Hydration, Porosity and Strength of Cementitious Materials
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Lecture - 20
Mass Concrete

Welcome to this 20th lecture titled mass concrete, in the series of lectures covering hydration porosity and strength of cementitious materials. This is our second lecture closely related to the previous one where we dealt with heat of hydration of cement and related issues.

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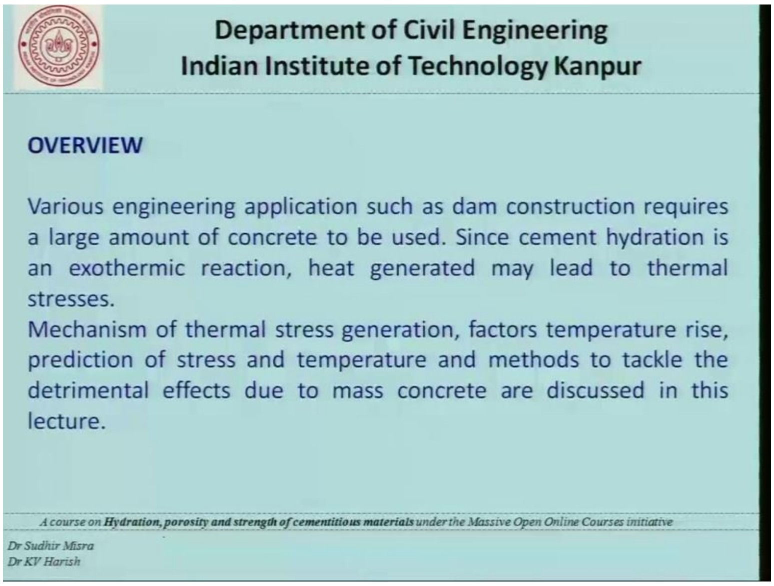

Now, here is the overview of what we will talk about. Various engineering applications such as dam construction requires a large amount of concrete to be used. Since cement hydration is an exothermic reaction the heat generated may lead to thermal stresses. In this lecture we will discuss the mechanism of these thermal stresses and how they are generated factors that affect the temperature rise prediction of stresses and it is temperature and methods to tackle the detrimental effects in these cases.

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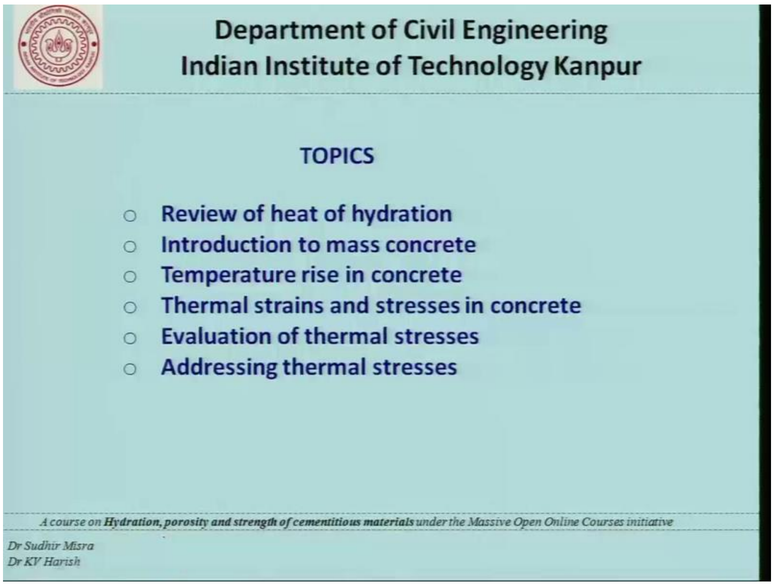

The discussion that we will have today will be briefly a review of the heat of hydration from the last class. Introduction to the subject of mass concrete it is definition and so on. The whole idea of temperature rises in concrete thermal stresses and strains in concrete evaluation of thermal stresses and how do we address the problem arising out of thermal stresses and mass concrete

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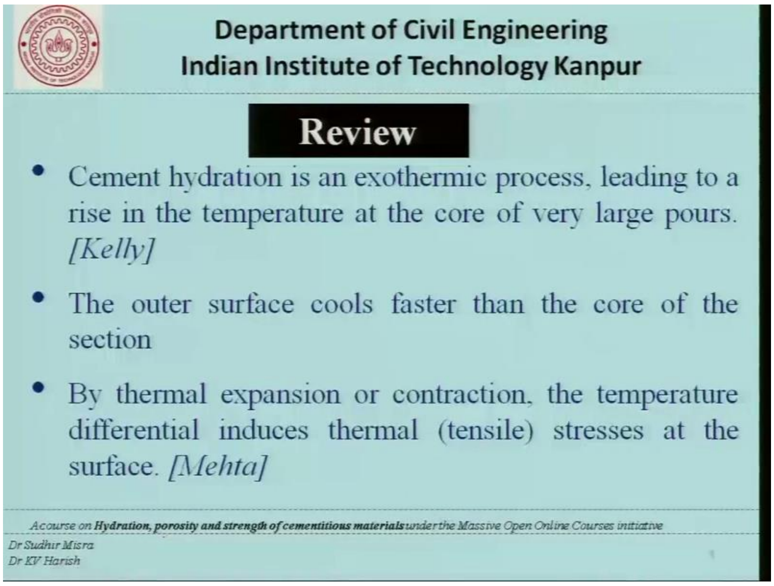

Now, coming to a review of what we have already done we know that cement hydration is an exothermic process leading to rise in temperature at the core of a very large pour.

And in those cases the outer surface cools faster than the core of the section you will recall that in our discussion yesterday in lecture 19 we talked about 2 issues. The heat evolution and the heat dissipation, so if the dissipation is not good enough for whatever reason there will be temperature rises especially in the core. The surface of concrete tries to remain in equilibrium with the environmental temperature by thermal expansion or contraction the temperature differential between the core and the surface induces thermal stresses which are tensile in nature and that is what we will study today. And since concrete is essentially a material which is weak in tension this introduces cracks in concrete which are referred to as thermal cracks.

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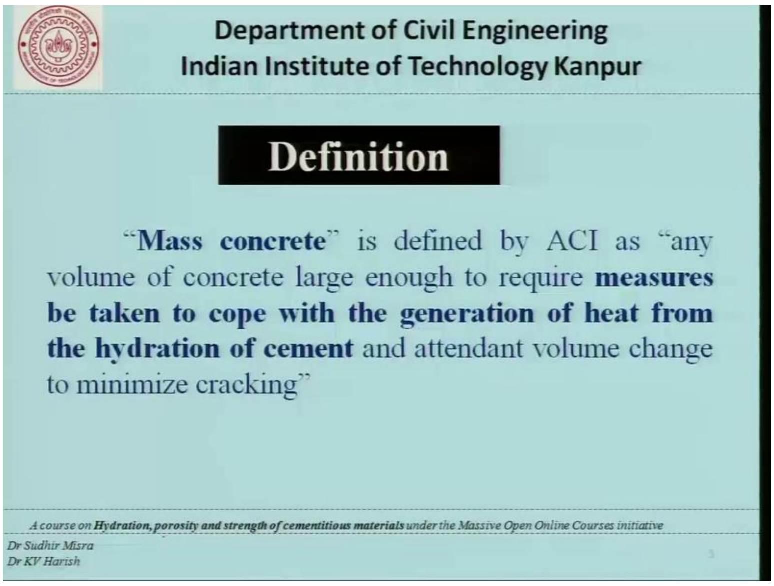

Now, coming to the definition of mass concrete the ACI or the American concrete institute has defined it as any volume of concrete which is large enough to require measures to be taken to cope with the generation of heat from the hydration of cement and attendant volume changes to minimize cracking. This definition; obviously, makes it clear that is not only the volume of the pour, but also other factors which will make it important or imperative for the engineer to consider a particular pour of concrete as mass concrete or not.

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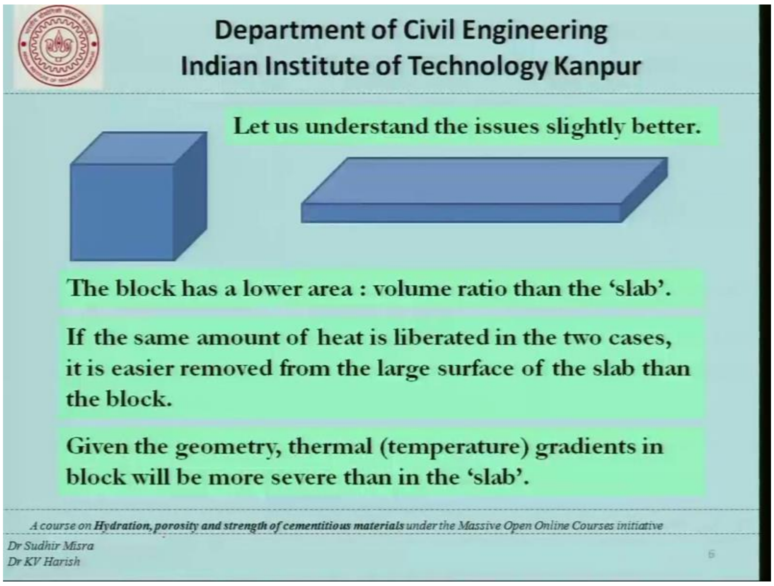

Now, let us understand these issues are little better let us consider these 2 shapes or 2 geometries in which the concrete is cast. One is the large block and the other is a slab may be of the same volume. Now the block has a lower area to volume ratio than the slab, the slab has a much larger area.

Now if the same amount of heat is liberated in the 2 cases it is easier to remove the heat from the large surface of the slab than in the block. Given the geometry the thermal gradients in the block will be more severe than in the slab. So, essentially what is being said is that is the volume of the 2 pours is the same the amount of heat generated in the 2 cases will be the same; however, when it comes to dissipation the dissipation is largely related to the surface area. And since the surface area of the slab is more than that of the block the dissipation is easier in the slab. Further the distance here is much smaller than the distance here. And therefore, the chances of a thermal gradient developing through the length of the slab are much smaller than the thermal gradients developing over this half-length.

So, these are the kind of considerations which become important when we talk about temperature rises.

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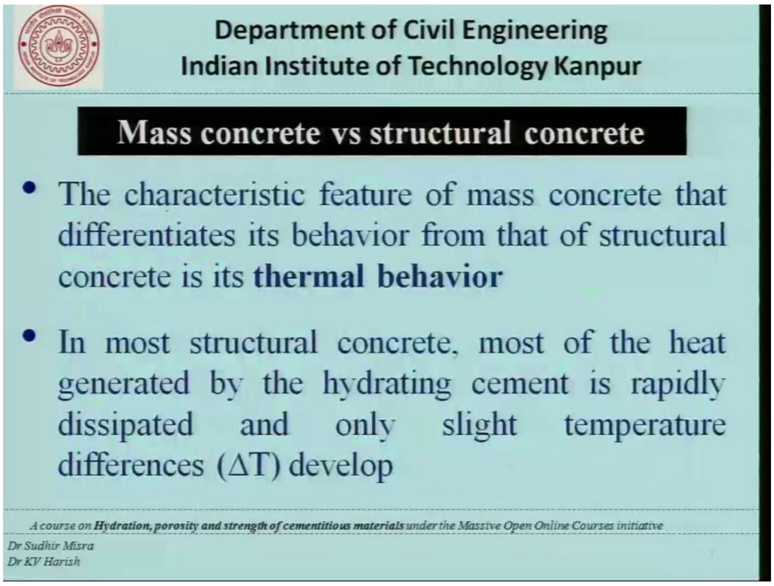

Now, what slightly differently if we compare mass concrete with structural concrete normal structural concrete. The characteristic feature of mass concrete that differentiates it is behavior from that of structural concrete or normal structural concrete is it is thermal behavior in most structural concrete most of the heat generated by the hydration of cement is rapidly dissipated, and only slight temperature rise is expected or arises and therefore, with most of all normal construction we do not really mean to bother about thermal stresses and the heat of the hydration of the cement.

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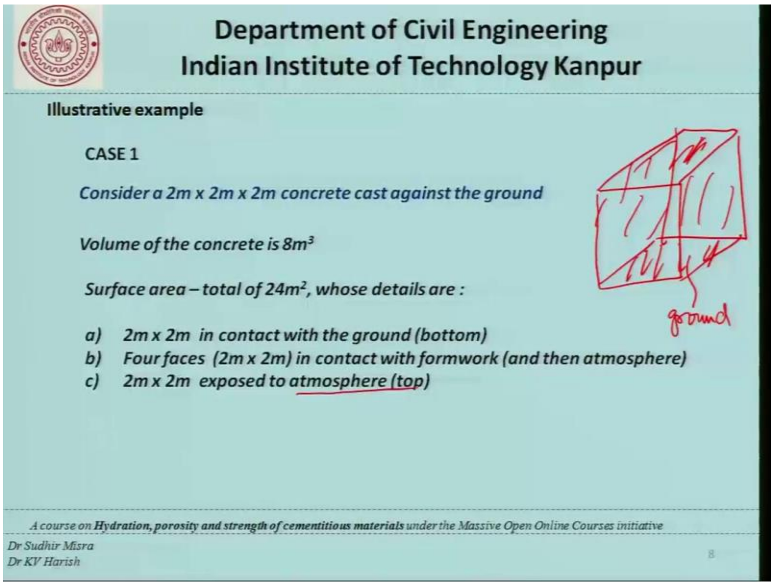

Now, to take an illustrative example let us consider a 2 meter by 2 meter by 2 meter concrete block which is cast against the ground. This volume of concrete is 8 cubic meters and the tools surface area is 24 square meters. Now what we have as detail is there will be a 2 meter 2 meter area which will be in contact with the ground, and 4 faces 2 meter by 2 meter by each in contact with the formwork and then the atmosphere. Basically what we will be doing is we will be casting a block like this and the bottom here will be in contact with the ground and these 4 faces will be having formwork and atmosphere outside. And one 2 meter by 2 meter face here on the top is the one that will be exposed to the atmosphere.

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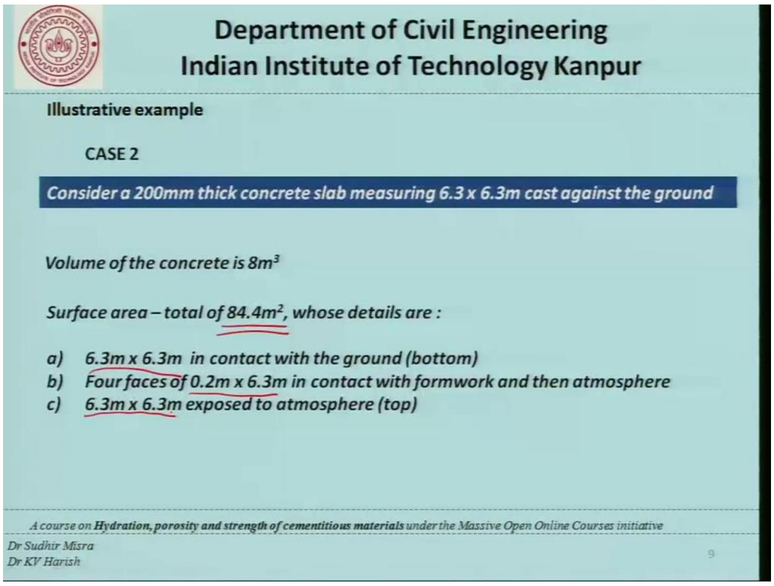

Now, as against this if we consider a situation where a 200 mm thick concrete slab measuring 6.3 meters and 6.3 meters is a guess 6.3 meters and 6.3 meters is cast against the ground the situation will be the volume of the pour will be the same 8 cubic meters and the total area will be 84.4 meter against 24 meters that we show last time in this case 6.6 into 6.6 will be in contact with the ground 4 small faces of 0.2 into 6.3 will be in the contact with the formwork and then will be atmosphere and a 6.3 into 6.3 will be exposed to the atmosphere at the top

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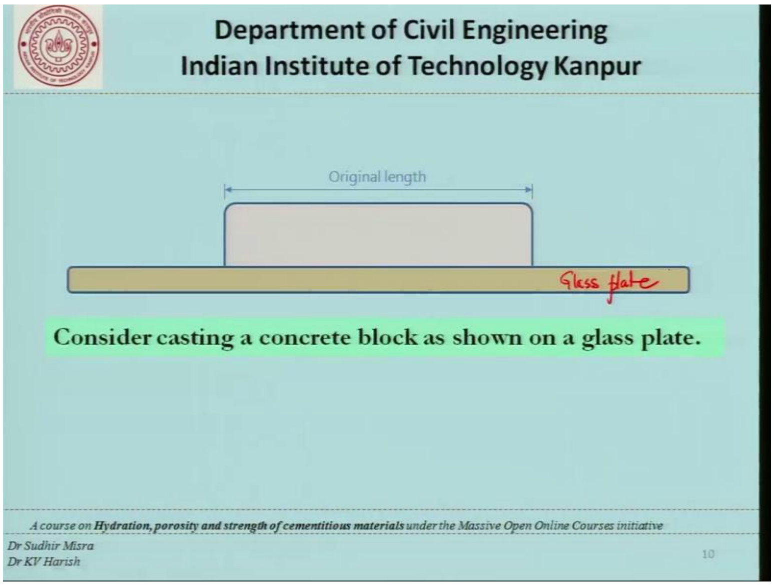

If we now look at a situation like this as a module with say the concrete is cast on a glass plate. So, this is a glass plate and the white is a glass plate is something which will become clear very soon. And if this is the original length of the concrete which is cast.

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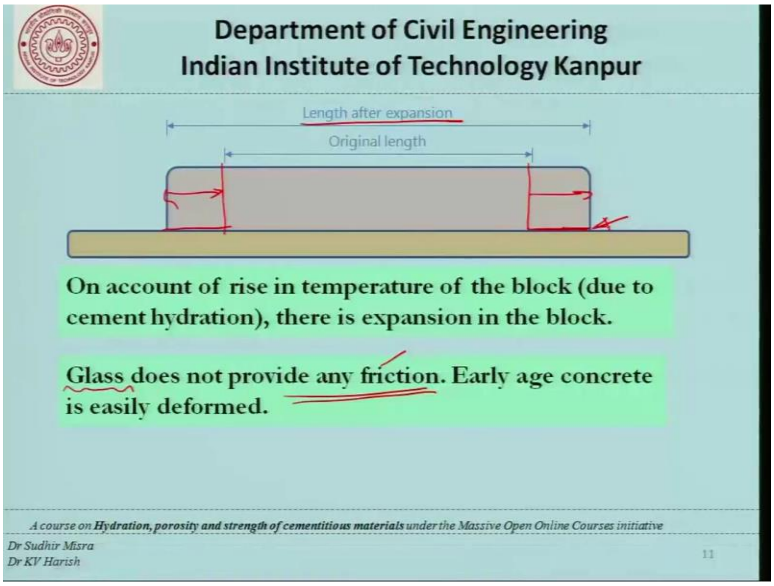

On account of rise in temperature of this block of the slab there will a rise in temperature and that will need to an expansion. So, this is the length after expansion. We must remember that this will happen when the concrete is still relatively young. And is more deformable. Now this expanded length of concrete is obliviously higher than the original length.

So, original length was only this much and we have seen. So, much expansion that has happened on account of rise in temperature the importance of having glass as a module is it does not provide any friction. And early age concrete is easily deformed as I said earlier. So, now, this not providing any friction is something which we must understand or keep note of because the illustrative examples that we talked about there the concrete was been cast against the ground. And ground do not have the same kind of friction characteristic for the ground concrete interfere does not have the same kind of friction characteristics as have been modeled now. Here what we are saying as because it does not provide any friction the concrete block is free to expand like this and the expansion here at the interface is the same as the expansion on the top.

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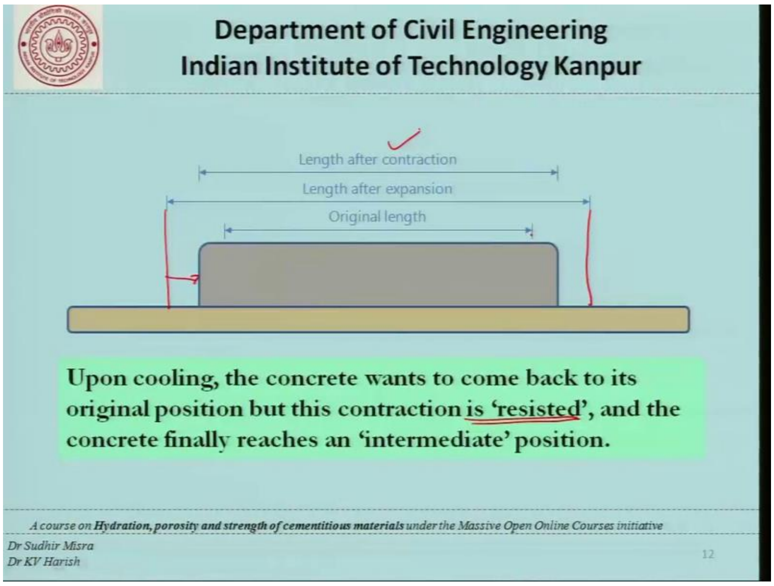

Now, the concrete does not remain at an elevated temperature all the time once it cools the concrete wants to come back to it is original position, but this contraction is resisted. And the concrete finally, reaches an intermediate position. So, now, this resistance comes on account of 2 things. One is that concrete at that early age is rapidly hardening. And therefore, it becomes more difficult for concrete to contract as it were to contract complete to the situation when it was expanding under the effect of elevated temperature. The second part of the resistance comes from the restrain which the interface offers. So, once we understand the principle that yes there is an original length there was an expanded length and finally, this is the length after contraction, we will be able to understand the concept of thermal stresses or thermal strains much better.

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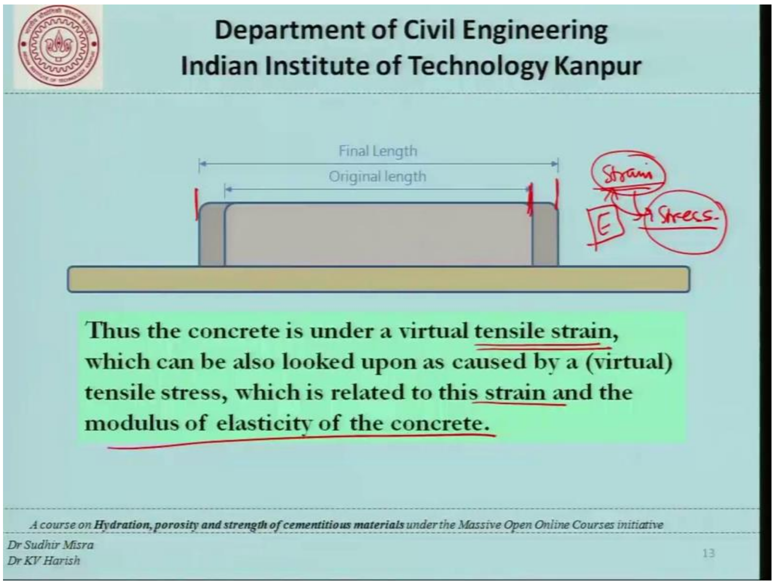

So, effectively what has happened is that we have the original length here and we have the final length as shown. And the concrete is under a virtual tensile strain. So, if this is the original length where the concrete wants to come back to and this is the length where the concrete is being held, this leads to a virtual tensile strain which can be looked upon as caused by a virtual tensile stress. And this is related to the modulus of elasticity of the concrete.

Now in another words if we know the strain how do we convert this to stress. What we must understand or what we try to model is this strain is arising out of a stress there is some kind of a stress acting on the concrete which has caused this kind of strain. In other words, this strain is effectively equivalent to this kind of a stress and when we are converting these 2 we need the modulus of elasticity of concrete.

Now, this modulus of elasticity of concrete is obliviously not that of hardened concrete this has to be that of the concrete at the age at which we are talking about.

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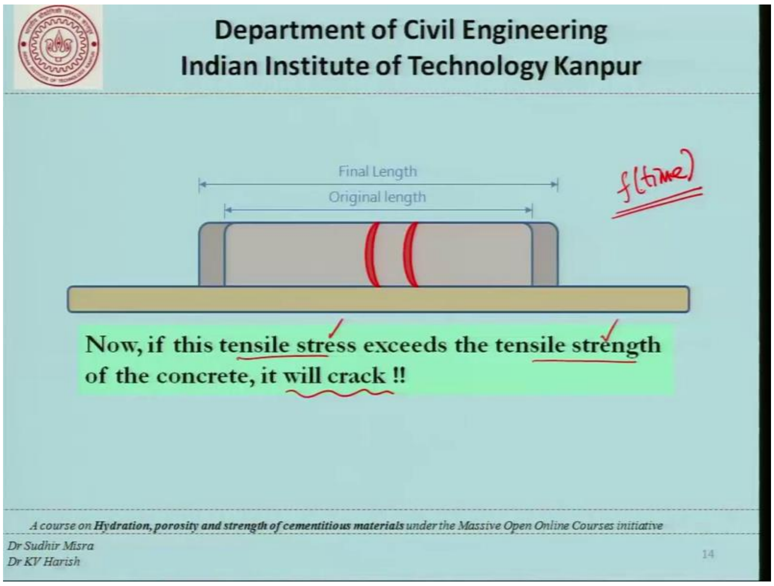

And if this tensile strength is exceeded by the tensile stress the concrete will crack, we must remember that when we are talking of this stress and this strength both are actually functions of time. And therefore, we must keep in mind a discussion as to how the tensile stresses develop over time and how the tensile strength develops over time equations and guidelines for 28 date strength of concrete to 28 day modulus elasticity of concrete are not really helpful.

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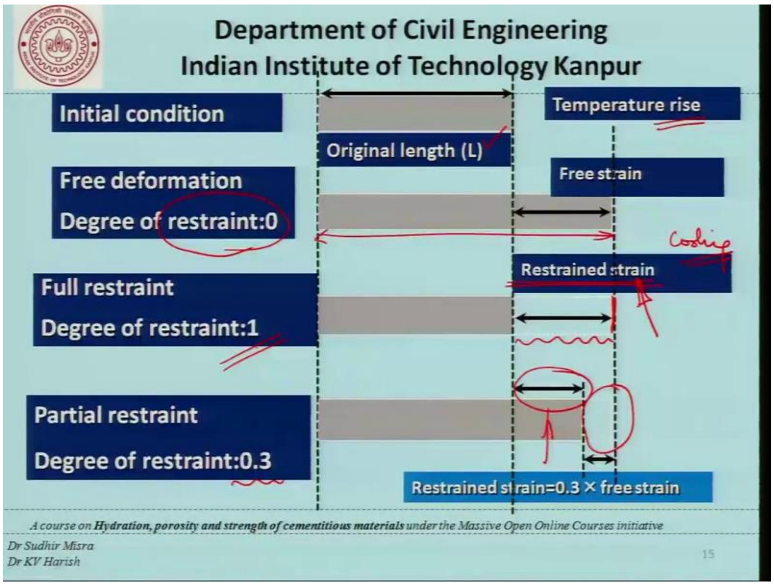

To recapitulate this discussion, let us look at this picture. We had an original length like this because of the temperature rise it expanded to this place, with no restraint that is what the glass plate was doing for us. If now at the time of cooling or during cooling or thereafter if it is fully restraint that is the degree of restraint is one, then the concrete will be held right here, and all this will become the restrained strain in the concrete. Now most of the time the degree of restraint is not one and if the restraint is anywhere between 0 and one there will be some amount of change in the length of the concrete, but there will be a certain amount of restraint which is still remaining. And this strain is what we need to take in to account when we are talking about converting the strain to the thermal stress.

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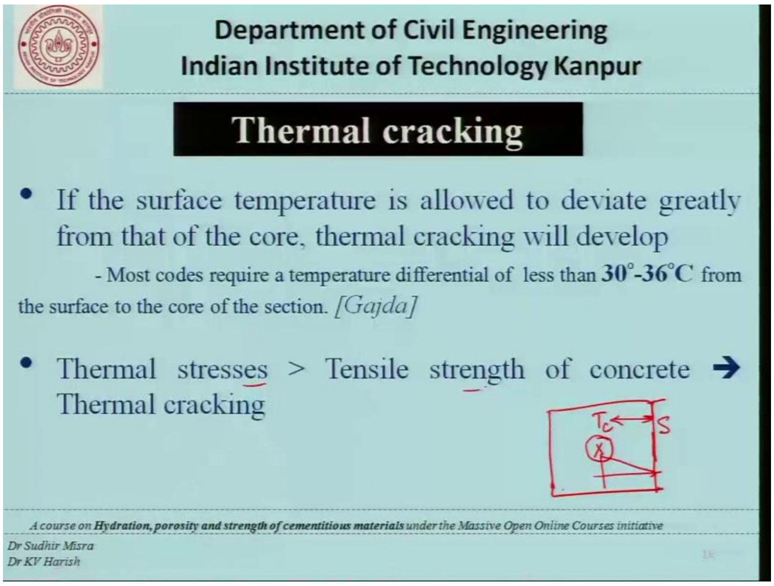

Recapitulating now if the surface temperature is allowed to deviate greatly from that of the core thermal cracking will develop. Basically what is been said is that if on account of thermal if on account of heat of hydration, the temperature of the core of concrete is allowed to be greatly different from that at the surface.

So, let say ts and the core if there is a large different between these 2 then there will be a certain amount of thermal gradient that will develop and that is what will induce the cracking. As you have seen if the thermal stress is greater than the tensile strength of concrete we will have cracks.

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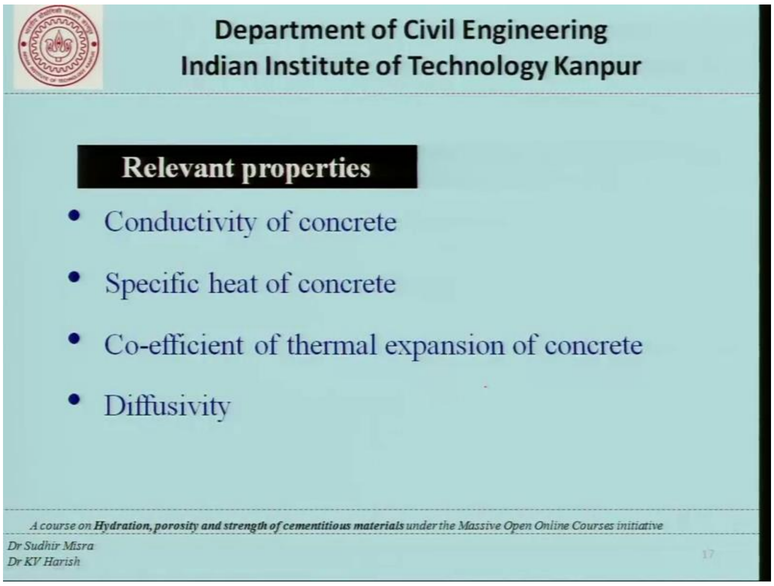

When it comes to the dissipation of heat as far revolution is concerned, the parameters are pretty cleared it largely depends on the cement type the composition and so on. When it comes to dissipation of the heat parameter such at the conductivity of concrete or the specific heat of the concrete the coefficient of thermal expansion of concrete and the aggregates diffusivity all these parameters become important. And these have to take as parameters for the concrete at the early age.

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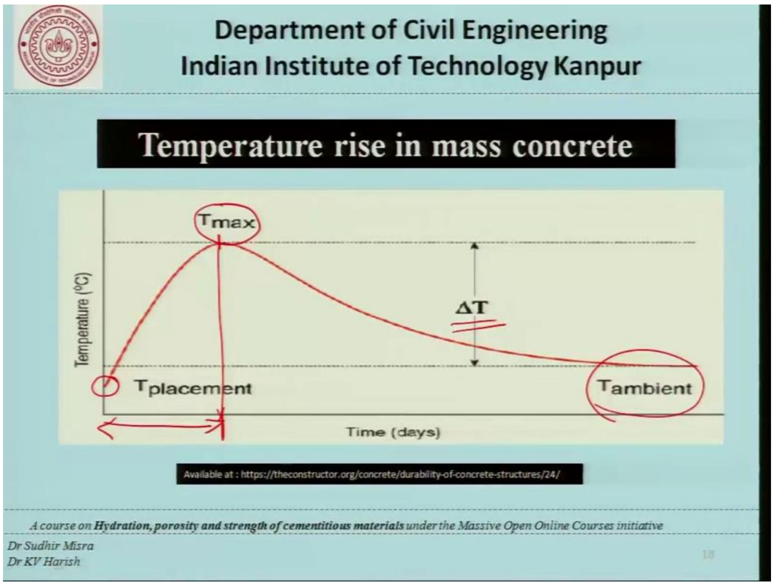

This is something which we had talked about yesterday also in lecture 19 that essentially we are looking at a situation where from the temperature at which the concrete is placed on account of the heat of hydration the evaluation of the heat and the dissipation the balance of the 2 the concrete reaches a certain peak temperature and that peck is reached at a certain time. And of course, at the end of the whole process the concrete goes back to the ambient temperature and this is a graph which had shown the other day also.

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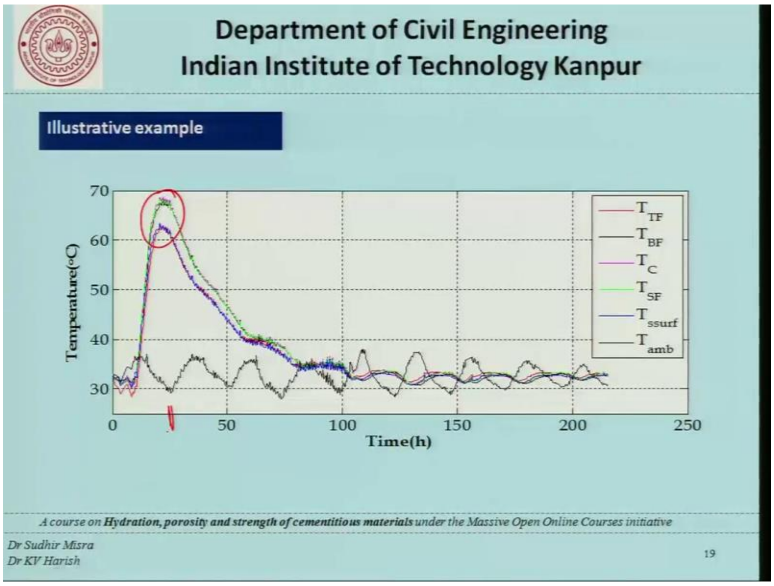

So, give you quantity feel of the numbers involved the peak temperature are in the range of 60 to 70 degrees and that would depend; obviously, on the size of the pour that is the size of the block and so on, and also the time in this case is about 24 hours. So, we must understand this picture here as 2 very important components the time at which this peak temperature is reached and the peak temperature itself because that tells us how much is the delta t which will be involved as far is cooling is concerned.

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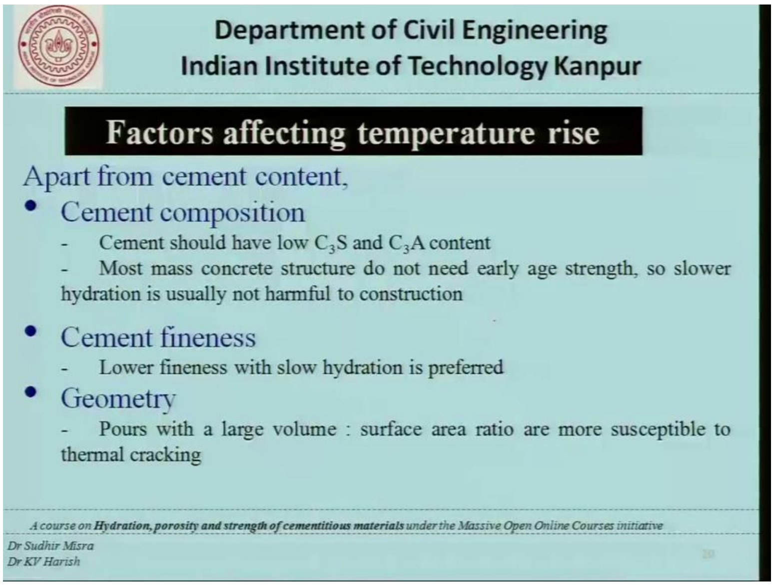

As for as the factor that affect the temperature rise are concerned apart from the cement content there is a cement composition. If we have a cement with low C3S and low C3A we can expect lesser of problems less temperature rise most mass concrete structure does not need early age strength and therefore, slower hydration is usually not harmful to the construction.

We have cement fineness as another player lower fineness with slow hydration is preferred. And then there is the geometry of the pour as we have talked about in this discussion earlier where the large volumes to surface area ratios are more susceptible to thermal cracking.

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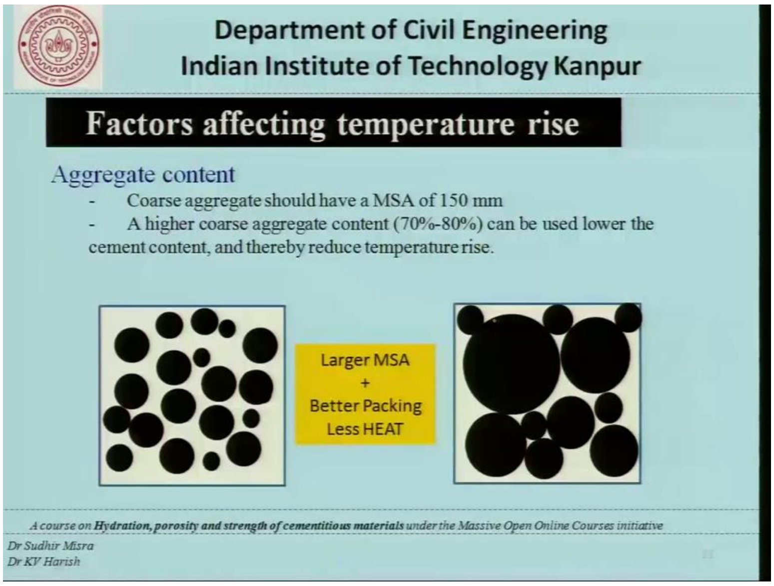

There another factor such as the course aggregate content.

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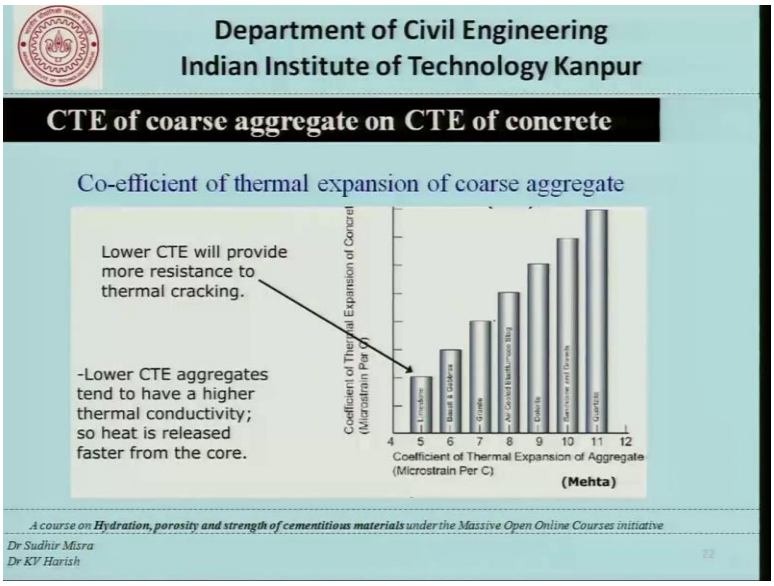

The coefficient of thermal expansion of the coarse aggregate.

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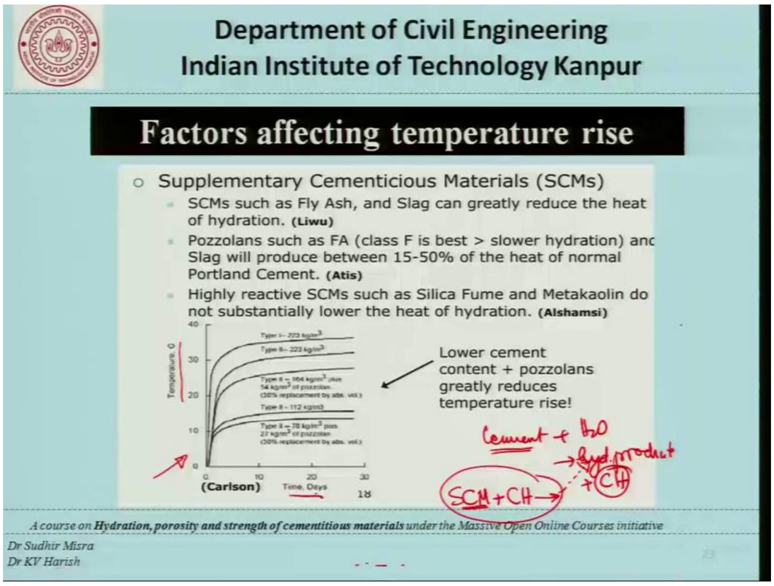

Use of supplementary cementitious materials; obviously, it is known that the hydration of cement is an exothermic reaction. Now if reduce the amount of cement and replace it with some other material which takes part not in the primary hydration, but the secondary hydration. We have seen earlier that when water is added to the cement

We get hydration products and calcium hydroxide; the supplementary cementitious materials they primarily react with the calcium hydroxide to give more or less similar hydration products. And that is the beauty of it that is this reaction is not exothermic. And therefore, if you want to control the heat that is generated in the certain pour if we replace a part of the cement by supplementary cementitious materials. We would go a long way in controlling the amount of heat that is generated and this graph here and similar graph which are available in literature will tell us how using supplementary cementitious material helps us reduce that temperature rise over time in different concretes.

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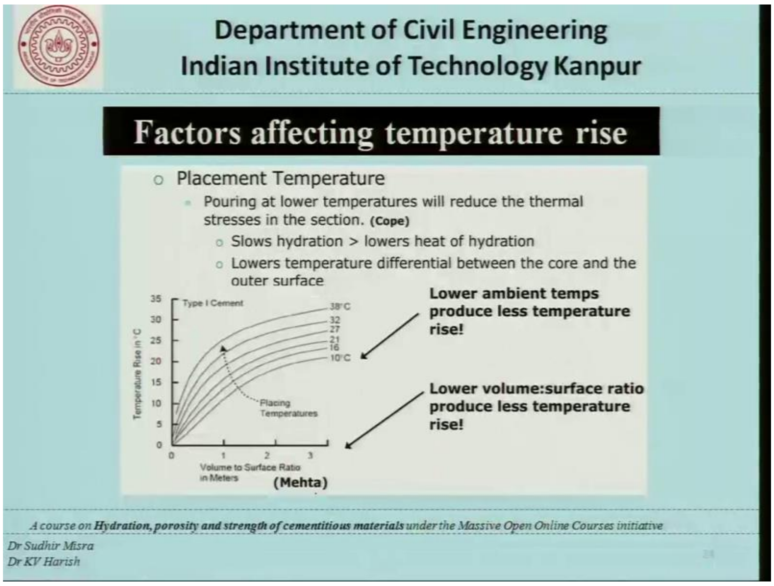

Another important parameter that affects the temperature rise is the placement temperature. Lower ambient temperature produces less temperature rise lower volume to surface ratio produces less temperature rise, and these are the kind of things which engineers keep playing with when they plan a mass concrete construction now let us try to understand.

How can we evaluate the danger or the vulnerability of the concrete to thermal stress and cracking on account of thermal stresses?

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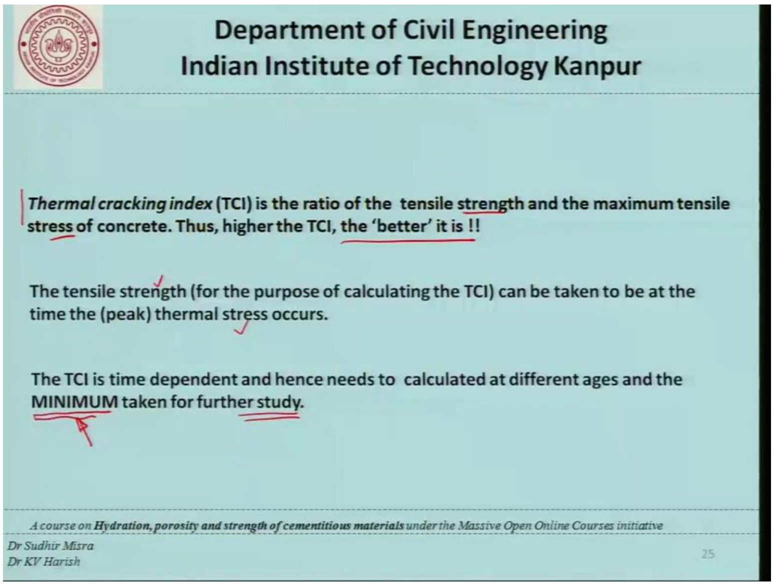

One such measure is the thermal cracking index which has been defined as the ratio of the tensile strength and the maximum tensile stress in concrete; obviously, since it is a ratio of by strength to the stress a higher value of TCI is better from the point of view of susceptibility to cracking. The tensile strength for the purpose of calculating the TCI can also be taken to be at the time when the peak thermal stress occurs. So, the TCI we must remember is time dependent and hence needs to be calculated at different ages and the minimum should be taken for further study or investigation. This aspect we have talked about a little earlier when we said that the tensile strength and the tensile stress are both functions of times. And therefore, if we are comparing the 2 we must make sure that we carry out that comparison over the entire period of time that is of interest to us and find the minimum value, because that is what should governor our design considerations.

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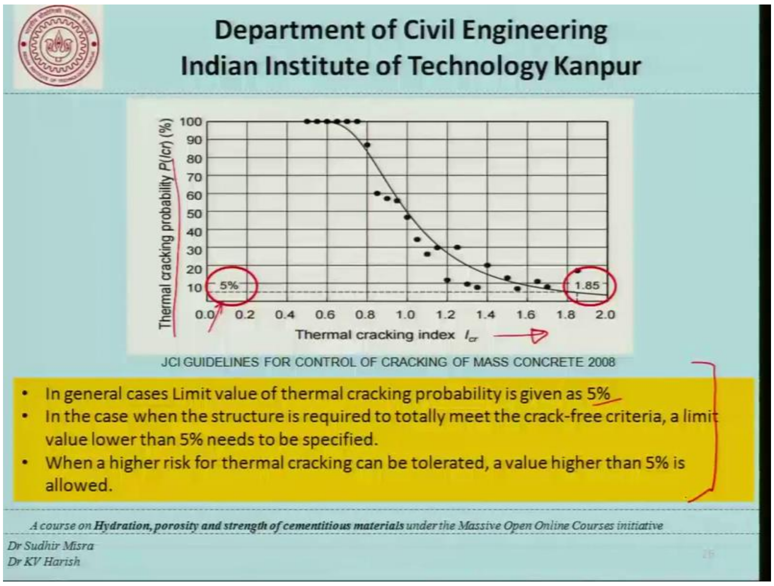

This here is from the guideline of the japan concrete institute that is TCI. And we can see that as the thermal cracking index increases the probability of thermal cracking reduces. And therefore, it is up to us to define or to pre decide as specification on what is the TCI that we are willing to work with in. Other words what is the probability of cracking that we are willing to live within a particular construction. So, in general limit the value of thermal cracking probability is given as 5 percent in cases whether a structure is required to be totally crack free a limit may be lower than 5 percent and when a high risk for thermal cracking can be tolerated or value higher than 5 percent maybe allowed. So, these are the kind of guidelines which an engineer must lay down when he is deciding on the kind of concrete to be used.

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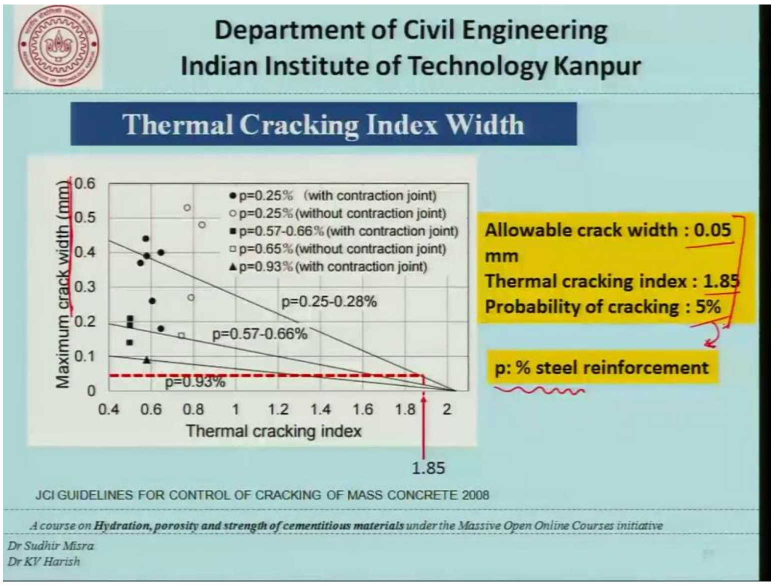

Yet another player in this game comes in the form of steel reinforcement; obviously, if we put steel reinforcement, the whole discussion in terms of the expansion of the concrete or the construction of the concrete and so on it changes.

So, there are 2 ways of looking at it or there are 2 aspects to this problem one is that in reinforcement concrete the steel is already there. And therefore, that steel provides additional restrain in the other situation we may have plain concrete, but we provide reinforcement in it to account for the thermal stresses. So, in either case it is the effect of the presence of steel bars in the concrete which needs to take into an account and also we get involved with the parameter called crack width.

It is much easier to say that yes concrete will crack, but what will be the width of that crack that is also an important parameter and we are not getting into the details of computation of those values, but as engineers we must know that yes these are important parameters, and if we want to if we need to we should go to an appropriate literature and find out the kind of guidelines which are available. So, for example, is given here that one may fix the maximum allowable crack width to be 0.05 mile meters the thermal cracking index to be one point 8 5 the probability of cracking to be 5 percent and then, try to see how much steel should be provided or how much additional steel should be provided in order to ensure that these parameters are met.

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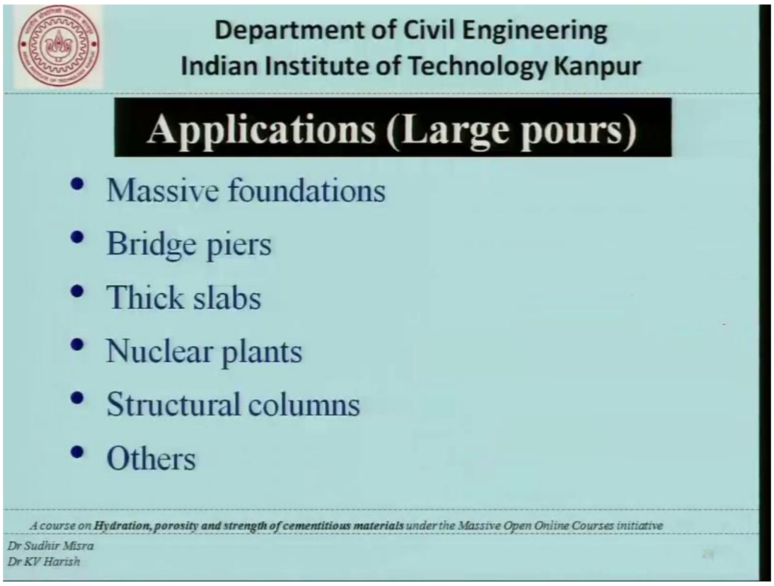

Where does this discussion have applications it has applications in massive foundations bridge piers thick slabs concreting in nuclear plants structure columns and. So, many others places.

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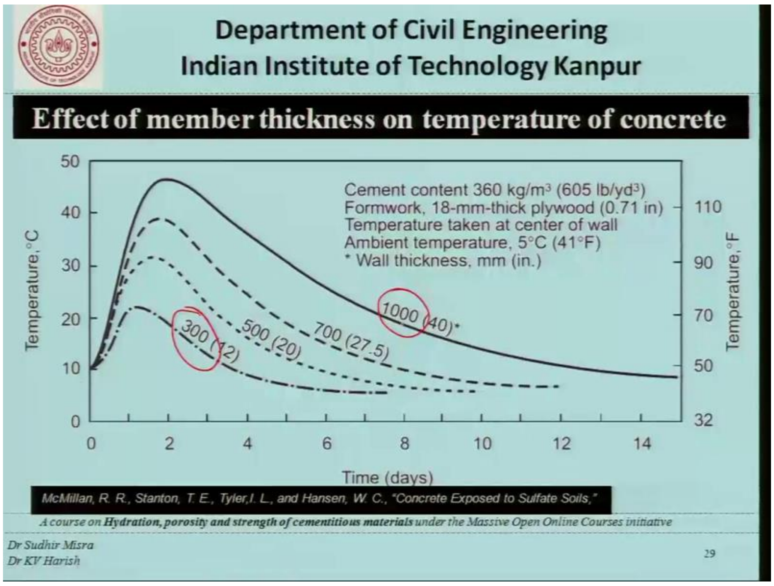

And this is another graph which we talked about yesterday which showed how the thickness of the concrete member affects the temperature rise and we can see that if the thickness is varied from 300 mm from 1000 mm there could be a substantial difference in the temperature rise that we see.

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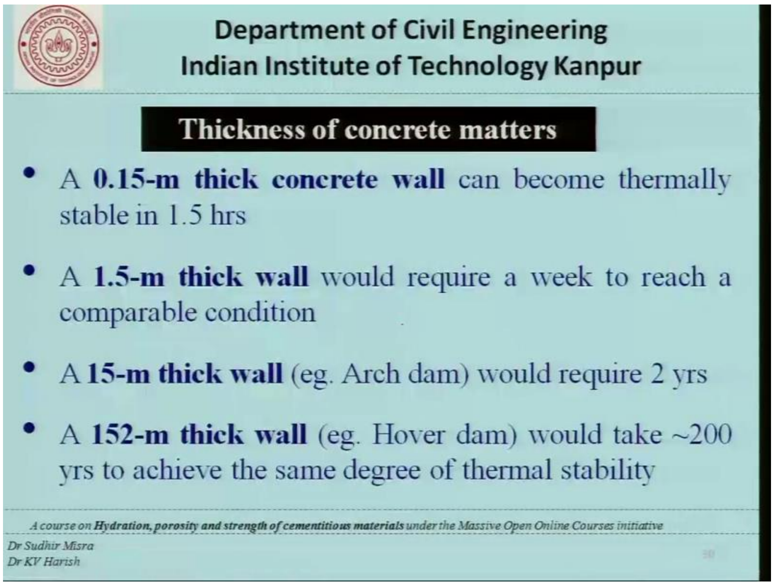

This is another text here we are writing the same thing in a more illustrative form as text where we say that a point one 5 meters that is 100 and 50 mile meter thick concrete wall can become thermally stable in 1.5 hours whereas 1.5 meters thick wall would require a week and a 15 meter thick wall would require 2 years and 100 and 52 meters thick wall would take 200 years to achieve the same degree of thermal stability.

Now, of course, we do not sometimes cast a 100 and 52 meter thick wall all at once or for that meter even perhaps a 15 meter thick wall all at once, and that gives us the flexibility or the idea that well can we cast this in parts that is where the important of the construction plans comes in when we are trying to address the problems of mass concrete.

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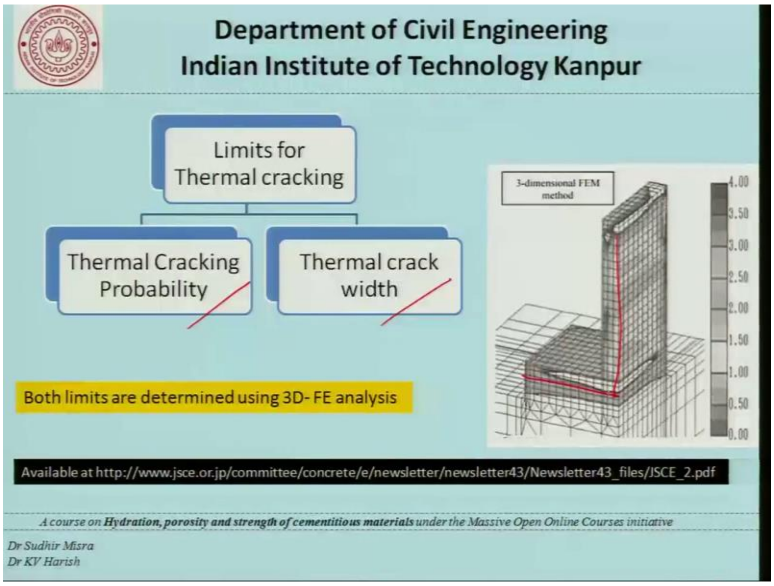

This is just another illustrative examples of how modern tools are available to helps us carry out the analysis in terms of determining the probability of cracking or the crack width we take a wall, this is a wall with the footing and we try to modulate using finite elements methods and So, many other tools which are available and try to understand areas which are more vulnerable to thermal cracking less vulnerable to thermal cracking when the thermal tracking is likely to happen and so on and so forth.

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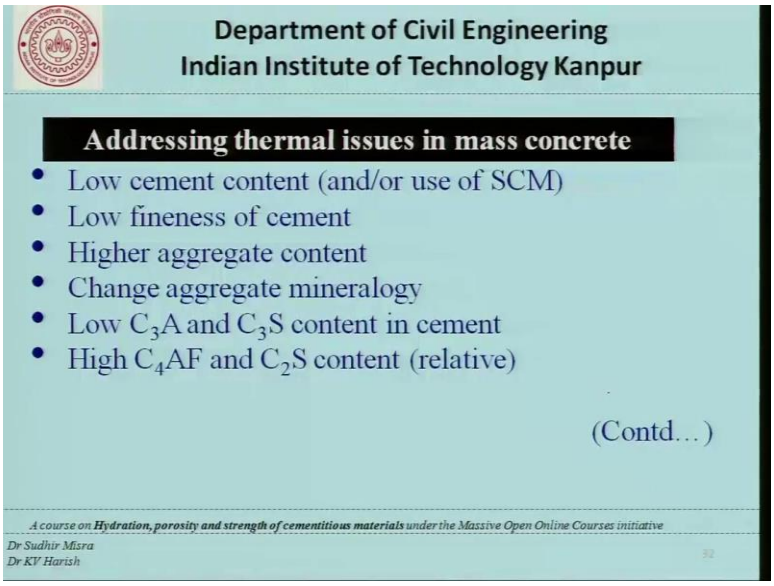

Now, coming to the steps that can be taken to address issues in mass concrete. We have eluded to them earlier in our discussion we could use low cement content and or use supplementary cementitious material, use low fineness of cements higher aggregate content change the aggregate mineralogy change the type of cement in terms of having low C3A and C3S high for F high C4A f and C2S which is a relative issue.

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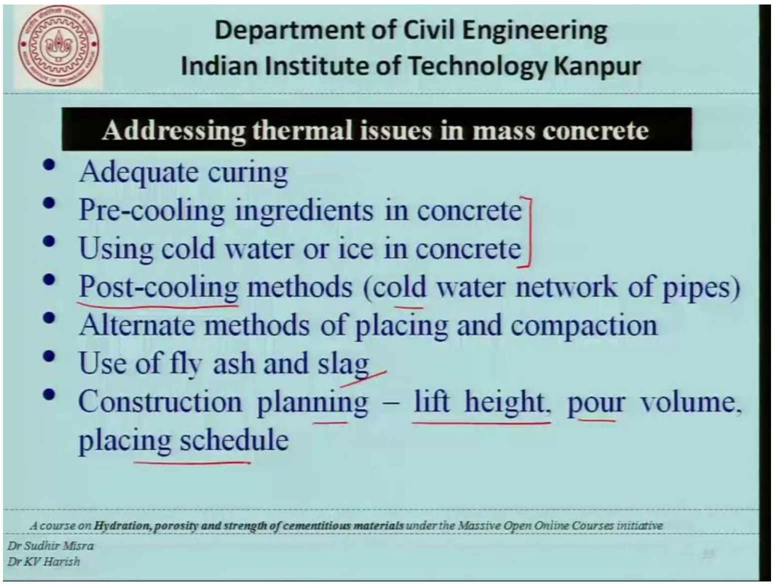

Then there are things like adequate curing. We can also get into measures such has pre cooling the ingredients or using cold water or ice in concrete. Now these help us lower the placing temperature of the concrete then there are method which are available which are call post cooling where we do that in with cold water networks of pipes. Alternative methods of placing and compaction use of fly ash and slag is supplementary cementitious materials and construction planning where we talk in terms of how much should be the lift height what should be the pour volume what should be the placing schedule because we know that if you want to cast a large block of concrete we can break it up into smaller blocks of different sizes.

So, if we are able to carry out simulation we say that well if we cast smaller blocks we will have lesser problems as for as thermal stresses are concerned, but at the same time that will become more difficult to do. So, if a simulation of that exercise which help us arrive at an optimal solution as to what is the best thing is to do.

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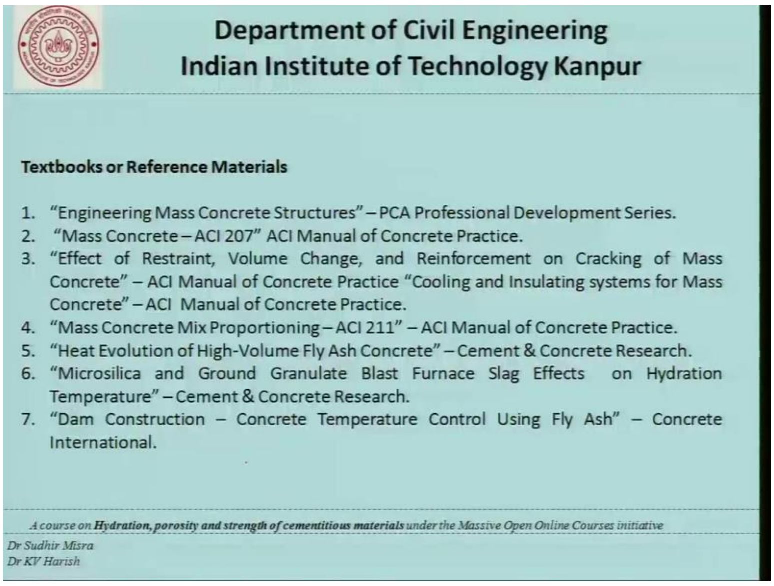

Now, this is a list of text and reference material which will help you better understand the topics which have been covered, and I would like to thank you for your attention.