Admixtures And Special Concretes

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Lecture 06

Overview of Concrete Performance: Basics of Hardened Concrete

fc v/s ft

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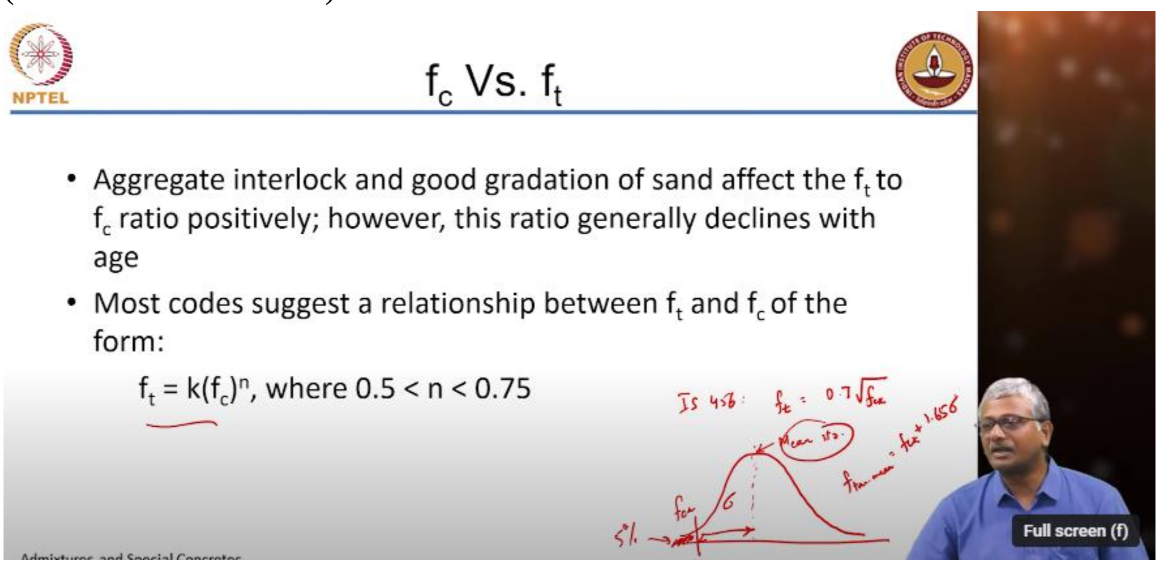

Our codes prescribe a relationship like this f_t ,

$$f_t = k(f_c)^n, \text{ where } 0.5 < n < 0.75$$

In IS 456,

$$\mathbf{f_{ck} = 0.7\sqrt{fck}}$$

Where, $\mathbf{f_{ck}}$ is the Characteristic strength of concrete

Characteristic strength of concrete why do we call it characteristic strength? How do we define characteristic strength? What is the distribution we assume for concrete compressive strength?

We assume a normal distribution. So what is the strength here? This is mean strength where the characteristic strength is it more than the mean or less than the mean? It is here that is f_{ck} so that this area is 5%. What does it mean technically it means that if you test 100 specimens only 5 or less should be lower than the characteristic strength 95 should be above that is the definition of characteristic strength. So when we design concrete in the laboratory we design for the mean strength. So you have to add this value for doing the design. How do you know that value? In a normal distribution you know that because of the standard deviation. In a normal distribution you can estimate the mean from the characteristic value with a standard deviation. So in this case,

$$f_{mean} = f_{ck} + 1.65\ \sigma$$

Now there are obviously distributions that may not be normal but for compressive strength it is hard to imagine that you will have a skewed distribution.

Modulus of elasticity:

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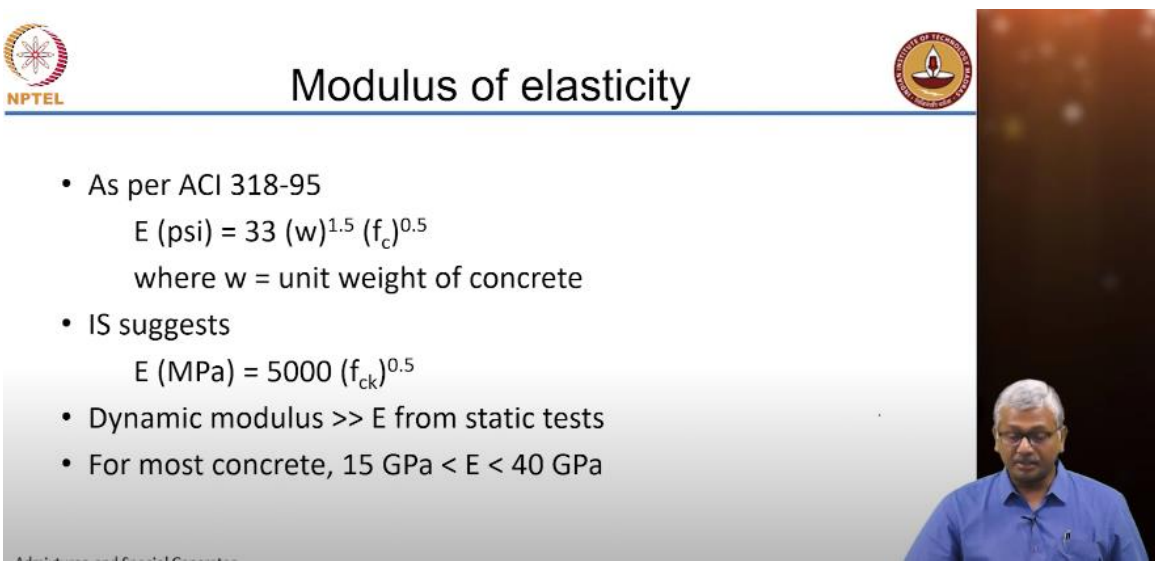

Modulus as I said is a material property very often we again take the help of data that is available to express modulus in terms of compressive strength. It is quite easy to do that so as engineers we would like to take things that are already available from literature. So all of these relationships, even this tensile strength relationship, there is no physical meaning of that. Why should one strength be related to the square root of another? Does not make sense. So it is basically all data that has been compiled over many years and people have taken advantage of the data to sort of prescribe this relationship that makes it easy in a construction project to proceed without testing the flexural strength directly. You can just do compression which is very easy to do. Flexural strength not everybody has the apparatus on site to do. Similarly modulus strength itself people may have but modulus is very unlikely that people will have the right apparatus to determine modulus of elasticity. In such cases we often go with these prescribed relationships for instance the ACI relationship is derived from this principle equation where the modulus is expressed as a function which depends on the unit weight of the concrete and the compressive strength of the concrete. And actually our IS relationship,

$$E\ (MPa) = 5000\ (f_{ck})^{0.5}$$

IS basically gives you a simpler suggestion, which is now going to go out of the window because new relationships are coming up based on data that has been recently collected. And this particular relationship is only valid for concrete of strength typically less than 50 or 55 MPa. Since we are using more and more of high strength concrete these days there is a need obviously to come up with more suitable relationships that reflect what we are using today. For most concrete modulus values will vary between 15 and 40 GPa obviously the higher the strength of the concrete the higher will be the modulus of elasticity.

Poisson's ratio:

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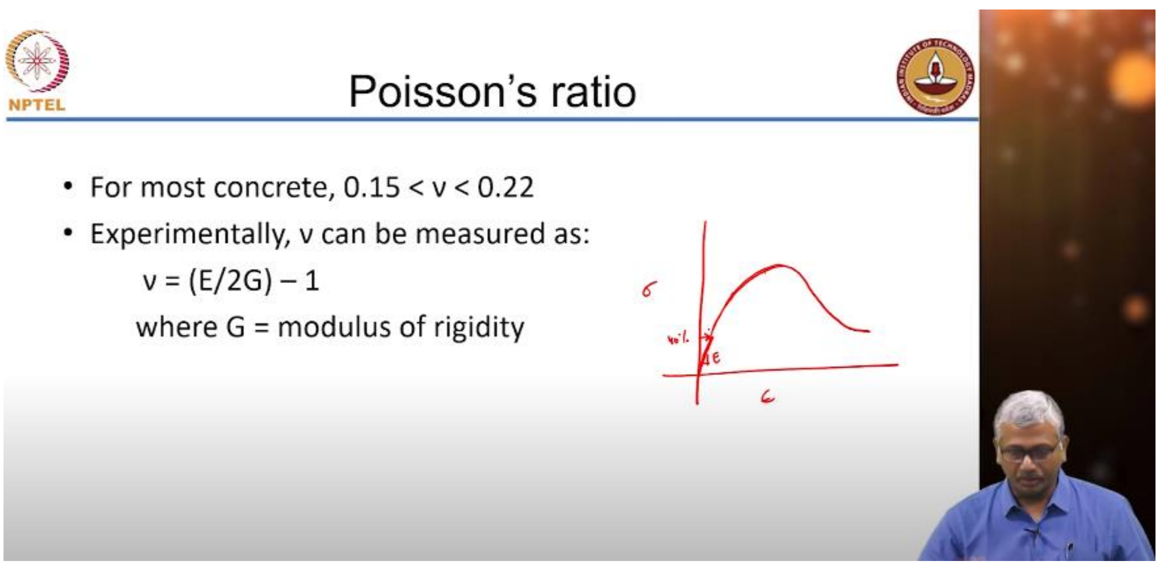

Poisson's ratio we do not typically measure it but in measurements that have been done Poisson's ratio value for concrete has been around 0.15 to 0.22. You can determine it indirectly by testing both the modulus of elasticity and modulus of rigidity and using the simple constitutive relationship.

In concrete it is a little bit more complicated because you do not really have a clear zone of a linear stress strain relationship. It is not that easy in concrete. Let me just anyway draw the stress strain relationship in concrete. So typically you have sort of a linear behavior in the beginning but mostly a non-linear behavior you reach the peak stress and then there is some bit of ductility beyond the peak stress. We do not call it ductility, we call it a quasi-ductile or quasi-brittle relationship in concrete. It is not like steel where you have a large extent of deformation that can actually happen. In concrete there is some deformation that can actually happen. What we do is we take the initial about 40% of the load or 40% of the peak stress and define our modulus and all our other constitutive properties like Poisson's ratio within this loading area. What happens beyond is a highly non-linear sort of a behavior which we do not really have the possibility to perfectly model and we cannot really predict what is happening there because of which the choice of modulus is only up to the first 40% of the load or if you go to the British standards is even 33%. So even there the relationship may not be perfectly linear but if you test fast enough you are likely to get a linear relation.

Because of the non-linear sort of a behavior you do not have a distinct point where concrete is expected to yield, there is no yielding of concrete, there is only failure, there is no true yield. In steel you have a distinct yield point. Even in steels that do not exhibit that distinct yield point you still assume that there is some strain level at which we can expect yielding to have occurred. What do we call that? Proof stress. We draw a line that is parallel to the initial linear portion wherever it intersects the curve that is basically the proof stress and we take that as the yield point.

Time dependent deformations:

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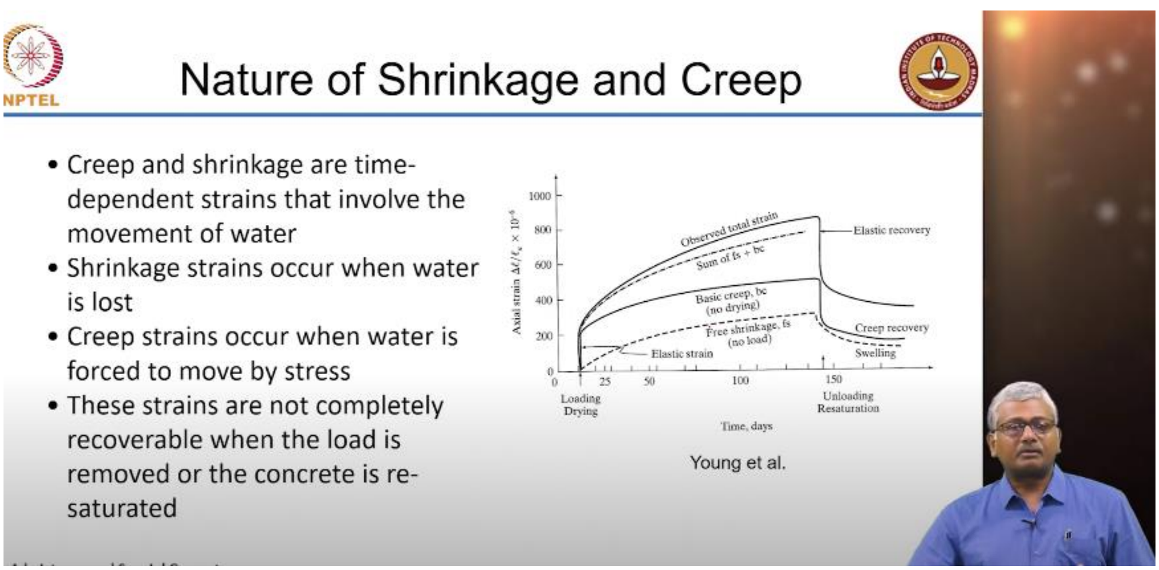

What happens in the long term is that concrete behavior is subjected to time dependent deformations. Primarily it is because there is water inside the concrete and this water will move either when you keep the load on for a long period of time just like the consolidation in soils. Why do soils consolidate? Because with the effect of the load over time there is dissipation of the water that is underneath in the soil. Similarly in concrete the longer you keep the load the water inside the concrete tends to move around and that adjusts the structure of your concrete. Because of this design for creep becomes quite significant in structures that are expected to be dimensionally stable.

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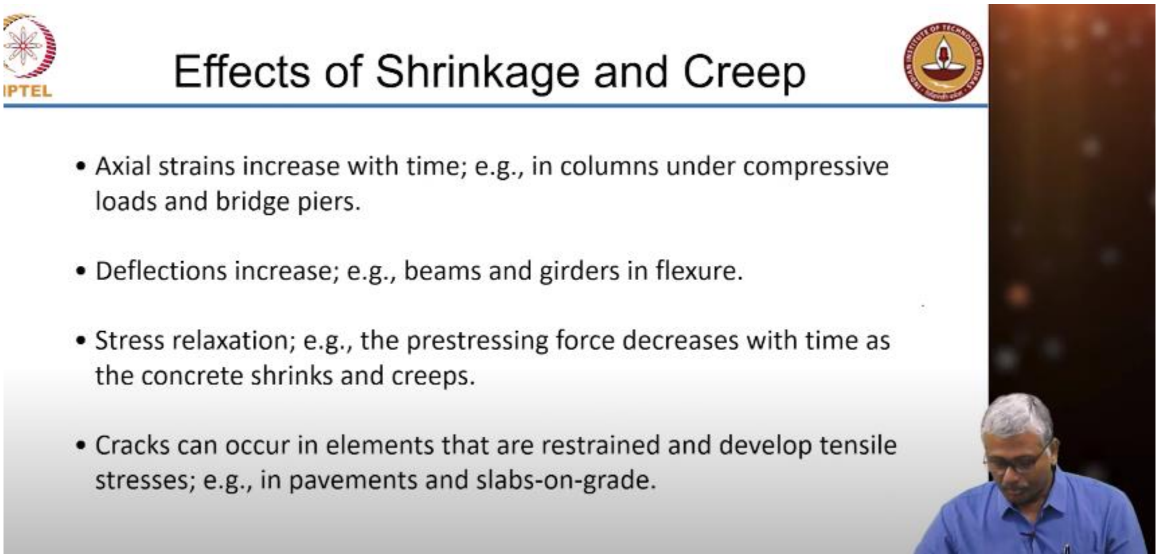

For instance if you have columns in tall buildings, ground storey columns are typically expected to be high strength concrete. Now if there is any change in height of the column over time that is going to affect the way that the load is distributed across the rest of the building. So it is very critical to define this extent of creep and have some means of actually measuring it properly. So if you take a typical axial strain versus time relationship for concrete, assuming you have a concrete column which is not subjected to any load. The water inside which is free now wants to come out, it wants to start drying. So there is free shrinkage in the case of drying, it is slowly drying out. Now imagine one more column which is totally cladded, the column is totally cladded there is no drying happening. In such a case what is going to happen? You will not have any shrinkage, assume there is no shrinkage. What is going to happen then? Because of the constant load in the column there is going to be some creep.

Basic creep is defined as when there is no drying. Let us take a polymer, in polymer there is no effect of drying. So there is only going to be basic creep in that case. But in concrete there is drying which leads to shrinkage and then there are load related effects which we call creep. Now when both of them happen together you can expect that you will get a strain which is a sum of your drying shrinkage and basic creep. But in reality you get actually a total strain that is greater than the drying shrinkage and basic creep and this is because of the presence of drying creep. In drying conditions the creep becomes greater.

So in reality let us say you take a metro structure, all the columns that are standing there are subjected to drying, they are subjected to a constant load. So you have both the effects of drying and the creep and this is going to lead to a sum total of the strain that is greater than the shrinkage and the basic creep that is determined separately. So because of this today the tall building code that is out for the last 3-4 years the tall building code actually tells you that when your strength of the concrete exceeds 60 or 70 MPa ensure that you have done the right tests to determine the effect of the creep. It is no longer the creep coefficients that are prescribed in IS 456; they are not permitted to be used anymore. You need to start measuring and that is where it becomes very critical to understand what is contributing to the overall deformation. But needless to say the movement happens because of the presence of water inside.

So when I test high strength concrete what is going to happen? Is the effect going to be small or big when I test high strength concrete? If there is less water in the system there will be less creep and less shrinkage overall as compared to moderate or low strength concrete your water is less so you will have less creep and less shrinkage. Now of course in the beginning when you start loading there is an elastic strain immediate response of the concrete. If at any stage you unload the concrete there will be an immediate elastic recovery. What elastic strain has been induced will be recovered immediately. Incidentally there is also a small strain that is recovered after that which is called creep recovery. But even after removing complete load you still have a permanently built up strain in the system which will never go away. And because of this creep and shrinkage can produce strains that are additive in nature leading to a quicker collapse of your structure. This is okay in the case of a column. You have compression so it is shortening the column you have shrinkage it is also shortening the column.

What about a beam? What is happening in the case of a beam? Let us say a simple simply supported beam is bending like this. The bottom is under tension because of the effects of the load. The tension is only going to increase the creep is going to increase the tensile stress or tensile strain rather. Creep is going to add to the tensile strain but what about shrinkage? Shrinkage is trying to push the member back so there the creep and shrinkage are acting in different directions. So depending upon the geometry of your structure and the way that the load is acting you may have creep and shrinkage either acting together or opposite.

Consider a prestressed beam. What is happening in prestressed concrete? You have steel which has been pulled and concrete that has been pushed. So what is going to happen with time? Loss of prestress will happen why? Because steel initially was subjected to a particular level of tensile stress it is relaxing with time. Steel starts relaxing you have seen this right when you tie a string with time it starts drooping because internal stress distribution happens we call it relaxation because of which that loss in the stress is happening inside. When the steel loses stress and the concrete starts creeping you will have a loss of prestress. So in prestressed members creep and shrinkage are going to be extremely critical to analyze and design for. And structures like columns and tall buildings are again going to be subjected to very high levels of creep and shrinkage.

Durability:

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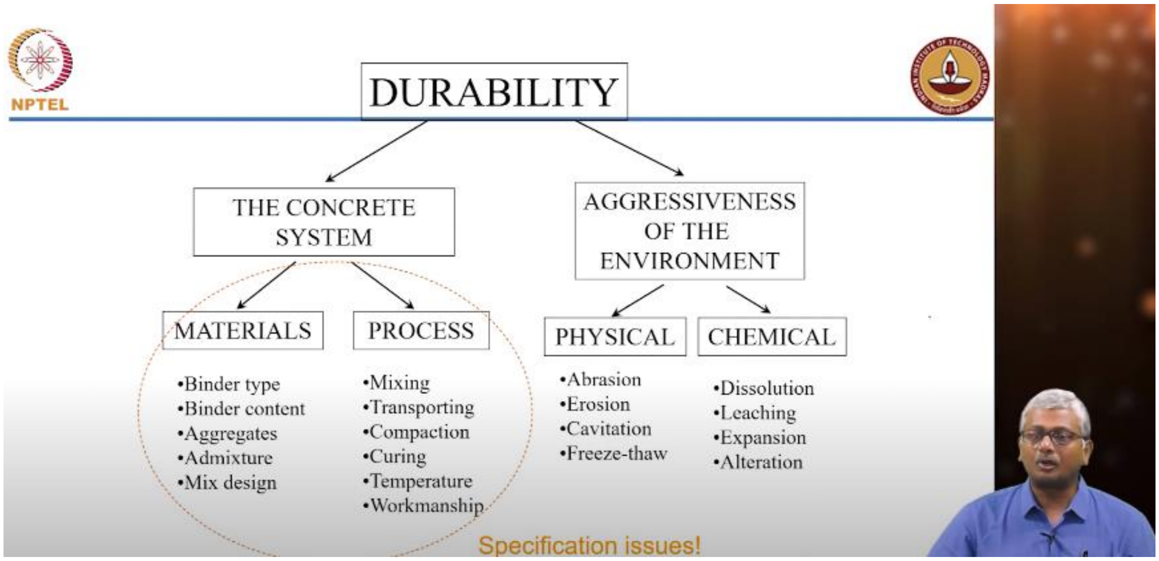

Now coming to the other long term aspect of concrete its durability. You design concrete considering the types of materials to be used and the process of actually putting the concrete together which includes mixing, transportation, compaction, curing, temperature and ultimately the workmanship. All of that goes into actually describing the properties of the concrete. If you do not cure well enough as we discussed earlier, strength may not get affected significantly but the curing is definitely affecting the durability of the concrete.

Now there is also the consideration of the type of environment and that dictates the type of processes that lead to deterioration. If you are in Chennai what the environment is, what kind of deterioration do you expect more? Chennai is a coastal city so expect corrosion. Corrosion of reinforcement is going to be primarily driven by chlorides which are present in the sea water or in zones slightly away from the coast the airborne salts that are taken up by the winds which will deposit the chlorides into the concrete and that will ultimately drive the corrosion of the steel. If you go further inland you do not have any chlorides but then atmospheric carbon dioxide can penetrate the concrete and lower the pH of the concrete causing corrosion. So all of those things you need to understand and design for.

There are physical mechanisms and chemical mechanisms. Abrasion: where do you need to design for abrasion? Abrasion of concrete. Pavements or aircraft runways you need to design for abrasion resistance for concrete.

What about erosion and cavitation? Abrasion is a very important part of the process because when the river is in spade it will carry huge rocks and boulders also along with it. So all that goes over the spillway and falls on the concrete and you really need to be worried about what is going to happen.

Cavitation of course happens because of the drop of water and the bubbles that finally end up bursting and that can create significant pressures that can damage your concrete.

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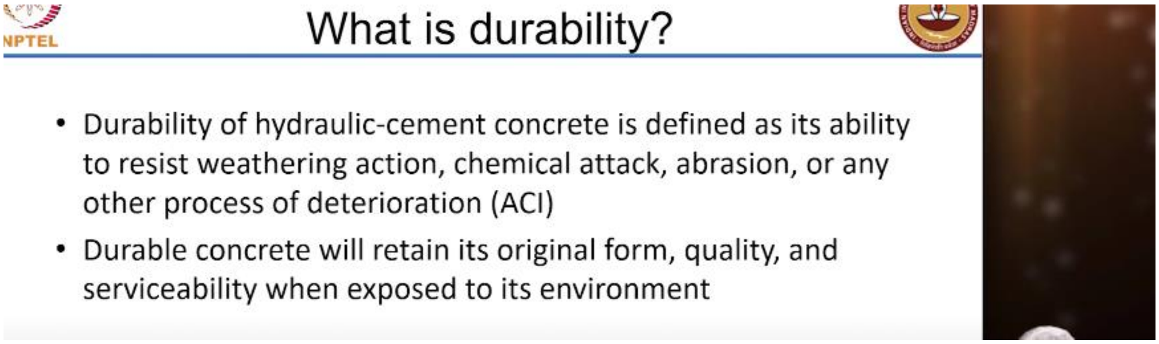

So durability is basically defined as the ability of concrete to withstand deterioration. All kinds of deterioration are not load related; mostly they are environment related, that is the distinction between a structural loading related problem and a durability related problem.

So durable concrete is expected to retain its original form, quality and serviceability when exposed to the environment. So we design for concrete durability based upon the environmental service. When we design in Chennai the considerations will be different as compared to designing in Bangalore because we have different mechanisms acting in different locations.

Durability problems:

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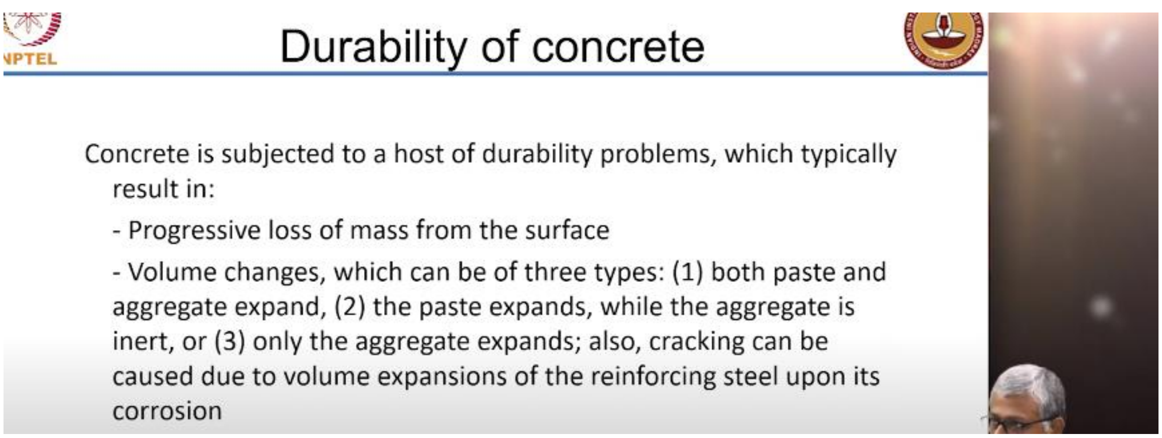

Now if you look at most durability problems you will see that they are resulting in manifestations that are not all that very different. Most of these problems will relate to some gradual deterioration or erosion of the surface of the concrete slowly losing mass from the surface. Alternatively many other durability problems may lead to expansion or volume change of the concrete. Now of course volume change also happens in creep and shrinkage but we do not consider that to be a durability issue truly speaking everything happens together but durability is taken as the effect of the environment and here volume change can either change the volume of the paste or the aggregate or the steel in corrosion steel volume also changes that leads to cracking in the concrete. So all of these have to be assessed separately and designed against.

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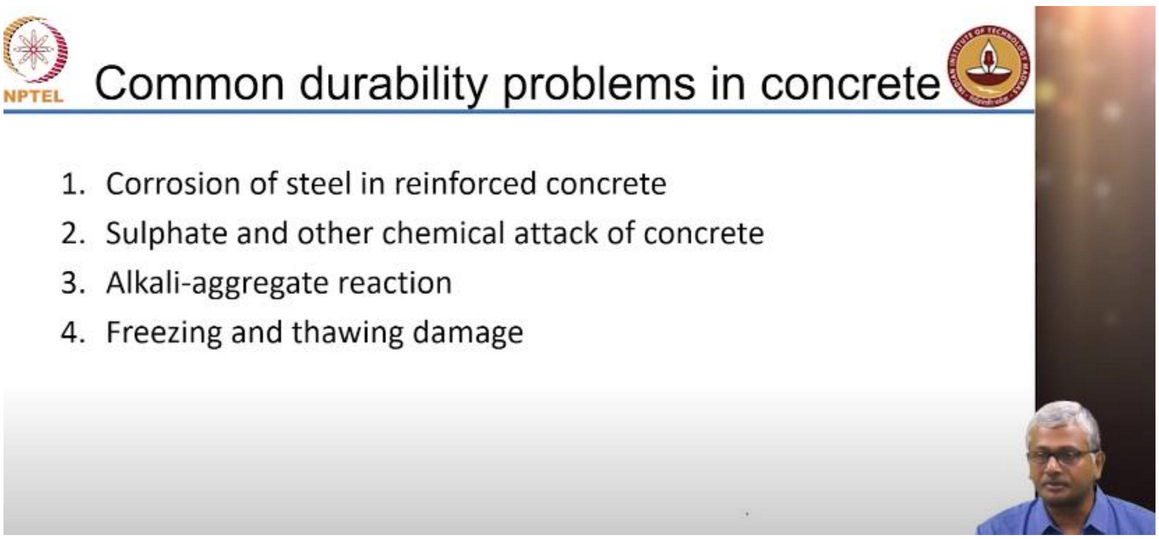

But if you look at all the common durability problems in concrete including corrosion, sulphate attack and chemical attack, alkali aggregate reaction, freezing and thawing.

The one common feature to all of these is what is common to all of these is water. Because of corrosion of steel you need moisture for the reactions to proceed, freezing and thawing obviously is the penetration of water, conversion to ice and so on. Chemical attack can only happen when the water penetrates the concrete with the salts that damage the concrete, alkali aggregate reaction the expansions happen because of the imbibition of water. So without water you do not really have a durability problem. So generally water is either involved in the reaction or is necessary for the manifestation to occur. So because of this if you keep concrete dry throughout its lifetime you do not have a durability problem. If you keep concrete water resistant for a longer time you do not really have any of the durability problems. So very rarely you will have a problem created because of factors other than water. So because of this we design concrete to be watertight or impermeable.

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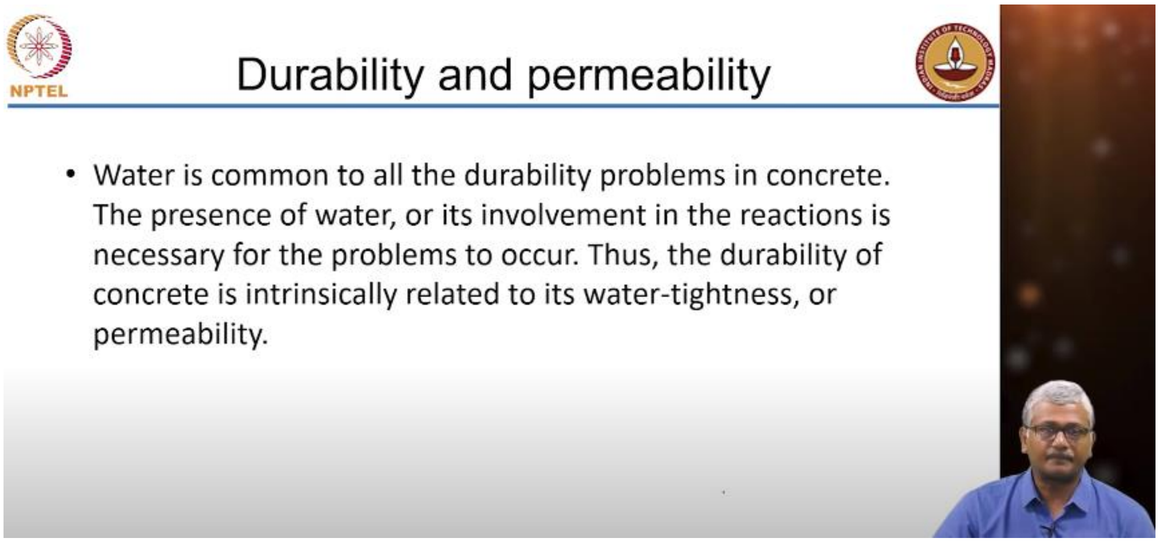

So durability is generally measured in terms of the permeability of the concrete the more permeable the concrete the less durable it is going to be. That has been the primary basis for defining the durability test methods that are typically carried out. We do not usually test the actual performance in different environments because each test may take several months to some years to actually perform. So because of this we define the concrete quality in terms of its impermeability measured by different means and we use that as an estimate of concrete durability.