Development and Applications of Special Concretes
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Lecture 04
Review of Normal Concretes Basic Properties

Namaskar and welcome back to this series of lectures on development and applications of special concretes. This is the first module that we are doing, review of normal concretes, where we are talking about the different properties. So far and having talked about the properties of fresh concrete in the last class. We will largely concentrate on the properties of hardened concrete and the acceptance criteria as laid down in IS456, which is the Indian code for construction of concrete structures. And, this is the 4th lecture in our series of this module.

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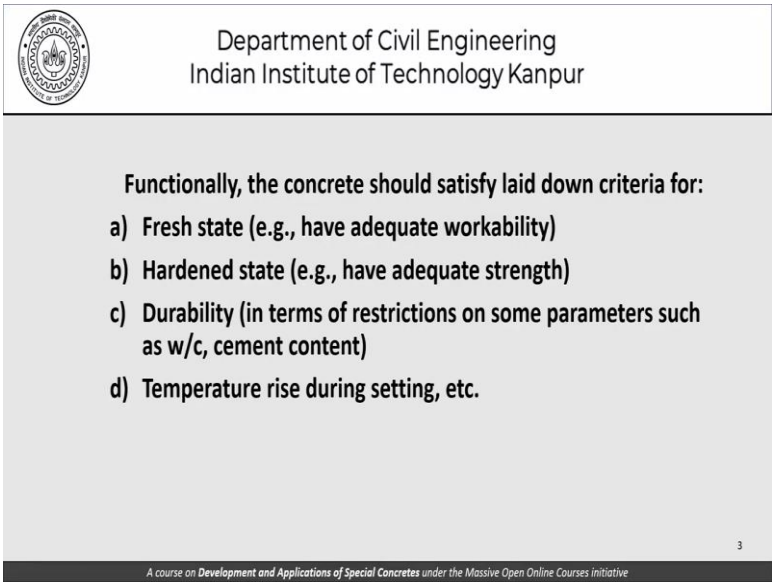

Resuming our discussion from where we are left let us recall functionally the concrete should satisfy the lay down criteria for fresh state, which could be in terms of workability or air content, setting time and so on. Hardened state should have adequate strength or whatever properties are required, there could be durability considerations in terms of parameters such as water cement ratio, cement content, temperature rise during setting and so on.

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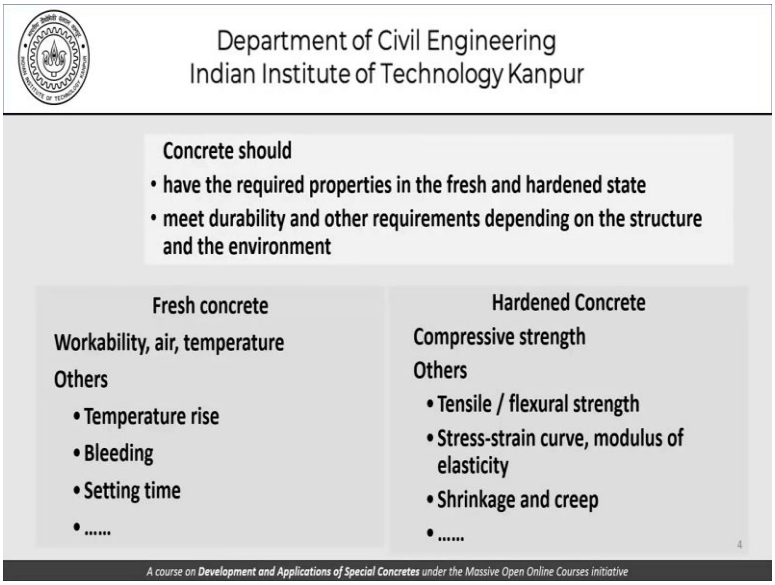

We also looked at this slide before, where we talked of the different properties associated with fresh concrete and we discussed each of them in the last class. And today our discussion will largely be on properties of hardened concrete. So, these are some of the properties in fresh state which we have already talked about.

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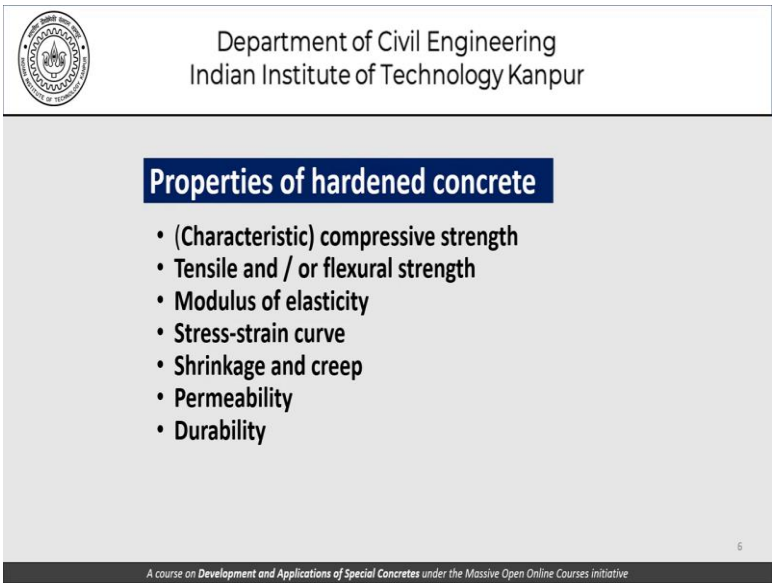

And we commence our discussion on properties of hard and concrete.

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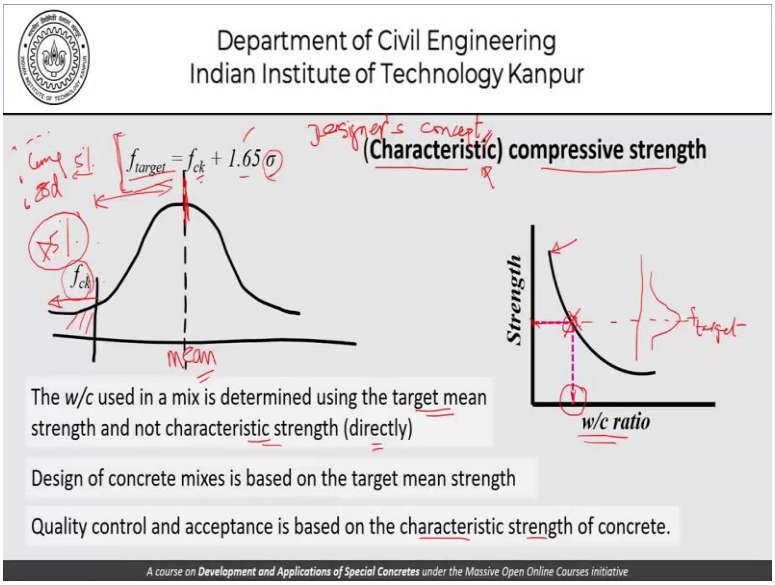

Now, coming to the first of them which is perhaps the most important is the idea and the property called characteristic compressive strength. Now, what is this characteristic compressive strength, we know that there is a compressive strength of a concrete as a cube, if it is tested, it will have a certain compressive strength i.e., beyond that load it will fail, whatever that failure means. But what is the characteristic part of it.

Now, here is the normal explanation for it, that if we take a large number of cubes, large number of cubes from a given concrete. For all kinds of reasons, we are not getting into those reasons here. But for all kinds of reasons, they will follow some kind of a distribution and this fck is called the characteristic strength and is defined in a manner that not more than 5% of the overall cubes are allowed to fall below this value with other conditions like when the strength is measured at 28 days, when the curing is standard, when cubes of specimens of a certain dimension are used, and so on and so forth.

So, the crux of the matter is that, when tested not more than 5% are expected to fall below this value. Now, this please remember, is a designer's concept i.e., concrete engineers that is at site, we are concerned with characteristic strength, we should know what is characteristic strength. But we design the mix for what is called the target strength i.e., fck + 1.65*sigma. Now, this normal distribution, if you want to assume it and that is what we do this is known to have 2 parameters that define it.

One is the mean and the other is the standard deviation. So, this 1.65 comes from the fact that we are talking of this distance being such that the area here on this side is 5% to do that we

get f target which is this value here f target is this value here this value is f ck + 1.65*the standard deviation that is associated with this distribution. So, if we want to have not more than 2% fall below the characteristic strength which is a new definition of characteristic strength then this 1.65 will change, if we are happy with 10% falling below them, then that number will change and so on.

So, having said that the normal definition is 5 below this value not more than that and therefore the mix is designed for a target strength of fck + 1.65*sigma. Having said that, we also know that the strength of concrete is inversely proportional to the water cement ratio, that we use and that is given by a curve like this we could even take it to be linear for all I care at this point.

It really does not matter the actual curve depends on the different kind of characteristics of the materials used, the kind of cement, the kind of aggregates and so on. But yes, in principle the relation is inverse that is if water cement ratio increases the strength decreases. So basically, for a given strength that we need, we use this curve to get to the water cement ratio that we need for that particular mix. More of this will do, when we try to do some proportioning, but for the time being we leave it at that.

So, the water cement ratio used in a mix is determined using the target mean strength and not the characteristic strength directly. Of course, the target means strength being a function of the fact of the characteristic strength indirectly of course, when we are choosing the water cement ratio, we are choosing the characteristic strength as well I mean, we are accounting for the characteristic strength as well.

But basically, on the from the y-axis we take the target mean strength. So basically, probably if you look at some of my older lectures, you will realize or you can find out that the strength at this point will be distributed for a certain value and this value here is the target strength that we did let me talk about. So, this is their target so for this target strength what should be the water cement ratio that we use?

This is the value that we use. Design of concrete mixes is based on the target mean strength and quality control and acceptance is based on the characteristic strength of concrete. This quality control acceptance is not based on target mean strength. In fact, the target mean

strength largely remains on the files, nobody really knows as far as the structure is concerned, as far as the designer is concerned, he is not even bothered, he or she is not even bothered about what was the target mean strength.

So, that or so long as they know that we have designed a structure for M20 concrete or M30 concrete meaning thereby that if it is M30 then the characteristic strength is 30 that means from that concrete mass that we have not more than 5% of those samples would be falling below 30 MPa. Now, that is what is the essence of this discussion. So, you have to have this picture very clear in your mind that there is something called characteristic strength.

There is something called target mean strength and the average value the expected value from a large mass of concrete, which has a certain water cement ratio, is actually the target strength is not it because the characteristic strength is an artificial construct that we have created in order to have certain design issues sorted out. Let me begin by asking you some questions.

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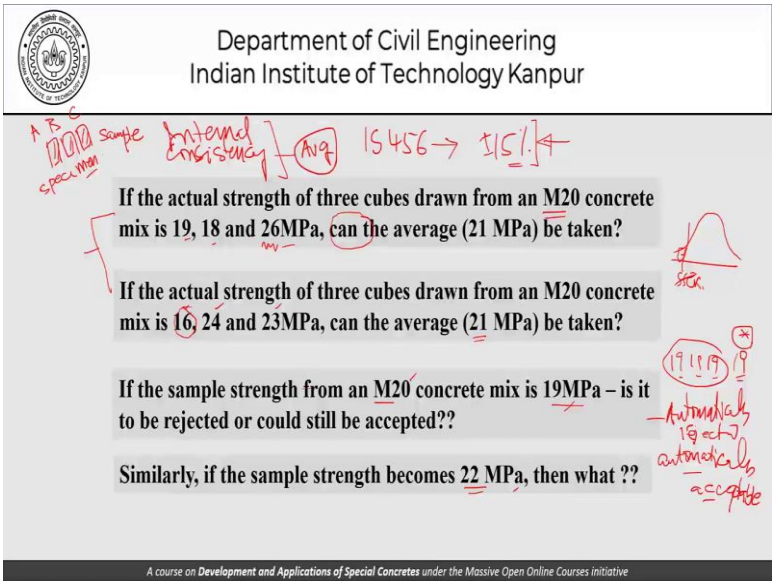

We know that we do our quality control using 3 cubes we have 3 cubes and we try to take the strength of these 3 cubes and that is what is represented by a sample and let us call the each of these cubes as a specimen. Now, having said that if the actual strength of 3 cubes drawn from an M20; concrete is 19, 18 and 26 MPa can the average of 21 MPa be taken. So, if you take the average, it will turn out to be 21 let us say.

Now, in this case is it fair to take this average that is what it is meant when it is said that can the average be taken obviously what I am alluding to is the fact that there is 19 and 18 sitting

here but then there is some kind of an outlier 26 should this be allowed to interfere in our average? Similarly, if there were the strength was 24, 23 and 16 so the outlier in this case is the smaller value.

Can the average of 21 MPa be taken, so the question in both these cases these hypothetical cases that I have put forward before you is, if I have these 3 cubes a, b and c, what should be the kind of consistency or more is precisely speaking the internal consistency in these readings in order that an average can be taken. Now, as far as IS456 is concerned, it gives you a guideline on that and that is where you are supposed to look up the + 15%, the + - 15% kind that guideline.

Internal variation should not be more than + - 15%. So, that is where this guideline comes in. So, this is the first step that we need to check as far as heart and concrete and acceptance is concerned that is the sample is indeed consistent and worthy of being considered further for acceptance whether it is acceptable or not. Please remember that being worthy of consideration does it make it acceptable.

Now, let us go to the next question if the sample strength from an M20 concrete is 19 MPa is it to be rejected or it could still be accepted. So, in this case for example the numbers turn out to be 19, 19, 19. All the 3 cubes consistently give us 19 MPa average of course will be 19 and now since it is an M20 concrete should this concrete be simply rejected? The argument is arising from the fact that we are talking of a normal distribution.

We said that ok there is a fck, there is a fck here and it is one sample falling just below the fck 5% were allowed to fall this one sample can we take a decision on this one sample if it only was the one sample which is available to us. Let us go the next step, if the strength the sample strength was 22 MPa, which is just on the other side instead of 20 MPa it becomes 22 MPa. Does it make this sample automatically acceptable?

What we talked about in the previous discussion was something which is automatically unacceptable that is automatically rejected and here we talk about automatic acceptance with just one side or the other of the characteristic strength. So, this question we need to answer, when it comes to the acceptance and that is a very important part of our understanding in terms of properties of hardened concrete is concerned.

Of course, the fact that it has a strength yes, the question is, is that excel, is that strength acceptable to us? Now, for that we need to go back to some kind of guidelines and here are the guidelines that are available from IS456 which is the Indian code.

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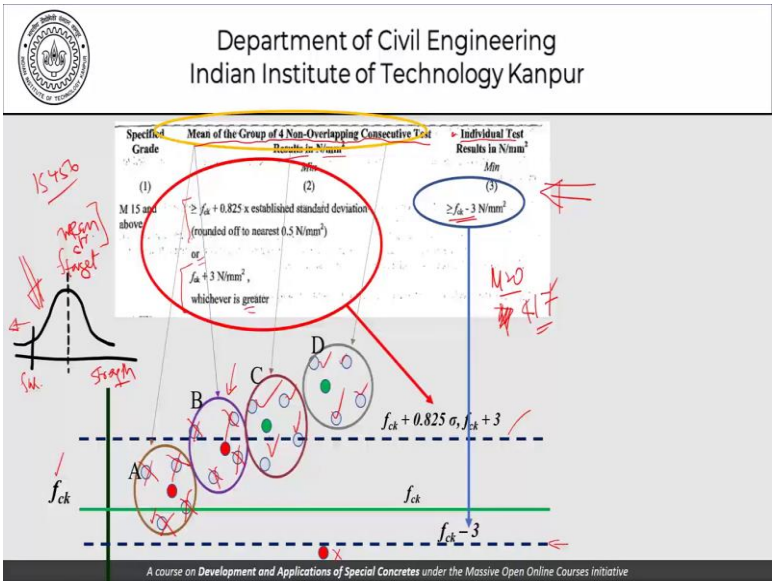

Now, this Indian code tells us 2 criteria one is the mean of the group of 4 non-overlapping consecutive test results in newtons per millimetre square should be greater than either this or this. So, we try to discuss this a little bit and the individual result should not be greater than or should not be less than or should be greater than fck - 3. So, it should not be far below the fck value. So, this is something which we will try to examine and understand what this means.

If we were to plot a line which says fck is here. We want to plot another line which is fck - 3. So, this here on this axis we are plotting something like compressive strength of samples as they come. So, here I have got another line fck - 3 and there is another line which is fck + 0.825 sigma or fck + 3. So, I can have 2 lines it says or whichever is greater. So, let us say that this is the line that represents the greater of the 2.

Now, the point that we have to discuss is with these parameters, how do we accept or reject concrete cubes. Suppose we have a value here this value is automatically rejected because it is an individual value which is lower than this line. So, this value is automatically rejected. We have to look at this acceptance criteria in light of this distribution that we talked about just a moment before.

There is a fck here and there is a fck target here, which of course instead of calling it target we can even call it the mean strength. So, this is the mean strength of the concrete that we have designed so we are not talking of nominal mixes here, we are talking of proper design mixes. So, those design mixes have been designed to have this value as the mean strength and we are trying to figure out whether concrete cubes or samples, which have been brought to us meet the acceptance criteria.

So, this is the individual which is failing these criteria. So, basically what is being said is that even though science allows 5% specimens to fall below this engineering tells us that we cannot be allowed to go far below this fck and in no case we will allow anybody in our concrete structure, any part of concrete to be further than fck - 3 from there. So, if you are having an M20 concrete. You cannot have a strength which is less than 16 MPa or 17 MPa.

So, 17 is acceptable under very certain special conditions as an individual test, yes, it is acceptable but if it is less than 17, it is not acceptable regardless of whatever else happens. So, having said that let us move forward and try to examine these clauses now. So, all these 4 samples are meeting this clause here. So, they are all above the fck - 3 line and we are trying to examine the acceptance or acceptability of these 4 specimens or these 4 samples, I should say with this clause.

So, what it says is the mean of these 3, so mean of these 4. So, the mean of a group of 4 non-overlapping consecutive. So, these are consecutive samples and this is the mean. So, this mean should be greater of the 2. So, now here is this mean which is just above fck. This fellow is below fck but higher than fck - 3 therefore this is acceptable. But the mean of these 4 is not clearing this line and therefore all of them become unacceptable.

Similarly, let us go to these 4-set b, all of them are greater than fck, okay, it is not that one of these guys is below fck, one of them is just about fck, all these fellows are above fck, but if the mean is below this line, still all these fellows will have deemed to have failed. However, if the values of these 4 samples was such that the mean was higher than this then all these 4 would be cleared everything is okay moving further.

Of course, if everything is above this line, obviously the mean will also be above this line and in that case all these guys are automatically. So, this is the kind of interpretation that can be given for this set of rules, which is given in IS456, what talks about individuals test results and then it talks of a group of 4 non-overlapping consecutive test results. So, these are consecutive test results they keep coming in one after another and you try to group them into 4 groups of non-overlapping consecutive, find their mean, keep checking.

If their mean is greater than this line and if it is not, then all these 4 guys have to be rejected and whatever the sample or whatever the part of the structure that they represent that needs to be redone. Redoing of course is an extreme step because there are provisions in the code about non-destructive testing and so on. In case the cube or the samples fail so that is a different matter that we will take up separately sometime.

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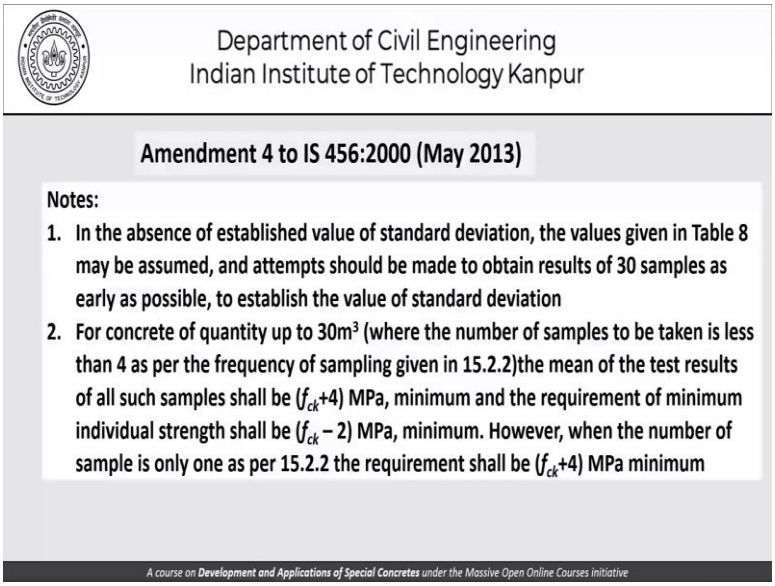

Interestingly, there have been also some amendments now amendment 4 in the IS-456 which was brought out in May-2013 said that in the absence of established values of standard deviation the values given in table 8 may be assumed and attempts should be made to obtain results of 30 samples as early as possible, to establish the value of the standard deviation. Now, the spirit of this provision is the fact that this table 8 gives you assumed values of sigma to be used for calculating the target mean strength.

Now, in the absence of anything else, they can be still used, but the real standard deviation that you have in terms of quality control should be available to the designer or should be available to the quality control manager. Actually, not so much the designer but the quality

control expert. So, that he or she knows exactly the kind of deviations that are occurring at site. So, that the corrections, the acceptance is as per the actual conditions and not the assumed value of the standard deviation that is one part of the notes, which has been clarified.

The second part of the notes, which is very important, is for concrete of quantity up to 30 cubic meters where the number of samples to be taken is less than 4 as per the frequency of sampling given in section 15.2.2 of the code. The mean of the test results of all such samples shall be fck + 4, minimum that is at least fck + 4 and the requirement of minimum individual strength shall be fck - 2 MPa minimum.

However, when the number of samples is only 1 as per 15.2.2, the requirement shall be fck + 4 minimum. So, what this tells us in these notes, what they tell us is that when we are interpreting the strength of concrete or acceptance for the strength of concrete, we had said that okay, there is an fck and there is an fck - 3 and an fck + 3 or whatever that number was 0.825 sigma and so on.

The greater of the 2, if the number is less than 4 then you have to clear fck + 4, if the number was less than 4. The number of 4 consecutive non overlapping samples if that number was less than 4, then the average should be greater than fck + 4 and the individual values cannot even go up to my fck - 3 but they are restricted to fck - 2. So, this is the kind of guidance that is available to us in IS456 and perhaps other documents to guide us about acceptance of concrete.

Now, this is something which as engineers, we must try to understand very clearly that the concrete mass has a certain mean strength. We are trying to evaluate it for acceptance not for the mean strength but from a characteristic strength standpoint. And therefore, it is slightly involved this discussion but once you sit down and think, I think you will be able to understand that the spirit of it is that, if this is the normal distribution that we have the first thing is that we cannot be allowing to have concrete far below this strength whether it is fck - 3 or fck - 2 in the case of an individual sample as part of 3 samples and so on.

We cannot have values which are much below fck. As far as a group of samples is concerned, we should try to be higher than fck by at least a certain margin. Now, whether this line coincides with this line and so on those are minor details those are statistical details which we

cannot get into discussion as far as this our module is concerned. I wanted to raise this issue so that you are becoming more aware, you do some soul searching and educate yourself better. Having said that, we go on to the next property that we want to talk about and that is the stress-strain curve and modulus of elasticity of concrete. You will recall that; I had mentioned to you that there is an excellent description of this in a book by professor P K Mehta.

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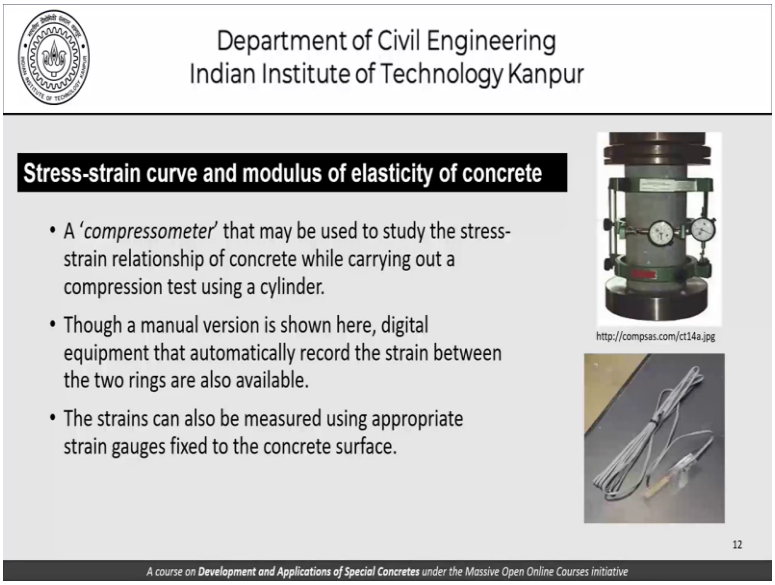

And, I had referred you to this description but let me just go through this quickly here a compressor-meter that may be used to study the stress-strain relationship of concrete by carrying out the compression test using a cylinder is shown here. Now, what this does is this is, the old-fashioned compressor meter where you try to have these rings, the 2 rings in fact separated by a certain distance and we are trying to measure the changes that happen in the length and in the diameter using dial gauges.

Of course, in this modern day and age, we do not use this kind of a compressor-meter with this kind of dial gauges, we use more sophisticated strain gauges and those strain gauges are fixed to the surface of concrete either along the direction of loading or in the circumferential direction and the load is applied, so this gives us information about the stress-strain curve. Now, of course, I would assume that you know what is the kind of idealized stress strength of a concrete which is given in IS456?

And also, the value of the modulus of elasticity which is given to you and that is 5000 let us say root fck. More importantly, what is the limitation, when does the code say you cannot use

this value, please try to read the code very carefully and see under what conditions you cannot use it. Let me give you a pointer 1 of those conditions is that, this strength of concrete is higher than a certain number.

At the end of it, these numbers or these kinds of empirical equations have been arrived at statistically and therefore the kind of data that you have is limited to the data that you normally get. In special conditions, that data is not available and therefore these kinds of empirical statistical equations cannot be extrapolated beyond a certain point. I can also add that in the modern day and age most of the testing devices the UTM's they have provisions to be able to record the stresses and strains not the stresses and strains exactly but the loads and displacements.

And, you can convert that to strains and stresses using initial values of the cube or the initial values of the dimensions of the cube and that is a fairly simple exercise to do. Moving forward, there is the property of tensile strength of concrete that we are sometimes concerned about. As far as, hardened concrete is concerned for an example, in the case of cracking we would like to know what is the tensile strength of concrete.

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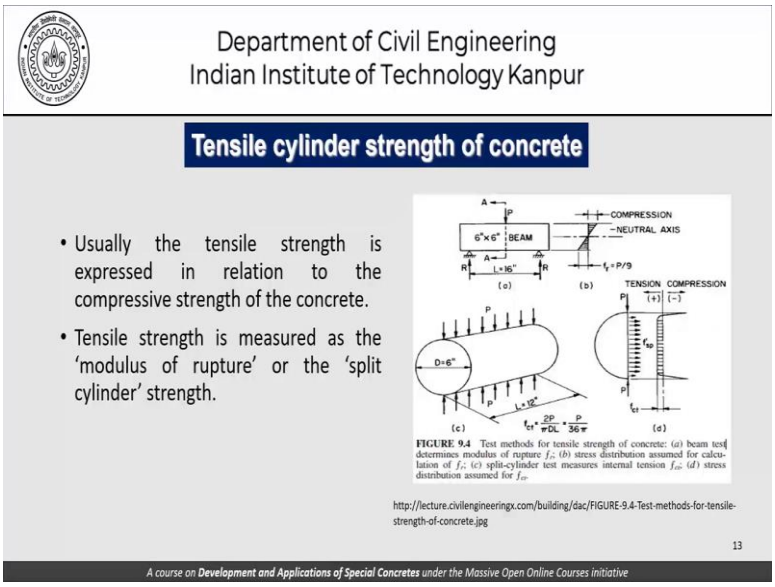

Now, usually the tensile strength is expressed or is available to us by way of a relationship with the compressive strength of concrete or more precisely the characteristic compressive strength of concrete. So, for example IS-456 kind of a document would give you that okay the tensile strength can be taken to be such as such fck to a certain power and so on and so forth, where this is the characteristic strength.

So, please remember or please try to understand be aware of the fact or the limitations of this kind of an equation, when it cannot be used and so on. As far as, experimental determination is concerned, the tensile strength is measured by either some kind of a modulus of rupture measurement, which we often use using beams or we use a split cylinder tensile strength which is shown here.

Both these values are acceptable, one of the prime examples where this kind of test is prescribed for fractional strength is in the construction of rigid pavements. So rigid pavements are one application of concrete, where the flexural strength of concrete is required. When it comes to the split cylinder tensile strength, I am leaving it to you to figure out or to investigate, learn that this is what the strains and stresses their distribution is along this diameter between which the loading is applied loading is applied along this long axis of the cylinder.

And, along the diameter of the cylinder, this is the strain and distress distributions and that is why it is called the split cylinder tensile strength. So, because of this more or less uniform tensile stresses that exist within this concrete here, this test gives us the split cylinder tensile strength and that is something which is very often used for quality control, if the tensile strength of concrete needs to be recorded.

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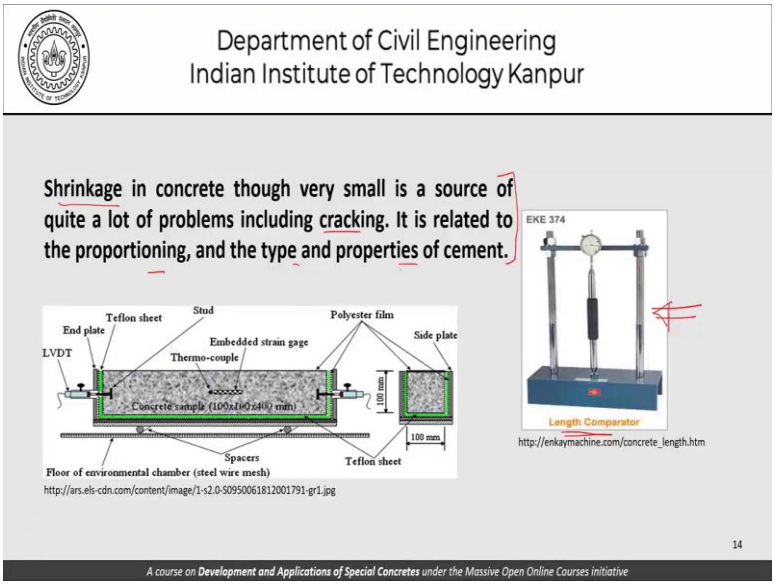

This slide here shows the discussion about an equipment which is used for or which can be used to study the shrinkage in concrete. Now, the shrinkage though it is very small is a source

of quite a lot of problems including cracking and at times durability and it is related to proportioning the type of cement and the properties of the cement that are used and at times, we really need to determine the amount of shrinkage that we have and that requires a very elaborate kind of setup.

And, this is one of those setups which is used a more common off the shelf solution that we have is by way of length comparators. So, these are some of the equipment which are used to understand a little bit more about the shrinkage in hardened concrete. We will probably talk about shrinkage and possibly creep as a special discussion sometime later on in one of the modules.

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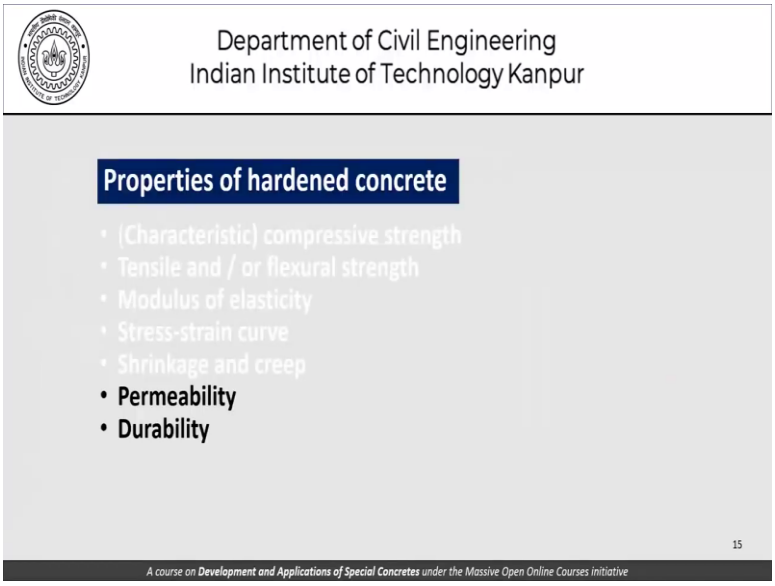

The next properties that we need to talk about are permeability and durability. Now, durability of course is a very difficult kind of a proposition because this is not a property, which can be directly measured this depends on the environment in which the concrete is, a concrete which is durable in marine environment may not be durable in freezing and thawing environment and vice versa.

The concrete should have certain characteristics, which we can measure in order that we are able to call that concrete durable, so this is something which will not talk about it explicitly at least in this discussion today. But probability yes, we would like to spend a minute on that we are not going to discuss too much about it but let us see.

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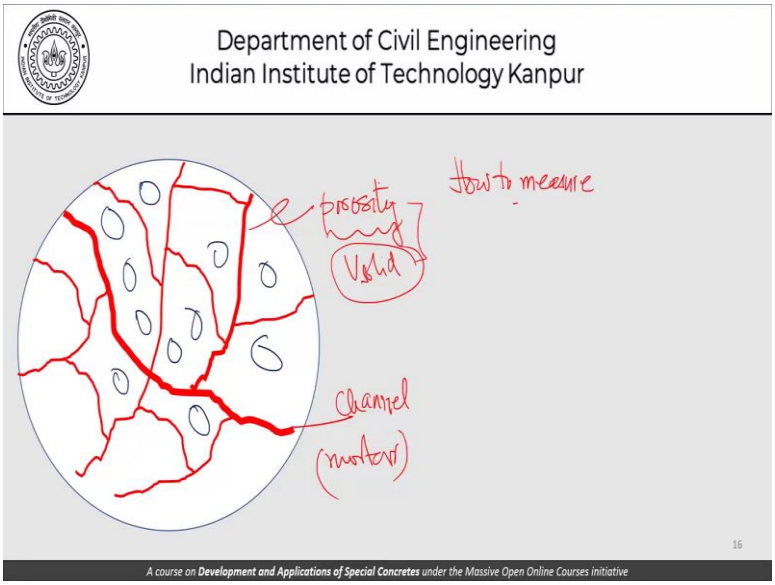

Here is a picture of concrete, I have not shown the aggregates and I could possibly show those aggregates, let us say those aggregates are all over the place here. So, we have aggregates and we are not talking of the internal porosity within the aggregates, these red channels are basically the channels of pores within the mortar. So, with these channels we can talk in terms of a certain porosity in concrete.

So, the volume of all these channels to the volume of solids some such measurement can be done to get or define parameters like porosity or void ratio and so on and so forth. Having said that, what is interesting is, how do we measure this? And this is something, which we have talked about in the previous discussion and I am leaving it to you to think about it go back to those discussions, do some literature survey reading and find out how do we measure the porosity of hardened concrete.

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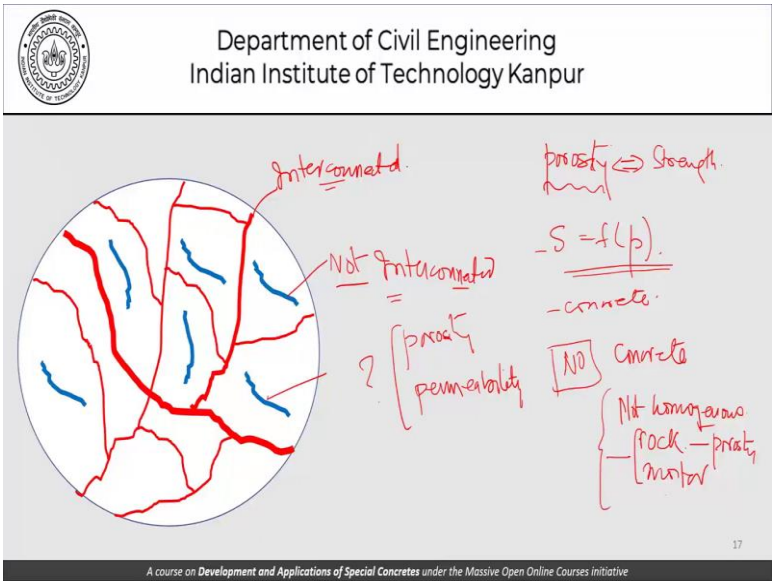

Now, we are introducing a complexity here are these blue pores the red pores are interconnected. The blue pores are not interconnected. Now, the question is, will the blue pores contribute to the porosity of the concrete or will they contribute to the permeability of the concrete. This is a question, that I am going to leave to you to think, when you measure the porosity of concrete, will you measure only the interconnected pores or will you be able to also measure the non-interconnected pores that would largely depend on the kind of method that you use.

So that is where, I want to leave it at that and have you think about it. Let me also point out that we are talking about or when we are talking about the porosity of concrete. This porosity is also related to strength. Go back to the literature and try to study the relationship between strength as a function of the porosity of the material. Now, how does this look like as far as concrete is concerned and can we use a relationship which has been established using other materials.

The answer is no, we cannot do that because concrete is not a homogeneous material. And, because it is not a homogeneous material, there are rocks inside which have a very different kind of porosity compared to the mortar. And, as a composite if you want to talk about then it is difficult to kind of relate the strength of concrete to the porosity of the mortar or the porosity of the much less the porosity of the aggregate or the rock.

So, these are some of the considerations that we are raising out of academic curiosity, academic rigor as far as concrete engineering is concerned, measurement of porosity directly

at least is still a matter of research. We have tools, we have methods by which we carry out the measurement of porosity in an indirect sense and possibly in one of the classes, we will cover all the methods or at least some of them which are commonly used to measure the porosity.

Now, they may measure some kind of permeability and we kind of take that to be a measure of the porosity.

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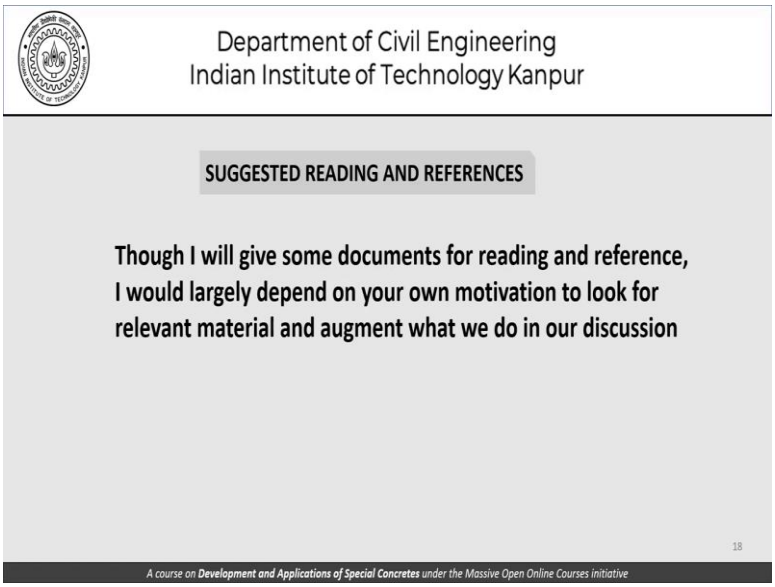

So, with this we come to an end of our discussion today and as already mentioned several times, I am relying on your own motivation to self learn and augment the material that we are covering in this course.

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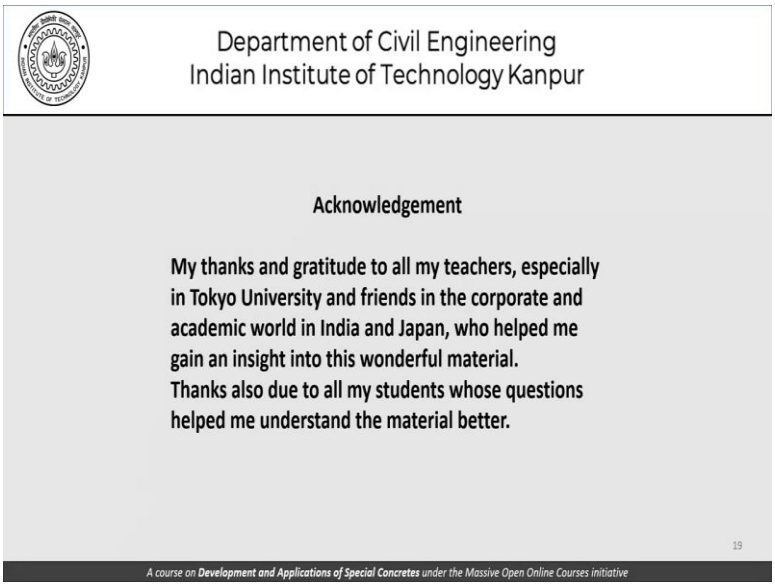

Once again, my regards and respects to all my teachers and friends who have helped me learn about this material and also to my students who have asked questions and helped me understand concrete better. Thank you and I look forward to seeing you in the next module, when we will be talking about proportioning of concrete mixes and other things before we move on to the real discussion on special concretes, thank you.