Development and Applications of Special Concretes

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Lecture 18
Self Compacting Concrete

Namaskar and welcome back to another module in our discussions on development and applications of special concretes we will start the discussion today in this module with self-compacting concrete.

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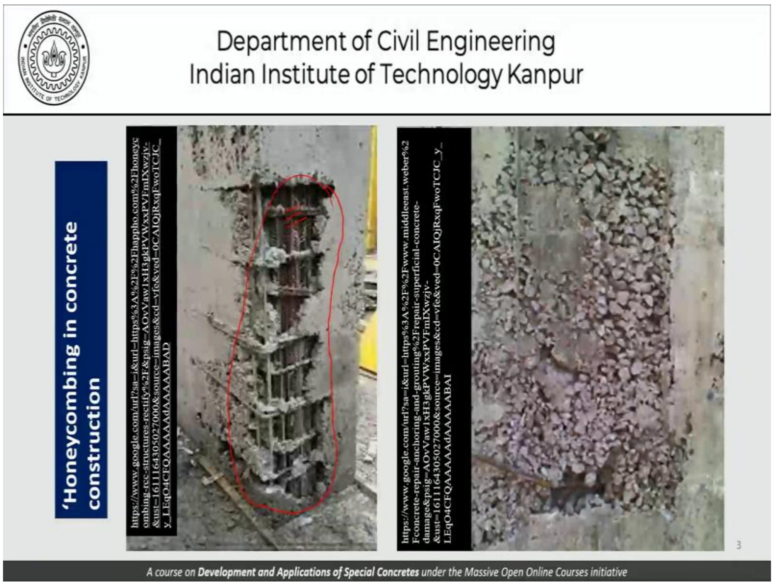

Before we get started with the discussion of self-compacting concrete let us try to take a look at two photographs both of them showing honeycombing. Now honeycombing in this case is that the concrete has not reached this area at all that is the reinforcement was such that it prevented the concrete from reaching the surface. In another case which is shown here the mortar has not reached or it has leaked out of the form work or whatever has happened result being an unpleasant looking unaesthetical concrete on the surface.

This is precisely what is not desirable at all as far as concrete construction is concerned. So having said that what do, we do at site if we encounter such a situation. We try to remove some loose concrete here some loose aggregates from somewhere here and plaster it. And hope that that plastered surface which will be difficult to make out for a naked eye or for a untrained person from with respect to the normal concrete surface here that will behave or that will be as durable as the normal concrete is.

That does not happen at all which means that this kind of a construction as far as concrete is concerned raises durability related concerns.

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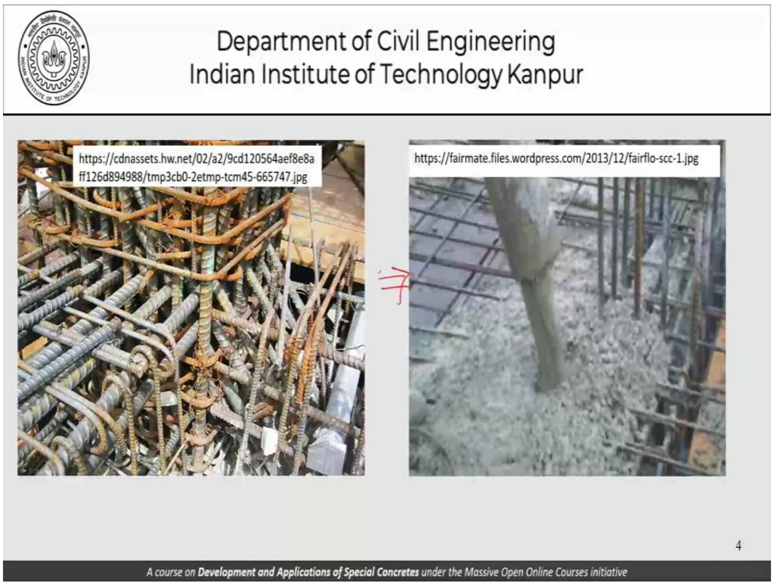

This picture here is that of congested reinforcement the kind of reinforcement that we saw in the previous slide. And you can see that it is very, very difficult for concrete to negotiate this kind of dense reinforcement. It is virtually impossible for needle vibrators to be placed through this reinforcement and try to compact the concrete for whatever it is worth. The answer to that is this kind of a situation where this concrete is simply being literally poured into the form work.

And while it is being poured we expect that this will behave as a liquid and it will occupy all the nooks and corners it will not need to be vibrated and so on. So this is what our image of self compacting concrete is and that is what we are trying to study as far as this module is concerned.

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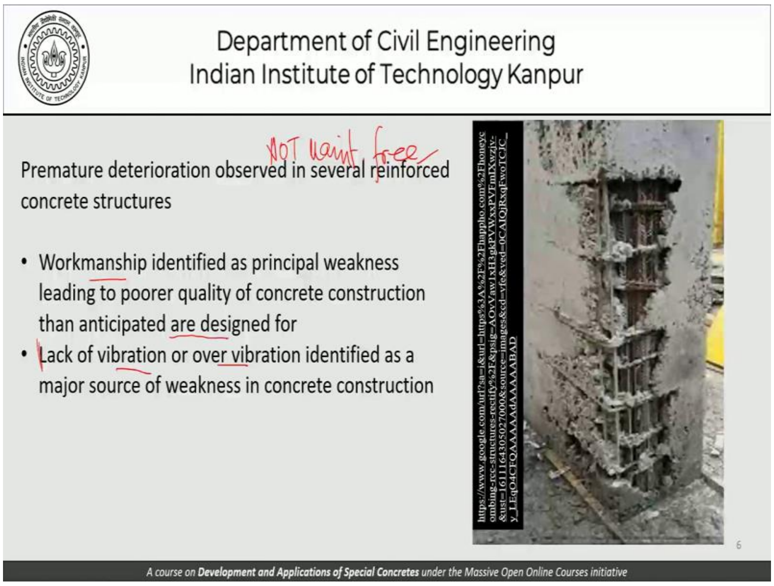

Now this is a sharp contrast what we saw last time this was a picture of roller compacted concrete. And try to see what this concrete looks like which is shown here and it is been compacted through vibratory rollers compared to a concrete like this which is freely flowing more or less and is being compacted into a reinforced concrete structure. So these are the kind of concretes which are special in nature.

Somewhere in between these two the roller compacted concrete kind of stiffness and the kind of self-compacting concrete kind of flowability somewhere in between those we have normal concrete. So that is the essence of our discussion as far as this entire set of lectures is concerned. We already know normal concrete and we are trying to study the issues involved when we get to special concretes and this module concentrates on self-compacting concrete.

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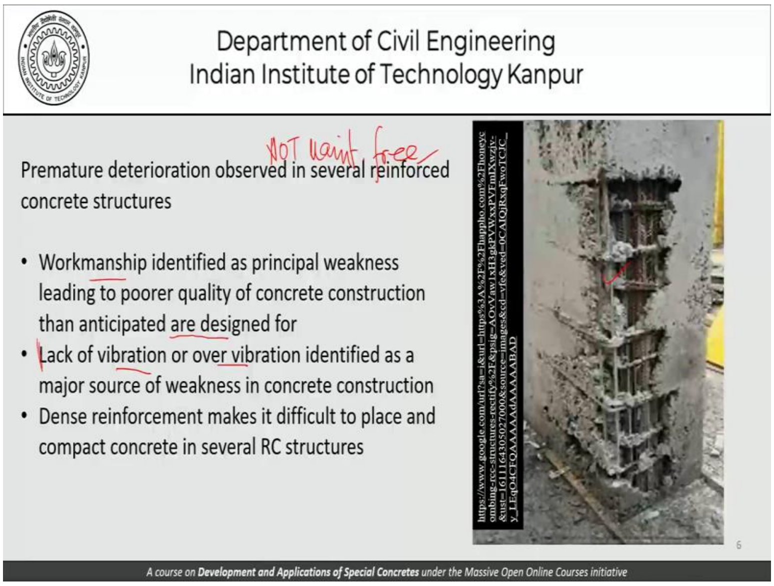

Now starting our discussion on self-compacting concretes in the late 70s early 80s premature deterioration was observed in several reinforced concrete structures which were built just after the Second World War. And it was finally concluded that concrete is not a maintenance free material. Investigations and inquiry was made into what caused this deterioration and workmanship was identified as the principal weakness leading to poorer quality of concrete construction than anticipated for in the designs.

What was the workmanship component lack of vibration or over vibration identified as a major source of weakness in concrete construction. So the lack of vibration on the one side reflects a purely workmanship issue in the sense that the vibrator cannot reach the concrete which is supposed to vibrate or it could also have a situation where the reinforcement is such that it is not possible to vibrate the concrete.

Whether we like it or not so in any case lack of vibration or the absence of vibration was identified as a major source of weakness. Remember this is structure remember the other structure that I showed you earlier and dense reinforcement makes it difficult to place and compact concrete in several reinforced concrete structures.

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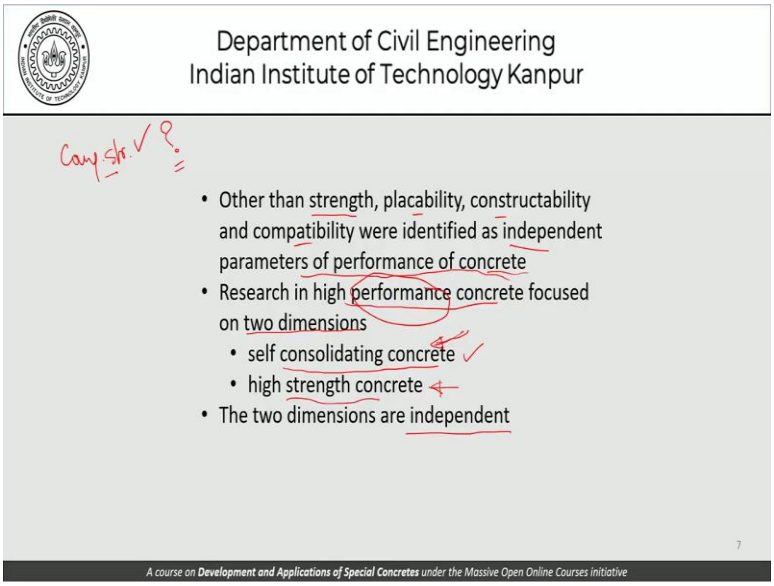

Around that time then other than strength placeability, constructability, compactability were identified as independent parameters of concrete performance. So the traditional thinking that as far as concrete is concerned so long as it meets certain criteria for compressive strength it is okay this was questioned. And people understood that it is not enough to have only compressive strength we also need the concrete to be such that it can be compacted easily, it can be placed easily and the structures should have a certain kind of constructability.

Now research in the area of high performance concrete in the 80s and 90s focused primarily on two dimensions one was to develop some kind of self-compacting concrete or self-consolidating concrete. The other was to develop high strength concrete. Now performance of concrete was deemed or interpreted in two different ways. One was in interpretation in terms of the expected quality in terms of durability and so on the concern was coming primarily from the durability side and that led to this self-compacting.

A self-consolidating concrete development flowing concrete development and the other performance parameter being obviously strength and that led to a lot of work on high strength concrete which was also called high performance concrete. We must remember that as far as we are concerned I have tried to emphasize that all the time that these two dimensions are quite independent. As far as self-compacting concrete is concerned a self-consolidating concrete is concerned it may or may not be high strength concrete.

Regular strength concrete also needs or also needs certain special attention to become self-compacting. High strength concrete whether it is self-consolidating or not again is an open question it need not be if it is so be it. So we have to understand what exactly are the performance parameters that we are talking about? So in this particular module of course we are concentrating primarily on the self-compacting nature of concrete.

And what imparts that nature to a given concrete what do we do as far as proportions are concerned? What do we do as far as testing is concerned that is the thrust in our discussion this module.

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1983	Concrete crisis in Japan, and concern for durability of concrete structures
1986	Basic concept by Prof. H. Okamura of Tokyo University.
1988	Prototype for field experiments and implementation
1989	Open experiment
1991	Jt. research project with construction companies
1993	"High Performance Concrete" established
1994	International Workshop on HPC in Bangkok
1997	Technical Committee in RILEM

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Now this is a bit of history as far as the development of self-compacting concrete is concerned it was developed in Japan and there was a concrete crisis and concern for durability of concrete structures. The basic concept for the self-compacting concrete was proposed by professor Okamura of the Tokyo University in about 1986. And it took about two years to reach the stage of prototype field experiments and implementation.

In 89 an open experiment was hosted to show the practitioners that well this is a new kind of concrete which has been developed why do, not we use it. Following that 1991 a joint research project was created and held with construction companies all the construction engineers got involved with the tokyo university tried to understand and educate themselves about the properties about the pitfalls quality control placing and so on as far as self-compacting concrete is concerned.

And in 1993 as far as Japan is concerned high performance concrete was established. Now this high performance concrete was not high strength necessarily but more by way of self-compaction. In 1994 there was an international workshop on high performance concrete in Bangkok in 1997 there was a technical committee in RILEM. So these 10-15 years was largely the history of self-compacting concrete in its development.

And I would encourage you to look at research papers in this period to get an insight into how exactly the development took place how to impart the kind of self-compactability to concrete what kind of research process happened? What kind of testing process happened and how the construction industry was brought on board? And the new material the new concrete was implemented as far as construction works is concerned. So that is something which is a matter of concrete history, let us move forward.

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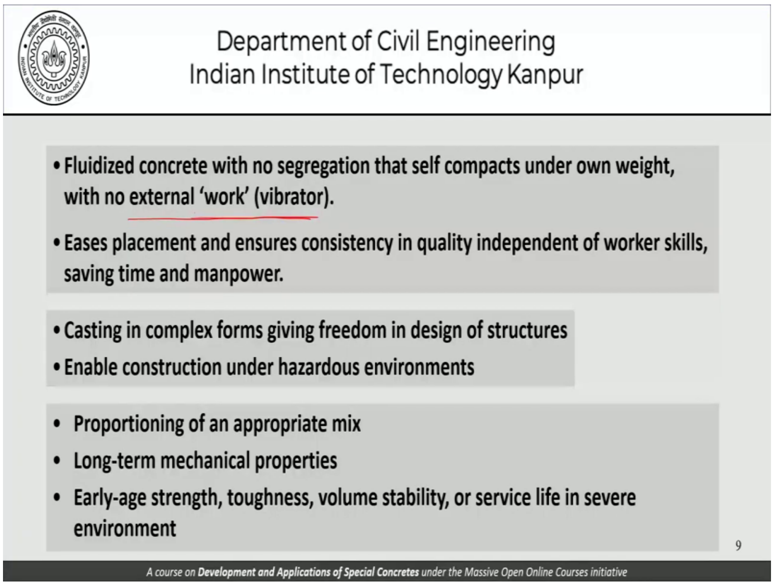

As far as self-compacting concrete is concerned is nothing but fluidized concrete with no segregation that self-compacts under its own weight with no external work needed. No vibration needed. It eases placement and ensures consistency in quality independent of worker skills saves time and manpower. It can be used for casting in complex forms giving the freedom to the designer to design more complex forms of structures.

Enables construction under hazardous environments where you may not like to risk manpower directly involved. The challenges are proportioning an appropriate mix long-term mechanical property, early age strength toughness, volume stability or service life and severe environment all these questions need to be answered to the satisfaction of all stakeholders. Concrete development is not something which happens only in the lab.

Once a material is developed in the lab the practitioners, this all stakeholders, users, owners all stakeholders have to accept that this is something which we will be willing to use. And that confidence has to come that is exactly what takes time.

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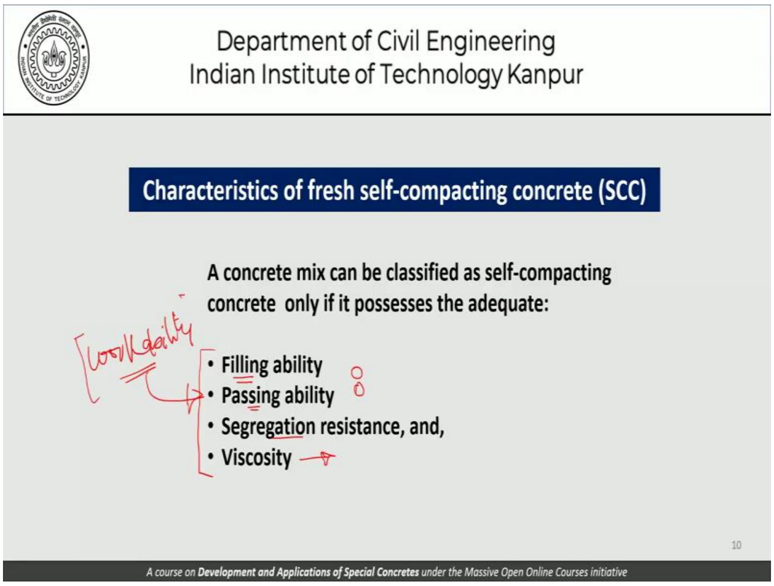

So as far as the characteristics of fresh self-compacting concrete are concerned it can be classified as self-compacting only if it posses the adequate fillability, passibility, segregation resistance and viscosity. So workability which was the earlier term which we used has now been broken up into some of these words which are being thrown in. The ability of concrete to just fill a volume the ability of concrete to pass through obstructions whether it is reinforcing bars or one corner of a formwork or another and so on.

Segregation resistance the fact that coarse aggregate should not separate from water sand should not separate from the paste water should not appear as bleeding water in excess. All these things viscosity of the mix these are kind of interrelated parameters which were all within this umbrella of workability. So when we started work or when we start work or studying self-compacting concrete we need to take a little bit closer look at we called just workability.

And try to understand the components of that and these are to be tested separately and finally integrated into a single concrete. They may be tested separately we can have different criteria as we shall see as far as test methods is concerned possibly in the next lecture. But finally we will get a single concrete which meets all our requirements.

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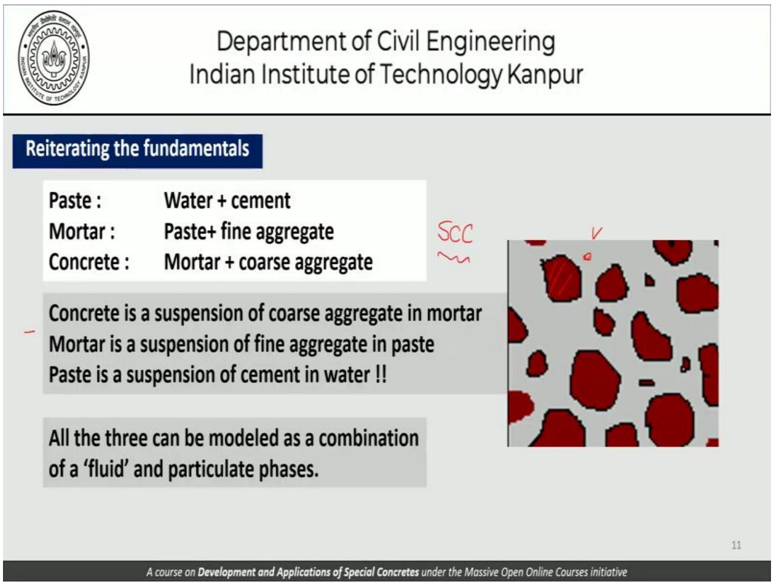

So having said that let us reiterate the fundamentals this picture is something which is coming after a long time we now know that this is the coarse aggregate or the fine aggregate and we have cement paste water outside here. Paste is water plus cement mortar is paste plus fine aggregate and concrete is mortar plus coarse aggregate. Again concrete is a suspension of coarse aggregate in mortar, mortar is a suspension of fine aggregate and paste and paste is a suspension of cement in water.

This reiteration is very, very critical when it comes to self compacting concrete as we shall see as we go along in this lecture today. All the three can be modelled as a combination of a fluid phase and a particulate phase what does that mean?

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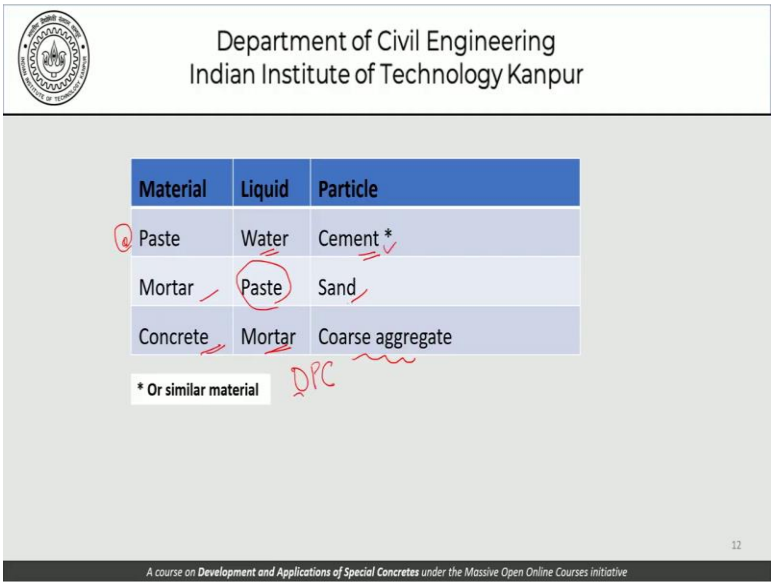

As far as paste is concerned the fluid phase is water and the particulate phase is cement. As far as mortar is concerned the fluid phase is paste and the particulate phase is sand. As far as concrete is concerned however the fluid phase is the mortar and coarse aggregates constitute the particulate phase. We must remember that when we talk of cement here in this sense it is not OPC alone we are talking of any other similar material.

Now what does the similar mean obviously the first characteristic from this point of view that comes in mind is the fineness. If we use in the concrete mix a material which is comparable in fineness to cement that will contribute to the paste phase. If we use some material which is comparable to sand as far as fineness is concerned that would be contributing to the mortar phase. This fine material may or may not contribute to the strength part of it.

Now the strength development and strength comes from hydration. Now whether that fine material takes part in the hydration reaction or not is a different story altogether. As far as the paste phase is concerned that fine material will be still considered a part of the paste.

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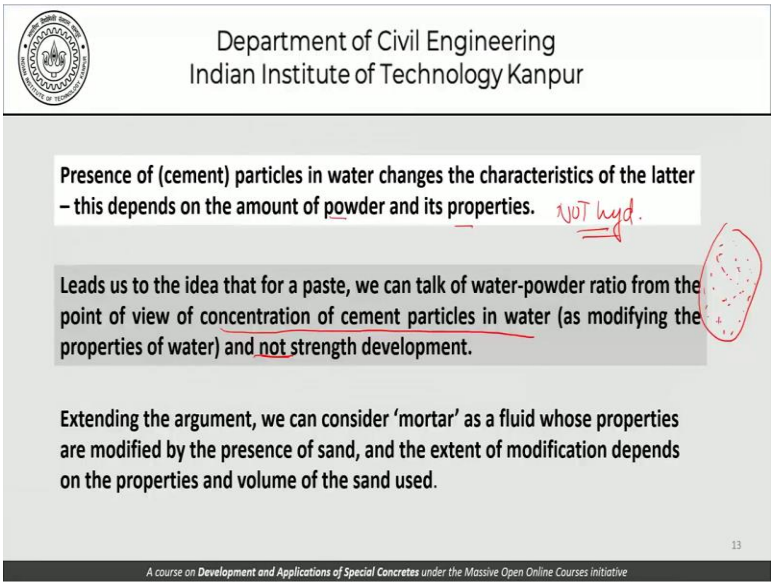

We will see the import of this presence of cement particles in water changes the characteristics of the latter and this depends on the amount of powder and its properties. So we know that if we have some water and we just put a few particles here and there the properties of water are not modified too much. But if we put too many particles here yes then we get a modification. So that is what we are saying here the presence of cement particles in water changes the characteristics of the latter here.

This is not about hydration even without hydration this statement is still true. This leads us to the idea that for a paste we can talk of water powder ratio from the point of view of concentration of cement particles in water. As modifying the properties of water and not only in terms of strength development not only from the point of view of strength development but also from the point of view of modification in the properties of water from the liquid phase to a less liquid if you want to call it.

Or a liquid of a different type that is something which will probably talk about it some other point what exactly is a liquid how do you define it whether it has a shape of its own and so on. That is something which we look at scientifically in a separate lecture but for the time being I am sure you understand what I am trying to put forward to you. Extending this argument we can consider mortar as a fluid whose properties are modified by the presence of sand and the extent of modification depends on the properties and the volume of the sand used.

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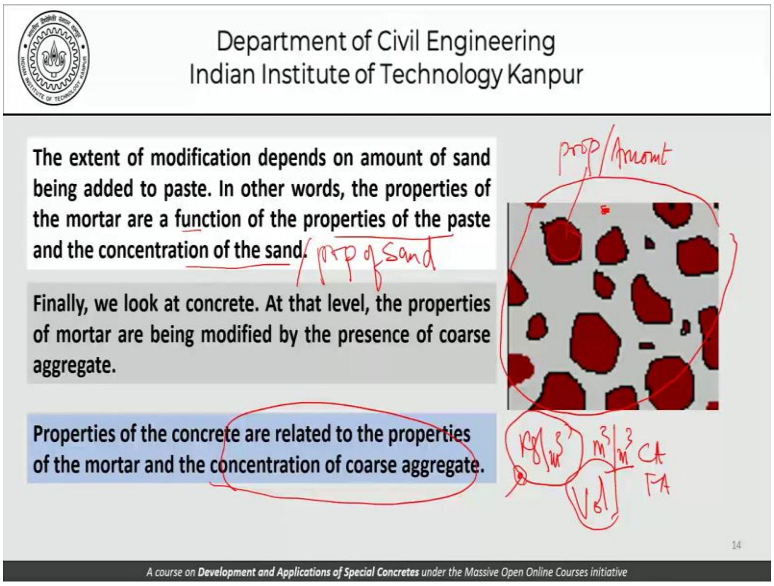

Go back to this picture obviously the properties of this particle and the amount of these particles that will depend on how much of a modification takes place as far as the whole property is concerned. As far as the properties of the entire mass is concerned. So the extent of modification depends on the amount of sand to be added to paste or the amount of sand being added to paste in other words the properties of the mortar are a function of the properties of the paste and the concentration of sand and the properties of sand.

We can achieve the same level of modification using a different concentration of sand or we can achieve that by changing the properties of the sand within a certain range. Finally we look at concrete and at that level the properties of mortar are being modified by the presence of coarse aggregates and the properties of concrete are therefore related to the properties of the mortar and the concentration of the coarse aggregates. So this concentration of coarse aggregate what we are talking about is nothing but the Kgs per cubic meter of the coarse aggregate that we talk about.

As far as proportioning is concerned except that in this discussion that we are doing in the context of self-compacting concrete it is not so much the Kgs per cubic meter that we are bothered about but the cubic meters to cubic meters that is the ratio by volume how much of aggregate is there in the concrete by volume. Go back to that story of the picture and see how much of coarse aggregate how much of fine aggregate and how much is the cement translating to how much paste how much mortar is there in your concrete volumetrically that something which is the crux of understanding self-compacting concrete and then proceeding to design the appropriate mixes and so on.

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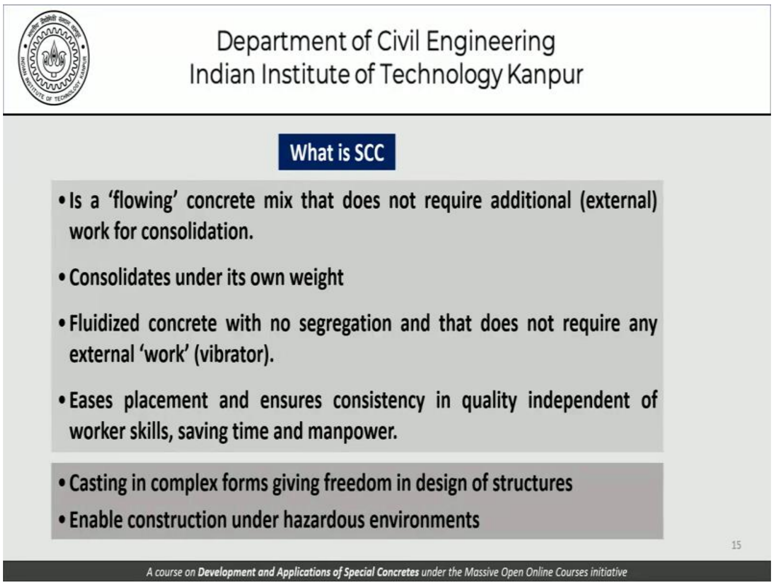

Now once again to reiterate what is the self-compacting concrete it is a flowing concrete mix that does not require additional vibration consolidates under its own weight. Fluidized concrete with no segregation does not require external work eases placement and ensures consistency in quality. So that is what we have already seen and this concrete can be cast in complex forms giving some freedom to the designer and enables construction in hazardous environment. So these things we have already seen this is a reiteration from there.

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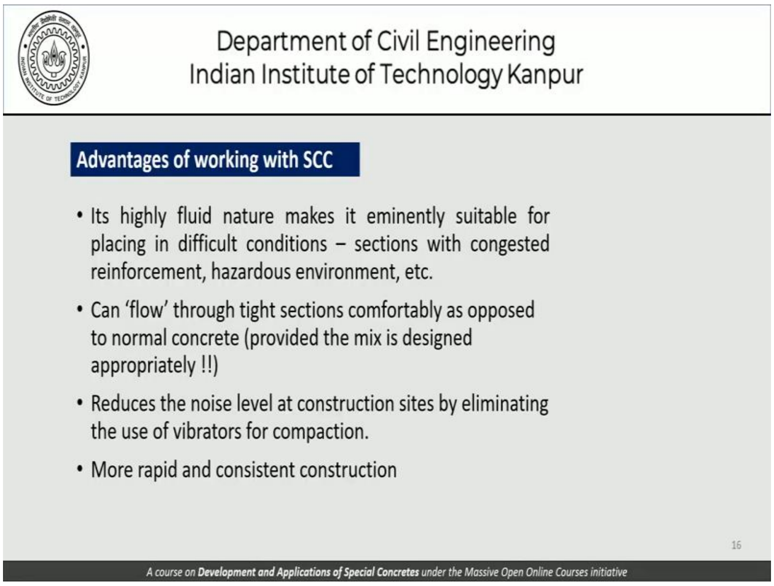

Now advantages of working with this kind of concrete is that its highly fluid nature makes it eminently suitable for placing in difficult conditions sections with congested reinforcement hazardous environment and so on. The concrete can flow through tight sections comfortably as opposed to normal concrete provided of course the mix is designed properly, reduces the noise level at construction sites by eliminating the use of vibrators for compaction more rapid and consistent construction. So this is the kind of overview of what advantages you will get.

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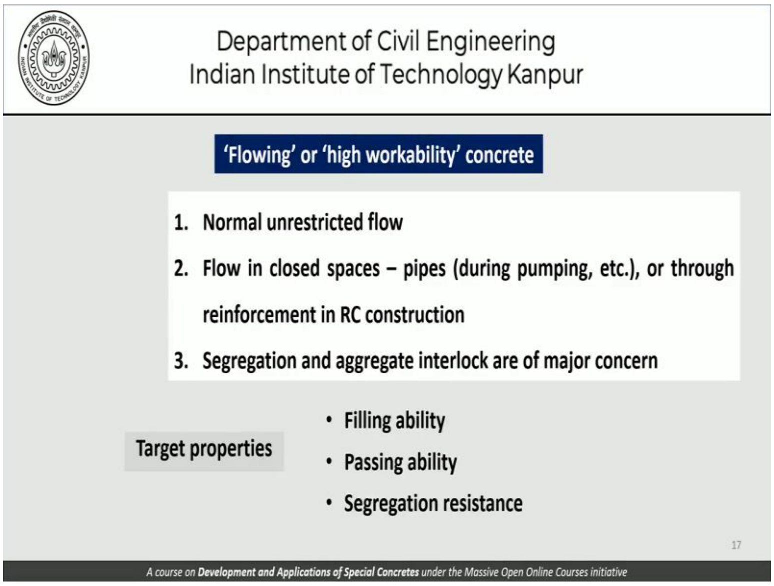

And as far as flowing or high workability concrete is concerned normal unrestricted flow. And flow in closed spaces that is pipes pumping or through reinforcement in construction these are things which we need to understand evaluate. And what we try to do also is things like segregation and aggregate interlock. These are major concerns as far as we are concerned when we are talking about studying self-compacting concrete from an academic standpoint. So what are the target properties that we are trying to study fillability passing ability and segregation resistance.

If we are able to do justice to these we are pretty much on our way to self-compacting concrete.

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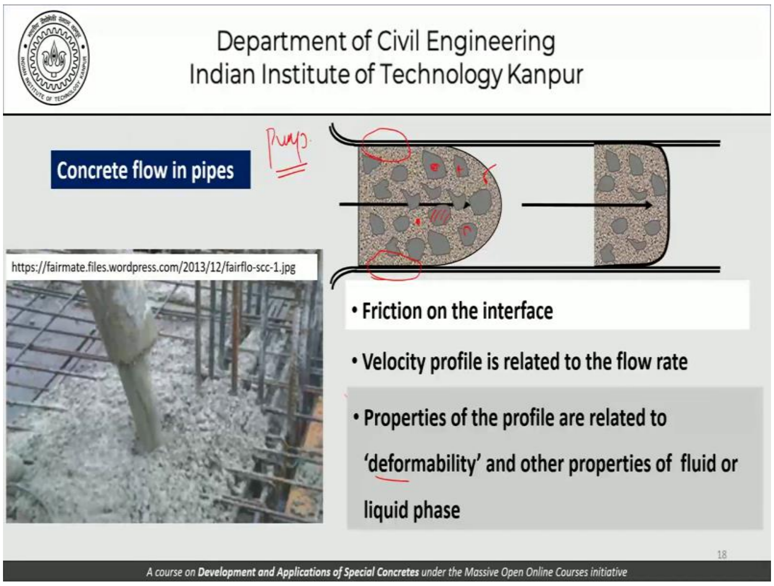

Now let us try to understand a little bit more schematically what happens when we are talking about concrete flow in pipes. So this is how concrete will flow as far as a pipe is concerned and we know that when we pump concrete this picture is not too bad when we are pumping concrete we expect that the concrete will flow through this pipe the way it is shown. And these are my coarse aggregates and this is the mortar.

We know that there will be friction as far as these interfaces are concerned. We know that the velocity profile will be related to the flow rate and we also know that the properties of the profile are related to the deformability and other properties of the fluid or the liquid phase. So basically when we pump concrete or the concrete flows through pipes or a self-compacting concrete and that is what is required of a self-compacting concrete.

The aggregates have to be carried by the mortar and therefore the mortar that we have should be such that it is able to carry and support the aggregates the way it is shown here without any segregation. So a lot of this would depend on the deformability and other properties of the mortar phase. Look at this picture once again this is the pipe through which we are expecting the concrete to flow and this liquid which is coming out of this is something like this.

It has coarse aggregates it has mortar and we want that the mortar should not be separated from the coarse aggregate not only while it is moving within the pipe but also as it negotiates the reinforcement. Negotiates the reinforcing bars and goes into the different corners as far as the form work is concerned.

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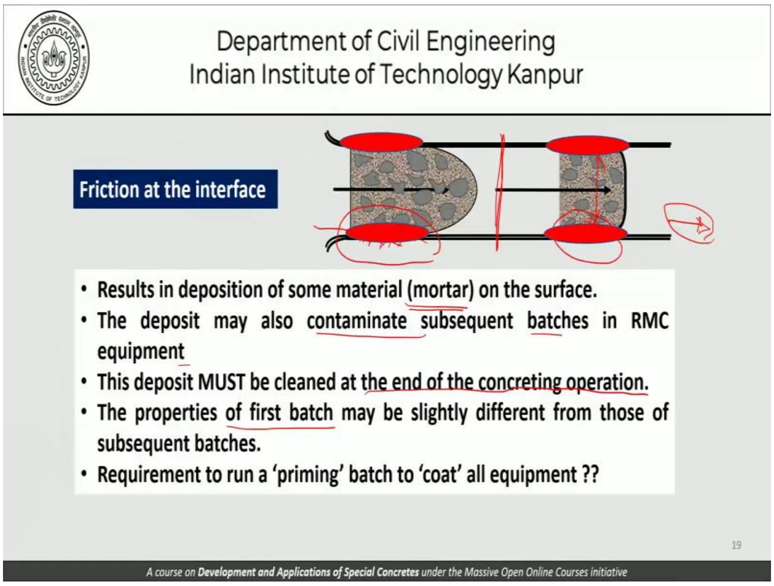

Moving forward this friction at the interface leads to a deposition of some material which in the case of concrete will be mortar on the surface of concrete here. Now what does that mean this deposit will contaminate subsequent batches of RMC equipment. So obviously this is a batch process quite often there is a batch of concrete that runs through the certain equipment it takes a little bit of time for more concrete to be brought in a different agitator truck.

And then again the concreting starts. So this mortar is not always cleaned at the end of each agitator truck each transit mixer. So this deposit here will tend to contaminate subsequent batches and therefore it should be ensured that all the batches that we are trying to cast at one point are of a consistent or a similar quality. This deposit must be cleaned at the end of the concreting operation because if it is not done then there are all kinds of things that happen.

For example the cross section of your pipe keeps on reducing because this concrete or this mortar here more specifically will obviously set. And when you come back the next day and try to push the concrete here the cross-sectional area is not this it is actually reduced. So if we do not want this to happen we have to clean these deposits at the end of the operation and the properties of the first batch may be slightly different from those in subsequent batches.

So when the concreting operation commences at that time there is no deposit here and therefore the deposit of mortar here will lead to a concrete coming out which is poorer as far as the mortar content is concerned which gives rise to the requirement of running a priming batch to coat all equipment. So those of you are interested or who are working in the field should keep this in mind that we always must prime the equipment that is we run a certain amount of concrete or mortar through it so that all these deposits and so on are taken care of.

So that the concrete that comes out even in the first batch is as good as the 10th batch or the 11th batch.

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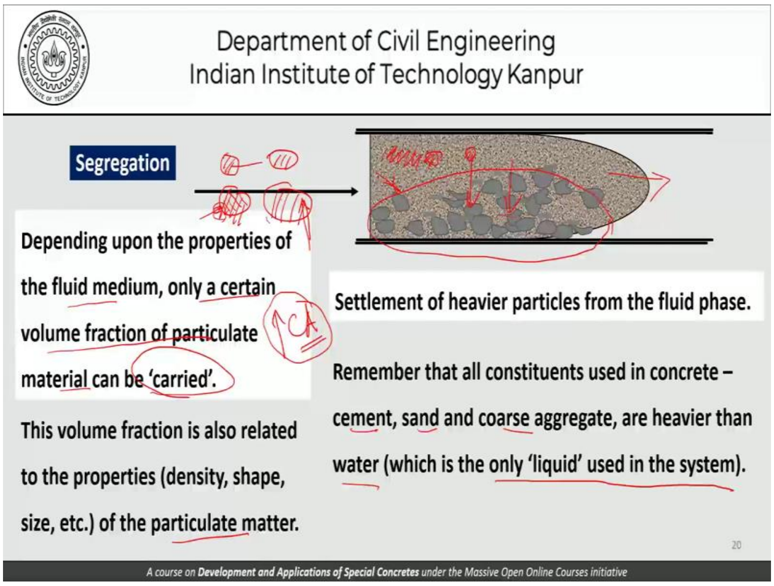

Now coming to the story of segregation this picture is showing you segregation. So the coarse aggregates have settled down because the properties of this mortar were such that it was not able to sustain all the coarse aggregates suspended in it and the coarse aggregates have settled down. And we can see mortar moving forward or mortar alone moving forward and that is a very undesirable situation obviously.

Settlement of heavier particles from the fluid phase remembers that all constituents used in concrete. Cement, sand and coarse aggregates are heavier than water which is the only liquid component as far as the concrete is concerned. And depending upon the properties of the fluid medium only a certain volume fraction of particulate material can be carried that is if we have a certain class of properties.

This can only support a certain amount of course aggregates unless we change the properties here we cannot change the or at least we cannot keep increasing the quantity of the course aggregates because this is what will happen. And from a concrete perspective we would like to increase the component of coarse aggregates because that is the cheapest but as we keep increasing this we need to increase the viscosity and so on of the mortar phase.

So that is the kind of balance that we need to drop and that is coming up in the next slide or two. This volume fraction is also related to the property which is the density shape etcetera of the particulate matter itself. So it is not only the amount of coarse aggregate that we want to use but also the properties of the coarse aggregate in terms of its density shape. And size we may be able to change some of these things here if we want to keep this property as fixed or this property cannot be changed beyond a certain point.

So that is the whole balance as far as we are concerned in concrete engineering when we are talking of the development and application of self-compacting concretes in construction.

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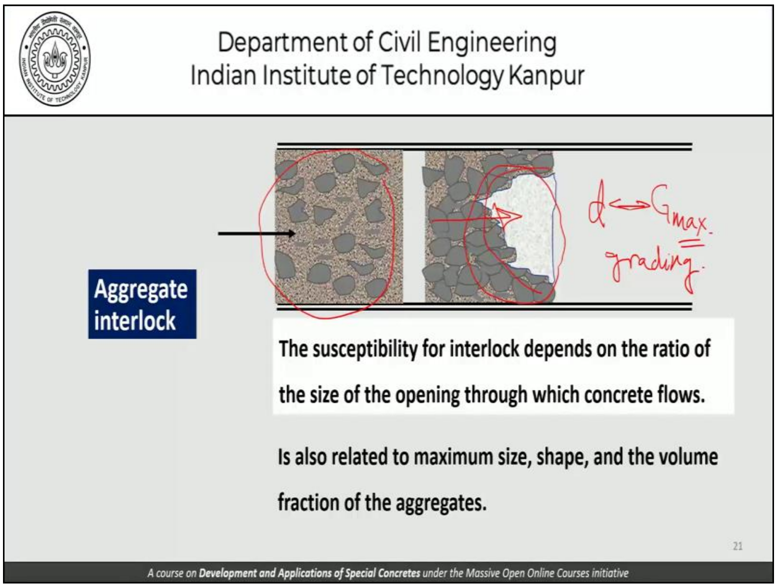

This is another problem that happens aggregate interlock. If we have this kind of concrete here and it moves the weight has been shown to be moving in the previous slides we may have a situation like this all this aggregate here forms an arch and blocks any kind of movement here. And that is one of the reasons why the diameter of these pipes should be somehow related to the maximum size of the coarse aggregates that you are using.

That is one of the reasons there are other reasons as well and obviously we do not want this aggregate interlock which is related not only to the maximum size but also the grading or particle size distribution as far as the coarse aggregates are concerned. So the susceptibility for interlock depends on the ratio of the size of the opening to the kind of size of the coarse aggregate that you are using in the concrete.

It is also related to the maximum size shape and the volume fraction of the coarse aggregates and the particle size distribution.

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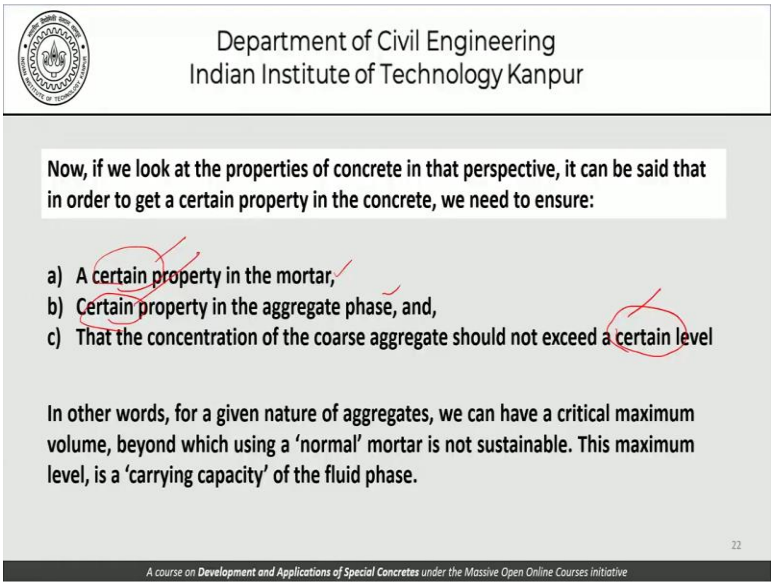

Now if you look at the properties of concrete in that perspective it can be said that in order to get a certain property in the concrete especially the fresh concrete we need to ensure that it has a certain property in the mortar. Certain property in the aggregate phases and that the concentration of coarse aggregates should not exceed a certain level. Now all these certains that we are talking about this is what is engineering all about.

Engineering basically means trying to assign some kind of numbers to these certains a certain property of mortar what property how to measure it certain property of the aggregate phase what property how to measure it certain concentration that cannot be exceeded the threshold levels what is it does it depend on this does it depend on this that is what we will try to understand as we go along.

In other words for a given nature of aggregates we can have a critical maximum volume beyond which using normal mortar is not sustainable. This maximum level is a carrying capacity of the fluid phase. We will probably look at it at some point in time either today or maybe in the next lectures how did we proportion a concrete mix. We proportioned it by first determining w water content based on workability then we added cement to it to the extent that is required using the water cement ratio relationship.

And then we said that we will divide the remaining volume between gravel or coarse aggregate and sand which is fine aggregate using the concept of s by a that is the sand in the total aggregate volume. This concept will undergo substantial revision when we try to apply it to self-compacting concretes where we are interested to see that the paste and the mortar they have the right kind of properties as far as the fresh state is concerned so that the concrete can be pumped placed and compacted without any external work that is it becomes self-compacting.

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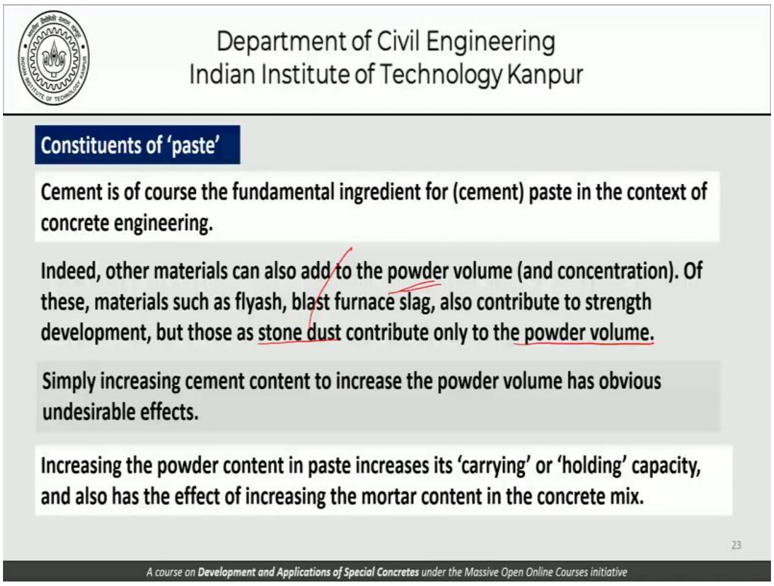

Now as far as the constituents of the paste are concerned obviously it is cement. As far as we are concerned in concrete engineering and other materials that can also add to the powder volume and powder is the word that we are using for very fine particles. Typically let us say cement other materials can also add to the powder volume and concentration. Of course these materials include fly ash blast furnace lag and they also contribute to strength.

But if we use stone dust that possibly contributes only to the volume. We do not expect stone dust to become a player as far as strength development or as far as hydration is concerned. But using stone dust along with cement will still add to the powder volume in the paste and modify the properties of the powder. Simply increasing the cement content to increase the powder volume is obviously undesirable.

What is undesirable about it one is cost and then there are properties like shrinkage. So we cannot keep increasing the cement content in a concrete indiscriminately. So we need to have some alternatives and stone dust fly ash all these fellows come in handy as far as a concrete engineer is concerned. Increasing the powder content paste increases its carrying or holding capacity and that also has the effect of increasing the mortar content in the concrete mix.

So if we increase the powder content the paste properties are different and also the mortar content is different apart from of course the properties of mortar being different.

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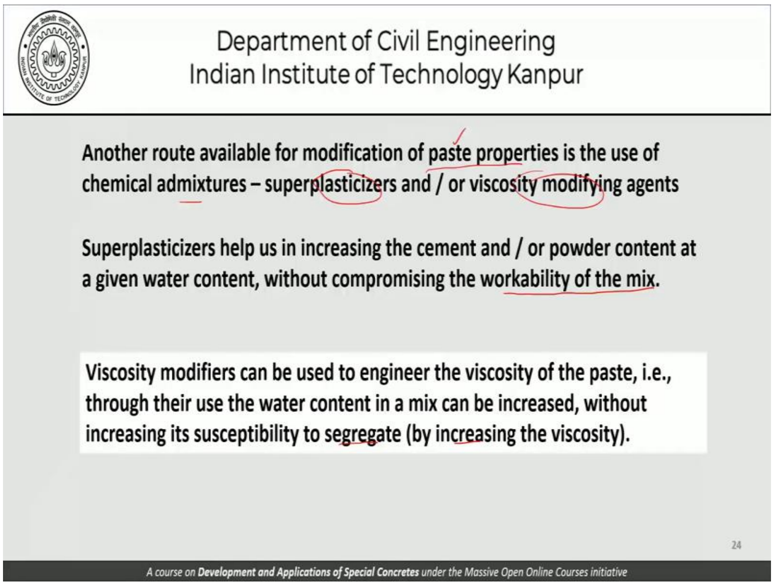

Another route available for the modification of the paste properties is the use of chemical admixtures super plasticizers and or viscosity modifying agents. So we can use either super plasticizers or viscosity modifiers to modify the properties of paste. And once we modified the properties of paste we have obviously modified the properties of mortar which obviously has modified the properties of the concrete.

So that is the kind of route that we take as we try to think of self-compacting concrete. Superplasticizers help us in increasing the cement and our powder content at a given water content without compromising the workability of the mix. These are things which we already talked about at different points as far as this module is concerned. Viscosity modifiers can be used to engineer the viscosity of the paste that is through their use the water content in the mix can be increased without increasing its susceptibility to segregate.

See what happens is that if we increase the water content in a paste it will become more susceptible to segregation the viscosity modifier prevents that that means we can increase the water content without being affected by the problem of segregation. As far as super plasticizers are concerned we can push the powder content higher for a given water content without getting involved with the workability related issues. So that is the kind of balance that we are talking about.

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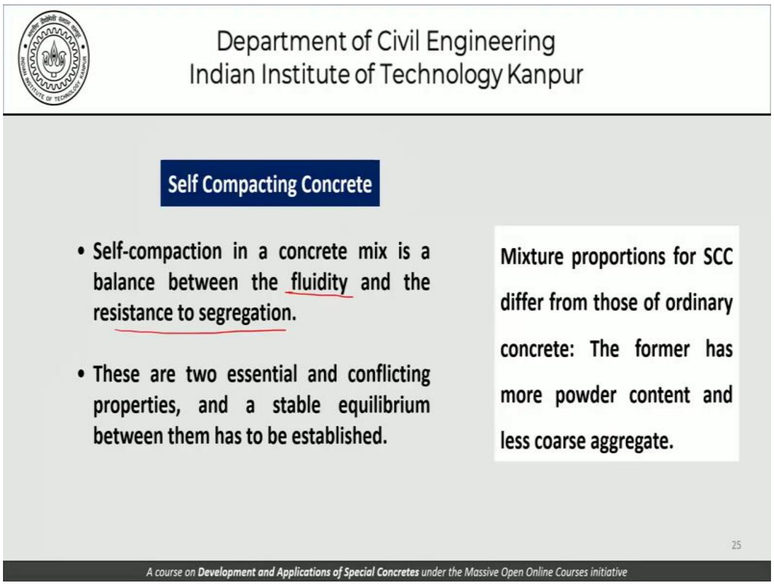

As for a self-compacting concrete is concerned once again to reiterate that it is a balance or it reflects a balance between the fluidity and the resistance to segregation that is the crux of self-compacting concrete. These two are essential properties and conflicting properties and a stable equilibrium between them has to be established. So mixed proportions for self-compacting concrete differ from those in ordinary concrete the former that is the self-compacting concrete has a lot more powder content and to that extent a lesser coarse aggregate content.

Remember that at the end of it all the constituents in concrete cannot exceed a 1000 liters per cubic meter because that is the fixed volume available to you. If we want to increase the powder content we have to remove or reduce something else.

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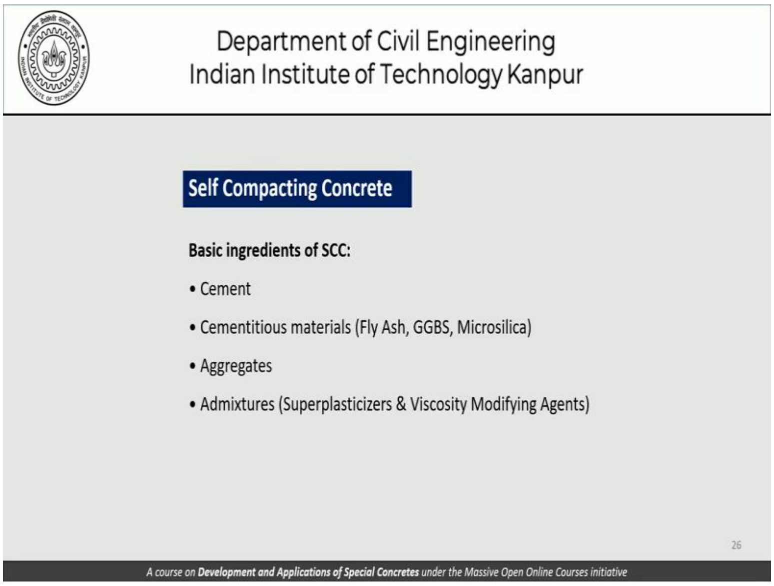

And now coming to the ingredients of self-compacting concrete the basic ingredients are very similar to that of normal concrete we have cement. Cementitious materials which could be fly ash ground granulated blast furnace slag, micro silica, stone dust and so on aggregates and admixtures plasticizers as well as viscosity modifiers. So this constitutes more or less the kind of ingredients that we use to get self-compacting concrete.

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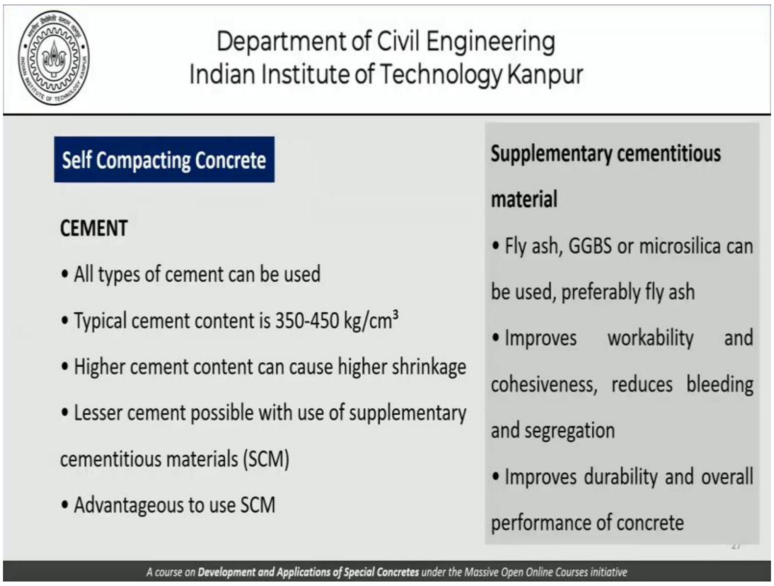

As far as cement is concerned all types of cements can be used. The typical cement content in self-compacting concretes is between 350 to 450 Kgs cubic meter. Higher cement contents can cause shrinkage that is why we have to be careful and in fact we try to replace a part of it using mineral admixtures. Lesser cement content is possible if you use supplementary cementitious materials or SCM's which is mineral admixtures.

And its advantages of course to use these materials for all kinds of reasons which we are already familiar with its advantages to use supplementary cementitious materials or SCM for all kinds of reasons reduce cement consumption industrial waste utilization lesser heat of hydration and so on. So as far as supplementary cementitious materials are concerned we use fly ash, slag, micro silica improves workability and cohesiveness reduces bleeding and segregation.

This is the advantage that we get out of using these mineral admixtures that increases the powder content in the mix giving you greater cohesiveness reducing the bleeding and segregation resistance, improves durability and overall performance of concrete. So that is what we do we use cement and supplementary cementitious materials together.

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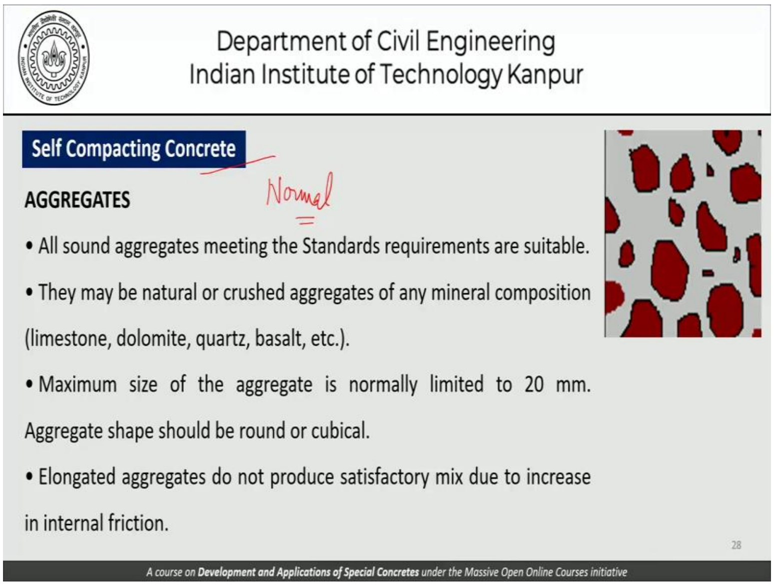

Now as far as aggregates are concerned all sound aggregates meeting the standard requirements are suitable. They may be natural or crushed aggregates of any mineral composition limestone, dolomite, quartz, basalt and so on. Maximum size of the aggregate is normally limited to 20 millimeters and the aggregate should preferably be round or cubical elongated aggregates do not produce satisfactory mix due to increased internal friction.

One must remember that as far as the development of self-compacting concrete is concerned it started with normal concrete and therefore effort was consciously made to ensure that the standards governing the materials being used in normal concrete are tampered with as little as possible. Therefore all aggregates which are normally available and used in normal concrete were used or were allowed to be used.

As far as self-compacting concrete is concerned. As far as the size and the shape of these aggregates is concerned is clear from this picture here. It is important and more stringent in the case of self-compacting concrete to follow these requirements because if these aggregates become larger they tend to segregate more. And the same thing happens as far as elongated aggregates is concerned because we are not allowing any vibration or there is no provision for a vibration it is difficult to handle a situation where these aggregates interlock in a normal situation it can be broken.

When we use vibrators but in the case like self-compacting concrete if elongated aggregates form an interlock somewhere with a void somewhere behind them it is not going to be broken and that would lead to unsatisfactory construction as such.

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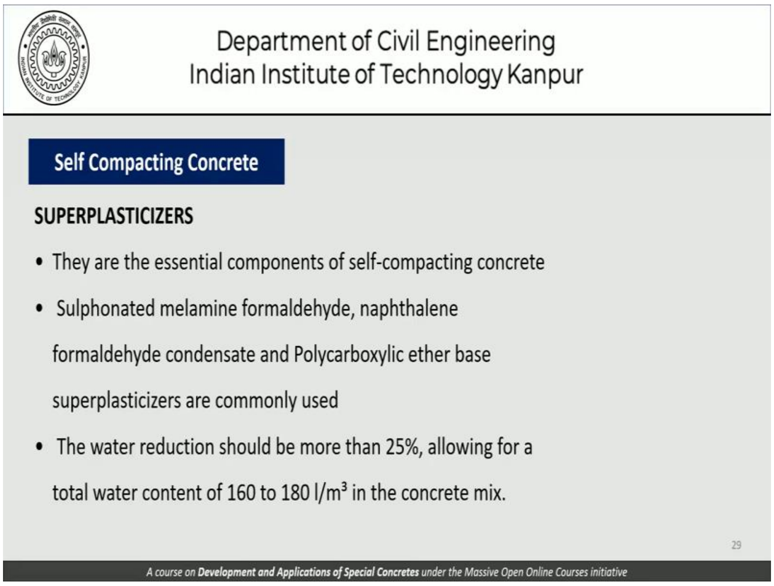

Continuing with the super plasticizers they are an essential component of the self compacting concrete and any kind of plasticizer which is useful is obviously acceptable for use as far as self compacting concrete is concerned as well. Sulfonated melamine formaldehyde naphthalene formaldehyde condensate and poly carboxylic, ether base super plasticizers are commonly used. So basically any super plasticizer can be used as far as self-compacting concrete is concerned.

The water reduction should be more than 25% allowing for a total water content of about 160 to 180 liters a cubic meter. So this becomes some kind of a guideline as far as design of self-compacting concrete is concerned. So this is the range in which we want to limit our water contents.

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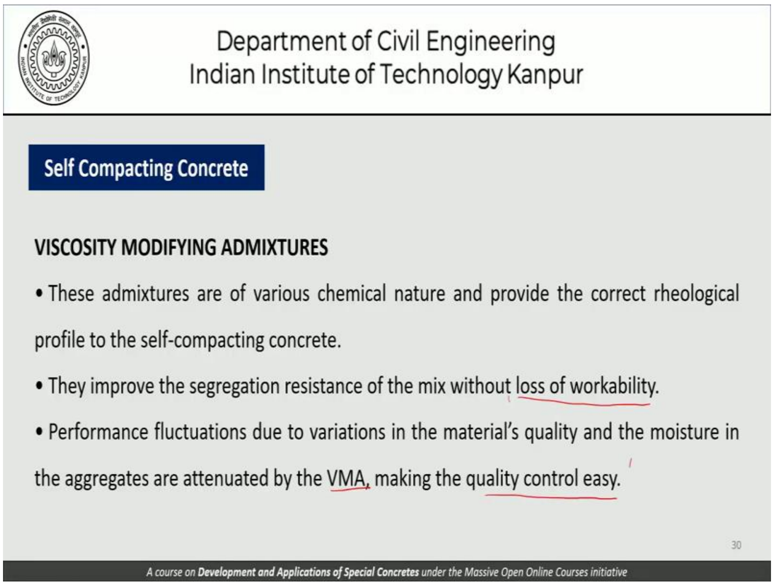

As far as the VMA's or the viscosity modifiers are concerned these admixtures are of various chemical natures and provide the required or the desired rheological profiles to the self-compacting concrete. They improve segregation resistance of the mix without a loss in workability and performance fluctuations due to variations in the material quality and the moisture in the aggregates are attenuated by the VMA's making quality control easier.

So these are some of the experiences which have emerged after using viscosity modifying admixtures and self-compacting concrete over the years.

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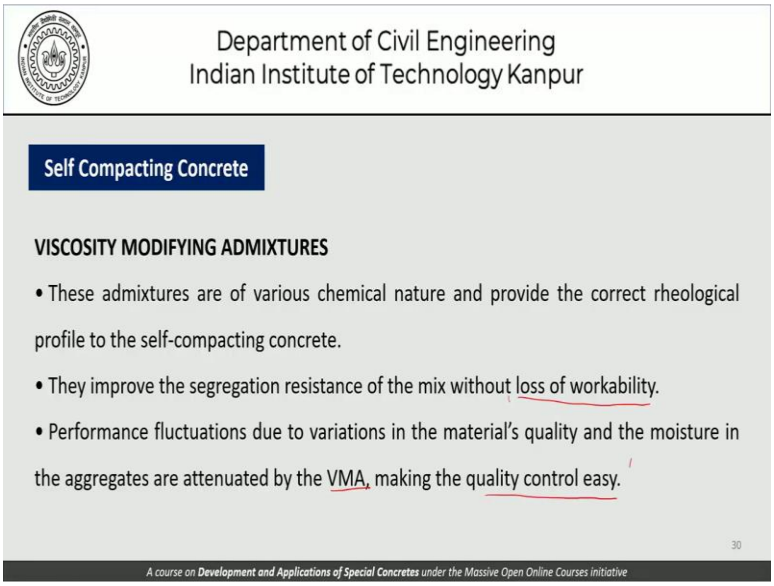

So now the strategy for self-compacting concrete is based on using large quantity of fines it could be about 500 to 650 kgs a cubic meter. Go back and check how much the fines that we are using in normal concretes having said that we also need to understand a little better as to what these fines mean that is not only cement? No, it is not only cement it includes all the other particles or all the other material or constituent materials which is similar to cement.

Another strategy for this is based on using viscosity modifying admixtures and of course this is in conjunction with use of high range water reducing super plasticizers which help you reduce the water demand by more than 25%.

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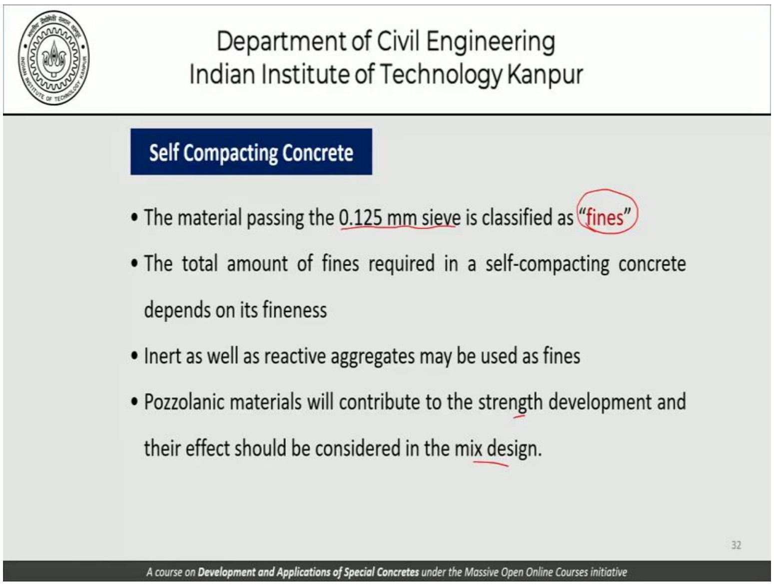

What are fines material passing 0.125 millimeter sieve is classified as fines as far as self-compacting concrete and the constituent materials are concerned. The total amount of fines required in a self-compacting concrete depends on its fineness. Inert as well as reactive aggregates may be used as fines. Pozzolanic material will contribute to their strength development and their effects should be considered in the mix design from the strength development point of view and also their participation in the first state as a fine material should also be borne in mind.

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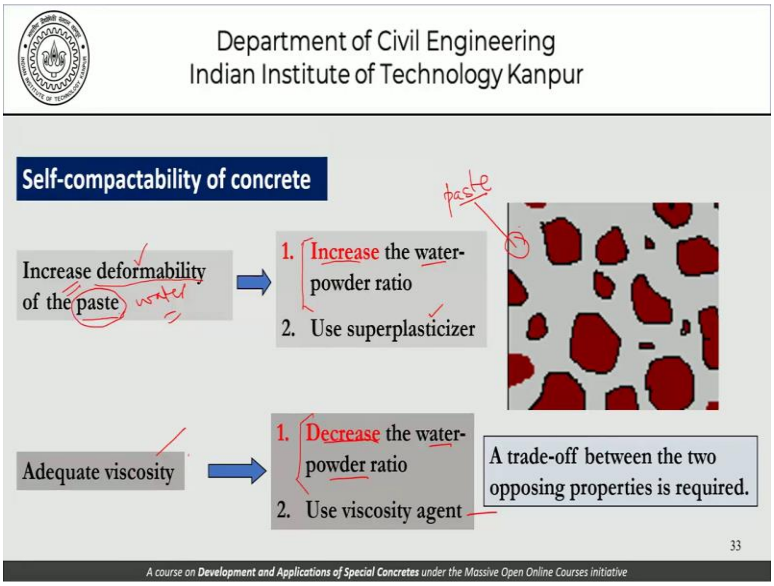

Looking at the self compactability of concrete once again one route or one important thing that we have to understand is that it involves using deformability of paste. That is increasing the deformability of paste remember that we are talking of paste here because that is the closest that we have to water. If we are able to increase the deformability of paste we would have increased the deformability of water and therefore that of concrete.

Now in order to increase the deformability we need to increase the water powder ratio more powder we put in the less deformable the material will become. The less powder we put in the more deformable the material will be this can of course also be achieved by using a superplasticizer. The other side of it is we need adequate viscosity as far as the paste phase is concerned. So this big part here is my paste.

You would notice that I keep using the same diagram and try to say that whether this part is paste or it is mortar depending on the context. So having said that in order to impart adequate viscosity to this phase we need to decrease the water powder ratio that is we want to increase the powder content and reduce the water content that will help us get viscosity we can achieve this also by using a viscosity agent.

So this slide here really summarizes the two strategies that we can use to develop a self-compacting concrete mix. Increase the water cement ratio the water powder ratio get increased deformability reduce the water cement ratio reduce the water powder ratio get adequate viscosity. So it is really a balance between these two things a trade-off between the two opposing properties is required one calls for increase in the water powder ratio and the other calls for a decrease in the same parameter.

As far as the chemical intervention is concerned we could use a plasticizer or we could use a viscosity agent. So in practice we will end up using both of these and use either this approach or this approach or a combination thereof.

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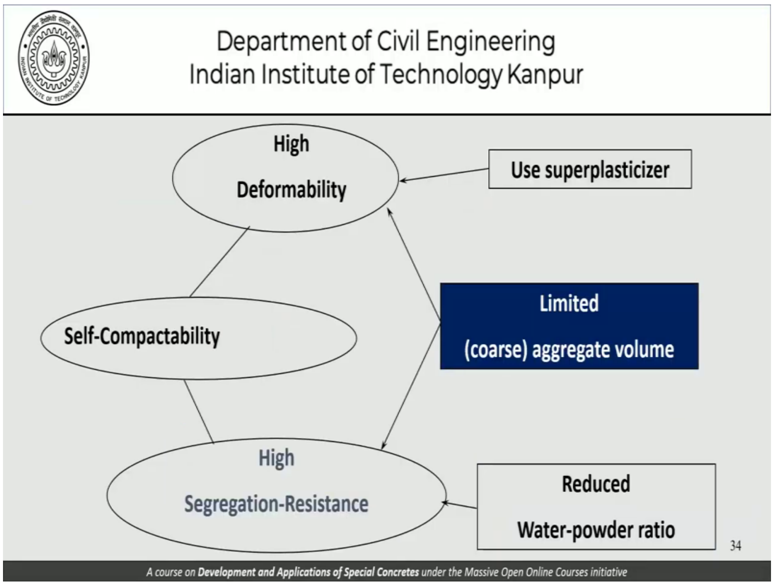

This picture here represents the same thing once again high deformability use a plasticizer, high segregation resistance, high viscosity, use a reduced water cement ratio about a powder ratio and in both cases we need to limit the coarse aggregate volume in the system. Back to this picture once again this picture tells you the congested reinforcement negotiating which the concrete has to go and compact.

And this here keeps reminding you of the fluid nature of concrete to the extent that it does not segregate and at the same time it moves into all nooks and corners carries the aggregate with it and so on.

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Material	Normal concrete (1)	SCC (2)	% (by wt.) (1)	% (by wt.) (2)
Water	160	159	6.9	6.9
Cement	320	155	13.9	6.7
Blast furnace slag	NA	171	NA	7.3
Flyash	NA	202	NA	8.7
FA	645	760	28.0	32.7
CA	1178	874	51.2	37.7
Total	2303	2321	====	

Typical mix proportions (weight)

Unit: kgs/m^3

Notes:

Chemical admixtures added not listed.

Low coarse aggregate content in SCC.

High fines and sand content in SCC.

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This picture here shows a typical mixed proportion by weight for normal concrete and self-compacting concrete. So if you can see here water, cement, glass furnace, slag, fly ash, fine aggregate, coarse aggregate and the total these values obviously are not different this value here is not so different the issue is these values here. So, total content of cement is 320 here 645 and 1178. Whereas this becomes 760 this goes down drastically to 874 and instead of 320 kgs of cement we are using almost 500 kgs of fine material.

That is translated here in terms of weight percentages from 51% the aggregate content is only 37, 38% the sand has gone up from about 28 to 32 but the issue is here. So this is much larger than this value here. That is the crux of getting self-compacting concrete or self-compactability in concrete.

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Typical mix proportions (%, volume)

Material / Concrete	W	C	Slag	Fly-ash	FA	CA	Total
Normal	16	10	NA	NA	25	44	95
SC	16	5	6	7	29	33	96

Item (by volume)	Normal concrete	SCC
Powder (fines) content	10	18
V_w to V_p ratio	16/10 = 1.6	16/18 = 0.89
Coarse aggregate	44	33

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Looking at those numbers by volume you get these values here and from there if we translate to the discussion that we were having in terms of powder content that is the finest content. In normal concrete it is only about 10 which goes up to 18% in this particular illustrative example of self-compacting concrete mix. As far as the water to powder ratio is concerned by volume it is about 1.6 here and is as small as 0.9 here.

The coarse aggregate content from 44% has gone down to 33 as far as the volume of coarse aggregate is concerned.

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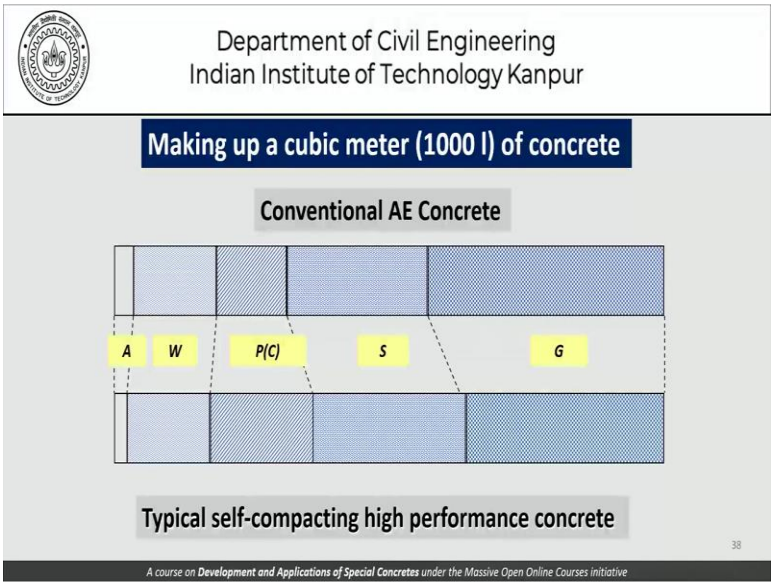

So if you look at the makeup of a cubic meter or 1000 liters of concrete here is the comparison for air water powder which is cement. In most cases of course in this case in the case of self-compacting concrete it is not only cement sand and coarse aggregate. These are the values that we have 18% of water does not really change much. But the powder content goes up to about double of that in the conventional concrete.

Sand does not change so much just a marginal increase. But the increase in the powder content is basically compensated by the loss in coarse aggregate content.

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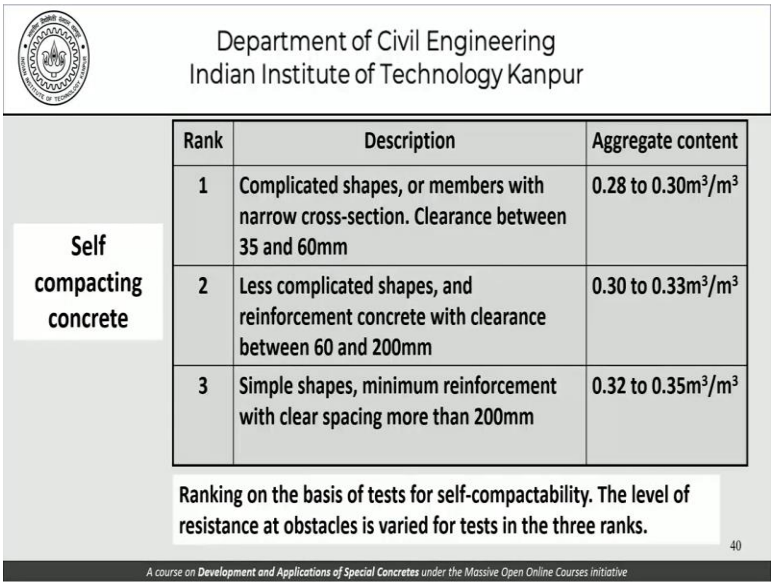

Now what it shows is that the self-compacting concrete can only support a certain amount of coarse aggregate. The mortar phase in the concrete can only support carry with it a certain amount of coarse aggregate. And that is what is shown here in the case of complicated shapes or members with narrow cross sections this aggregate content can only be 0.28 to 0.3 cubic meters per cubic meter which means about 28 to 30%.

In less complicated shapes and reinforcement in concrete having a clearance of 60 to 200 mm we can support slightly more it could be about 30 to 33% by volume whereas if the shapes are simple and the minimum reinforcement such that the clearance is more than 200 mm it can be as much as 30 to 35%. But these values are still smaller compared to conventional concrete. So the ranking on the basis of test for self-compactability which is given here have been developed on that basis.

The level of resistance obstacles is varied for the tests in the three ranks and we will look at some of the tests that are carried out for determining the self-compactability of concrete maybe in the next class. And then you will probably appreciate some of these things better.

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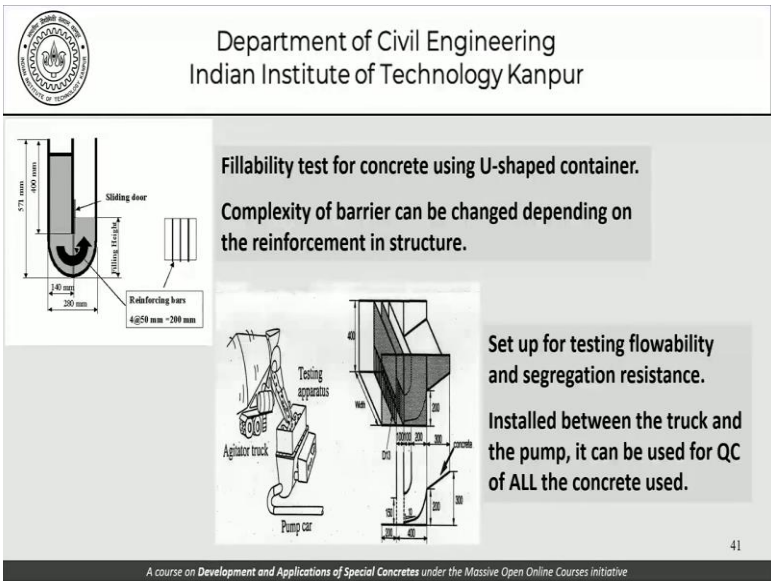

This picture here shows one of the tests the fillability test where the U-box is filled with concrete on one side and the concrete is allowed to move to the other side after this gate is opened. And we try to measure the change or the difference in this height here concrete flow taking place through these kind of simulated reinforcement present in the gate. And this kind of a picture or this kind of a test can be used just after a agitator truck or a transit mixer to make sure that the concrete that you are actually placing all of it meets the requirements of self-compactability.

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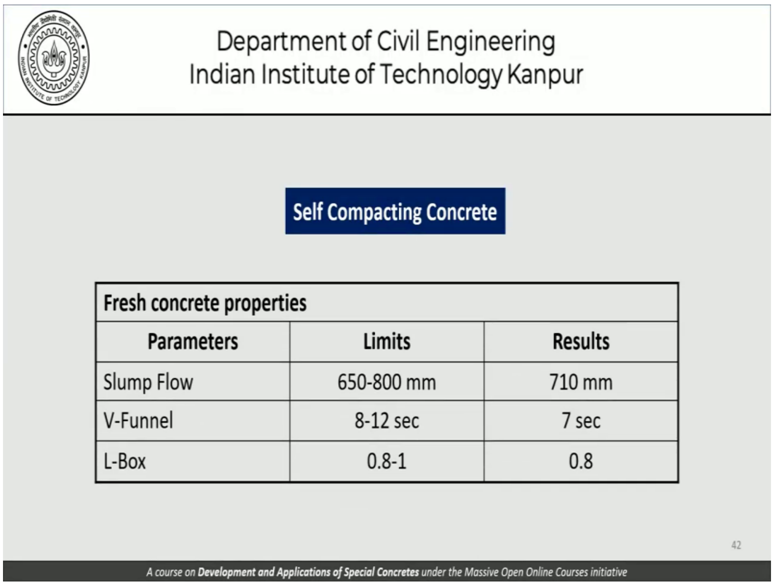

This picture here shows some of the limits on the slump flow the V funnel and the L box we will talk about these tests and these limits after we have had a brief discussion on how each of these tests is to be carried out. But what can be said is that well self-compacting concrete is not necessarily defined by just one parameter it can be defined in terms of two or three parameters which have to be independently determined and appropriate specifications met.

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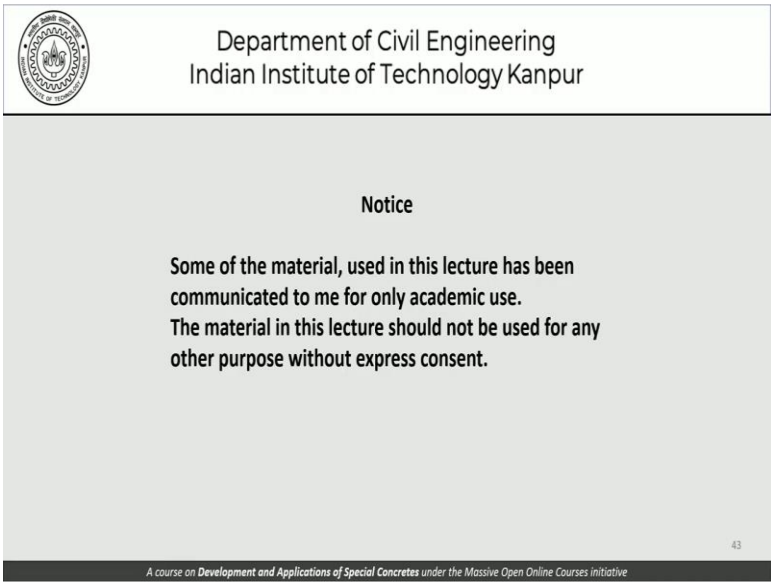

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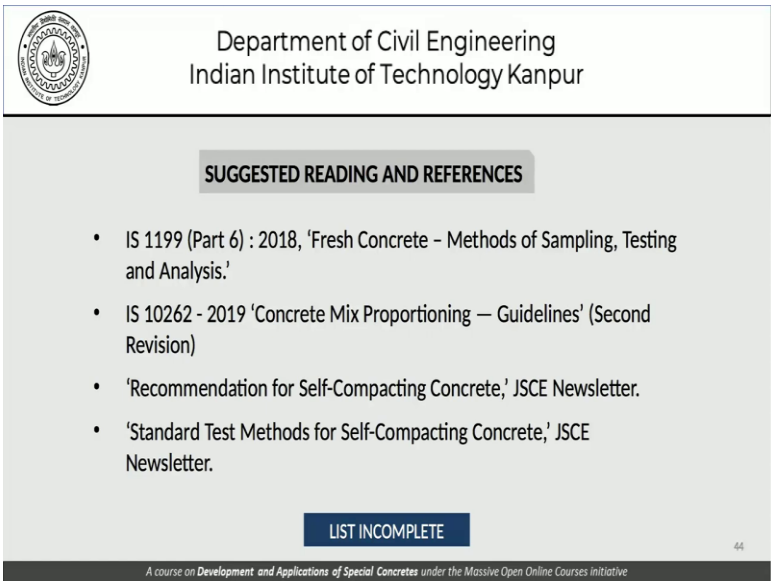

So moving forward and with this we come to an end of our discussion today and this picture here shows you some of the readings that you can do. And of course this list is incomplete you may please continue your reading in with other material and enrich yourself as far as your understanding of self-compacting concrete is concerned.

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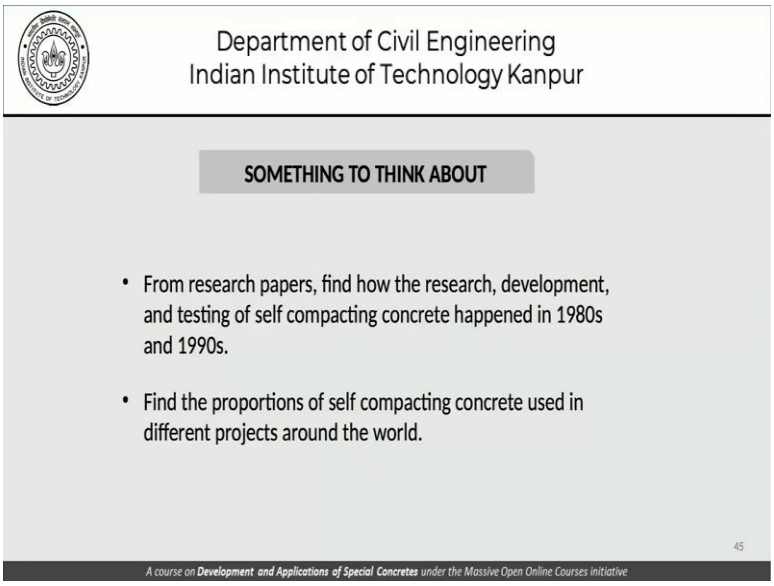

These are some points that we have emphasized during the lecture today and summarized here once again which give you a direction in which you can think a little bit more.

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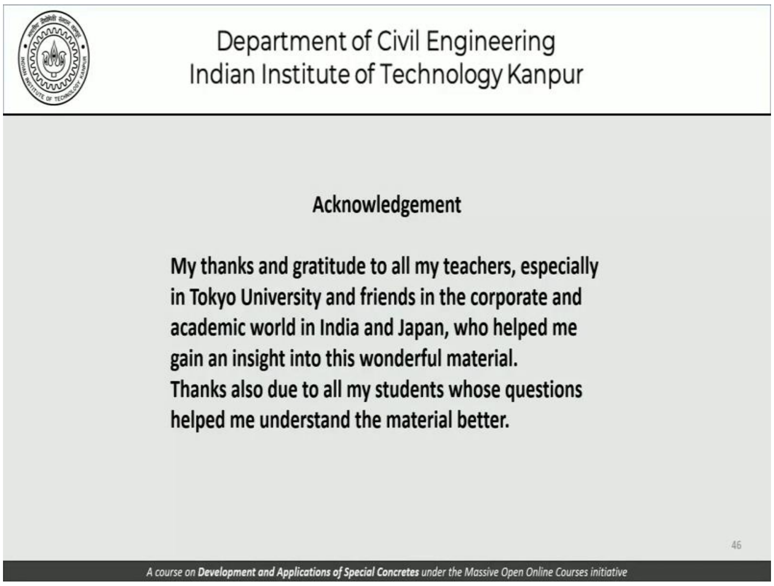

And closing our discussion today let me once again thank my teachers friends colleagues and students who have helped me understand this material better. Thank you once again and I look forward to seeing you in other discussions relating to self-compacting concrete and some of the other special concretes that we will address. As far as this series of lectures is concerned.