Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 34
Measuring Permeability of Concrete

[FL] and welcome to this lecture 34 in this course on Hydration, Porosity and Strength of Cementitious Materials and as promised today we will be talking of measuring permeability of concrete.

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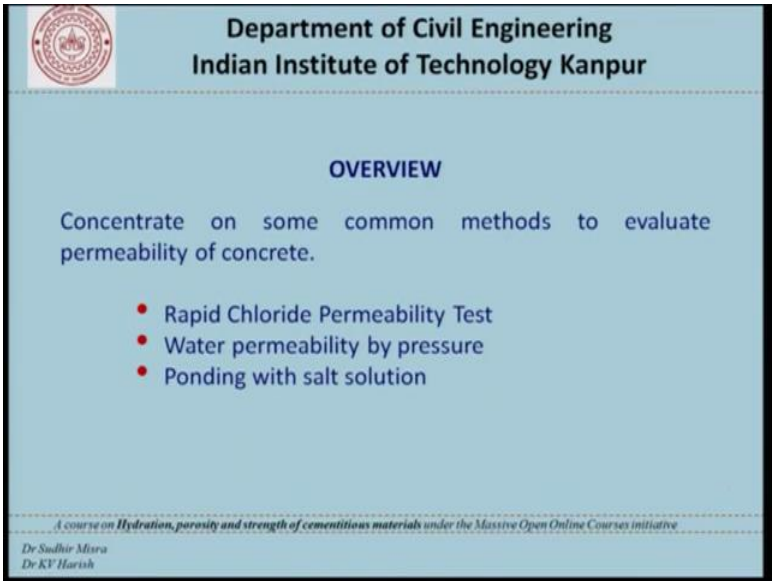

We will basically concentrate on some common methods that are available to us to evaluate the permeability of concrete and take up discussion with the rapid chloride permeability test, water permeability of concrete by pressure and ponding with salt solution.

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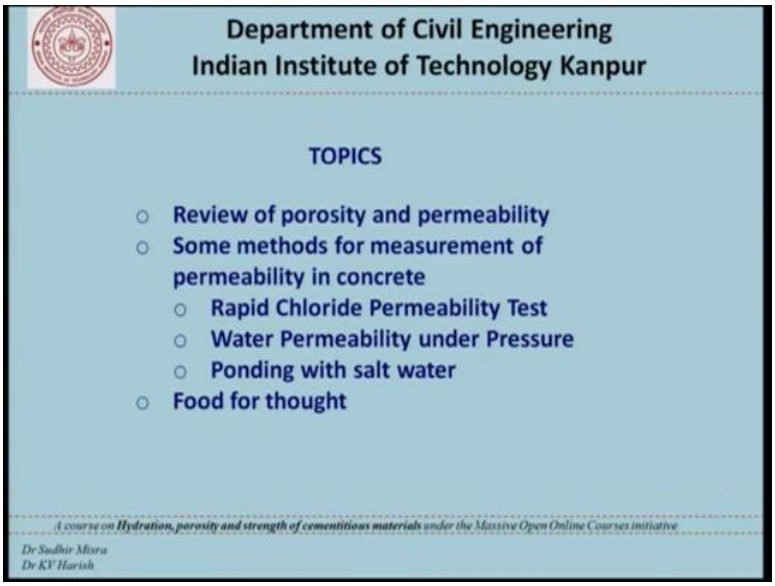

Our discussion will be largely divided into a review of porosity and permeability and of course, we will talk about the methods for the measurement where RCPT or the rapid chloride permeability test the water permeability under pressure and ponding the salt water. And of course, at the end of it I will leave you with some food for thought questions that you may like to ponder about to get a better idea of what we have covered today.

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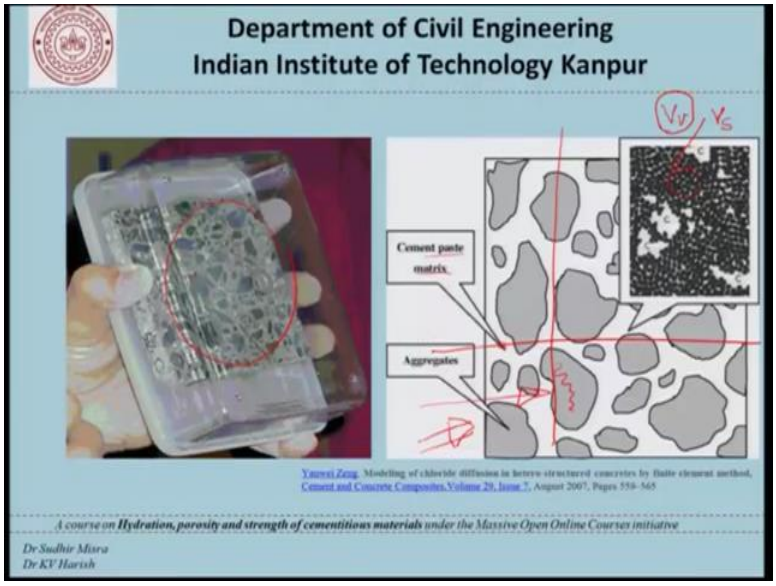

So, now this is where we had stopped the last time. We had seen that concrete is a composite material comprising of the aggregates which are shown here and the cement paste matrix which is shown here which itself comprises of solids and voids. So, when it comes to permeability and porosity of concrete we are really looking at the porosity and permeability of the paste phase basically because we can assume that the porosity of aggregates is very small. But having said that we need to evaluate the permeability of this concrete composite which is shown here whether it is in this direction or it is in this direction and we are looking at deleterious ions or deleterious material from the atmosphere permeating into concrete through the voids in the paste.

Now what kind of ions are what kind of material permeates into the concrete would depend on what kind of an environment the concrete structure that we are talking about is located. If the structure is located in a marine environment we are often confronted with the problem of chloride ion penetration if it is a ground water attack from sulphate ions, then we are bothered about sulphate ion penetration, if it is a structure in the atmosphere then we are sometimes bothered with the carbon dioxide, I am present we have bothered with the carbon dioxide penetration into the concrete. Obviously, depending on whether the permeating material is a gas or an ions or a fluid the permeability will be different for the same ferocity.

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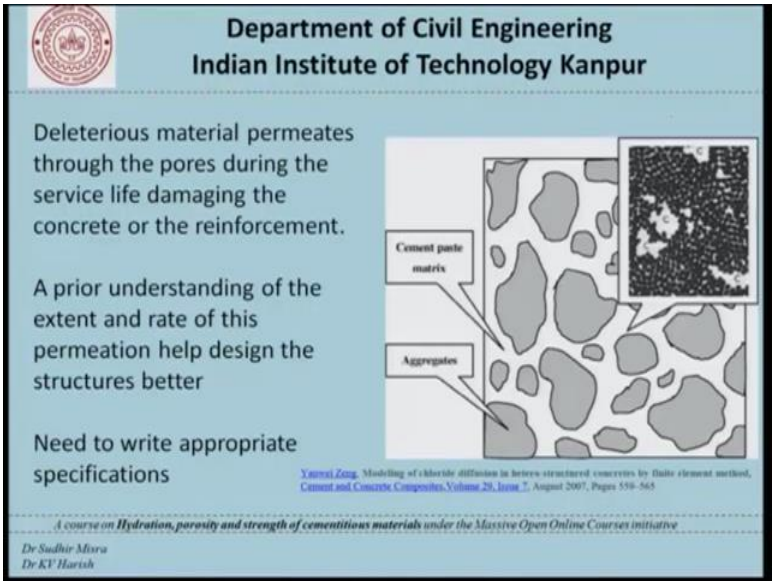

So, now taking forward this what we said deleterious material permeates through the pores during the service life damaging the concrete or the reinforcement that lies just under the reinforce; that lies just under the surface protected by a cover concrete. And a prior understanding of the extent and the rate of this permeation helps us to better design their structures in order to be able to do that we need to be able to write appropriate specifications. Now this is something which will be at the back of our mind when we talk about the different tests that we use or we can use to measure the permeability of concrete as a composite material.

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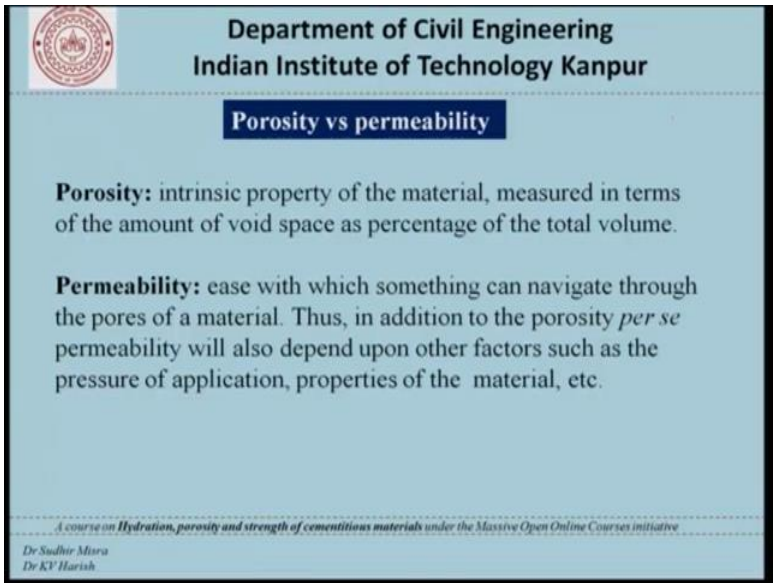

Now to review our concepts of porosity and permeability porosity is the intrinsic property of the material measured in terms of the amount of void space as a percentage of the total volume whereas, permeability is the ease with which something can navigate through the pores of that material. Thus in addition to the porosity per se what permeability would also depend upon other factors such as the pressure of application the properties of the material that is permeating and. so on.

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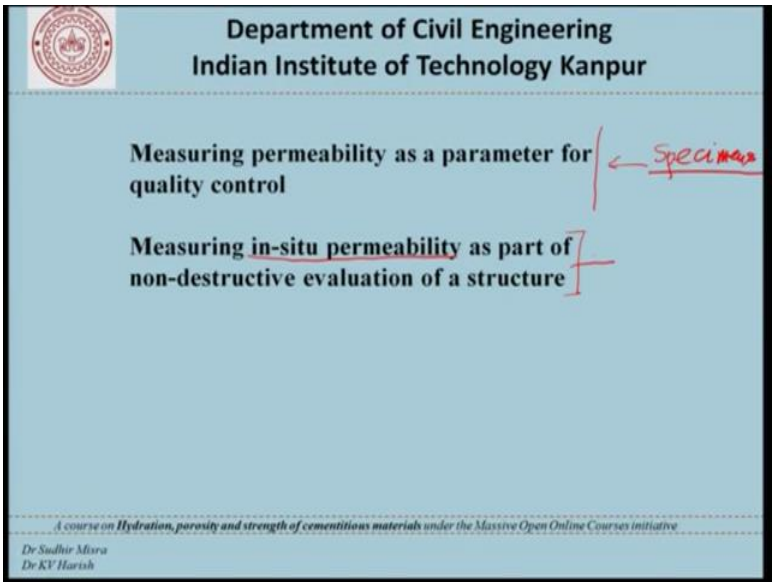

Our discussion when we come to measuring permeability of concrete often gets divided into two parts - one is measuring permeability as a parameter for quality control specifications and so on which is basically an effort to understand the permeability as a property of the material that we are using or we are going to use. Sometimes as engineers we are also called upon to measure the in situ permeability of an existing structure which could be 10 years or 20 years or 40 years old and try to figure out as part of the non destructive evaluation of the structure what is the extent of permeability in that structure.

So, now, in this case we can often work with specimens that is we take concrete and make it into a specific shape and size and test the permeability in the case of an in situ measurement the option or the freedom to generate a specimen is very often not there and we need tests, we need apparatus to take to the structure and carry out some measurements which will enable us to understand the properties of that concrete in that structure.

Today's discussion however, we largely concentrate on this part which is measuring permeability as a parameter for quality control.

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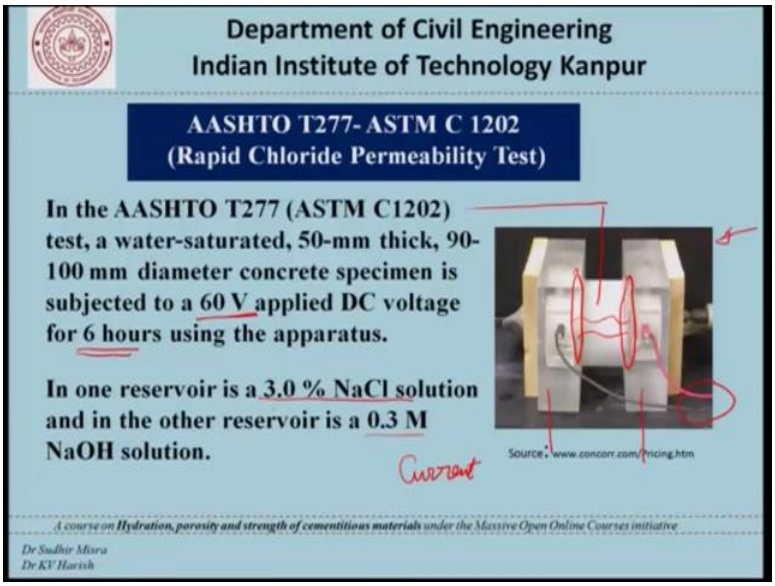

Now, coming to the first test of that nature let us talk about the rapid chloride permeability test. This is the schematic sketch or a photograph in fact, of the test setup which is used here is the concrete the specimen being described a water saturated 50 mm thick 90 to 100 mm diameter concrete specimen which is placed between two reservoirs there is a reservoir here and the reservoir here - one of them has a 3 percent sodium chloride solution and the other has 0.3 m sodium hydroxide solution and we try to apply voltage between these two phases of concrete on this phase and this phase to the extent of 60 volts, continue this measurement over 6 hours and record the current that is flowing between these two phases. So, that in principle is the physics of this test.

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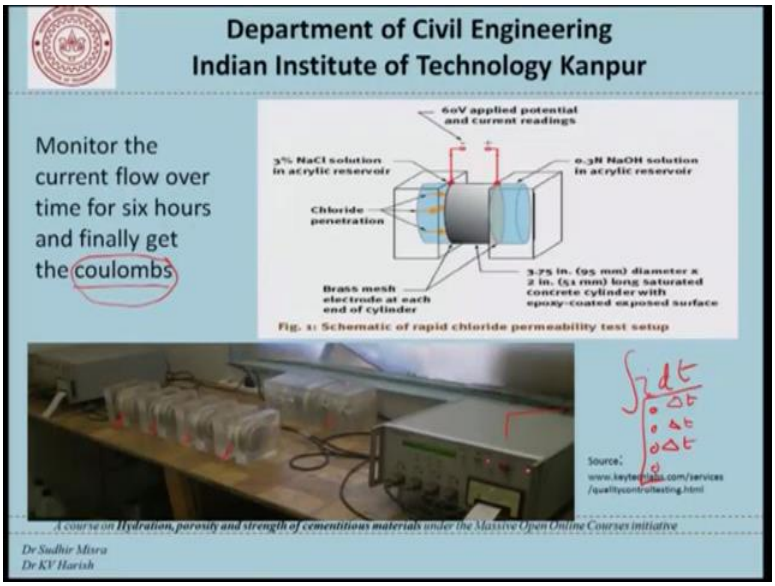

What we do is to monitor the current flow over time for a period of 6 hours and finally, get the coulombs that is the charge that is passed we know that if we integrate current over time we get the charge that is past. So, what we do is keep measuring the, I at different points in time and sum it up using the time steps that we have used here to get the coulombs. This test need not be carried out individually. So, we have apparatus which is available to be able to carry out several such cells at the same time.

So, now what we get at the end of this test is the coulomb value. So, this coulomb value has been found to be related to the chloride permeability of the concrete that we have tested here.

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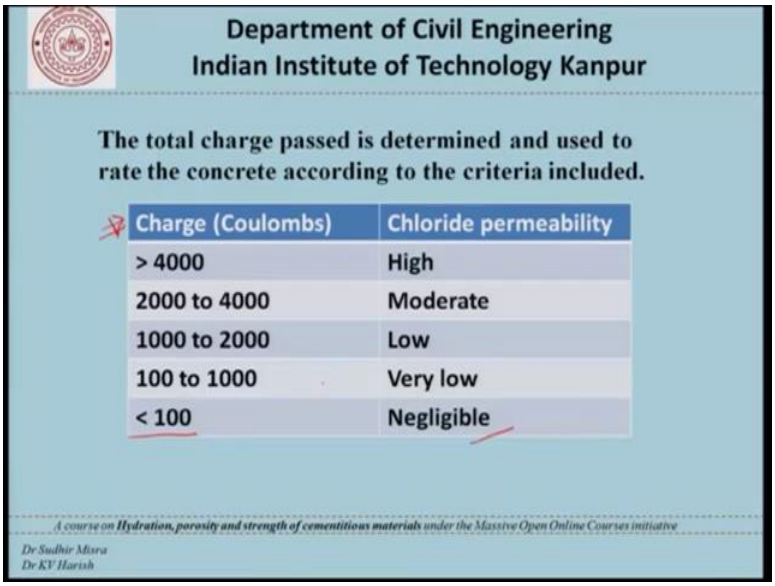

So, now ASTM and the AS and the as to give us a guideline to comment or evaluate the chloride permeability depending upon the charge that we pass or the charge that flows through if the charge is more than 4000 coulombs the permeability is rated as high and if it is less than 100 coulombs the permeability is rated as negligible. In between of course, there are other classifications which tell us that well the chloride permeability is moderate or low or very low. So, this is how this test is carried out and the valuation is done.

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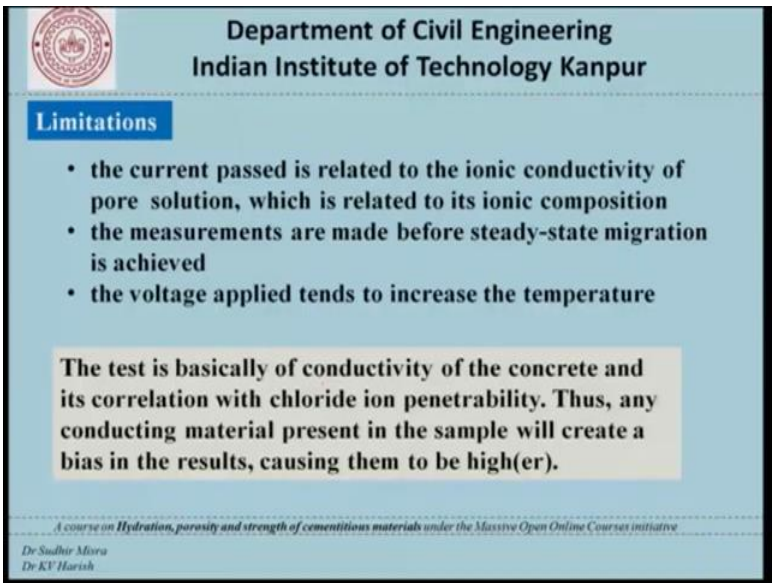

Let us understand the limitations of this test the current past is related basically to the ionic conductivity of the pore solution which is related to the ionic composition and therefore, the composition of cement and so on becomes an important parameter that could affect the results.

The measurements are made before any kind of steady state migration is achieved. So, this test is not really a test of physically the chlorides moving from one side of concrete to the other it is not that best, it is a test of the current flowing through the concrete disc and its relationship with the chloride permeability. The voltage applied tends to increase the temperature and therefore, if for some reason excessive heating is observed the test needs to be stopped. The test is basically of conductivity of the concrete and its correlation with chloride ion permeability thus any conducting material present in the sample will create a bias in the results causing them to be higher having said all this the test serves a very useful purpose.

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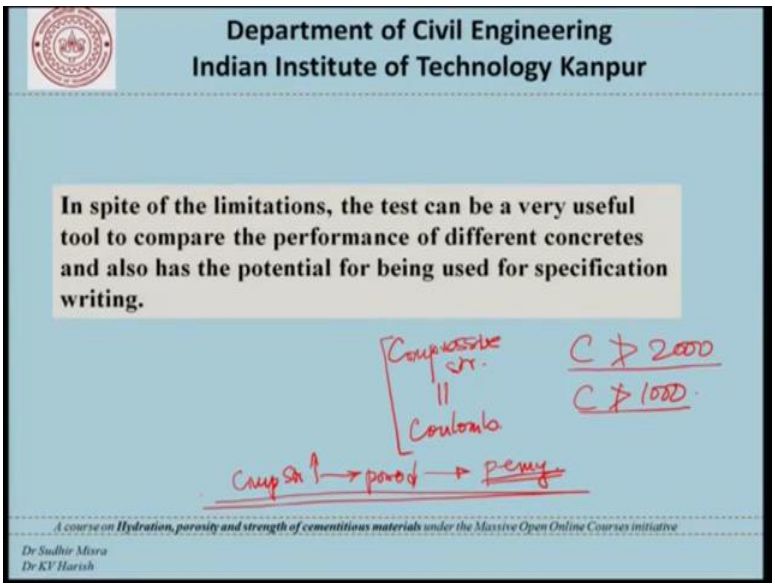

And that is it can be a very useful tool to compare the performance of different concretes and also has the potential for being used for a specification writing, what that means is that we can number one compare the performance of different concretes made with different types of cement different, aggregates different, water cement ratios perhaps different chemical add mixtures and decide which is more permeable or less permeable.

The second thing is that we can use this as a basis for saying that well for a particular application I want a concrete that has a maximum coulomb value of say 2000. We can say that we want a concrete with a coulomb value not exceeding 2000, in a certain other application we can say this is a more stringent application and therefore, the coulomb value should not exceed 1000. So, apart from strength which is usually used as, a parameter to prescribe the concrete this test gives us the opportunity to specify concrete in a slightly different way including the issue of permeability directly.

I am leaving it to you to try to study the literature and try to see if work has been carried out to relate the compressive strength of concrete to the coulomb values. So, traditional wisdom would tell us that as the strength of the concrete increases the coulomb values would go down. Basically as the compressive strength increases what really is happening is that the porosity is going down we are reducing the porosity and if the porosity is going down, so also will the permeability. So, this traditional wisdom is confirmed and can be quantified using an RCPT kind of a test. So, that is the importance of such a specification.

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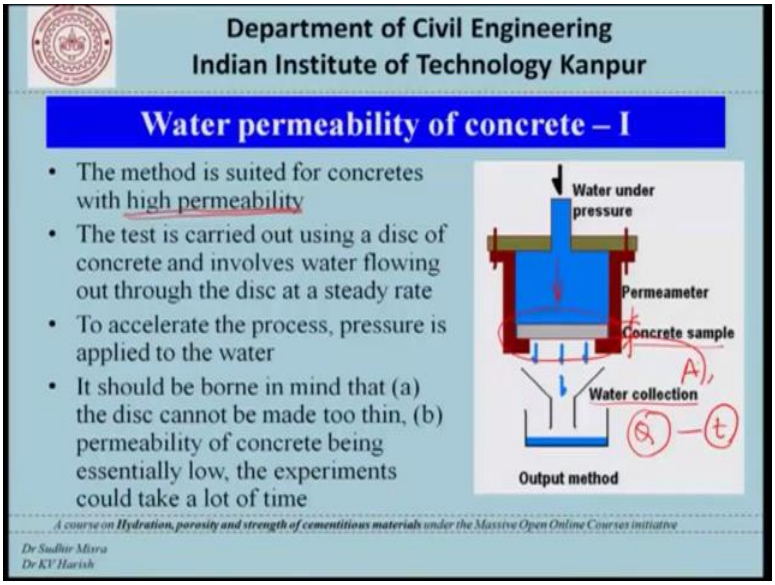

Now let us go to something else we talk of water permeability of concrete the first variation of this test basically has a concrete disc here and water under pressure is pushed through this disc and collected at the other end. So, this test is especially suited for concrete's with high probability. Otherwise you can imagine that it will take either

immense pressure to push the concrete through or it will take a lot of time. The test is carried out using a disc of concrete and involves water flowing through the disc at a steady rate to accelerate the process pressure is applied to the water and it should be borne in mind that the disc cannot be made too thin and the permeability of concrete being essentially low experiments could take a long time. The disc thickness is obviously, a parameter and has to be determined in the light of the pressure being used if there is too much pressure the disc should not basically break.

Now once we know the amount of water that collects here over a period of time we know the cross sectional area and the thickness that we have here we can calculate the permeability in the traditional manner.

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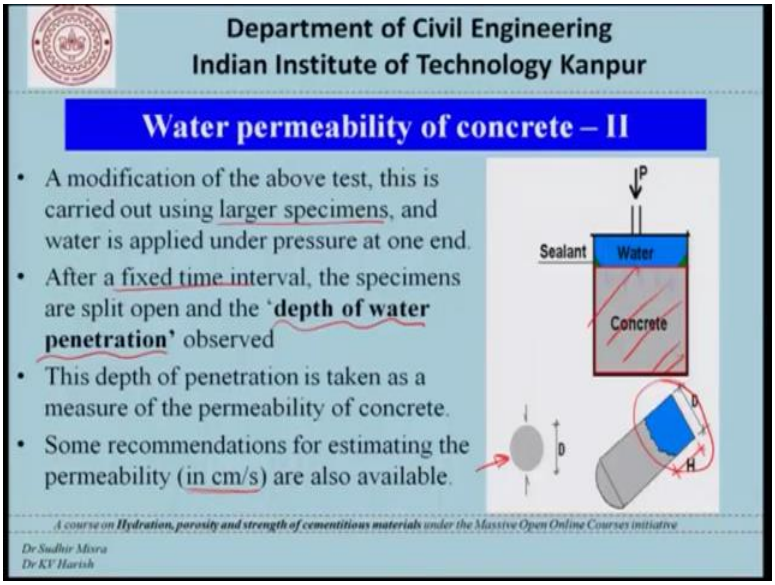

Now, a variation of that test in which the water does not necessarily have to appear at the other end is this test which says that the specimen is the larger specimens. So, this whole thing is concrete here and water is ponded on one side and pressure is applied and after a fixed time the specimen is split and the depth of water penetration is observed. So, as we apply pressure on the water on the one face of concrete it permeates into the concrete and after certain fixed time, if we split this test if we split this cylinder we get something like this and this depth of penetration of water becomes an indicative parameter for the permeability of concrete. This depth is taken as a measure of the permeability and some

recommendations for estimating the permeability in centimeters per second or meters per second are also available relating it to this height.

So, this two is not a direct measurement of permeability in the traditional units of centimeters per second, but in indirect measure of the water permeability of concrete. Like the previous test this test also has the potential of being used for specification writing and also for comparing the performance of different concrete's.

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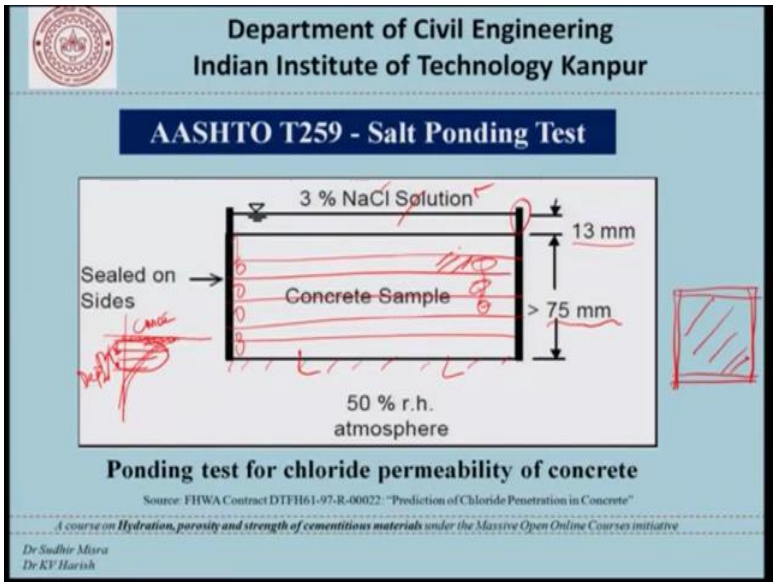

In fact now, let us go to the third test which is the last one for the day and that is the AASHTO T259 salt ponding test you can imagine that chloride penetration in concrete is one of the most severe reasons for deterioration of concrete structures and therefore, has attracted the attention of researchers more than lot of other mechanisms perhaps. So this one here is a salt ponding test where the concrete sample is sealed on the sides and the three percent sodium chloride solution is ponded, we build a dike here on the surface it is like a slab of concrete with dikes on the surface being flooded with a three percent sodium chloride solution about 13 millimeters or half an inch and this concrete sample should be more than about say 75 millimeters and allowed to stand.

Obviously, the environmental conditions in which this test is to be carried out have to be very carefully laid down as well as followed the results of this test for example, would be very different if we take this entire test set up and put it outside in a desert. A lot of this sodium chloride solution would simply evaporate or we take it in a room which is very

cold. So, that really takes us to the point that when we are doing any of these tests the conditions for the test are very important and it should be followed in later and spirit to the extent possible. Now how do we interpret the results of this test?

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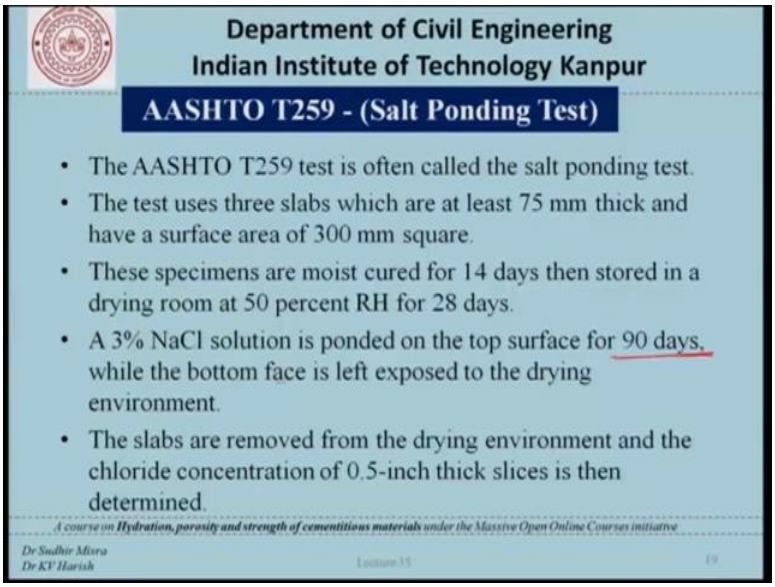

Well this is the description of this test is often called the salt ponding test uses slabs which are at least 75 mm thick and have a surface area of at least 300 mm square. These specimens are moist cured for 14 days and stored in a drying room at 50 percent RH for 28 days. So, this is basically the testing protocol, the method or the conditions of the environment in the specimen preparation which is so important in determining this test or in determining the results of this test. A 3 percent sodium chloride solution is ponded on the top surface for 90 days. So, here we are talking of ponding for 90 days while the bottom face is left exposed to the drying environment.

So, this condition here of the bottom face being left open is to basically allow the water to permeate through if it comes to that the results; obviously, will be very different if we were to seal the bottom as well. So, these are the kind of things which has a student of civil engineering or a student of concrete engineering one must understand. The conditions of the specimen and the specimen preparation are a very very important tool in determining the accuracy the reliability the reproducibility of these testing, reliability of the tests and the results that you obtain. So, now, once we do that for 90 days the slabs are removed from the drying environment and the chloride concentration of a half inch

thick slices is then determined the slabs are then remove from the drying environment and the chloride concentration of half inch thick slices is then determined.

So, basically what is being done is that after the completion of this test we try to figure out how much chloride has penetrated in different layers of this concrete, what is the expected result? If the concrete is impervious it has very low chloride permeability we would expect zero values at layers which are just below the surface.

On the other hand if the concrete was more permeable we would expect chlorides to have permeated deeper. So, what we try to essentially plot is that what is the chloride concentration profile this is the depth that we have and this is the concentration that we get. So, at the surface of course, there will be some amount of chlorides which will be there what happens at half inch discs or discs of say 12 mm 13 mm which we cut out of the sample we may have a core and then try to slice and so on and determine the chloride concentration in those discs and use either the profile or the chloride concentration at a certain depth as a tool or as a parameter for evaluating the concrete. This test too has the potential of being used as a specification writing method that ok.

For this particular application if we carry out this test the chloride concentration in the second disc should not exceed a certain number this could be apart from the strength requirements and so on. We must remember that even though it takes 90 days or 3 months to carry out this test a lot of large projects we have enough lead time to plan our concrete, we have the time to decide what kind of concrete will be used that amount of the amount of planning in fact, we do to ensure the quality of construction the quality of concrete that we use the specifications that we write that is exactly a stitch in time saves nine kind of a situation where if we are spending some time applying our mind and writing the right kind of specifications we will have durable concrete.

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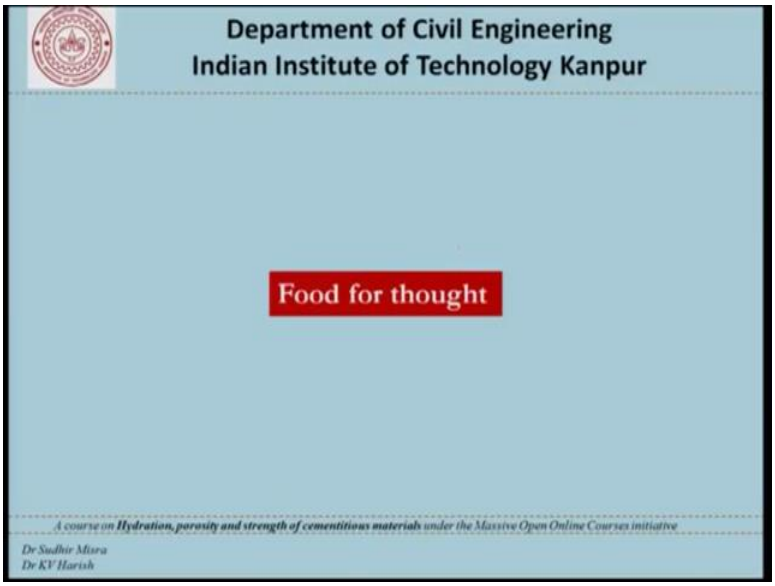

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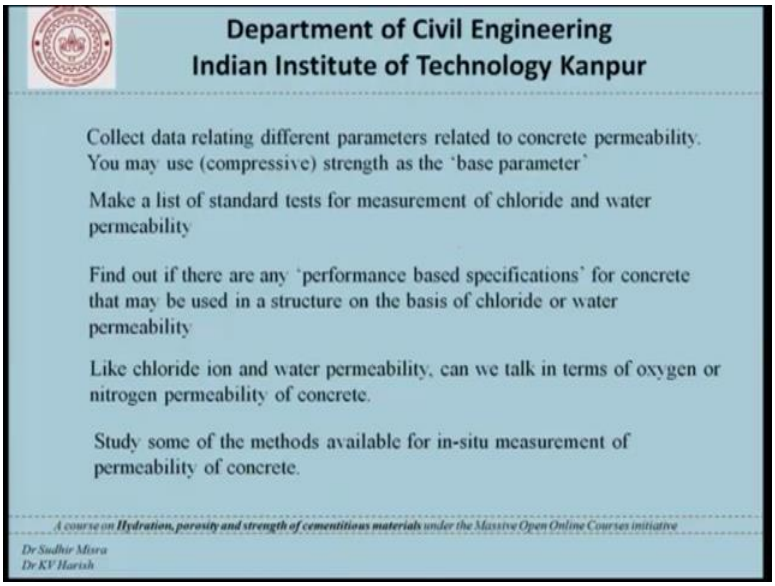

Now with these three tests let us move on let us try to see what all can we do from this point onwards. You could try to collect data relating the different parameters related to concrete permeability using compressive strength as the base parameter that is what I had mentioned in the first test that try to get data relating the compressive strength to the RCPT coulombs or the water permeability or the salt ponding test and so on. You could make a list of standard tests for measurement of chlorides and water permeability this surely is not the only test there are others and those of you who are interested to do that could easily look up the literature and try to find some of these tests and the standards

associated with them and find out if there is any performance based specifications for concrete that may be used in the structure on the basis of chloride, water permeability a kind of specifications that I alluded to in the discussion today.

Like, chloride ion and water permeability can we talk in terms of oxygen and nitrogen permeability of concrete. Oxygen permeability of concrete is also important carbon dioxide is also important from the point of view of reinforcement corrosion and that is something which we are not discussing in great detail today, but if you go to the literature you surely find documents and research work which relates or talks about what are the parameters that determine the oxygen permeability or carbon dioxide permeability of concrete.

You could also study and make a list of the methods available for in situ measurement of permeability. You can imagine that none of the tests that we use today are very amenable to being carried out in field. So, in the field there are different tests and I would like to leave that as homework for you.

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Here is a list of references which will help you understand the subject better.

Thank you.