Admixtures And Special Concretes

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Lecture -65

Special concretes - Mass concrete - Temperature differential measurement, Design

Specifics & consideration for mass concrete:

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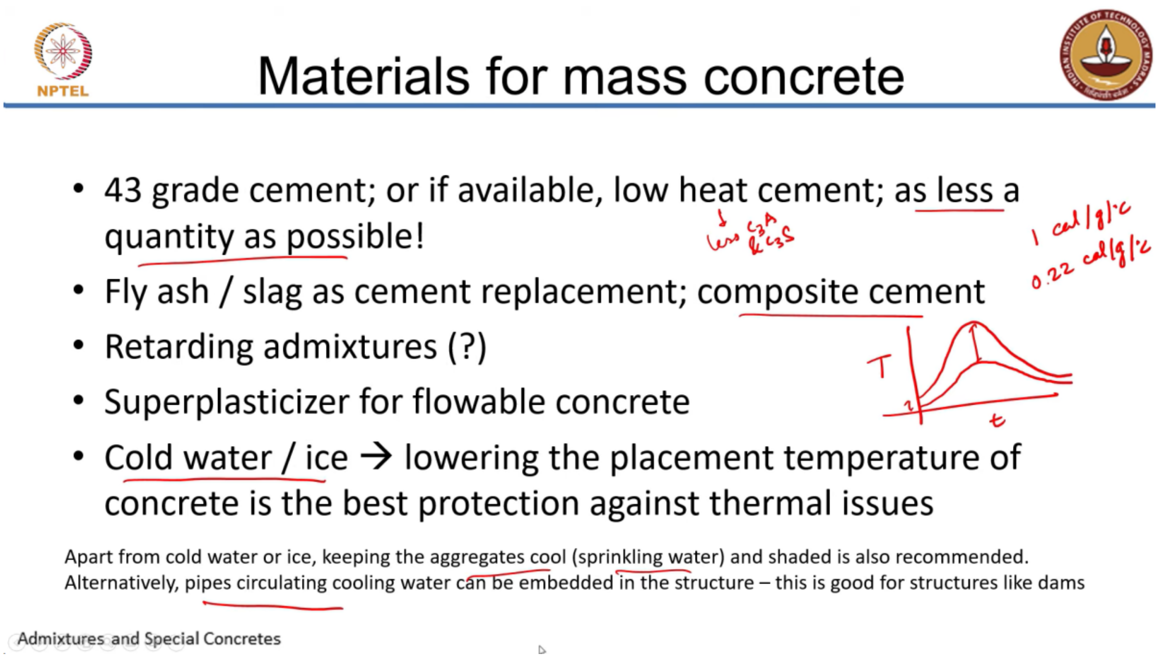

Good afternoon all. So, let's resume our discussion on mass concrete that we started yesterday. So we were talking about specifics about what type of materials to be used for mass concrete, what are the primary considerations with respect to how the design is done.

Thermal Cracking

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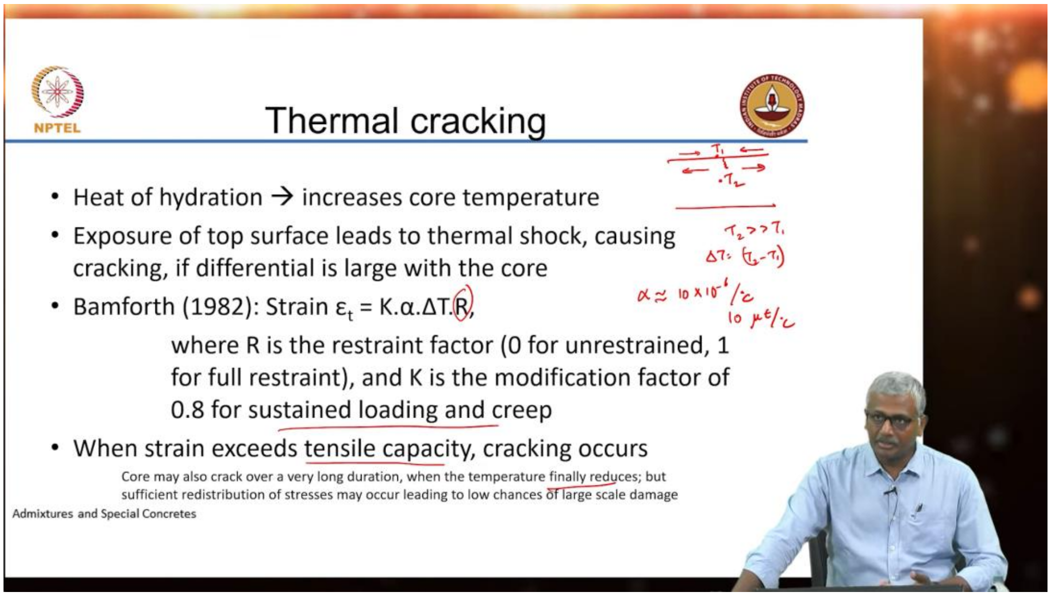

This is primarily from the perspective of thermal cracking and the thermal cracking can be of two types, one that arises because of temperature differentials between the core and the surface, the other which happens because you have internal problems such as delayed trigger formation that may happen at very high temperatures.

Typical guidelines to avoid cracking:

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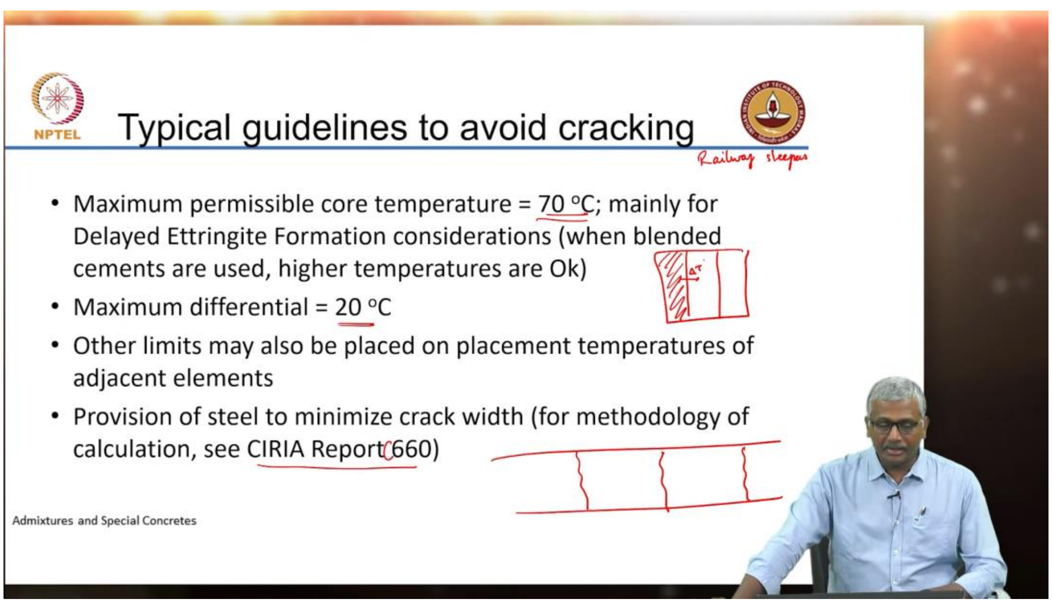

We were talking about typical guidelines that are used for avoiding cracking, some documents that are available for people to do a design protecting the structure against thermal stresses.

Calculation of temperature differential allowed:

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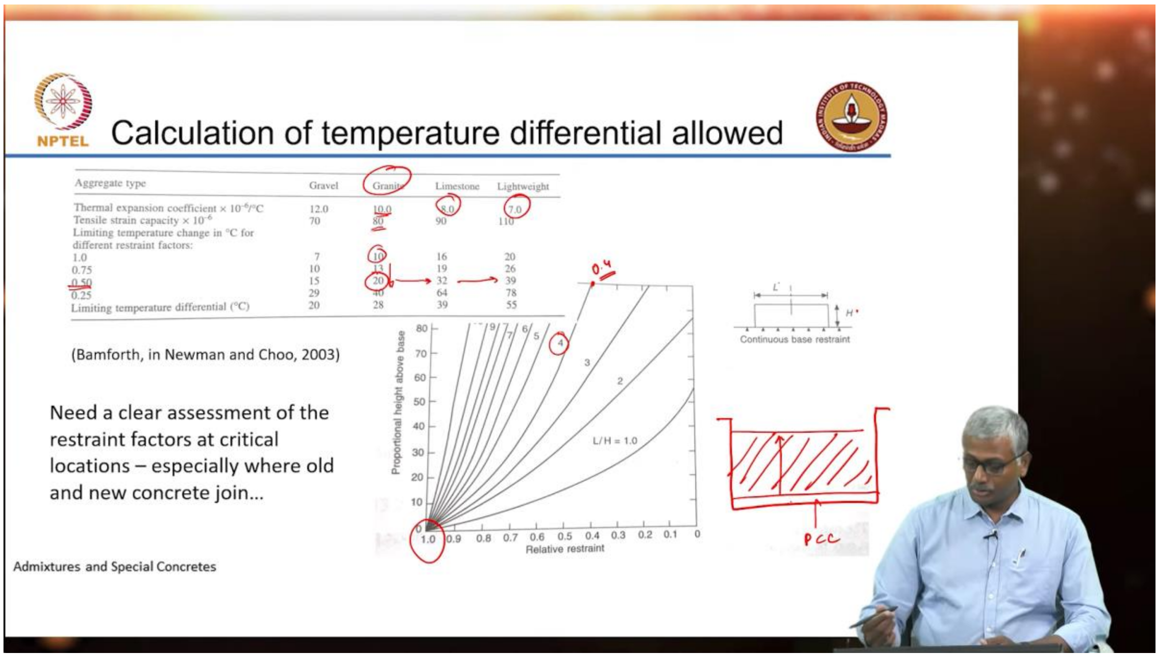

And then we were talking specifically about issues where you can have different types of materials leading to varying properties of the concrete that leads to improved strategies for thermal protection. For instance, if you use a limestone aggregate or a lightweight aggregate instead of granite you have a better chance at protecting the structure because your allowable temperature differentials now increase thanks to the lower expansion coefficients exhibited by these aggregates and resultant concrete also obviously will depend a lot on the type of aggregates that are used.

Coming to the other problem of your concrete slab resting on a base which can provide some restraint to the movement which is likely to create cracking and this restraint factor will depend upon the size of your slab and the relative thickness or the size-to-thickness ratio will determine the extent of restraint that is felt at the top of the slab. And as we discussed earlier the primary consideration for temperature differential is from the core of the slab to the top of the slab and so that is why we want to calculate what is the degree of restraint at the top which then needs to go into this formula to try and figure out the extent of tensile strain that is created at the top surface. Now of course similarly you are going to be creating strain at the bottom surface also. Your strain will also be there at bottom surface because your restraint is maximum but you then because the restraint is maximum your concrete is actually under tension there but still it is confined so you really do not see the effects of the cracking that are happening on the other side.

You see that primarily when you have an exposed surface. Secondly, your temperature differential between the core and the bottom of the concrete is not going to be as significant because the bottom is solid rock or plain cement concrete which is not going to be dissipating heat at the same rate as the top surface which is heat that is flowing out into the ambient conditions. So, in that manner, the differential between the core and the bottom of the slab is not that much of a concern as it is between the core and the top of the slab.

52 x 52 x 4 m raft for high-rise building

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Now I was talking about this case study of this 52 by 52 by 4-meter rack for the high-rise building which was earlier planned in Amravati.

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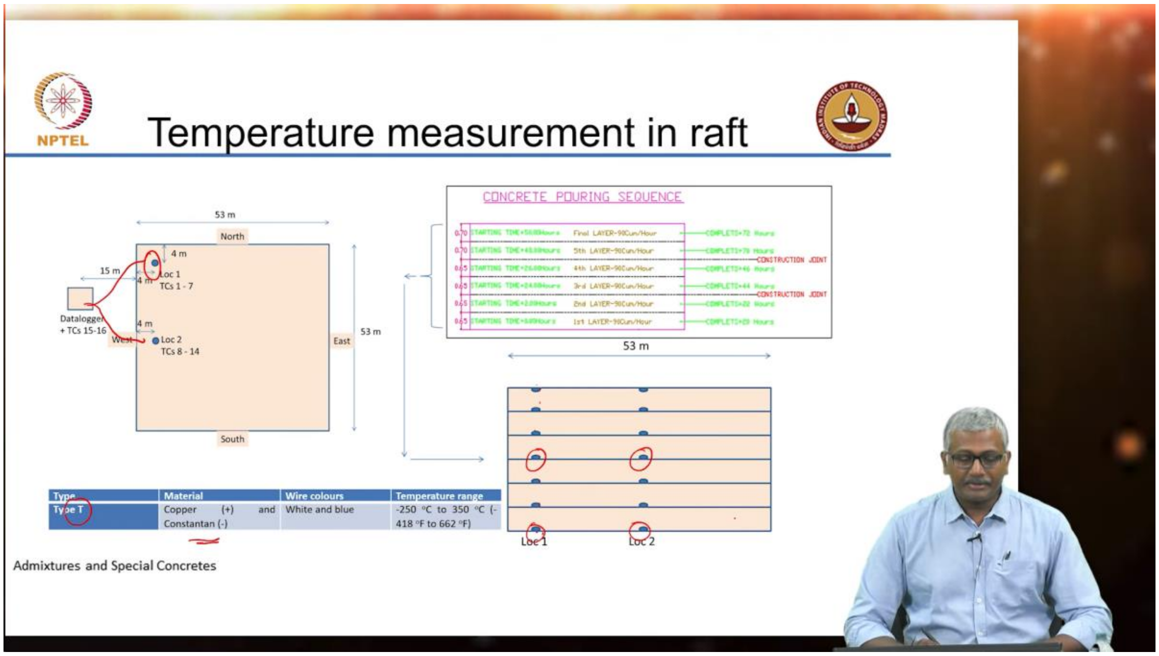
So, we were talking about the fact that the entire concreting operation was taken up by the means of 6 boom placers and 1 concrete pump so that the entire segment could be filled up in stages which were uniform with respect to the layer height throughout the 50 meter dimension of the member and then thermocouples were placed at different locations to get an estimate of the temperature rise.



Results discussion:

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And I was also explaining to you the fact that the core of the slab which was 4 meters thick so the core is at exactly 2 meters from the top or from the bottom at this location the temperature even after 1 month had not changed significantly. You still had a very high temperature about 75 degrees after 1 month and after about 6 weeks the temperature was down at about 60 to 65 Celsius. By this time the ambient conditions also had warmed up significantly. The ambient conditions the temperature during this time had gone up to nearly about 35 to 40 degrees Celsius. So that temperature difference again came down.

So this goes to show that in certain seasons the temperature differential will be a lot more stringent as compared to other seasons. For instance, you are doing concrete in winter. The exterior, in Chennai there is not much of winter but if you go to a place where there is actually a winter temperature let us say 15 degrees Celsius ambient on average if 15 degrees Celsius is there on average on the outside. That implies that if the surface is open to the ambient conditions the core should be only 15 plus 20 which is 35 degrees Celsius. Now how do you maintain the core at 35 that is going to be a big challenge.

So let us say now we have a concrete that is going to be cast with a placement temperature of 15 degrees Celsius. Let us say the concrete temperature goes up to about 40 to 45 degrees. In that winter condition where the exterior temperature is only 15 your concrete is not safe. So, what could you do in such an instance? What could you do? You want to cover the top surface. You want to prevent the top surface from becoming equal to the ambient conditions.

So that way you reduce your temperature differentials. Now the same concrete when you did in summer let us say the ambient condition was 30 degrees- 30 to 35 degrees and the core reached 45 degrees maximum. So, in such a case, you do not really have a problem because the temperature differential can be controlled very well within 20 degrees Celsius. This 20 degrees is a guideline.

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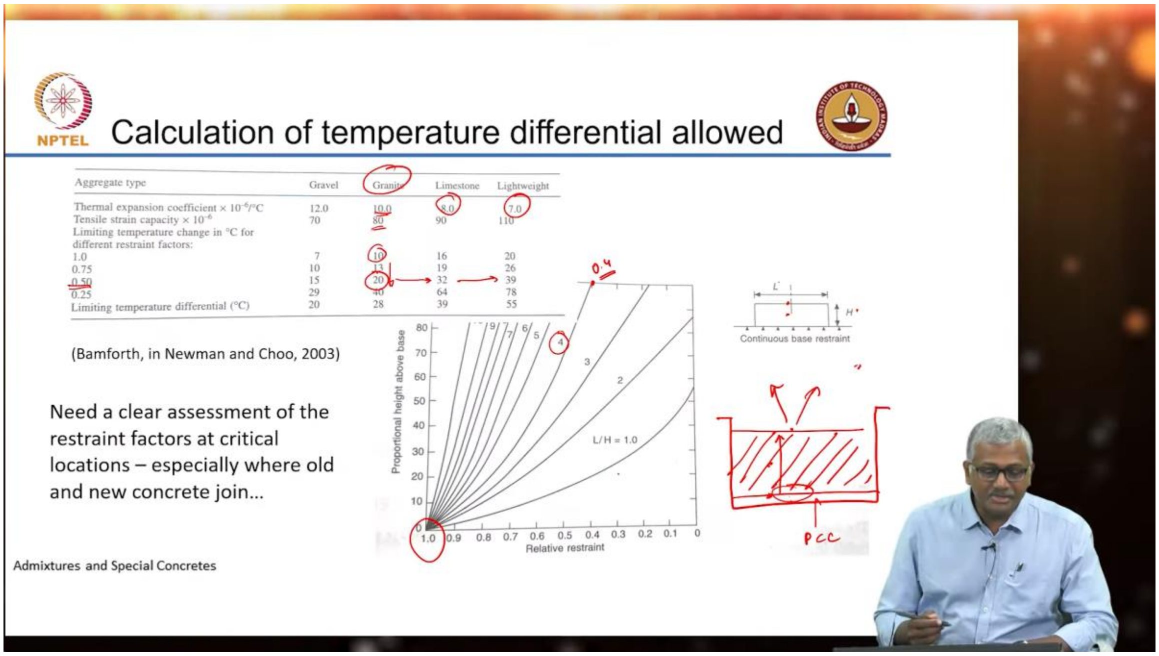

Now as we see from the table, I showed you previously in some instances depending on the extent of restraint even a lesser amount of temperature difference can result in cracking.

So, you need to be careful about when you prescribe this 20 degrees Celsius. It is better to have as little of a differential as possible until the concrete has gained sufficient strength. Let us say by 7 days or 14 days when the concrete has gained sufficient strength at that point of time even if there is a differential of close to 20 degrees Celsius it may be able to take that. Tensile stress or tensile strength also would have developed to an extent that concrete is able to take that level of tension caused because of this temperature differential. The season of construction can also have an impact on the way that you design the sequence of placement, the use of insulation, and so on and so forth.

So, it is a slightly complicated topic to completely address with just one experience of the job site. You will have different demands at different job sites which will have probably unique solutions that you need to deal with.

Temperature in raft

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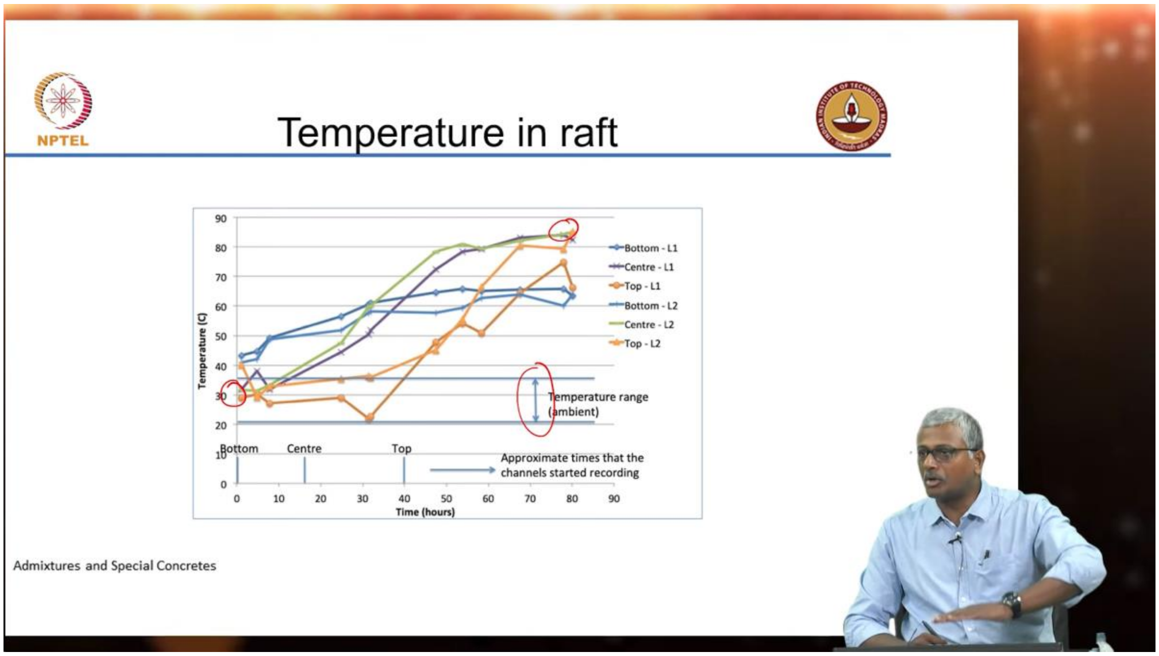

This is again more consolidated temperature in the raft. As I said the temperature in the core had reached up to about 85 to 90 degrees Celsius, a significant temperature rise. But you can see here that the placement temperatures as per the spec the placement temperatures were allowed up to 30 degrees Celsius.

Now that is one point that construction companies must also take very carefully. Yes, the spec allows 30 but does that mean you can go with 30, look at the temperature rise it has gone up to 85 degrees Celsius. Now the basic consideration is that we do not want concrete core temperature to go beyond 70 that is from the point of view of a conservative estimate against delayed reticulation formation. When you are using blended cement, you can go up to 80-85 without really any problem. Unfortunately, there is no spec or guideline written in that fashion.

It is only something that people have gained by experience by research on BEF and so on that when blended cement concrete is used, BEF is not such a big problem until you reach much higher temperatures. But there is no spec, the spec only is available at say 70 degrees Celsius. So very often the client would tell the contractor I want a concrete which will not go beyond 70 degrees Celsius and yet in the same spec they would have allowed a placement temperature of 30 degrees Celsius. So, the contractor has to ensure that they are addressing this problem holistically. The first and foremost step in designing mass concrete is to lower the placement temperature as much as possible.

So, in job sites where there are significantly large quantities of concrete to be delivered, it is almost essential to set up an ice plant to ensure that you can use ice for preparation of the mass concrete. Deliver concrete at as low a temperature as possible. Now again depending on the season, this may be still different. In the winter season, it is easier to provide concrete at low temperatures because your aggregates will be at low temperature, they are stored outside, and getting the water cooled down to a low temperature will not be too much of a problem. In summer aggregates are hot unless you do sprinkling and shading, aggregates cannot be cooled down significantly.

But we saw that the insulation requirements and temperature differential assume a slightly different phase when you come to summer or winter. So, again holistically you need to plan this strategy because most construction projects that we deal with, large infrastructure projects are certainly much more than 2 seasons, they last for much longer. So, you need to have methods in place that can tackle all these problems. So let us continue with this. So again, here the temperature range ambient conditions is given about 36 degrees to about 20 degrees.

I think this placement took place in February, around February is when the concrete was placed in this raft. So, again you see that the temperature rise is delayed and that depends obviously on when the thermocouple really started recording because you start filling from the bottom up so the bottom portion will start recording first, the middle will be next and the top portion will be last.

Design of concrete

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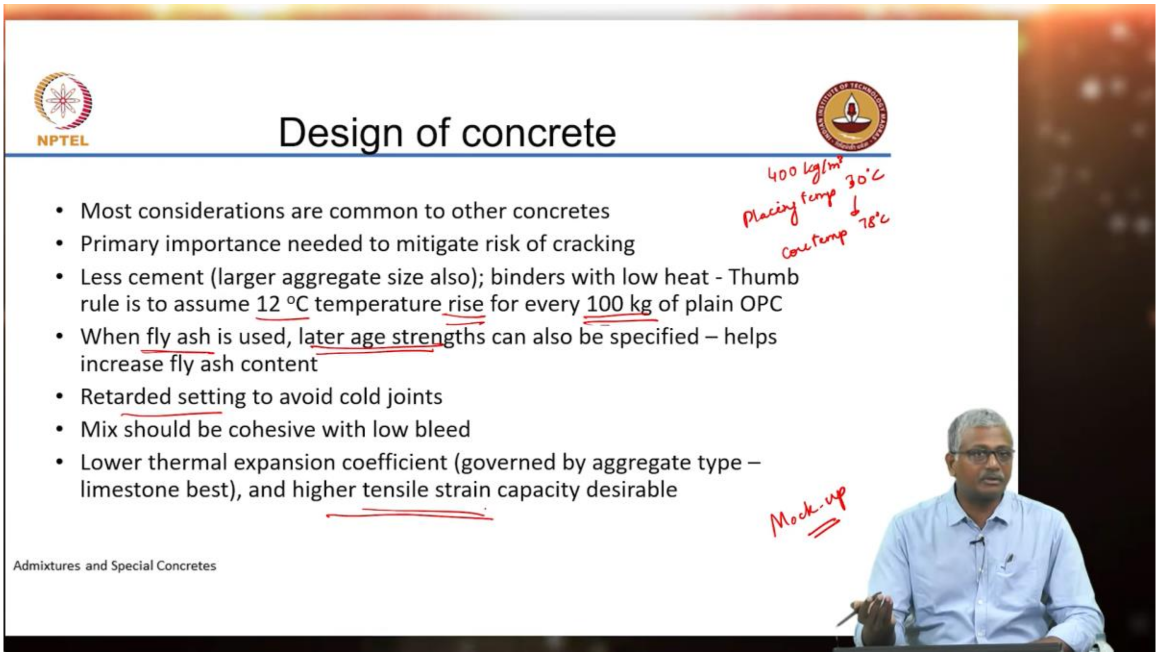

So, again most considerations for the design of raft concrete are similar to other concrete. But then all these aspects about temperature differentials, generation of high temperature in the core, all these have to be looked at carefully. So minimizing or mitigating the risk of cracking is absolutely important.

Less cement is obviously the most preferred way to do it. Temperature aggregate size also helps. Binders with low heat are essential to be used. A thumb rule if you do not have any data about temperature rise, a thumb rule is to assume that you will have a 12-degree rise in temperature for every 100 kilograms of plain OPC that you use in your system. If your mix is going to be cement plus slag, you can probably reduce it by 1 degree, 11 degrees per 100 kilograms.

If you have cement plus 30% or more fly ash, then you can assume that this temperature will be only about 8 to 9 degrees rise per 100 kilograms of the cementing material that you are using in your system. So let us say I am having a mix design of 400 kilogram per cubic meter of my cement which could be blended or let us say OPC just for the sake of calculation. My placement temperature let us say is 30 degrees Celsius. So as per this thumb rule, my final temperature or core temperature will go up to 30 plus 12 into 4, 30 plus 12 into 4 which is 78 degrees Celsius.

It is a quick estimation. Now you can obviously estimate accurately by putting in a thermocouple but then you cannot always do that in the actual structure. So sometimes in many of these construction projects where mass concrete is taken up, they go with a mock-up structure and I will show you the details of the mock-up structure that was undertaken for the construction of this raft that we are just talking about. Now in general when we are dealing with a raft foundation, just like in a dam, the requirement of strength in a dam is very low. For a gravity dam, the requirement is only 10 to 15 megapascals. For a raft also, you can plan the size in such a way that you minimize the strength requirement.

Why am I saying it is important to minimize the strength? Why should we minimize strength requirement in a raft or in any mass concrete structure? Because we will use less cement. We will use less cement in the system. Less cement perhaps a little more water. More water means rising of temperature of this concrete is going to be more difficult because more water means more heat absorption will take place. Less cement means less heat development will take place.

So, in general always when designing structural members that are likely to be mass concrete, it is best to go with a lower grade, as lower grade as possible. Now in certain instances, your requirement of durability may trump the strength requirement. So let us say that your strength requirement is only M30, but for the purpose of durability, you may have to adopt a slightly higher grade of concrete. Now that is again because we are always thinking in terms of OPC. It is possible to produce more durable concrete with a greater percentage replacement of the cement by fly ash or slag.

Even with moderate strength, we saw that in the data that we looked at during the discussion on mineral admixtures. Even with grades of concrete like 25 to 30 MPa grades which are used for residential concrete purposes, you can still produce high quality or high durability concrete. But when you do that, when you increase the replacement level of cement, what will happen to the strength development? It will slow down. When you use a higher amount of fly ash in the system because reducing heat, the best potential material is to use fly ash. When you do that, you should be able to accept later age strengths.

Now why are we so stuck up on 28 days? In engineering projects, why do we say 28 days strength always? Why cannot we prescribe a strength at 3 months? No, see again we are still thinking about OPC. OPC concrete will reach almost its potential strength or at least 90 to 95% of its potential strength at 28 days. But concrete with blended cements, especially those blended with fly ash will take much longer to reach their potential strengths. So why not delay our strength expectation to 56 days or 91 days? Why do we want to get stuck with this 28 days? Again, another thing that you will have to discuss with your bosses and the people who actually make the financial decisions because waiting longer for the strength means that you may have to do a little bit more curing. That will have financial implications.

But at the same time, it is going to actually ensure that you get a performance that you want because you do not really need high strength at early ages. How much of load transfer happens at early ages? Again, this is something that I have been through several projects but somehow we are not able to convince clients that it is okay to wait 56 days or 90 days for the strength. Nothing wrong with that. What you need to do obviously to show that strength gain will not be hampered beyond 28 days is to ensure that you have data for the concrete mix that shows the strength development so that based on an early age strength you can still predict for that particular mix what will be the long term strength development.

That data should be available to you. So that means you need more time for mix design if you need to produce data like this. You cannot ask for the mix design when the concrete is ready to be poured on-site. So you need data, you need time to produce this data. So all of these show that with a careful consideration of the quality of concrete that is required for a particular project you can actually meet the demands. So as I said choose as low a strength as possible for the raft or for the footing or for any mass concrete structure.

Use as much replacement of cement as possible and because of the delay that will give in your strength development try to go for a later age strength for approval of the mix and not 28 days strength. Generally, any such concrete which has potential to be used in a mass concrete structure you want to avoid cold joints as far as possible. For that retarded setting is better, more beneficial right. Especially when you are using fly ash you will get retarded setting so you do not really have to worry too much about it automatically that will happen. So, you need to avoid cold joints and build up the structure in such a way that you avoid any major cold joints between your structure.

The mix that you use for raft concrete or for mass concrete should be cohesive with less bleeding. We do not want bleed because bleed will increase the water-to-cement ratio on the surface of the concrete and that is detrimental from the perspective of durability. We want as low a thermal expansion coefficient as possible and as I showed you earlier it is governed by the aggregate type. If you have a choice, choose aggregates that will produce lower coefficient of thermal expansion in the concrete and higher tensile strain capacity. Now of course, that we do not have much of a control on tensile strain capacity will be determined primarily by the modulus of rupture of your concrete that will again depend on the mix design, again depend on the grade of the concrete.

All of those factors will determine your tensile strain capacity.

Effects of fly ash and slag:

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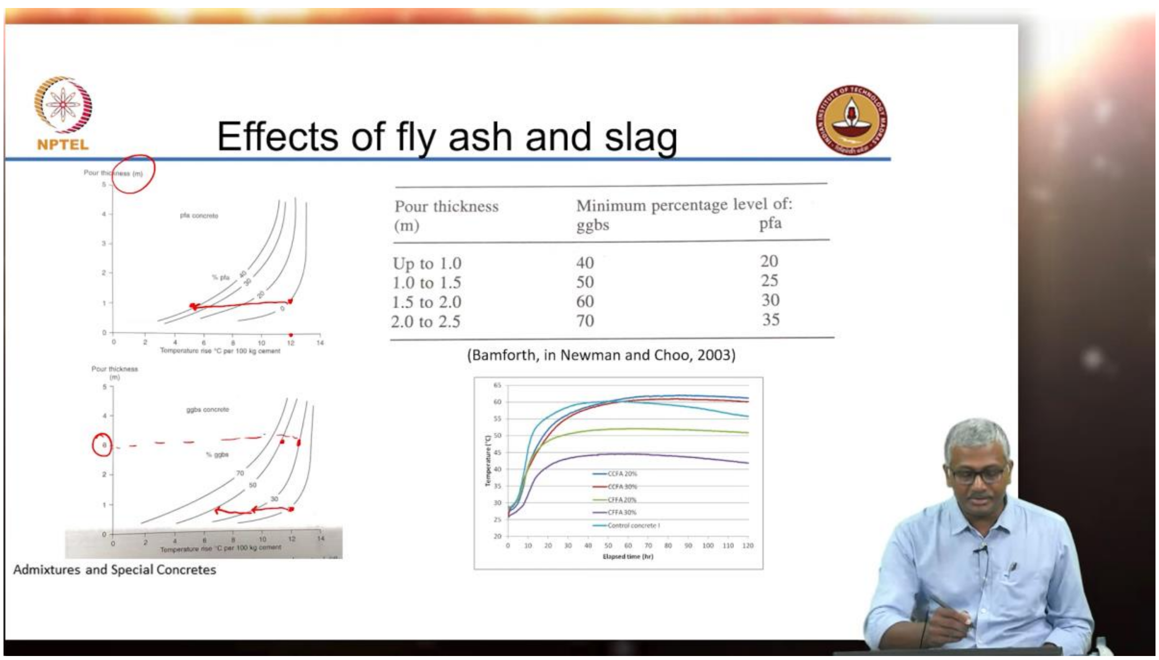

Now again needless to say when you use fly ash or slag you get extremely beneficial conditions for mass concrete. Now we also saw earlier that there is cements like low-heat cements that are potentially available which has higher C2S and low C3S content but for a cement company to produce low-heat cement requires a major change of their process and many cement companies are not ready to do this. For them, it is much easier to do this blending in the concrete when you can increase fly ash contents to about 40%. So, see what happens here let us say 12 degrees temperature rise per 100 kilograms of cement is possible.

So, pore thickness is also given here. So, if I have a pore thickness of 1 meter, I am without any fly ash in the system it gives me 12 degrees temperature rise. But if I increase my fly ash to 40%, I can come down to even a 5-degree temperature rise per 100 kilograms of cement. So, with fly ash, I get maximum advantage with slag maybe not as much let us say here and when we move to 30% it is coming down to about 9 at 50 and 70% possibly, I can go down but that effect will reduce significantly when I increase the size of my concrete member. So, for instance, if I have a 3-meter member if I choose a blend with 50% slag or 30% slag, I still get the 12-degree temperature rise. The size of the member as it goes up the benefits for my slag will reduce significantly.

But if I choose 50%, I can bring it down to about 10 degrees or slightly less than 10 degrees when I choose 70% slag. So, I have to choose very large amounts of replacement to get the benefit of lower temperature.