Development and Applications of Special Concretes
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Lecture 03
Review of Normal Concretes Basic Properties

Namaskar and welcome back once again to another lecture in our module on development and applications of special concretes under the MOOCS program of the Government of India. This is the third lecture in the first module, where we are reviewing the normal concretes and the discussion today is on basic properties. The properties that; we would normally associate with normal concretes.

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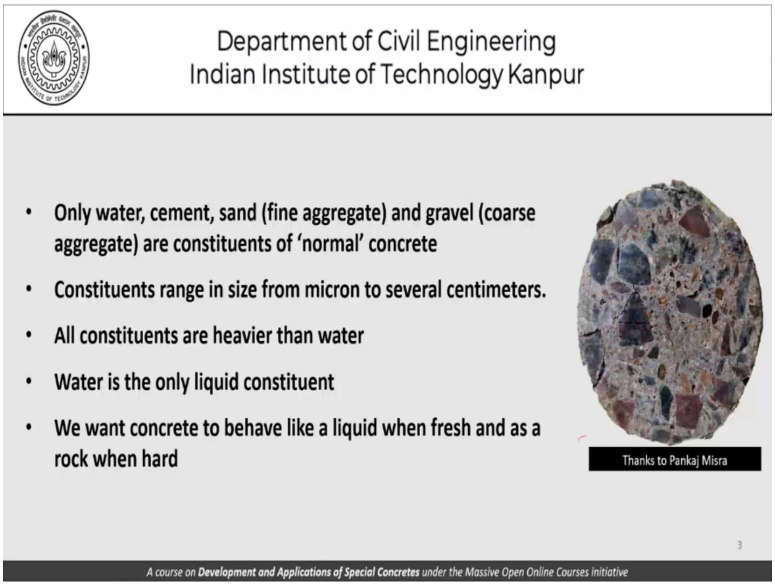

Of course, these slides we have seen earlier also and I will just run through them. Water is the only liquid constituent of concrete and that is something which was speaking borne in mind all the time. We want concrete to behave like a fluid and fresh and as a rock when it is hard and that is something, which is important to understand and keep at the back of your mind all the time, when we are talking of properties of concrete.

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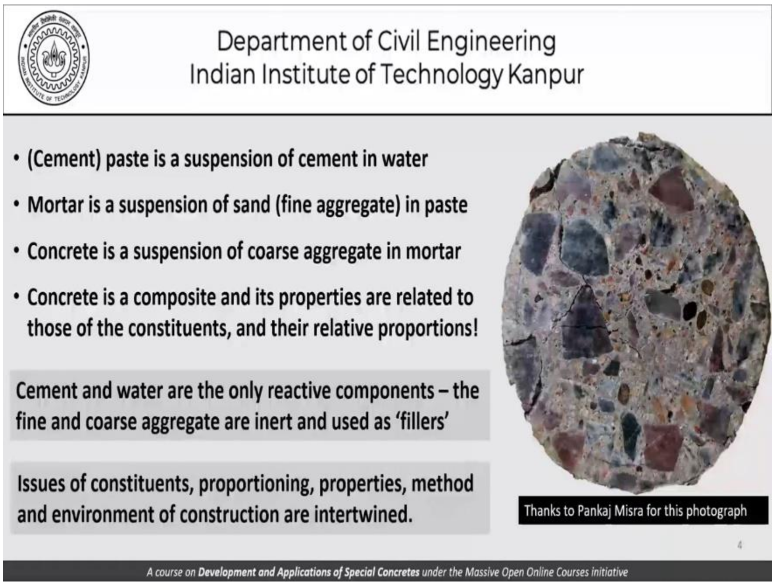

Again, the suspension model cement paste is a suspension of cement in water, water is a suspension of sand in paste, concrete is a suspension of coarse aggregated mortar, concrete is a composite and we have seen it as a three-phase composite in the previous discussion. And, its properties are related to those of its constituents and their relative proportions. Cement and water are the only reactive components, the rest of it fine and coarse aggregates is basically filler material and is inert it does not normally take part in the chemical reactions or the hardening process and so on.

Issues of constituents proportioning properties and method and environment of construction are intertwined. Having said all that we should remember all the time that this slice of concrete and that is why, I keep showing you all the time this particular slice. This slice of concrete which shows orientations or existence of coarse aggregates, fine aggregates, paste and so on in different places in the hardened state.

This must have been the same orientation the same place for these materials even in the fresh state. So, that does not change, I mean we did not plant aggregates there so the aggregates remained where they are as the hydration process continued. And, it became more and more difficult impossible at the end of it for the aggregates to settle down which they would normally do given the fact that all of them are heavier than water.

I would leave it to you to work out the densities of paste mortar and concrete based on the specific gravities and the volumetric contributions of these constituent materials. Let us now do that we of course know that the specific gravity of water is one and that is relative to which everything else is defined.

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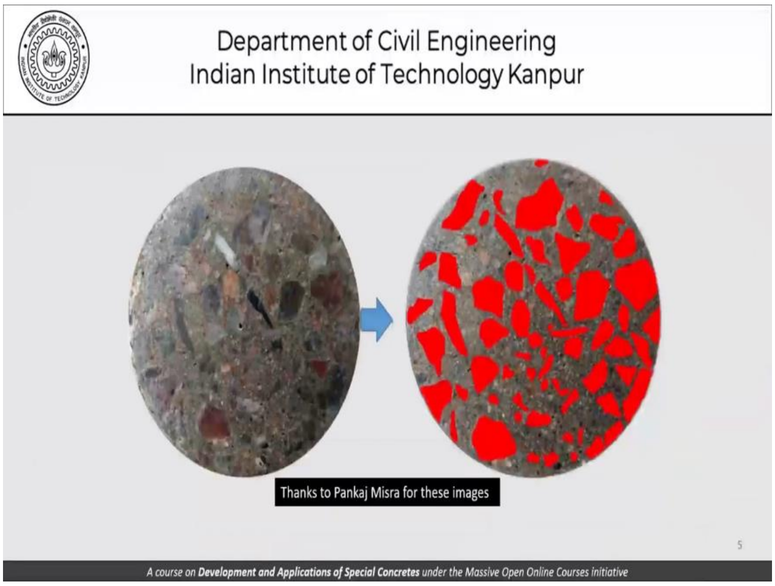

This picture also I have shown you basically to tell you that okay this is the model for separated aggregates rest of it is mortar. The aggregates are not in contact that is something which we have seen in the three models also. Now, let us try to get started with our discussion on properties in a list a review of that.

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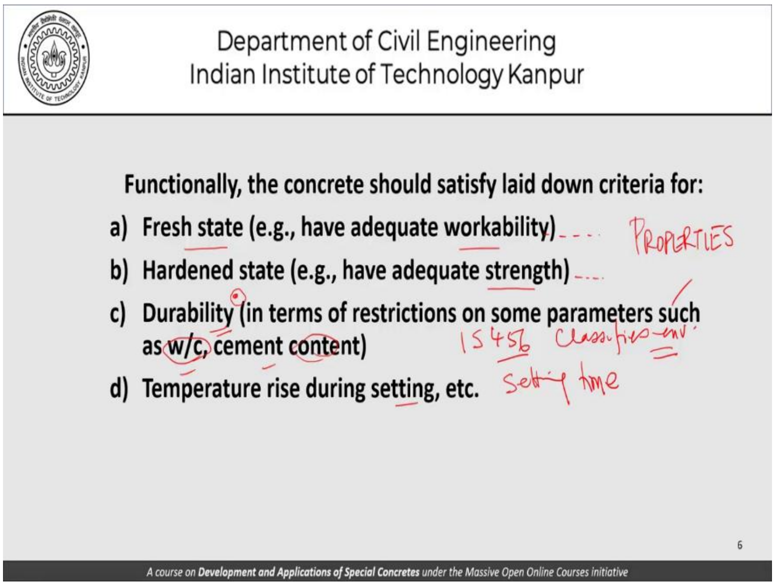

Functionally, the concrete should satisfy laid down criteria for the fresh state that is it should have adequate workability and other criteria that may be laid down. And, in the hardened state it should have adequate strength and any other criteria that is laid down. Apart from that those of you are familiar with concrete design or concrete technology a little bit more will remember that it is not only fresh state and hardened state but then there are certain other conditions which are imposed when we are trying to design a concrete mix.

For example, it could be durability, which means since this quantity is not very clearly understood or defined sometimes codes place restrictions on parameters such as the water cement ratio and the cement content. For example, in India we use IS-456 for the design of concrete structures and that has a full table which classifies the environment and says that for different environments. What are the acceptable values, what is cement ratio and cement content regardless of other conditions which could be imposed in terms of slump or in terms of strength?

Then there are other conditions which could be imposed as far as concrete is concerned that could be temperature rise during setting, it could be setting time. So, these are the kind of set of parameters which define in the larger sense properties of concrete, whether it is fresh concrete hard and concrete or any other kind of discussion that we have it could be in terms of durability, it could be have or it could be in terms of temperature rise, setting time that is basically the time frame from fresh state transitioning towards the hardened state.

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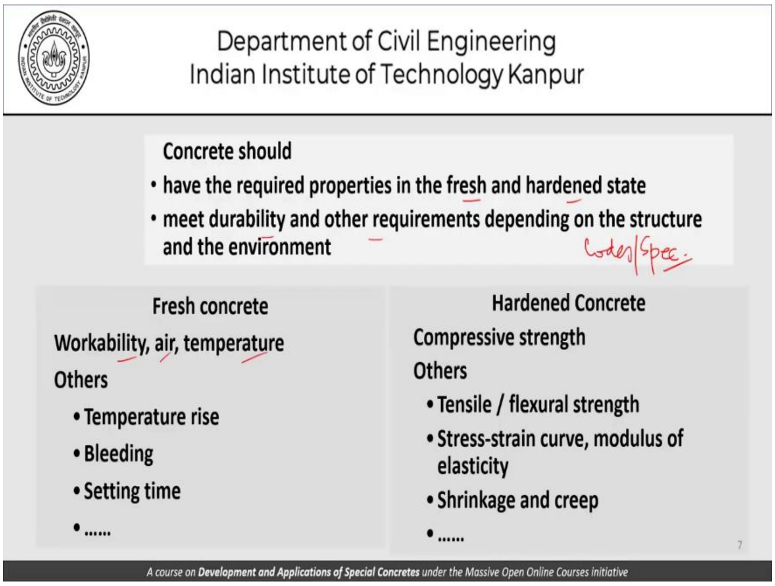

Now, concrete should have these properties in the fresh and hardened state and also meet durability and other requirements depending on the structure and the environment. So, this is something which is laid down in the codes and specifications, which are kind of sacrosanct to us as engineers when we are working with concrete. Now, in the fresh state the properties could be workability, air content, the temperature of fresh concrete per se.

Other properties could be the temperature rise, bleeding, setting time and whatever else you may like to add there are different parameters which are representative of workability. For example, it could be in terms of slump, it could be in terms of compaction factor, it could be in terms of any other test. Similarly, when it comes to hardened concrete the most common parameter is compressive strength and there too, I am sure you are familiar with the fact that some codes prescribe the compressive strength in terms of the strength observed or obtained using cylindrical specimens it could be in terms of cubes.

In India we use cubes of 15 centimetre/15 centimetres, in certain countries they use cylinders which are 10 into 20, 10-centimetre diameter 20 centimetres height. Now, I am leaving it to you to just think what is sacrosanct about 15/15 or 10/20 kind of size of these specimens. Why cannot it be 10/10? Why cannot this be 15 centimetres/30 centimetres or 5 centimetres/10 centimetres? Why should this ratio be 2 and not any other?

These are questions which should bother us, when we are talking about an academic discussion. We have standards yes; those standards tell us exactly what to do but those standards have been developed for normal conditions for usual conditions. So, long as we are talking about usual conditions, we can say that yes these are standards which have been developed for normal conditions and therefore they are applicable in our case.

The moment we move towards special conditions, that is where the situation will become different and one may like to deviate from standard conditions whether it is compressive strength or its workability, its temperature rise anything. Continuing our discussion at least on the properties of hardened concrete is concerned, it is not only compressive strength, there is also tensile strength, flexural strength, the stress strain curve, modulus of elasticity, shrinkage creep and so on.

Please remember that again codes give us certain relationships that okay the tensile strength of concrete or the flexural strength of concrete can be taken to be a certain factor times the compressive strength of concrete and that is represented more often not than not by a characteristic compressive strength not the actual compressive strength. So, do remember that there are two strengths that we talk about characteristic strength and the actual strength.

The actual strength is not the characteristic strength and that is something which we spend some time talking about it when we do mixed design but that is more important from the point of view of quality control and that is something which we will touch upon a little bit when we are talking about issues relating to quality control and acceptance in concrete. But this relationship which is given is a statistical relationship.

And, statistical means it has been arrived at using certain data, it is not a scientific relationship in that sense and therefore it has its limitations. You have a large amount of data in a certain strength range and therefore you can say with a certain amount of confidence that yes in order to estimate the tensile strength of concrete this is the formula you can use and this discussion is true even for the modulus of elasticity.

When we say that in India E is equal to $(5000)\ \hat{}^{0.5}*fck$ or some such relationship is there in other codes this is a statistical relationship this is something which is a suggestion that okay. So, long as you do not have real data to estimate the modulus velocity or to estimate the tensile strength of concrete here is a guideline that we are giving you, we mean the codes. Which are standards and I emphasize that these standards should be looked upon with healthy disrespect.

Healthy disrespect because healthy means there is a lot of wisdom in it and therefore, we should respect them disrespect because they were all at the end of it developed for certain standard conditions and if you are deviating from them. We do not have to necessarily follow those standards. In fact, it is written very clearly that these standards are not applicable beyond a certain point and engineers are expected to do their own homework and come up with the relationships the actual values of these parameters whether it is their side strength or flexible strength, the modulus, velocity and so on.

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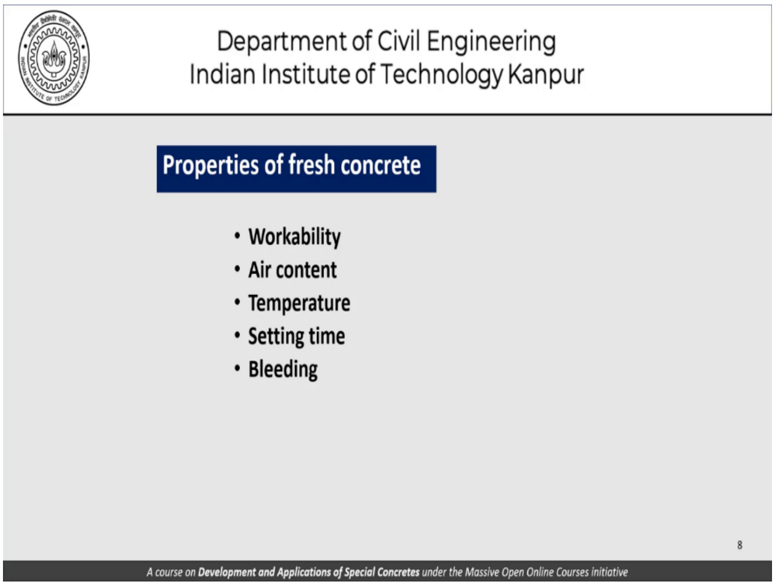

Continuing further let us try to understand the properties of fresh concrete slightly better workability, air content, temperature rise, setting time and bleeding. Let us try to just study a little bit about these properties alone.

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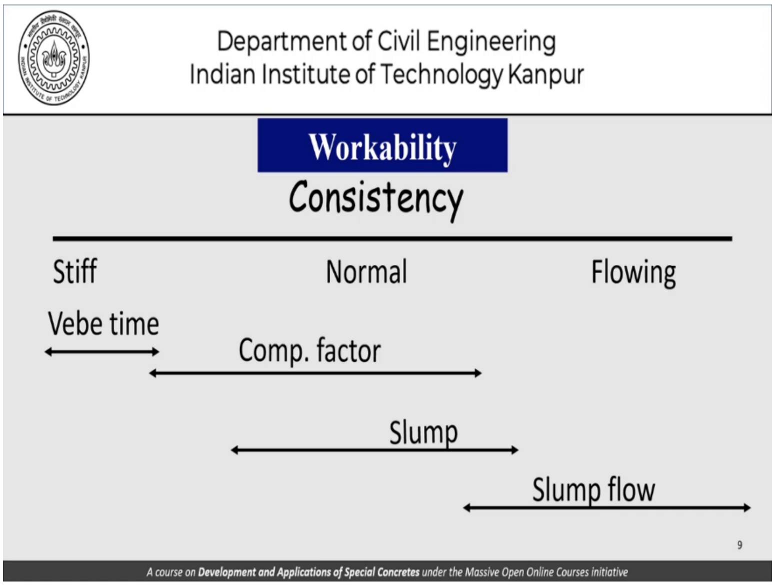

As far as workability is concerned, there is another word which is often used along with it and that is consistency but as far as this course is concerned, we will stick to our definition of workability which means that concretes which are flowing are more workable having said that this workability ranges from very stiff concretes to flowing concretes so there is a whole range here. And, here we have a few tests which are available to us.

The Vebe time, the compaction factor, the slump, the slump flow and they have their own regions of workability, where they are effective in discerning the workability of a concrete from the other. Slump for example, does not have the discerning ability, when it comes to this range here because all concretes in this range of workability will give you zero slump. Similarly, all concretes in this range will give you a slump greater than say 18 centimetres or 180 mm which to my mind does not make any sense, as far as slump is concerned.

But in this range, we can use slump flow, in this range we can use Vebe time. So, that is the kind of discernment that we need to use, when we are talking about a method that we want to adopt or adapt in our measurement in our measurement of workability in this case. Slump and slump flow once again, I have included them in the discussion for normal concretes because that is becoming more and more of a normal range, people do measure slump people do measure slump flow, but they do not measure certain other things which we will talk about later.

What is the limitation of the slump test for that matter even the slum flow? Both these tests are for unrestricted flow of concrete, whether you use the word flow or you use the word deformation that is a matter of semantics. But it is not restricted the slump also you fill the concrete in layers remove the slump cone and the concrete is allowed to deform there are no barriers to it. The slump flow again you lift the slump cone let the concrete flow there is no barrier.

Having said that, in all reinforced concrete construction concrete must negotiate the reinforcement, it should go around the reinforcement and therefore one may argue that slump flow or slump is not necessarily the best test to measure the real flowing power of concrete or negotiating power of concrete through bars. These bars could be very dense they could be very sparse. So, the fact remains that if you want to represent or get this factor into your workability test, that is up to you.

And, that is where the special concrete is coming, we have to understand that what is our need for which we want to test the concrete, whether slump or slum flow is good enough, whether vebe time is good enough, compaction factor is good enough and so on. So, when it comes to development using special concretes, the onus is a lot more on the engineer to understand the issues involved and write the appropriate or the right kind of specifications insist on the right kind of test to be carried out.

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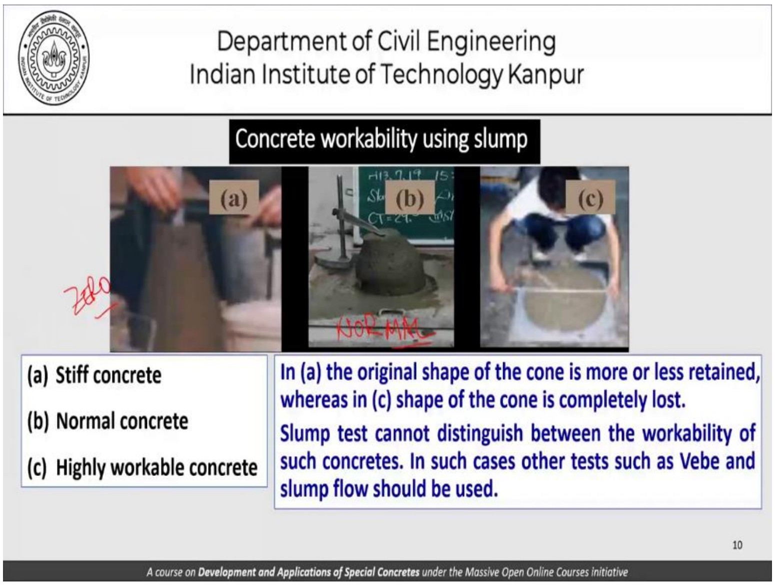

Now, here is a comparative statement of concrete workability using slump. Here we have something like zero slump concrete which is very stiff, this I would call normal slump concrete maybe about 8 centimetres 10 centimetres that kind of a number, and here we are talking of slump flow. And again, as I already mentioned both this test as well as this test, they do not have any reinforcement or any barriers through which the concrete has to negotiate.

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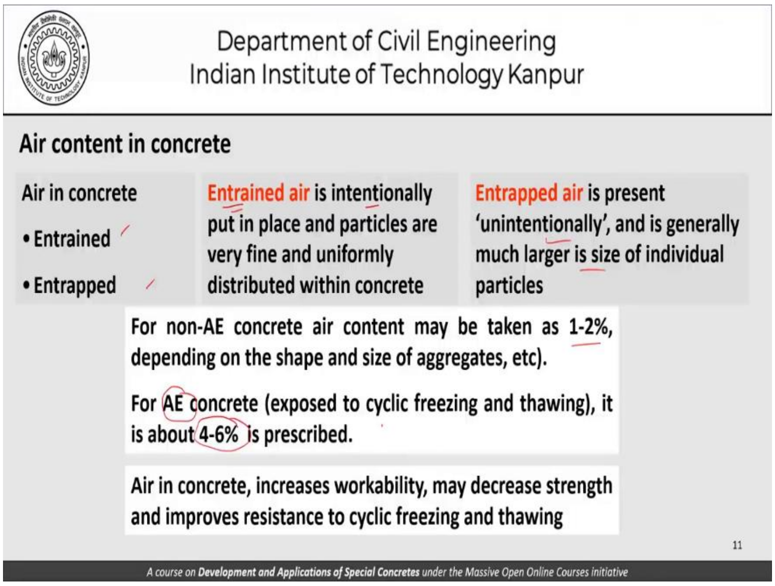

As far as air content is concerned that is the second property that we talked about there are 2 types of air in concrete and entrained in entrapped, and entrained air as the name suggests is intentionally put in place and particles are very fine and uniformly distributed throughout the concrete. As far as entrapped air is concerned, it is unintentional and generally the particle size of air is much larger.

As far as non-air entrained concrete is concerned, the air content may be taken to be about one to 2% by volume depending on the shape and the size of aggregates. For air entrained concrete, which is a requirement for concrete exposed to freezing and throwing cyclically, it is supposed to be between 4 and 6%. And these kinds of things are prescribed in certain codes. For example, in India we will have IS-456 in certain other countries, they will have other codes but these numbers are prescribed there.

Air in concrete increases the workability may decrease the strength and improves the resistance to cyclic freezing and thawing, how it does is something which you already done in the previous course and I am giving it to you to go back and brush it up a little bit either through the lectures or through appropriate references.

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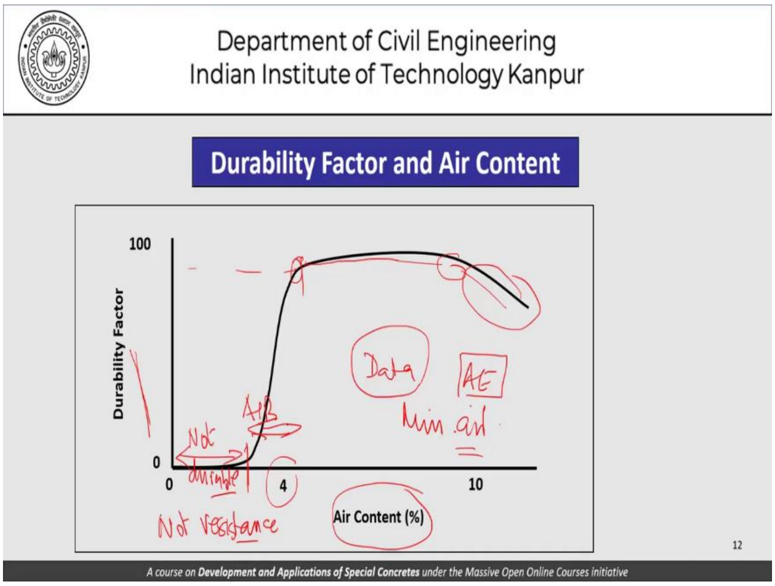

Now, this is the way we test the effectiveness of air against freezing and point. So, if we have something called a durability factor. Now, this durability factor what it is, I am leaving it out right now, it is beyond the discussion here. So long as there is no air in the concrete, we are talking of zero to say 2.5- 3% air the durability factor is zero that is the concrete is not durable. It does not have the kind of resistance that is needed for cyclic freezing and point at around 4% 4.5 %.

Suddenly, this is the range where air is extremely effective, beyond this point the air is extremely effective, and increases the durability factor to a very high number maybe 85%- 90% whatever it is. And, beyond that of course the durability factor does not change and beyond this point in fact it starts falling again. So, as far as engineering is concerned the first step is to get hold of this data.

The first step is to get the data to find out okay how much is the minimum air that I need to put in, so that I will get a reasonable protection against cyclic freezing and time. Once, we have that, we know how much of an air entraining at mixture that we need to put in to get to that air content. So, this how we really go about designing concrete for special purposes.

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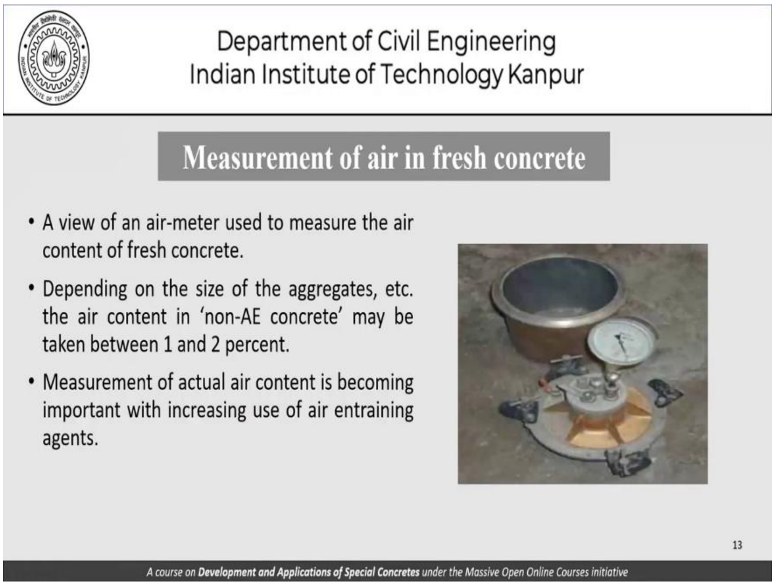

This is just one example, how is air measured, the air in fresh concrete how is it measured. In India it is not very common to measure, it but it is part of or it should be a part of the measurement of fresh properties of concrete all the time. This is a view of an air meter, which is used and depending on the size of aggregates the air content could be between 1% and 2% in all air in all the concretes and it could be 4% to 6% depending on how much of air content or how much of the air and training admixture you put in.

And, this is becoming more and more important when we are using air entraining agents in concrete. There is something important because air and training agents also will increase the workability, the air increases the workability of concrete also. The fresh concrete because of these air particles which are spherical in nature, they have this ball bearing kind of action which causes the coarse aggregate and all these fine aggregates to slide over each other more easily leading to increased workability. Therefore, unless we measure the air content, we could almost be using an air entraining admixture as a plasticizer and that is something which we do not want to do. So, here is an air meter which is used and I would think that you guys should try to understand a little bit more about it.

Try to find out where you can buy it; try to see how you can use, it in order to determine the air content of fresh concrete. Moving to the next property of fresh concrete that we need to talk about that is temperature rise.

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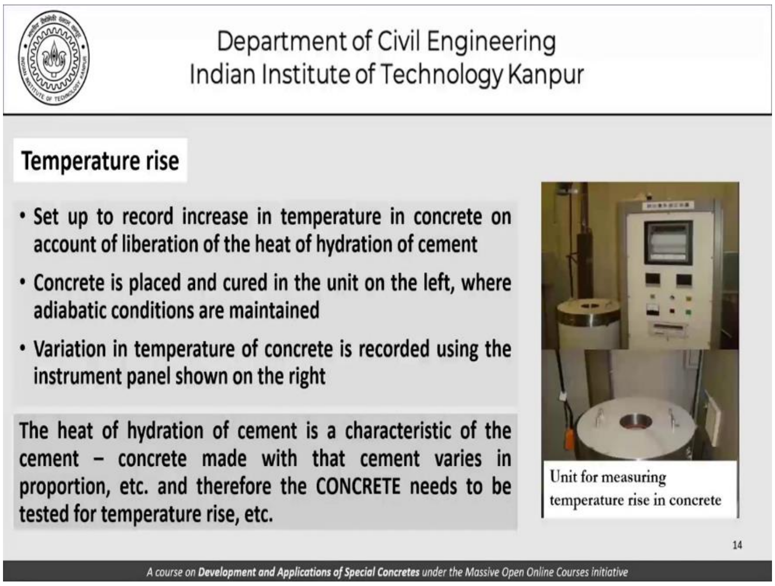

Now, set up to record the increase in temperature in concrete on account of liberation of heat of hydration of cement. So, cement hydration being an exothermic process leads to liberation of heat as the cement hydrates. Now, this heat unless it is allowed to escape or it is taken away from the concrete will cause the temperature to increase. Now, concrete is placed and cured in a unit on the left which is somewhere here.

And, graduating conditions are maintained variation in the temperature of concrete is recorded using an instrument and so on. So, this is the panel which records the temperature here is the concrete a large container of concrete this how it is simply measured. Now, the issue is why do we want to measure this, because this is not a standard property of concrete. Why it is not a standard property of concrete because as far as cement is concerned, as far as cement is concerned, yes one may say that under standard conditions, we have cement particles and these cement particles when they hydrate in a certain manner, with a certain water cement ratio and so on. They will give a certain amount of kilo joules per kilogram kind of heat. Now, this is the property of cement having said that as far as concrete is concerned the amount of cement that is used in this concrete could be varying, the water cement ratio could be varying, the conditions in which the concrete is being placed could be varying. And therefore, to extend this number no matter what this number here is to even estimate the amount of heat that will be liberated, when a cubic meter of concrete hydrates it is at the end of it only an empirical exercise and it needs to be validated through experiments. Very rarely we do this kind of a study to be able to actually determine and design a concrete mix.

In fact, that is what is done in large projects where it is said that okay the temperature rise should not be greater than 30 degree centigrade or should not be greater than 35 degree centigrade, oh sorry this is not percentages it should not be more than 30 degree centigrade or 35 degree centigrade. Once, these specifications are given the only way to meet these specifications is to carry out a test like this.

And, then come up with the proportion that okay if this is the mix that we use then the observed temperature rise meets the requirements of the standards that is what I have written here. The heat of hydration of cement is a characteristic of the cement the concrete made with that cement varies in proportion etcetera and therefore the concrete needs to be tested for temperature rise in its own right.

This is something which we must keep at the back of our mind all the time, when we are dealing with cement and concrete that cement has certain properties. Concrete has related properties the properties are governed to a large extent from the cement properties but not necessarily the same.

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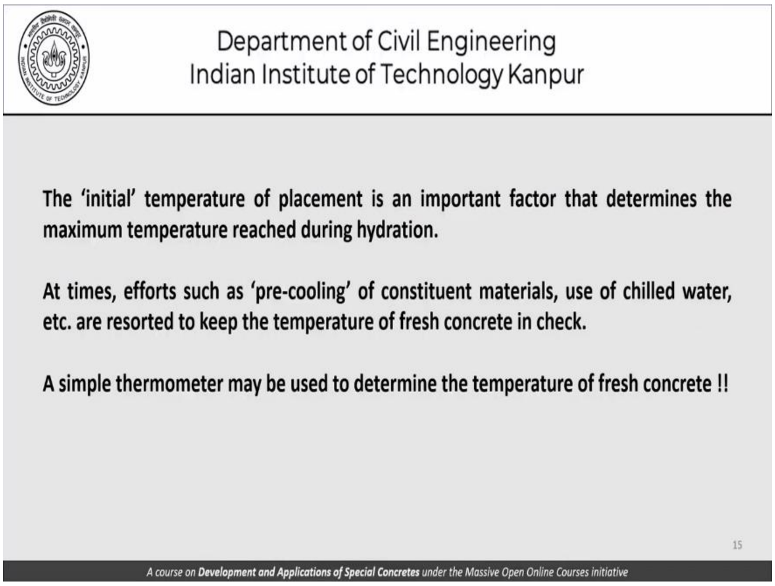

The initial temperature of placement is an important factor that determines the maximum temperature reached during hydration at times efforts such as pre-cooling of constituent materials, use of chilled water etc are sorted too to keep the temperature of concrete the fresh concrete in check, in fact there may be specifications which tell us that the temperature of fresh concrete when placed should not exceed 20 degrees centigrade or 18 degrees centigrade.

Now, how you maintain this is by chilling the water that the first thing then perhaps pre-cooling the constituent materials is the next thing and so on. A simple thermometer is all that is needed to determine the temperature of fresh concrete of course when it comes to the temperature rise more elaborate setup is required, if you want to do a study. But, as far as just getting the data is concerned all that you need is some thermocouples buried in concrete at the appropriate places, and you will get those numbers my submission to those of you who have access to concrete sites is to actually do determine this temperature rise in some concrete placements that you do. Try to do it with a normal slab when I say a normal slab, I am saying that ok the concrete slab should not have a thickness which is exceeding, let us say 30 centimetres, 300 mm or 400 mm at most. Now, the moment it starts exceeding 400 mm or 450 mm the things become different.

So, try to get the temperature rise and slab kind of concrete members compare that to larger concrete members which could be large columns maybe a meter in size, bridge piers try to get the temperature variations not only at the surface, but also in the core try to see how the temperature at this place location A and location B, how it varies with time, you try to get this graph temperature and time, and see where you start and where you reach the peak and come down.

More off this discussion we will do when we are talking of hot weather cold weather concretes and mass concrete but this is just to start the discussion getting started prime the whole thought process.

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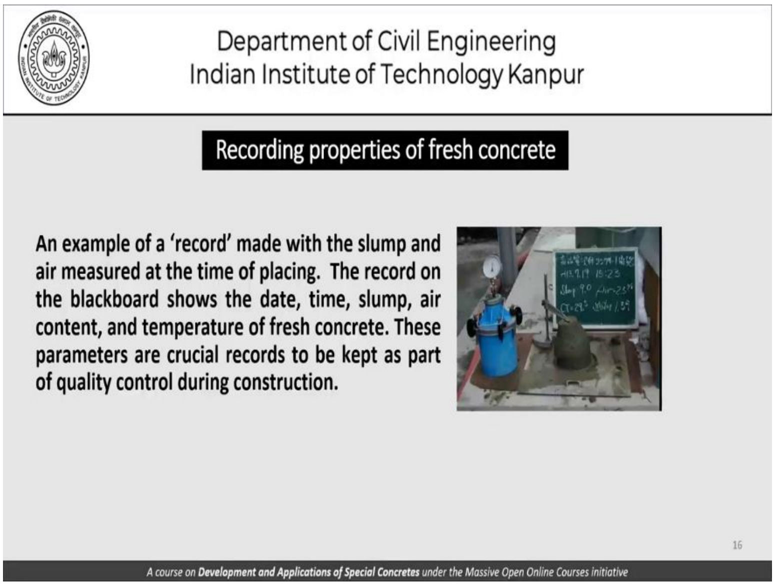

Now, as far as recording the properties of fresh concrete is concerned this shows an example of a record the air meter with a certain reading which is shown here. The concrete temperature which is 29 degrees here the slump which is I do not know how much slump is 9 centimetres here. So, this is how this photograph if they are kept with the location where the concrete has been used that becomes some kind of a record, all the time at sites you need to have this kind of record.

So, that you know and it is archived that when we used the concrete in the construction of this column or that beam or that wall, what was the temperature, what was the date when it was cast, what was the ambient temperature the ambient temperature is also an important thing, did we cast it in the summer, as far as India is concerned it will be casted in the winter and so on. So, these are simple parameters that can be measured without too much of an effort.

So, we should try to do that these are low hanging fruits and we should not try to cut corners of this when it comes to quality control. These are things which are all related, so as far as quality control during construction is concerned this is perhaps the very first preliminary step.

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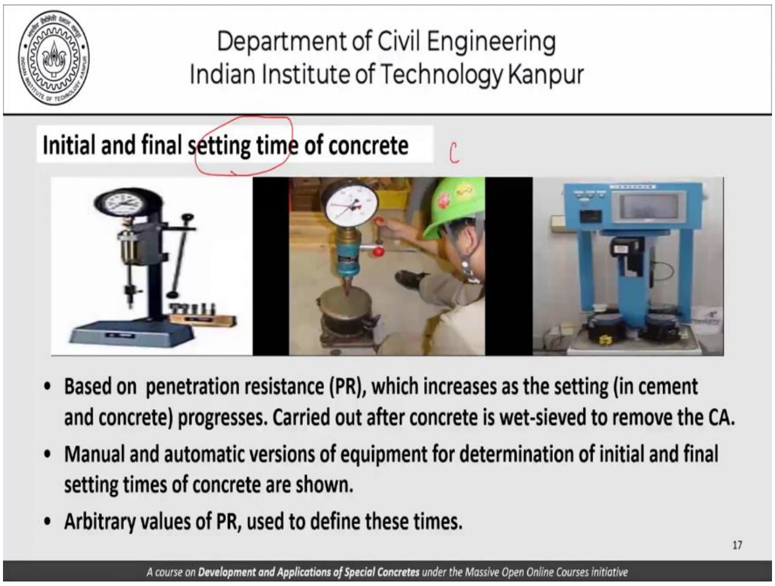

Now, we talk about setting time of concrete. We are already familiar with the setting time of cement and that is based on the principle of penetration resistance, so go back and see how the Vicat tests are done. Vicat needles and the Vicat apparatus try to understand that. Now, having said that as far as concrete is concerned, the test is the same it is based on penetration resistance, which increases as the setting in cement and concrete progresses, and is carried out with the concrete wet sieved to remove the coarse aggregate, and I will tell you the reason why in a minute. Manual and automatic versions of the equipment are available and we use initial and final setting times of concrete. Arbitrary values of penetration resistance are used to define these times these times means the initial setting time and the final setting time of concrete.

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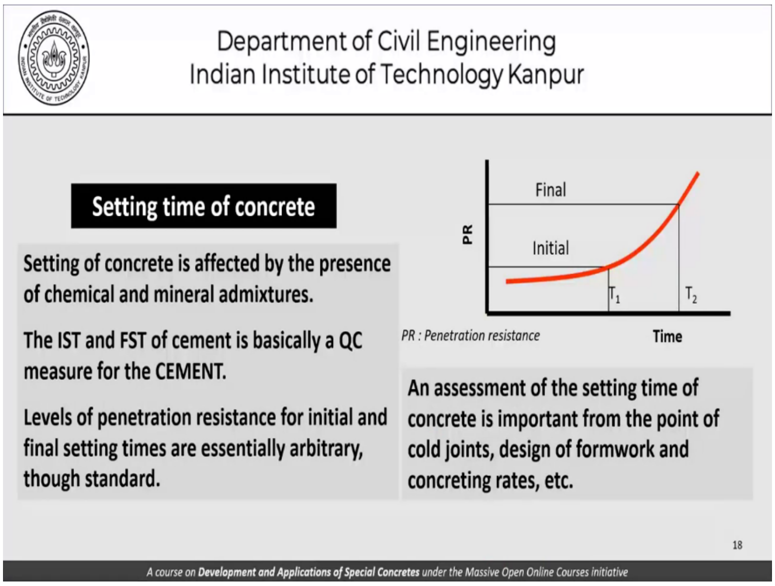

This is what the principle is the setting of concrete is affected by the presence of chemical and mineral admixtures. Now, the argument basically is that the penetration resistance increases with time on account of hydration. If we are somehow able to measure the penetration resistance, and are able to define this value, and this value, we can say that okay once the penetration resistance is higher than this value.

This time is, what we will call the initial setting time which is designated as T1, and similarly for the final setting time we have a higher penetration resistance value and this is given the tag of final setting time of concrete. Now, when it is coming to concrete, if we look at concrete, what is happening, how will it look like? It will have these kinds of coarse aggregates here, and what we are trying to do is to put a needle to measure the penetration resistance.

If this needle hits the coarse aggregate here or misses the coarse aggregate here maybe a smaller aggregate somewhere here these readings will be unnecessarily, the variations will be much larger. The size of the needle, unless the size of the needle, is such that this effect of coarse aggregates can be taken care of. Now, if we want to increase the size of the needle, what is the problem? The specimen size will increase.

Now, we cannot have a large specimen, we would like to minimize the size of the specimen. In order to do that and assuming the fact or thinking of the fact that the presence of these coarse aggregates does not really materially alter the hydration process going on in the mortar, we say that well let us wet sieve. We take the concrete and we wet save it to remove the coarse aggregate then we have a simple mortar specimen, and this mortar we can test with a certain set of needles as we saw in the previous picture.

I forgot to mention it, but you can go back and look at it that is where those needles are and those needles can be used. Now, why not use the mortar itself? Why not mix the mortar and do it? The simple reason is again engineering judgment that the properties of mortar as obtained from here may be different from what we obtained if we proportion and mix and obtain only the mortar.

So, it is only a matter of engineering judgment it is only a matter of being able to say that this is acceptable to me and that is not. So, there is very little to that extent science here and this is a lot more of engineering. So, concrete at least, I believe that concrete has a lot more has a reasonable amount of at least engineering judgment related issues than scientific issues. Except that of course our engineering judgment issues are all related to science at least that is what we like to believe.

The arbitrariness is that whether it should be this level of penetration resistance, this level of penetration resistance is a different matter but somehow the standards tell us that these values have been taken and we are happy with them. For most of our construction, we are happy and this is required, when we are trying to do a discussion of cold joints, design of form work, concreting rates and all these kinds of stuff.

Now, in normal construction where the pace of construction was at some level, this discussion was probably not so relevant. But, when it comes to special constructions, larger constructions, different methods of placing concrete then we need to have a better understanding of the setting process of concrete itself, and not only the cement that we used. Let us move forward we go to bleeding.

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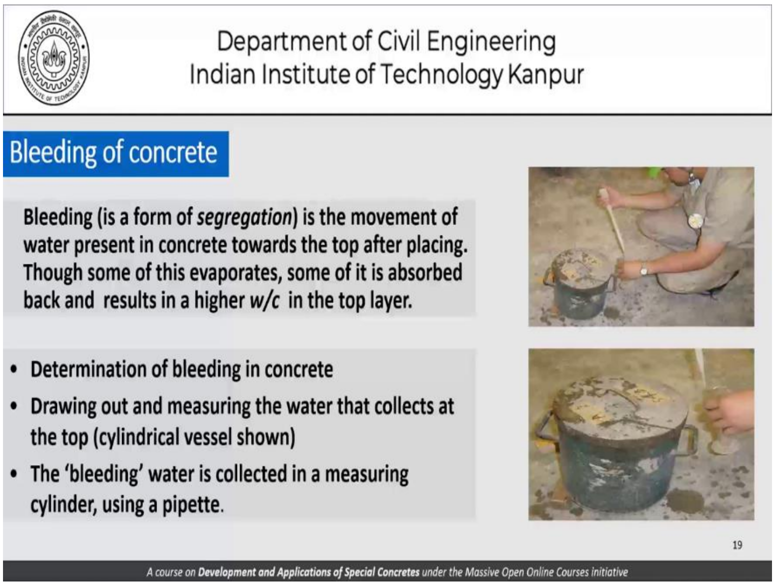

Now, bleeding is a form of segregation and is the movement of water present in concrete towards the top after placing, some of it evaporates, some of it is absorbed back and results in a higher water cement ratio in the top layer. I am going to show it to you diagrammatically in the next slide. This picture here shows the measurement of bleeding the determination of bleeding in concrete drawing out and measuring the water that collects at the top.

So, you have a cylindrical small vessel here you fill it up with concrete and as water accumulates here you remove it using a pipette or up any other similar device and you try to measure it with the measuring cylinder. How much water has been removed, and you will be actually surprised that you can collect a reasonable amount of water when we do a bleeding test? I would encourage you again those of you who have access to concrete try to do it yourself.

Even if it is not a standard condition try to put it in a bucket try to see how much water accumulates as you keep removing it you will find how much water you can remove quantitatively. Then try to relate that amount of water that you remove to the amount of water that is present in this concrete that you can get from the proportions. Suppose, I use 180 kgs of water per cubic meter and I take 20 litres of this concrete.

So, we know how much water we have used here from here if we are able to remove 50cc or 60cc, we know how much is the percentage of water that has been removed as bleeding water.

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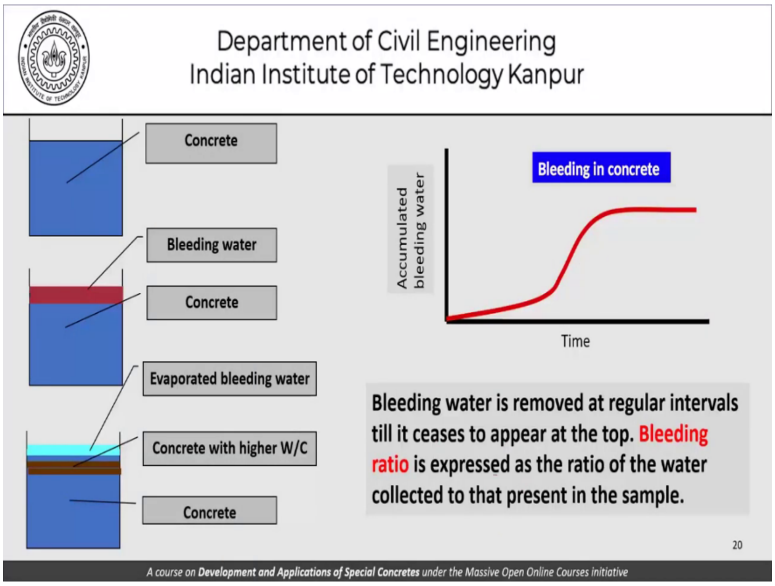

Now, this slide here shows you the diagrammatic or a schematic representation of this whole bleeding process if you put the concrete here this bleed water accumulates at the top. Now, part of this evaporates into the air and part of it becomes trapped on the top layer of concrete, and this leads to this layer having a higher water cement ratio than the concrete here right. Now, this is at the bottom of our thought process, when we call for removal of latency across cold joints.

Because, at the end of it this small layer of concrete, which has a higher water cement ratio, basically what does it mean it means that the mortar there has a higher water cement ratio the coarse aggregate is all right. So, what we do is if this is the layer there are coarse aggregates sitting here. So, what we try to do is get rid of all this mortar and expose these coarse aggregates. So, that when we cast the concrete above this, this gone these coarse aggregates here become a part of this new concrete.

This is what we had cast as the old concrete. So, this is the kind of philosophy or the thought process that happens, when we call for removal of laitance largely based on the principle that there will be accumulation of water at the top, which needs to be removed, and you cannot remove water, you remove the mortar from there. This shows you, how the bleeding water will actually appear at the surface, initially it will be slow then you will have a lot of water appearing here finally it will stop.

So, that is where you say that okay this is the amount of water that has been drawn out that 50 or 60 cc, which I had talked about last time that could be somewhere here and you need to find out that okay, what is the time again you need standards to determine when you should stop collecting the data, this test is actually carried out by collecting the water every five minutes to begin with or maybe 10 minutes to begin with going down to every five minutes and finally going to 20 minutes, 15 minutes and so on, and finally stopping it.

So, when should you stop collecting the water, is laid down next standard? With this we come to an end of the properties of fresh concrete that we wanted to cover and we move on to hardened concrete in the next discussion.

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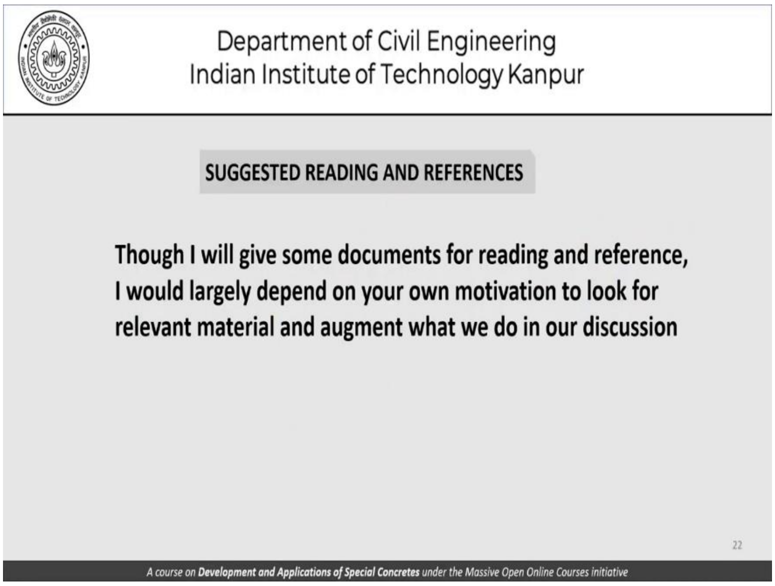

As far as suggested readings and references are concerned, there are enough books enough notes available on the internet and I am sure you are already having some of them and as I said earlier, I am relying more on your own motivation and self-study. So, these lectures or these discussions are only to give direction to your thought process, and you have to do your own readings to augment what we do in our discussion.

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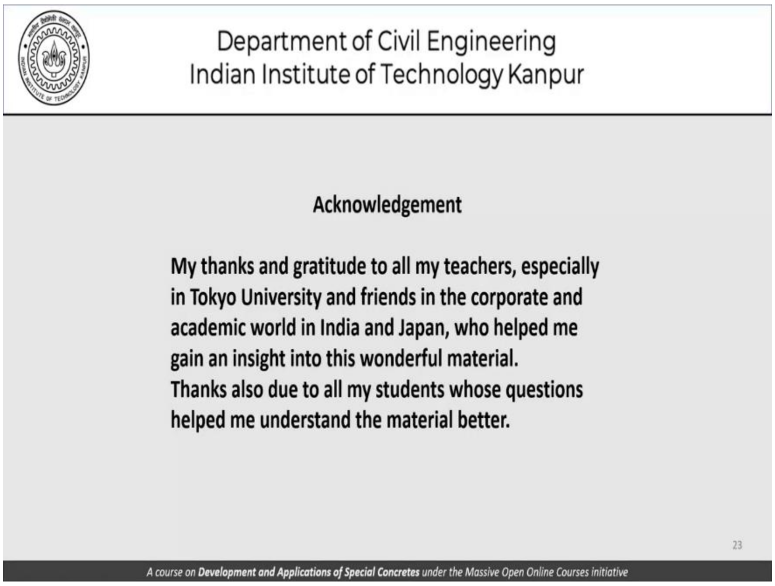

Another disclaimer kind of slide, I am always grateful to my teachers and my friends, my students, who have helped me understand concrete better.

Thank you and I look forward to seeing you as we go along deeper into concrete understand the hardened concrete and then probably move on to some other things.