Concrete Engineering and Technology

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Lecture - 17
Mass concrete (Part 2 of 2)

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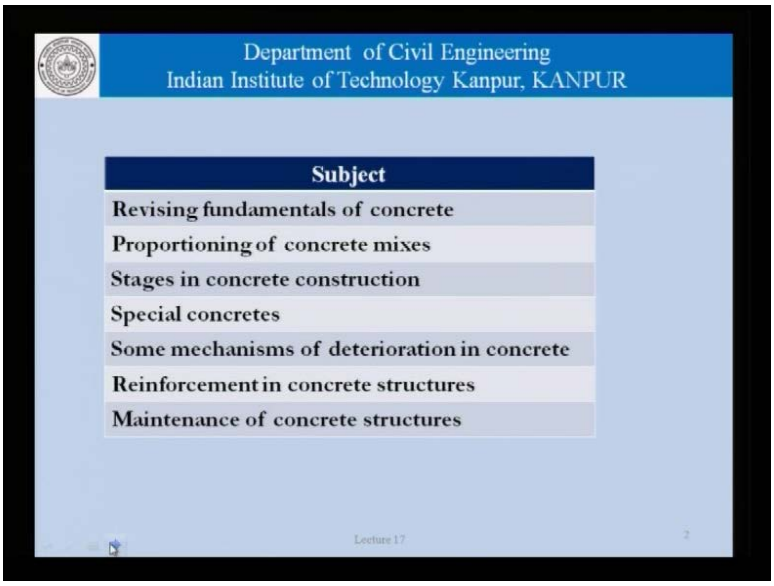

And hello, welcome back to this series of lecture on concrete engineering and technology, where we are trying to study the fundamentals of concrete once again in the light of developments that have taken place in the last 15-20 years. We are trying to understand better the concepts in proportioning of concrete mixes, stages in concrete construction, special concretes, mechanisms of deterioration in concrete, reinforcement and concrete structures and their maintenance. So, in the last couple of discussion, we are focused on special concretes and within that mass concrete was the focus of discussion in last class.

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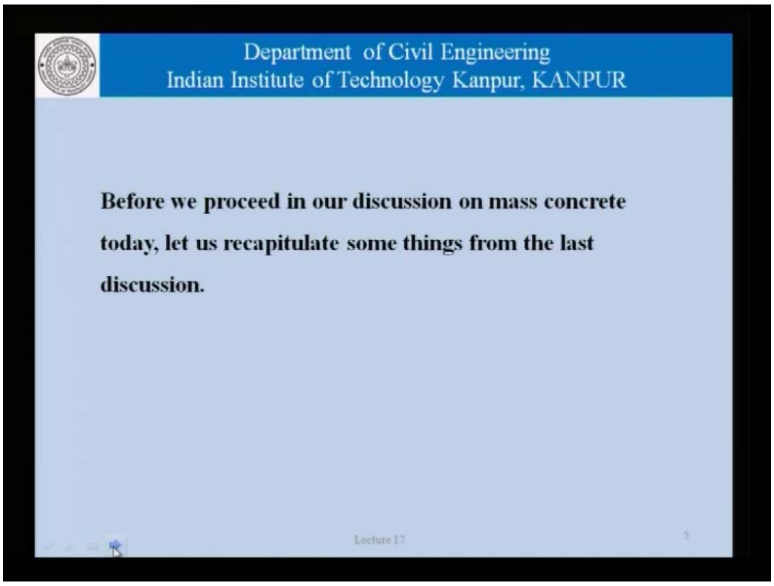

Now, before we proceed in our discussion on the subject today. Let us recapitulate some of the things that we did last time.

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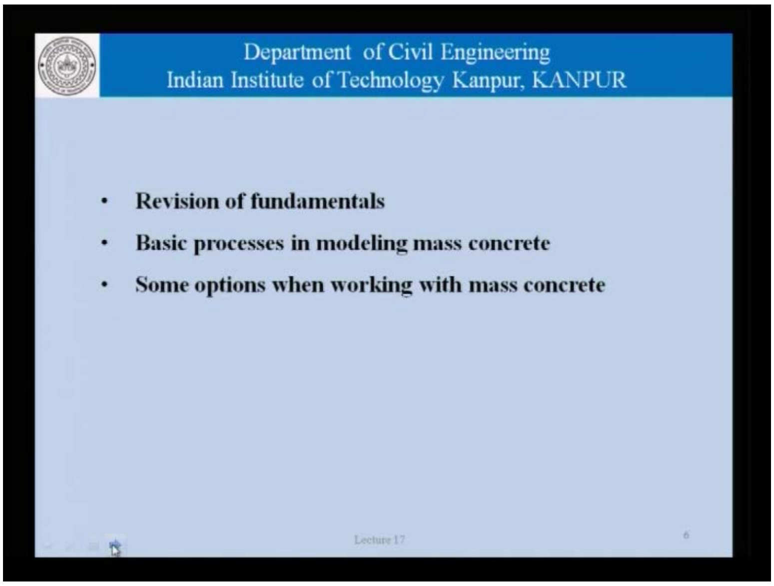

Last time the focus was on revision of fundamentals from the point of view of mass concrete. We try to understand some basic processes in modeling mass concrete and also some options which were available with us in terms of working with mass concrete.

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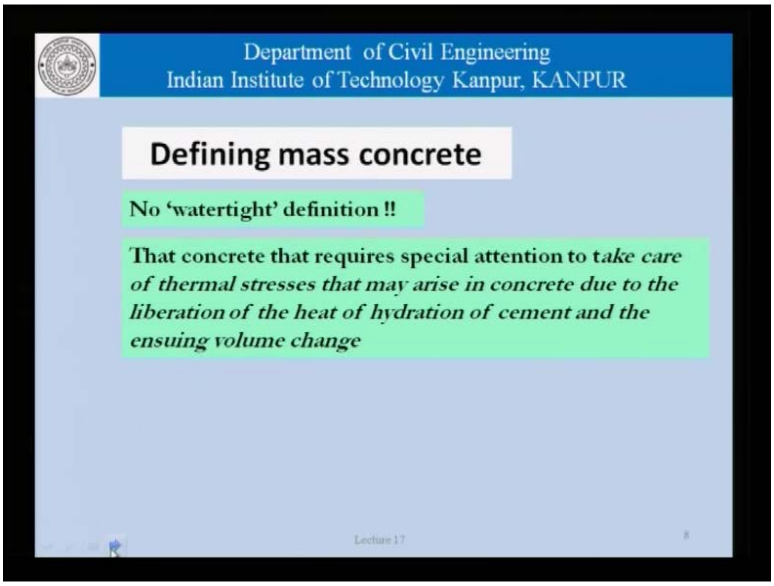

So, going over these once again quickly, as far as the fundamentals are concerned we saw that they were no basic definition or no watertight definition that this is what is mass concrete. It is any concrete that requires a special attention to take care of thermal stresses that may arise in concrete due to the liberation of heat of hydration of cement and the ensuing volume changes.

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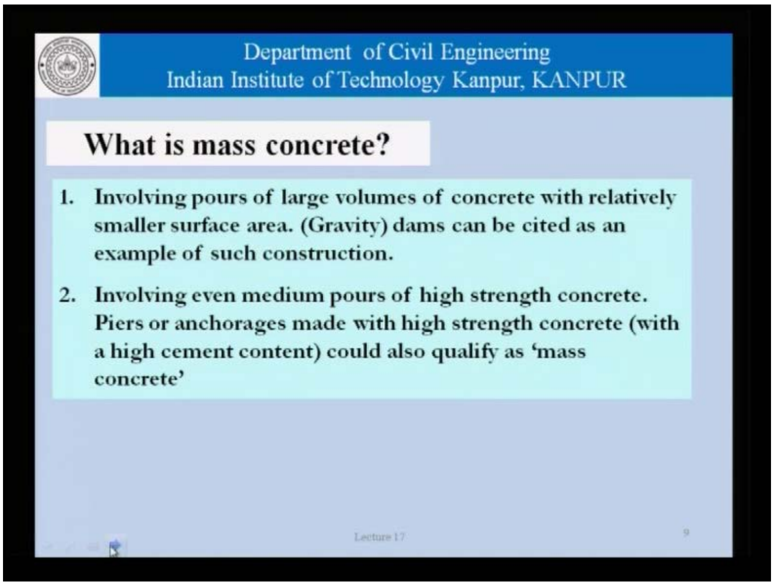

And therefore, the situation of mass concrete could arise, in say in cases where there are large pours of concrete with relatively small surface area and gravity dams can be cited as an example of such construction. It could arise in situation where the pours are medium size but, the concrete is high strength which entails that the cement content will be high and therefore, amount of heat liberated is going to be large.

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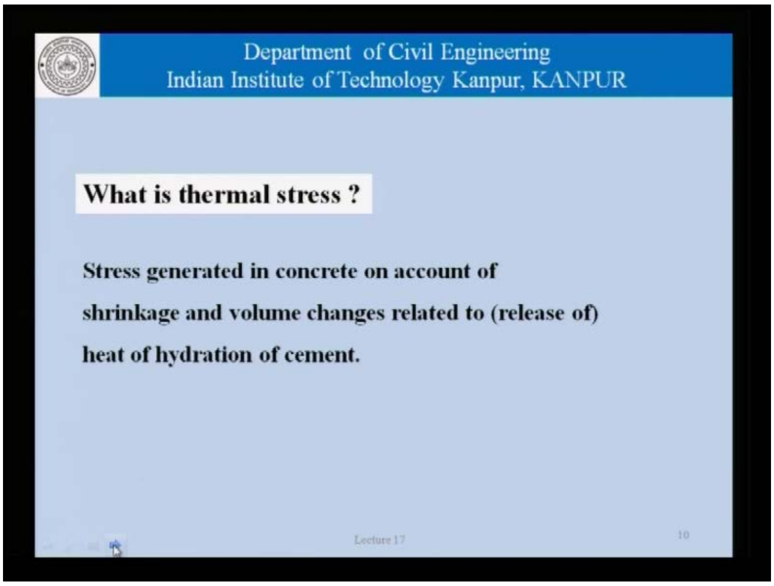

As far as thermal stresses are concerned we said that these are the stresses generated in concrete on account of shrinkage and volume changes related to the release of heat hydration is cement.

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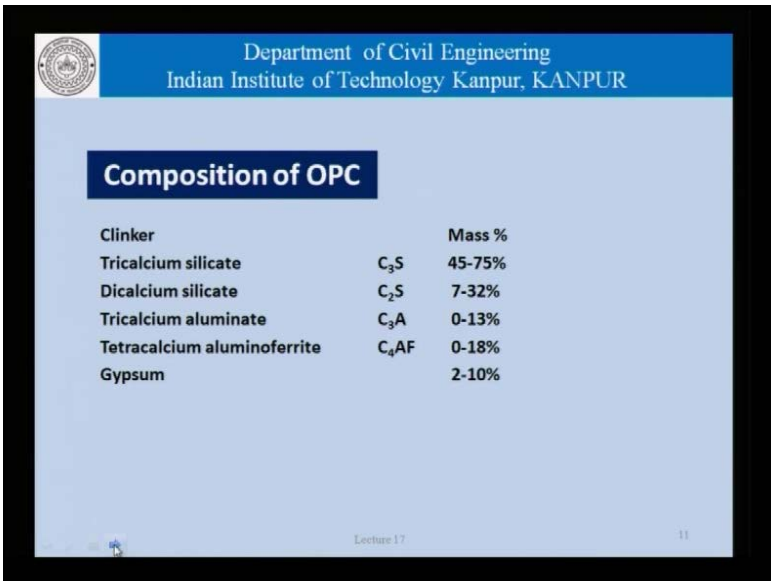

We once again saw the composition of cement in terms of its solid complexes. And all these sold complexes they have their own rates of hydration, their own heat of hydrations that they liberate while they hydrate.

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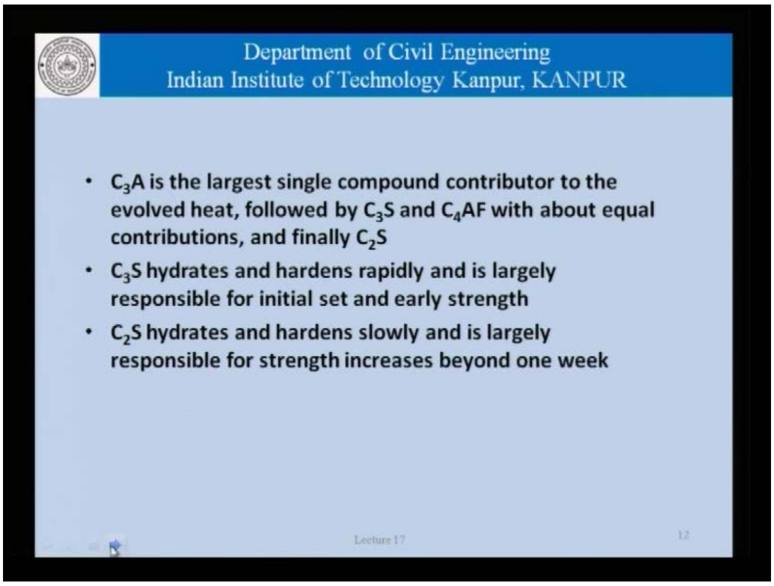

And we also know that C 3 A or the tricalcium aluminates, is the largest single compound contributed to the evolve heat and followed by C 3 S and C 4 A F which are more or less equal and then finally, C 2 S we have also seen that C 2 S hydrates and hardens rapidly and is largely responsible for the initial set and early strength and concrete and C 3 S hydrates and hardens slowly and is largely responsible for the strength beyond 1 week.

So, depending on what kind of concrete we are talking about, we need to control the chemical composition of cement. If it high strength concrete: we need one type of cement. If we want really low heat of hydration cements from an early strength point of view or from a mass concrete application with large volumes where strength is not really a consideration then, we need a different chemical composition. So, the whole definition of low heat of hydration cement comes into question and we have to appropriately defined it depending on the kind of use that we want the cement or the kind of function, that we want a concrete to discharge.

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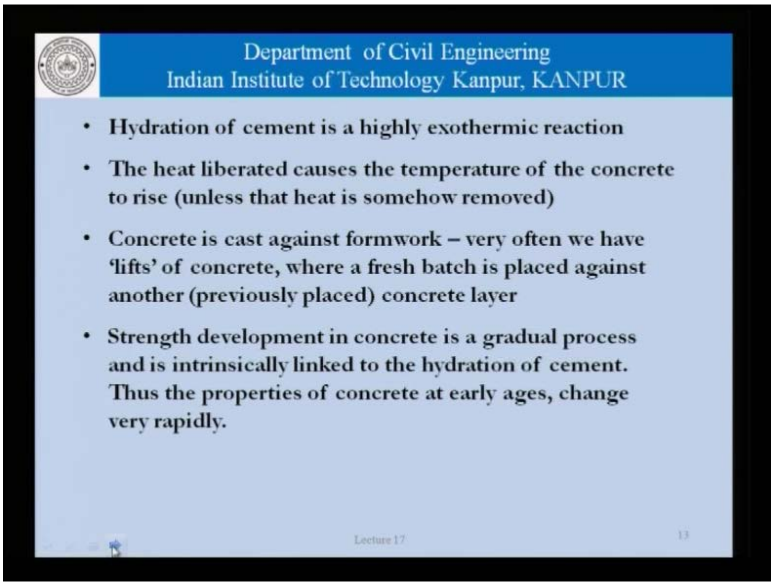

This is the summery of what fundamentals that we studied last time. Hydration of cement is a highly exothermic reaction; the heat liberated causes the temperature of the concrete to rise unless we are able to remove the heat from the body of concrete very quickly. We should remember that concrete is cast against formwork and very often we have lifts of concrete where a fresh batch is placed against another one which could be previously placed level of concrete or against rock or ground or whatever it is.

Strength development in concrete is a gradual process and is intrinsically linked to the hydration of cement and thus the properties of concrete at early ages change rapidly. And therefore, if we are talking about considering or studying effect of a certain property of concrete then, we should really take into account a time dependence of that property especially in the early stages and that is where mass concrete considerations are very important.'

Depending upon the geometry of the member or the portion of concrete being cast, the temperature of the core of a large concrete block will be higher than the portion closer to the surface. And the difference in temperatures of the core and techniques portion close to the surface sets up thermal gradients which are the root cause of thermal stresses.

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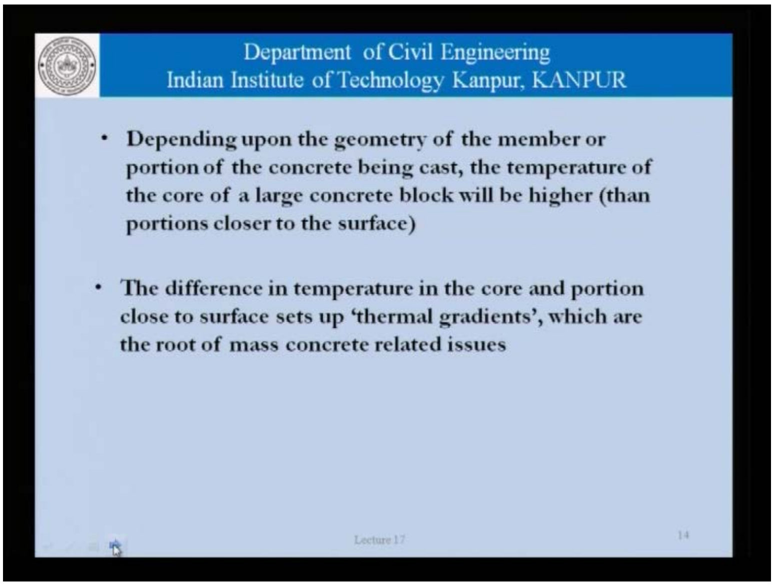

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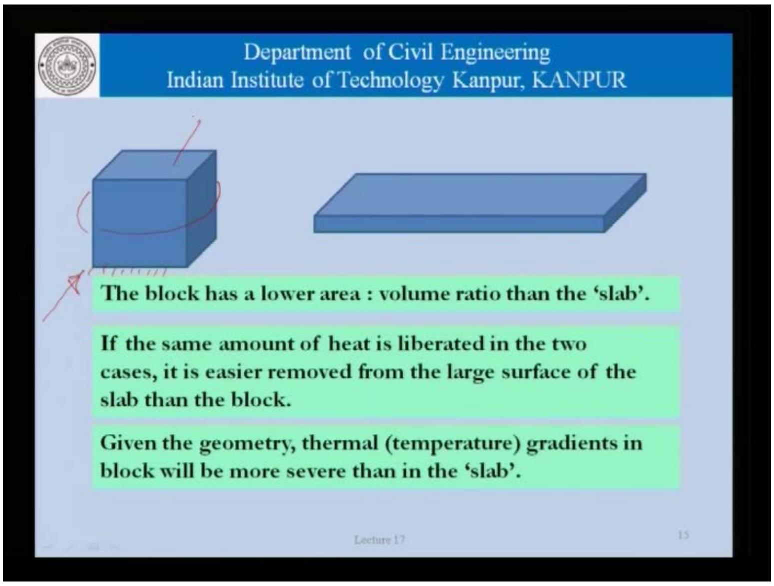

We have gone over this example where we had looked at a block of concrete measuring 2 meters by 2 meters by 2 meters and the thin slab of 200 thick and measuring about 6.3 or 6.4 meters square. And try to understand how the same amount of heat liberated can be taken care of or dissipated from the surface areas of these 2 cases and the surface area we saw in the case of slabs is much larger than that of the cube.

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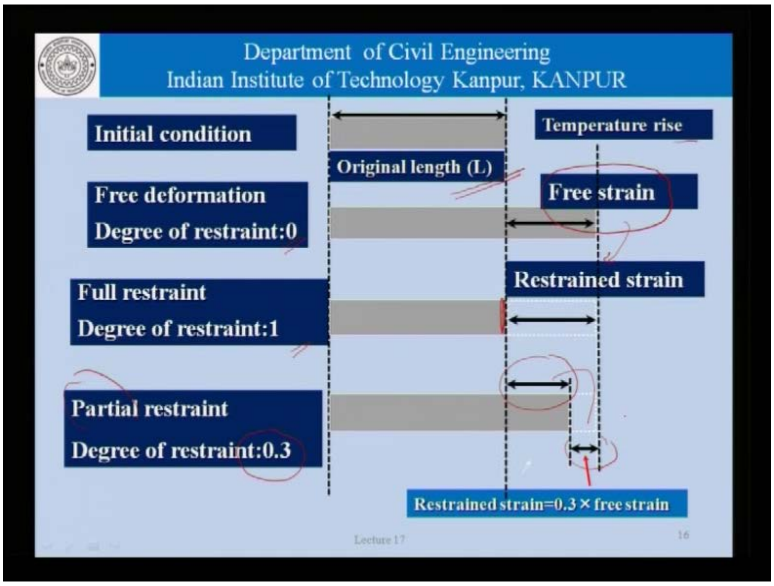

We had also discussed that these concretes are cast against a certain previously placed concrete at the bottom and then that is the formwork which is there at the around and this block and this surface is exposed atmosphere.

So, depending upon the exposure conditions, how the dissipation changes or the characteristics of this patience change depending on the characteristics of the surface or the boundary conditions on the surface here. We also studied a schematic diagram like this where we had discussed that if a concrete is cast within original length of l which is shown here and the temperature rises there is a free strain in case the degree of restrained is 0 that is something like concrete being cast on a glass plate that is what we have talked about. Against they had if the degree of restrained is 1 that is, it is completely restrained

Then this entire free strain becomes restrained strain and the concrete does not expand beyond this point. Similarly, if there is a partial restraint then we can have a combination of a certain amount of restrained strain and the certain amount of free strain. And depending on the ratio of these 2 with respect to the total restrain we can define the concept of degree of restrain and if we have 0.3 then, we have this to be 30 percent of the total strain.

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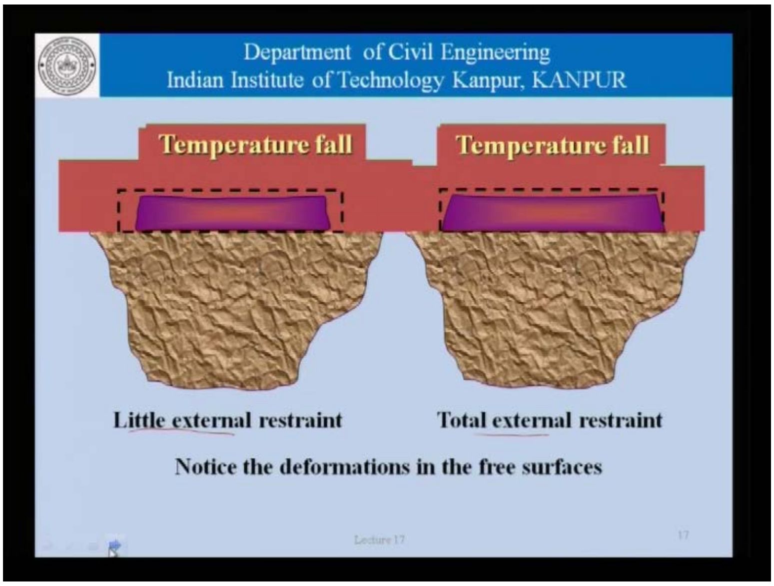

We had discussed this example which was the more realistic example of a concrete block being cast against the surface of previous concrete or a rock bed and seen how the situation changes with little external strain and a total external strain at the time of temperature rise and also at the time of the temperature fall, that is the cooling of concrete.

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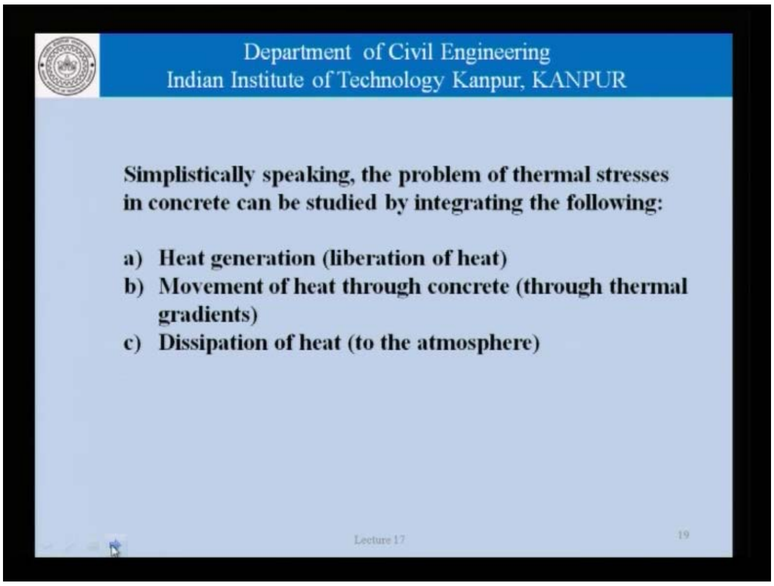

Having done all that we had discussed the 3 basic processes which are involved when we model mass concrete, the heat generation or liberation which is related primarily to the cement content and the characteristics of cement fineness chemical composition and so on.

We had talked about the movement of heat through the concrete, through thermal gradients and we had talked about the dissipation of heat to the atmosphere depending upon the characteristics of the surface against which the concrete is cast, the kind of formwork that is used and the kind of curing condition that are applied after the formwork has been removed in built condition such as wind rain and so on, also contribute to changing the characteristics as far as the heat dissipation is concerned. So, this was our discussion as far as modeling of concrete is concerned from the point of view of mask concrete or trying to understand the kind of temperatures that are built up on account of heat of hydration of cements.

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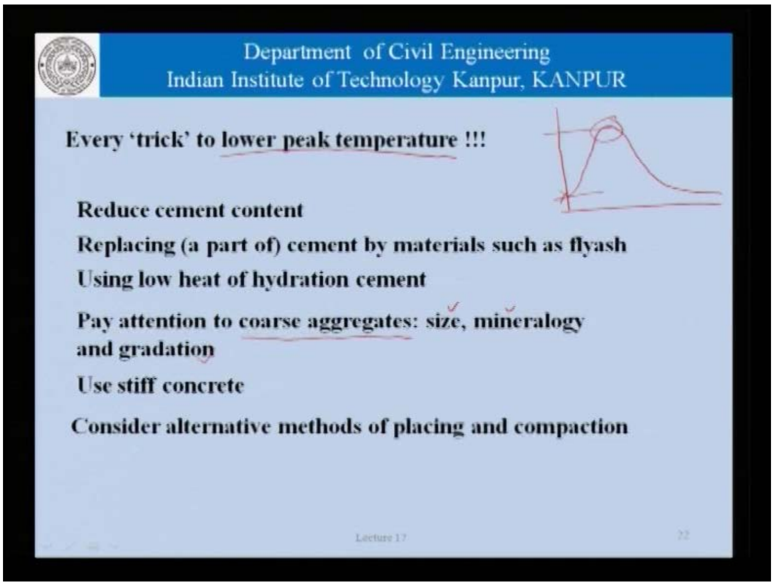

So, with this discussion we had gone on to discuss some of the option that we have when we deal with mass concrete applications. And the bottom line was that every trick that can be used to lower the peak temperature of concrete. Basically, we had seen a diagram which said that from an initial temperature the concrete temperature rises and goes back finally, to a stable value. So, whatever we can do to control this temperature rise or this peak temperature we must try to do and that will help us a lot in controlling the thermal stresses or the thermal strains in concrete. One of them could be reduce the cement content; another could be replacing a part of cement with materials such as flyash which does not liberates so much heat on account of hydration.

And the secondary hydration processes in the case of pozzolanic reactions of flyash and so on. Use low heat of hydration cement, if we introduce the amount of heat that is generated from the cement by changing the chemical composition of the cement that helps, we should try to pay special attention to the properties of coarse aggregates the size, the mineralogy and the gradation. Because all these properties contribute to the properties of concrete and when it comes to modeling of thermal stresses then, properties such as the thermal expansion of concrete or the module of elasticity they all depend heavily on the properties of coarse aggregate. And we do not really bother about them in normal construction but, as far as modeling for mass concrete application as concerned they become very important.

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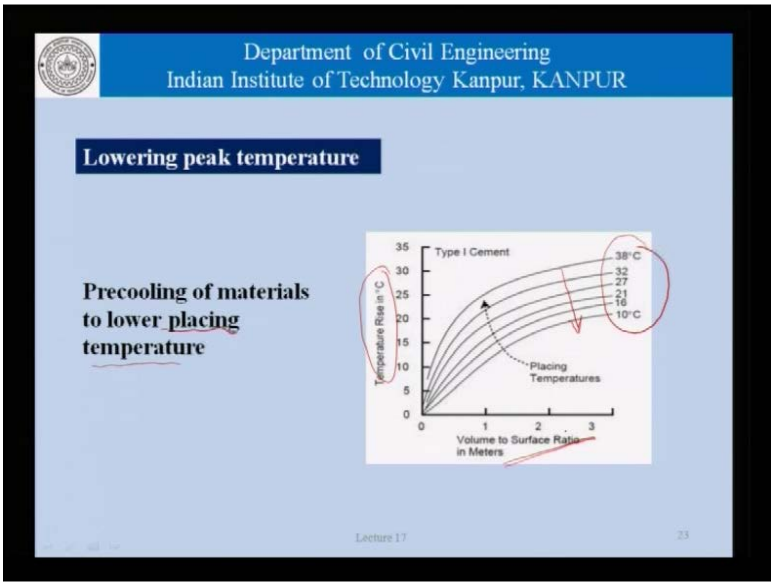

We should use as stiff concrete as possible because if we use stiff concrete basically, what we do is reduce the water content and if you reduce the water content by definition by simple arithmetic we reduce the cement content and that contributes to the reduction in the amount of fluid that is generated. We should actually consider alternative methods of placing and compaction using roller compacted concrete or roller compaction is a process by which we can reduce the layer thickness. So, instead of casting concrete blocks of large thickness, we can consider the option of cast in concrete in layers and that is what is the technology of roller compacted concrete construction. Given the volumes involved all these measures help us greatly in reducing the thermal stresses.

We have talked about pre-cooling that is the use of materials such as crust ice cooling of aggregates and so on in order to lower the placing temperature. Now, how much should placing temperature be is a different discussion that engineers need to do. But, from this graph here we can see that if we are able to reduce the placing temperature this way then the amount of temperature rise that we get for a given volume to surface area ratio becomes smaller and that is what our target should be.

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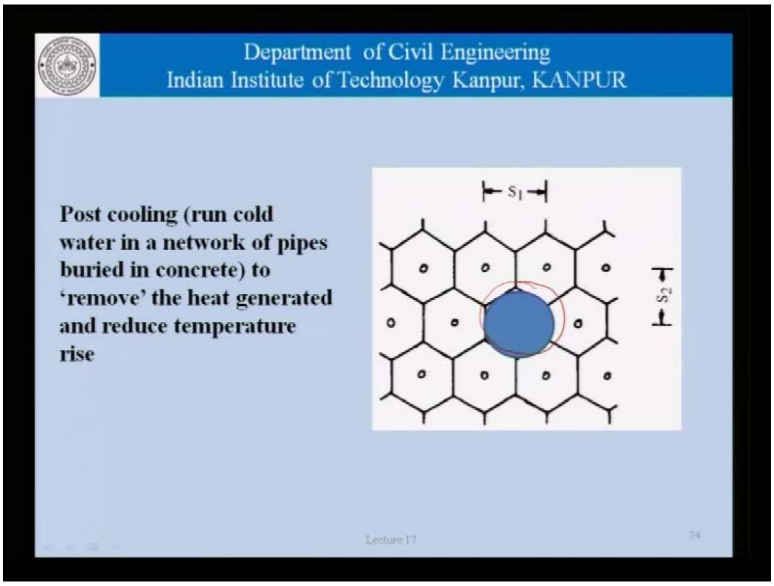

Similarly, we had talked about post cooling: which involves running of cold water in a networks of pipes buries in concrete to remove the heat generated on account of cement hydration and therefore, reduce the temperature rise and we had talked about how these pipes and the water running through these pipes helps us cool a certain amount of concrete around those concrete around those buried pipes.

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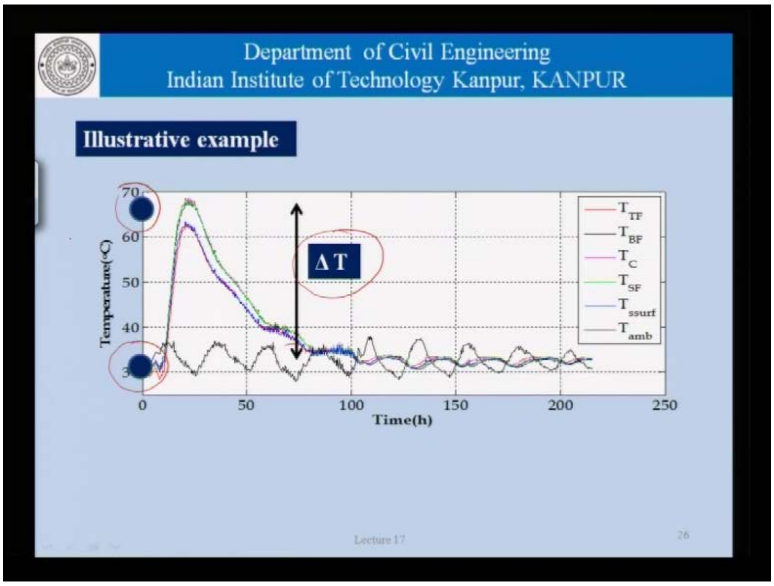

Having said all that, we were trying to discuss an illustrative example where we have this as an placing temperature, this as the amount of temperature rise. I am not differentiating between the temperature rise and temperature fall because, the temperature rise is the rise from the placing temperature to the peak temperature, the temperature fall is the difference of the peak temperature and the inbuilt temperature to which it falls. So, in this case I have taken to be more or less the same. I have taken this line to be not really very different and of course we have the peak temperature itself.

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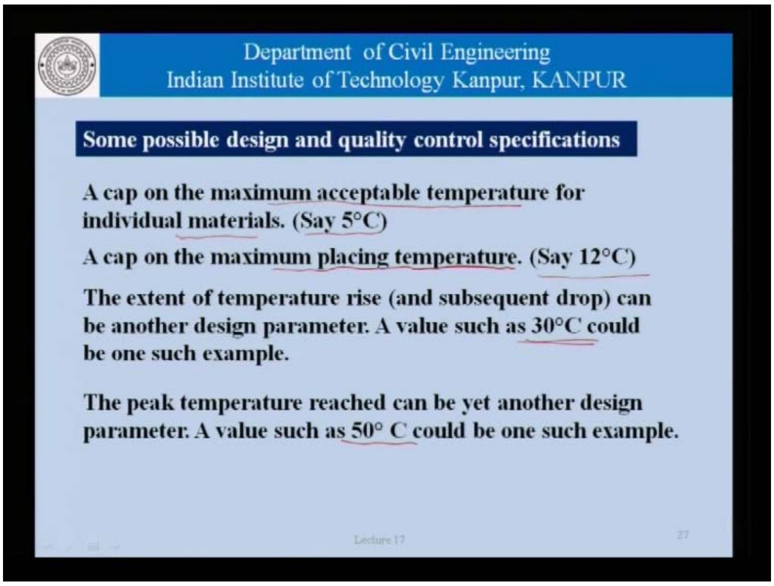

So, as far as design and quality control specifications are concerned, we can talk in terms of a maximum acceptable temperature for individual materials and that is what we can achieve or we will have to achieve though moves like pre-cooling. We could put a number like 5 degree centigrade or 7 degree centigrade. Similarly, we can put a cap on the maximum placing temperature which is a function of the proportions and the temperature of the constituent materials. We can put a cap on the maximum placing temperature at say 12 degree centigrade or 14 degree centigrade. Continuing this discussion we can fix or put a maximum amount on the extent of temperature rise and the drop as a design parameter. Specification can say that no more than 30 degree centigrade or no more than 25 degree centigrade of a temperature rise of all should be allowed whatever means need to be taken have to be adopted.

The peak temperature reached can be yet another design parameter and the value such as 50 degree centigrade could be an example. So, as a designer a concrete engineer has various options which are available to him to specify and then it is up to us and it our innovativeness to figure out ways and means of how those targets can be achieved.

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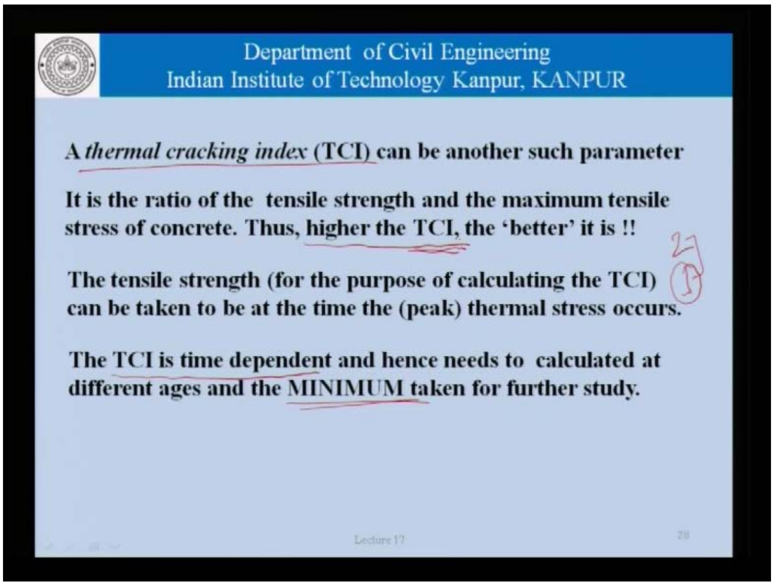

Yet another parameter which is interesting is, a thermal cracking index, which is what I am calling TCI. This is the ratio of the tensile strength and the maximum tensile stress of concrete at a given point and time. So, we are talking of tensile strength which develops over period of time and the tensile stresses which change over a period of time depending on what the characteristics of the temperature rise and the other properties of concrete are. So, at any instance of time if we take the ratio of the tensile strength and the tensile stress, a maximum tensile stress in the block then, we can talk in terms of a thermal cracking index and the higher it is the better it is. Because, what a higher TCI would indicate that the tensile strength at that point and time is so much higher than the maximum tensile stress.

So, if we have a tensile strength of 2 M P a and tensile stress of 1 M P a then, our TCI will be 2 which means that we have sufficient strength to sustain or withstand the kind of tensile stresses that are formed. Now, the tensile strength for the purpose of calculating the TCI can be taken to be at the time of the peak thermal stress, it cannot be a constant. And as I have said the TCI will be now time dependent because that both the tensile strength as well as the tensile stress they keep changing with time because a temperature change with time, the tensile strength changes with time and therefore, the TCI is time dependent and what we need to do is to take the minimum TCI and see whether our concrete meets that criteria that we have set for it or not.

We have already studied or we have already discussed that we would like to have as higher TCI is possible because that will give us more caution as far as our ability or the ability of the concrete to withstand our tensile stress, if the tensile stress and is higher than the tensile strength obviously, the concrete is going to crack and that is something which we want to avoid. So, that principle is what is manifested in a thermal cracking index, the ratio of tensile strength and the tensile stress at a given point and time.

So, if you look at it graphically this is schematic diagram showing the probability of cracking and the thermal cracking index. So, if we have a thermal cracking index of 1, that is the tensile strength and concrete is the same as the maximum tensile stress. Then, the concrete is as likely to crack as an unlikely to crack of course, we do not know much about it and therefore, this is taken as 0.5. Whereas, if the thermal cracking index becomes less than 1 its more or less certain that the concrete will crack.

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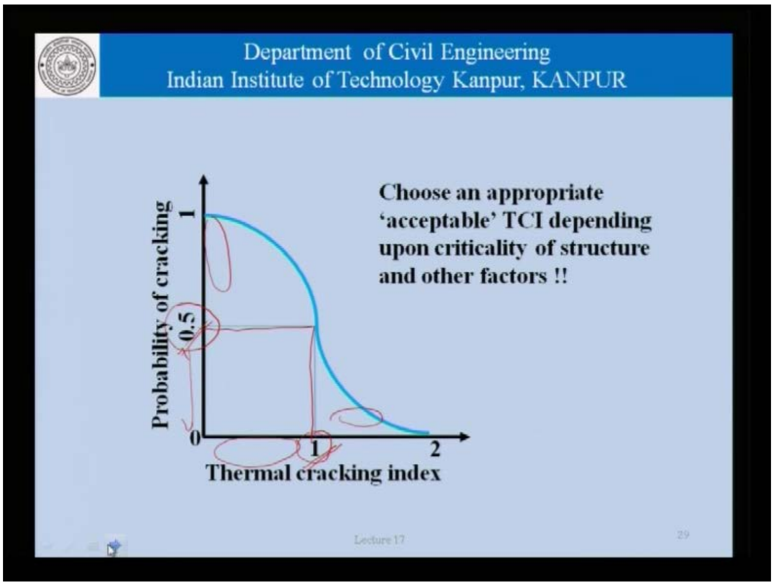

If it increases and becomes greater than 1 then the probability of cracking goes down and we are operating in this range. What we should remember is that, cracking at the end of it is a very difficult phenomenon to predict. And therefore, even with a high cracking index the possibility that we will miss out some portion of concrete which may have cracks cannot be ruled out. And similarly, at low values of the TCI it is not really sure that cracks will always be found and formed everywhere and therefore, there is a possibility that the cracks will not found and that is why this diagram has been drawn the way it has been drawn and the probability of cracking and the thermal cracking index of 1 has been taken to be 0.5.

Now, depending upon the criticality of the structure and other factors we can choose an appropriate TCI. So, the designer can specify a TCI that well for a particular construction we want that the minimum thermal cracking index should be 1.5 or 1.7. And then, the entire discussion becomes focused on whether we are able to get that thermal cracking index considering the heat generation as well as heat dissipation.

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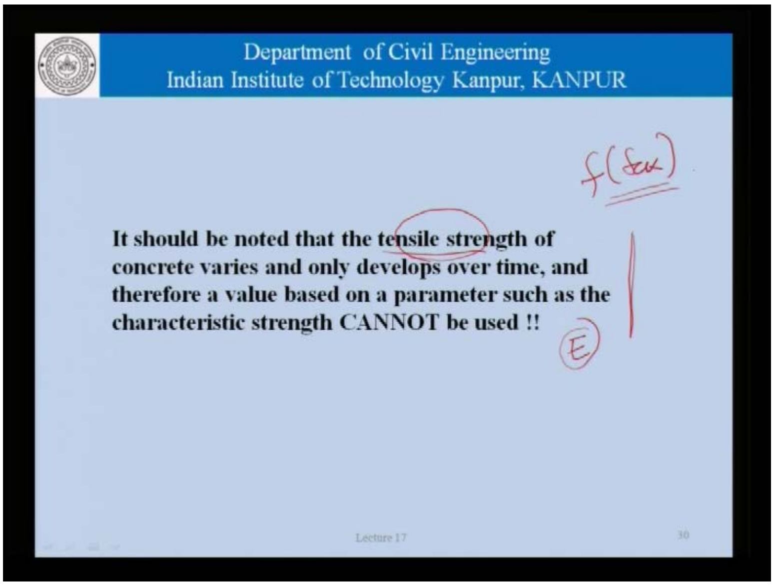

It should be noted that the tensile strength of concrete varies with time and only develops gradually and therefore, the value based on the parameters such as the characteristics strength cannot be used. What we want to say here is that, whether it is a tensile strength or it is a modulus of elasticity course often give us these values as a function of the characteristics strength 5,000 times c k, 0.7 times f c k and so on and so forth. But, these values are different than those that should be used for mass concrete applications because these values which are given in terms of the characteristics strength are valid for mature concrete, concrete which has sufficiently hydrated and gain strength.

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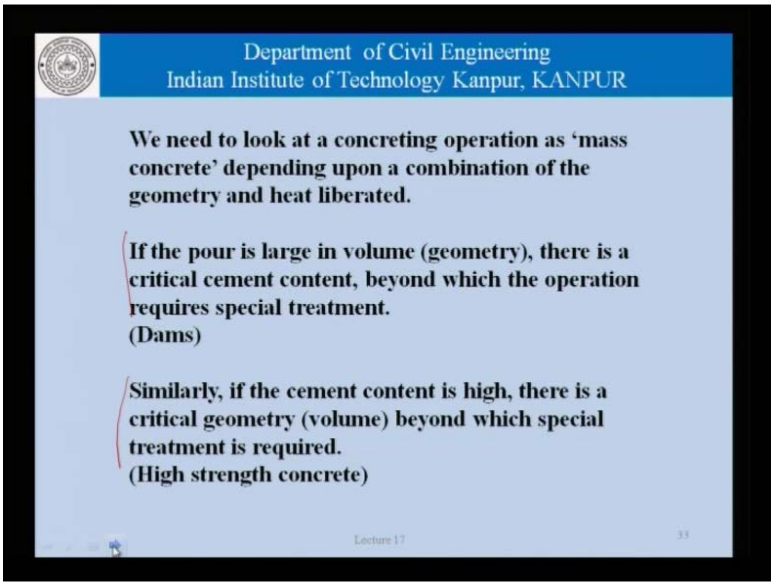

What we are talking mass concrete applications is instantaneous values in the early stages of concrete and therefore, we should use, we need to determine these values as we go along in our discussion, as we go along with the concrete construction. Summarizing, what I would like to say is that we need to look at a concreting operation as mass concrete depending upon a combination of the geometry and the heat liberated. If the pour is large volume that is the geometry there is a critical cement content beyond which the operation requires a special treatment.

Similarly, if he cement content is high there is a critical geometry or the volume beyond which special treatment is required. You can obviously, recognize this part as relevant for dam construction where we have large volumes of concrete been poured, we are not particularly bothered about the strength of the concrete 10 M Pa, 12 M Pa. I think these are the numbers that we mention last time.

Similarly, as far as this part is concerned we are talking about high strength concrete and in high strength concrete there is a geometry beyond which special treatment is required. In the case of dams there is a critical cement content which will make it important, which will necessity considerations of mass concrete to be applied. With this we come to an end of 1 part of our discussion.

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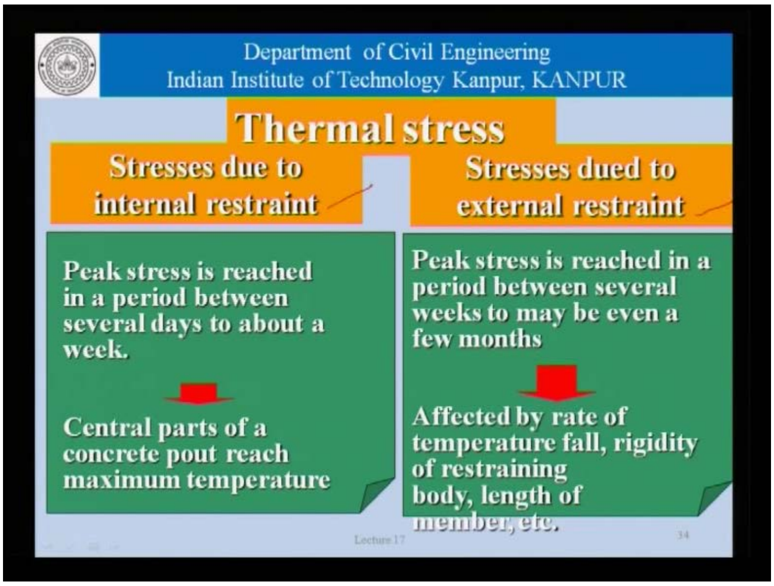

Now the second part of the discussion today, deals with the concept of thermal stresses due to internal restraint and external restraint. Now, in the case of internal restraint we have bothered about peak stresses been reached in a period between several days to about a week. And the central part of a concrete pour reaching of maximum temperature and the temperature difference between the core of the concrete and the surface. In the case of external restrained, we are talking about peak stresses been reached in a period which varies from several weeks and may be few months. In the case of external restraint the discussion is effected by the rate of temperature fall rigidity of the restraining body length of the member and so on.

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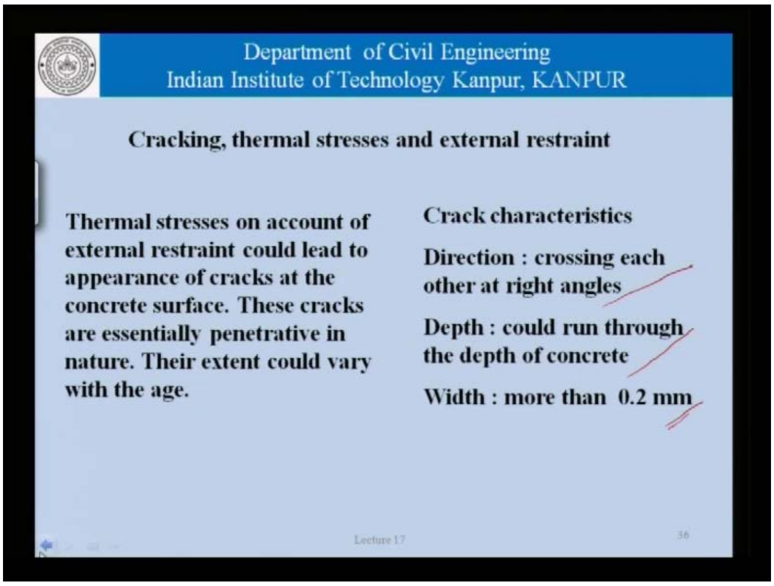

As far as cracking thermal stresses in internal restraint is concerned, the thermal stresses on account of internal restrain could lead to appearance of cracks and the concrete surface which are either vertical or horizontal, which could be several centimeters to several times of centimeter deep. But, they are only about point 1 mm as far as width is concerned they are not very void cracks. Whereas, the cracking on account of external restraint, these cracks are essentially penetrative in nature and their restraint could vary with age they sometimes cross at right angle and run right through the depth of concrete and measure more than point 2 mm width. In fact, you would recall a kind of cracks that we showed in an example last class, in an example in the last discussion where we showed formation of cracks and we showed, and we showed that those cracks run through the body of concrete.

This closes our discussion on the basic theory of mass concrete or a theoretical qualitative discussion on mass concrete from this point onwards what I am going to share with you is the work of the gradual student who did his piyius with professor D C Rai in our institute and worked on thermal stresses in mass concrete at early ages. So, in this presentation or parts of this presentation we would see the actual numbers that were obtained in a laboratory study which illustrate the kind of discussion that we have been doing in terms of temperature rise, temperature fall, and the temperature at different parts of the concrete and so on and so forth.

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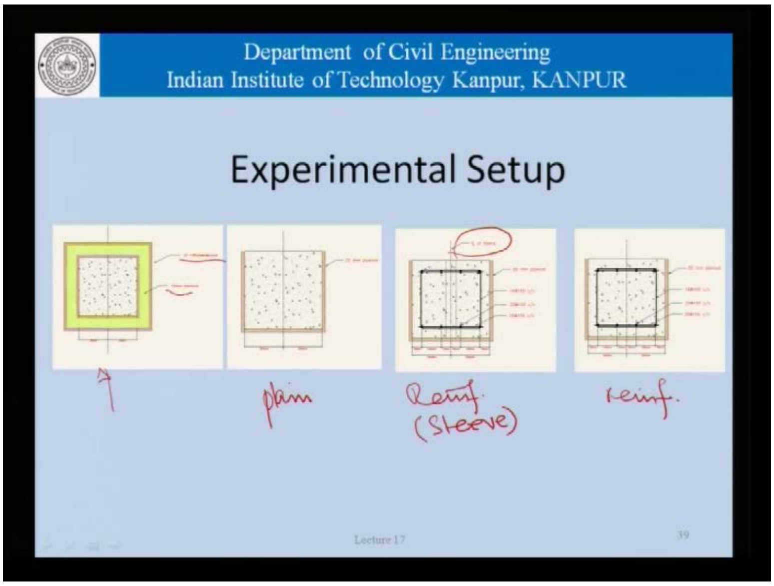

This picture shows the experimental setup which was used. This is a plain concrete block that was cast, this here is a reinforced concrete block that was cast and this here is a reinforced concrete block cast with a sleeve where, water was run to stimulate the conditions of pipe cooling or post cooling, this here is a representation of the formwork where we used a 20 mm thick ply or a 25 mm thick ply with a 100 mm thick insulations with these blocks

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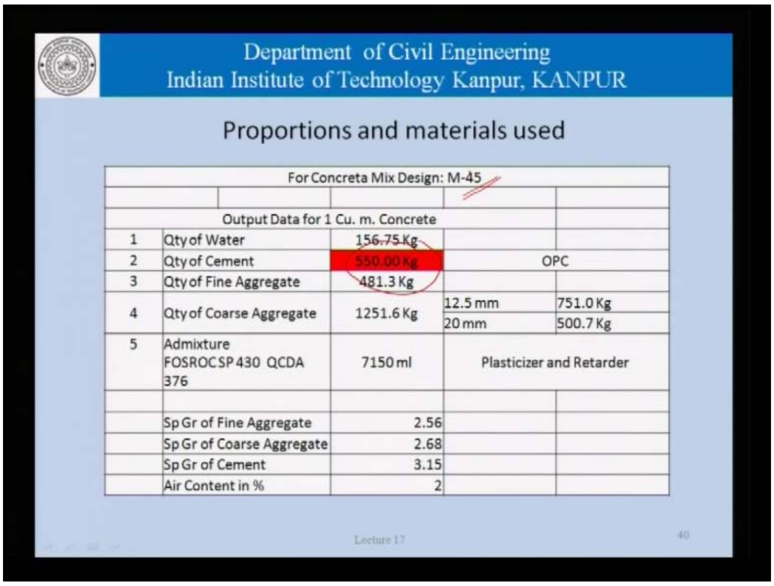

For Concreta Mix Design: M-45				
	Output Data for 1 Cu. m. Concrete			
1	Qty of Water	156.75 Kg		
2	Qty of Cement	550.00 Kg	OPC	
3	Qty of Fine Aggregate	481.3 Kg		
4	Qty of Coarse Aggregate	1251.6 Kg	12.5 mm	751.0 Kg
			20 mm	500.7 Kg
5	Admixture FOSROC SP 430 QCDA 376	7150 ml	Plasticizer and Retarder	
	Sp Gr of Fine Aggregate	2.56		
	Sp Gr of Coarse Aggregate	2.68		
	Sp Gr of Cement	3.15		
	Air Content in %	2		

The experiments were carried out using a concrete with different concretes. Blocks which we talked about last time were cast using different concretes and this is an illustrative example. The cement content is very large because we are trying to work with relatively high strength concrete, and m 45 concretes which and N M 45 concrete which could have a compressive strength about say 55, 56 M P a. So, with this high cement content,

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These are the kind of blocks that were cast. So, this shows the different blocks made with or the form work for the blocks made of plywood and this shows the concrete that has been cast and this here is the representation of the sleeve which was left out or not or the sleeve which was later used for running of water pipes.

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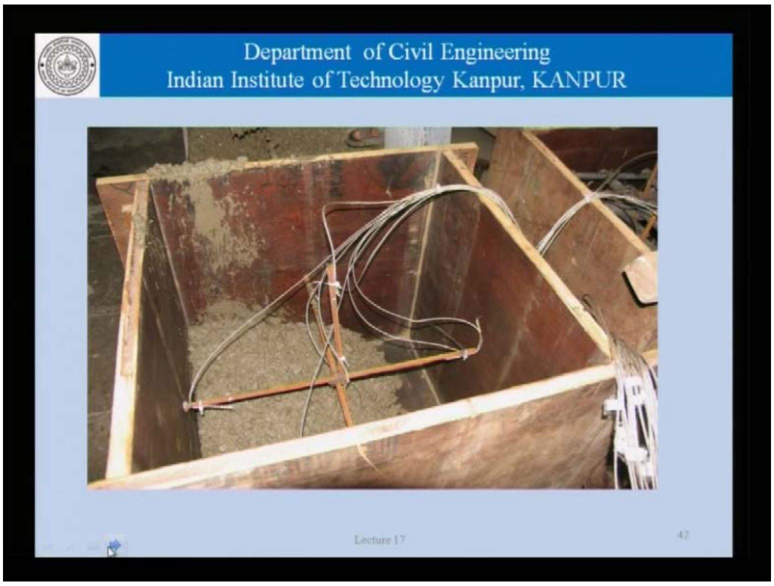

Now, this is the half filed block with thermocouples being used at different places to monitor the temperature of concrete during the hydration of cement and the subsequent cooling and here is the insulation.

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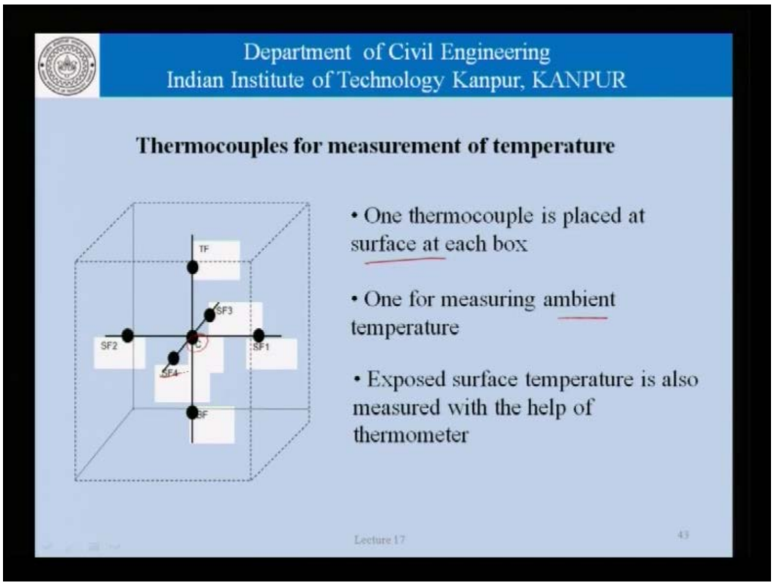

This is the diagrammatic representation of the different thermocouples that were used for measurement of temperature. Thermocouples were placed at the surface of each box. Ambient temperature, exposed surface temperature is also measured with the help of thermometer. There is a center and there is a faith, there are these phases and there is the bottom there is the top.

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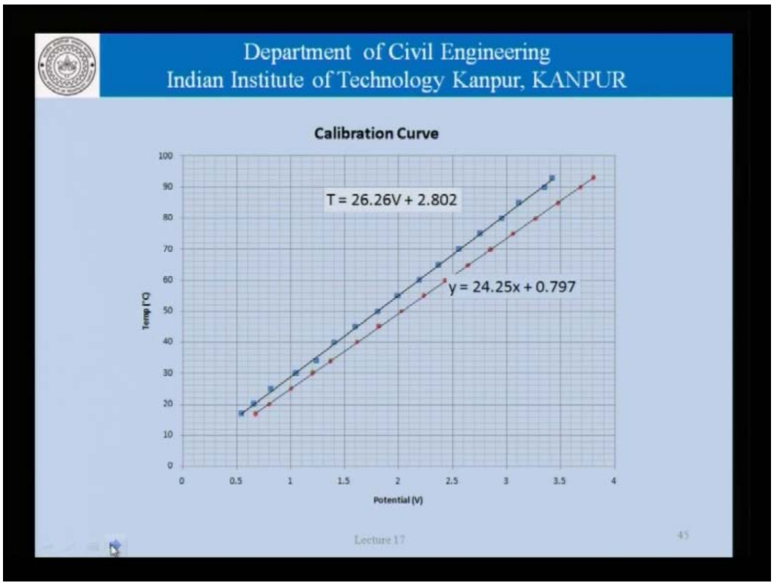

So, thermocouples were used to monitor the temperature at different points in the concrete and was validated using water to give us these kind of values which basically showed at the thermocouples were working properly and within a range of let us say 0 degrees to 100 degrees, we have reasonably accurate way of understanding or measuring the temperature.

Now, after the concrete had been cast and all these thermocouples were in place with different blocks and the different kinds of concrete indeed, the data acquisition becomes the problem. So, a data acquisition system was used as can be seen here different kinds of software's whatever they are used in the laboratory are used to acquire all the temperature changes or all the measured values of temperature at different locations in the concrete of the plain concrete block, the reinforced concrete block and the concrete block with reinforcement and the sleeve that ran through it.

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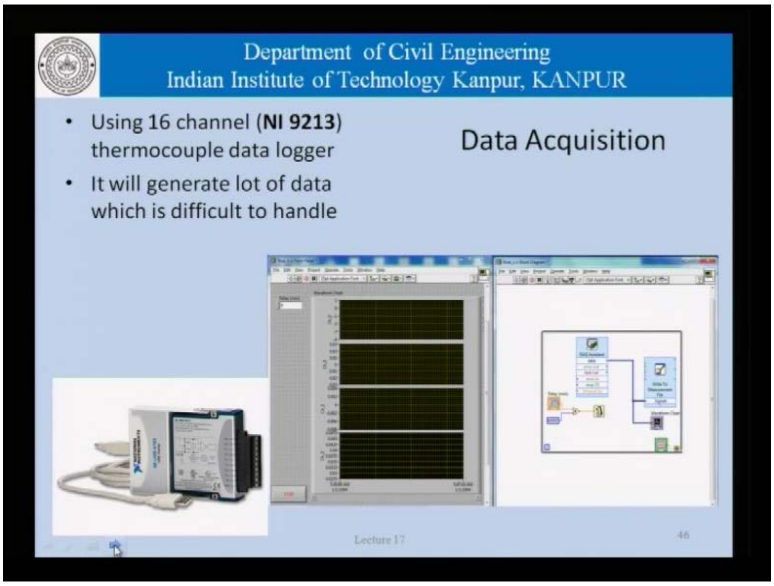

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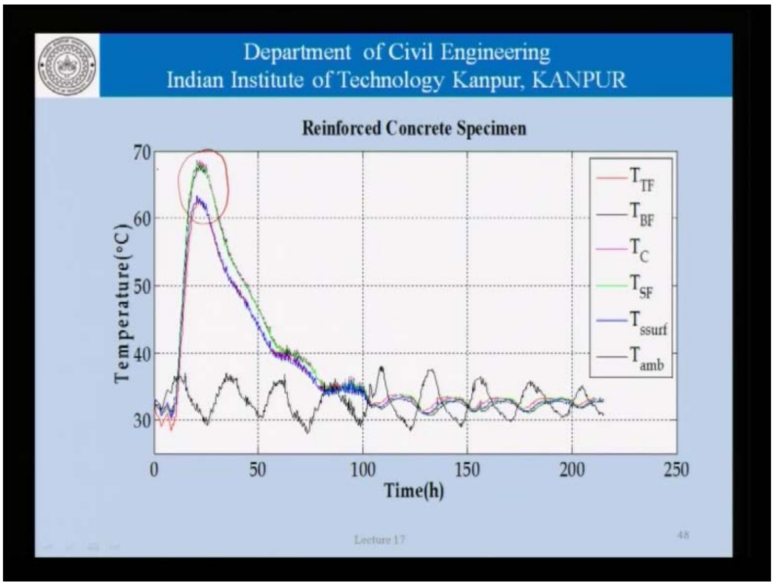

Now here are the results. So, if you look at the concrete specimen there are different readings that we have, the peak temperature that we get in terms of hours is somewhere here and the values range from say, 60 to 70 degree centigrade. With the ambient temperature varying the weight is shown here similarly, for the reinforced concrete specimen. Now it is interesting to see that as far as the reinforced concrete specimen is concerned, the peak temperature is not very much different from the plain concrete and that is the way it possibly should be because the presence of reinforcement per say does not alter the amount of heat liberated, what the reinforcement does is, to restrict the movement of concrete as far as expansion or construction is concerned but, as far as the temperatures are concerned they may still be rising the way they should rise.

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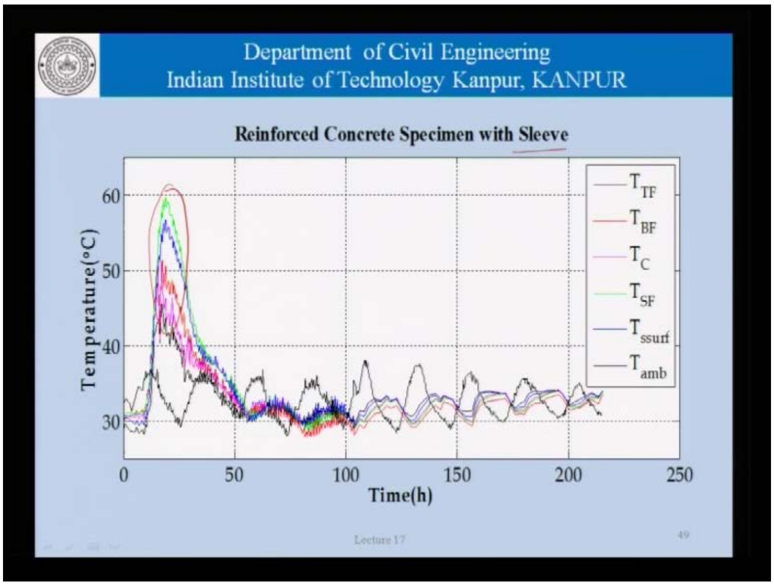

Coming to the temperature of the concrete specimen with sleeve these temperatures are 10 to 15 degrees lower than those observed in the case of plain concrete and the normally reinforced concrete and that shows the importance of the heat being gotten rid of through the sleeve.

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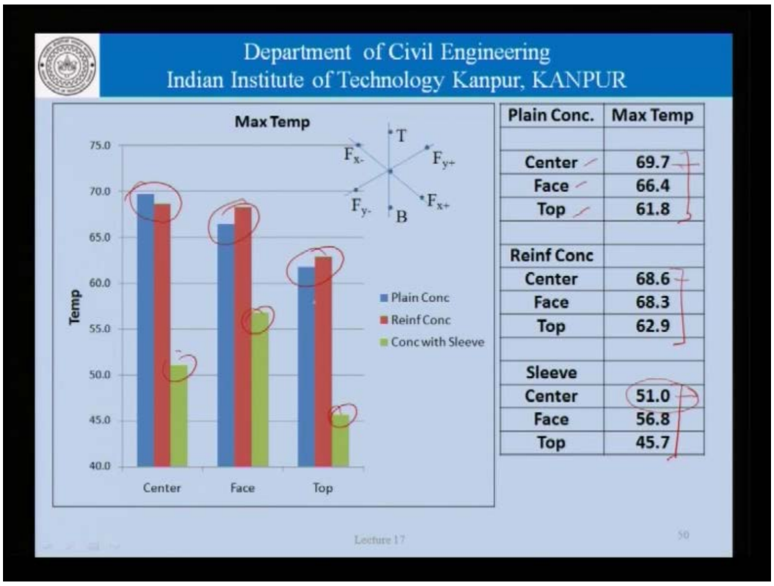

If we look at a graphical representation of these temperatures, if we look at plain concrete; the center; the phase and the top these are the values in reinforced concrete, these are the values and the center or the sleeve or the specimen with sleeve these are the values. So, it is interesting to see that even though in this case the center is higher than at other locations and that is the kind of concept that we are talking of in terms of a core of concrete. Here this center is at a lower value because we have a sleeve there and that is helping us get rid of the temperatures or getting rid of the heat which results in lower temperatures. And this is a graphical representation of the temperatures with these temperatures be more or less similar and these temperatures being actually much lower than what is observed in the other two cases.

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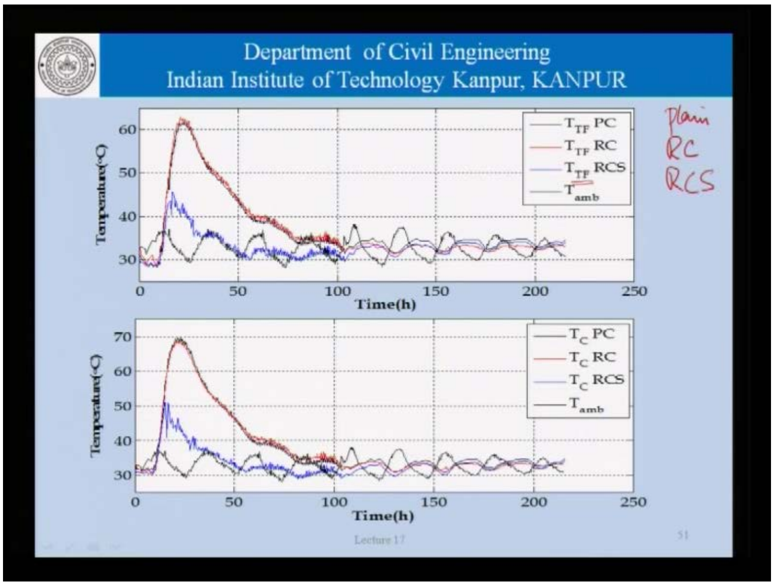

These pictures compare the temperature histories obtain for the plain concrete, the reinforced concrete and the reinforced concrete with the sleeve. So, here we have the temperature at the top and here we have the temperature at the center for these 3 specimens.

Similarly, in this case we have the bottom phase. At the bottom phase again the results are similar. And the side phases, at the side phases the difference is much smaller because at the sides the effect of having a sleeve is reduced but, still there to cause some difference in the peak temperatures.

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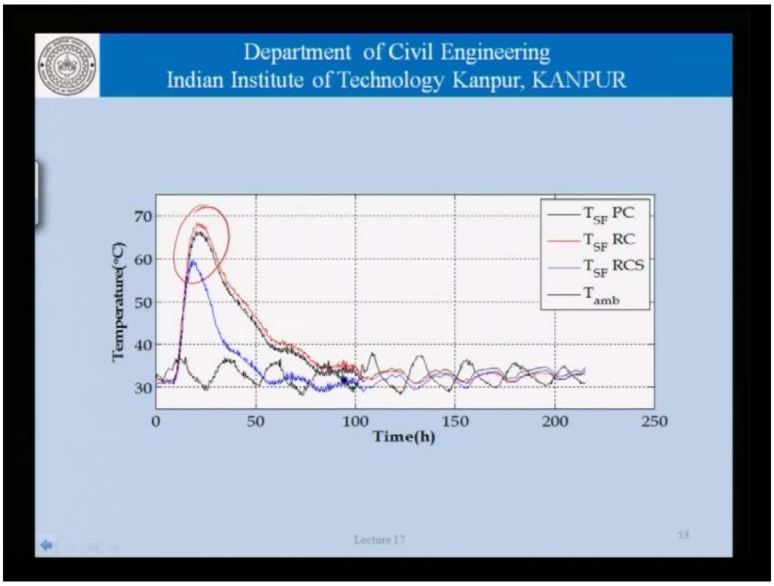

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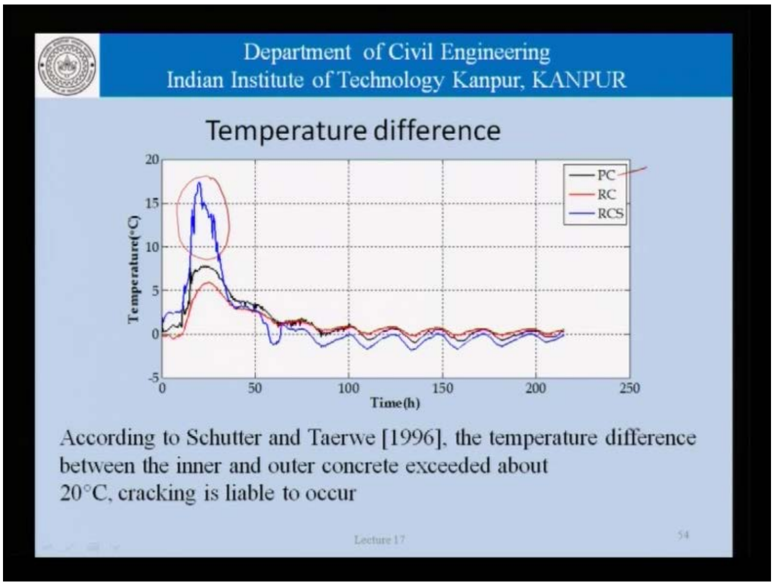

Now, if you look at the temperature differences then we look at plain concrete, the reinforced concrete and the reinforce concrete with sleeve. Then, we find that the temperature difference is the highest. Now having seen the experimental result, let us try to see what goes on in a numerical simulation or an analytical study of mass concrete.

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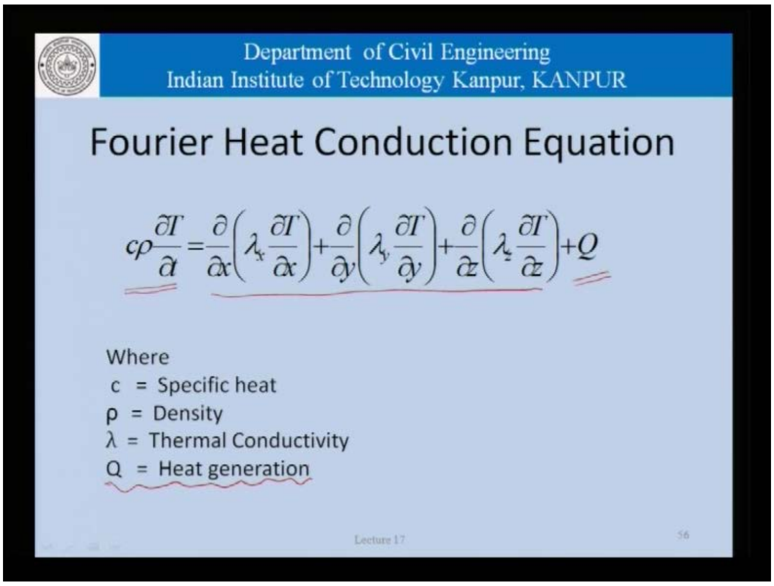

What we really need to solve is the Fourier heat conduction equation, which gives us how the temperature varies with time in a three-dimensional plot or in a 3 dimensional space when there is a certain amount of heat generation taking place in that block of concrete. And in order to solve this equation what we need is a lot of boundary conditions.

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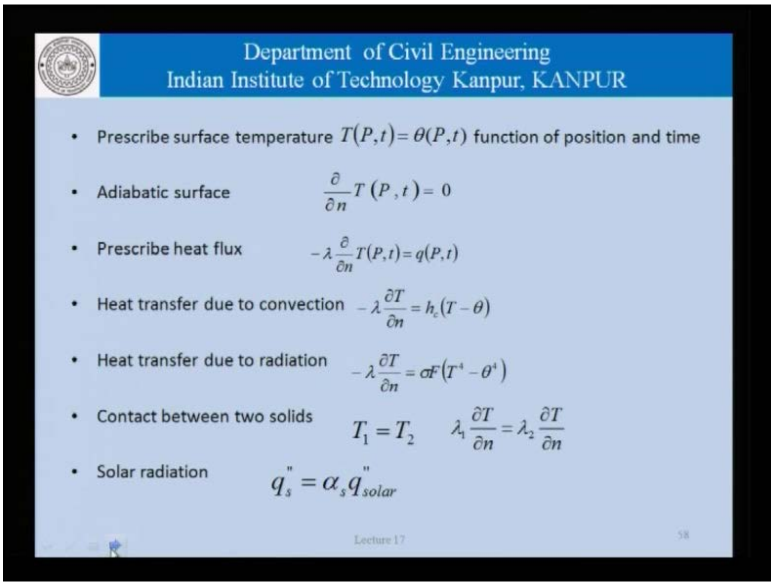

And these boundary conditions could be in terms of the prescribed surface temperature, the adiabatic surface temperature, the prescribed heat flux, heat transfer due to convection, heat transfer due to radiation, the contact between 2 solids, solar radiation and so on and so forth.

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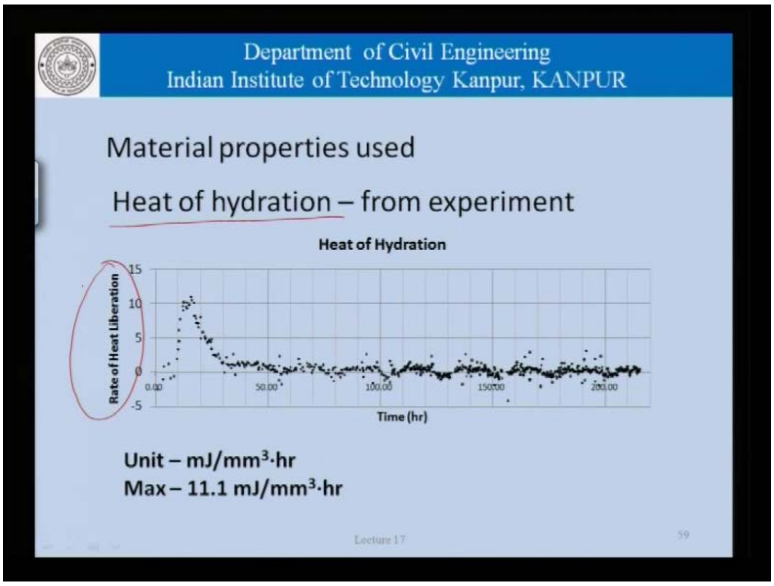

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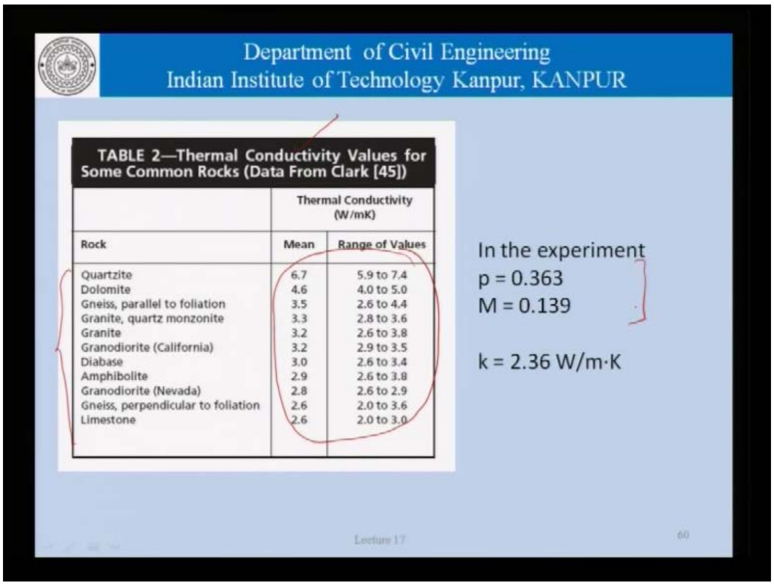

	Thermal Conductivity (W/mK)	
Rock	Mean	Range of Values
Quartzite	6.7	5.9 to 7.4
Dolomite	4.6	4.0 to 5.0
Gneiss, parallel to foliation	3.5	2.6 to 4.4
Granite, quartz monzonite	3.3	2.8 to 3.6
Granite	3.2	2.6 to 3.8
Granodiorite (California)	3.2	2.9 to 3.5
Diabase	3.0	2.6 to 3.4
Amphibolite	2.9	2.6 to 3.8
Granodiorite (Nevada)	2.8	2.6 to 2.9
Gneiss, perpendicular to foliation	2.6	2.0 to 3.6
Limestone	2.6	2.0 to 3.0

So, if we do that kind of analysis we have to understand also the material properties and these are the kind of material properties that we need to determine in the lab. So, apart from the doing techniques experiments with concrete specimens we also need to understand the heat of hydration of cement and this is the plot of the rate of heat of hydration or the rate of liberation of the heat of hydration and this becomes an important input in our simulation exercise.

Then, we have been talking about the effect of the properties of rock on the properties of concrete in terms of thermal conductivity. Now these are the values that are given for thermal conductivity in the literature. So, we can use some set of values based on the published values literature and the kind of aggregates that we actually use in the study.

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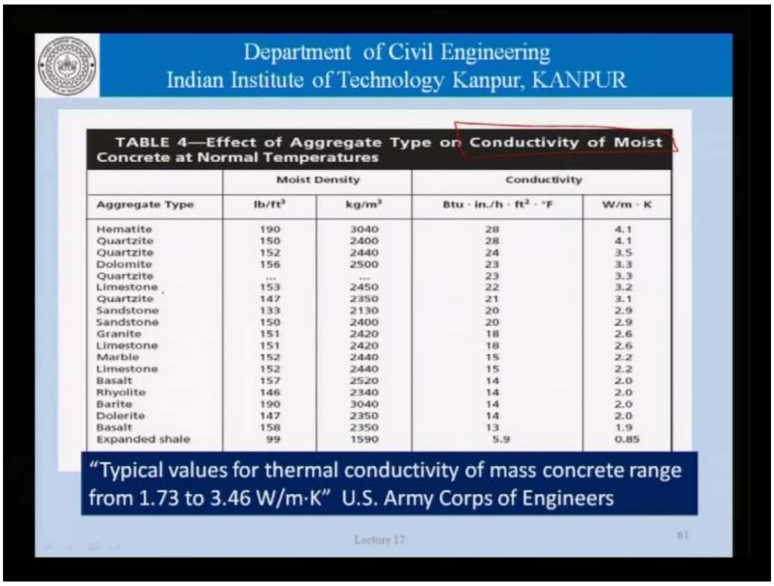

TABLE 4—Effect of Aggregate Type on Conductivity of Moist Concrete at Normal Temperatures

	Moist Density		Conductivity	
Aggregate Type	lb/ft³	kg/m³	Btu · in./h · ft² · °F	W/m · K
Hematite	190	3040	28	4.1
Quartzite	150	2400	28	4.1
Quartzite	152	2440	24	3.5
Dolomite	156	2500	23	3.3
Quartzite	...	...	23	3.3
Limestone	153	2450	22	3.2
Quartzite	147	2350	21	3.1
Sandstone	133	2130	20	2.9
Sandstone	150	2400	20	2.9
Granite	151	2420	18	2.6
Limestone	151	2420	18	2.6
Marble	152	2440	15	2.2
Limestone	152	2440	15	2.2
Basalt	157	2520	14	2.0
Rhyolite	146	2340	14	2.0
Barite	190	3040	14	2.0
Dolerite	147	2350	14	2.0
Basalt	158	2350	13	1.9
Expanded shale	99	1590	5.9	0.85

We also need information about the effect of aggregate type on the conductivity of the concrete. Now, concrete needs to conduct the heat that is heat needs to flow through concrete and that again depends on the properties of the aggregate. Because we should remember that the end of it concrete has about 50 to 55 may be even 60 percent in case of mass concrete it could be even more volume fraction of coarse aggregates.

So, if the heat is been conducted through the concrete the concrete will behave as a heterogeneous material, comprising of the mortar phase and the aggregate phase. And that aggregate phase will have an important varying of the properties of that aggregate phase will have an important varying in determining properties such as the conductivity of heat is concerned. So, depending on the aggregate type we will have different densities and different conductivities.

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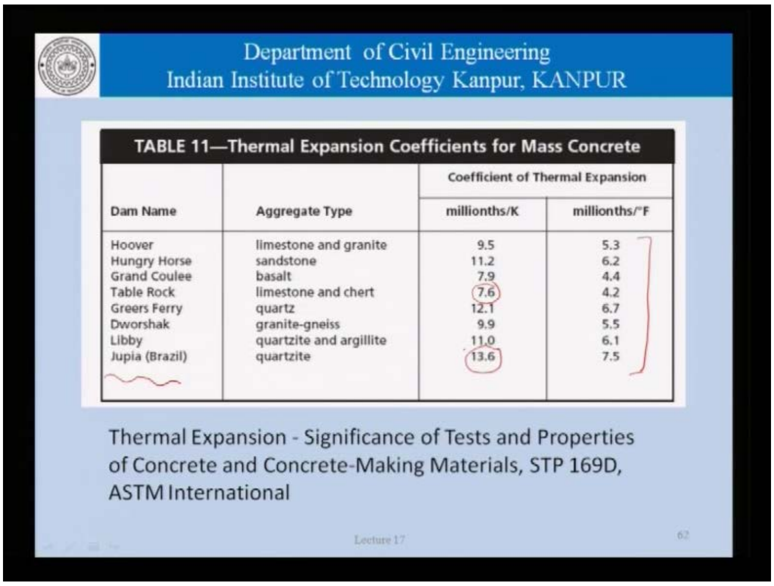

We also need to have data for coefficient of thermal expansion of concrete. And that again varies from aggregate to aggregate and these are the data which have been obtained for different dams, different aggregate types and are listed here. So, we can see that the difference could be as much as let say 7.6 is possibly the minimum here and 13.6 is the maximum. So, it is not really twice but it is something which needs to be kept in mind when we are doing the simulation or analysis.

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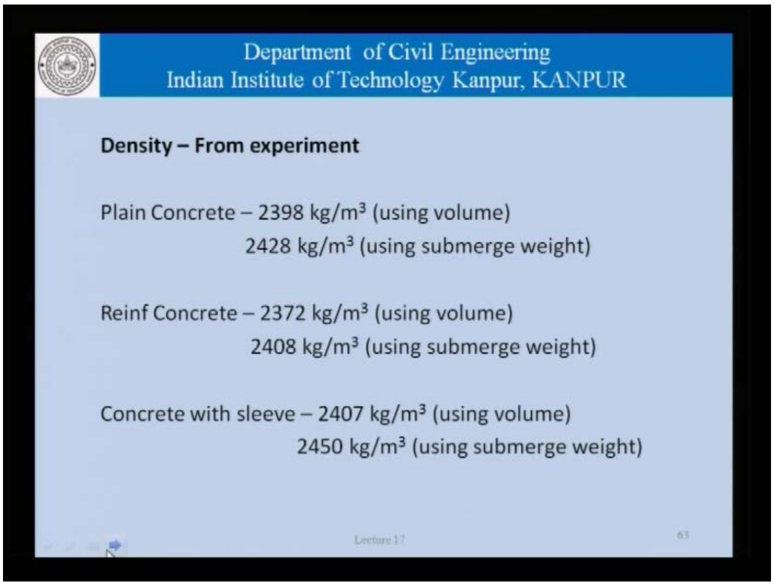

The density of course, another important parameter and we have plain concrete, reinforce concrete, the concrete with the sleeve in this case. And these densities also become important when we are carrying out analysis. Experiments in this study were also carried out using small or smaller blocks.

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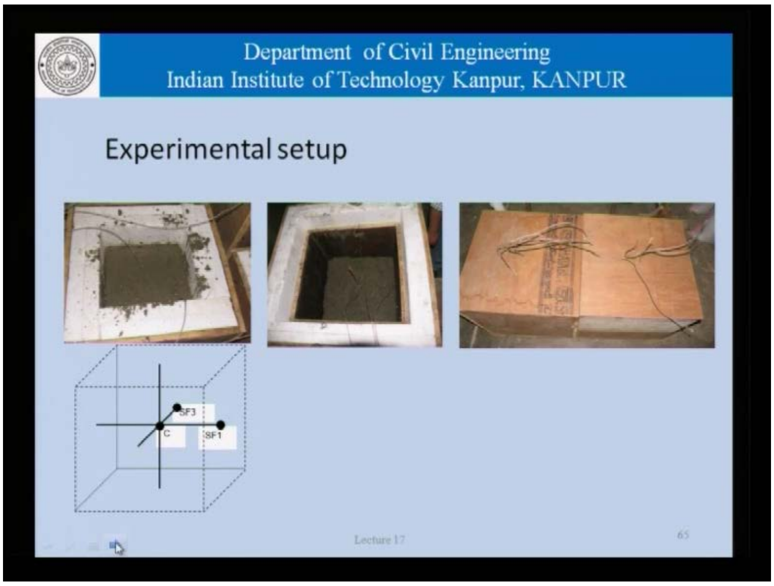

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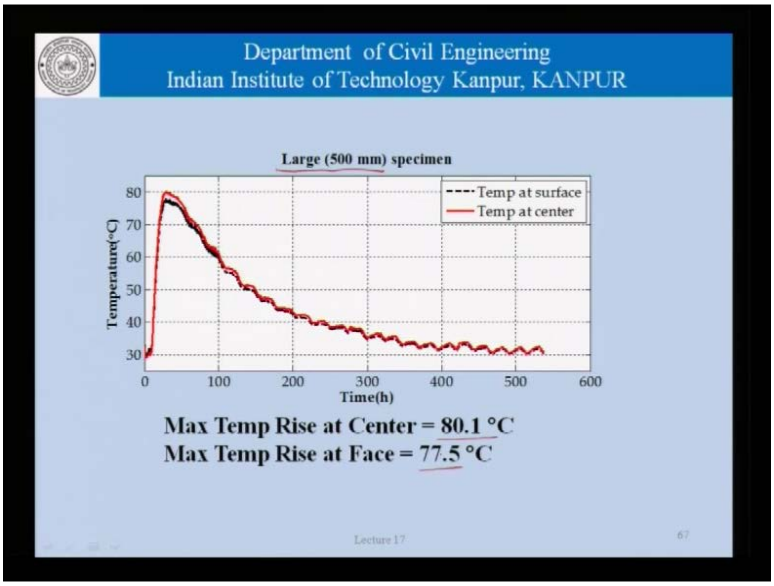

Width 150 mm and there we try to measure the temperature of concrete at the center and the surface and given the size here the difference is not much a 67.2 and 66.8 as far as the temperatures are concerned and that is why we can call it a semi adiabatic cube, that is not there we do not accept much heat transfer to be taking place between the core and the surface if the temperatures are similar. Similarly, if the size of the cube is 500 mm as 50 centimeter cube of concrete then, the temperature difference is about 80.1 versus 77.5. So, these are the kind of data that help us better model a large pour of concrete or a larger pour of concrete which was used in the study here.

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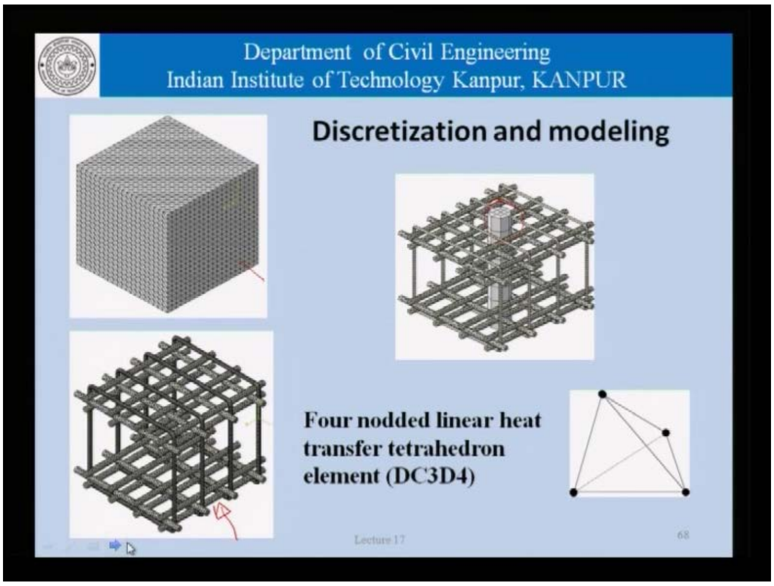

If we look at the Discretization and the Modeling issues, this is the mesh of reinforcement which was used in the concrete, this here is the sleeve which has been kept and this of course, is the plain concrete. 4 nodded linear heat transfer tetrahedron elements were used in the analysis and these are the results that we get in terms of temperatures for the plain concrete specimens.

So, this is the half space that is the section of this cube and we can see these temperatures 65 degrees and so on whereas, the corners here are the coolest at about 51 degrees. Similarly, for the reinforcement concrete these are the reinforcing bars that we see here and we can see in this picture what is the temperature is of these bars and the center core and so on and so forth.

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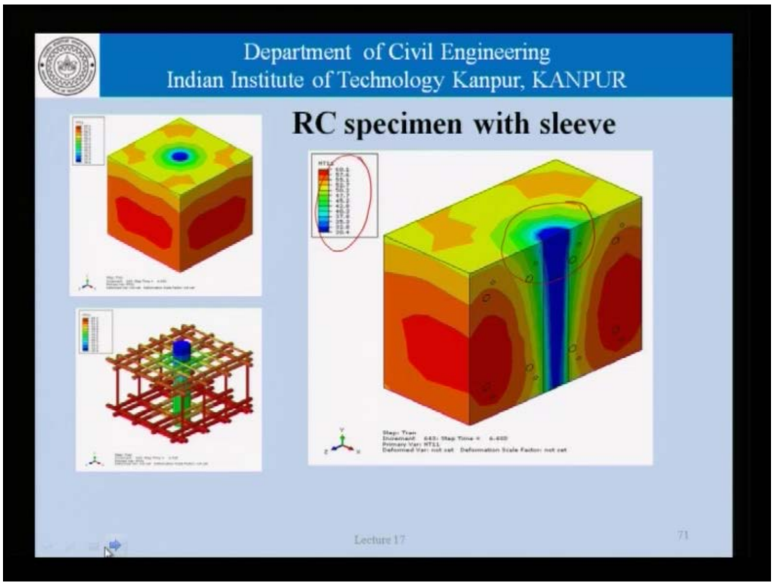

Similarly, for the reinforced concrete specimen with the sleeve we have this temperature distribution which is making it much cooler in the neighborhood of the core and this is scale is quite different the red here is only 60.1 whereas, the 60.1 kind of a number here in this picture would correspond to a green. So, one must remember that these pictures the color itself does not have any significance unless we read what temperature the color is representing.

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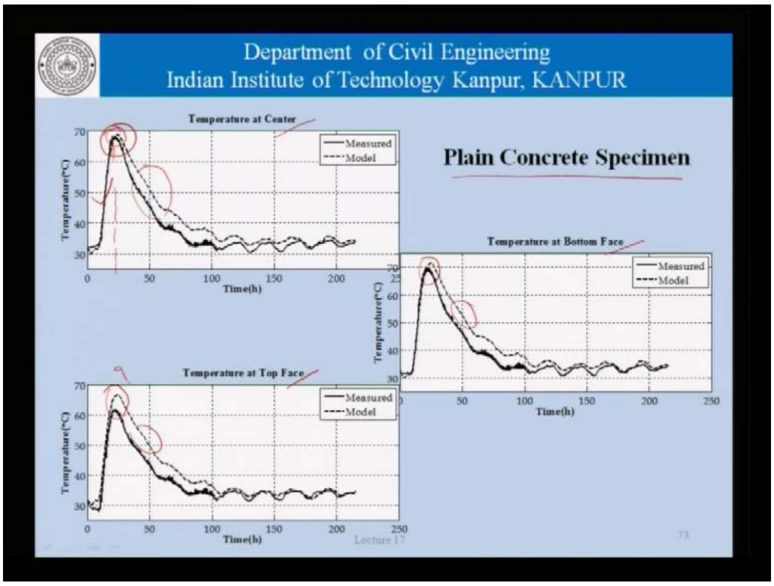

Now, if we compare the results of the measured values and the analytical values. These are some of the comparisons that we get in terms of the plain concretes specimen. This is for the temperature at the center the top phase and the bottom phase. There are two things which we should be looking for when we are talking of when we are discussing these results, one is the peak temperature itself what is the number. The second is the time at which is reached and of course, then we have these rates or the variations during the cooling phase and the heating phase.

So, if we can see from here that the simulation or analysis using the parameters that have been determined or use from the literature is pretty much all right as far as the rising part is concerned. It is quite all right here as far as the peak temperature is concerned it is acceptable here perhaps but, here there is some problem.

Similarly, as far as the falling side of temperature as far as the cooling of concrete is concerned there is some difference and the module is giving higher values than the measured values and that is what we need to rectify, what happens is or what this shows is that the parameters which were importance for the dissipation part of concrete there is some error which is creeping into our calculations which is giving a higher result.

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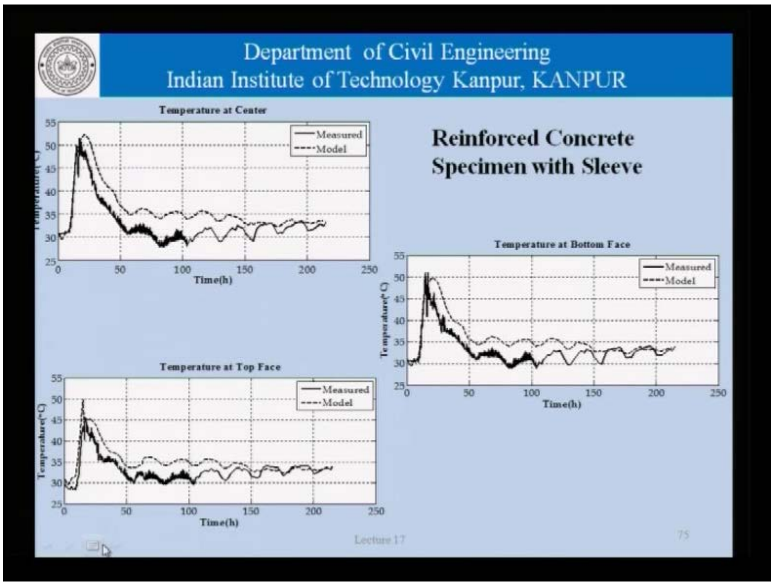

Similarly, for the reinforced concrete specimen or for that matter the concrete specimen with the sleeve. So, in all these cases we see that the rate of temperature rise the peak temperature these are fairly well represented by the model that has been used, the time at which the peak temperature occurs that is also more or less captured but, the model that was adopted was not good enough, if they are looking at the falling side of temperature that is the cooling phase of concrete is concerned.

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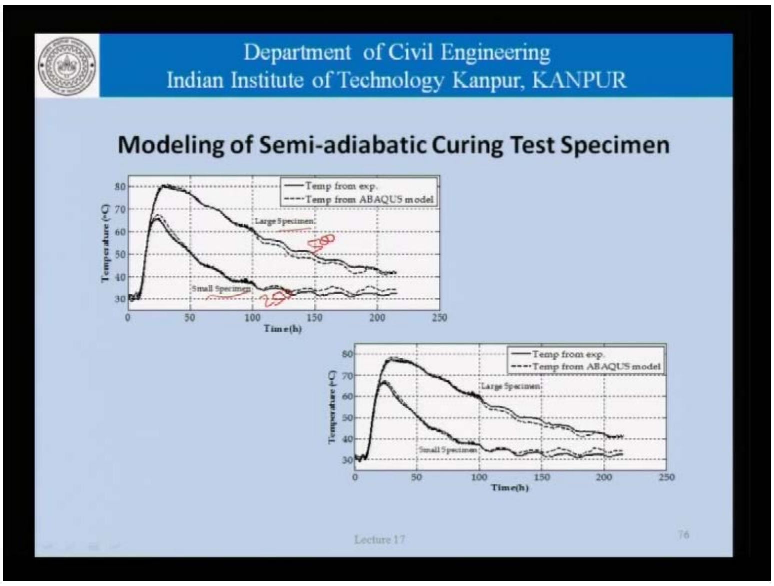

But as far as the semi adiabatic condition is concerned using abacus the results are pretty much in agreement for the smallest specimen as well as the large specimen. The smallest specimen was 200 and 50 mm and the largest specimen was 500 mm.

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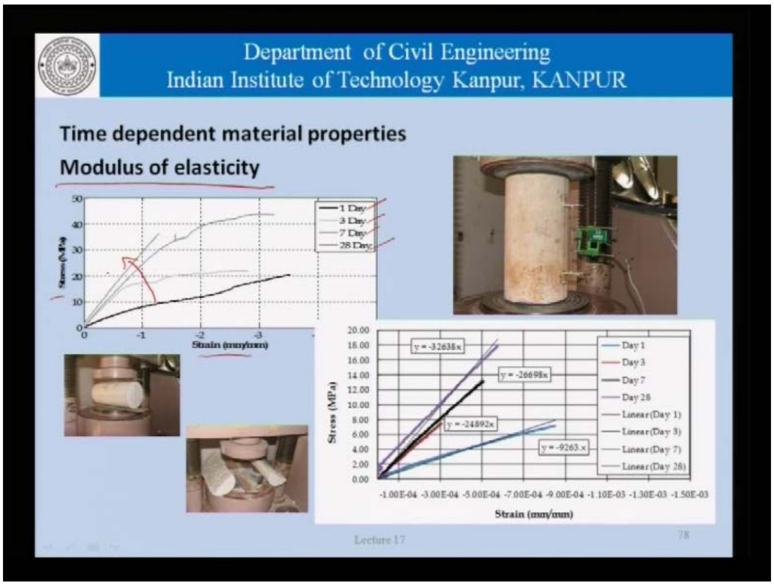

Moving on to this stress analysis, we need to have the modulus of elasticity which is determined. So, if you carry out experiments to determine the modulus of elasticity at 1 day, 3 day, 7 day or 28 day these curves here gives you the a stress strain of concrete. And we can see that as the edge increases the concrete becomes stiffer and if we calculate and if we calculate the values of the modulus of elasticity.

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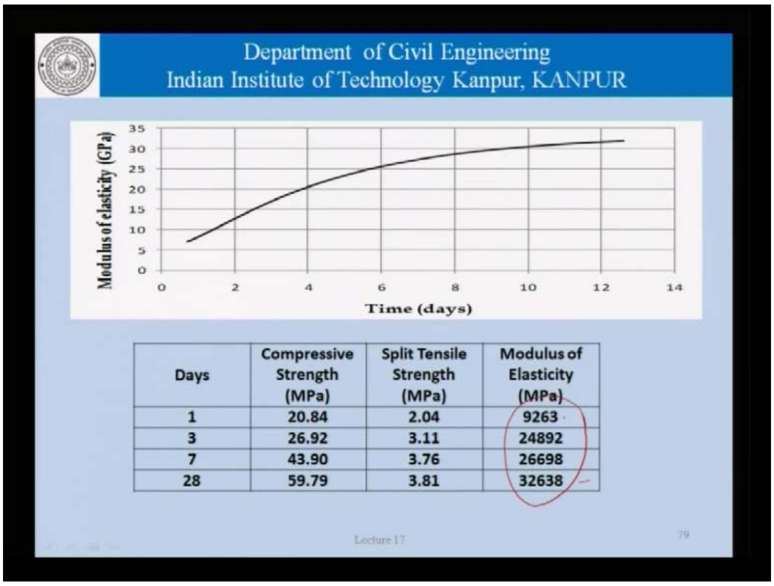

Days	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Modulus of Elasticity (MPa)
1	20.84	2.04	9263
3	26.92	3.11	24892
7	43.90	3.76	26698
28	59.79	3.81	32638

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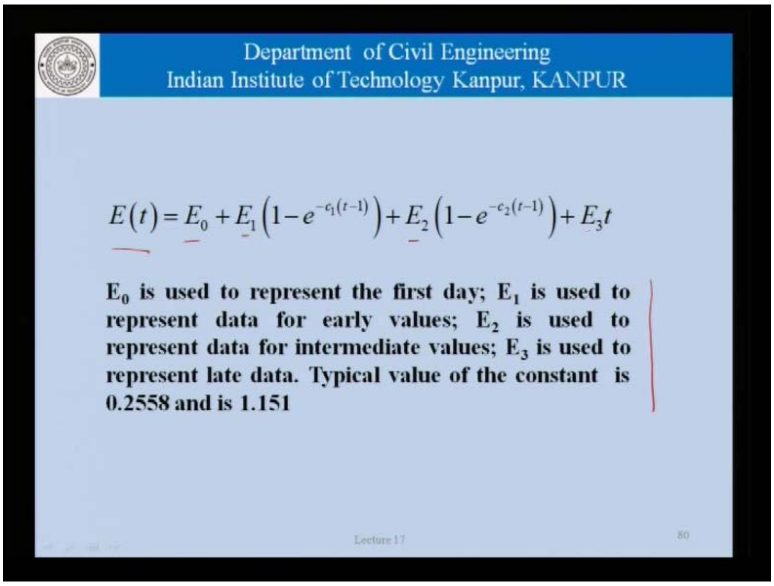

At different points and time, we get these values in terms of M P a for 9,000 to 24,000 to 26 and half thousand may be 32000 at 28 days. So, there is a difference of more than 3 times and therefore, when we try to talk in terms of stress development we must take this into account and incorporate that in the model. So, this is the representation which was used in this model to analytically determine or estimate the values of E as the function of time using E 0, E 1 and E 2 which are defined here and E 3.

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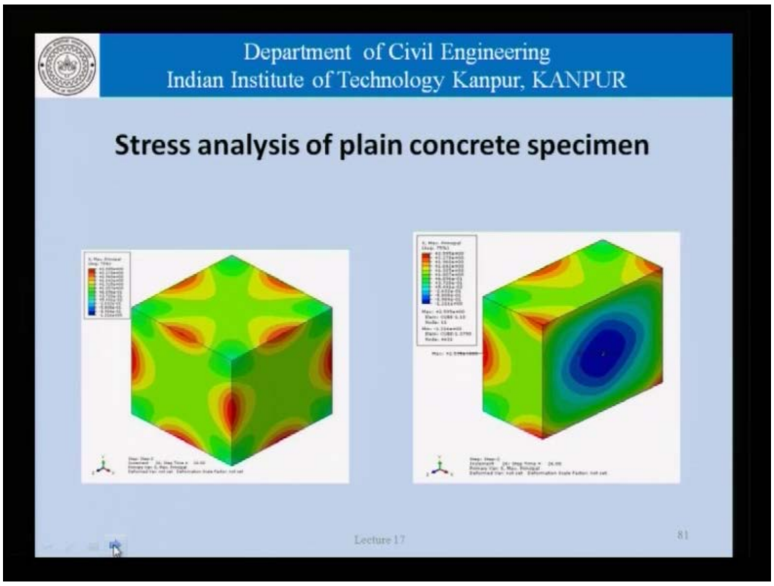

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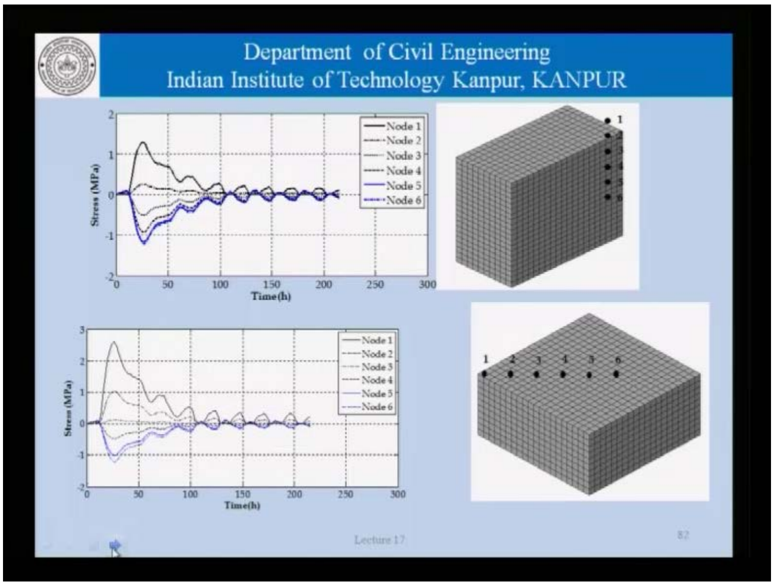

And based on that, we got to do a stress analysis, we find these stress values which are shown in this graph. Being stressed or the thrust in showing these numbers or showing these graphs or pictures is not to understand the quantitative nature of the problem so much as it is to understand that yes, there is a serious amount of mathematics, there is a serious amount of modeling that goes into the process, and we are able to do it, and get results which are closed to that obtained in the experiments.

So, if we look at the stress variation with time we find that the stresses are varying at different nodes or different locations in the concrete lock as a function of time. And this is exactly the kind of concept that we have to keep in mind when we are trying to understand whether or not the concrete will crack. If a certain stresses developed then at that point in time the concrete should have sufficient strength to withstand that stress.

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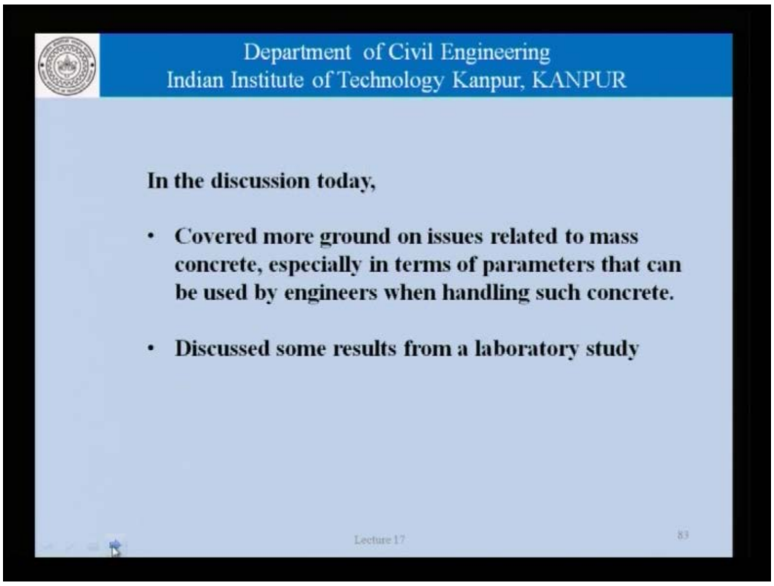

So, in our discussion today we have covered more ground on issues relating to mass concrete especially, in terms parameters that can be used by engineers when handling such concrete and we have discussed some results from a laboratory study to would the discussion in the first part in perspective.

And before we close as usual, let us try to see if we can understand a little bit more about the properties of concrete in the bracket of let us say 3 to 7 days more closely we get information about the effect of the properties of coarse aggregate on the property such as thermal expansion or conductivity or we modulus elasticity of concrete and study available a suggested methods for the estimation of temperature of fresh concrete as a function of the temperature and proportions of the constituent materials.

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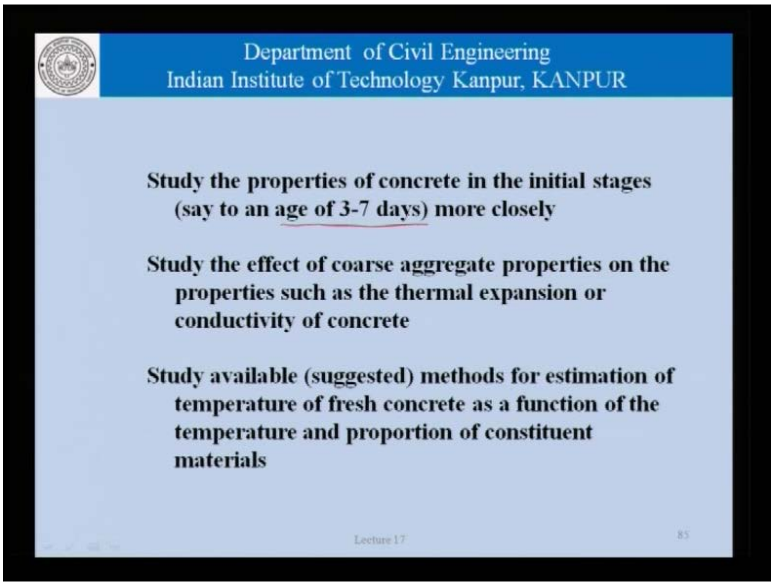

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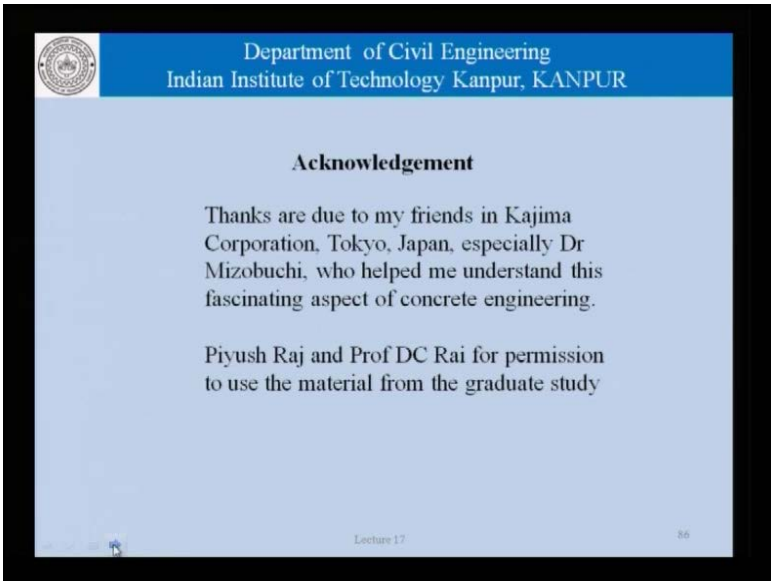

Now, before I close. I would like to thank my friends in Kajima Corporation in Japan especially, Dr Mizobuchi who helped me understand this fascinating aspect of concrete engineering and also to Piyush Raj and Professor Rai for permission to use the material from the graduate study.

Thank you.