Development and Applications of Special Concretes
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Lecture 01
Review of Normal Concretes Some Starting Points

Hello and welcome to this NPTEL MOOCS course on development and applications of special concretes. My name is Sudhir Misra and I am from IIT Kanpur. Beginning this discussion today we will start with a review of normal concretes and I have called this lecture, some starting points, because this will basically set the ground or set the starting points for some of our discussions, so that we are all on the same page.

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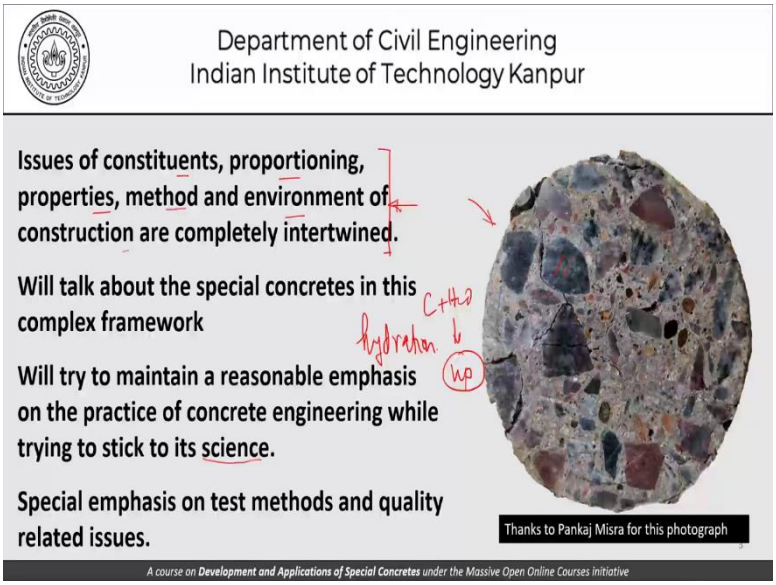

Now, as far as concrete is concerned, the issues of the constituents of concrete, the proportioning of the different ingredients, the properties that we get whether it is in the fresh state or the hardened state, the method and environment of construction are completely intertwined. They just depend on one another and we have to keep all these things in mind when we try to build a concrete structure.

Now, this picture here is that of a concrete core and the inside of it. So, you can see some coarse aggregates, you can see some finer aggregates, you can see some cracks. We will talk about this in much greater detail and I would like you to keep this picture at the back of your mind all the time, it is a very useful picture helps you understand concrete the complexities of it, the beauty of it and so on.

We will talk about special concretes in the complex framework of this interdependence that we have. For normal concretes, we have to understand a few things and that is what we are trying to do in this week or possibly a part of the next week when we will try to do basic concrete engineering. And, then go on to develop our concepts into special concretes. We will try to maintain as far as this course is concerned a reasonable emphasis on practice of concrete engineering while we try to stick to its science.

Now, what is science? And what is engineering? Science is basically a study of whatever is seen, for example hydration. Hydration is nothing but the reaction of cement with water to give you hydration products. Now, this is a science there is a science involved in hydration, there is the chemistry of cement, that is the chemistry of hydration, that is the thermodynamics of hydration, there is a rate of hydration, it depends on temperature, it depends on a lot of other things but the engineering part of it is, how do we use the scientific knowledge in real life.

So, we will keep track of this real-life scenario very, very closely as we go along in this course. The emphasis will be on test methods and quality related issues this is something which is very important because as we move towards special concretes. We really need to have special testing methods, we need to have special protocols for quality control because only then, we will be able to maintain the quality, we will be able to do good quality construction using special concretes, whether it is fibre reinforced concrete or anti washout concrete or roller compacted concrete or whatever it is.

So, we need to understand what is different in those concretes from the normal concrete and then try to figure out, what are the special methods that we need to adopt what are the special things that we need to do in order to carry out the right kind of tests, have the right kind of protocol for quality control in place.

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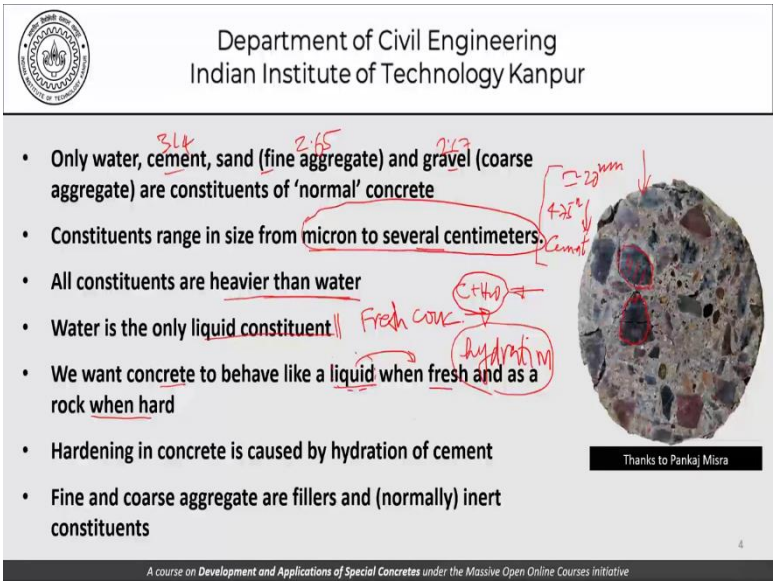

Now, as far as normal concrete is concerned the only constants that we will consider is water, cement, sand which is fine aggregate and gravel which is coarse aggregate. Constituents in

concrete as you can see range from microns to several centimetres. This picture, I told you is a very useful picture and I will probably keep referring to it all the time. So, you can see this. So, this aggregate here which is a coarse aggregate.

This aggregate also coarse aggregate these aggregates are of the order of maybe 20 millimetres, whereas sand is typically about 4.75 millimetres and below cement is much finer than that. So, all these solids mix together, water added to them create a composite material, which is expected to be homogeneous and this is what this material finally in the hardened state looks like. That is something which is very important to understand that the constitution of concrete has particles which range from several microns or millimetres to several centimetres.

It does not go beyond 10 centimetres and 20 centimetres, it is about 2 to 3 centimetres in the normal case, of course we have 40 mm aggregates and we have larger plums which are used in special concretes, but that is something which is beyond the normal. All these constituents, whether it is cement, sand or coarse aggregated, all of them are heavier than water. So, this is a very important assumption, or that is the very important point that you need to keep in mind.

That is all these particles whether it is cement or sand or coarse aggregate, they will all sink in water very clearly the specific gravities for cement, for example is 3.14 or something of that order the coarse aggregate and fine are aggregates is about 2.65 or 2.67, whatever those numbers are but they are very clearly heavier than water. So, that is something which you need to bear in mind all the time.

Water is the only liquid constituent, that is water is the only constituent, which can cause the concrete to flow, this is something important to appreciate absolutely remember, why we are trying to understand the properties especially of fresh concrete because in fresh state, we want the concrete to be flowing. Now, how does it flow, the constituents should be such that it allows them to flow or allows the concrete to flow and that can happen only with water because that is your only fluid involved.

As far as, we are concerned or as far as what we want from concrete is concerned, we want the material concrete to behave more or less like a liquid when fresh and as a rock when hard. Now, there is this transition from the liquid phase to the solid phase the heart and face and so on as we go along and this is the result of hydration. So, this is the physics that you cannot forget, no matter what special concrete we are talking about, the fact that in the fresh state we want some amount of fluidity.

It depends on what kind of application you have in mind, whether you want to do very stiff concrete fine in that case you do not want very liquid or very flowing concrete but in certain cases you do not want a very flowing concrete with neither case the cement and the water are

the only reactive components. These aggregates whether they are coarse aggregates or fine aggregates they are only fillers and they only are there to complete the volume to provide the volume that is involved that is one part of it.

They of course also contribute to strength, so do not hold me that you do say that I told you that aggregates do not contribute or they are not important when we talk about strength of concrete no that is not true. Having said that, as far as hydration is concerned, as far as the reactivity is concerned, as far as the chemistry is concerned or the chemical changes involved is concerned that happens only with cement and water.

The aggregates more or less always remain as they are. Hardening is caused by hydration of cement, that is what I just talked about fine and coarse aggregates are fillers and are normally inert constituents. So, as far as this concrete is concerned the only thing which we need to bother about as far as the chemistry is concerned is largely the cement and water. But, as far as other properties are concerned of course we are concerned with the properties of coarse aggregates not only the densities, the size distribution, the shape, and so on.

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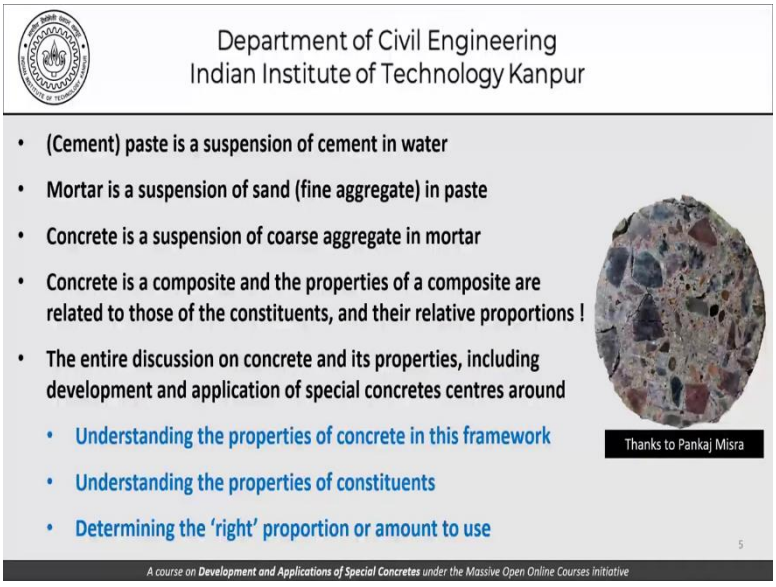

Another fundamental aspect, cement paste is nothing but a suspension of cement in water. So, that is one thing which you remember, that we take water and if we add cement to it we get what is called paste and this paste can be considered as a suspension of cement in water. Once we get this paste then what we do we add fine aggregate to it and what we get is mortar. So, mortar can be considered a suspension of sand in paste.

Concrete, is a step of head and that is really the suspension of coarse aggregates in mortar. In other words, if you have water which you started with a certain property in terms of flowing, in terms of viscosity or whatever it is, then if we add a certain amount of cement to it let us say

the flowability reduces, how much it will reduce? That will depend upon the amount of cement you add to it.

Having said that, paste is still a reasonably flowing material, could be a reasonably flowing material depending on what is the water to cement ratio that you use, those of you have done tests of standard consistency or setting time of cement you know that at about 30% what kind of paste that we have. If you have 30% water cement ratio you have a reasonably stiff paste. But, if you have 40% it becomes a lot more flowing, but it is much less than that of water.

So, now paste has a certain amount of fluidity which is less than that of water. Having said that, now, once we add sand to it, we get mortar, and the fluidity of mortar is even lesser compared to paste. And, how much the modification happens depends on the amount of sand, the properties of sand, and of course the initial fluidity of paste. You go that step one once again, and try to create the fluidity or study the fluidity of concrete.

When you modify the viscosity or the flow ability or the flowing properties of mortar by adding coarse aggregate to it, so there is this 3-4 phase changes that you make when you try to get or at the end of it which you get concrete. So, you start with water which is a flowing material, you add cement to it you get paste which is less flowing, then you add sand you get mortar which is even less flowing.

And, finally you add coarse aggregate and you get concrete which is even less flowing. Therefore, in other words if you want concrete to have a certain amount of flow ability all that you have to do or what you have to do is to somehow increase the water content because you cannot increase the viscosity or the flow ability of water and that something which is given to you, you really normally do not do it.

It is very difficult to do, therefore you have to increase the amount of water, that is why, I said the proportioning is very much related to the kind of properties that you want. And, then you try to add certain amount of cement, get the fluidity in paste, get the fluidity in water, and finally get the fluidity in concrete. Now, concrete is a composite and the properties of the composite are related to those the constants and their relative proportions.

This is something which will be clear if you follow this line of argument, then if we want a certain property in concrete and what we want is how much sand do we put in? How much cement do we put in, depending on that you will get the properties of the composite. It is not only the properties of the constituents not solid not only the properties but also their relative proportions. The entire discussion on concrete and its properties including the developments and application of special concrete; centres around understanding the properties of concrete in this framework.

That is the framework of cement being added to water to get paste sand being added to paste to get mortar and coarse aggregates being added to mortar to get concrete. So, this is how we will approach this subject. Understanding the properties of the constituents this is something which will not do greatly in this course we will assume that you know how to carry out the tests and how to determine the properties of the constituents whether it is sand or it is cement coarse aggregates and so on.

Determining the right proportion or the amount of the use. Now, the right part of it is something which will be very specific to certain applications and therefore what we basically be doing is trying to study the impact of varying proportions. If you add this if you subtract that if you add more of that or reduce some of this how does the property of the material change. Now, this picture gives you exactly this kind of a framework.

Now, here you can see that these coarse aggregates can indeed be looked upon as suspended in some form of mortar of course it is not possible to see the fine aggregates but you can imagine that this analogy of coarse aggregates being suspended in a pool of mortar can be extended to fine aggregates being suspended in a pool of paste and cement being suspended in water. I would like you to do that experiment and try to convince yourself that this is how we can understand the properties of concrete very, very clearly and possibly simply.

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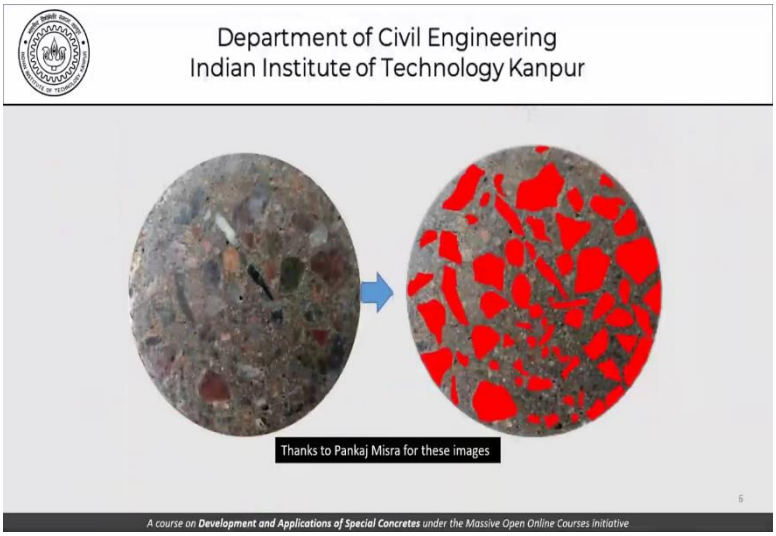

Here is a picture where this concrete slice has been transformed into this image now what are the conclusions that we can draw as far as this image is concerned. This image has been drawn primarily to show you the fact that coarse aggregates are indeed, a suspension in mortar. So, you can see that the coarse aggregates are suspended in mortar. Now, what does this word suspension imply, the word suspension implies that the coarse aggregates are separate from each other.

What does this separation really mean, we will try to examine this business of separation and its implications on different things shortly? This is not the type of material where the coarse aggregates are in contact with each other and there is a certain amount of void here which is filled with mortar? No. The coarse aggregates are suspended they are separated from each other while we come to that picture or why we come to that part as an assignment just try to think, how will this material behave under load application?

Now, obviously once load is applied then if the particles are in contact and if the particles are not in contact how will the load transfer be different? Let us try to think about it, we will answer this question possibly today or maybe subsequently in one of the lectures but just think about it. Now, the issue of constituents proportioning properties, methods of construction is closely intertwined this is something which we have already stated several times and is being emphasized once again.

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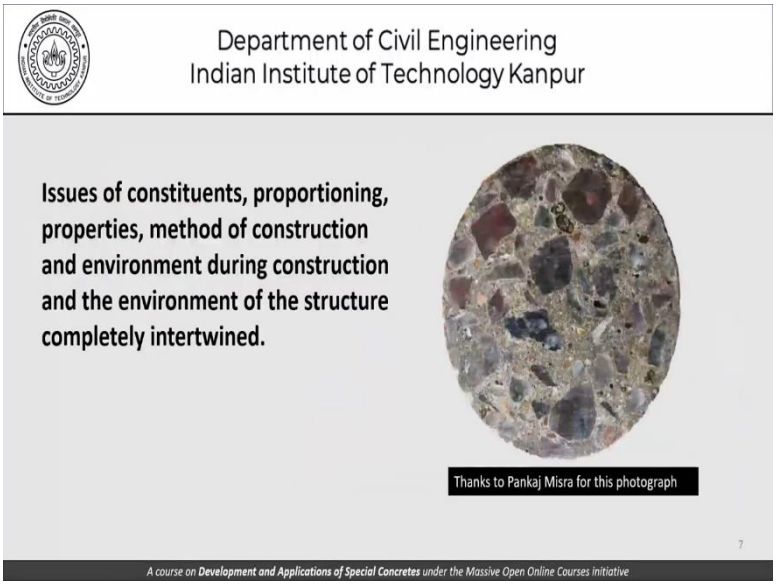

We will talk about special concretes in this complex framework. Let us try to commence our discussion on that now.

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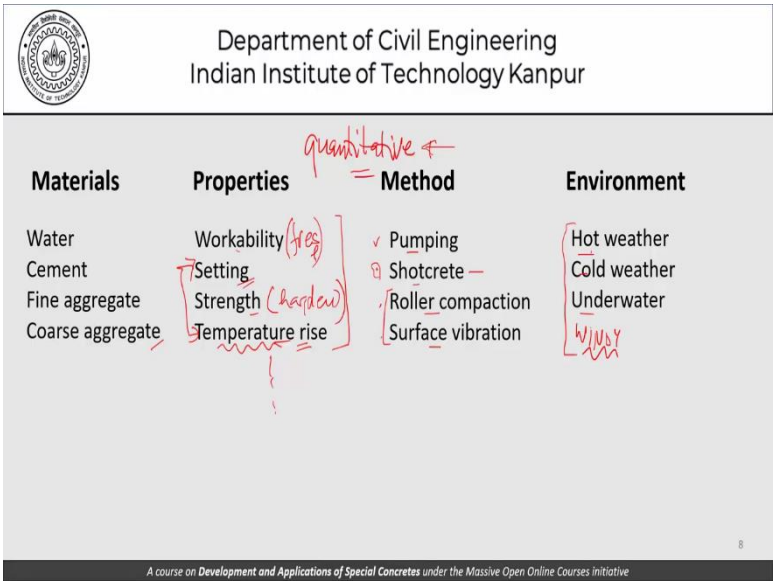

As far as, materials are concerned, I have already told you that will talk about water, cement, fine aggregates and coarse aggregates as our basic constituents. Now, what are the properties that we talk about, we talk about workability, setting, strength and temperature rise. There could be other properties, that we talk about but let us confine our attention so far or for the time being into these properties.

Now, workability is something which we are concerned with in the fresh state, strength is something which we are bothered about in the hardened state and the setting and temperature rise are somewhere in between, I mean setting is a process by which we say that okay from the fresh state it is moving towards hardened state and how much time does it take is it rapid setting or is it not traffic sitting how much setting time do we need in order for a particular application to be completed.

In repair works for example you would like the setting process to be fast, in certain other processes you really do not care because they let things take their own course of hydration and so on. As far as temperature rise is concerned this is complex and it is related to this idea of setting and sometimes you may say that ok this amount of temperature rise is acceptable, sometimes you may say it is not acceptable and so on.

So basically, what we must understand is there are these properties that we have as far as concrete is concerned and we need to proportion our materials possibly choose our materials appropriately. And these properties have to be also chosen keeping in mind what will be the method of construction. So, here I have listed just a few pumping of concrete whether it is involved or not whether you are trying to do something like shortcreting, you are doing roller compaction, you are doing surface vibration, what are you trying to do?

If you are trying to pump concrete, obviously you would not like to have very dry concrete. If you are trying to do shortcreting, what are the limitations or constraints under which you will work, you may possibly not be able to work with very large coarse aggregates and so on. You may like to have a concrete which sets very quickly because shortcreting is a metal process by which you gunite or you deposit concrete under pressure that concrete could rebound.

So, before this rebound and so on happens you would like the concrete to set so that all this rebounding is stopped. Similarly with roller compaction, similarly with surface vibration there are constraints, there are special requirements that are imposed on materials, one thing I would also like to point out that for that method, when you say that okay we need this property or that property it is always important to emphasize and always prescribe what is the property that you want and what is the quantitative method of evaluating it.

Unless you do that, sometimes I understand of course that it is not possible to do it but keep that in mind that unless we are quantitative in defining our properties, defining our specifications as to what we want, we will not be able to have a very clear picture and there will be confusion among concrete engineers the clients want something the contractors provide something else and so on.

We will try to keep this aspect in mind, when we discuss this with issue of special concretes especially in this course and that is what I meant, when I said we keep the emphasis on practice. As far as environment of placement is concerned, we could be talking about hot weather or cold weather, we could be talking under water, we could be talking windy conditions.

So, what happens is that depending on what kind of weather or what kind of the environment in which concrete is being placed there are certain methods, which are acceptable certain methods, which are desirable, new methods need to be developed and then that takes us back to properties and that takes us back to materials and the proportions. So, that is what is the complex relationships between all these aspects? Or all these dimensions of concrete let engineering.

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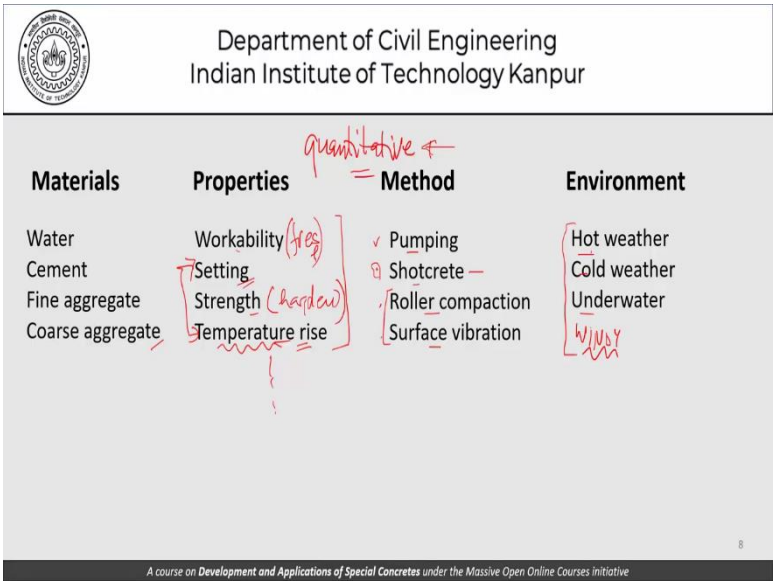

Take an example of fibre reinforced concrete. What do we do in fibre reinforced concrete we add short random fibres to normal concrete? Now, that gives us fibre reinforced concrete but is it as simple as that what happens is that it gives us increased ductility and improved post cracking behaviour. We will examine this aspect as we go along when we spend some more time on fibre reinforced concrete.

But yes, it stands to reason that ok if you have a concrete block and I have a fibre sitting here this crack will not so easily propagate there will be a fibre which will arrest this. So, in one sense fibres act as short reinforcements much like normal reinforced concrete except that a normal reinforced concrete we do not talk of fibres, we have normal reinforcement that is if you have a beam, we have a reinforced concrete means this is a long steel bar.

And, this steel bar prevents any flexural crack from propagating. So, this is something which we know from our understanding of reinforced concrete having said that fibre reinforced concrete is basically saying that okay here in this part of the concrete or this part of the concrete or the concrete in this beam we will have short fibres added to this concrete in order that whatever cracking happens here is arrested.

And, of course it has implications because the concrete will be here as well, it will have implications in terms of making the flexible cracks smaller, distributing it differently and so on and so forth. So basically, what we get is increased ductility and improve post locking what we get is increased ductility and improved post cracking behaviour. But what it implies is increases water and mortar demand.

This concrete that is fibre reinforced concrete has to have a higher mortar content. We will talk about it more, when we come to proportioning but we can talk in terms of mortar content of a concrete and for fibre reinforced concrete, we need more water content that means, we need to

have less coarse aggregates. So, we cannot have the same kind of coarse aggregate content in fibre reinforced concrete as normal concrete.

And therefore, to say that fibre reinforced concrete is simply short random fibres added to normal concrete that has to be taken with a pinch of salt because you just cannot take normal concrete add some fibres to it and hope that the properties of it will not be modified. The addition of fibres completely modifies the properties of fresh as well as hardened concrete. Similarly, if we talk of roller compacted concrete, the concrete that we need is very stiff and needs to be placed in layers and compacted using surface vibratory rollers.

What you need there is minimum water and fines, in other words we have to have or we go with large volumes of coarse aggregate. How do we do the sampling for strength? How do we quantify the compaction? What should be the maximum size of aggregate these are questions, which we need to encounter, and we need to answer if we are using roller compacted concrete.

Of course, to make a long story short basically what you are trying to do is that, if I want to cast a concrete which is having a certain amount of height here what we do is we cast that concrete in layers. And as we cast each layer, we have a vibratory roller down on it and that compacts this concrete. So, this vibratory roller that we use should compact this layer of concrete and then we go to the next layer and this layer of concrete gets compacted and so on.

So therefore, the issue of what should be this height, what should be the thickness of a layer, what should be the properties of this concrete in order that this roller compaction is effective over this depth. So, these are all issues which are related to one another that is what needs to be resolved. As far as sampling for strength is concerned the issue is how do we take samples from here.

How do we take normal samples? We take normal samples by taking cylinders or cubes from the concrete that comes to site can we do that here? The concrete that is being brought to site can we just take that sample test its strength as usual will that be a fair way of doing it just think about it, we will probably answer this question as we go along in this course.

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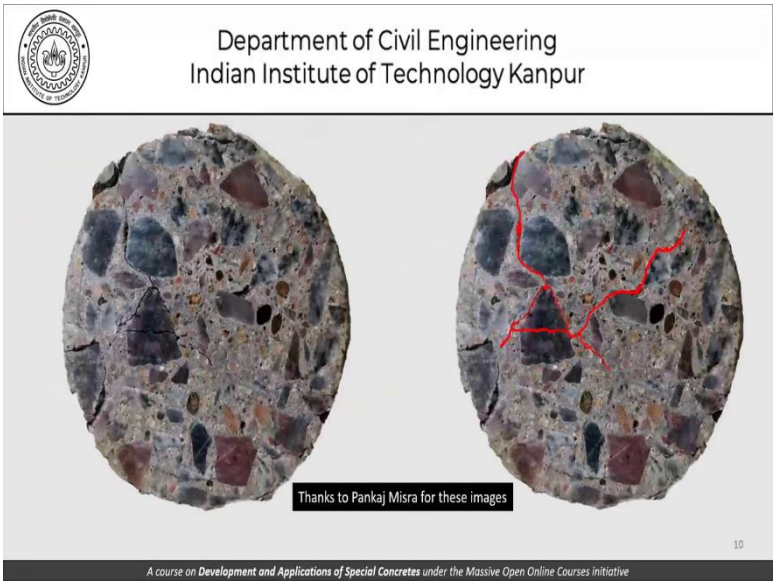

Now, let us talk about crack propagation load carrying mechanism as far as concrete is concerned. Now, here this picture again has been transformed into this picture with the cracks which you can see here being mapped using this red pen right. So, what do you see here that upon load application this crack goes like this I do not know where it started I mean that is not the point but the crack goes through this phase.

Now, this phase is the mortar phase and very rarely do you see cracks going through the aggregate. Of course, here is an exception here we have the coarse aggregate has cracked. So, this is something which you need to clearly keep in mind that something very interesting here also whatever crack you see is all around the aggregate this is all around the aggregate this goes around the aggregate.

So, this is something you keep in mind that when you talk about the strength of concrete what is happening is strength and cracking, they are related right. So, now since they are related and crack propagation is taking place through the mortar that really gives credibility to our belief that strength is related to water cement ratio. Now, what does what does cement ratio do water cement ratio is the parameter that governs whatever paste you used.

And, whatever mortar you used so that really is an important issue and you see the cracks are going through this the fact that the aggregates rarely crack, normally they do not crack and cracks go around the aggregates that happens because of the type of aggregates that you use. I am not going to talk about it more than that only later we will talk about it. Just think about this issue and we will come back to it later.

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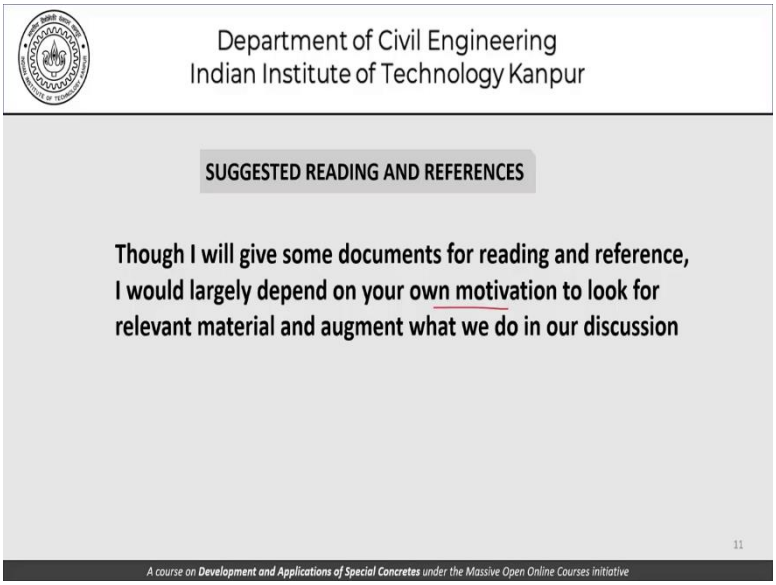

As far as reading is concerned, I have already told you that, I would depend on you and your self-motivation to learn in this course. We will try to give you some reading materials and references but try to do your own search try to create a model for concrete in your own mind the properties of concrete in your own mind. And that will be truly a learning experience that was something which will hold you in good stead all the time.

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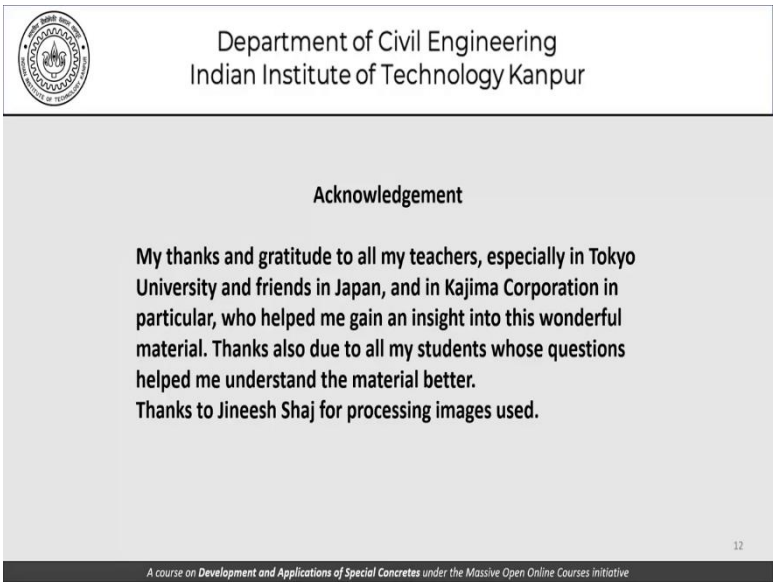

And, I of course have already said this in the introductory video, I am very grateful to all my teachers especially in Tokyo university and my friends in Japan, the corporate friends in Kajima corporation and other industries who have helped me gain an insight into this wonderful material. I hope some of that information some of that models or images that I have, I can successfully communicate to you through this course, thank you.