Development and Applications of Special Concretes
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Lecture 02
Review of Normal Concretes: A Composite Material

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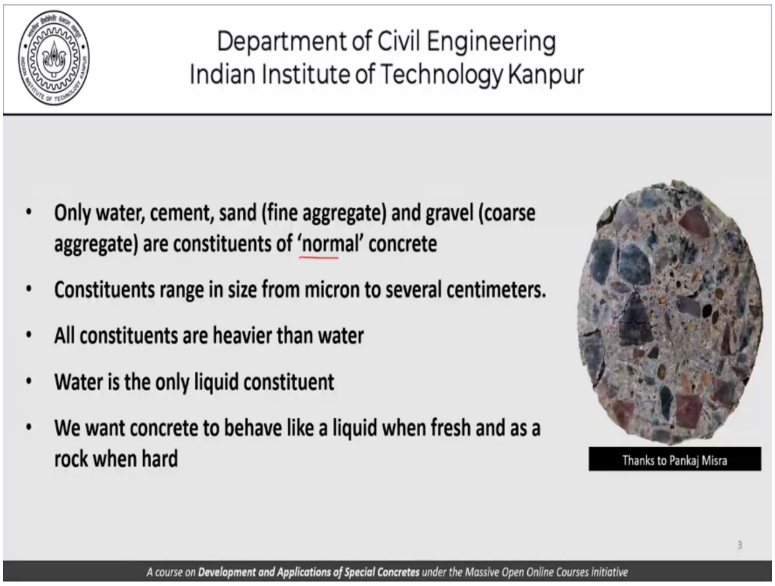

Namaskar and welcome back to this series of lectures on development and applications of special concretes, we are on lecture two today and we continue our discussion of normal concretes. We are trying to review the properties the composition and the application of normal concrete. Today, the title is concrete composite material, we try to understand how we model and what are the implications of that model as far as concrete is concerned as a composite material.

Let us begin by trying to review what we had done last time we had looked at this slide this picture, which is a slice of concrete from the inside of a concrete core. And, we had said that okay as far as normal concrete is concerned, we take the constituents to be water, cement sand and coarse aggregate only. No admixtures, no special ingredients and we said that well the constituents of this concrete range from microns to several centimetres and that is very interesting aspect of it and that is a very challenging part of it.

All constituents are heavier than water that is something which we must keep in mind water is the only liquid constituent and that is the only thing that really contributes to or brings about workability the flowability part of concrete. We want concrete to behave like a liquid when fresh and as a rock when hard.

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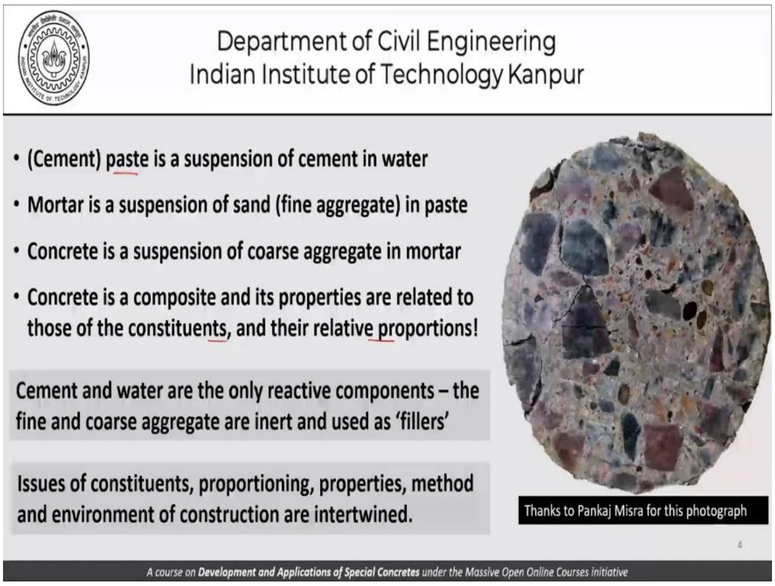

And, we had said that well as far as the basic model is concerned, we will talk of cement paste as a suspension of cement in water, mortar as a suspension of sand in paste and concrete as a suspension of coarse aggregate in mortar. So, with this understanding we move forward and said that concrete is a composite and its properties are related to those of its constituents and the relative proportions primarily.

There are other things that govern the properties but these are the primary constituents cement and water are the only reactive components the fine and coarse aggregates are inert and used as fillers. Issues of constituents proportioning, properties, method and environment of construction are all intertwined.

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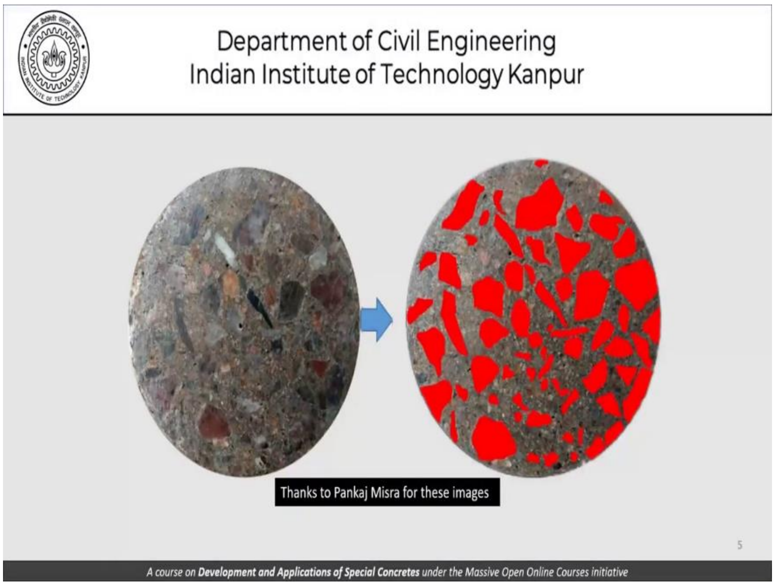

We have discussed this aspect at length, having said that this is another picture we had seen last time which shows this kind of aggregates all over the place and which are separated. You can see there is a separation between different coarse aggregates. As we can see, in fact if those of you who have probably read some books on concrete engineering would remember that what we say in those books sometimes is that that mortar should be able to coat the surface of coarse aggregates and the paste by that token should be able to coat the surface of sand and so on.

So, I think we will not get into that so much but yes that is the principle and that is what governs our thought process that the aggregates are suspended in mortar the coarse aggregates are suspended in water that is what makes concrete.

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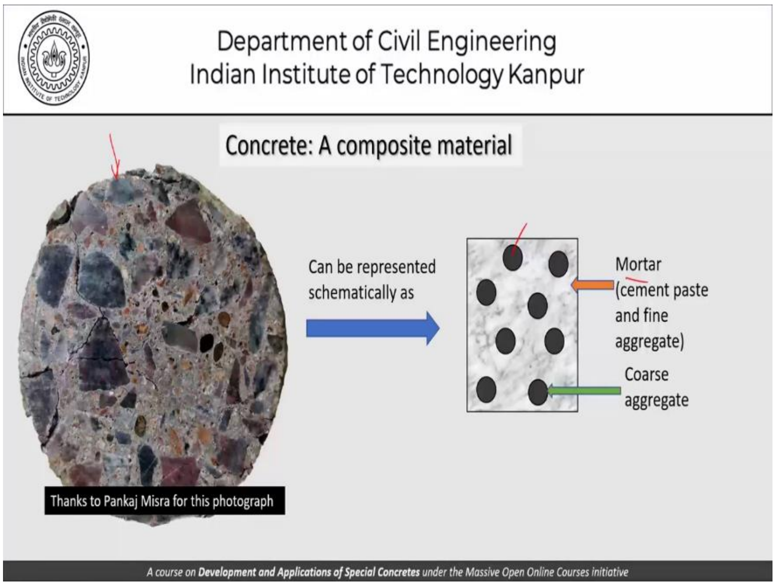

Now, moving forward when it comes to a composite material this picture here that is the concrete can be schematically represented the way it is shown here with aggregates like this and they are suspended in mortar. So, this is what we have talked about that these are aggregates suspended in mortar, having said that of course this is schematic representation and this is a gross simplification these distances and so on.

Do not bother about them, we have taken the aggregates to be spherical do not bother about that either. So, the point is that we want to try to do this discussion for a simple for a specific reason.

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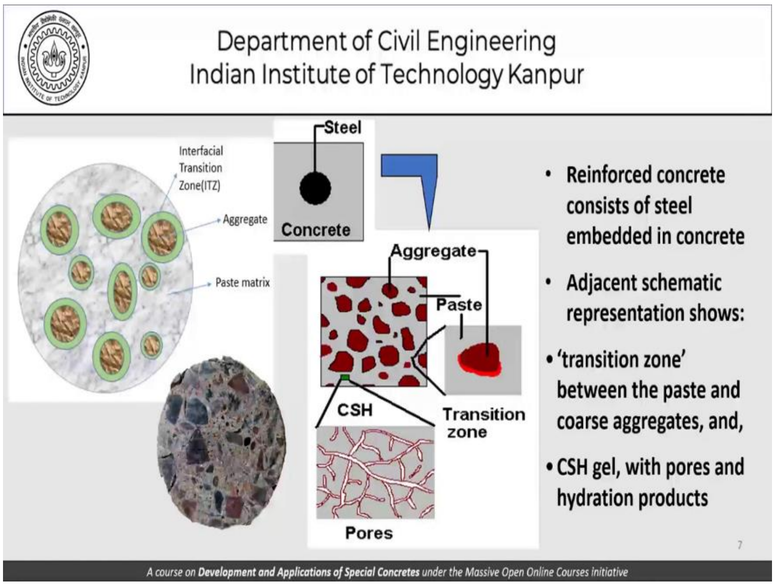

This is how, it goes carrying our understanding or our thought process further, reinforced concrete consists of steel embedded in concrete. So, this is the steel bar this is the concrete around it, this concrete looks like this, which we say that it can be modelled something like this. Now, what I have introduced here apart from the mortar and the coarse aggregate is this green zone around these aggregates and that is called the interfacial or intermediate transition zone that is the ITZ.

Now, we must remember that this ITZ is formed as the concrete hydrates hardens and reaches its final form. To begin with, there is no ITZ the aggregates are mixed together with the mortar and that that is what concrete is but due to various reasons. Let me mention one of them, bleeding is the primary reason for the formation of this ITZ, we will probably talk about it at some point in time.

But yes, that leads to the formation of this ITZ, now this ITZ really means that the properties of mortar here and the properties of mortar here, that is in the immediate vicinity of the coarse aggregate that is somewhat different. Now, what causes it? How much is it different? What is the thickness of this ITZ? Those are things which we need to examine a little bit more detail and I think I will leave it to you to do some more reading.

We will try to discuss it a little bit to some extent in our course here. Now, having said that this adjacent schematic representation shows the transition zone between the paste and coarse aggregates and now if we take a small picture out of this mortar here the main body mortar, this is what it looks like, which means that we have the CHS gel sitting here these are the solid part of our cement hydration products call them CHS.

And, we have these what I have represented like channels, I mean of course there are no channels running inside concrete but yes that is the schematic representation, these are the pores within the hydration products. So, there is this mortar here which has a certain amount of porosity, we know about it we can go back to our previous course and try to discuss that aspect there is a certain amount of porosity which is represented by this kind of pores in this place.

And, trick will be that this is what we are talking about here. So, this is the porosity that we have here what about the porosity in the ITZ obviously the fact that we are talking about ITZ So much, means that this part has its own porosity and this porosity is greater than the porosity in the main mortar, this main mortar means somewhere here this is the main mortar and there is a porosity here.

Why it happens, is because of bleeding the weight shown here cement particles tend to settle down and water accumulates, at the top here near the aggregate, at the bottom of the aggregate, in fact this kind of a phenomenon occurs even in the reinforcing bar. So, this place here water tends to settle leading to some kind of a zone of weakness between the steel bar and the concrete it is a representation of bleeding.

So, ITZ is a form of bleeding it represents bleeding, so that is what we are as far as concrete is concerned, now this ITZ and its formation is actually responsible for these kind of crack propagations that we have, where the crack propagates around the aggregate, we say when we say when it cracks negotiates around the aggregates, what we are really saying is that it goes through the ITZ.

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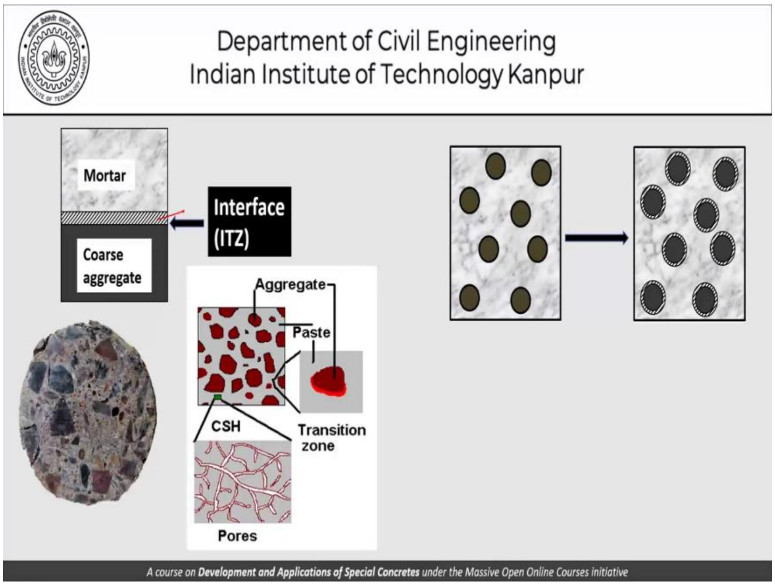

If we look at it a little more schematically, we try to represent all this ITZ as one place here we say that is a coarse aggregate, there is mortar around it and we have this ITZ which has been formed at the interface of the coarse aggregate in the mortar, this is what we are representing. This can be represented something like this and now let us try to understand the phases.

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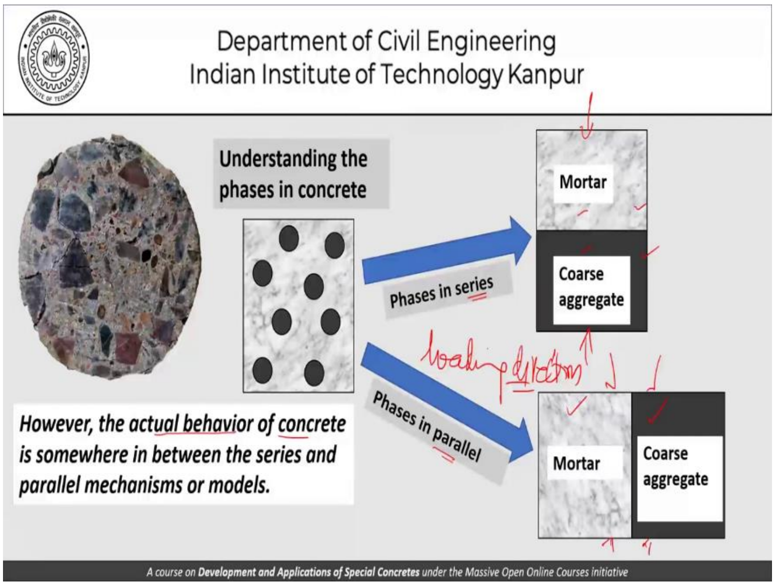

If we try to divide this discussion into phases part of it, we can talk of the phases in series. Now, what the series part of it will come in a minute, this is what it is so here we have mortar and coarse aggregate aligned like this, when it comes to parallel, we can talk of mortar and coarse aggregate align like this. The series and parallel is a nomenclature, which I am using in the light of or considering the loading direction.

So, when we load the concrete whether the mortar and the coarse aggregate are in series that is if you are applying the load like this or they are in parallel. So, if you are applying the load like this so they are both taking the different load transfer mechanisms. This actual behaviour of coarse aggregate, in concrete now you can imagine that this is the concrete that we are trying to model, it is very difficult to say that whether this aggregate is in series or parallel with the mortar around it.

So, if we want to really model it a schematic representation for ease of simplification for being able to do some mathematics with it. It is a combination of the series and parallel models or mechanisms. Let us try to understand this a little bit more.

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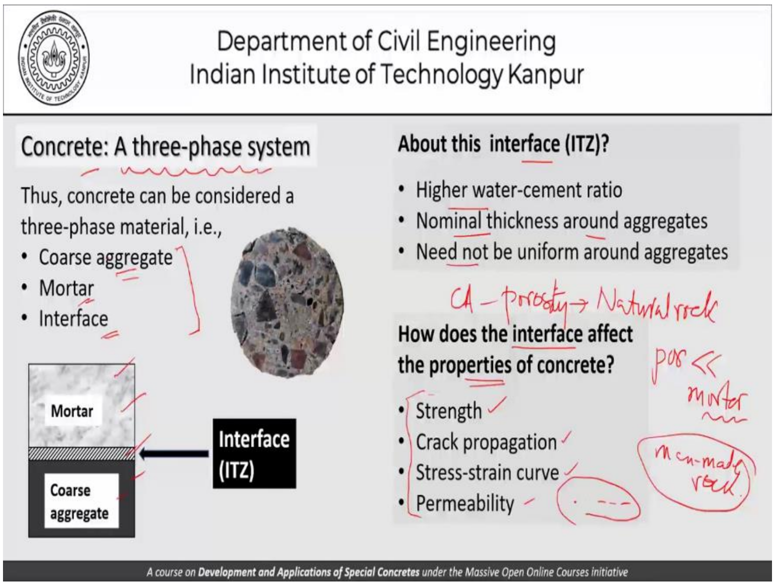

We now have three players in this whole game the coarse aggregate, the mortar and the interface. So, these three fellows they constitute the concrete, so we are trying to talk about it as a three-phase system. And, about this ITZ, it has a higher water cement ratio, it has a nominal thickness around aggregates and of course, it need not be uniform around aggregates. You must remember that this creation of ITZ that kind of model that I represented try to explain it to you, is a gross simplification of the ITZ and the concrete and so on.

So, you try to think about it yourself try to create a model for yourself in your mind and then you will be probably better off. What we have to do as concrete engineers, is to understand how does this interface affect the properties of concrete. Now, what properties of concrete are we talking about? Let us say strength, crack propagation, the stress strain curve, permeability or whatever property you want to have.

So, whatever property you choose to discuss as far as concrete is concerned, we should know or we would like to look at it in the framework of concrete comprising the coarse aggregate, the mortar and the ITZ. We must also remember that coarse aggregates have their own porosity except that they are natural rock most of the time and their porosities are much lower than the mortar that we create.

And, this mortar to that extent when it hardens, so for that matter even concrete, when it hardens is like a man-made rock right. So, if because it is a man-made rock made up of phases the mortar phase has porosity, the interference zone has its porosity and the coarse aggregate has its porosity. So, now which of them becomes the weakest link in the chain that is what has to be determined, when we are talking about modelling, we are trying to understand the impact of the ITZ on the properties of concrete.

Or we actually try to understand or model the properties of concrete and interpret it in terms of the properties of mortar in terms of the properties of coarse aggregate. Having said that let us look at something like this.

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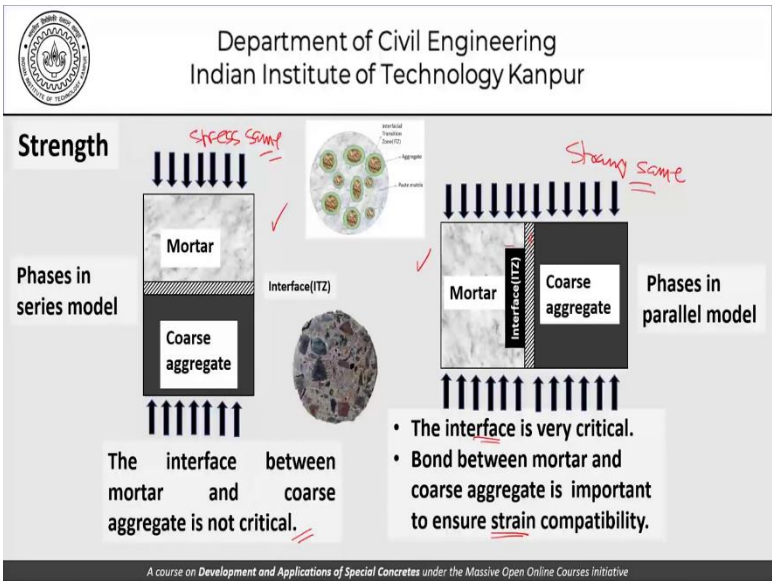

So, this is what you I was telling you we are talking of load application here and load application here. So, these are the two cases, this is what I was calling the series model and this what I was calling the parallel model. Now, in the series model the interface between the mortar and coarse aggregate is not all that critical as far as the load application is concerned I mean because of reasons which I am leaving to you to just think.

We will probably answer them in a minute. In the parallel model, where the faces are in parallel and the interfacial or the interfacial transition zone is located the way, it is located here. There, the interface is very critical and the bond between the mortar and coarse aggregate is important to ensure strain compatibility. So basically, what we are saying is that as far as this load transfer is concerned the strains in the three models or in the three components have to be the same.

And, for that to happen there has to be a good bond here and that is why it is important to have the interface having certain properties, if the interface is weak, the bond is weak and this concrete will behave very differently. As far as this model is concerned the interfacial transition zone or the interface does not play a major role because here the stresses are the same in all the three phases.

So, they will deform differently here they will deform to an equal extent and the rest will follow.

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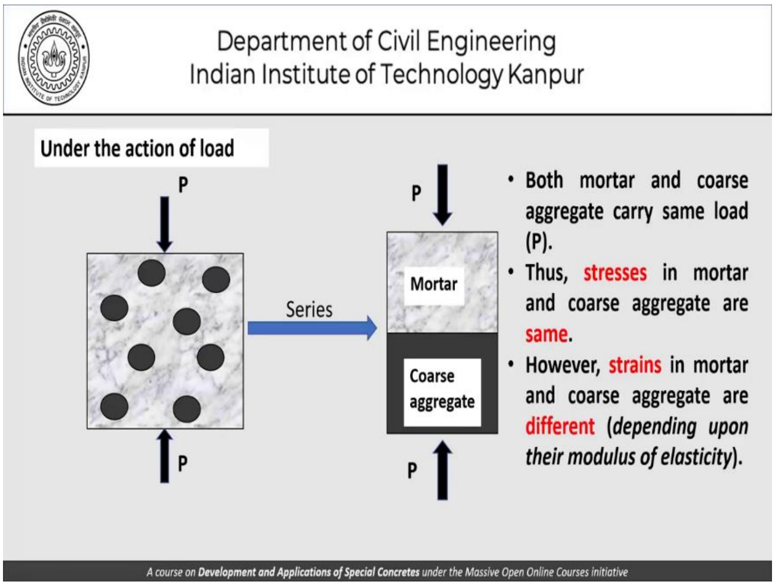

Having said that, the action under load as far as series is concerned is something like this both mortar and coarse aggregate carry the same load P. The stresses in water and the coarse aggregate are the same and the strains in mortar and coarse aggregate are different departing depending upon their modulus of elasticity and so on.

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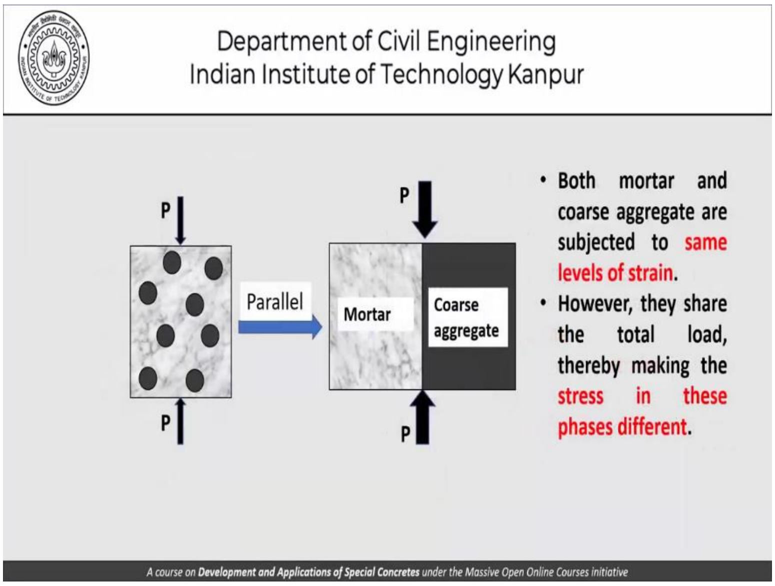

When it comes to parallel, both the mortar and coarse aggregate are subjected to the same level of strain. However, they share the total load thereby making the stresses in these phases different. So that is the kind of impact that the ITZ has on the strength of concrete.

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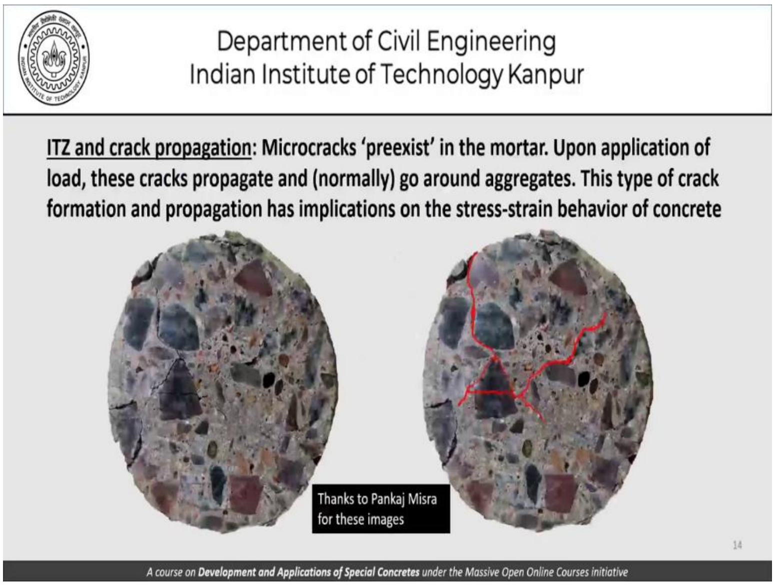

When it comes to crack propagation, it is very clear from the picture that I have been showing you all the time micro cracks pre-exist in the mortar. Upon application of load these cracks propagate and normally go around the aggregates. Now, I have already said that this going around the aggregate really means going through the ITZ. This type of crack formation and propagation has implications on the stress strain behaviour of concrete.

I would like to refer you to an excellent description of the stress strain behaviour of concrete under the action of, of course load given by a book by professor P K Mehta on concrete microstructure and properties, there is an excellent description on how this crack initiation happens? How it propagates through the mortar phase then quickly runs through the aggregate phase and so on. And, why the concrete stress strain curve is the way it is okay.

So, I think I will leave it at that we have talked about it in the previous discussion also in the previous course. We move forward as far as we are concerned.

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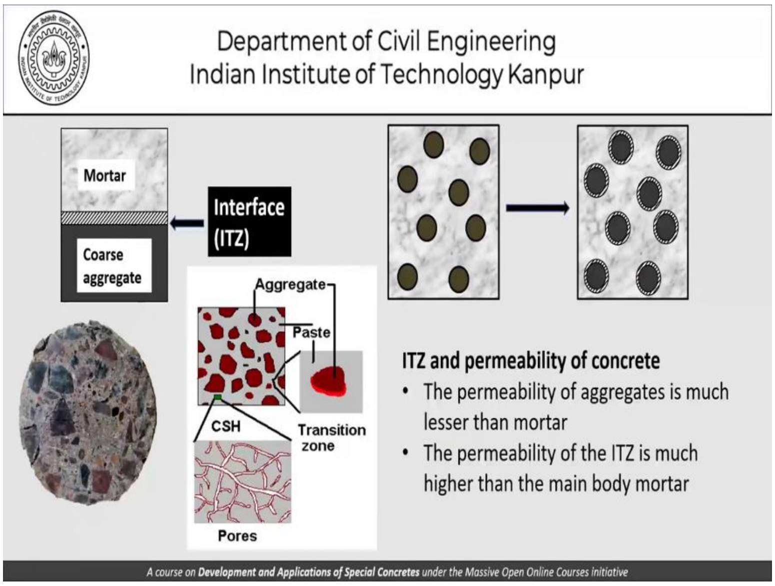

For this course, this is what we have already discussed that the model for concrete is like this it has this ITZ surrounding it. And, this ITZ and permeability part of it is what this slide really wants to show. The permeability of aggregates is much lower than that of mortar, I have already discussed that because these are natural rocks in most cases. The permeability of the ITZ is much higher than that of main body mortar.

The main body mortar is the mortar here and the ITZ is here. So, this is the main body model here this is ITZ here. So, the ITZ porosity is higher than that in main body mortar and this kind of a discussion is what determines the permeability of concrete.

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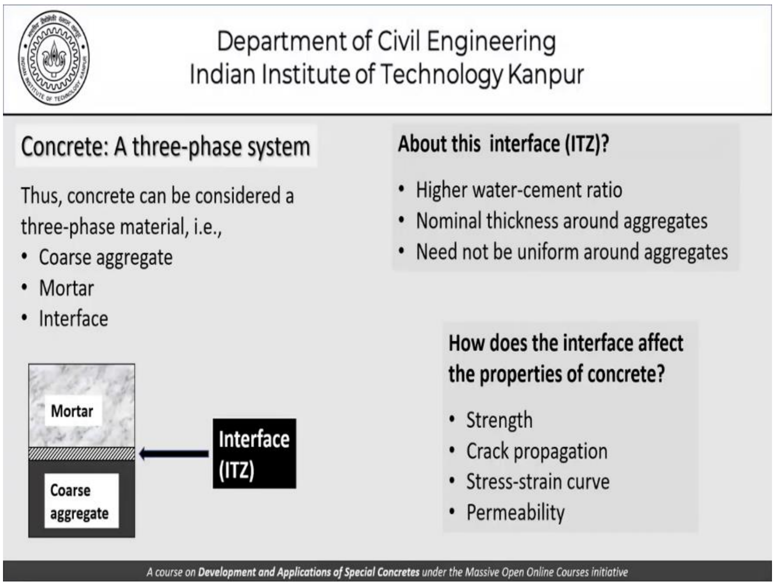

So, as far as our brief discussion today is concerned, we have talked of the concrete as a three-phase material the coarse aggregate, mortar and interface and we have discussed how the ITZ affects the strength, crack propagation and the stress strain curve. The stress strain curve I have not discussed so much, I have just left it to you with a reference, I hope that would be good for you to have an understanding of that and you will be better off with reading.

The document, we will probably post a little bit of information about it in one of our forums. The strength and crack propagation are what we have discussed, permeability we just discussed, is governed by the not so much by the aggregates but by the permeability of the mortar and the ITZ. In fact, this discussion that the mortar governs certain properties, the ITZ governs certain properties, is at the backbone of our understanding that the water cement ratio is a very important parameter that governs the properties of concrete.

We do not control or we cannot really control the porosity or the strength of coarse aggregates but the water cement ratio is what we can control and that more or less governs our or controls the properties of the mortars that we use. So, the fact that we always talk about strength depending on what the cement ratio really means that we know that the water cement ratio and the mortar therefore is the weakest link in the chain.

And, within that system, the ITZ is actually the real culprit, the real weak chain or the real weak link is the ITZ. So, if we are somehow able to control the properties of ITZ we are able to control the formation of ITZ, the thickness of ITZ and so on that happens through a control of bleeding in concrete. Then, we will probably be able to create a much better concrete because then we will be able to utilize the mortar's strength to the maximum.

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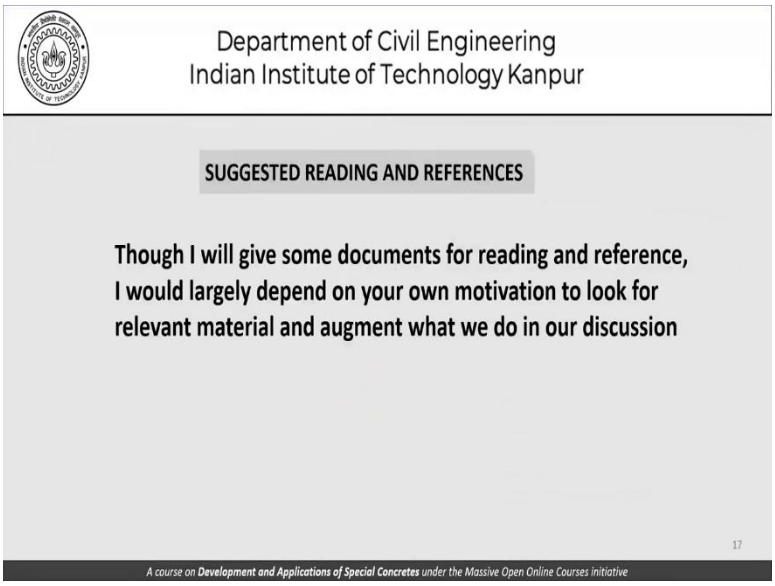

I have already mentioned that we will be giving some documents to read and for reference but I would largely depend on your own motivation as far as this course is concerned and the internet is an excellent source of information and with the kind of discussion that we are having in the course and possibly will augment that in the forum. You will be very well informed if you do your own readings.

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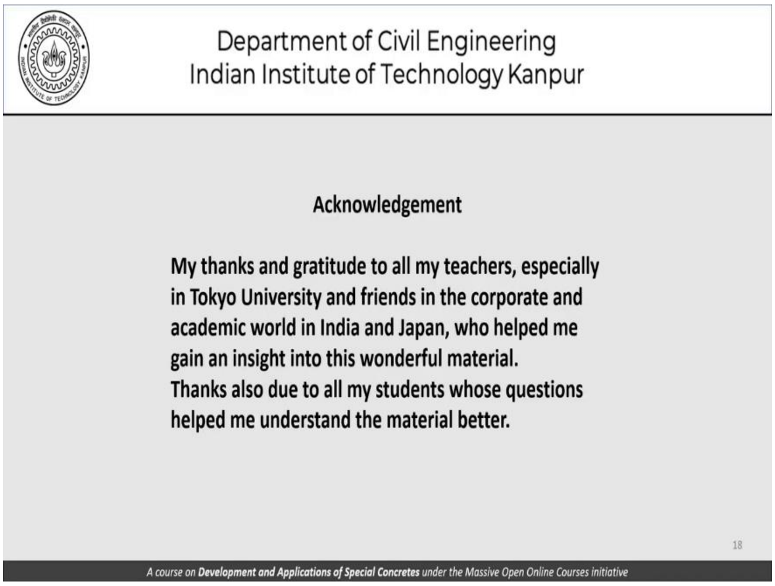

As usual, I would always use a slide for acknowledgement in my presentations to express my gratitude to my teachers and my friends and my students, who have helped me understand this material better.

Thank you and I look forward to seeing you in another class.