Concrete Engineering and Technology
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Lecture - 21
Self-compacting concrete

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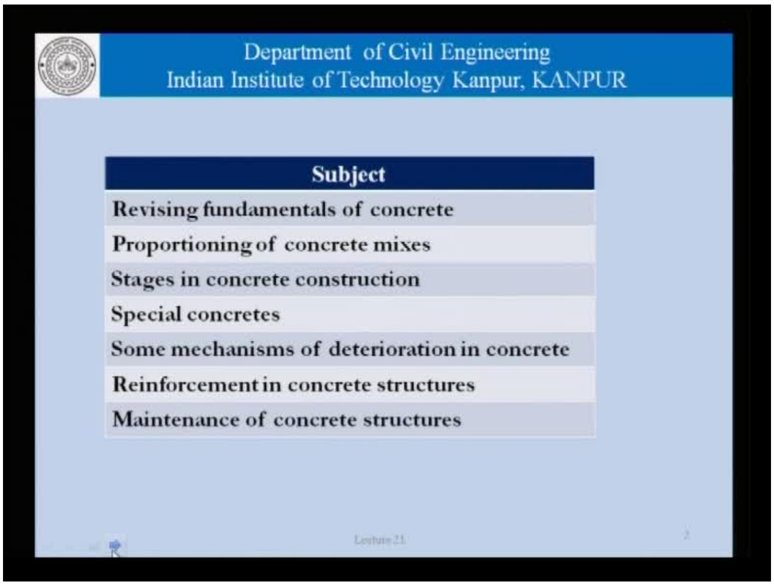

Welcome back to this lecture on Concrete Engineering and Technology. In this module of lectures, we have been talking about subjects ranging from fundamentals of concrete, to proportioning concrete mixes, stages in concrete construction, special concretes; mechanisms of deterioration and concrete structures, reinforcement and maintenance of the structures.

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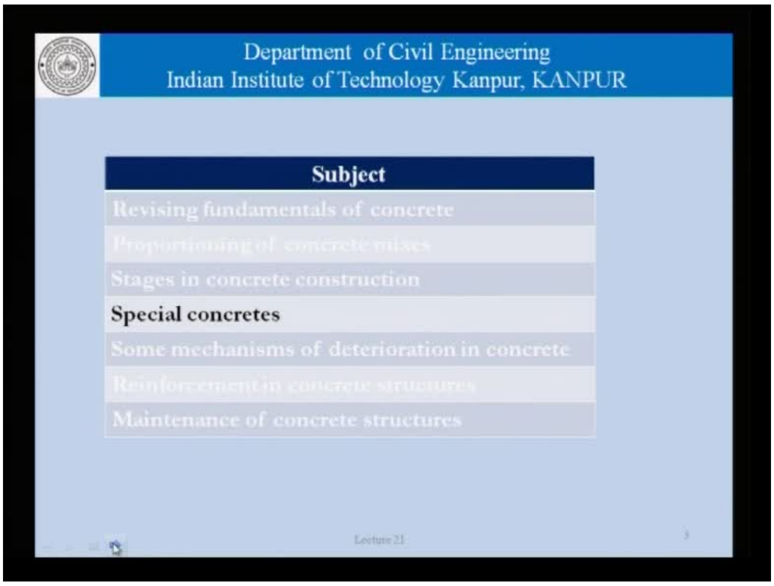

And we will continue our discussion today toward the special concretes.

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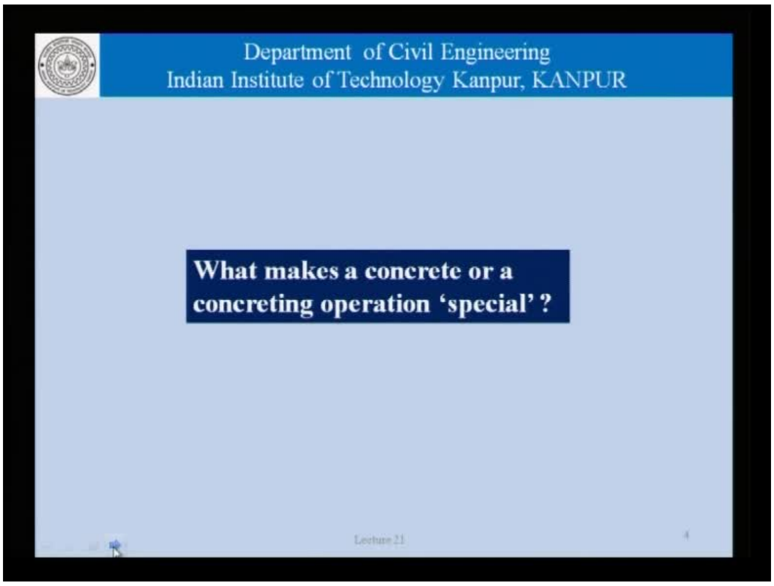

And we have talked about it before as to what, makes a concrete special or a concrete operation special.

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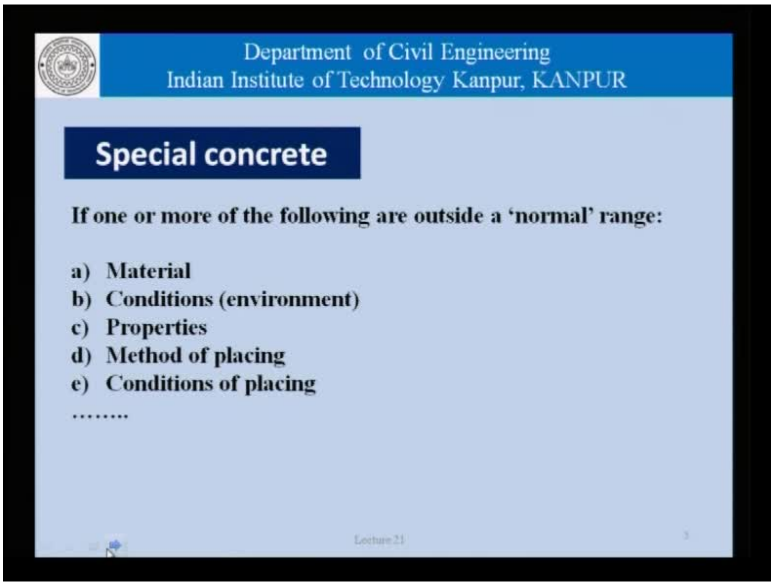

And that could arise from any one or more of the following conditions, use of special materials, special environmental conditions, special properties, special methods of placing or the conditions in which the concrete is placed. So, under any of these conditions the concrete becomes special, and we need to be careful when we are dealing with any of the operations involved whether it is mixing or it is material selection or it is transportation and so on.

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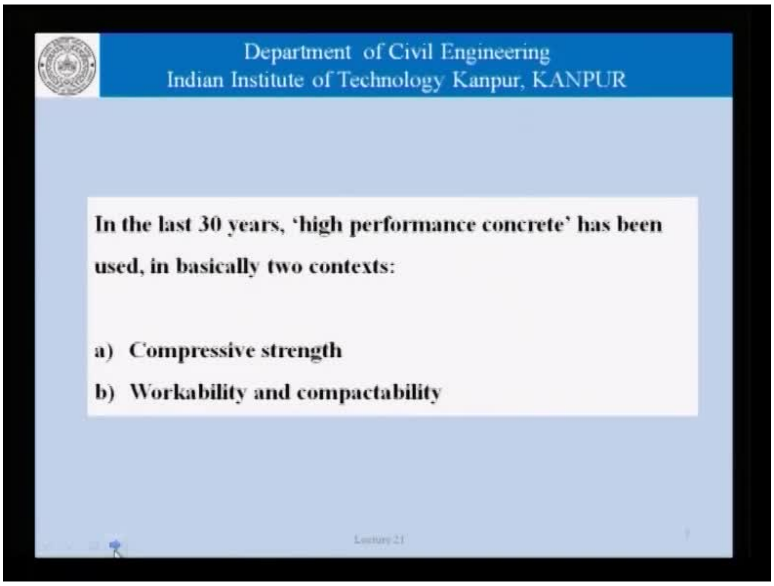

Now having said that we continue our discussion with properties, and in the last above 30 years high performance concrete, and performance is related to properties, depending on the property that we choose to have, we could have a high performance concrete. And in the last 30 years, we have talked of high performance concrete primarily in two concretes, it is easy to guess. One is compressive strength that is we have talked of high performance concrete in terms of high strength concrete, because the strength or compressive strength to be more precise is the fundamental property of concrete.

Having said that workability and compactability is another very important property of concrete, fresh concrete in fact, where we can talk in terms of high performance concrete; there is the concrete should be so workable, that it becomes self-compactable. So, in this discussion today we will be primarily talking in terms of high workability concretes, and let me go back and trace a little bit about the history of self-compacting concretes.

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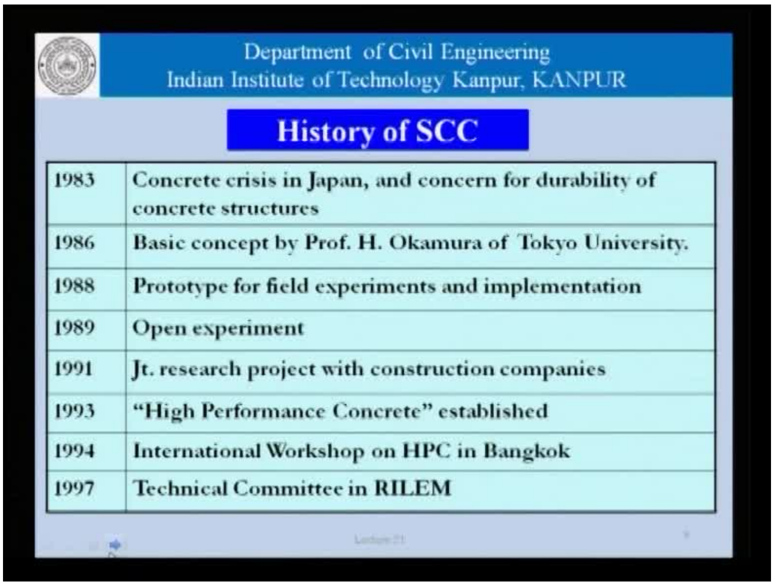

That is one of those concretes which is very highly workable, and now what is a highly workable concrete is something which we need to think about a little bit, and we will probably answer the question couple of slides later. But, getting back to the history of the self-compacting concrete, it was about 1983 that there was a major concern in Japan, arising out of durability of concrete structures.

And the professionals there looking at different aspects felt, that one of the reasons for concrete structures to be having the problem of prematurity relation, was the fact that concrete could not be vibrated properly, that it was not compacted properly. It showed signs of some kind of segregation or the other, and with that kind of a backdrop professor Okamura from the University of Tokyo, developed the basic concept of self-compacting concrete with his colleagues.

It took about 2 years to develop the field experiments and implementation, and about 1989 there was an open experiment in the university, where professionals from different construction companies and so on, they participated. And so what self-compacting concrete was, this lead to a joint research project with the different construction companies participating, and knowledge were shared, the concepts were understood better. And it leads to a more spread application of self-compacting concrete, and is a landmark as far as the concrete engineering is concerned.

In 1993, the concept of including self-compacting concrete or concretes with high workability as part of the high performance concrete was clearly established. And then in 1994 and 97, we can see international symposia and workshops being held professional bodies, recognizing the concept as an important landmark in the history of concrete engineering.

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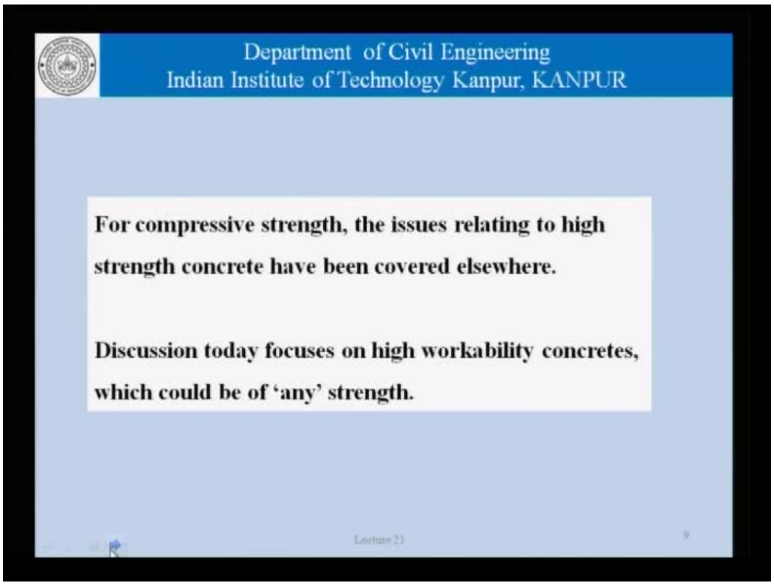

So, as far as compressive strength is concerned, the issue relating to high strength concrete, is being dealt with separately as far as this series of lectures is concerned. And today, we will talk about high workability concretes which could be of any strength, so basically we are separating the issue of strength from that of workability. High strength concrete may or may not be highly workable and similarly, self-compacting concrete or highly workability concrete need not be high strength.

So, having said that what is high workability concrete, it is difficult to define, because there is no clear definition as to what high workability concrete is, but perhaps what we could say, is that a concrete where the workability cannot be measured, in terms of let us say the slump test. And we enter the domain of slump flow that is one of the tests that we need to check for defining high workability concretes. Now, if we recall the height of the slump cone is above 300 mm, it is difficult for the slump test to be used when the slump exceeds, let us say 80 centimeters or above 180 or 200 mm.

So, high workability concretes are those concretes which have a slump higher than that, let us say about 180 to 200 mm. And we need a separate set of tests to check the quality, to differentiate one concrete from another, and use them at site as part of our regular quality assurance programs; those tests are not what we are going to talk about today.

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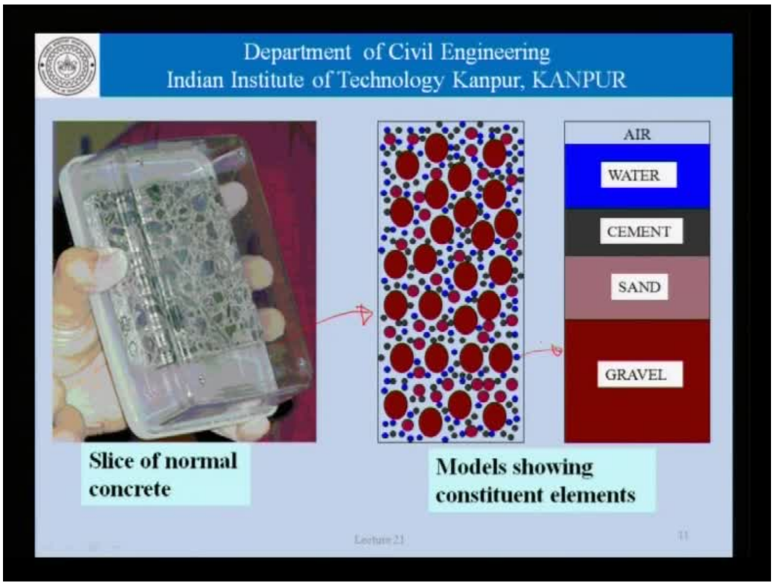

What we will talk about is the fundamentals, and going back to this picture here which shows a slice of concrete, modeled as another picture here where the course and the fine aggregates have been taken to the randomly distributed. And we have a lot of space filled in with cement particles water and so on. If all this gets consolidated, we have a certain volume of gravel which is coarse aggregate, a certain volume of sand, a certain volume of cement, water and air in a concrete mix.

Now, this picture is what we have seen several times, and what we will do today is to relook at this picture and try to revise and revisit some of the fundamental definitions, as far as concrete engineering is concerned.

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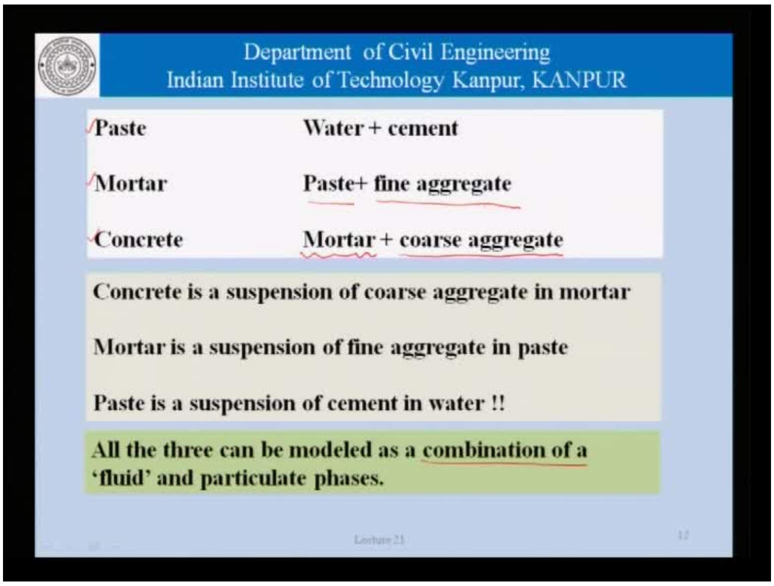

We know that paste is a combination of water and cement, mortar is a combination of paste and fine aggregate that is water and cement with fine aggregate, and concrete is a combination of mortar and coarse aggregate. Now, if we look at it in a different way, concrete is a suspension of coarse aggregate in mortar, so it is a suspension of coarse aggregate in mortar.

Similarly, mortar is a suspension of fine aggregate in paste, so we have a paste phase and we have fine aggregate. So, when fine aggregate is suspended in paste, we have what is called mortar, and going the other way around paste is a suspension of cement in water. Now, all these three that is paste mortar and cement can therefore, now be modeled are looked upon as a combination of a fluid, and a particle at phase.

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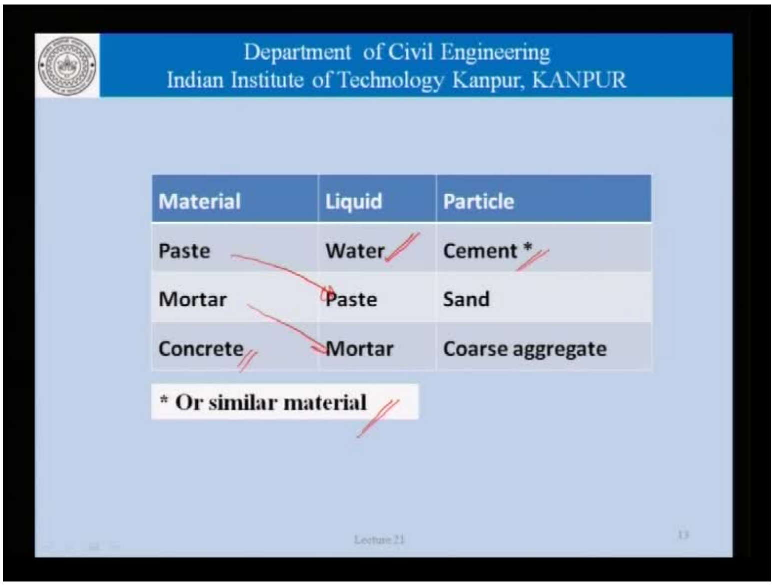

As far as the paste is concerned, water is obviously the fluid, and cement or any other similar material that is the particle at phase, as far as the paste is concerned; when it comes to mortar, this paste serves as the fluid phase. And the sand serves as the particle material, finally concrete the mortar that we have serves as the fluid phase, and the coarse aggregate is the particle at. This understanding of concrete, in terms of relating it to the fundamental properties of paste and then mortar is important, when we try to study or understand the behavior of high workability concretes.

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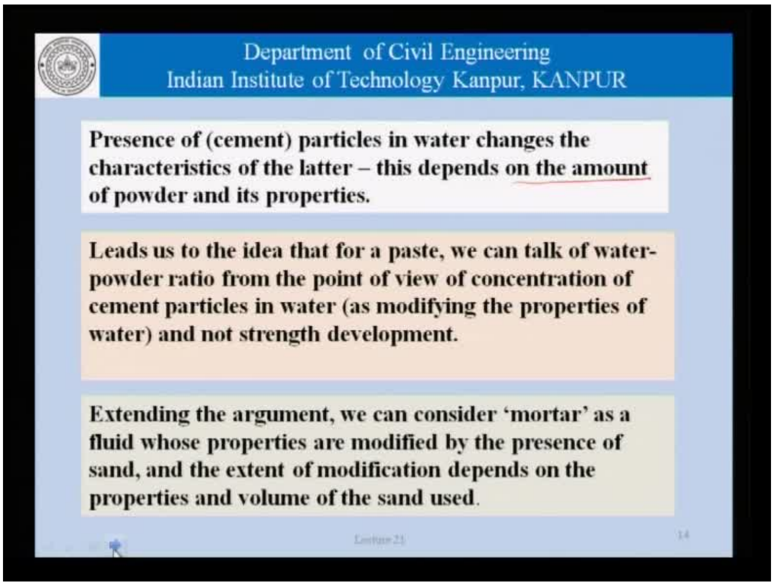

Changes the characteristics of the latter, now the presence of cement particles and water, changes the characteristics of the latter that is water, which we know is a fluid is a liquid. The properties of water in terms of it is viscosity and so on, they change when cement particles are added to it. When we are talking of addition of cement particles in water today, we are not including in fact, we are trying to exclude the discussion of hydration. We are looking at cement as purely some particles which are added to water, and if they are added in a certain degree that is the amount of cement particles that are added, it is not that you take a liter of water and just add a gram of cement and it becomes a paste, no. We have to add a certain amount of powder, in order that the properties of water are modified and it becomes and behaves like a paste.

We are not getting into the numbers today; I am leaving that out as an assignment, as to what is the kind of numbers or what is the concentration, what is the amount of cement that needs to be added. In order that the properties of water are modified to the level that, it is looked upon as a paste, in fact the more powder we add the more paste like, or the viscosity, the more paste like behavior we will have as far as the water is concerned.

So, we have to keep in mind today that addition of particles beyond a certain threshold limit, lead to fundamental changes in the viscosity, or the rheology of the fluid phase. And that is something that progressively happens when we are looking at concrete.

So, as far as the paste concerned the presence of cement particles, or in fact any other particles which are similar in size, obviously you can imagine that is we add coarse aggregate to water, we will hardly get paste. But, if we add fly ash in a certain amount; we surely will get some kind of paste, whether it hydrates or it does not is a different matter, so we are not talking of hydration, and strength development today.

Our concentration today is in terms of understanding the behavior of fresh concrete, and workability of the fresh concrete. So, in that context let me reiterate that the presence of particles in water, primarily cement, in the case of concrete engineering, changes the characteristics of water, and this depends on the amount of powder and it is properties. If we have one cement, we may get certain paste like properties at a certain concentration; in another cement those properties would be achieved if the concentrations are higher, or lower depending on what are the properties of cement that we talk about.

An example that comes to my mind is the fact that if you have done, the tests relating to standard consistency of cement, you have a picture in mind that if we add say 30 percent or 32 percent of water, what is that nature of the paste that we get, compare that with the natural paste, if the water content is about 40 percent and so on. So, in this case we are not talking in terms of water cement ratio, from the point find out view of strength development, but we are talking about the powder concentration, in order to get paste like behavior.

Now, this leads us to the idea that for a paste, we can talk in terms of a water powder ratio from the point of view of concentration of cement particles in water, as modifying the properties of water, and not really strength development. Extending this argument, we can consider mortar as a fluid whose properties are modified by the presence of sand, and the extend of modification depends on the properties and the volume of the sand that is used.

So, in the same manner that if we continue to increase or decrease or whatever, the cement particles in water the properties of the paste will keep changing. Similarly, if we alter the concentration of sand or the amount of sand that is added to a paste, the properties of the mortar will keep changing. And depending on the paste that we begin with the situation could be quite different, for a given volume of sand that is added to the mortar.

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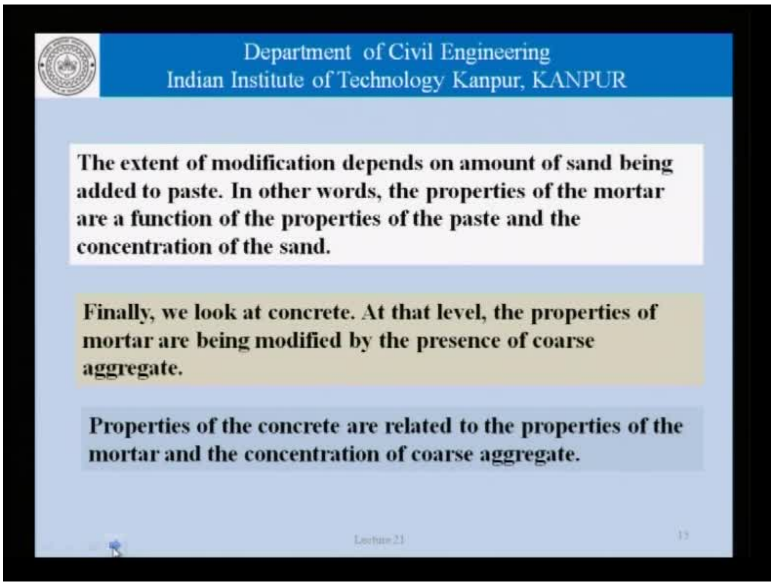

Now, if that is clear we can say that the extent of modification in the properties depends upon the amount of sand that is been added to the paste. If we have a paste of a certain rheology, and we add some sand there will be some changes, if we add more sand there will be more changes and so on. In other words, the properties of the mortar are a function of the properties of the paste, and the concentration of sand besides of course, the properties of sand.

If the sand is fine, the extent of modification will be different compare to sand which is coarse, and this fineness or coarseness of sand can be measured in terms of fineness modulus. Now of course, our interest primarily is concrete and therefore, if we find in look at concrete, at that level the properties of mortar are being modified by the presence of coarse aggregates.

So, given a property, viscosity or any kind of logical behavior of a mortar that gets modified, when we add coarse aggregate to it. And the extent of modification again depends upon the properties of the coarse aggregate that is added, the amount of coarse aggregate that is added. And of course, the final product depends on the initial properties of the mortar itself.

In other words, what we can now say that the properties of the concrete are related to the properties of the mortar, and the concentration of coarse aggregate and of course, the properties of the coarse aggregate themselves. Now, what are the properties of coarse aggregate that could be important, they could be size, shape, gradation, density and so on.

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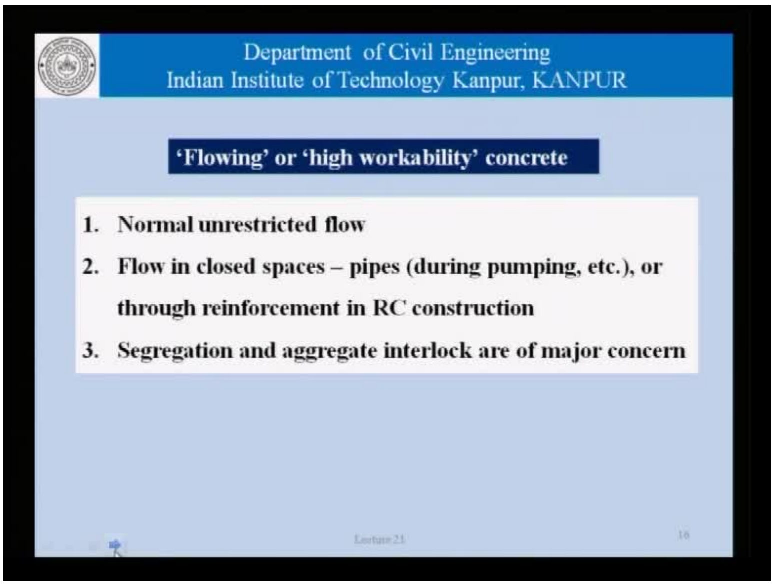

Now, once we are talking about flowing or high workability concretes, then we could be talking of a concrete which would flow normally that is, if we want to just pour concrete in a large unreinforced section. Or at times we have concrete flowing in closed spaced for example, in pipes when the concretes are being pumped, or when the concrete even moves through reinforcement, in reinforced concrete construction.

In either case, it is important that we are careful about two properties, one disaggregation and the other is aggregate interlock. Both these issues are of major importance, when we are dealing with high workability concretes.

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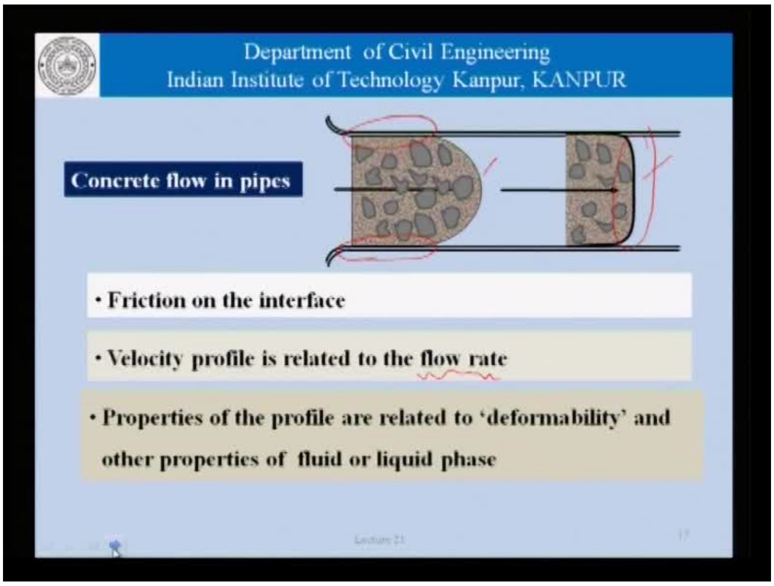

Now, let us take a look at the concrete flowing pipes for example, we obviously we will have some friction at the interfaces that is at the surface of the pipe. And depending on this friction and other factors, the velocity profile could be this or it could be something closer to this that is, that not so much change, across the cross section of the pile as far as the velocity is concerned. And of course, the velocity is also related to the flow rate of concrete though the pipe and this is related to the energy that we are importing to the concrete at the pump.

So, properties of the profile are related to the deformability, and their properties of the fluid and the liquid phase. We have reason about theoretical background developed as far as fluid mechanics is concerned, where all these issues in terms of fluid flow in pipes, under pressure and so on, that is very well understood. As far as concrete is concerned that raises certain problems for concrete engineers, and for construction sites.

And that is something which we must also keep in mind when we are talking in terms of highly workable concretes, or flowing concretes, or concretes that are being pumped through pipes and it is been placed at different locations.

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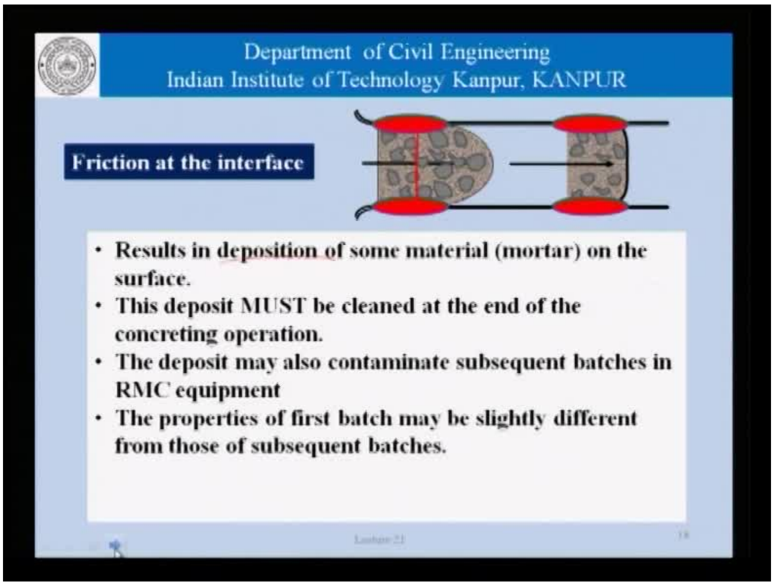

Now, this business of friction, on the interface results in deposition of some material which is primarily mortar on the surface. Now, how does this deposition affect us, this deposit indeed must be cleaned at the end of a concreting operation, for the simple reason that, the deposit can reduce the cross section area. Because, initially the deposit is fresh, but as more hydration takes place it hardens, and the kind of cross section is available for concrete flow reduces, if this deposit is not removed.

Also in case of RMC equipment that is the ready mix concrete equipment being used for different mixes, this deposit will tend to contaminate subsequent mixes; if the equipment is not clean at the end of each operation involving a certain kind of concrete. In fact, the properties of first batch may be slightly different from those of subsequent batches, because only the first batch, we will have this kind of a deposit problem more than the other batches.

So, in fact, in certain constructions where we are extremely concerned about the quality of concrete be used, we have to make sure that all the equipment that is used is properly primed or coated, with the kind of concrete that is going to be actually used. So, we need to run a batch of grout or mortar or may be even concrete, and throughout a way without actually using it. Only to ensure that all the equipment that is used, is having a coating of a kind of concrete that is going to be used in that construction.

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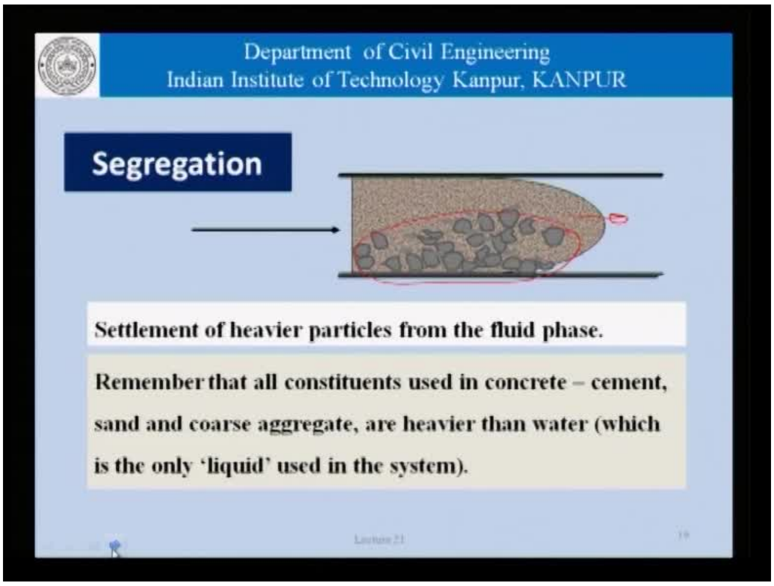

Now, coming to segregation, this slide here shows the segregations of coarse aggregates, that is the coarse aggregates have separated from the concrete, and primarily it is the mortar which is flowing ahead. Segregation basically means settlement of heavier particles from the fluid phase, and that can happen as far as concrete is concerned when coarse aggregate settles out to mortar, as I shown here. Or sand settling out of paste in the case of mortar, and perhaps even cements settling out of water as far as paste is concerned.

And in fact to that extent bleeding is indeed a measure or a form of segregation in concrete. Now, we must remember when we are talking of concrete that all constituents, that is cement sand and coarse aggregate are heavier than water, and which is the only liquid in the system. So, have to make sure that the liquid phase that is the paste and the mortar has right kind of properties to ensure that segregation does not happen, that is the coarse aggregates are actually carried along with the mortar. When the concrete is moved, either under pressure through pipes, or it flows on its own under gravity and so on, if it is moving in an unrestricted manner.

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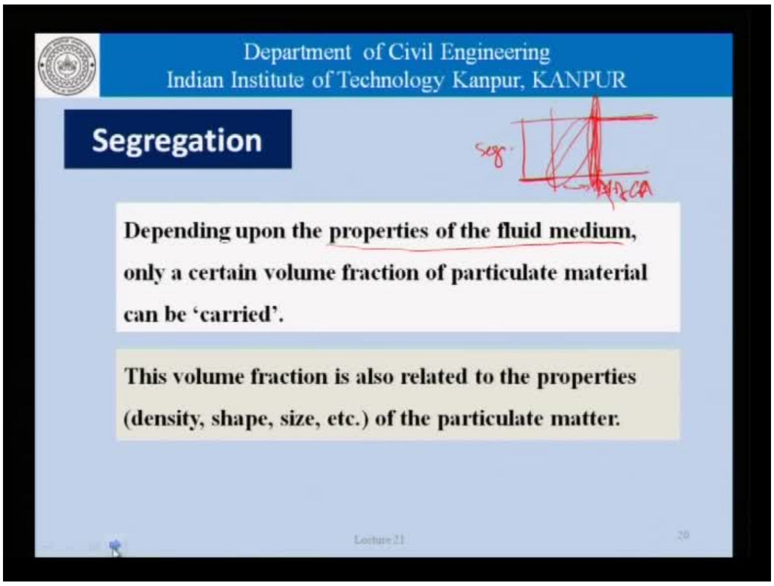

Now, depending on the properties of the fluid medium, only a certain volume fraction of the particulate material can be carried. Now, this is the qualitative argument, which basically says that for a given fluid medium, a given mortar in our case. If we pack more coarse aggregate in that, then it can carry the possibility of segregation increases. Whereas, if the amount of coarse aggregate is very small is relatively easier for the mortar to carry that amount of aggregate.

Looking at the whole thing from another point of view, we need to maximize the amount of coarse aggregate in our concrete, because that is the cheapest material. If that argument is coupled with the kind of argument which is put forward here, we really see that for a given type of mortar. Or a mortar with the given rheological properties, we can only pack in a certain amount of, maximum amount of coarse aggregate in that mortar, without running the risk of segregation.

The segregation definitely will happen, if the coarse aggregate content is higher than a number, it may not it will surely not happen if the amount of coarse aggregate is less than a certain number. And in between there will be a zone where the segregation may happen or may not happen, so if we look at the chances of segregation happening, and this is the chance or this is the level at which definitely will happen. And we plot the volume of coarse aggregate here, beyond a certain point the chance of segregation happening a very high, and below a certain level here they are more or less negligible.

And in this case here, well there is a possibility there is segregation may happen or may not happen depending on all kinds of factors. So, it is important for concrete engineers to appreciate that there is only this amount of coarse aggregate that we can pack in to a mortar. Now, this amount here is related to the properties of the mortar as far as concrete is concerned, and this amount will depend on the properties of the paste as far as a mortar is concerned.

This volume fraction is also related to the properties of the particulate matter that is, what is the kind of size, gradation, density, shape and so on, of the particles. So, if we have one set of aggregates, the volume could be 44 percent, and for another set of aggregates it could be 40 percent or 49 percent or whatever that number is.

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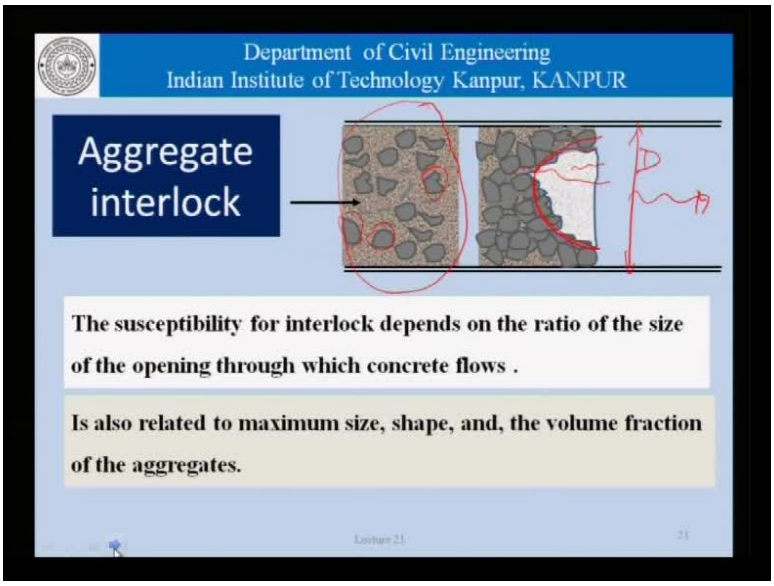

The second matter of concern that was mentioned earlier was aggregate interlock, when concrete flows the way it is shown here in a pipe, there are chances that this kind of an interlock or arching is observed at times. Now, this formation of an arch, makes it difficult for concrete to actually negotiate through the aggregates. And we do not get concrete flow here, or at best we may get some kind of mortar flowing through the voids in the aggregate system, so we cannot afford to have aggregate interlock.

And this interlock or the susceptibility of a concrete to have aggregate interlock, is related to the ratio of the size of the opening through which the concrete flows. So, if the susceptibility for interlock depends on the ratio of the size of the opening through, which the concrete flows to the size of the coarse aggregate. So, if this diameter here of the pipe is very much larger compare to the size of these particles here, the chances of aggregate interlock happening are very, very small.

Whereas, if this diameter d is much smaller or is small, and we are trying to push through aggregates or concrete having aggregates which are larger, then the chances of some kind of an aggregate interlock occurring preventing the kind of concrete to flow through is very high. So, now the chances for aggregate interlock or the susceptibility to aggregate interlock is also related to the maximum size, shape and the volume fraction of the aggregates.

So, if the volume fraction of aggregates is small, then again the chances of aggregate interlock are small whereas, if we keep having more and more aggregates in the system, for a given shape size and so on. If simply the volume of fraction is increased, the chances of the interlock keeping increasing, now that is something again which a person who is trying to proportion a concrete mix of this kind of consistency, of flowability must be aware of.

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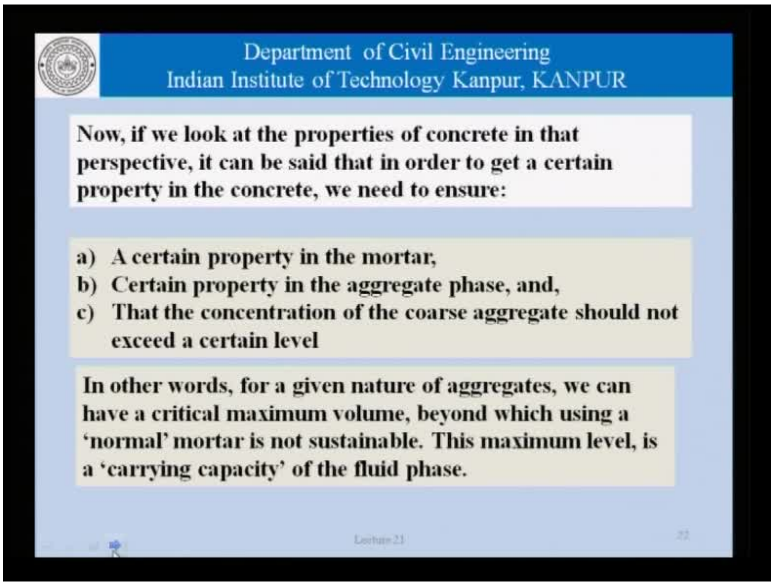

Now, if we summarize or we look at the properties of concrete in totality, we can say that the properties of concrete in this perspective, it can be said that in order to get a certain property as far as concrete is concerned. We need to ensure that mortar has a certain property, we need to ensure that the aggregate has a certain property that is in terms of it is gradation, density, particle size, and so on. And the concentration of aggregates is below the threshold concentration that we talked about.

In other words for a given nature of aggregates, we can have a critical maximum volume beyond which using a normal mortar is not sustainable, this maximum level can be called a carrying capacity of the fluid phase or the mortar.

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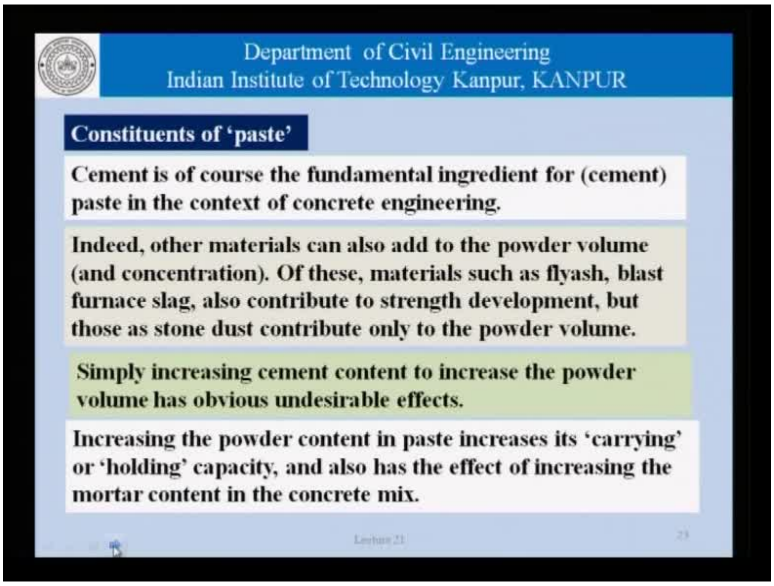

Now, let us talk a little bit about the constituents and the paste, cement is of course, the fundamental ingredient, because cement paste in the context of concrete engineering definitely has cement. But, it can have other particles as well, other materials can also be added to the powder volume, and concentration of course, out of these material such as, flyash, blast furnace flag and so on.

They also contribute to the strength development, and hydration of the cement and the cement products, and also contributed to the strength development, hydration products being formed and so on, whereas those such as stone dust contribute only to the powder volume, but play an important role when it comes to modifying the properties of the paste. Simply increasing the cement content to increase the powder volume has obvious undesirable effects, primarily on account of economy, and the fact that cement has an associated heat of hydration.

And we would not like to use more cement then is absolutely required, but if we require a higher powder volume, then we need to turn to material such as flyash or stone dust and so on. Increasing the powder content in the paste increases, it is carrying capacity or the holding capacity that we defined just now, and also has the effect of increasing the mortar content in the concrete mix. So, even though we are talking about paste here, but if we use materials such as flyash or stone dust, it contributes to the paste volume; but nonce we increase the paste volume, we also increase the mortar volume in the concrete.

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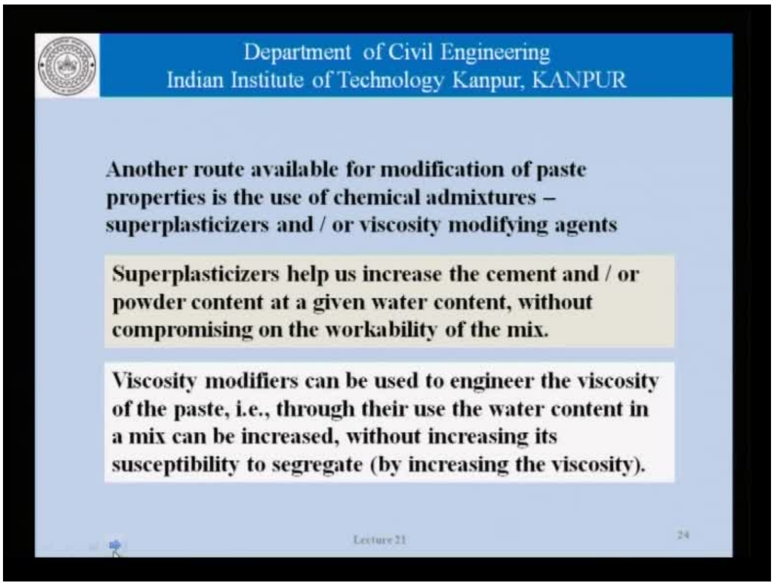

Let another root apart from increasing the powder content which is available for modification of paste properties, is the use of chemical admixture, which could be superplasticizers or viscosity modifying agents. Of these superplasticizers help us increase the cement and or powder content at given water content, without compromising on the workability of the mix that is the whole principle of superplasticizers or a plasticizer.

That we can have more powder at the same level of workability, our fundamental understanding in this course so far, and that is what is going to be practiced in even other discussions, other than the discussion that we are having today is that in order to increase the workability, we need to increase water. In this case here, we are saying that it is not necessary to increase water, we can do that with also using plasticizers.

Viscosity modifiers or the other set of chemical admixtures can be used to engineer the viscosity of the paste. That is through their use the water content in a mix can be increased, without increasing the susceptibility to segregate, by increasing the viscosity of the paste.

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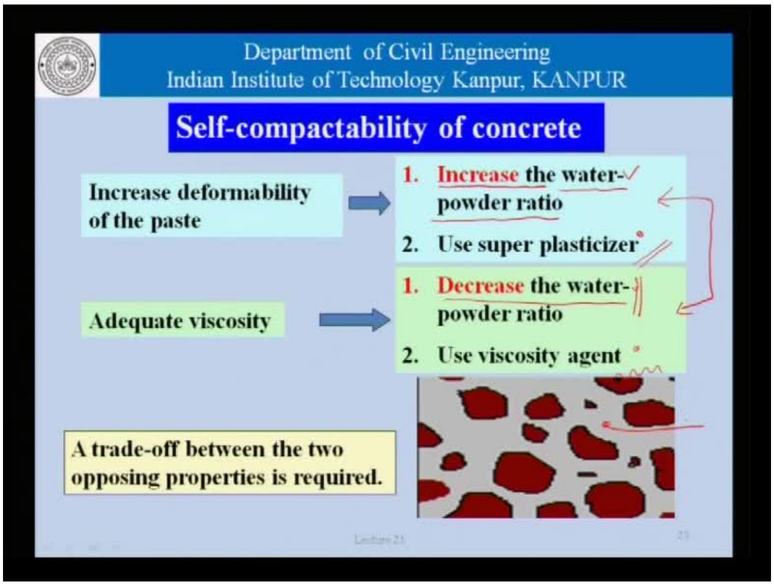

Now, when we are talking of the self compactability of such concretes, we have to understand that we would like to increase the deformability of the paste. The paste should be such that, can be deformed to more easily, now in order to deform the paste we need to use more water, we some how need to increase the water powder ratio. A paste which has a higher water powder ratio is easier to deform, which means that we need to use superplasticizers for such pastes.

But, at the same time we also need adequate viscosity, and for that we need to decrease the water powder ratio, and in order to get this thing, we need to use viscosity agents or what we called, viscosity modifiers in the last slide. Now, it is a trade-off between these two, what is the kind of water powder ratio to be used, and what combination of plasticizers and the viscosity agents is used, in order that the paste phase here has the right kind of rheological properties, to be able to support a given system of coarse aggregates or of sand.

Depending on what you are talking about, if you are talking about mortar then we are talking off paste and sand together, if you are talking of concrete then this here is really the mortar and this is the coarse aggregate. So, the principle remains the same that is on the one hand, we are talking of the need to increase the water powder ratio have more water basically in the system, in order that the fluid phase becomes more deformable. And on the other hand, we are talking of the need to decrease amount of water in the system, increase the powder content in the system, to have adequate viscosity, and segregation resistance.

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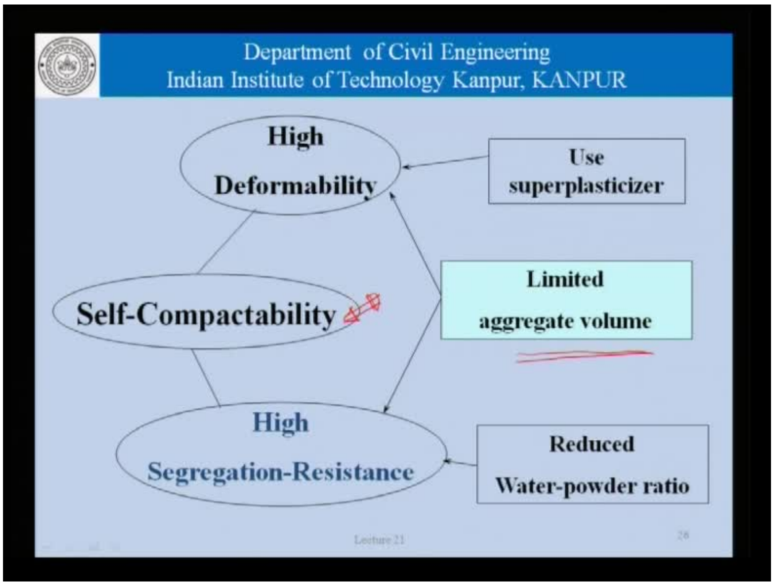

With this picture here is a representation of more or less, the same thing that we saw previously, we talk in terms of high deformability getting it through plasticizers. Then we talk of high segregation resistance, we get it through the reduced water powder ratio, and we have a limited aggregate volume. So, we try to limit the volume of coarse aggregates in the system and finally, we land up with the property of self compactability, or it could be basically very high flowability concretes.

Very high flowability concretes need not be self-compacting for example, very often we have concretes which are highly flowable, and all those governing high flow ability concretes will apply. Accept for the fact that, we would still need some amount of external energy or vibration in order to make sure that the concrete is properly compacted.

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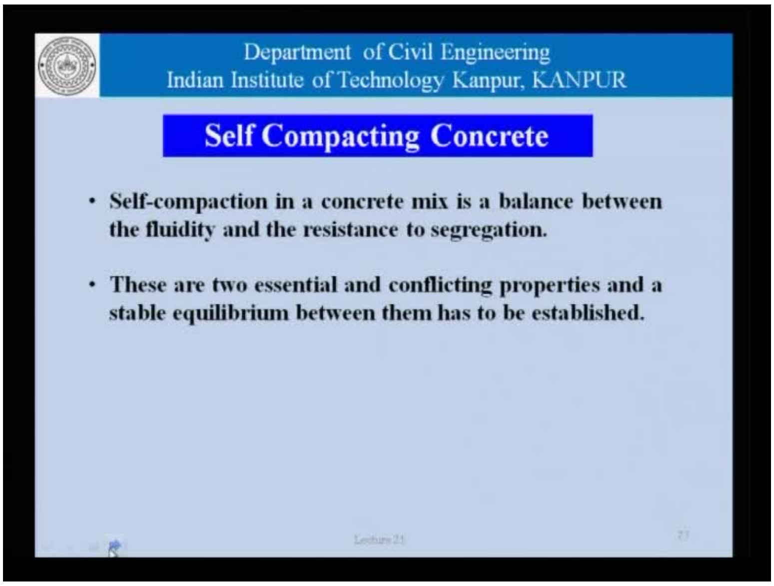

Now, as far as self-compacting concrete as we have discussed, it is a balance between the fluidity and the resistance to segregation, and these two are essentially conflicting properties, and a stable equilibrium between these two needs to be established.

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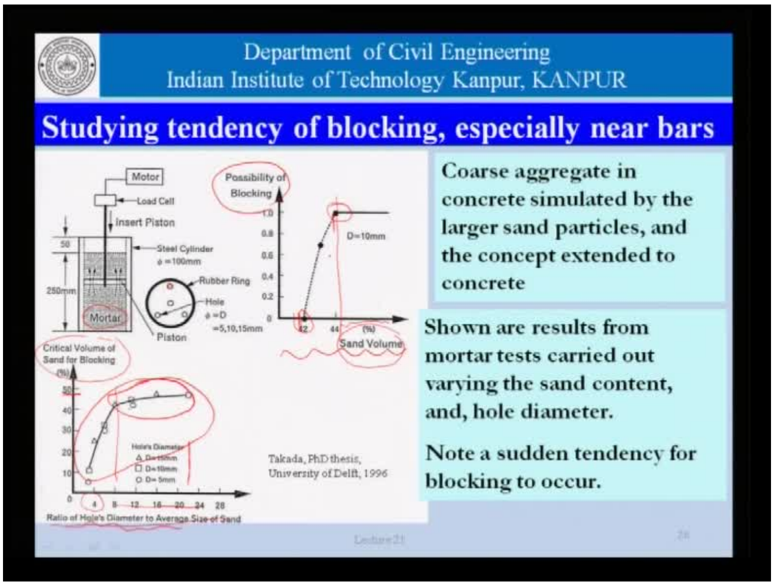

Now, let us look at the tendency of blocking in concrete especially near the bars, now if we consider this thought experiment or natural experiment. We can actually carry out this experiment and collect the data, or even just think about how this experiment would work. If we fill mortar in this cylinder, and we push a plate which has this kind of a configuration which has holes here, and this plate is pushed into this mortar what do we expect will happen.

If this material here was purely water, then as the piston is inserted, the water will simply flow out of these holes, however if this material here is not water, and is actually mortar which has cement paste and sand. Then we can draw pictures such as these, where we say, if we keep changing the volume of given sand in the mortar, then what is the possibility that the flow of mortar through these holes will be blocked.

We we will find that, if the sand volume for example, is greater than 44 percent as seen here, the chances of blocking are almost one whereas, if it is less than this number, let us say 42. The chances are that we can still push the piston, and this plate through the mortar with the mortar continues to flow out. Another thing which is important to understand as far as this kind of an experiment is concerned is the relationship between the diameter of the hole, through which we are forcing the mortar to flow and the diameter or the particle size of the sand.

So, if we plot that or if we keep that in mind, then we try to find out what is the critical volume of sand which is required, or which can be supported without blocking. Then we find that depending on the ratio of the holes diameter to the average size of sand, the behavior is something like this; that is no matter what this ratio is if the critical volume or the volume of sand exceeds 40 to 45 percent the flow is still blocked. This kind of a discussion really sets the rules, for talking in terms of high flowability concretes or self-compacting concretes and so on.

Concretes are special, in this context concretes become special when we start to talk in terms of these kinds of things that is what is the kind of flow pattern. What is the kind of flow that expect the concrete, what is the kind of relationship between the maximum particles size, that is the maximum size of the coarse aggregate that we have, in relation to the kind of properties in the mortar. As far as the viscosity and deformability is concerned, how does that impact the flow of concrete to pipes and so on.

So, if we read the text here, we say that coarse aggregate in concrete simulated by larger cement particles, we could easily extend this discussion, or this kind of an experimental concrete except that we will need or much larger set up. Because, in that case when we talk of the ratio of the hole diameter to be particle size, we could be talking of a single hole being at least say 80 mm or 100 mm and so on.

Assuming that we are going to be using say 20 mm kind of particles, also shown here are results from mortar tests carried out by varying, the sand content, the hole diameter and it can be noted that there is a sudden tendency for blocking to occur. So, whether it is this picture here or it is this value here, the blocking is some how a very sudden behavior, or it is happens very abruptly; so it is not that gradually it will happen, but it happens very abruptly. So, at a certain percentage of the particulate matter or concentration of particulate matter beyond that, suddenly we find that the material does not move.

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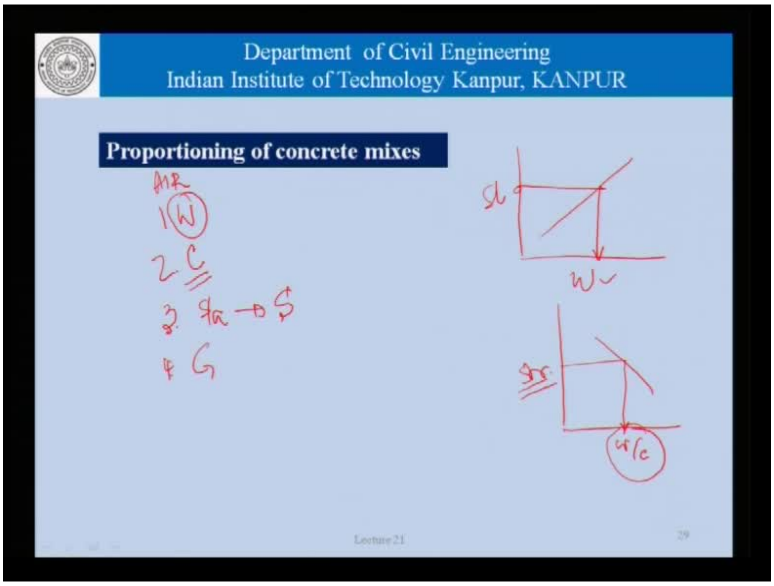

Now, once it comes to proportioning of concrete mixes, as far as our traditional system is concerned, we are talked in terms of unit water content and a slump, and we said that the relationship is more or less linear. And we had said that we can talk in terms of a water cement ratio and a strength relationship, where the strength and a water cement ratio are inversely related. And couple with this what we had said was for a given slump, we first determine the water content, so the first thing that gets determined is the water content, the second thing that it gets determined based on this water cement ratio.

And the strength that we have knowing the water content is the cement content, and the third thing that we get using the s by a is this sand content in the mix and finally, we get the coarse aggregate content. So, this was our fundamental flow of thought process, when we are talking in terms of the proportioning of normal concrete mixes. Of course, to begin with we had to know what the amount of air is in fresh concrete.

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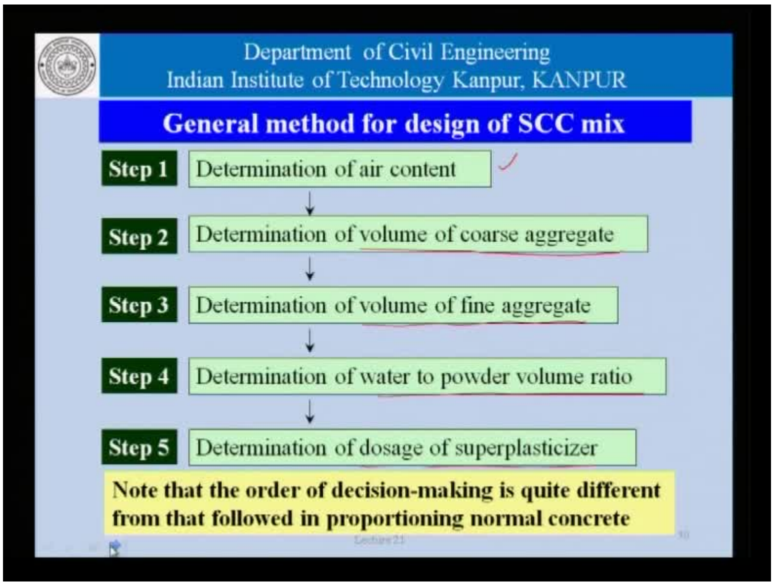

So, now once we look at the self-compacting concrete kind of mix proportioning, we find that the steps are quite different, and one of the strategy is that has been put forward is to decide what is the air content that is going to be used. And then come to the volume of coarse aggregate remember that, the volume of coarse aggregate in the normal mixes was determined last. But, in this case we are trying to get that thing at the first instance, because that is the amount of maximum amount of aggregate that can be supported by the mortar.

So, what is the kind of volume of coarse aggregate that can be supported from there by the same argument, we and then determine the volume of fine aggregate that the paste can support. We determine the water to powder volume ratio, and then we determine the dosage of plasticizers and chemical admixtures. So, the thought process here is quite different from that followed in proportioning normal concrete mixes, where the waters determine first, then the cement, then the sand, then the coarse aggregate.

In this case, it is the coarse aggregate, fine aggregate, water to powder volume and finally, the chemical admixtures. In order to ensure that the paste and then the mortar have the right kind of rheological properties to ensure that, the concrete can be high flowing without segregating.

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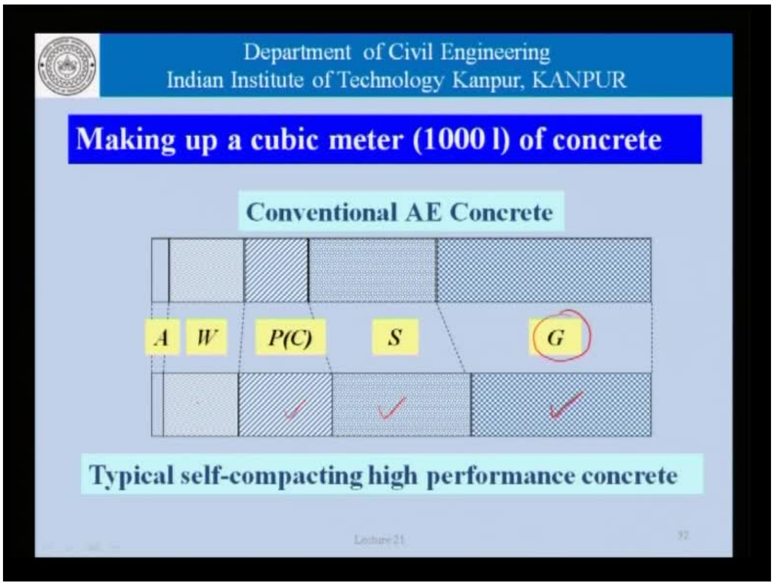

Now, if you look at how a cubic meter or a 1000 liters of concrete is made up, as far as conventional air entrained concrete and self-compacting concrete is concerned. We find that the amount of coarse aggregate is lesser here, the sand is higher, and the powder content is higher but not so much the water content. So, the viscosity in the paste phase or the mortar phase is imparted by the increased powder content, and use of appropriate mixtures. And by reducing the amount of coarse aggregate in the system, we have reduced the chances of aggregate interlock, and made it easier for the concrete to be transported without segregation.

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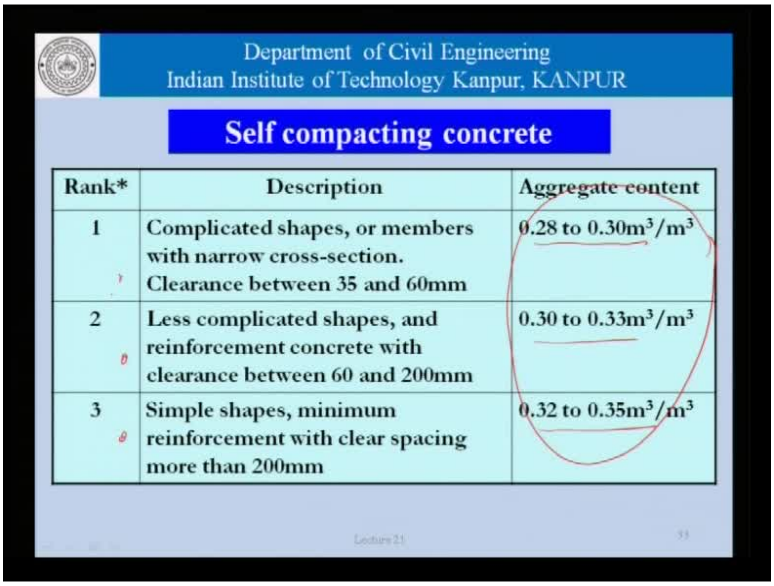

Now, in the case of self-compacting concrete, this aggregate content which ranges from say 28 percent or 30 percent, 30 percent or 33 percent or may be 35 percent, this really determines or this is determined from the kind of construction that we are using the concrete for. If the concrete is being placed in open spaces without obstructions, we can use more coarse aggregate, whereas if we want the concrete to be moving through or negotiating complicated passages, then the amount of fabricate that can be supported is smaller.

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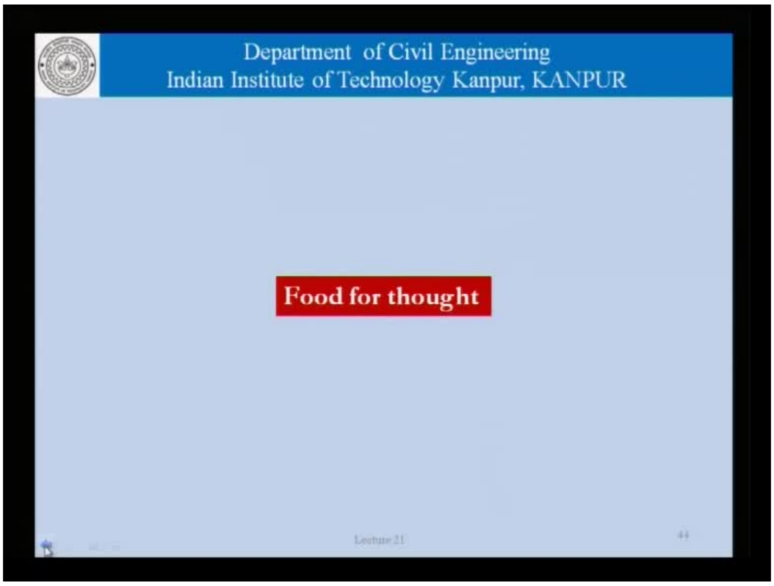

So, in our discussion today, what we have done is established the ground rules for a self-compacting concrete, or a very high flowability concrete which is moved around more like a fluid. What we have done is, talk in terms of the modification of the fluid properties, on account of the presence of particulate matter; and talked in terms of a critical volume of the particulate matter that a given fluid can sustain without segregation. Now, having done that, we will see the measurement of the workability of concrete such as the self-compacting concrete, in the subsequent discussion.

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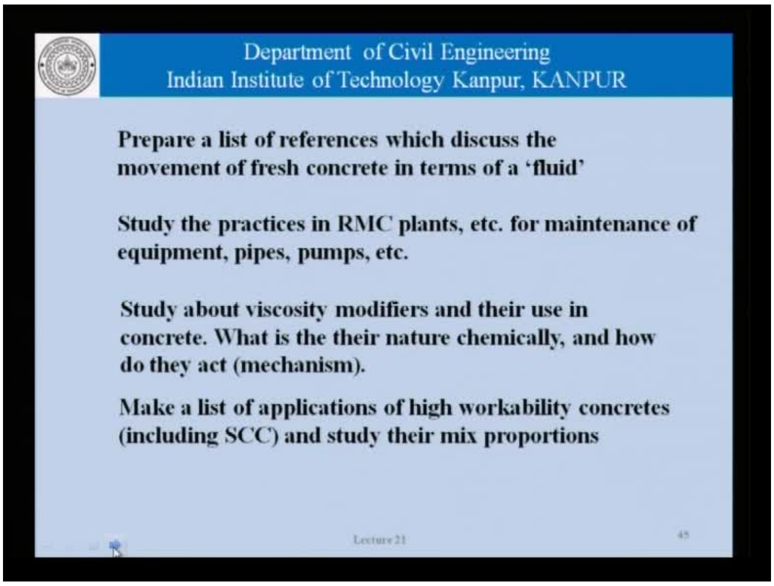

But, let us close our discussion with some questions, we could prepare a list of references, which discuss the movement of fresh concrete in terms of a fluid, where concrete is looked upon more as a fluid. We could study basically rheology of fresh concrete, we could study practices in ready mix concrete plants, for maintenance of equipment pipes and pumps etcetera. As to how they tackle the problem of deposition of mortar and concrete in the surface, or on the surface of concrete near the bends and so on.

And we could study about viscosity modifiers, and their use in concrete, what is their nature as far as the chemistry is concerned, and the mechanism of their action as far as hydration products, and so on is concerned. And we could make a list of applications of high workability concretes, including the self-consolidating or self-compacting concretes, and study their mix proportion, from the point of view of the maximum coarse aggregate size used; the contribution or the volumetric proportion of the coarse aggregates sand, and so on.

I must acknowledge, the help and the interesting discussions that I had with my friend (( )), and some part of this discussion here in in today's presentation, has been taken from his PhD thesis which is submitted, at the University of Delft.

Thank you.