Admixtures And Special Concretes

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Lecture -63

Special concretes - Mass concrete - Introduction, materials, thermal cracking

Introduction:

So, in today's session we will start talking about mass concrete. The other two special concretes that I had in mind were light weight and heavy weight concrete as well as 3D printed concrete. Now I feel given the kind of work that you will be doing and the kind of opportunities that come your way in terms of concreting, mass concrete is a subject that you cannot avoid so just in case. So mass concrete today is a really big challenge. People have known about it for a long time of course because concrete in huge masses has been used for many applications. Primarily we are talking about water retaining structures like dams.

Gravity dams are really massive concrete structures and of course in terms of gravity applications the concrete strengths are only M10 to M15 at the most but special applications within dam structures like spillways and things like that also require the use of high strength concrete. But what we are concerned primarily with are the instances where concrete is used in very large segments. So, the mass concrete in the dam is definitely a challenge to deal with in terms of the heat generation and how to avoid concrete damage because of that. Secondly there are issues of mass concrete also in applications like raft foundations.

So, raft which is basically a massive block of reinforced concrete supporting tall structure typically and this raft can have thicknesses as much as 4 to 6 meters. So, in such cases it is very important for us to ensure that the concrete is protected from the effects that may arise because of temperature changes. So that is what the primary idea about mass concrete is.

What is mass concrete?

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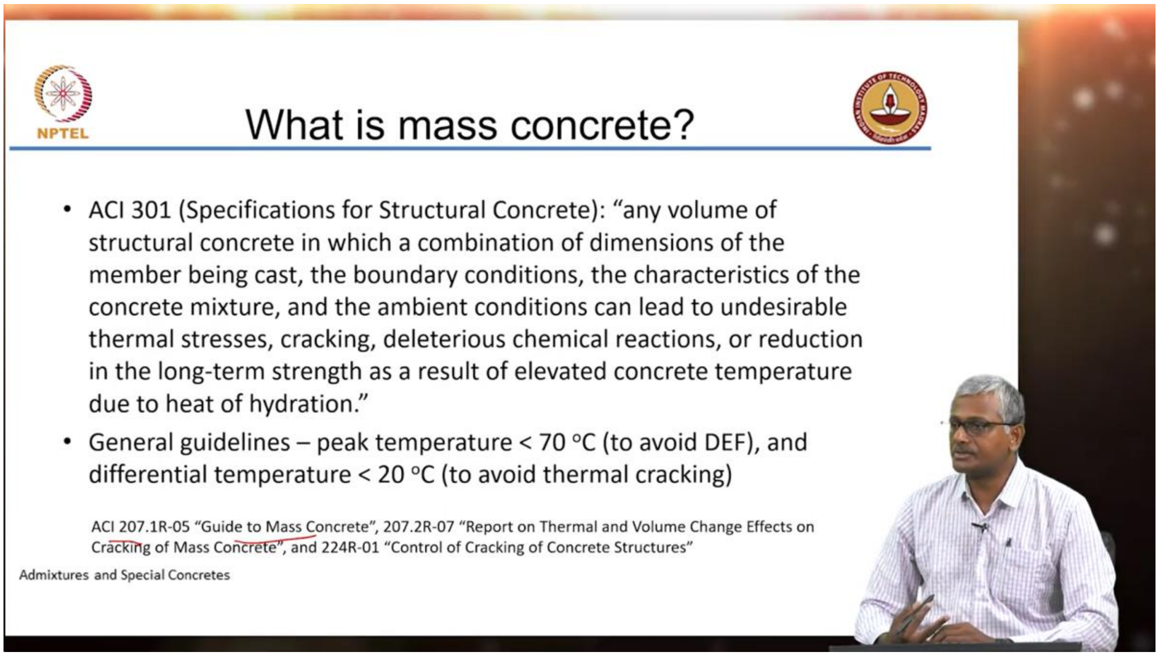

As per ACI 301 which is basically the specifications for structural concrete it defines mass concrete as any volume of structural concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions or reduction in the long term strength as a result of elevated concrete temperature due to heat of hydration. So, very clearly it specifies that it is not just one reason but a multitude of reasons that can together work to create this issue of either long term strength and durability getting reduced or cracking getting created in the system.

General guidelines that most projects tend to follow is to keep the peak temperature of the concrete inside the concrete to less than 70 degrees Celsius which is a very conservative estimate. It is primarily for the purpose of avoiding a chemical reaction known as delayed ettringite formation. Now I will talk about that in more detail later and the other guideline typically followed in most construction projects is to keep the differential temperature down to less than 20 degrees Celsius. Differential implying between different segments of concrete you keep the temperature difference down to below 20 degrees Celsius because at that level you expect that the thermal stresses that are generated are not high enough to cause cracking. So, cracking will happen whenever the thermal stress is greater than the tensile strength of the concrete.

So, in such an instance you need to ensure that the concrete has either a high tensile strength by the time the differentials are high or low differentials to ensure that the tensile strength is never exceeded. Now it is very important for you to also read these reports ACI 207.1 R05 which is the guide to mass concrete. So, as I said you can become free members of ACI as student members and download these documents it is actually quite useful. ACI 207.2 R07 is the report on thermal and volume change effects on cracking of mass concrete and 224 R01 is control of cracking in concrete structures. So, all of these in some way or the other address the issue of cracking due to temperature differentials and mass concrete.

What size qualifies for mass concrete?

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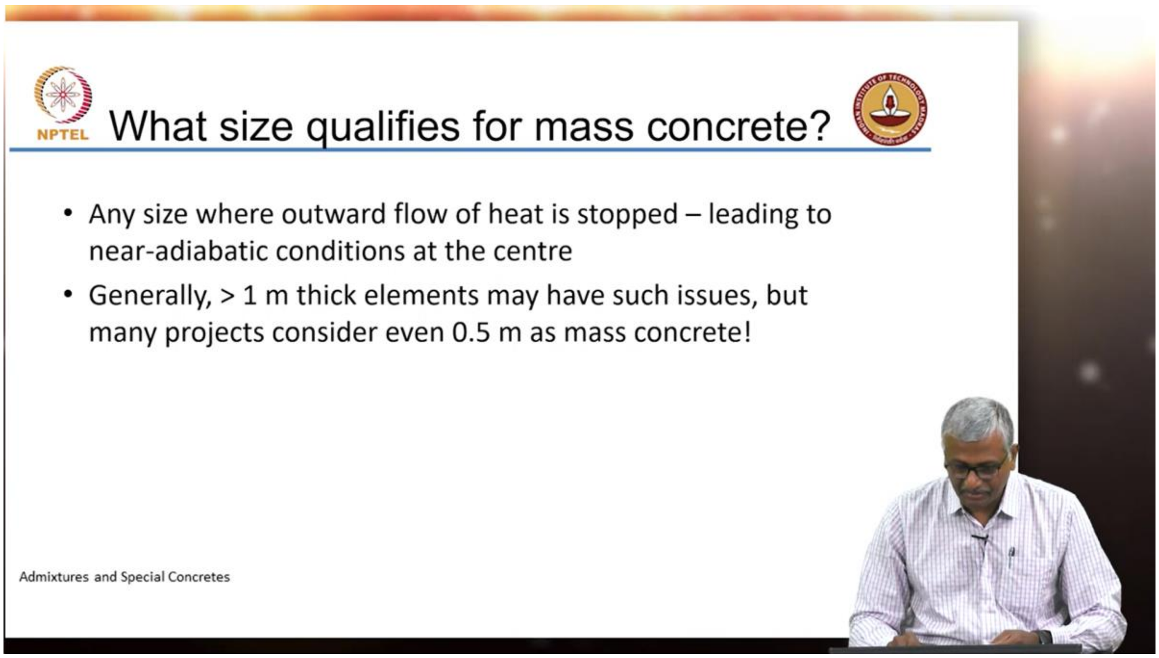

Now how do we define a particular size for mass concrete? What we have to look at is any structural member where the outward flow of heat is slow or is completely stopped creating almost adiabatic conditions in the core of the concrete. What is adiabatic again? Essentially, there is no outward or inward flow of heat from the system. So, that is called an adiabatic system.

So, the core of concrete when the concrete has a massive size the core will be almost in an adiabatic condition. That means the heat is not able to go out and no additional heat is able to come in to this concrete. Generally, this will happen when elements are at least 1 meter thick. But if you read the reports and the codes very carefully even structures which are half a meter thick are also treated as mass concrete. So, that is something that you need to remember that mass concrete effects can be felt even in thinner structures which are just about 0.5 meter. But most definitely you will feel the effect of the mass concrete heat development in structures that are at least 1 meter thick. So, you have to ensure that whenever you have, you are dealing with concrete of that thickness you have to provide special consideration to the temperature effects of mass concrete.

Considerations in mass concrete pours:

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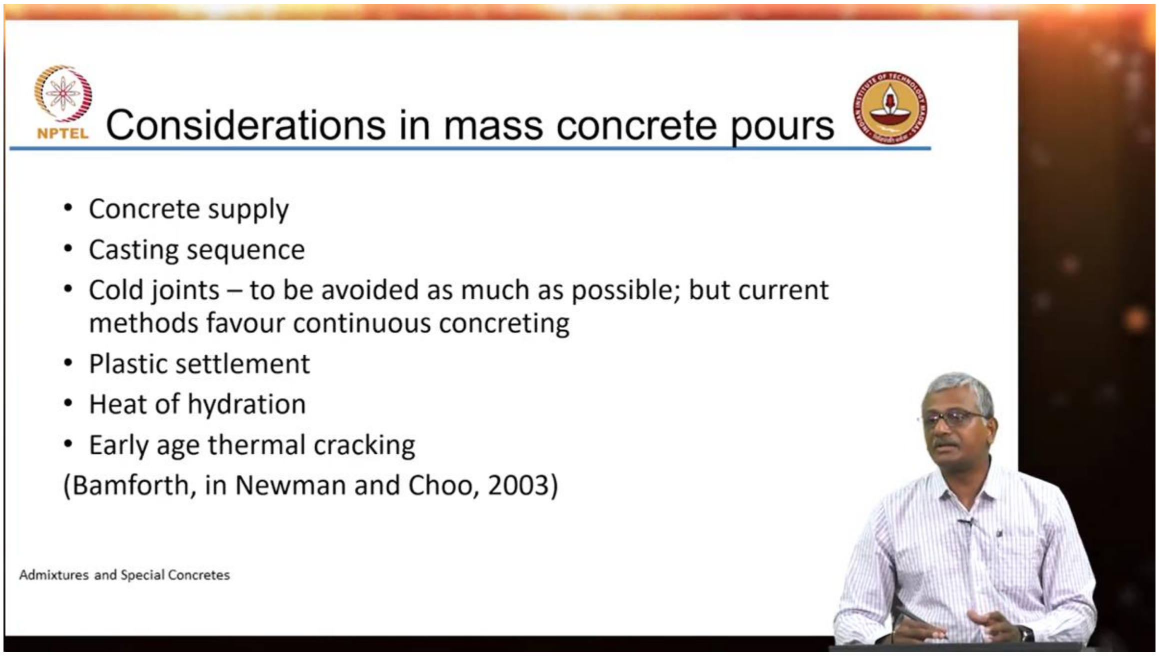

Now in mass concrete pours there are several things to look at. One is concrete supply because you are casting a massive structure. So, you need to ensure that the concrete supply is continuous to be able to continuously cast it.

You need to also ensure that you have clearly worked out the casting sequence with which you are pouring the concrete. Where do you start? How do you move? Do you move from one end to the other or do you move complete the entire thing together and then move up? All of those things are required to be decided before the concrete is placed. Because all of this is necessary to avoid cold joints. You need to avoid cold joints as much as possible. In some instances, depending upon your concrete supply avoiding cold joints may not be possible.

But then in a reinforced structure there is sufficient reinforcement to act as the shear key or binding between the different layers of concrete. So, in reinforced concrete you do not really have to worry too much but then still you need to avoid it as much as possible. So, today's methods essentially favor continuous concreting. That means whatever be the size of the concrete raft or mass concrete that you are doing you continuously supply the concrete to finish up the entire concreting operation. One problem that can arise is plastic settlement also because again we talked about the fact that your top cover is not adequately measured and because of which if your concrete has a high degree of flow there is a substantial opportunity for the aggregates to subside causing a cracking right above the rebar.

That is called plastic settlement cracking. Heat of hydration is obviously the main consideration which we will talk about an early age thermal cracking arising because of this heat of hydration is the other thing that we need to look at.

Materials of mass concrete:

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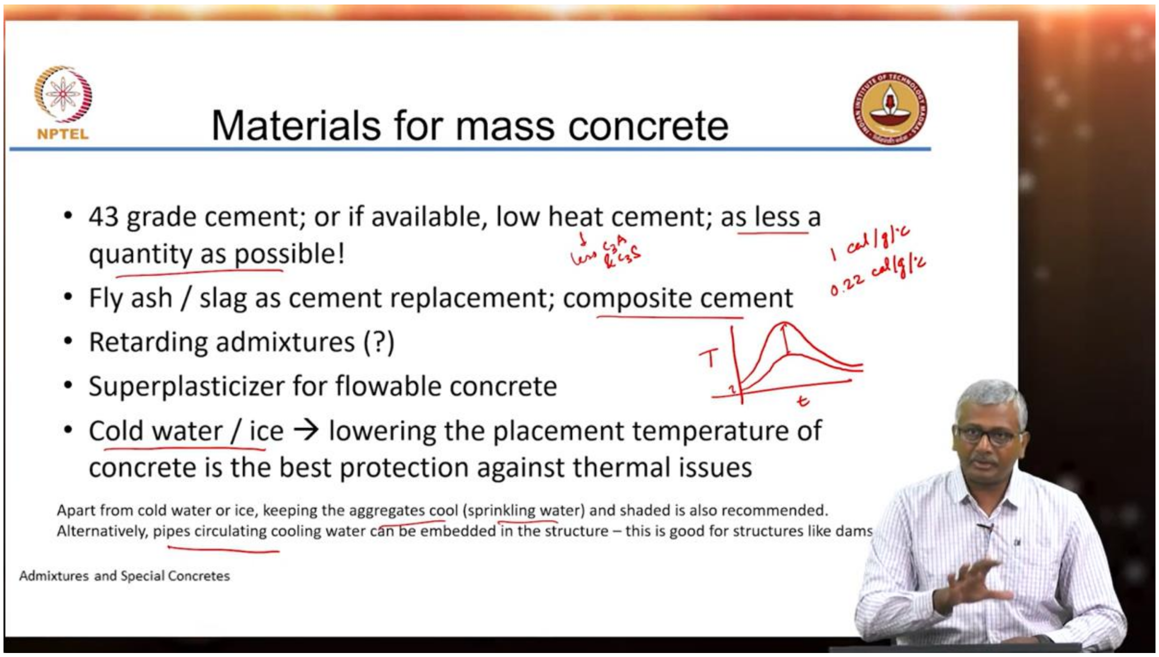

What kind of materials do you want to use? As I said heat of hydration is a primary consideration so you want to use concrete which will evolve less heat and for that you can choose a cement that is a low grade that is 43 grade instead of 53 or if available you can choose a low heat cement. What is the characteristic of low-heat cement? Less C_3A and C_3S. In the case of low-heat cement you will have more C_2S and C_4AF and less C_3A and C_3S.

Now other thing to realize is that to keep the heat of hydration down cement is the only one which is creating this heat. As less a quantity of cement is possible in the concrete. Once again you can adopt strategies like particle packing. Maximize the aggregate content, minimize the cement that you put in your system. Fly ash or slag as cement replacements are almost always a must to do that, especially fly ash because slag does not have as much of a drastic heat reduction effect as fly ash.

Right, because most of the slags that are available in the industry are of a fineness that is equal to more than cement because of which the reaction could be quite fast you may not really get significant reduction unless you go for very high percentage replacements 50-60% replacement then you will start seeing the benefits of slag also. But fly ash even at 20-30% will lead to a major reduction in the overall heat that is coming from the system. And of course, today you also have the potential of using composite cement. If you look at the IS composite cement standard it talks about a cement which has only about 35% clinker and remaining 65% of course you also have to have gypsum. The remaining 65% is a mixture of fly ash and slag.

Very soon composite cement standard will also include limestone, calcined clay cement but of course you will not be able to use limestone, calcined clay cement in applications which need reduction in heat because LC3 does not really cause a major reduction in heat. It will cause some reduction but not a major reduction. But fly ash and slag at high replacement levels can definitely lead to very good heat reduction. You could use retarding admixtures but you need to be careful because sometimes retarding admixtures may just push the dormant period. They may not overall reduce the heat rate.

What I am trying to say is if your heat rate curve looks like this, your use of retarding admixture may simply prolong this and you may still get the same peak. What you need to do is reduce this peak and with retarding admixtures you may or may not get that depending upon the type of admixture. You will definitely get that with the help of fly ash. In many instances the raft, I am primarily talking about rafts as mass concrete or even shear walls are going to be heavily reinforced. Raft is going to be heavily reinforced why? Because what do we need to avoid for raft? If it is a foundation it needs to avoid differential settlement.

For that we need to reinforce the rafts significantly. Similarly shear walls obviously they are providing the major resistance of the ground stories of tall buildings. Shear walls also are heavily reinforced as a result of which the concrete you use in such mass concrete situations will often be flowable or even self-compacting. Especially if your raft is massive placement of the concrete can become a problem if it is not high workability concrete. Because of that it is very important for you to design the concrete that is able to properly flow and completely encapsulate the reinforcement.

So, it will be flowable. So a superplasticizer is inevitable you have to use a superplasticizer. Then the main ingredient cold water or ice. We will talk about this in more detail later. Ice is obviously more desirable than cold water because it has the potential of reducing temperature significantly. So what you are trying to do here by using cold water or ice.

So, let us say this is my temperature versus time graph. I start off at the temperature of placement, temperature of concrete goes up and then reduces to ambient conditions. The problem comes when different segments of the concrete are exposed to different temperatures. This delta T is what we worry about. So what do you do when we use ice what we are trying to do is lower the placement temperature itself and that completely lowers the peak temperature that you get in the system.

Now lowering the placement temperature by x does not mean that the peak temperature also comes out, comes down with the same x. It can come down by more than that also. It can come down by more than that also but more or less it is nearly the same. So, if you want to really reduce the heat in your concrete the best and most optimal strategy is to simply reduce the temperature of placement to as low as possible. Now it is not just enough of course why do we want to always play around with the water in terms of temperature?

Why not other ingredients because water is the amount, the least amount that we use in concrete. In 2400 kilograms of concrete we will be hardly using 180 kilograms of water. Why do we want to only control the water? Water has the highest specific heat capacity amongst all concrete ingredients. So to increase or lower the temperature of water you require much more heat to increase temperature and you require to take out much more heat to lower the temperature of water. As compared to your other solid ingredients water has 5 times as much specific heat capacity.

So, you remember the specific heat capacity of water is 1 calorie per gram per degree Celsius. On the other hand, comparatively, the specific heat capacity of your cement and your coarse aggregate and fine aggregate is only about 0.22 cal per gram per degree Celsius. So, it is a major difference in terms of specific heat capacity. So, nevertheless we know that when we are operating in conditions of really hot weather your aggregate and cement are also quite hot.

Cement whatever weather you are operating at will be hot. Why is that? Why is cement hot? In large batching plants, the cement is transported by? From the cement plant do we get it in cement bags? No, we get it in bulkers. Fresh from production the cement is taken in bulkers and stored in silos at the batching plant. The cement inside these silos can be quite hot because the bulkers can remove the cement. The bags obviously will be using cement which is cooled down to a certain temperature but the bulkers can take really fresh cement.

So, the temperature of cement inside the silos can be sometimes as high as 60 to 70 degree Celsius. So cement temperature will be very high. You need to keep that in mind while planning your concrete mixture. But the other materials that are lying out in the open like aggregates, you can keep the aggregates cooled by sprinkling water and also providing a shade over the aggregates as much as possible. In good quality construction sites, the batching plants are planned with sprinklers and with shade in place to ensure that the aggregates do not get very hot themselves because aggregates are present in very large quantities.

So, even if they have less specific heat capacity the quantity that you use is significant because of which you want to bring down the aggregate temperature also. Now in very massive structures like dams where you have to absolutely keep the concrete cool, you can have pipes circulating cooling water embedded inside the concrete. So, that obviously requires lot of pre-planning and understanding the requirements of the structure and so on to keep the concrete temperature down for a long period of time you need to ensure that you get good reduction of heat in the interior caused by cooling water that or cooled water that goes around in pipes.

Thermal Cracking:

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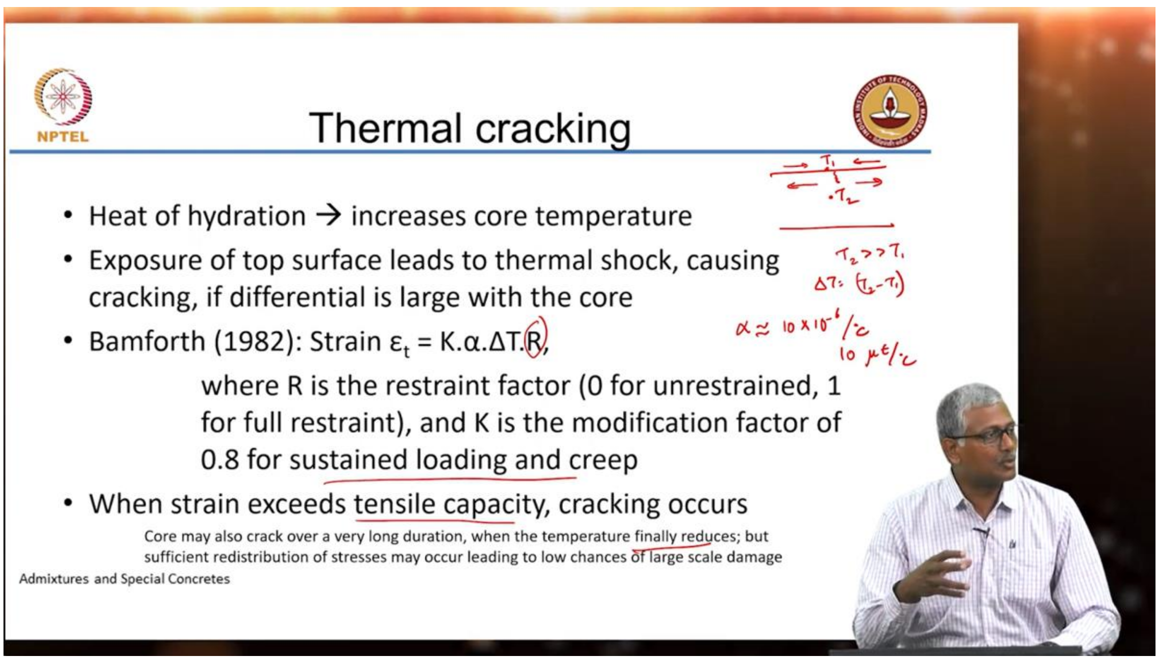

So, thermal cracking is the problem that we are trying to solve as we expect the heat of hydration caused by cement reaction with water will increase the core temperature. The exterior surface is going to cool faster than the core and this temperature differential will cause cracking.

So, if you are considering a raft or a slab the top temperature and the core temperature so T2 is much greater than T1 ($T_2 \gg T_1$). The top temperature is going to cool down to ambient conditions quite rapidly if the top is open. You cast the concrete, leave the top open, start curing and stuff then what happens is your top temperature is very low as compared to your core temperature. R is the restraints depending upon the amount of restraint you have you can calculate the thermal strain caused by this temperature difference T2 minus T1 ($\Delta T = (T_2 - T_1)$) as strain is equal to k into alpha into delta T times R where k is a modification factor that accounts for the time dependency modification factor for sustained loading and creep.

$$Strain\ \varepsilon_t = K.\alpha.\Delta T.R$$

See this thermal shock does not happen instantaneously, it happens over a small period of time to take into account the effects of redistribution of strains you can lower the amount of strain that comes to your system by adopting this value k.

So, if k is 1 that means we are not considering the effect of time at all. We are considering thermal shock when k is 1 but in reality, that is not the condition. So that is why this k factor is taken and it is usually about 0.8 for sustained loading and creep. Alpha is the coefficient of thermal expansion of the concrete.

How much is alpha? 10 into 10 power minus 6 per degree Celsius ($10 \times 10^{-6}/°C$) or 10 microstrain per degree Celsius ($10\ \mu t\ /°C$). That is the coefficient of thermal expansion of concrete. Steel also has a similar coefficient of thermal expansion. This tensile strain that is created because of thermal differential when it exceeds tensile capacity cracking occurs. When the tensile strain capacity is exceeded by the thermal strain that is created because of temperature differential you will have cracking in the system.

Now what we are not thinking about is that this is only at the surface. So, where will the cracking appear? It will appear at the surface because the surface wants to contract because low temperature is there. Core is preventing it from contracting causing it to become a zone in tension. So that is why you get a cracking on the surface. So, thermal cracking because of temperature differentials occurs at the surface.

However, you have to imagine that the core is not going to stay at that temperature with time may be with long period of time depending upon how massive your structure is the core may tend to reduce its temperature and the associated contraction of the concrete in the core may also lead to cracks in the core of the system. But that will happen over a very long period of time when temperature finally reduces in the core there will be contraction and the movement because of the contraction when it is resisted by the reinforcing steel will obviously cause cracking. But because the presence of the steel the crack widths will be limited in the core and it is not really going to be a debilitating problem for your system. In dams, it may become a problem because there is no steel really inside. So, when your interior core starts cracking in dams it will provide channels for water to come out.

So in most dams, you see major signs of leaching. That leaching only becomes worsened because the interior core also has started cracking after some period of time. In massive concrete structures that are reinforced, this is not going to be a major issue.