Concrete Engineering and Technology
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Lecture - 16
Mass concrete (Part 1 of 2)

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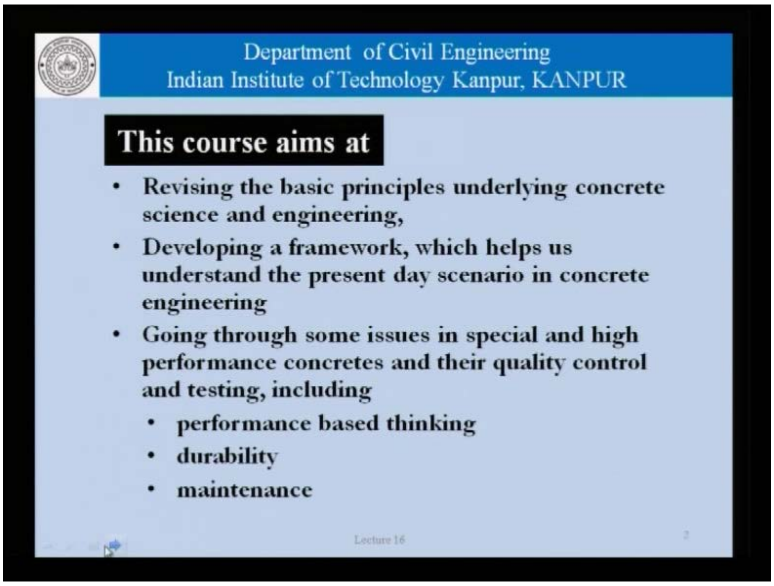

And welcome back to a session on concrete engineering and technology, where we are talking about basic principles and concrete science and engineering, and developing a frame work, where the different topics which are of importance in modern day construction. As far as concrete construction is concerned can be taken care of and studied. Some of the issues that we are trying to deal with are in terms of special and high performance concretes, their quality control and testing especially, related to performance base thinking durability and maintenance.

And we are trying to study the fundamentals, proportioning of concrete mixes, the stages in concrete constructions, special concretes, mechanisms of deterioration, reinforcement and maintenance. Now we will continue our discussion on special concretes today.

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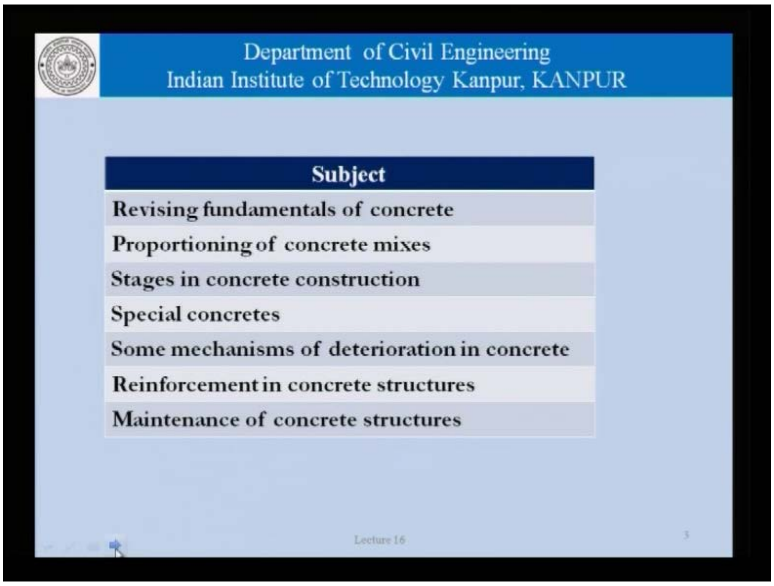

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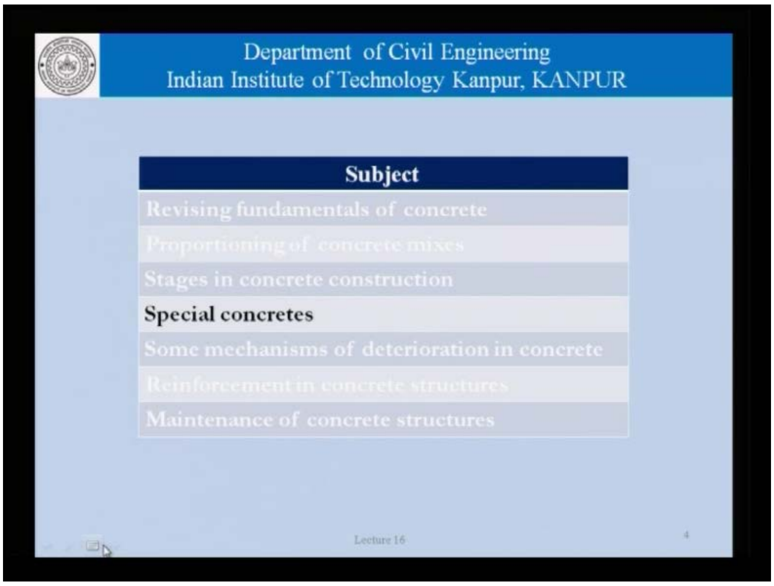

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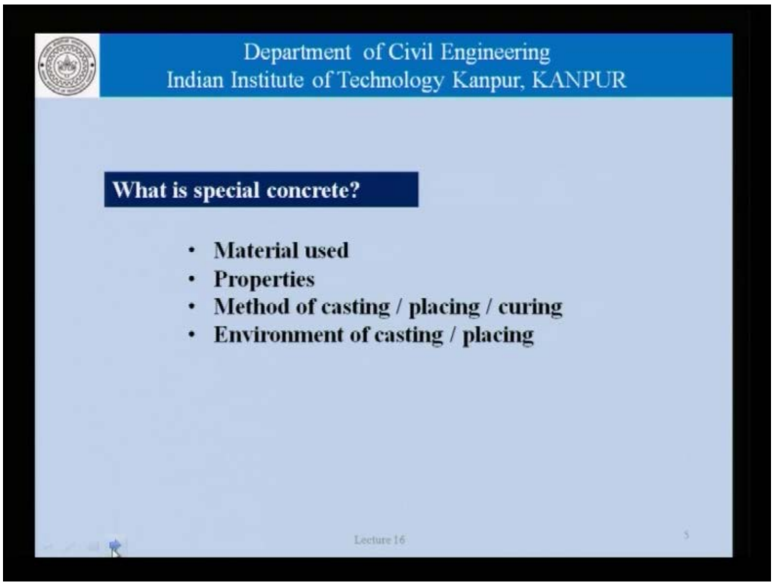

And like we have said, what is the special concrete? It could be in terms of the material that we use other than the normal sand, ordinary Portland cement, water. And course aggregate, it could be in terms of the properties that we except from the concrete in terms of strength, workability and so on. It could be in the terms of the method of casting, placing, or curing short creating is an example of that. It could be in terms of the environment in which the concrete discussed for example, under water and so on.

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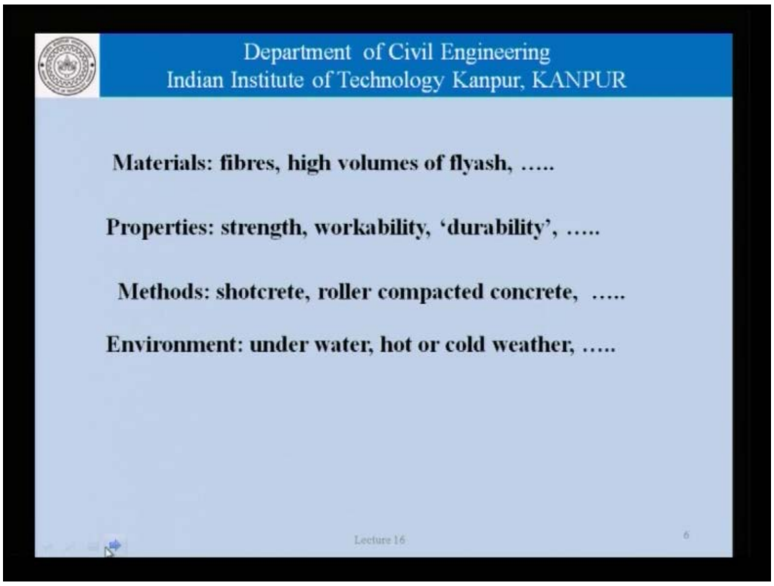

As far as materials are concerned, it could be the use of fibers, high volumes of flash and things like that. As far as properties are concerned: like a mention it could be strength, workability, durability and so on accept the durability of very very difficult property to quantify. As far as methods is concerned: it could be shotcrete, it could be roller compacted concrete. As far as the environment is concerned, it could be under water as I mention it could be hot or cold weather and so on.

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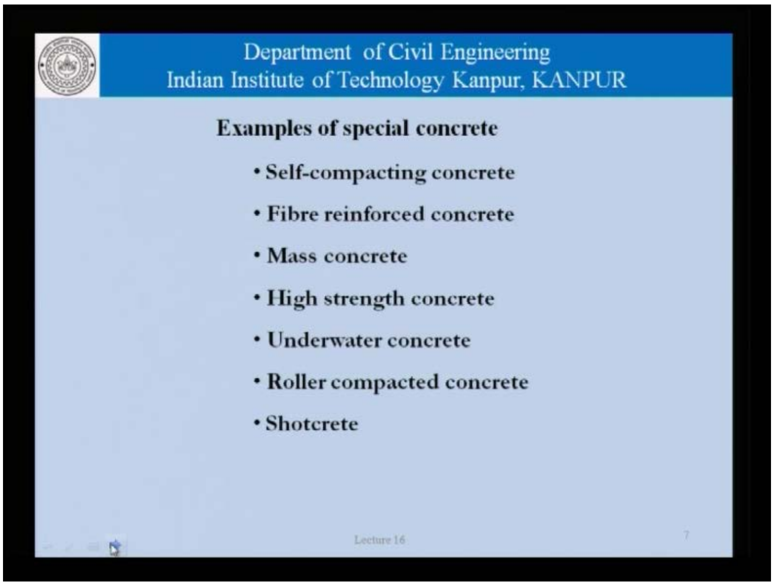

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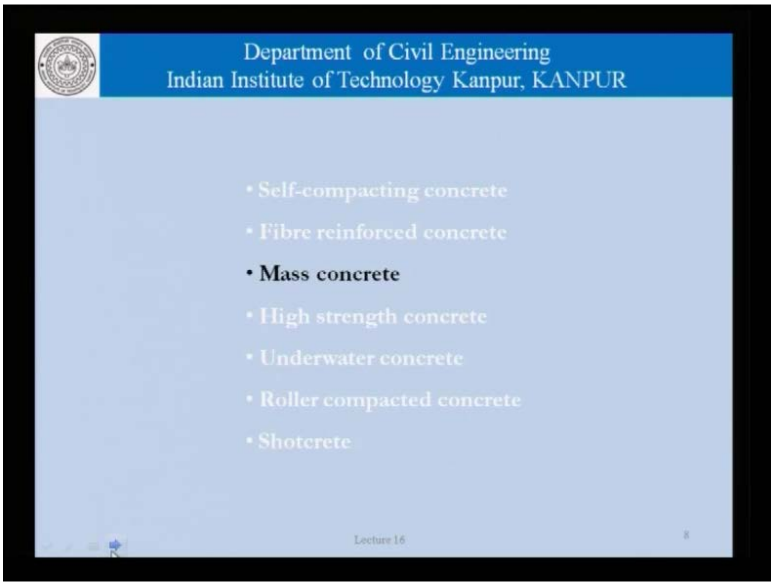

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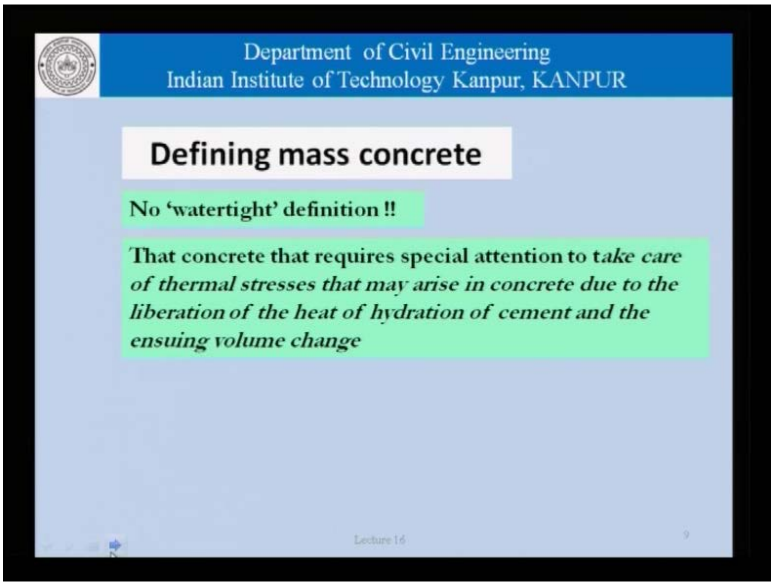

These are some of the examples of special concretes. And today, we will focus or intension on mass concrete. Now, how do we define mass concrete? There is no watertight definition, there is no definition that can be given that ok this is what mass concrete is, accept that the connotation is that it is a large volume of concrete. If you want to define it technically, the ACI and other documents will help us and we can call mass concrete as that which requires is special attention to take care of thermal stresses that may arise in concrete due to the liberation of the heat of hydration of cement and the ensuing volume changes.

So, we are looking at a concrete where, the exothermic reaction of hydration of the ordinary Portland cement which is in integral part of concrete causes temperature rise to such an extent that special measures in need to be taken to take care of that temperature rise because that temperature rise is a complete by formation of stresses within the concrete may be it could result in tracking and also volume changes. So, if there is a special need to specifically take care of the thermal stresses the temperature rise and so on then, that can be called mass concrete.

Now, it is interesting to see that now we are taking up mass concrete as a special concrete where we are trying to invoke temperature rise, development of thermal stresses and so on, as a very very special property of concrete which normally does not require attention but acquires some significance in certain contexts. So, that is what is going to be the subject of discussion today.

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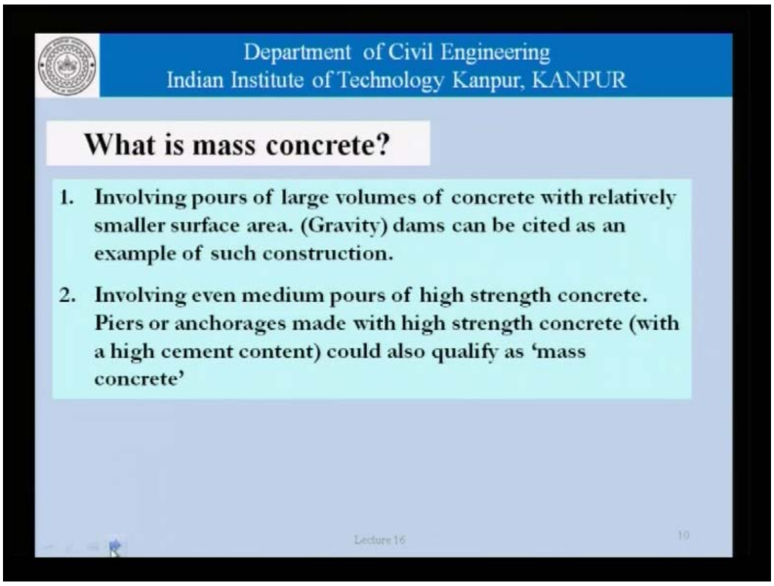

Such concretes could involve pores of large volumes of concrete with relatively small service area and gravity dams, can be sited as an in example of such construction. So, dams are an example where there is a very large volume of concrete cast. In a report, dams are not cast in a single pore, where cast in thousands of pores. So, but each pore is itself a large volume of concrete and cast in a manner that the surface area is very small relatively speaking. And we will see these discussions coming up again and again as we go along in a discussion today. Another situation where mass concrete considerations will apply would be in cases where the volume of concrete pore could be relatively smaller; it could be a medium pore in terms of volume.

But, the concrete used could be high strength concrete. And this high strength concrete has a large amount of cement and if it has a large amount of cement the total amount of heat that is liberated during its hydration is large. And therefore, again the issue of temperature rise, thermal stresses, volume changes all this has to be taken into an account. As far as the construction process concerned: these constructions could involve piers or anchorages where sometimes we try to use high strength concrete in modern day construction.

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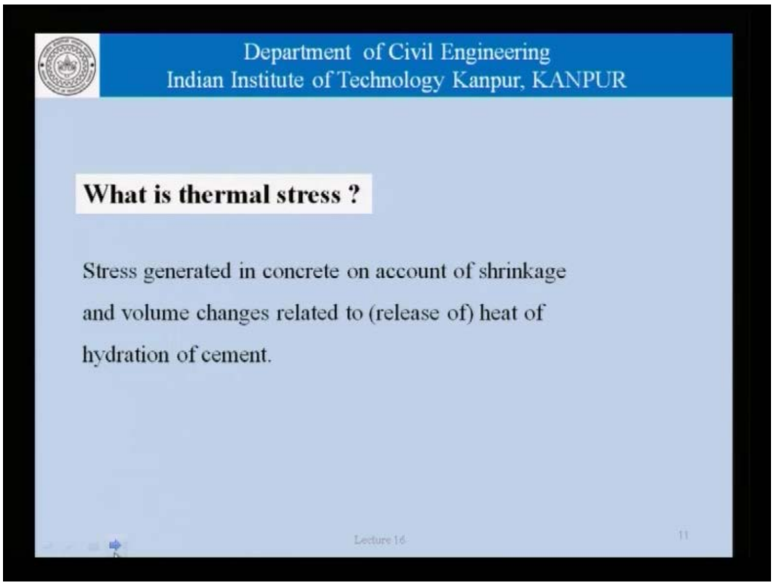

Now, we will talk of thermal stress. Now, what is the thermal stress? It is the stress generated in concrete on account of shrinkage and volume changes related to the release of the hydration of cement that is very much related to internal and external restrains, as we shall see in our discussion as part of this module of concrete discussion.

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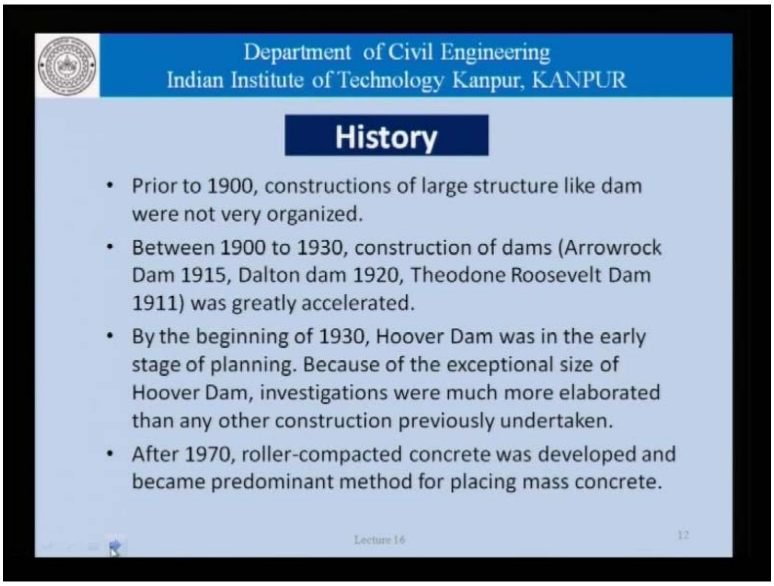

Now, little bit of historical background. Before well, well before 1900 the construction of large structures like dams was not very organized and we do not have two much recorded information about it. But, between 1900 and 1930 that is about 100 years ago, 8200 year ago construction of dams such as the Arrow Rock dam in 1915, the Dalton dam in 1920, the Theodone Roosevelt dam in 1911 was greatly accelerated and lot of information came about 2 concrete engineers or civil engineers. And around 1930, the Hoover dam was in the early stages of planning. And because of the exceptional size of the Hoover dam, investigations what a lot more an elaborate than any other constructions under taken previously using ordinary Portland cement.

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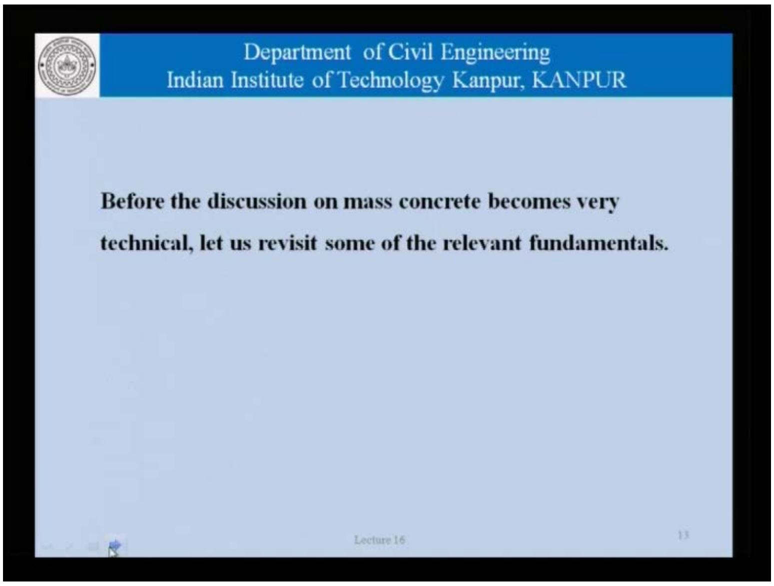

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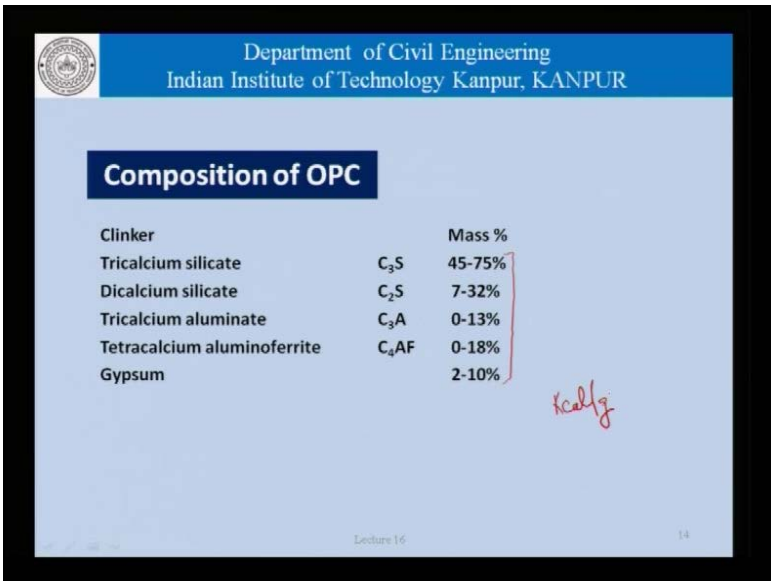

Of course, after the 1970s when the behavior of concrete was much better understood, the construction equipment's at a evolved, roller compacted and so on came into vogue, came into use and it became one of the promising alternatives as for as placing mass concrete is concerned. Now before the discussion on mass concrete becomes technical or very technical, let us revisit some of the relevant fundamentals once again.

What is the composition of ordinary Portland cement? We know that it consist of Tricalcium silicate, Dicalcium silicate, Tricalcium aluminate, Tetracalcium aluminoferrite and gypsum. And the percentages that are given here are representative; a cement could contain 45 to 75 percent of C 3 S, 72 to 32 percent of C 2 S, about 5 to10 percent of C 3 A and up to 18 percent of C 4 F in addition to gypsum.

Now, we also know that once water is added to the cement all these phases undergo hydration and these phases liberate different amounts of heat as far as the heat measured in let us say kilo calories per gram of these phases concerned. And therefore, for given cement we can work out the total heat liberated in terms of kilo calories or joules per gram or per kilo gram depending on the chemical composition of that cement. We must remember that this heat is liberated over a long period of time. Hydration does not stop in 3 days of 7 days or even 28 days for that matter, it continues for a much longer time.

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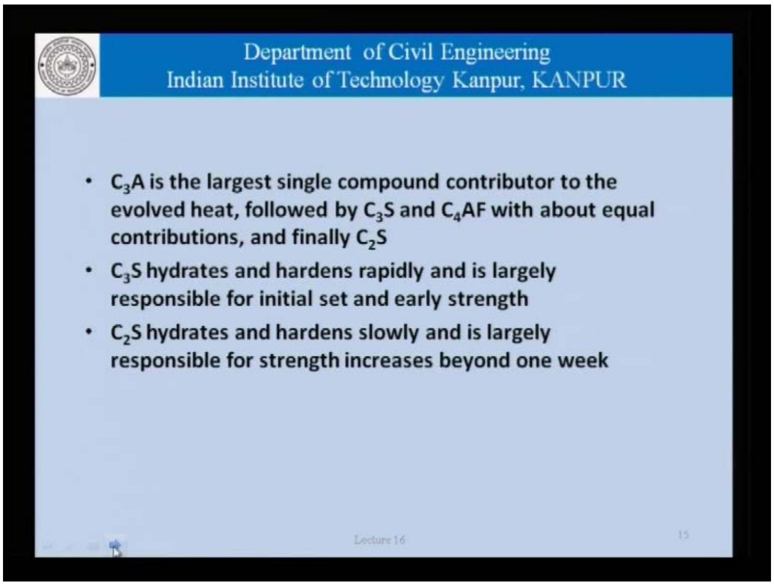

And how long that hydration continues also depends upon the individual phases. These phases react and hydrate at different rates. As far as concrete is concerned, the hydration may continue for a very long time if, supplementary cement issues material like fly ash a blast for a slag is used. And then this directly impacts the rate of heat liberated and this is something very important as far as our discussion today is concerned.

As far as C 3 A is concerned: the Tricalcium aluminate, it is the largest single compound contributed to the evolved heat followed by C 3 S and C 4 F which are about equal and finally C 2 S. C 3 S hydrates and hardens rapidly and is largely responsible for the initial set and the early strength and also therefore the early heat. C 3 A also contributes to early heat. C 2 S hydrates and hardens slowly and is largely responsible for the strength increases beyond let say a week or 10 days. And that is also true as far as the heat liberated on account of C 2 S hydration is concerned. So, in fact depending on what construction we are doing, we may like to control the chemical composition of the cement that we use. If we are using a concrete where we need a lot of strength, we would like to increase the C 2 S and the C 3 S but, given the fact that C 3 S is not friendly as far as heat liberated is concerned.

We may like to increase the C 2 S content. What we must understand that it the hydration is C 2 S will be slow and therefore this strength development could be slightly slower and if we are willing to that that is alright.

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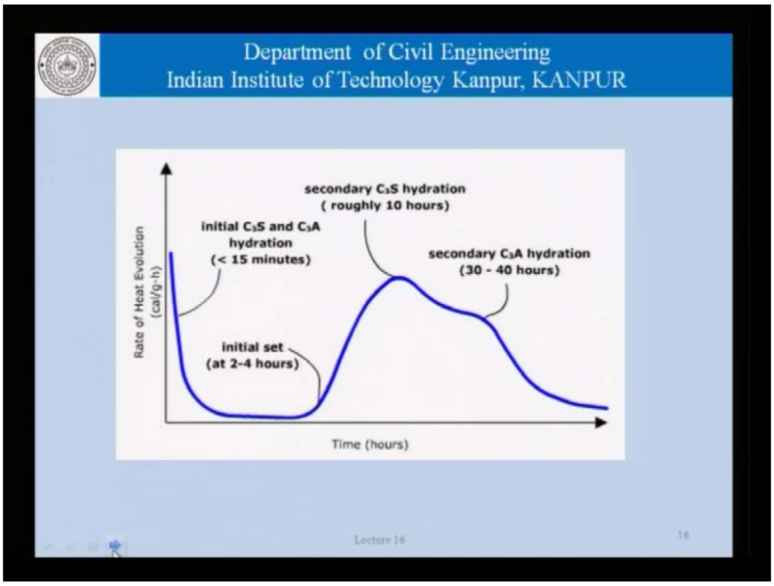

This diagram here shows are rough picture of the rate of heat evolution and also highlights some of the phenomenon that is occurring at that point in time. For example, initial there is a C 3 S and the C 3 A hydration which is in a few minutes. Then there is an initial set and finally C 3 S hydration continues, C 3 A enters into a secondary hydration phases and so on and so forth.

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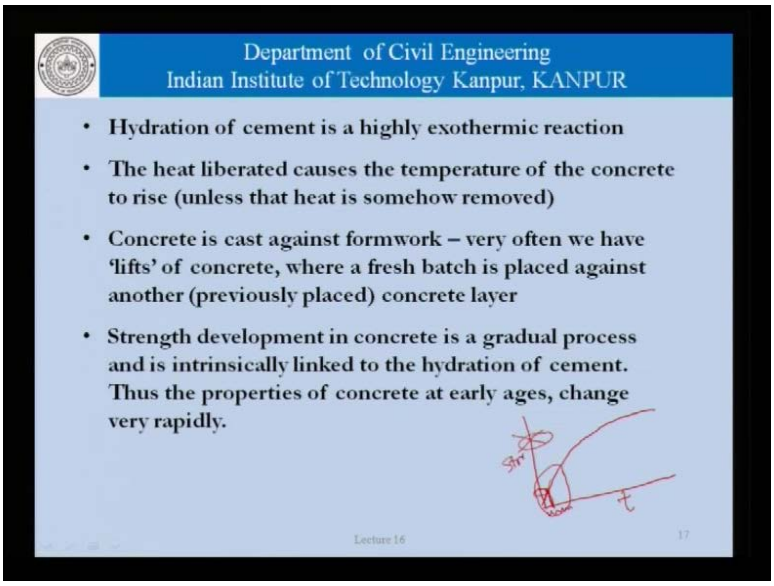

Now, coming back to the fundamentals and bulleting them, noting them points. Hydration of cement is a highly exothermic reaction. So, there is a lot of heat liberated when ordinary Portland cement hydrates. The heat liberated causes the temperature of the concrete to rise, unless that heat is somehow removed specific cast of block of concrete which has cement that heat that is liberated over period of time will cause the temperature of that concrete to rise. Unless the situation is such that the heat that is liberated is also removed from the concrete and dissipated into the atmosphere. We must also remember that concrete is cast against form work, very often we have lifts of concrete which means that a concrete is placed on top phenomena the concrete. So, the bottom of the concrete is not in contact with the form work but with the previous placed concrete or sometimes PCC's that is the plain concrete or ground or any other material.

As far as form work is concerned, it could be plywood, steel or any other material that we may choose to use. And then there is exports surface, most of the time concrete has an expose surface. And now, this surface of concrete plays very important role in decapitating the heat and that is what will be another subject of discussion today.

Strength development in concrete is gradual processes and is intrinsically link to the hydration of cement. Thus, the properties of concrete at early ages change very rapidly.

We have drawn this picture repeatedly that the strength of concrete changes likes this, if this is time and this strength. What we are talking of as far as mass concrete consideration is concerned is in the early stages and at this point in time or in this period of time the properties of concrete are changing very rapidly. And therefore, if something is of interest to us at this point in time we must remember that the properties of concrete at that point in time are here and not here, which is the property that is the concrete will acquire in a fully mature or a fully hydrated state.

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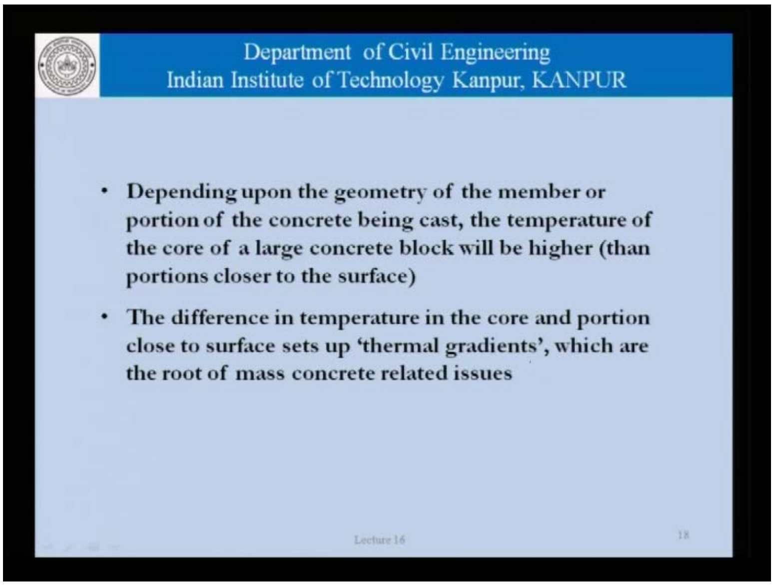

Continuing on discussion, depending upon the geometry of the member or the portion of concrete being cast, the temperature of the core of a large block of concrete will be higher than the portion closed to the surface. If we cast the concrete block like this, I am showing it as a two dimensional picture, depending on the size of this block, the temperature of this block, that is the core of the concrete will be very different from the temperature of the surface anywhere. And we discussed earlier that this surface could be in contact with form work here or it could be in contact with the ground or it could be exposed to air.

So, these 4 surfaces here that is, if we call them as 1, 2, 3 and 4. 2 and 4 we have reason to believe that will be similar. But, 1, 2 and 3 there is no reason to believe that temperature of these surfaces will be same and there is no reason to believe that these temperatures at the surface will be the same as the temperature in the heart of the concrete. All this discussion assumes that the concrete block has a certain size. If the size is very small then of course, the heat is being taken away as the concrete has been cast or as it is as the concrete as a hardening and temperature differences may not be substantial.

Now the difference in the temperatures in the core and the portion close to the surface sets up ‘thermal gradients’, which are the root of mass concrete related issues. So, if this thermal gradients can be avoided a lot of heart problems as for response concrete is concerned can be soft.

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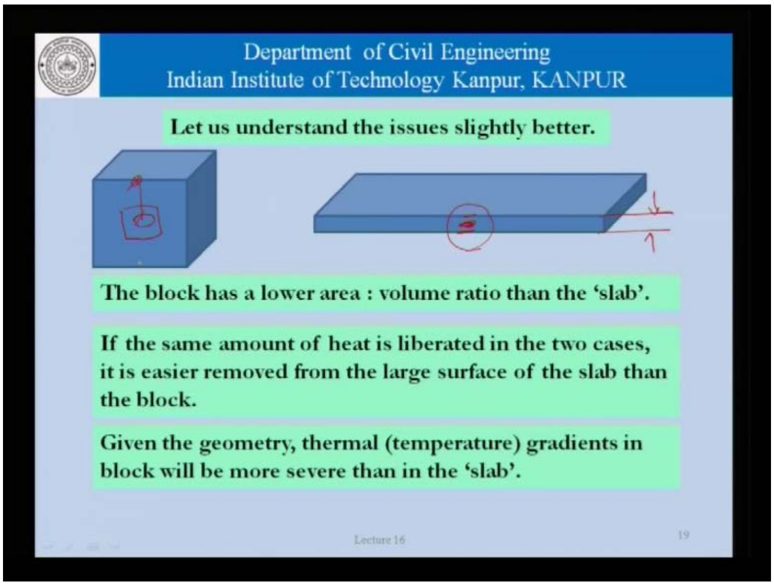

Now let us understand this little better through another example. Let us consider this block and compared this with this very thin slab. You may say that the volumes of these two worth same and there we realize that the block has a lower area to volume ratio then the slab. That is, for a given volume the surface area of the block is much smaller compare to that of the slab or the surface area of the slab is larger than that of the block that is shown here for a given volume of concrete. Now, if the same amount of heat is liberated in the two cases it is easier removed from the large surface of the slab than from the block. The heat is dissipated into that atmosphere or the earth through the surface which is in contact with it. The top surface is in contact with the atmosphere the bottom surface is in contact with the earth or the previous lift of concrete and so on.

And the size and contact with the form work. So, the heat is dissipated through these surfaces. And in the case of slabs, that is much easier because the surface area is larger. Further, given the geometry, the thermal, or temperature gradients in the block will be lot atmosphere than in the slab because in the slab the heat is been removed relatively quickly because this dimension is small. So, the temperatures in the middle here and the temperature is at the surface may not be very much different. This is not the case in the case of a concrete block, where this distance is substantial and therefore, there is reason to believe that the core will become hotter than the surface.

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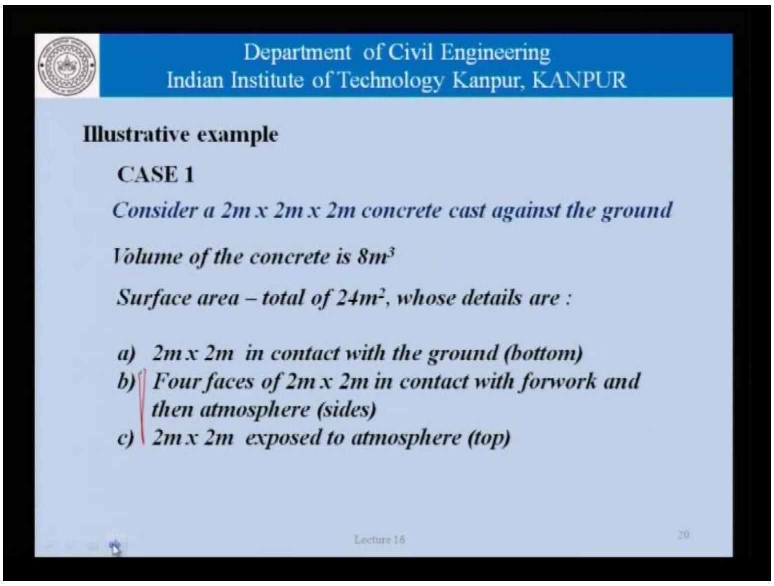

Now let us take an illustrated example and consider a 2 meter by 2 meter by 2 meter concrete cast against the ground. Volume of this concrete is 8 cubic meters and the surface area that is 6 phases of 2 by 2 which is 24 square meters is distributed as given in a, b and c. There is a 2 meter by 2 meter surface which is in contact with the ground which becomes the bottom. There are 4 phases of 2 meters by 2 meters which are in contact with the form work and then the atmosphere after the form work will be removed. And then, there is a 2 meter by 2 meter surface which is exposed to the atmosphere on the top. And this b and c finally becomes exposed to that atmosphere, a is not expose to that atmosphere.

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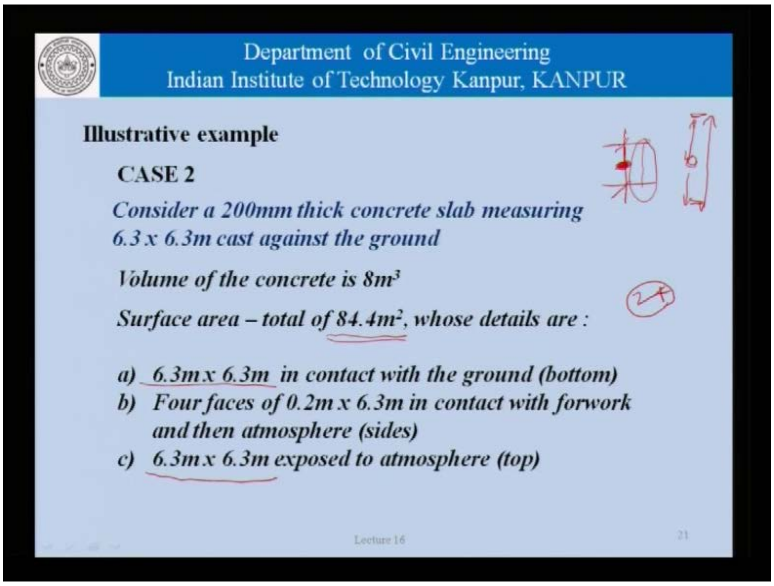

Now, remember these figures and let us consider the second case, where we are talking about a 200 mm thick concrete slab measuring 6.3 by 6.3 meters cast against the ground. Now, the 6.3 has been chosen for a specific purpose in order to make the volume of the concrete the same that is, 8 cubic meters. So, 6.3 into 6.3 into 0.2 would still give you approximately 8 cubic meters of the concrete.

Now, this 8 cubic meters of the concrete now has a total area of 84.4 is square meters as against the 24 square meters that we had at the previous case. As far as the distribution of this 84 square meters is concerned, there is a 6.3 by 6.3 meters in contact with the ground which becomes the bottom and there are 4 phases of 0.2 into 6.3 which are in contact with the form work and then the atmosphere and there is a 6.3 by 6.3 expose to the atmosphere on the top.

So, through this top and this bottom the heat that is liberated in the slab or the concrete which is been used to cast the slab is dissipated into the atmosphere or taken into the ground for ultimate dissipation. As we can see that, if there is only a 200mm difference here then, the possibility or the extent of the thermal gradient that will develop between the core temperature here and the tops or the bottom is quite small. We can virtually assume that the temperature throughout the slab remains constant and this is an assumption which we cannot make in the case of a block.

Let us take a look at the block once again and this is an assumption which we cannot make for the 2 meter by 2 meter by 2 meter concrete block where the top and the bottom they are separated by 2 meters and the core here is 1 meter away from the nearest surface. As far as of course the slab is concerned this being a much smaller distance, that is a top and the bottom being closer the distance between the sides does not really matter because as far as heat is concerned we can assume it to be quickly dissipating in the direction which is closest to the surface.

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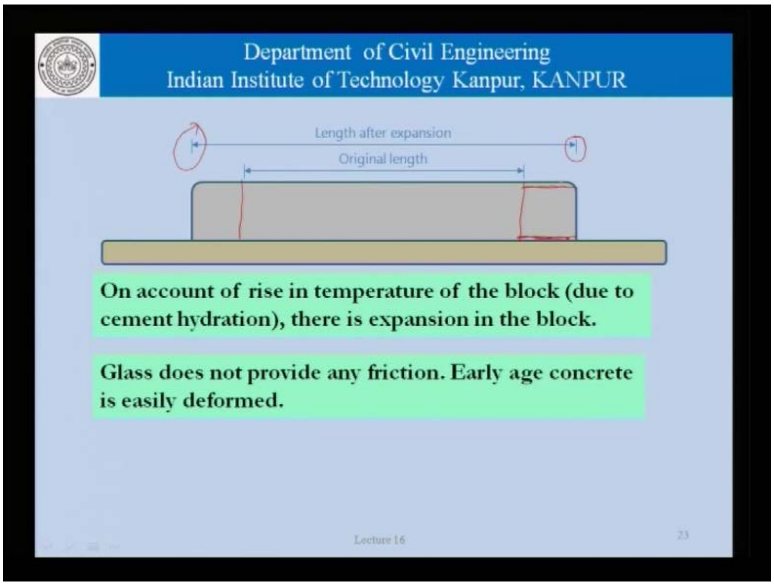

Now let us take a look at a concrete block which is cast against a glass plate and there is a certain original length of the concrete block. Once the concrete has been cast on account of the rise in temperature of the block due to the cement hydration there is an expansion so, this original length which was here has now changed to these values on account of the expansion in the block. We have assumed that glass does not wide any friction or restrict that is this surface here as far as the concrete is concerned expands to the same extent as the surface on the top that is the free surface.

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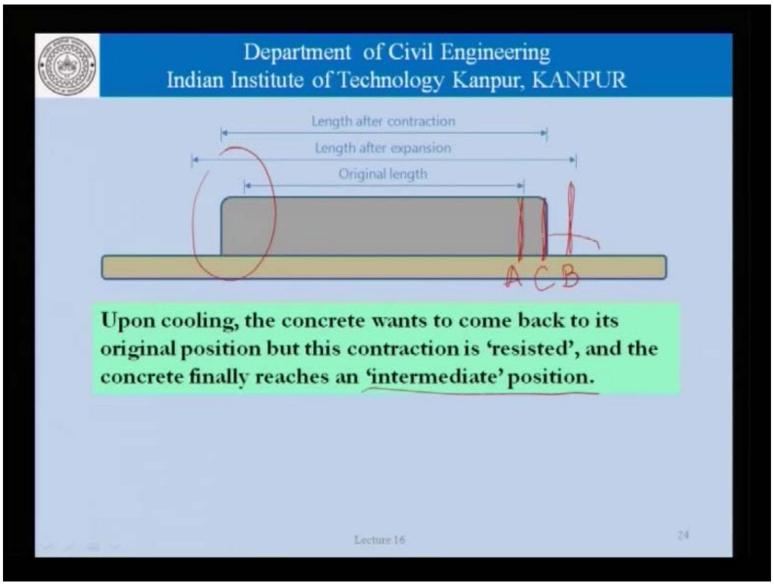

Once the concrete is cooling, that is the pick temperature has been reached and the concrete begins to cool, after all hydration does stop it does the heat liberation does not continue all the time. So, after certain point of time the block will start to cool and once starts cooling the concrete tends to wants to come back to its original position but, this contraction is resistant, as the concrete has now acquired a lot most stiffness than it had in the initial stages and this is the kind of discussion which requires as to very clear understand that the concrete properties every hour, every day are changing.

And therefore, the properties of concrete that for allowing to expand when the heating was going on have changed to an extent that they would resist the change in the opposite direction. So, as a result of which the concrete takes an intermediate position that is the length of the concrete from this point and time from this maximum level has come to this point here and not this point here. So, the concrete which was at a went to b and has come back to c and the same thing is on the side here.

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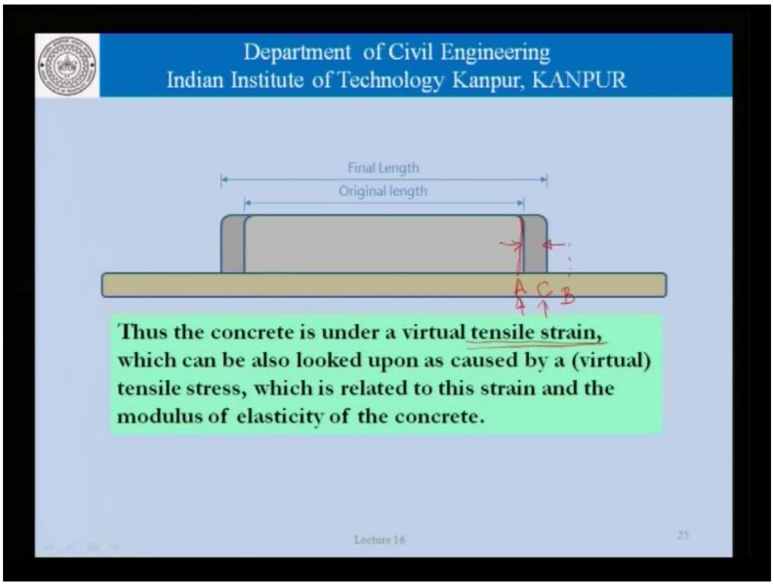

So, once we understand this part. What that means is that there is a final length and there is an original length and the concrete is under a virtual tensile strain. So, the concrete feels as if this amount of extension in the concrete is a tensile strain and this can be looked upon as a this can be looked upon as being cost by a virtual tensile strain. So, it is as if there is a tensile stress which has caused or which has brought about the expansion or an increase in the length of concrete to the extent of if we use the previous nomenclature it is a and c. That is the original position and the final position. The b which was the position after expansion is somewhere here. Now, this thermal tensile stress is related to the modulus of elasticity of the concrete which again is the property at that point in time.

Continuing over discussion, if this tensile stress that the concrete is under exceeds the tensile strain of the concrete, at that point in time concrete will crack. That is, will have cracks form like this and these are the cracks which have been induced by the tensile thermal stresses on account of the heat that was generated when the cement was hydrating and the heat dissipation was not proper and the concrete could not come back to its original position and therefore, cracks.

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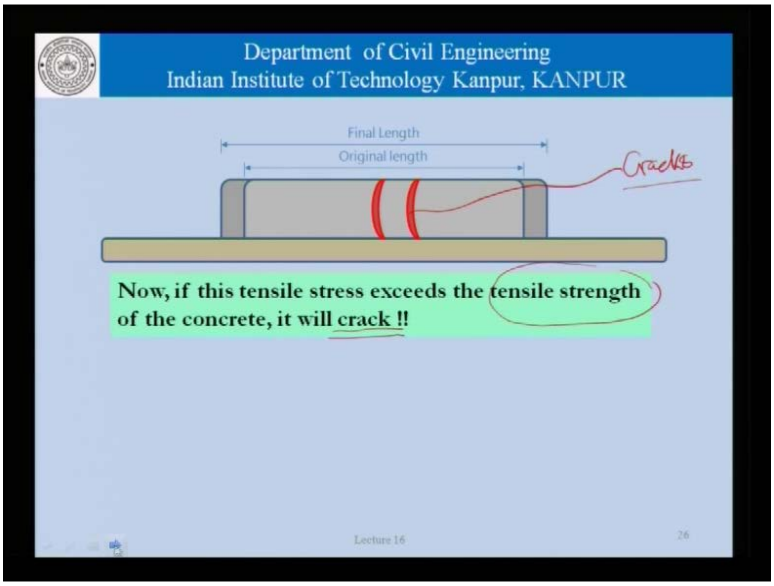

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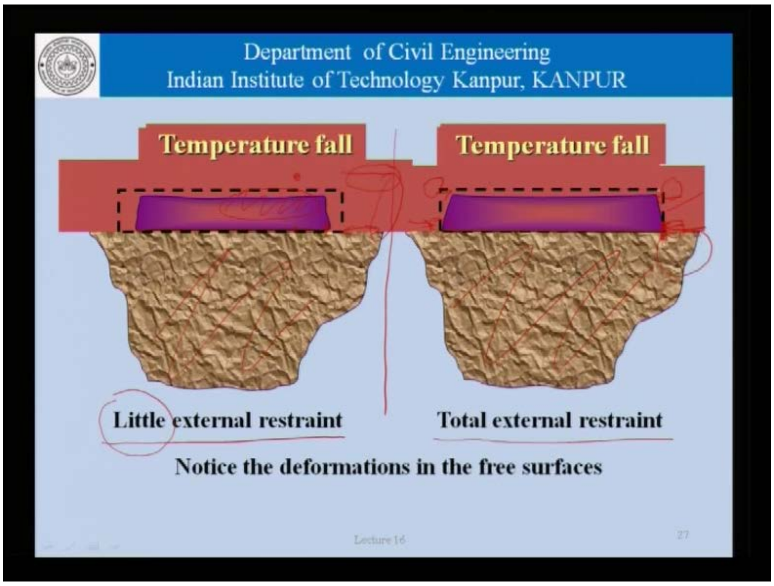

Now let us consider the concrete being cast in an actual condition and not a glass plate. So, this here represents let us say ground or a previously cast concrete and these are the concrete blocks that we are casting. So, if this is the initial condition of the cast concrete, in this case there is little external restrained and in this case there is total external restrained. Let us see what happens when the temperature increases that is during the rising part of the temperature this is what will happen to the concrete.

The concrete will expand at the bottom as well as at the top accept that the expansion at the top will be slightly more than that of concrete at the bottom because after all even though there is little external restrained if not set that it is 0. The second thing we should notice is that, there is the core of concrete which has been shaded in a slightly different color and this temperature is not really the same as a temperature at the top and the bottom. Compare to these set of pictures, let us see what is happening at the other side when we have total external restrained.

Now, as there is total external strained the ground here does not allow the concrete that has been cast to expand and therefore, there is no change in the dimension of the concrete at the bottom and because there is no change at the bottom this effect is carried over even to the top and the extent of deformation at the top is also restricted.

Now, let us look at what happens when the temperature falls. The temperature falls because there is little restrained. As far as the picture on the left is concerned the concrete comes back to its original position. Whereas, in this case it remains where it is and the concrete at the free surface has contracted.

So, this is something which we must understand and keep at the back of our mind that concrete expands and contracts they extent of expansion or contraction is governed by the principles of heat that is in terms of the coefficient of thermal expansion and so on. The amount of heat liberated, coefficient of thermal expansion, the stresses, the strains and all that and also related to the degree of restrained that the environment offers to it and in this case then environment is primarily they external environment which is the ground or the base against which the concrete is cast. So, it is not a friction less surface. So, these things if we keep at the back of for mind we are prepared for a more analytical or a more quantitative discussion of considerations is in mass concrete.

To revise our situation, to finally revise the principles once again there is a initial condition where there is in original length l, followed by temperature rise if there is free deformation the degree of restrained being 0, the concrete expands as shown up to this point here and which means that there is a free strained as shown. Compare to this, if the degree of restrained is one that is there is full restrained the concrete remains where it was and there is a restrained distained equal to them amount of free strained. When there is partial restrained there is the degree of restrained this point 0.3 and that 0.3 means that the restrained strength is 0.3 times or 30 percent of this strength and this is the free strain that we get.

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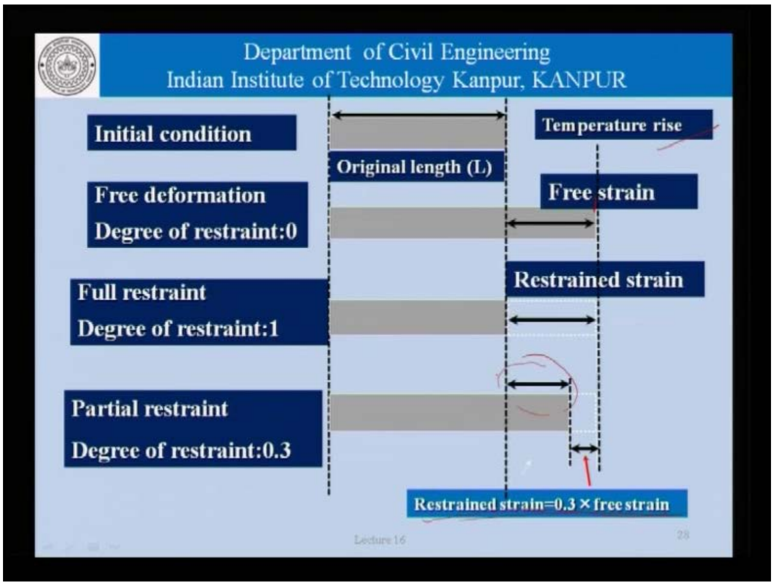

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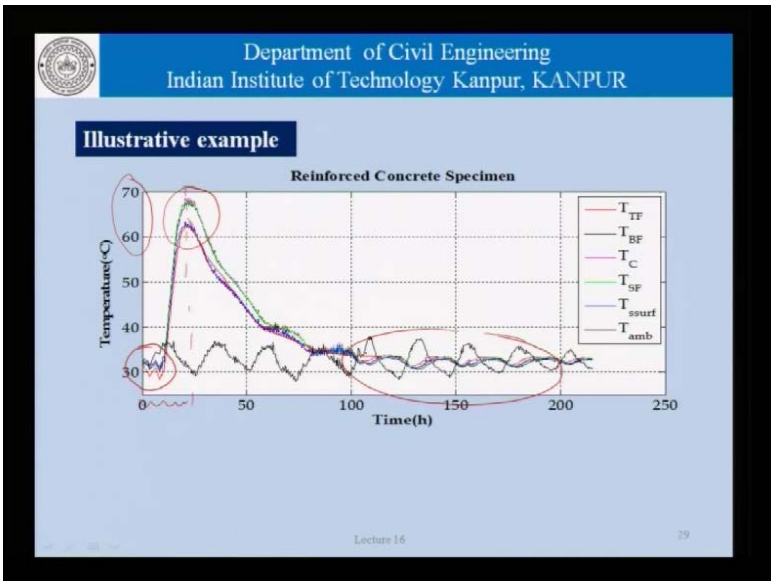

Now, this is an illustrative example of actual data obtained from laboratory studies in a block. We will talk about the actual conditions and so on later on but, I thought I will share this with you today to give you an idea as to what is the kind of temperature that we are looking at. Let us not bother about the end of conditions and so on and so forth. So, five sis to say that if we begin with an initial temperature of about 30 degrees the peak temperatures could be of the order of 60 to 70 degrees. That is, the extent of increase in temperature is of the order of about 30 to 40 degree centigrade and this happens within a certain period of time.

So, if you look at the peak temperature and when it is reached we will get this number here. Having said that finally, the concrete block does go to an equilibrium temperature at the end of a certain amount of time once again and this process is a lot more gradual. So, this is the kind of actual numbers that we are talking about keep that in mind when we study principles of mass concrete, we try to do the analysis, we try to do design in this particular module of course will probably not do very quantitative treatment. But, we must remember these numbers and keep the met the back of our mind.

So that we are able to at least appreciate the principles of design, the principles involve be construction where mass concrete considerations are important.

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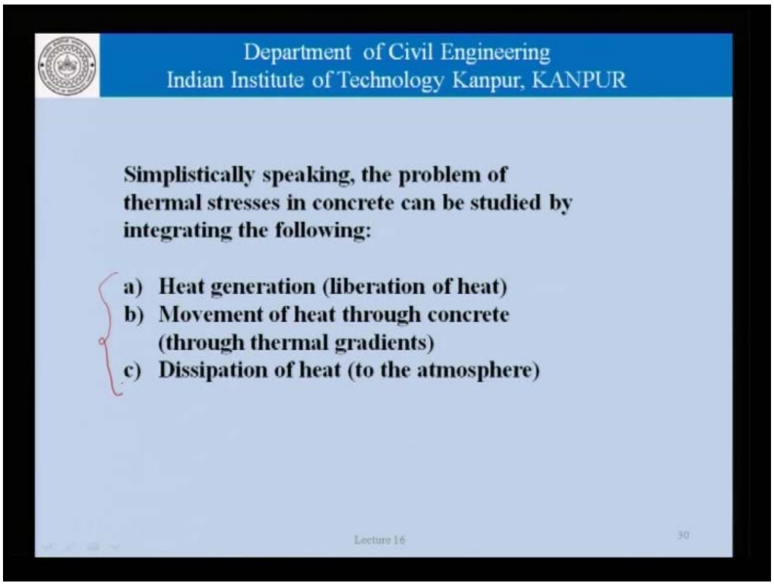

Now, simplistically speaking, the problem of thermal stresses in concrete can be studied by integrating the following: heat generation, which is liberation of heat, movement of heat through the concrete through thermal gradients and dissipation of heat to the atmosphere. So, if you are able to integrate these 3 ideas that we understand from physics, we can understand how to handle situations in mass concrete or how to handle thermal stresses in mass concrete.

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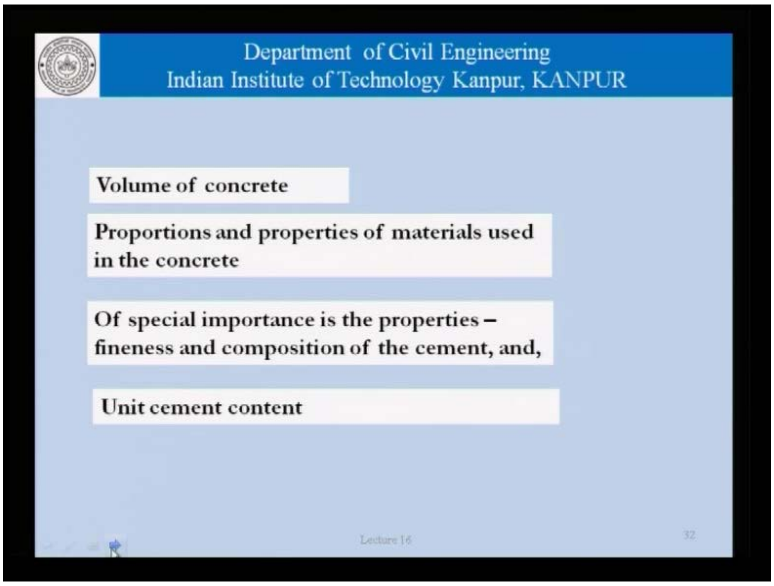

Now, as far as heat generated is concerned, it is related to the volume of concrete and the proportions and properties of the materials used. So, if there is a certain volume of concrete amount of heat generated there would depend on what is the property of the material that we have used, cement aggregate and so on and what is the proportional, how much of these individual materials went into a cubic meter of that concrete. Of special importance to us would be the properties of cement that is the finest and the composition. The finest and composition will both being important for us to understand the rate, at which the heat is liberated, the rate at which different phases hydrated. And finally of course, the Unit Cement content. These are the principle factors that help us understand the heat generated part.

Now, if we come to the heat movement through the concrete, we have the properties of concrete such as conductive and specific heat which help us understand or model. How much heat will be transferred from one place in concrete to another? And another factor is the temperature difference between neighboring concrete elements, if you are using any kind of a finite element or such software.

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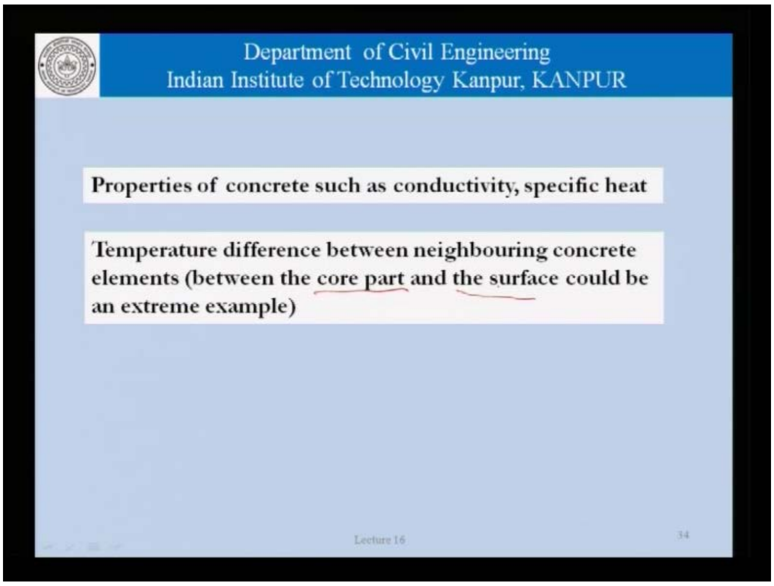

We must understand, what is the difference between the temperatures at neighboring points? And once we understand the difference then we can calculate or model the amount of heat that will be transfer. As an extreme example it is the core part of the concrete and the surface. So, if we just consider concrete to be met of core and the surface we know we will try to understand how much the temperature difference between the core and the surface.

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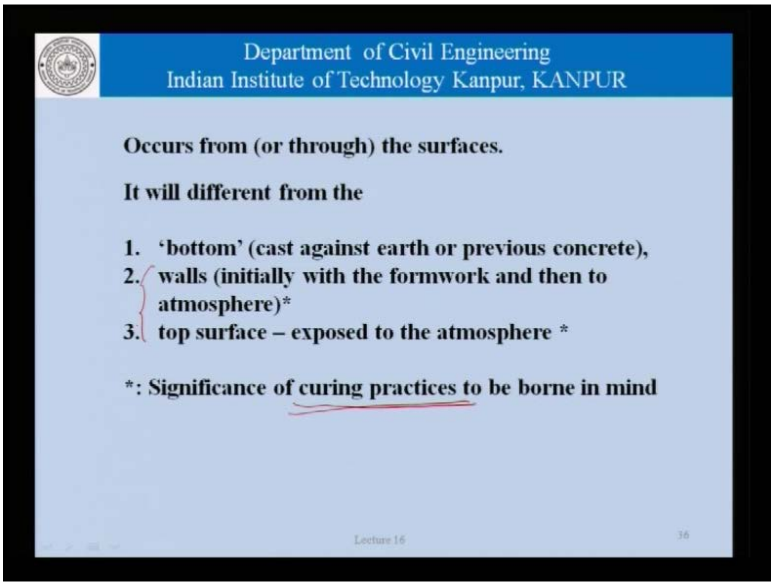

Now as far as heat removal and dissipation is concerned, it occurs from the surfaces and we must remember that as far as heat dissipation through the surface is concerned, curing is a very important factor. If we put water on the surface it changes the characteristics as far as the heat dissipation is concerned. So, curing is important as its implications not only in terms of a strength development and hydration of cement but, also in terms of controlling or affecting the thermal gradients, the temperature and so on at the surface. And these this amount of dissipation will be different in the case of bottom of the concrete where its cast against the earth or a previous concrete. Similarly, the dissipation will be different from was which are initially in contact with the form work and then with the atmosphere once the form work has been removed and the top surface which is exposed to the atmosphere.

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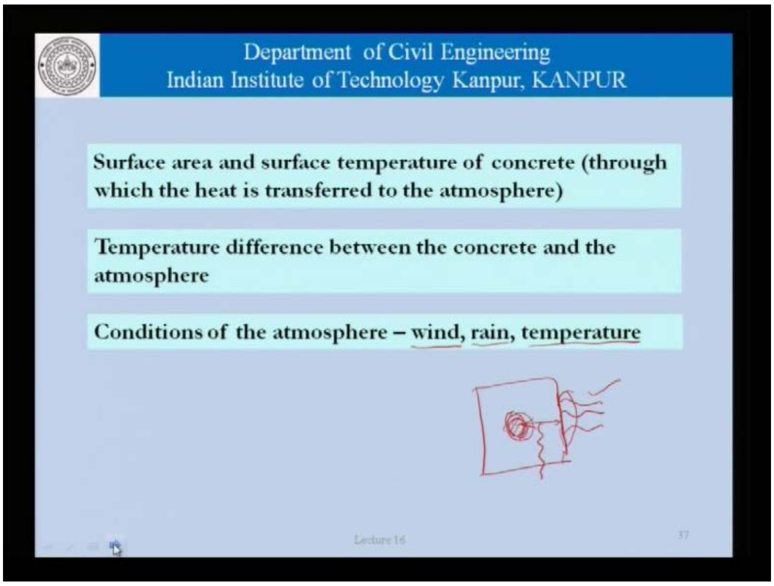

So, in these two cases curing is very critical from the point of view of understanding or modeling the dissipation of heat through the concrete surfaces. It is important that we understand the surface area and surface temperature of concrete through which the heat is transferred the atmosphere. That also will be an important player in the understanding or in modeling the heat dissipation, the temperature the difference in the temperature between the concrete and the atmosphere and also the conditions in the atmosphere. For example, if the wind rain temperature all these things would affect the extent of heat transfer the takes place from the concrete surface into the atmosphere.

So, once we are doing numerical model, where we are trying to understand that we cast this concrete block and now we want to understand how soon or how much later the heat here will be dissipated through the surface here. We must understand some number 1: how much heat is generated here, number 2: how easier difficult is it to pass through the concrete and then what is the properties or what are the properties at the surface what is happening in the ambient region wind rain temperature and so on and so forth.

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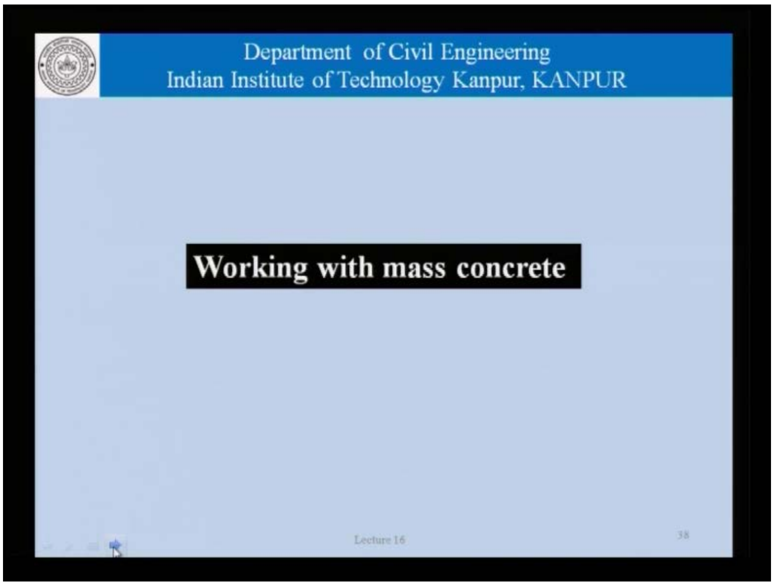

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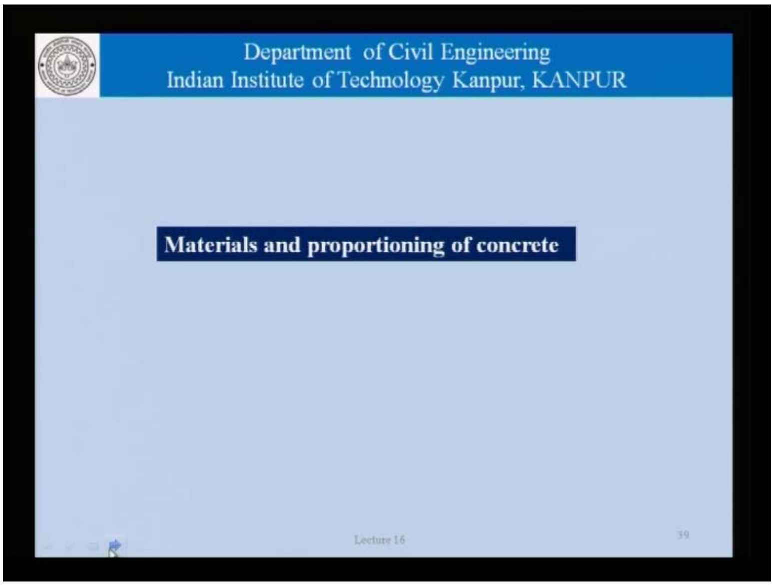

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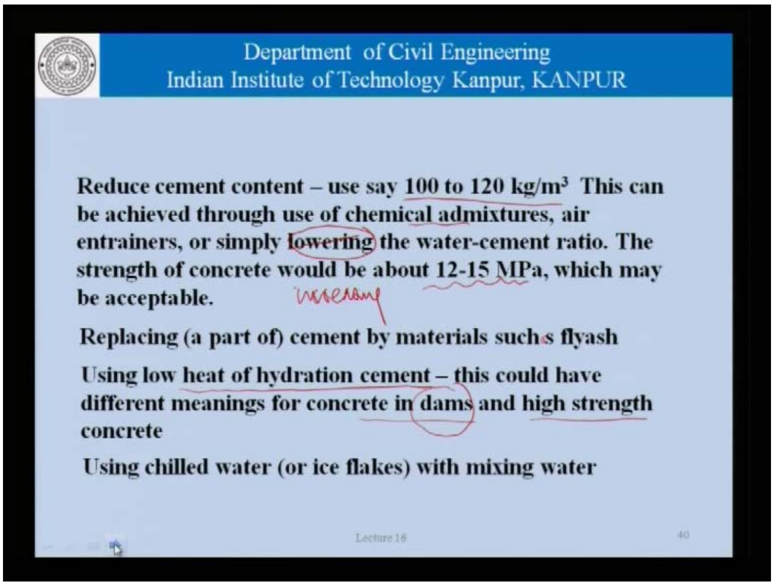

Now when it comes to working with mass concrete how do we handle it? What are the things that are important? We try to control the materials and proportioning of concrete, we try to reduce the cement content to as little as 100 to 200 and 20 kg's per cubic meter. This can be achieved through the use of chemical admixtures, air in trainers or simply this is some stack it should be simply increasing the water-cement ratio. So, we use high water-cement ratios may be even has a highest, may be even as highest 70580 percent because the strength we are looking for in this cases is pretty small, it could be just 12 to 15 M Pa for example, in gravity dams.

So, we used chemical admixtures to reduce the water demand, we use air and trainers and that also helps us get the water demand down, we try to replace the part of cement by artificial materials such as fly ash, we try to use low heat of hydration cement and this idea of a low heat of hydration cement could be different in the case when concrete is used in dams and in the case when the concrete has high strength. In the case of dams, we are looking at minimizing the amount of heat that will be generated initially and we are not particularly bothered about whether or not a large amount of a strength development happens later on.

In the case of high strength concrete, we are concerned with this strength at the later stages but, also we are concerned with the heat. So, therefore, I would like you to recall the discussion that we had early in this discussion today when we said that C 2 S and C 3

S, C 3 A, they all react and hydrate, liberate heat at different rates and depending on what we want, whether we want high strength we are willing to leave with is strength development taking place later as far as concrete is concerned, we do not want to compromise on the amount of heat liberated C 2 S and c three s have to be balance in a proper manner. C 3 A needs to be taken out or minimized if we need to that and so on. We can use chilled water or ice flakes with mixing water to reduce the temperature of mixing water.

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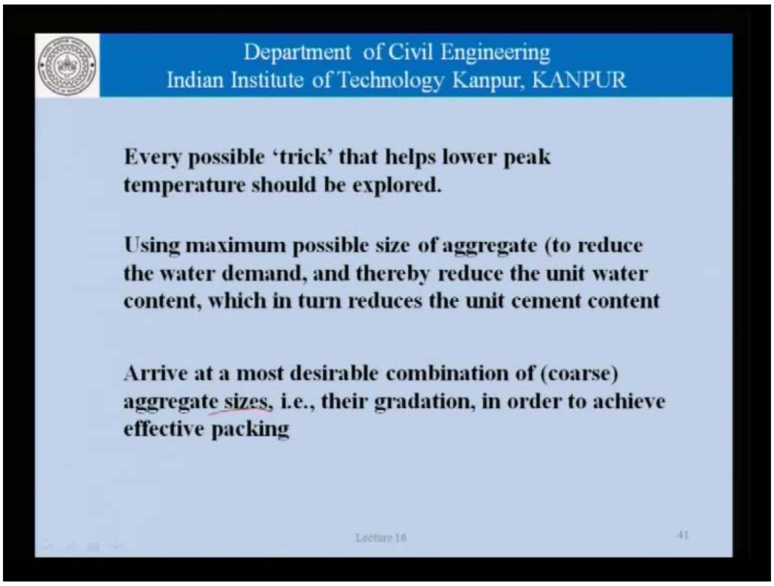

Basically, every possible trick that helps us lower the peak temperature should be explored. We have seen that the peak temperature could be as higher 65-70 centigrade we need to somehow keep it as low as possible. And therefore, we should use every trick there. We use the maximum possible size of aggregate and this reduces the water demand and thereby the unit water content and therefore, the unit cements content for given water content use the largest possible size of aggregate. We should try to arrive at the most desirable or an optimum combination of aggregate sizes.

So that, the water demand is reduced in construction of structures like dam's there is so much concrete being used that even a small amount of adjustment can make a large amount of difference as far as the total amount of cement is concerned or the heat generated is concerned.

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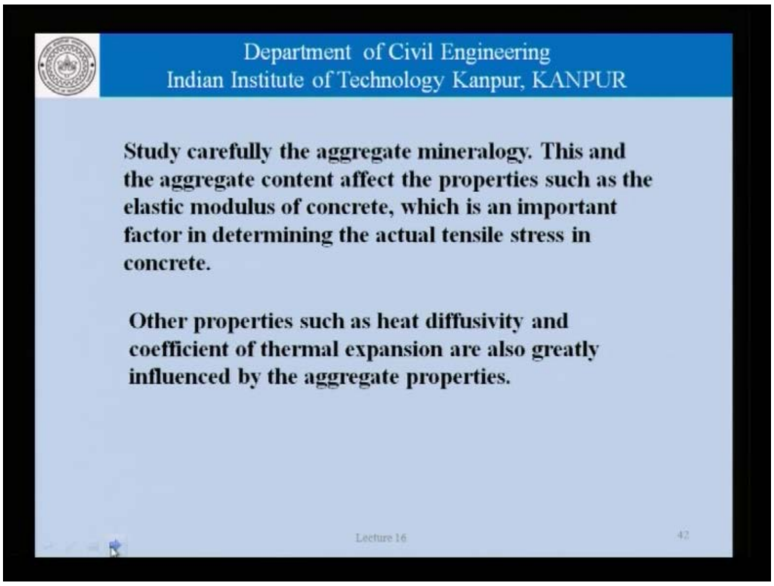

When it comes to transferring the discussion from the temperature to stresses then, the properties of aggregate also become very important. So, we need to study the aggregate mineralogy and this mineralogy and the aggregate content effect the properties such as, the elastic models concrete which is in important factor in determining the actual tensile stresses in the material. We need to study the properties such has heat diffusivity and the coefficient of thermal expansion which are also greatly affected by the aggregate.

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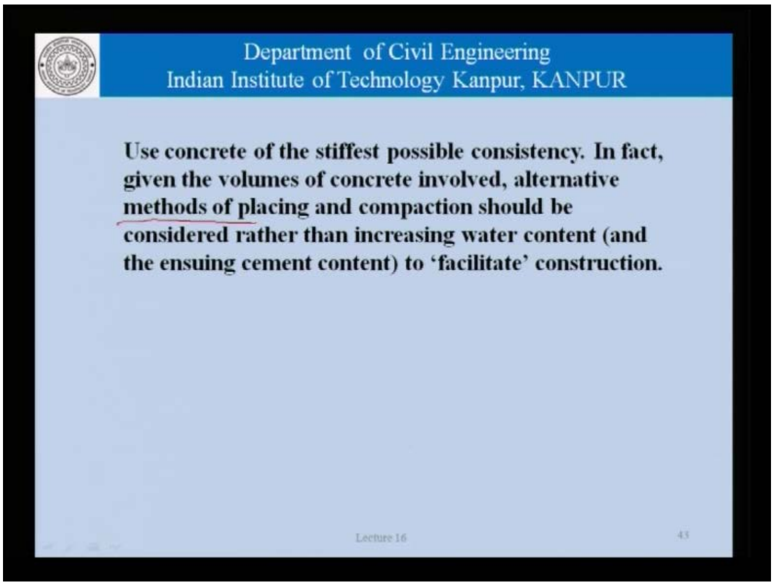

Basically, we should use concrete with the stiffest possible constituency. In fact given the volumes of concrete involved, alternative methods of placing and compaction should be considered rather than increasing the water content and the assuming cement content to facilitate construction. And this alternative method of placing and compaction this discussion has taken us to the roller compact concrete construction. Instead of constructing dams and such structures with blocks of concrete, the thought process transformed to create large layers of concrete which were compacted using vibrated the rollers and once the concrete of block gets transformed into the concrete in layers then, as we have seen in several of are examples today, the problem of thermal stresses can be minimized if not the avoided.

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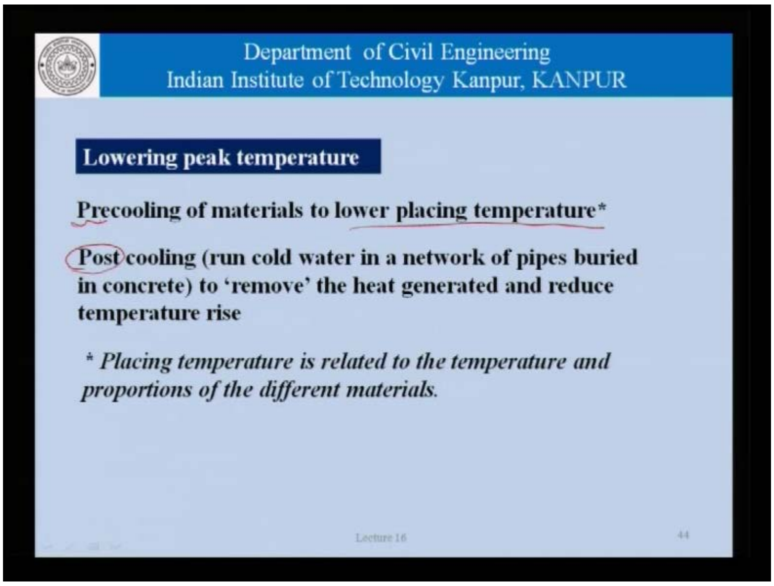

As far as lowering the peak temperature is concerned, we need to or we could try the option of 'pre-cooling' the materials to a lower placing temperature. So, this placing temperature is the temperature of fresh concrete and is related to the proportions and the temperature of the individual materials. So, if you pre cool the materials we will get a lower placing temperature or the temperature of fresh concrete. We could also try post cooling as against pre-cooling and post cooling involves a run cold water in network of pipes buried in concrete to remove the heat generated and reduce the temperature rise.

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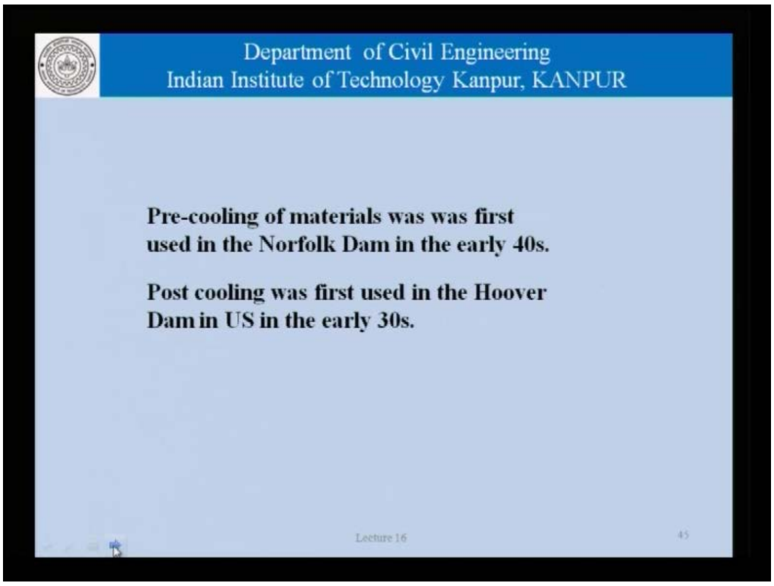

Both these options have been used. Post cooling was first used in the Hoover dam in US in the early 30s. So, you can imagine there are those times without compute, without even calculators perhaps of any form; engineers did used techniques which were highly innovative. Pre-cooling was used for the first time in the 1940. So, what we are doing now is giving a quantitative meaning to qualitative suggestions or steps which are of which have been taken which are logical and which have a already been taken in (( )) modern day construction.

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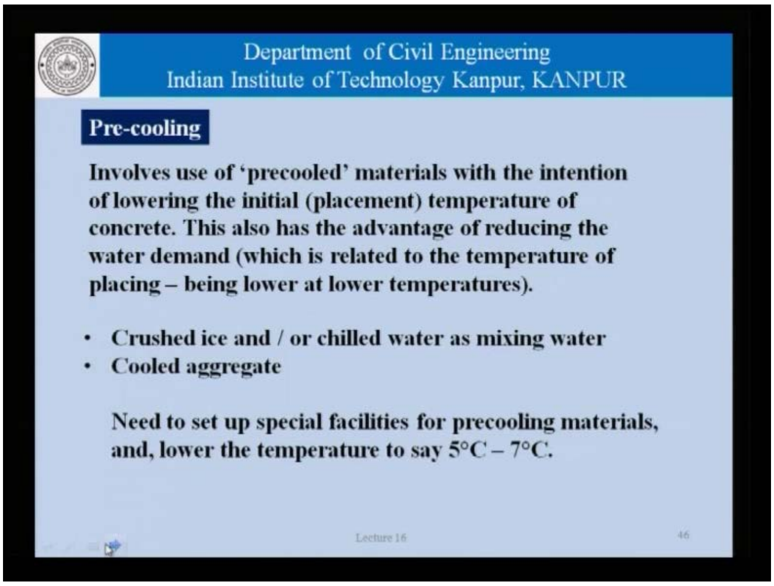

So that our constructions become more effective, they become more accurate, our calculations are more reproducible, they are closer to the actual behavior in the field and so on. As far as pre-cooling is concerned: it involves use of pre-cooled material with the intension of lowering the initial of placement temperature of concrete and has the advantage of reducing the water demand a little bit which is also related to the temperature of placing being lower at lower temperatures, we could use crushed ice and or chilled water as far as mixing is concerned, we could cooled aggregates using liquid nitrogen, spring it we chilled water and so on. But for that we need to set up special facilities to pre-cool these materials and lower the temperature to say 5 degrees and 7 degrees and so on.

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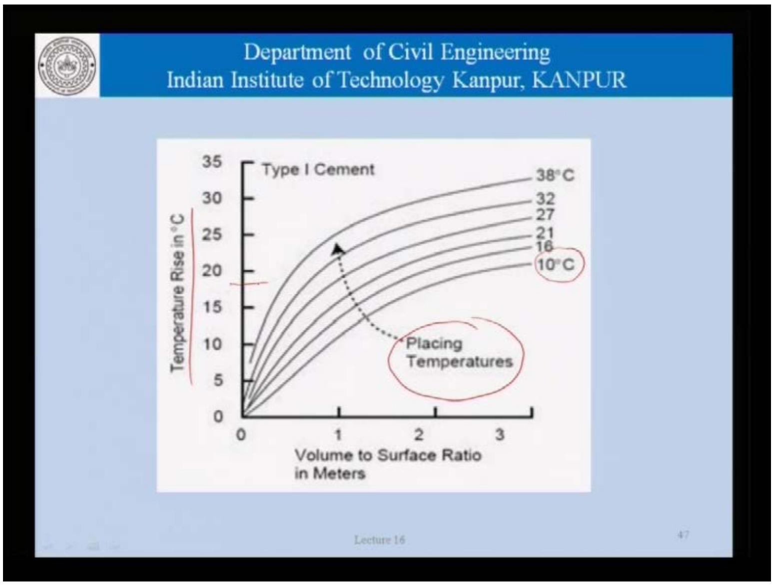

This here is a representative diagram which tells us how the temperature rise changes, if the placing temperatures are different. So, if the placing temperatures of concrete are lower, the temperature rises lower and so long as temperature rises kept in control, the problems relating to mass concrete can be kept in control. With that understanding or with that thought processes we try to takes steps in order to reduce the placing temperatures.

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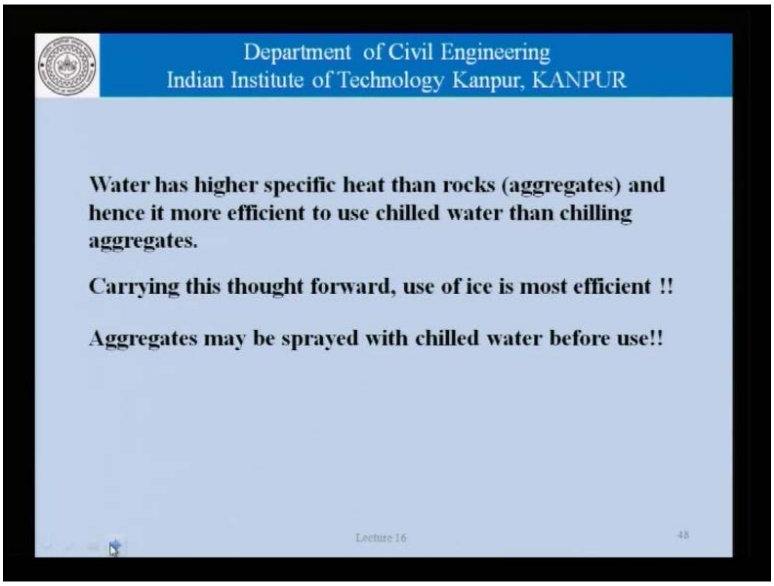

What is more effective water being a higher specific heat those rocks or aggregates. It is more efficient to use child water than chilling the aggregates and carrying this thought forward we could use ice instead of water for mixing.

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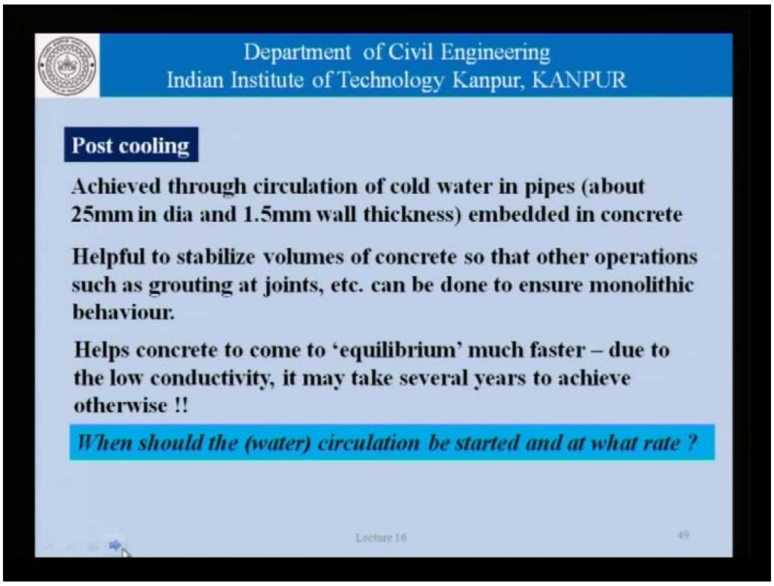

As far as post cooling: it is concerned it is achieved through circulation of cold water in pipes which are about 25 mm in diameter, 1.5 mm in wall thickness which are embedded in concrete. This helps us is stabilized the volumes of concretes.

So that other operation such as grouting at joint etcetera can be carried out and monolithic construction can be ensured. It helps the concrete to come to equilibrium much faster due to low conductivity it may takes several years to achieve otherwise. So, what we saw earlier the cooling in the natural course is a very very long drawn process and therefore, post cooling helps us quickly get read of the heat and get the concrete into equilibrium. What should be the time when the water circulation is start at and at what rate should be done?

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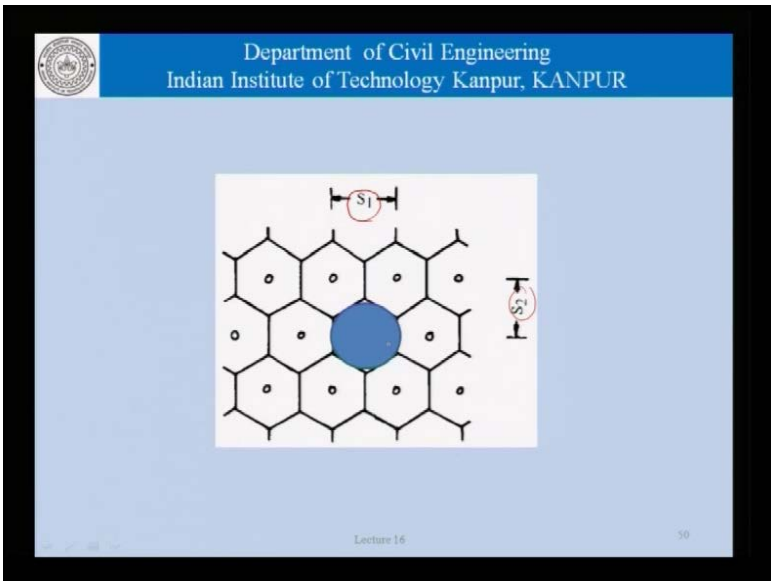

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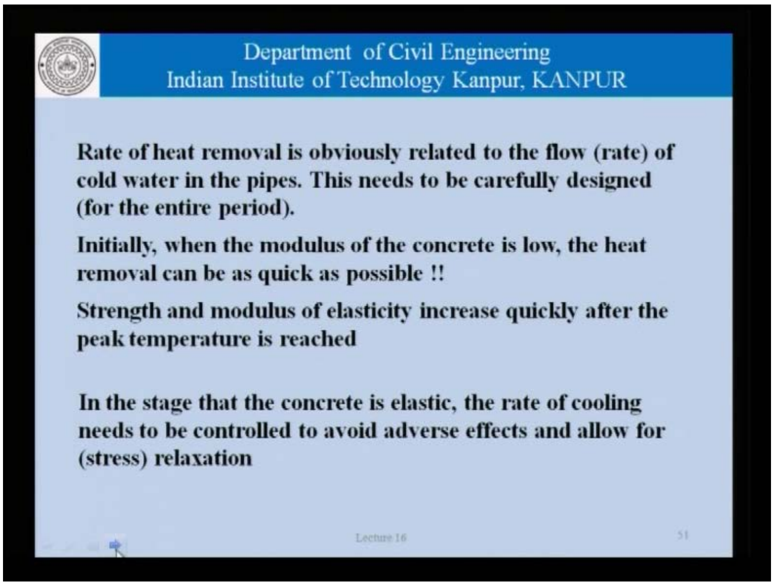

Now this is a picture of embedded water pipes and at distances which is S 1 and S 2 which is shown. You should remember that once we run the cooling water there is a region around the pipe which will be cooled by that particular pipe. So, depending on the modeling at the analysis that we do we need to arrive at these spacing S 1 and S 2 and also the flow rate of water.

The rate of heat removal is obviously related to the flow rate of water in pipes and needs to the carefully designed for the entire purpose or for the entire period of concrete construction. Initially, when the model of concrete is low the heat removal can be as quick as possible we need to have a flow rate which is able to do that. Later on when they strength and the model of elasticity increases and the peak temperature is reached, at that time the flow rates needs to be adjusted.

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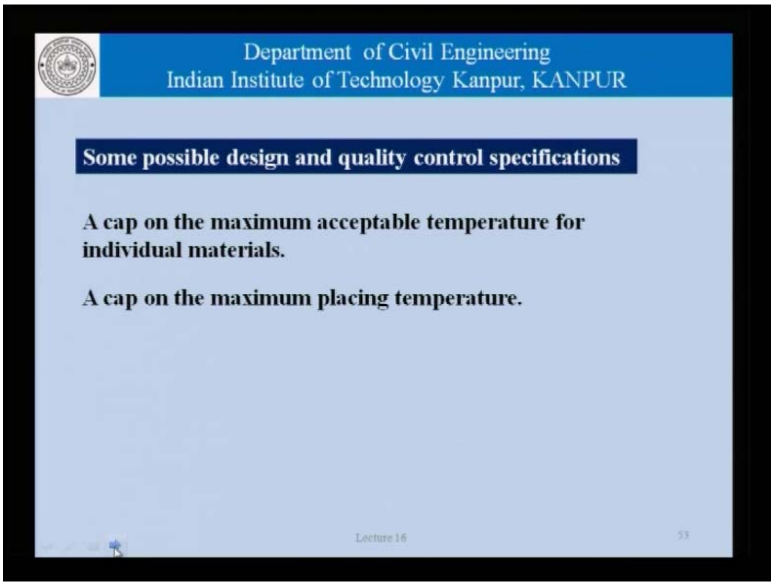

Continuing with our discussion as for as working is concerned we come to some design and quality control is specifications. There can be a cap or a maximum limit on the acceptable temperature for individual materials, there can be cap on the maximum placing temperature of concrete.

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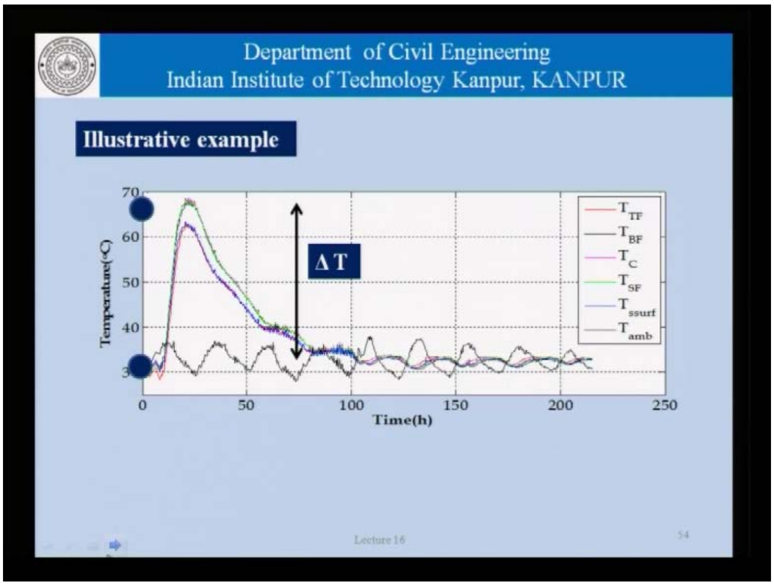

As we have seen in the illustrate example we can cap this temperature here which is the placing temperature, we can cap this temperature rise, we can cap the peak temperature. So, these are some of the specifications which a designer can give as far as prevention of cracking or handling thermal stresses in concrete is concerned.

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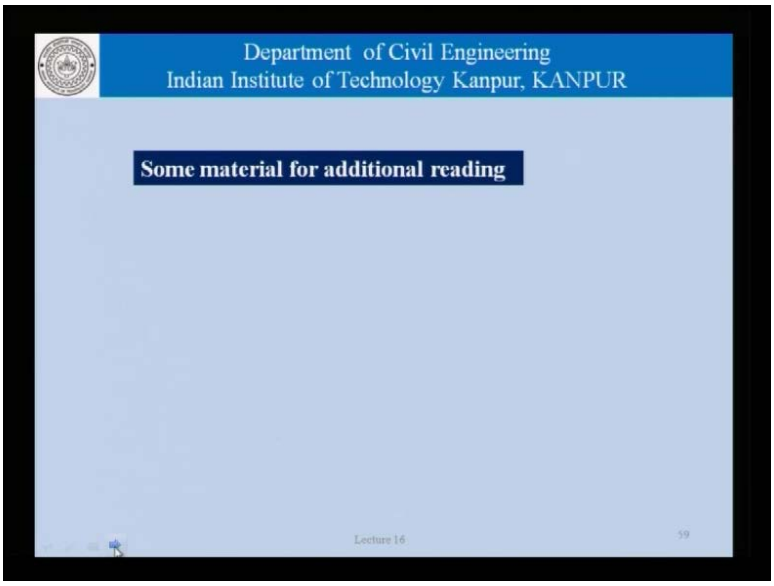

Now, we will continue with the discussion in the next class and let me give you some material which you can refer to, for reading. This is a list of such material and I would like to thank.

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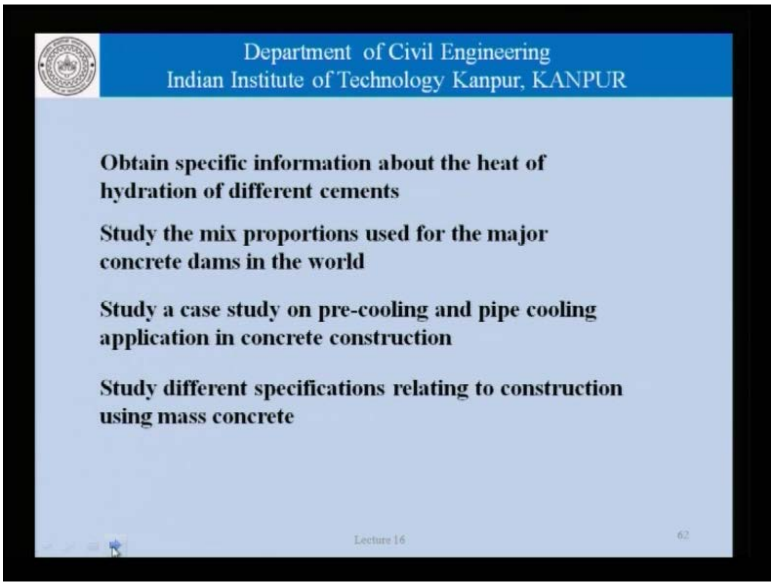

So and so for the discussion before we close, there are some questions which you can take as home assignment, try to obtain specific information about the heat of hydration of different cements. Study the mix proportion as used for major concrete dams in the world, study a case study on pre-cooling and pipe cooling application in concrete construction, study different specifications relating to concrete construction using mass concrete.

Thank you.