Concrete Engineering and Technology
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Lecture - 6
Basic properties of concrete

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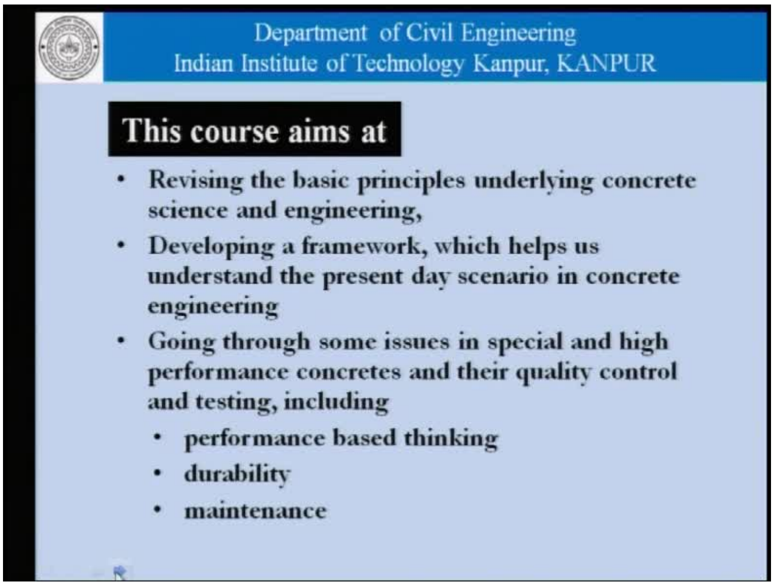

And welcome to this lecture on concrete engineering and technology, which is a course where we are trying to revise the basic principle underlying concrete science and engineering developing a framework, which helps us understand the present day scenario in concrete construction. Going through some of the issues involved in special and high performance concrete and their quality control testing, which includes performance based thinking; durability and maintenance as far as concrete structures are concerned.

Now, we have seen this picture before, which gives as basic model as to how we are going to view reinforced concrete in this discussion. This is the concrete surrounding the reinforcing steel which is an integral part of reinforced concrete construction, and this concrete is made up of coarse aggregates suspended in mortar, or paste which is cement and water.

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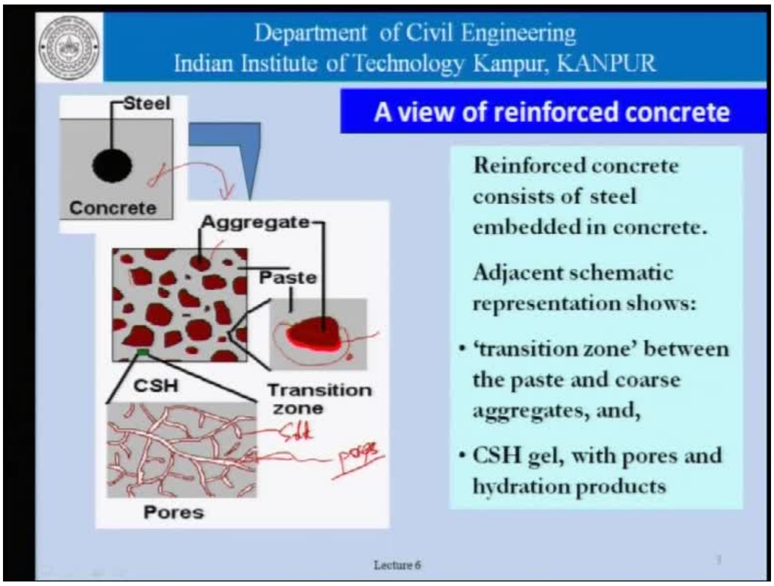

And if you look around the coarse aggregate particles, or the fine aggregate particles for that matter, we have a transition zone which defines the transition from the real solid cement paste to the aggregate phase, and if we look at blown up picture of the cement paste, we have solid hydration products somewhere here and that is interspersed with these pore spaces. We have seen how this pore spaces come about that is basically, on account of the access water that we use in concrete, over and above that which is required for hydration of the cement.

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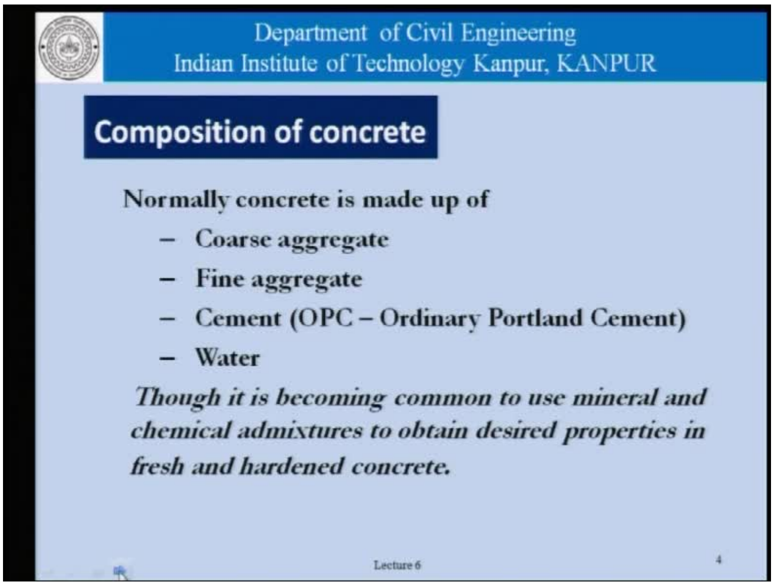

We also have gone through the constitution or the composition of normal concrete, which consist of course, aggregate, fine aggregate cement and water.

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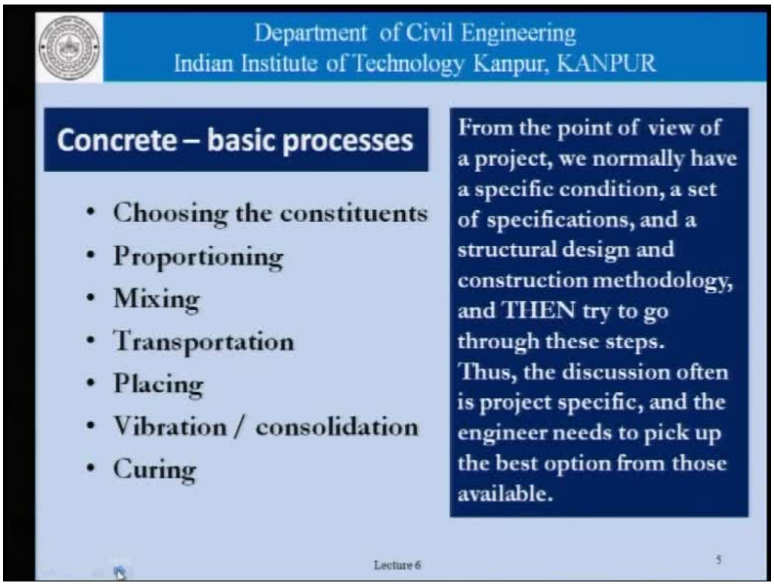

And the basic processes proportioning, mixing, transportation, placing vibration consolidation curing and from the point of view of a project, we normally have specific conditions a set of specifications and structural design and construction methodology, and then we go through this steps. Thus the discussion as far as the project is concerned is very specific to that project and the engineer needs to pick and choose, the best option as far as proportioning is concerned, mixing is concerned, transportation for that project is concerned and so on and so forth.

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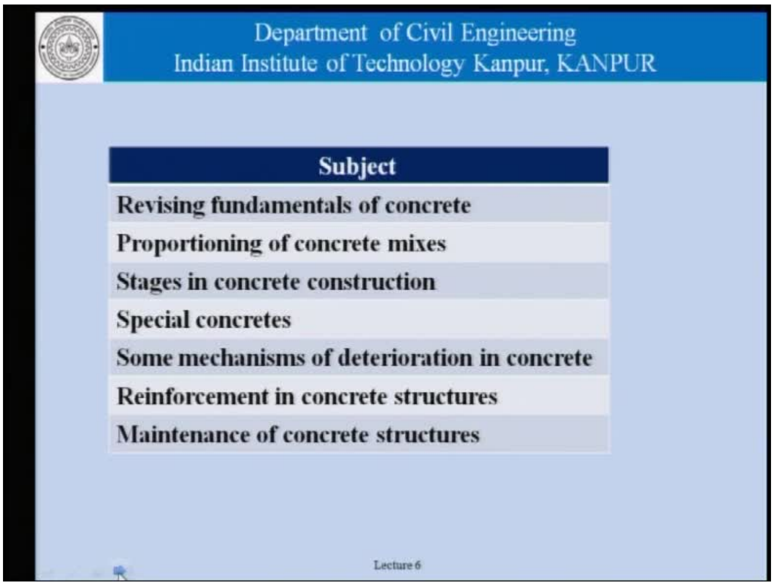

Now, coming to the subject of concrete engineering and technology, this is the outline which we have defined for ourselves, as far as revising the fundamentals of concrete and that is what we are doing now.

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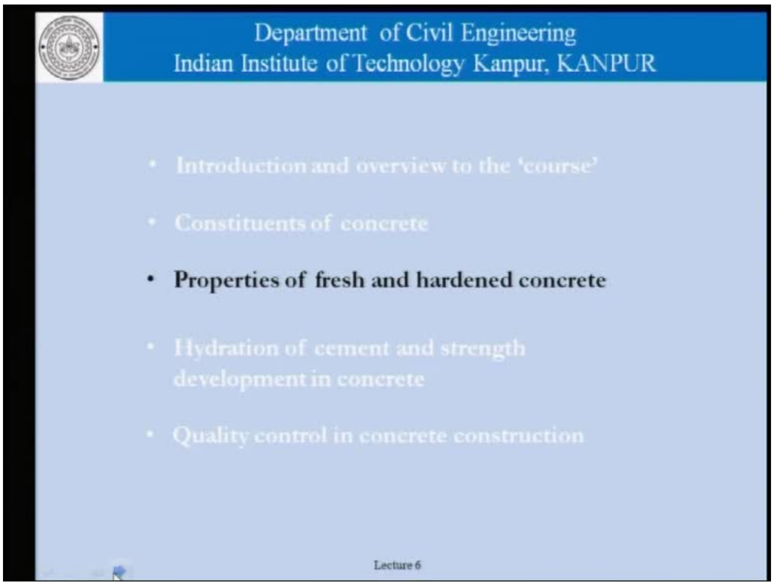

Today's discussion will be largely focused on properties of fresh and hardened concrete, as we know them. We will confine our discussion to very simple concrete, we will not get involve with complicated concretes, we will not get involve with special concretes as far as normal concrete is concerned. What are the properties of fresh and hardened concrete? We will discuss them in a framework that will help us better understand, special concretes.

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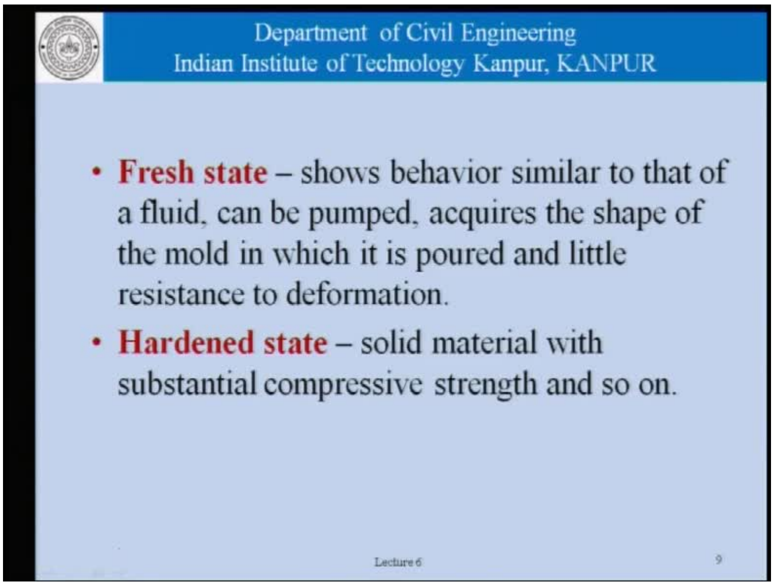

Now, concrete has basically two distinct states, the first state where it shows behavior similar to that of a fluid, which can be pumped, it acquires the shape of the mold, in which it is poured and has little resistance to deformation. In fact this property is at the root of the popularity of concrete as a construction material in the present day. As far as the hardened state is concerned, concrete transforms itself into a solid material with substantial compressive strength and so on. This transformation is brought about by hydration, and the hydrates of cement provide the basic structure of the chemical products that give strength to the concrete.

Functionally, concrete should satisfy laid down criteria for the fresh state that is it should have adequate workability and so on. As far as the hardened state is concerned, it should have adequate strength as may be decided by the designer. Then there are specific requirements, which may be in terms of durability. For example, there may be restrictions on parameters such as the water cement ratio, the cement content and so on. And there may be some requirements in terms of temperature rise during setting, and so on and so forth. So, basically the properties of concrete that we study have to be around these functional requirements that are concrete needs to satisfy.

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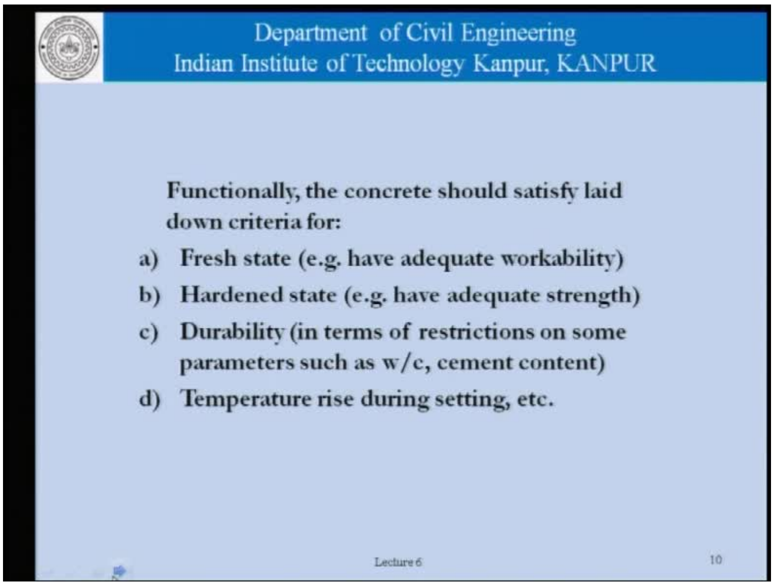

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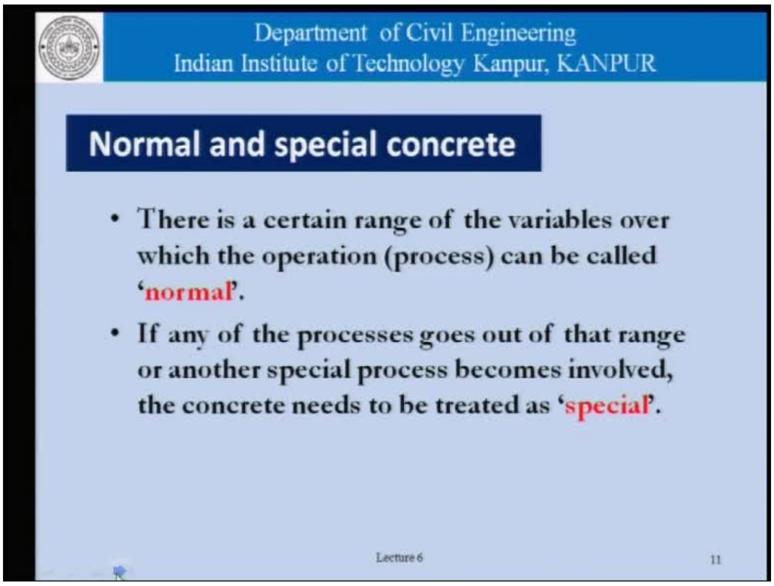

A word about normal and special concretes, there has to be a certain range of the variables over which the operation or the process can be called normal. And if any of these processes goes out of that range, or another special process becomes involved, the concrete needs to be treated as special. This is something which we must keep at the back of our minds, when we are talking of properties and quality control, which involves testing of concretes. So, the discussion today would be largely confine to normal concretes.

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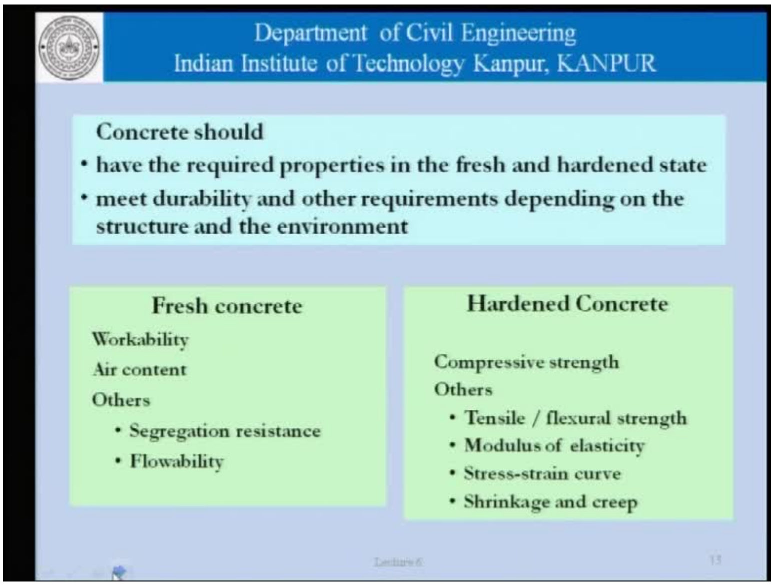

Coming to the properties of fresh and hardened concrete, we know that it should have the required properties in the fresh and hardened state, meet durability requirements. And here are some of the properties which are actually listed, fresh concrete workability, air content, segregation resistance, flow ability in hardened concrete, we have compressive strength may be tensile, and flexural strength, stress strain curve, creep and shrinkage and so on.

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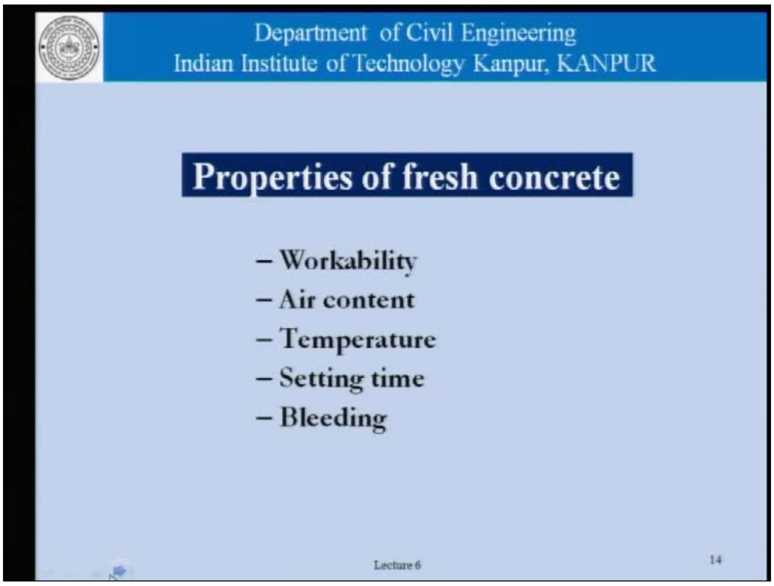

So, this here is the list of properties that we will be talking about in our discussion today, as far as the properties of fresh concrete are concerned, workability, air content, temperature setting time and bleeding. As far as hardened concrete is concerned, we will try to focus on compressive strength, tensile and flexural strength, the modulus of elasticity, the stress strain curve, creep and shrinkage, permeability and durability and see where we go.

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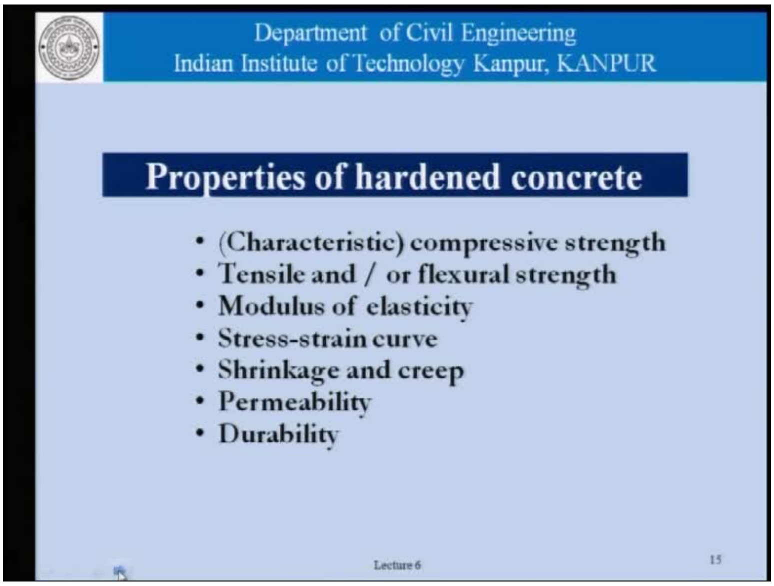

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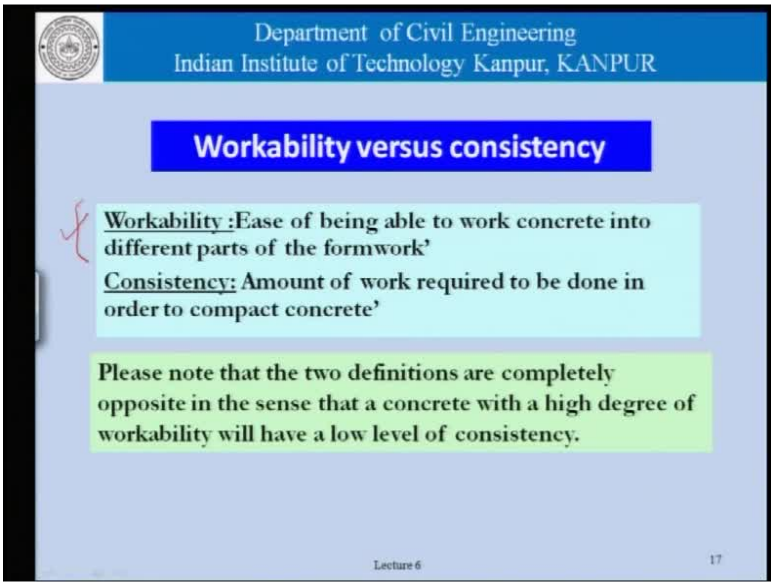

Now, coming to the workability part of it, what is workability? We often see in literature term is workability and consistency. And if you look at the definitions, which may be available in different texts, workability is defined as the ease of being able to work concrete into different parts of a formwork. Consistency on the other hand, is sometimes defined as the amount of work required to be done, in order to compact the concrete. Please note that the two definitions are completely opposite in the sense that a concrete with a high degree of workability, will have a low level of consistency

Now, given a concrete if it is very highly workable by the definition that is proposed here, what it means is that it will easily occupy, the different corners of a mold and is very easy to work with. It naturally implies that the amount of work done, or the amount of work required to be done, in order that the concrete is compacted would be very low.

As far as we are concerned in this discussion not only in the discussion today, but also in the discussion during the course of the different lectures, in this course we will follow this definition of workability. When we say that the concrete is highly workable we mean that it is very easy to work with, when it is harsh or less workable the concrete requires a lot of work to be done, in order to compact it or in order to make sure that it occupies the different corners in a formwork, and so on and so forth.

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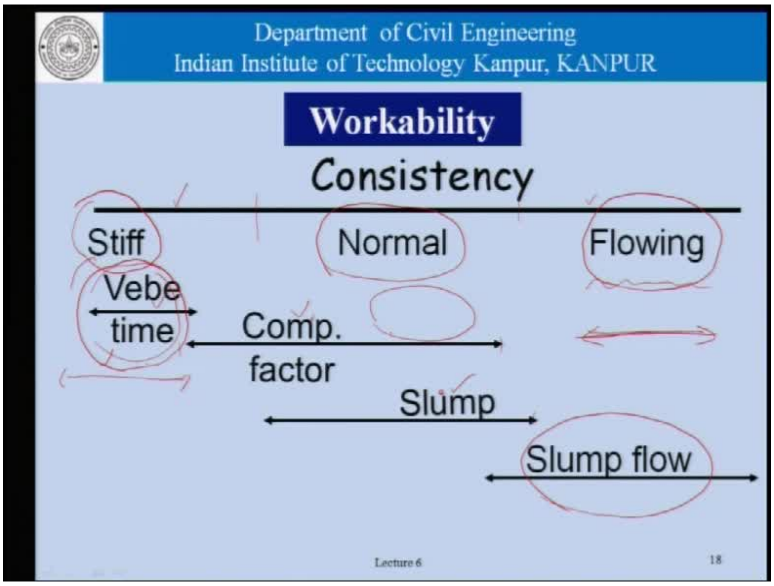

Now, let us come to a schematic or a qualitative description of workability. Workability has a range from a stiff concrete to flowing concretes, and then in between here we have what can be called a normal concrete and that is what I said that, in order for a concrete to be classified normally. We have to understand that we are talking of a certain range of workability, both on this side as well as on this side the concrete needs to be treated as a special concrete and different tests, different specifications need to be brought into play.

So, as far as the methods for measuring quantitatively, the workability of normal concrete is concerned. We have two tests the slump and the compaction factor there is a slightly different range over which these tests help us, differentiate between two concretes. When we go towards stiff concrete, the workability is better represented by a test called the vebe time. When we go into the regime, where the concrete begins to flow then the workability is better represented by a test like the slump flow.

What we must remember from this diagram is that in this range for example, the slump or the compaction factor test is not a discerning test, it will not be able to differentiate between the workability’s of one concrete versus another. Similarly, in this range the slump and the compaction factor will be unsuccessful, in any attempt to classify the concrete or characterize the concrete, or better understand their workability’s and we need to go to the vebe time.

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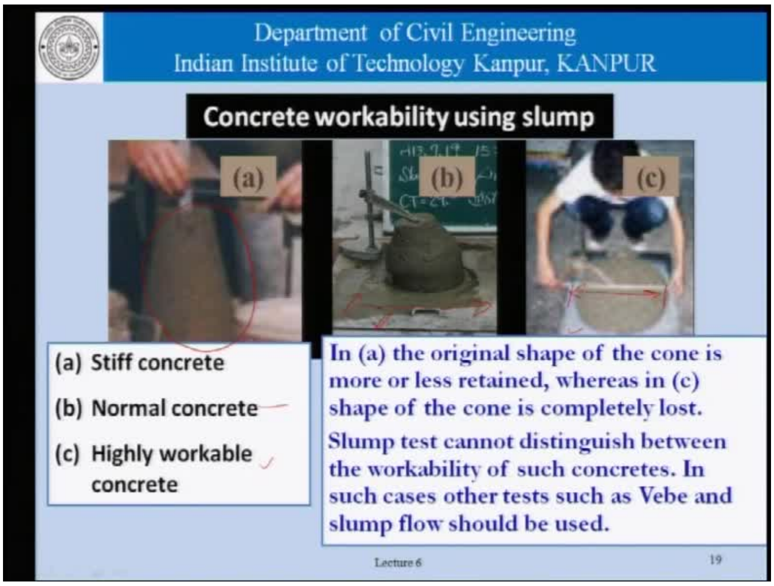

On the other hand vebe time will not be the best test, to carry out if the concrete consistency or the workability is in this range. The times will almost mix the same that is something, which we must remember when we pick and choose a particular test, we should be careful then the test is appropriate and helps us, actually be able to differentiate between two concretes or a concrete mix today, and tomorrow and so on and so forth.

Now, coming to a few test let us look at the slump. This is the slump that we have for a stiff concrete, if you notice the slump cone has largely retained with shape and we have more or less a zero slump kind of concrete. Whereas, this test here is the slump, which is normal and it is a normal concrete where the slump can be used, as a discerning test.

On this side here we have a highly workable concrete, and the slump cone completely collapsed. And we need to differentiate or we need to measure the workability of concrete not in terms of the slump, but in terms of the diameter of this is spread, this is something which we will talk about in greater detail, when we are talking about special high flowing concretes like the self compacting concrete and so on.

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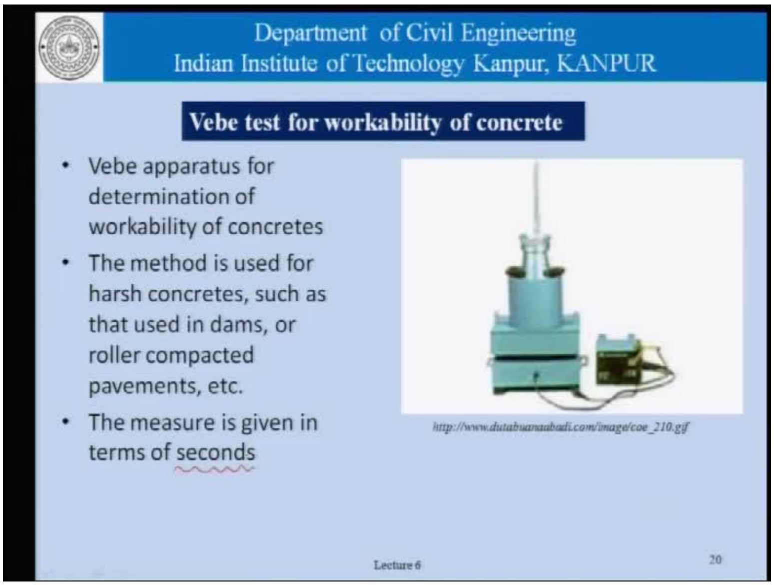

For the sake of completeness, this picture here shows the vebe apparatus for determination of workability of concretes which are stiff, these concretes are used in applications such as dams, roller compacted concrete pavements and so on. And the measure that is the vebe test gives us a response in terms of seconds, I am leaving the actual method out of the discussion today, and expect that you will be able to read it on your own and know that how we determine, the actual seconds involve or the time involved for the test to be completed and those seconds or that amount of time helps us, quantify the workability of the concrete in terms of the vebe time.

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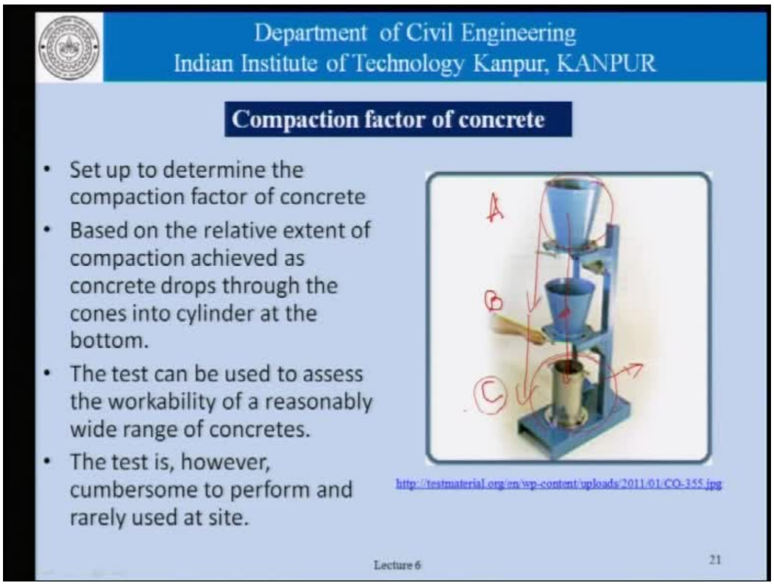

Continuing from there let us talk of the compaction factor test basically, what this test does is allows the concrete to fall from one container to another and then to another. And we compare the density of the concrete obtained here, with respect to another density which is obtained by filling the same container, and compacting the concrete using vibrators and so on. So, that we get the maximum possible density.

So, the compaction factor is a measure of how much, the concrete allowed to fall from this place to this place, and this place to this place how much has that been compacted with respect to a properly compacted concrete, and with as far as that is concerned we get numbers like 0.8, 0.9, 0.95 which moves towards more and more workable concretes. If a concrete has a compaction factor of 1 what it means, is that the compaction achieve by along the concrete to fall from container a to container b and finally, to container c is the same as the amount of compaction that was obtained by filling the container c, with the concrete and trying to compact it to the extent possible using internal vibrators, and so on.

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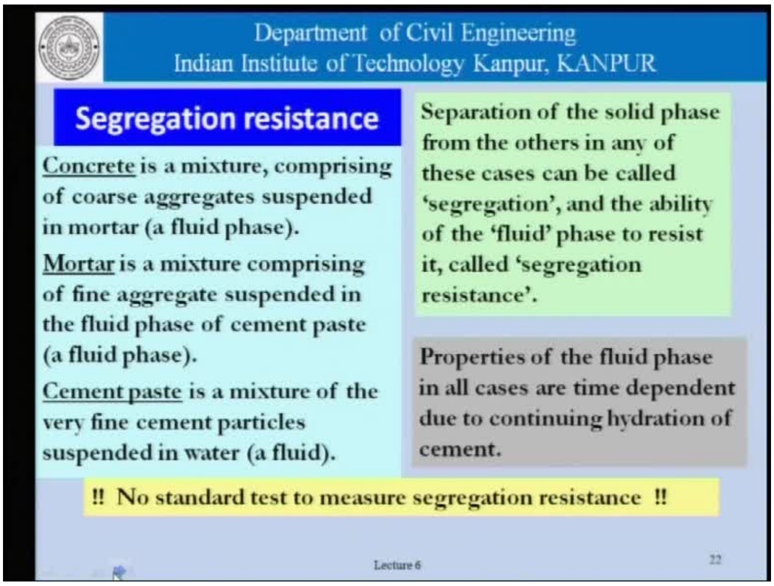

Now, let us come to segregation resistance which is a slightly different property concrete we know is a mixture comprising of coarse aggregates suspended in mortar. Mortar being a mixture comprising of fine aggregates suspended in a fluid phase of cement paste, and a cement paste itself is a mixture of very fine cement particles suspended in water, which is a fluid.

Now, separation of the solid phase from others in any of these cases whether, it is concrete or it is mortal or it is paste can be called segregation. And the ability of the fluid phase to resist it is called segregation resistance. So, as far as concrete is concerned for example, if the mortal moves forward leaving all the coarse aggregate behind, we say that the concrete, we say that the concrete does not have adequate segregation resistance because the fluid that is mortar is not able to resist the separation of the coarse aggregate from it.

Similarly, we can talk in terms of segregation a mortar and in the case of cement paste segregation really boils on to the separation between water, and the cement particles. We must remember that the properties of the fluid phase in all these cases, are time dependent due to the continue hydration of cement, which starts as soon as the water and cement come together and that happens in the mixture itself.

Accept that of course, in the first few minutes or the first few tens of minutes, we may assume that that something which we have to live with. Having said all this there are no standard tests to measure segregation resistance, and we can only talk in terms of segregation resistance in qualitative terms that is we look at a concrete, or look at a model and say that segregation has occurred, we are not able to quantify this so far, and it is a challenge to concrete engineers to develop an appropriate and a robust test.

One of the important things we must remember, as far as concrete engineering is concerned is that all the test that we do should be robust. We should be able to carry out these tests in the field, often with not very sophisticated equipment often using not very well educated or very highly qualified professionals. There may be professionals with the lot of experience, but they may not have all the background that is required to understand the hydration process, or the strength development process and all that.

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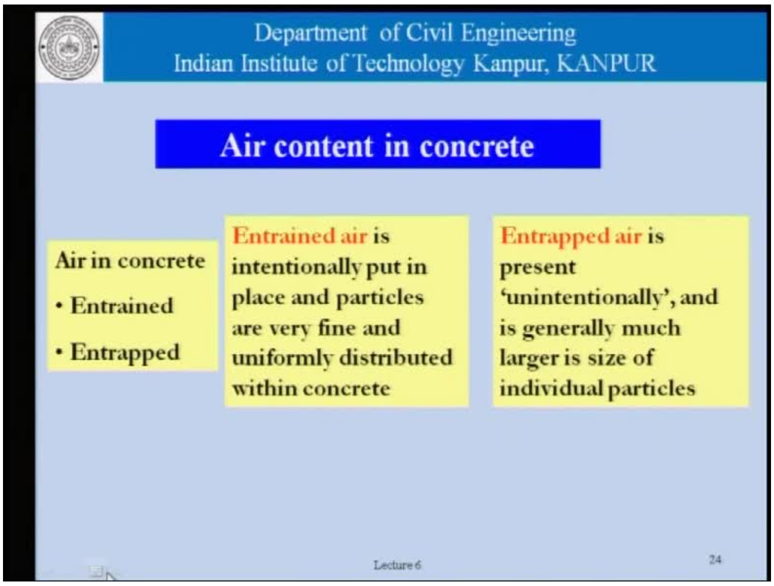

Now, coming to air content, air in concrete as we have already said in our earlier discussion is entrained or entrapped, entrained air is intentionally put in place and the particles are very fine and uniformly distributed within the concrete, and this is achieved by using an appropriate air entraining at mixture. Whereas, entrapped air is present unintentionally and is generally much larger in size, as far as individual particles are concerned. When it comes to measurement of course, any measurement method would not be able to distinguish between air, which is entrained or entrapped.

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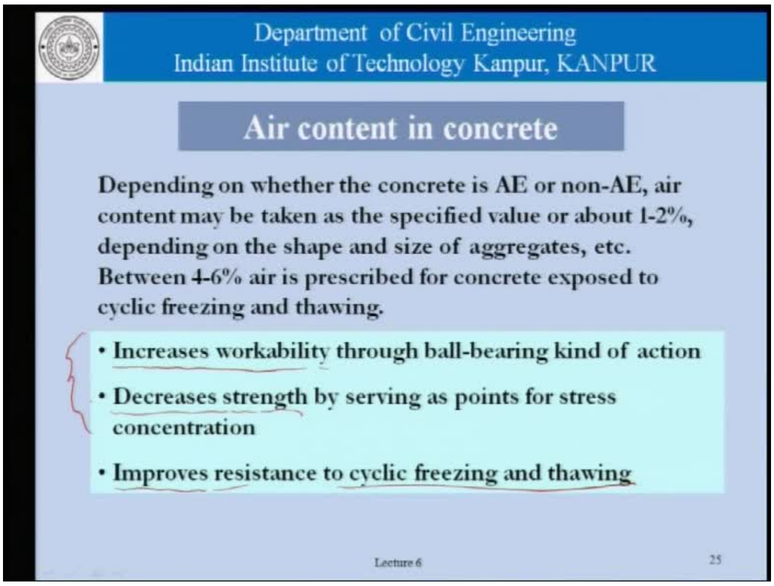

Let us take a look now as far as a content is concerned depending on whether, the concrete is air entrained or non air entrained that is it has an air entraining at mixture, or it does not have an air entraining at mixture. The air content may be taken as a specific value may be about 1 and 2 percent depending on the shape, and size of aggregates etcetera. However, and air content of about 4 to 6 percent is prescribed for concretes which are exposed to cyclic freezing and thawing and what the air. Now, what is the air entrainment to there are three things involved, one is increase in workability, air entrainment increases workability through the ball bearing action of air particles.

There is a tendency for some decrement in strength, as the air particles serve as points for stress concentration and also basically, they are voids and at the end of it higher the voids the strength has to be low. Then it improves the resistance to cyclic freezing and thawing so basically there are these three things, which we must keep in mind when we are talking of air entrainment concrete.

As far as an interplay between these two is concerned, it will not be very fair to say that air entrainment decreases the strength, though I have said here that air content decreases the strength, we should remember that air entraining at mixtures also tend to disperse the cement particles and that helps us get a larger, area available for the hydration of cement and that tends to increase the strength of the cement paste or the concrete.

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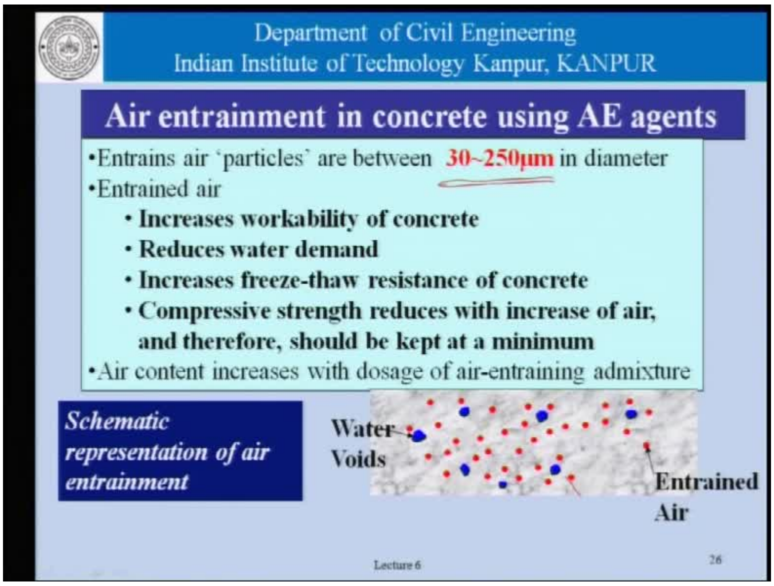

So, really speaking air entrainment does not necessarily lead to a net reduction in strength, but in principle yes, as we increase the air the strength tends to go down. Now, taking a closure look at the air entrainment concrete using air entraining agents, these particles are in the range of about 30 to 250 micrometers and diameter, and they set in a concrete matrix much the way this these red dots are shown. And there are water voids which are all over the place and so on.

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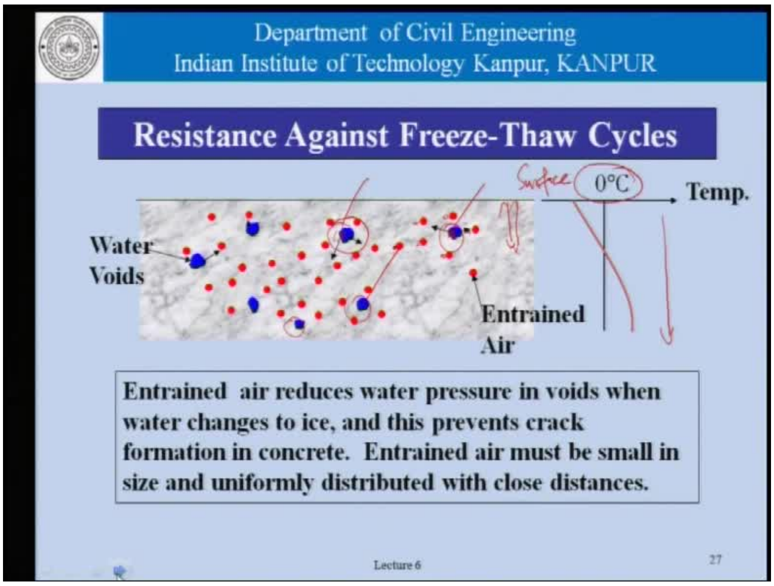

When it comes to the resistance against freezing and thawing, what we are trying to do really is to see how these air particles help, in dissipating the forces that will arise or the pressures that will arise, when these water voids or these voids full of water. The water in these voids tends to freeze on account of a temperature in the atmosphere, which may go below 0.

So, as the temperature goes below 0 here at the surface of concrete there is a thermal gradient the temperature distribution within the concrete is established, and we see that near the surface this water in the pores or pore spaces or voids that tends to freeze. And once this water freezes it expands, and these air particles around the water they provide some kind of a outlet for the water that is getting pushed out, on account of the freezing action thereby, holding the concrete together in this area and that is how the kind of loosely or simplistically explain, better performance of air entraining concretes as far as freezing and thawing is concerned.

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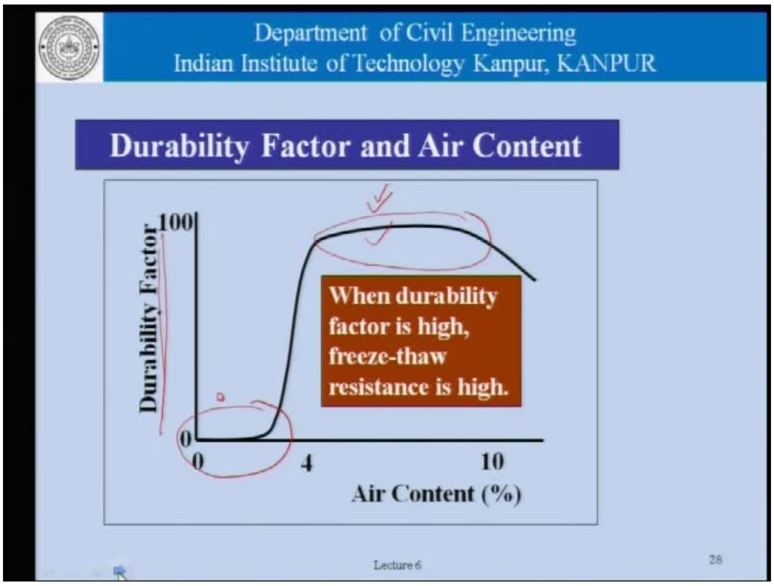

This is another schematic representation of how, we rate the durability factor and the air content. This really is the result of a lot of test carried out with concretes in this range of air content that is between 0 and say 1 and a half 2, 3 percent and concrete having air content of 4 percent to 5, 7, 8 percent and there we see that the performance as far as the durability factor is concerned, and this durability factor is a measure of the performance of concrete under cyclic freezing and thawing.

This test being carried out by exposing the concrete to cyclic freezing and thawing, and see how the pore structure in the concrete deteriorates or undergoes the stress, under the action of these forces and we find that these concretes perform much better than the concretes in this area, that is to say air entrainment helps the performance of concrete in freezing and thawing.

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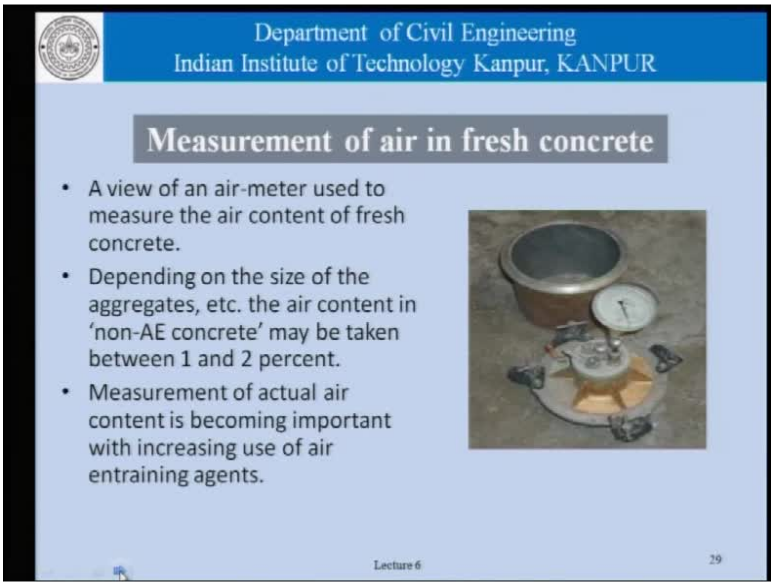

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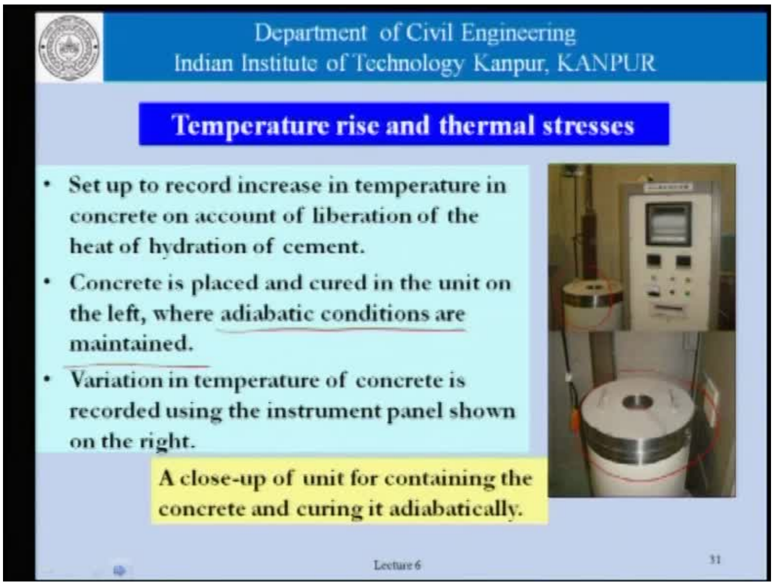

This is a simple device of measuring, the air in fresh concrete and the importance of using air measurement or air content measurement in fresh concrete, is becoming more and more important, as we are using air entrained or air entraining at mixtures. Now, coming to the temperature this here is a setup which is sometimes used to study, the changes in temperature on account of the liberation of the heat of hydration, we have seen that when cement hydrates it liberates a lot of heat, and that heat liberation leads to an increase in the temperature of concrete, and we want to monitor this temperature rise which is at the root of the formation or introduction of thermal stresses in the concrete.

And this setup which is shown here records, the increase in temperature in concrete on account of the liberation of heat of hydration of cement. So, what we really do is place the concrete which to use in a particular application. So, it is a test which is semi field oriented, we decide the mix to be used in a particular project, use exactly that mix the same materials especially, the cement and then try to study how the temperature rises for that particular cement for that particular proportion, and we maintain adiabatic conditions to get standard results. And variation in temperature of concrete is recorded through an instrument panel as shown and of course, this is a close up of this container which houses the concrete.

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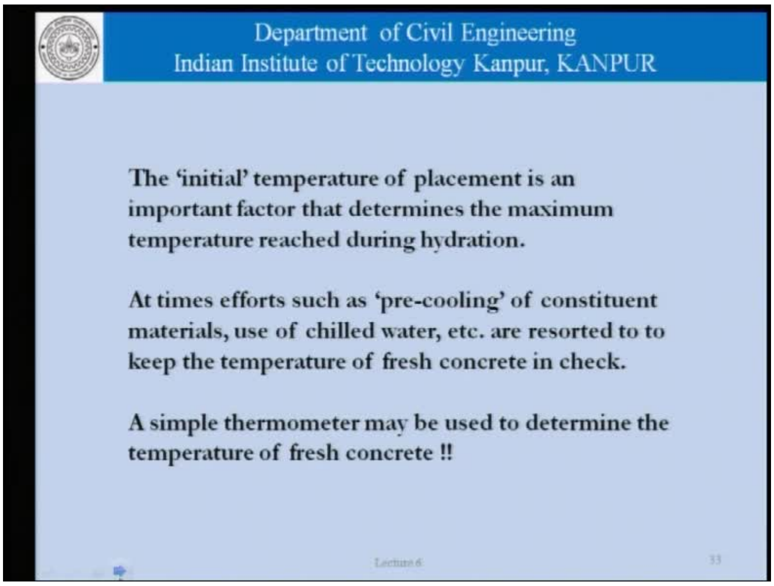

The initial temperature of placement is an important factor that determines, the maximum temperature reached during hydration. At times efforts such as pre-cooling of constituent materials, use of chilled water and so on are resorted to keep the temperature of fresh concrete in check because there may be specifications, which say that the temperature of fresh concrete should not exceed a certain number, may be 20 degree centigrade may be 18 degree centigrade and so on, depending on the application.

So, measurement of the temperature of fresh concrete is a very important parameter, as far as the quality control of concrete is concerned in those projects, that temperature of fresh concrete is important when we try to understand, what will be the maximum temperature that is reached during the hydration process. If we lower the temperature of fresh concrete, we will get a lower peak temperature reached.

And if we are able to reduce the peak temperature raised, we will be addressed the problem of introduction of thermal stresses in concrete construction. This discussion is especially relevant, when we are talking of mass concrete applications such as though that such as, those in dams sometimes in roller compacted concretes and also, sometimes in high strength concretes where the amount of cement being used is really large.

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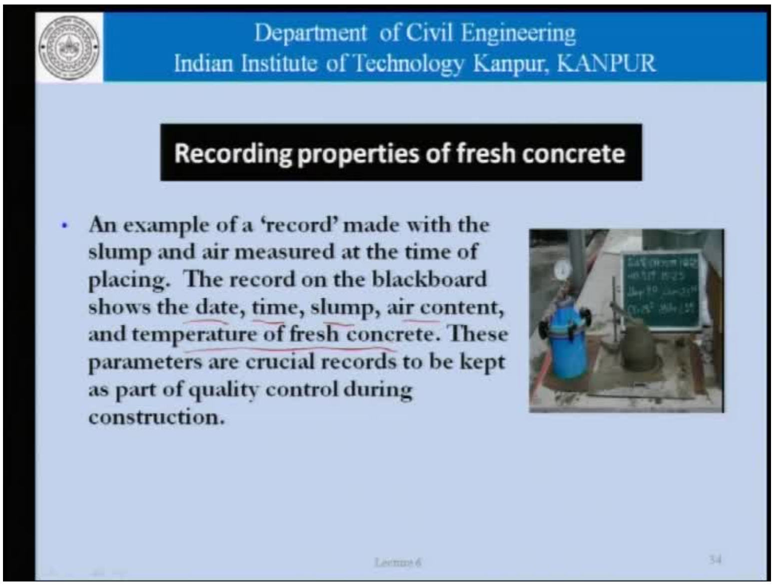

Of course, as far as measurement is concerned a simple thermometer is used to determine the temperature of fresh concrete. We simply take at thermometer, inserted in the mass of fresh concrete and we get the temperature that is good enough. Now, this here is a method or a simple representation of how properties of fresh concrete should be recorded, we should record the date and time of placing the concrete, the slump, air content and the temperature of fresh concrete, which are all very crucial from the point of view of good record keeping or archiving of properties of concrete used, in the different pores of a concrete construction.

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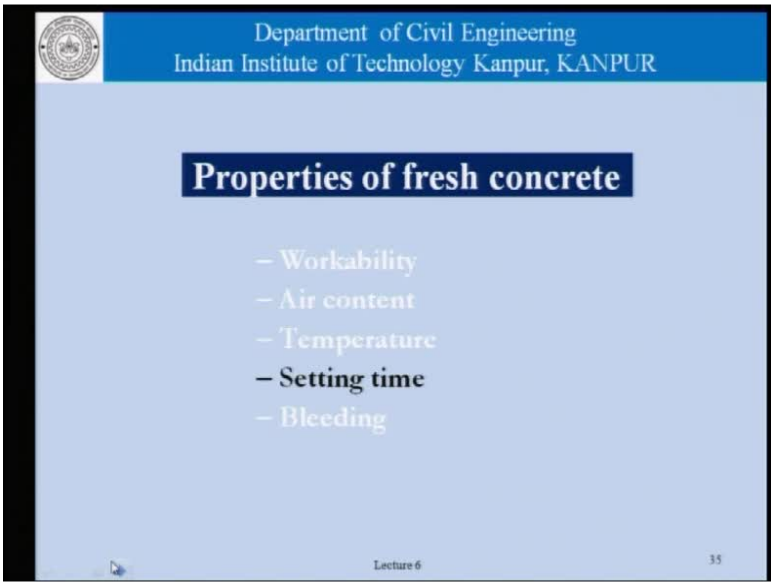

Now, coming to setting time…

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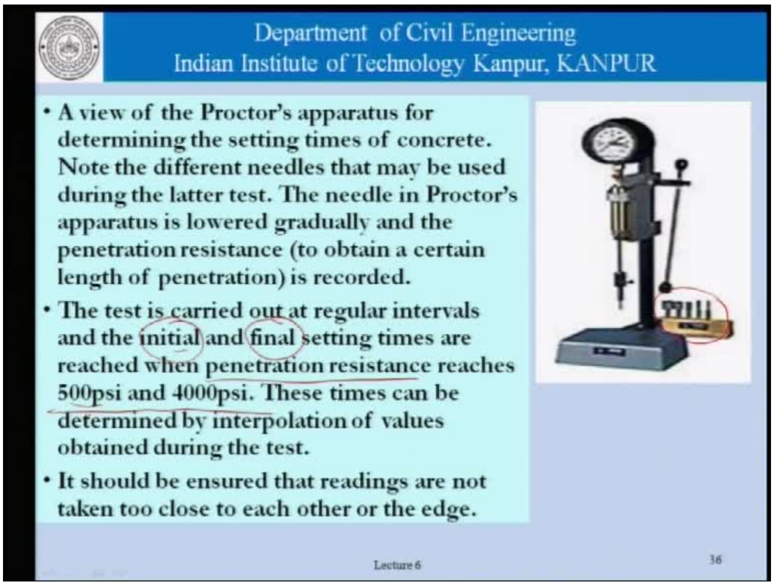

Concrete sets overtime, as a result of the formation of more and more hydration products, during hydration. Now, we are familiar with the setting of cement and we know the initial setting time, and the final setting time of cement is a quality control parameter. And we have specifications which say, that the cement should not have a initial setting time higher than something or lower than something, it should not have a final setting time, which is higher than something or lower than something.

Now, even though in the case of concrete the setting time of concrete itself is somewhat related to that of cement, but it is obviously exactly not the same because the cement setting times are determined using paste. Whereas, concrete is not a paste, concrete has vary amounts of cement it has varying amounts of what a cement ratio, it is placed under different conditions and therefore, it is not proper to talk in terms of relating directly, the setting time of cement and that of concrete.

This picture here shows the view of the proctor's apparatus, which is used for determining the setting time of concrete, the principle is the same as that you use in the vicat apparatus for cement and that is penetration resistance of course, we use a set of needles as shown here, and these needles are changed over a period of time as more and more setting takes place.

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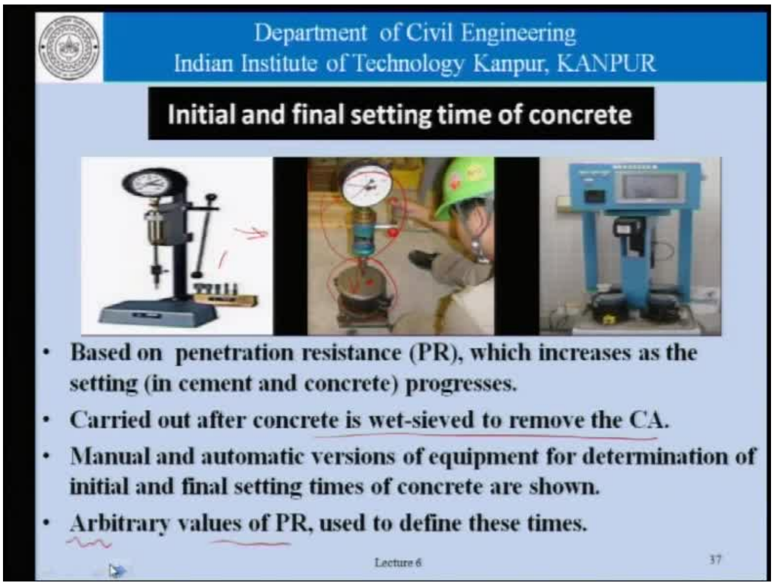

The test is carried out at regular intervals, we try to study the penetration of these needles, and once the penetration resistance reaches a level of 500 PSI, and 4000 PSI. And leaving in the conversion to the SI units out of here, please do it at your end, and when the penetration resistance reaches these levels, we say that the concrete has reached initial set and final set. The initial set corresponds to a penetration resistance of 500 PSI and the final set refers to a penetration resistance of 4000 PSI, and of course, we must make sure that that it is not taken very close to each other, or close to the edge.

We will talk about a little more, when we look at the actual set up, this shows the actual set up this of course, is the same picture as we saw just now, this is the test for the setting times being actually, carried out we can see that there is a mold which has been filled with mortar. Now, the concrete is wet sieved to remove the coarse aggregate from the concrete; and then we have basically, what is left here is mortar and here is the proctor apparatus, where we are trying to plunge a needle into the concrete and observing the penetration resistance on the dial gauge. There is a manual version there are automatic version so on, which are available and at the end of it based on the values that we have 500 and 4000 that we talked about in the last slide, which are essentially arbitrary in nature, we can define the times for the initial and final set.

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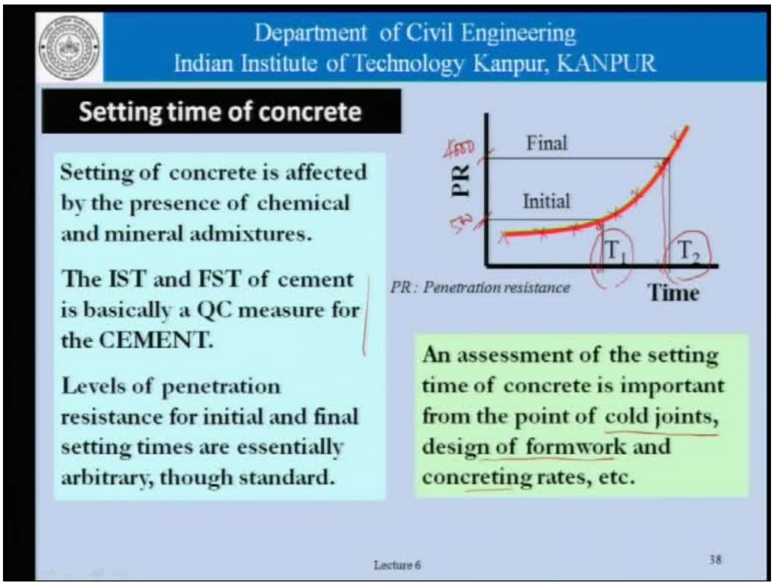

This here is the schematic representation what really goes on, the setting time can be affected by the presence of chemical and mineral admixtures. The initial setting time and final setting time of cement is basically, a quality control measure for cement and not for concrete. So, we may have a situation where if you plot penetration resistance, we can get these values and what we try to do is to say that at this penetration resistance, which is 500 P S I and at this penetration resistance which is 4000 PSI.

What are the times that correspond to the penetration resistance, and we take t 1 and t 2 to be the initial and final setting times. What is the importance of the setting time of concrete as far as concrete and engineering is concerned, that is from the point of view of cold joints, design of formwork removal, concreting rates as far as these things are concerned, we are very much interested to know, what exactly is the setting time of concrete. How much is the initial setting time, how much is the final setting time that will help us better control formations of cold joints design of formwork, removal concreting the rates of concreting and so on.

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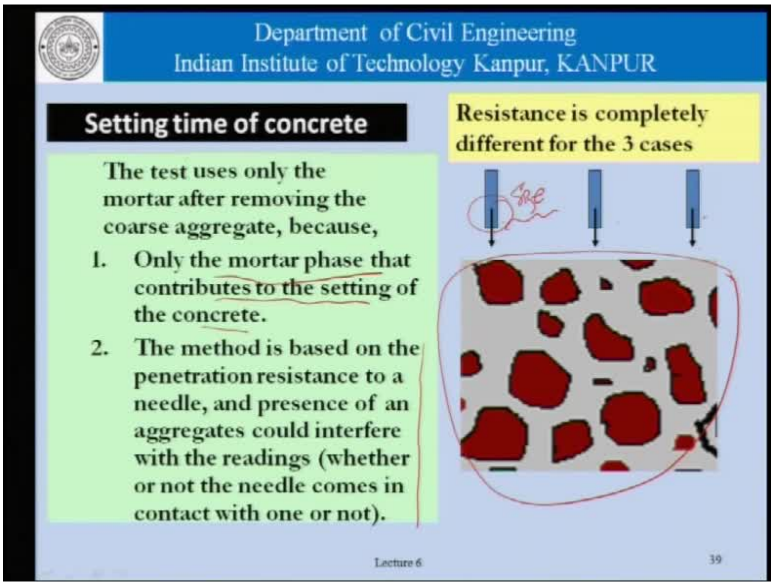

When we are doing setting time for concrete, when we are trying to do the setting time of concrete or measure the setting time of concrete, we said that the concrete is wet sieved to remove the coarse aggregate. Now, the logic for that is given here, it is only the mortar phase that contributes to the setting of concrete. Coarse aggregates their presence does not really affect the hydration process.

And therefore, we may say that we can actually, neglect them or ignore their presence and just work with the mortar, as far as the setting time is concerned. Though in principle, we can extend that argument to mortar as well and try to remove the sand, but the engineering difficulty in removing sand from a concrete mixture, mix impossible for us to do that and therefore, we are happy or we have to live with the fact, that we will work with mortar, and try to call that as the setting time of concrete.

The method is based on penetration resistance to the needle, and the presence of an aggregate, coarse aggregate could interfere with the readings whether or not the needle comes in contact with the coarse aggregate or not as shown here. So, if there is a needle here and we have a coarse aggregate setting, very close to the surface or coarse aggregate is setting somewhere here, which is away from the surface the reading in this three cases will be quite different.

So, in order to get rid or make sure that the readings that we get are independent of the position of the coarse aggregate within the mass, we remove the coarse aggregate of course, if we want to use the coarse aggregate then the size of the needle also, needs to be changed. The size of the needle is decided on the basis of the size of the particles, that the needle is trying to penetrate, but needle size should be larger than most of that particle size. In fact, all the particles that are present in the phase that we are trying to study here.

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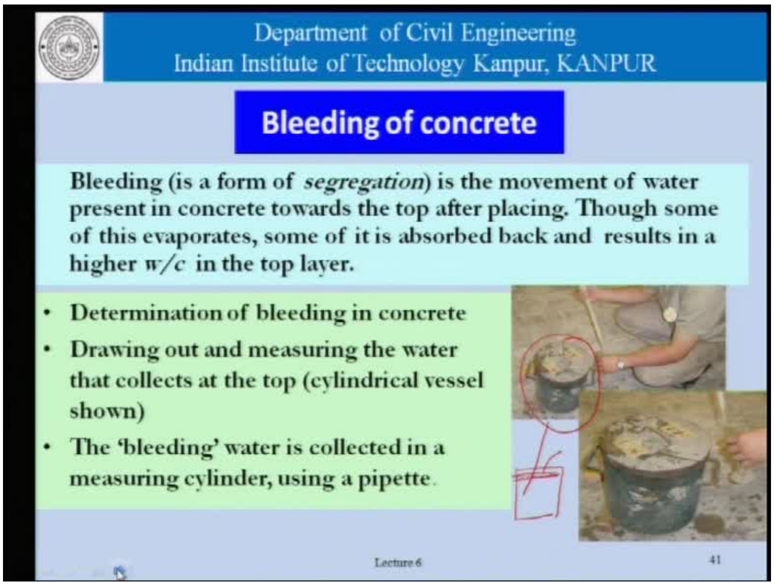

Now, coming to the last property of fresh concrete that we will discuss, that is bleeding. Bleeding is a form of segregation and is the movement of water, present in concrete towards the top of the placing. The some of this evaporate the water that cumulates or appears in the surface some of it evaporates, some of it is absorbed back and results in the higher water cement ratio in the top layer, we will try to take a look at the schematic representation of this process in a later slide.

Here what is shown is how the bleeding is determined, we try to draw out and measure the water that appears or collects at the top of a cylindrical vessel, and the bleeding water is collected using a measuring cylinder and a pipette. So, what we do is collect the concrete in a cylindrical vessel like this, which is covered with the lid and as the water if we have this is the cylindrical lid we fill the concrete up to this point. Whatever, water appears at the surface here that is drawn out, and the lid is closed back. This process is continued till such time, as the water seizes to appear on the surface.

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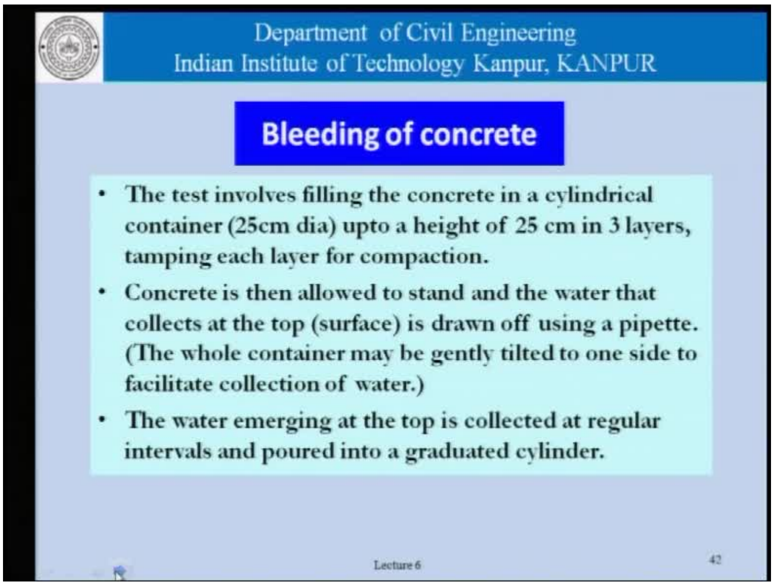

The test as it says, here involves filling up the concrete in a cylindrical vessel 25 centimeters in diameter up to height of 25 centimeters in three layers, damping each layer for compaction. Concrete is then allowed to stand and the water collects at the top surface is drawn off, using a pipette and the whole container may be gently tilted to one side to facilitate collection of water, the water emerging at the top is collected at regular intervals. And we continue this process till such time as the water seizes to appear.

This series of pictures here shows, what goes on in the bleeding process as water that accumulates at the top during bleeding, part of it evaporates as shown here and part of it is reabsorbed in the concrete and therefore, this concrete here becomes a small layer of concrete, which has a water cement ratio which is higher than the main body concrete here because this is the concrete, which has a water cement ratio of the original mix more or less.

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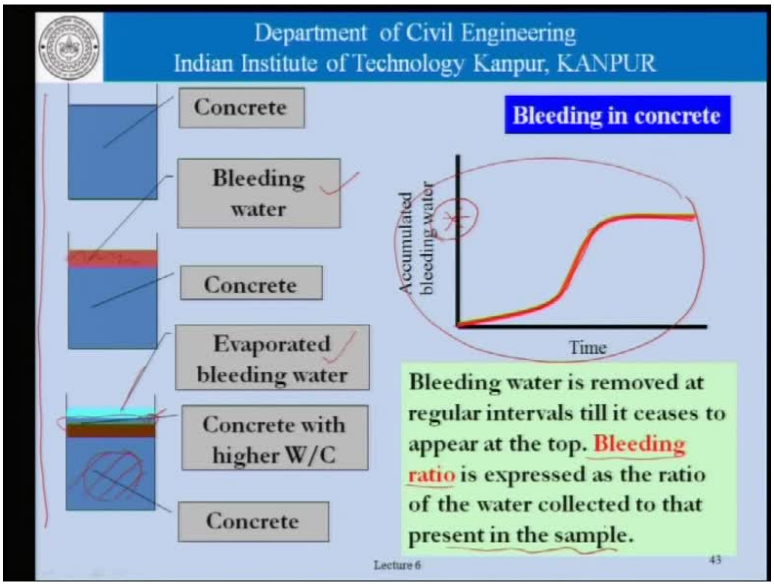

Whereas, this is the concrete here which has more water, the water in the mix as well as the water that first appear at the top and that was reabsorbed on account of bleeding, bleeding is measured in terms of a bleeding ratio, which is expressed as the ratio of the water collected to that present in the sample. So, once we know the amount of concrete that we have taken we know the mix proportion that concrete. So, we know the amount of water in that sample depending, on how much water we have what proportion of it is collected or is removed in the bleeding test, gives us the bleeding ratio.

And this diagram here shows how the accumulated water or accumulated bleeding water moves initially, we do not have too much water coming, but gradually you find that a lot of water moves in appears in the surface and finally, no more water appears at the surface and that is the end of the bleeding test. We have this as the total amount of water that has appeared, and this is the thing this parameter is compared with the water present in the sample to give us the bleeding ratio.

Now, coming to the properties of hardened concrete as far as the characteristic compressive strength is concerned, this here is a picture of how the strength that we determine or variation of compressive strength goes in more or less, take it to be a normal distribution about a certain mean. And the characteristic compressive strength is defined as that number here, below which not more than 5 percent values fall that is the area of under the curve below here area under the curve, up to this point is not more than 5 percent.

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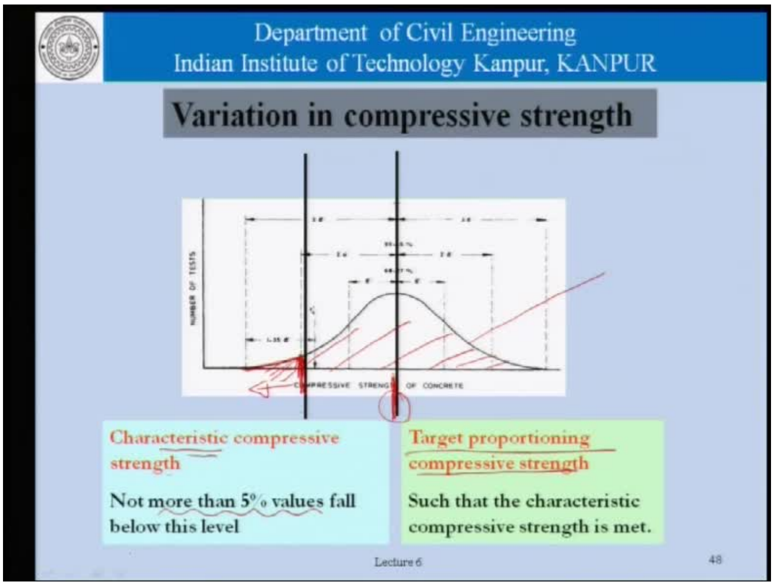

In other words, the area on this side of the curve which is the portion, which is higher than the characteristic strength is 95 percent. And once we have this picture, we have what is called the target proportioning compressive strength that is the strength, which is used to proportional concrete mix and that is the mean value here. So, we need to target the concrete proportions in a manner that the mean strength is here, which is higher than the characteristic compressive strength by an amount, which is related to the standard deviation that are obtained.

Such that once a large number of samples are tested, not more than 5 percent of those samples will fall below the characteristic strength. Now, that is something which is part of the discussion, when we do compressive strength determinations and do quality control of hardened concrete, and try to see acceptance criteria and so on as we shall see later on when we talk about quality control, and concrete construction.

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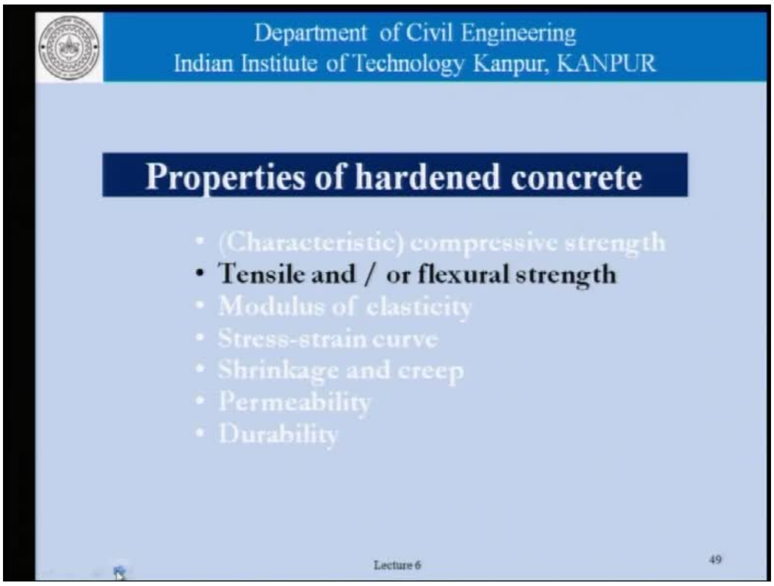

Now, coming to tensile and flexural strength, these strengths or the tensile strength or the flexural strength of the concrete are often given in terms of the compressive strength, codes may give expressions to enable a designer to estimate the tensile or the flexural strength, in certain cases where it is these parameters that really govern the design and that happens for example, in road construction, repair works and all that, there in the absence of data if we do not determine these parameters directly, they are allowed to determine the or estimate, the tensile and flexural strength on compressive strength.

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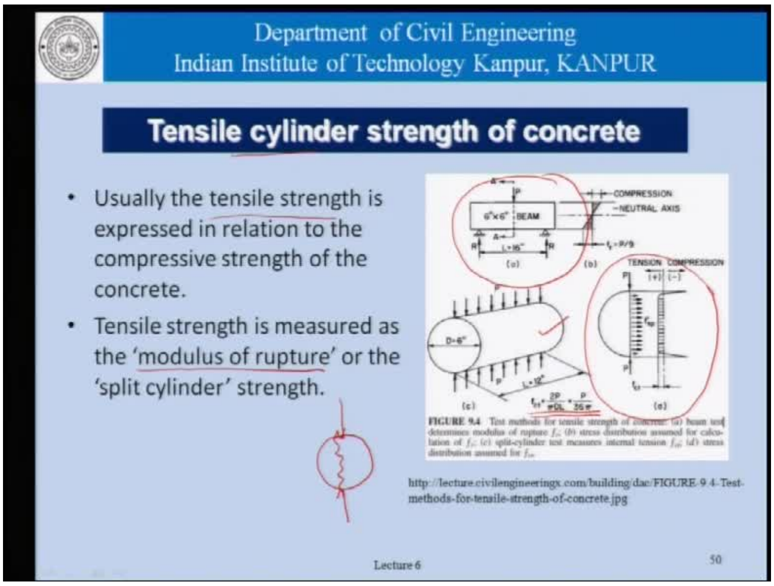

But if we have to actually determine them, this here are two methods which is a modulus of rupture or the split cylinder test, which are used to estimate the tensile strength of concrete maybe tensile cylinder strength or the modulus of rupture. Modulus of rupture being determined by a prismatic beam and the split cylinder test, being carried out as shown in this picture which essentially, involves applying the load on a cylinder in this fashion, which gives us a stress distribution as shown here and causes the cylinder to split along the diameter. So, this gives us the tensile strength or the split cylinder tensile strength and that is how it determines tensile strength, should that be required in a particular application.

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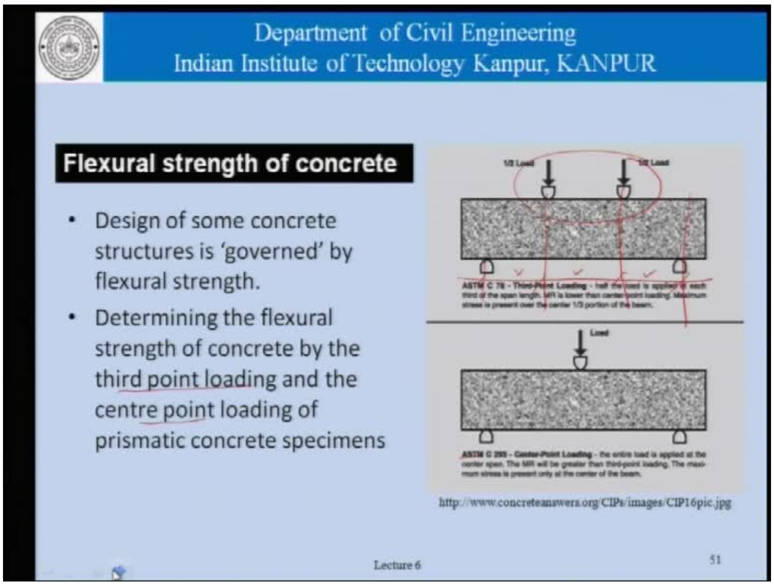

When it comes to flexural strength, which again is required in certain structure which are governed by flexural strength. The ASTM for example, gives us the alternative of the third point loading or the center point loading. The third point loading basically, says that we have a prismatic beam and we apply the load at two places on the top, and these three spans are equal.

So, we have the third point loading that is what call the third point loading whereas in this case the load is applied at the center. And depending on what method you are following particular standard, we follow in a particular country, we determine the flexural strength of concrete directly because this is indeed concrete failing in flexure, directly we get this is indeed failure of concrete in flexure.

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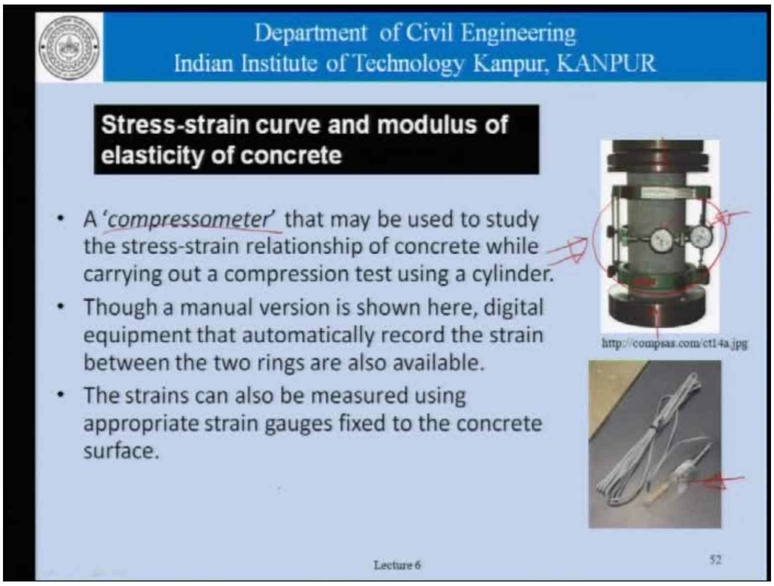

Now, coming to the stress strain curve and the modulus of elasticity of concrete that again is a very important property, and sometimes we use a compressometer as shown here using a cylindrical specimen, and the load being applied to the cylindrical specimen and the deformation in the cylindrical being measured, or recorded using either dial gauges that shown here in a compressometer, or using normal strain gauges which are fixed to the surface of concrete. And we get the stress strain curve of the concrete and based on the stress strain curve, we can calculate the modulus of elasticity.

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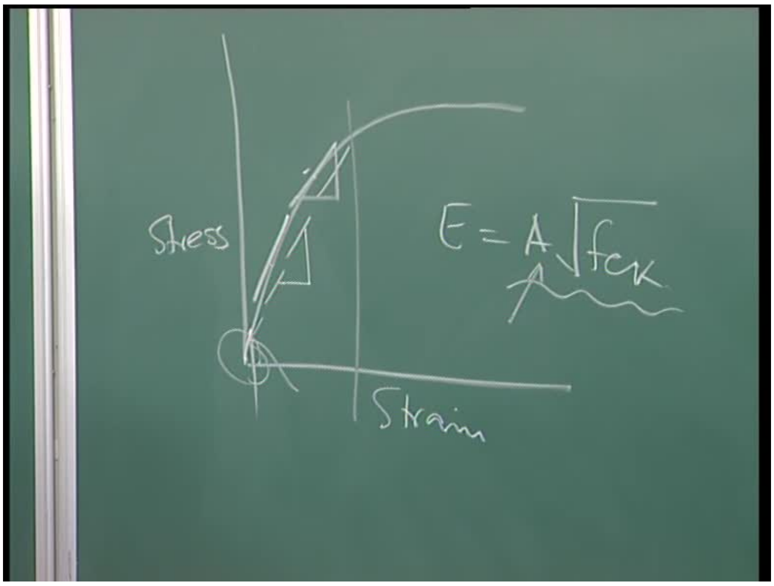

Now, in the case of concrete the stress strain curve is often non-linear and then flat, we are talking of strain at this axis and stress here. So, how do we determine or estimate the modulus of elasticity of a material, which has a stress strain curve which is not really linear. So, as far as concrete is concerned there are different definitions which tell us, either we can take the tangents at different points and time, and the we can take the tangents at different points, along the stress strain curve and that gives us the slope of these lines, gives us the modulus of elasticity or we can talk in terms of a certain part of this graph and try to talk in terms of a modulus of elasticity, which is essentially defined by the slope of this line.

Another possibility is to talk in terms of the modulus of elasticity or the slope of the line at the initial point of the stress strain curve. So, there are different ways of defining the stress strain curve of concrete and different specifications, do different things. Specifications also allow us to use an expression, which is of the type that the modulus of velocity is equal to sum constant times, the root of characteristic strength or some such expression, where this constant is given and this is an empirical equation which allows a designer to estimate the modulus of elasticity, from only the characteristic compressive strength, in the absence of the actual stress strain curve that can be obtained.

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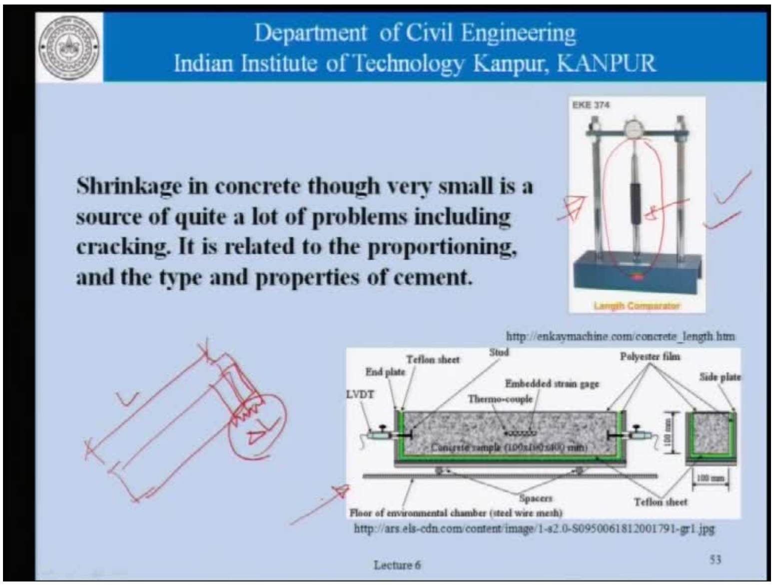

Continue on the properties of hardened concrete, we talked about shrinkage in concrete and the creep. Now, as far as shrinkage is concerned though the shrinkage itself is very small, but it is the source of quite lot of problem including cracking. There is shrinkage cracking that occurs in concrete unless steps are taken to ensure that shrinkage is kept under control, and extent of shrinkage that we get is related to the proportions of concrete constituents and specially the type and properties of the cement, and the size of aggregates.

So, this here is a length comparator which has a standard length bar, and based on this length we can use the frame shown here to study the small changes in length, that occur in a concrete prism which could be of a certain size. So, if we have a concrete prism which is shown here and we have a length corresponding to that, the changes in this length here, sometimes concrete expands or it contracts whatever dimensional changes take place here that can be measured using a comparator. As far as the laboratory techniques are concerned, there are often very sophisticated equipment which needs to be fabricated and used, if we are doing a research work using shrinkage of concrete.

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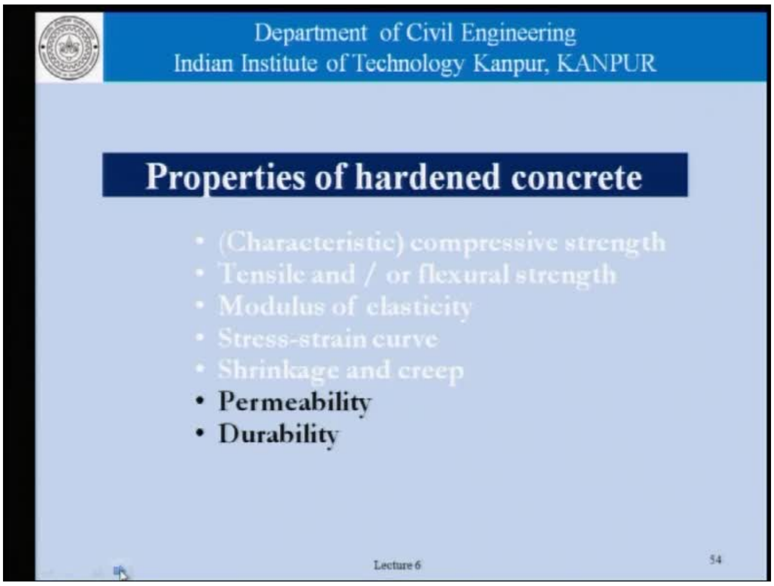

Coming to the last two properties permeability and durability, well take them up in a separate discussion when we are talking in terms of the porosity of concrete relating it to permeability, and both these parameters are very closely linked to durability studies. So, there is something which we will do later.

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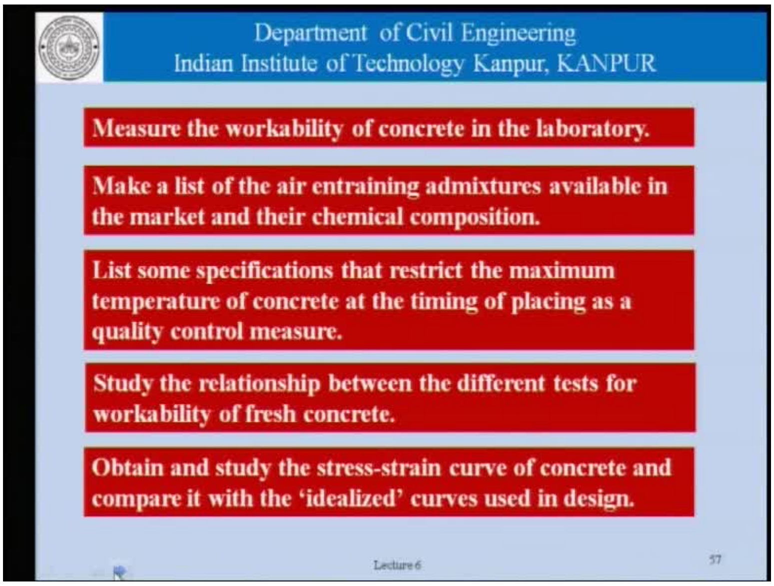

And at this point we are ready to conclude the discussion for the day, and we should try to see what else we need to know about to complete or understanding of what, we have talked about today. I would like you to measure the workability of concrete in the laboratory, and try to see how it varies, how it varies once we change especially the what a content of the concrete. I would like you to make a list of air entraining admixtures available in the market, and their chemical composition, it will be a good exercise to understand, the chemistry involved at least to some extent of the interaction between the chemical admixtures, and the cement and so on in terms of the air entrainment.

If we make a list of specifications that restrict the maximum temperature of concrete at the time of placing as a quality control measure that will enable you to understand or having appreciation of the fact as to why we need to measure, and record the temperature of fresh concrete. We talked of three different test the vebe test, the normal slump test and the slump flow kind of test, the compaction factor kind of test and of course, in regions, where these tests can actually be used together they are obviously, is a relationship between this test, if the compaction factor is increasing for different concretes a, b, c and d which are increased, which are arranged in the order of increasing compaction factors, how will this slumps vary.

What is a relationship between slump and a vebe test? A study of these relationships between the different tests will help you understand, the whole idea of measurement of workability better, and the last thing that I have here is to obtain and study the stress strain curve of concrete, and compare it with an idealized curve, which is often used by a designer; with this we come to an end of the discussion for the day.

Thank you.