discussed, we looked at electrical resistivity of concrete permeability of oxygen through the concrete and looked at water permeability, chloride permeability and then accelerated carbonation test and split tensile strength flexural strength all these we discussed, there are specified test methods available.

This is a very good handbook where various durability related tests have been put together. So, this handbook it is available if you are interested you can get it from contact through this email contact ICI, Indian Concrete Institute through this email. The good thing about this handbook case it gives all the information related to the principles behind various tests and how the tests can be done more details.

And then also how what are the things to look at when you actually do in a critical evaluation of various tests. And how this the test results can be used for design purposes. So all that is covered in this Handbook, I think it is a very good collection of information.

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And these are the references which were used to make this lecture note.

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And in the next lecture we will look at how to assess the corrosion and the properties of steel in concrete.