Admixtures And Special Concretes

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Lecture -66

Special concretes - Mass concrete - Temperature monitoring, nomogram, minimizing restraints

Temperature monitoring- Mock up

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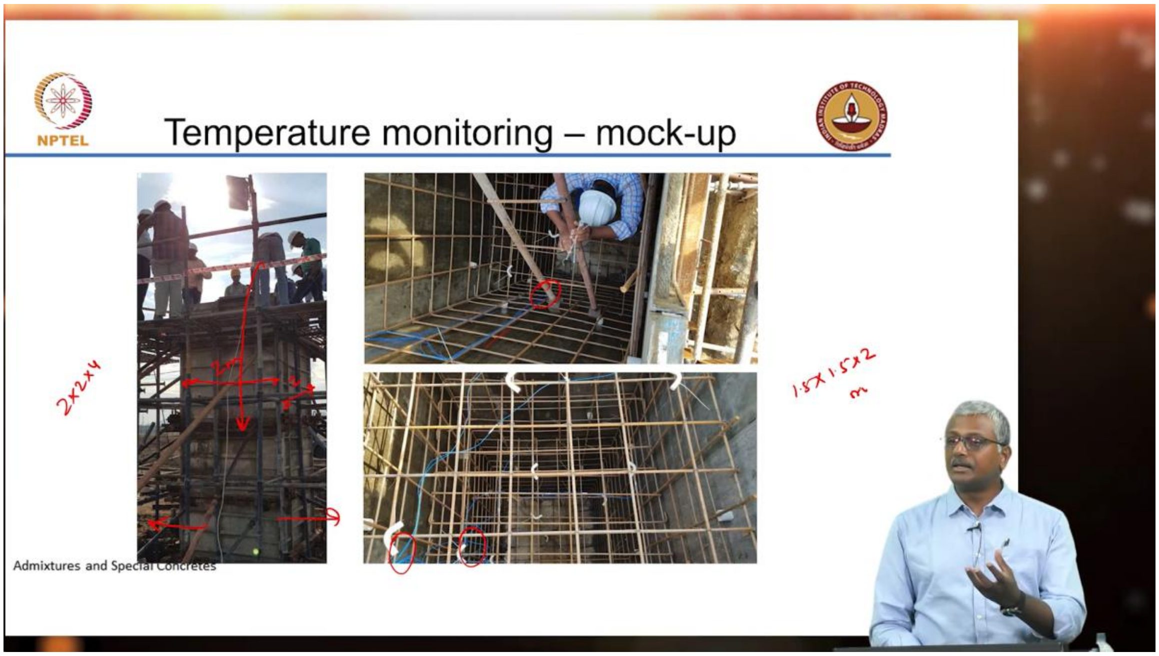

So, as I said in most projects involving mass concrete, you have to do a temperature monitoring in a mock up structure. The advantage of doing a mock up structure is you can also do an actual strength development assessment on the mock up itself. You can take course from the mock up and then determine the strength. So, in this case this raft of 50 by 50 by 4 meter, we actually did a mockup of 2 by 2 by 4 meter. So, this is 2 meters 2 by 2 by 4. Now, interestingly what happened in this case was a disaster because we had this reinforcement inside, you can see we also fixed these thermocouples at various locations, the blue wires are all thermocouple wires, they are fixed at various locations.

Now the problem was that contractor in this case had not paid attention to the fact that the concrete is self-compacting. So, when we poured the concrete inside, the formwork simply burst and the concrete came out. So, this mock up structure got wasted. To do something immediately, they actually had a 1.5 by 1.5 by 2 meters mock up also. So, this was 2 by 2 by 4 meters, 4 meters because we want to get an estimation of the depth of the actual raft. So, they later moved on to 1.5 by 1.5 by 2-meter size because they had something ready already.

So, we did not really get the use of the actual mock up because they did not consider the fact that this concrete is self-compacting. So, from this mock up you can generate the temperature profile and assuming you are maintaining this adiabatic condition in the center, you can then say that the same thing will happen in your structure. If you are still not convinced, it is better to also do monitoring of the structure using thermocouples or using these days as I said there are temperature sensors that you can embed in the concrete and use a mobile phone with RFID to determine the temperature.

Use of ice or cold water

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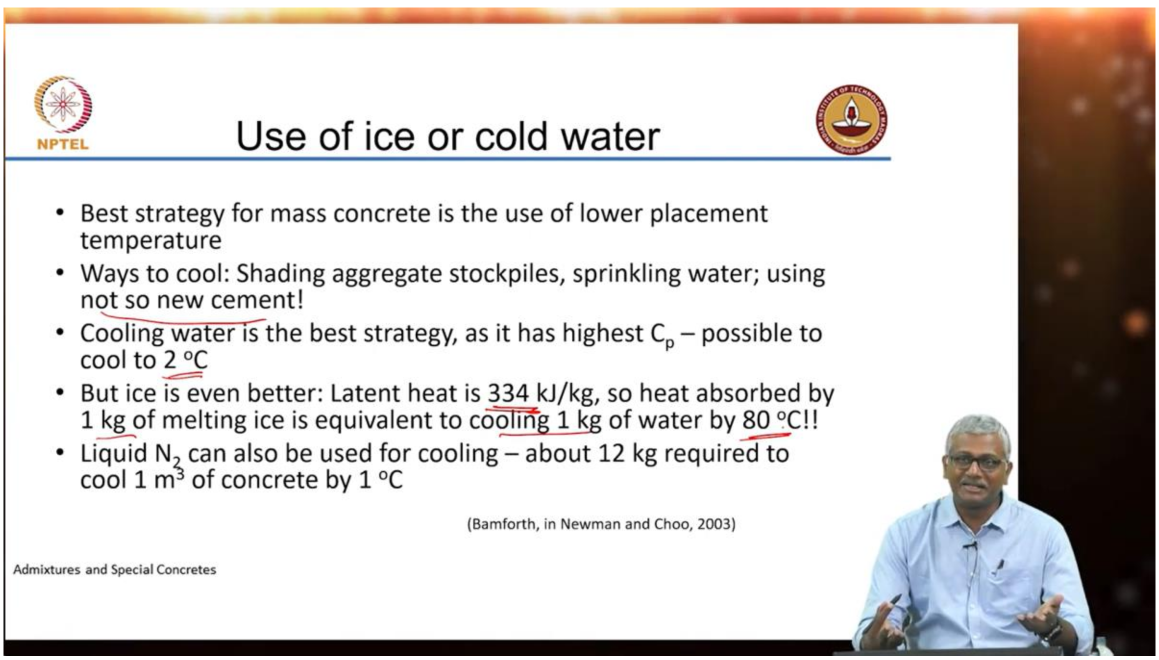

Now as I said the best strategy to do mass concreting is to reduce temperature and there use of ice of cold water is probably the best means possible.

You can shade the aggregate stockpiles, you can sprinkle water and using not so new cement. Why do I say that? Because when cement is very fresh it is quite hot. As I said when you soot it in the silo your temperatures could be 50-60 degree Celsius for the cement.

At that temperature the cement will also contribute a lot to the heat. So, make sure that but at the same time you do not want to use cement that is more than a month old, more than 2 months old because the property of cement also will change with time, there will be effect of moisture causing pre-hydration and so on and so forth.

So, you need to be careful with using cement that is very old. So, you want to use cement as fresh as possible but when you do that in a mass concrete project you will have to contend with the high temperature of the cement also. Cooling water is a good strategy, water has the highest specific heat capacity amongst all the ingredients of concrete. So, you can cool water down to possibly around 2 degrees Celsius. But you have to remember that even if you cool the water down to 2 degrees, water is in terms of mass how much is the quantity of water in terms of mass as a fraction of the concrete mass.

Maximum you will be using about 200 kilogram in a cubic meter, concrete is 2400. So, one twelfth of the concrete mass is only water. So, cooling the water down to as much as possible is necessary to ensure that you are able to restrict or heat development over the entire concrete. But use of ice is the best strategy here because ice has a latent heat of 334 kilo joules per kilogram that means to melt 1 kilogram of ice you can take up 334 kilo joules of heat that is the extent of heat it will remove from the system just to melt. So just melting heat absorbed by 1 kg of melting ice is equivalent to cooling 1 kg of water by 80 degrees Celsius that is a massive implication.

So, using ice is a better strategy than using cool water in construction projects related to mass concrete. So very important. People have also used liquid nitrogen; liquid nitrogen is much lower temperatures I think it is 77 Kelvin is the temperature of liquid nitrogen. So, we are much below ice obviously ice is at 0, liquid nitrogen is at close to minus 200 degree Celsius. So about 12 kilograms is required to cool 1 cubic meter of concrete by 1 degree Celsius, 12 kilograms of liquid nitrogen for 1 cubic meter of concrete.

Now of course it may seem like too much of an effort to use liquid nitrogen because you need to first get liquid nitrogen which is not easy, expensive, ice is much easier, better. So, in most large construction projects the first thing to do is set up an ice plant to get ice to lower the temperature.

Nomogram for concrete mix temperature:

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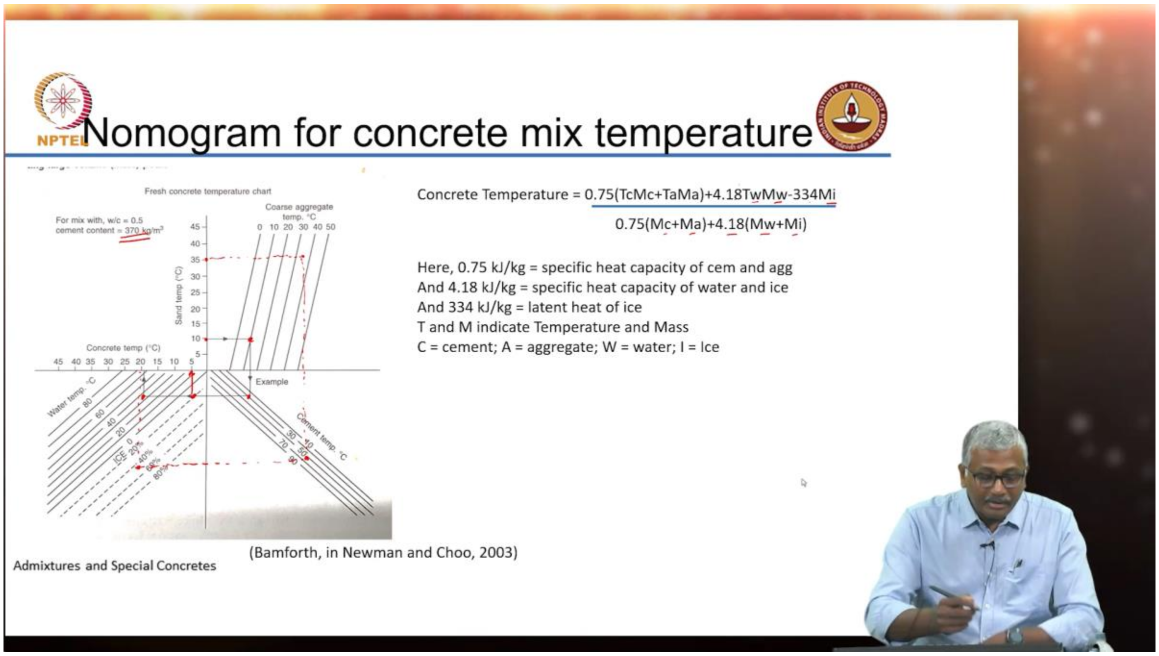

So there is a nomogram available for concrete mix temperature determination which you can use for understanding what should be the temperature of the ingredients for making the concrete and how much ice you should be using in your system. So this is done for a simple concrete mix with 370 kilograms of cement and 0.5 water to cement ratio.

So now you have your sand is at certain temperature, your coarse aggregate is at certain temperature, your cement is at a certain temperature. Let us say sand temperature is 10 degrees Celsius, coarse aggregate is also 10, you come down and read the cement temperature. Here in this case, they are fixing it as 30, then you move to this quadrant and depending upon the amount of ice that you are using you can determine the concrete temperature. So with these ingredients sand coarse aggregate being at 10 and cement at 30, if you have the water temperature close to about 30 degree Celsius you can achieve a concrete temperature close to 30 degree Celsius you can achieve a concrete temperature close to 20. Now let us see if I use ice what will happen? If I use 20 percent of my water as ice I have already brought down the temperature to 5 degree Celsius for the concrete.

Now let us assume a more realistic scenario which happens in our job sites. Let us say sand temperature is 35, coarse aggregate also let us say is around the same 35. Let us say cement is at 50, my lines are not perfect but still. Now if I want a placement temperature of concrete of 20 degree Celsius, so I go this way, I need to drop down this line here, see where it intersects that means close to about 50 percent of your mixed water should be ice-close to 50 percent. It is a good initial start and this is from a simple calculation. So, you can determine the concrete temperature from the temperature of the ingredients that are used for mixing the concrete.

$$Concrete\ temperature = \frac{0.75\ (TcMc + TaMa) + 4.18\ TwMw - 334Mi}{0.75(Mc + Ma) + 4.18\ (Mw + Mi)}$$

0.75 kJ/kg = specific heat capacity of cement and aggregate

4.18 kJ/kg = specific heat capacity of water and ice

334 kJ/kg = Latent heat of ice

T= Temperature; M= Mass; C= cement; A= Aggregate; I= Ice

So, 0.75 multiplied by Tc that is temperature of the cement multiplied by mass of cement plus Ta temperature of aggregate multiplied by mass of aggregate 0.75 the specific heat capacity in SI units joules per kilogram per degree Celsius rather than calorie per gram per degree Celsius it is in joules per kilogram per degree Celsius. 4.18 is that of water 4.18 is temperature of water into mass of the water minus 334 into mass of the ice because ice is going to extract the heat. 334 is the latent heat capacity divide that by overall system that is 0.75 into mass of cement plus mass of aggregate. 4.18 into mass of water plus mass of ice. So that gives you the concrete temperature based upon initial starting temperatures of your different ingredients. This is based on the simple calculation which takes into account the specific heat capacities of different materials and the initial starting temperatures. The same equation has been transferred into this nomogram which gives you a clear estimate.

So, in the same example if I wanted to use only cool water at close to 0, if I only wanted to use cool water my temperature of concrete would have been 35 degrees Celsius. So, we are not really getting the desired results of keeping the temperature down to as low as possible. No, this is the placing temperature it is not predicting the core temperature. So just for core temperature you have to do the mock-up study or you need to do a calorimetry study in the laboratory.

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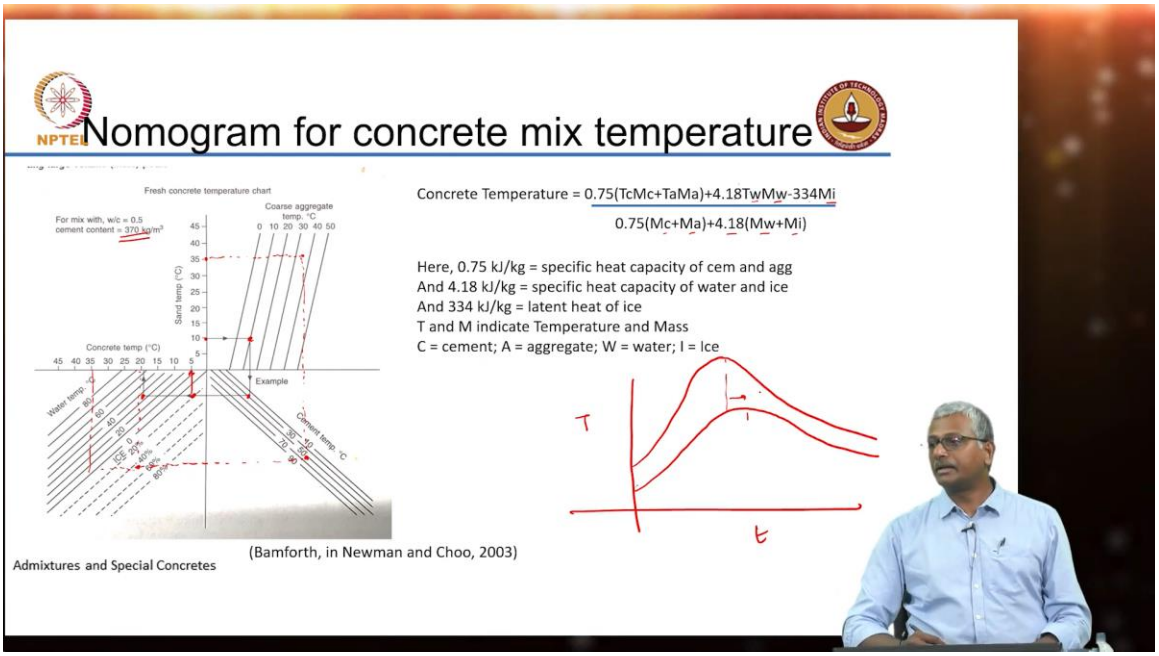

So again, just going back to that core temperature issue let us say this is the temperature (Y- Axis) and this is the time (X- Axis). If I start off with a high placement temperature my core temperature goes up and then it will take some time to cool off and come back to the ambient condition. If I start off at a lower placement temperature there are two possibilities that may happen. I may simply offset the other curve; I may simply offset the other curve exactly. Alternatively, I may have a system that develops heat more slowly also, I may shift the location of the peak also when I choose a temperature that is lower. That may also happen based upon the speed of your reactions you will also sometimes see the shift in the time at which the peak temperature appears.

So that also affects the strategy with which you decide on formwork removal, insulation removal or a combination of both. So that is why when you do mass concreting all these have to be worked out prior to the construction project.

Minimizing Restraints:

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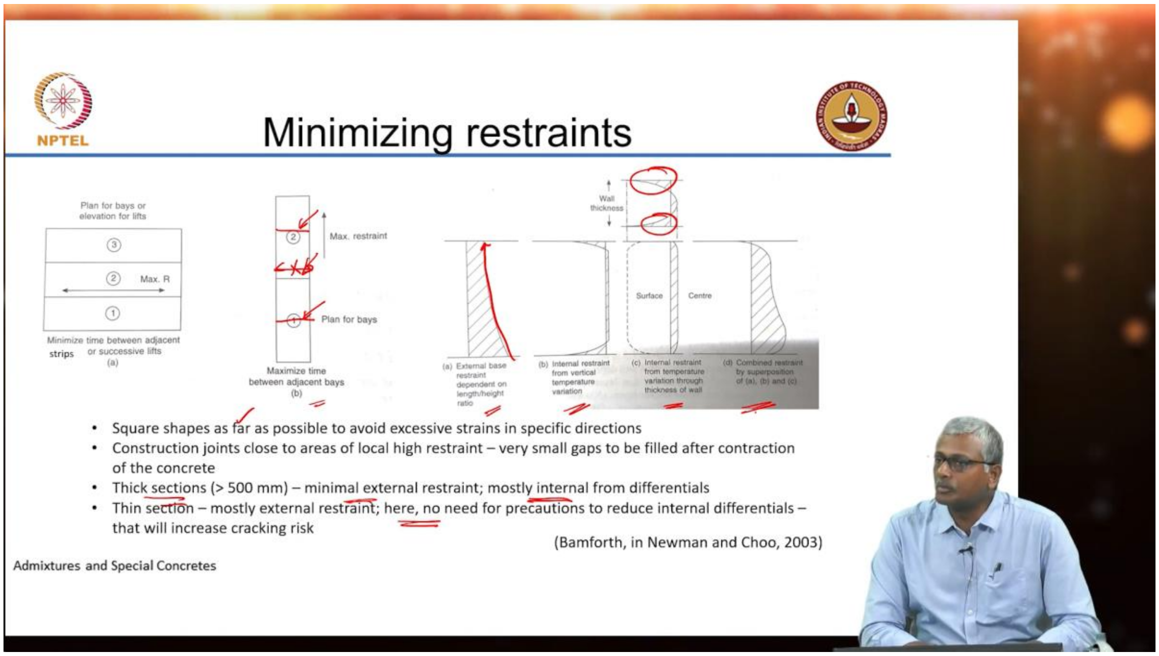


Now the other way to minimize cracking is to also minimize the restraint. Now how do you minimize restraint? There are ways to plan your structure. For instance if you are having adjacent strips coming up or if you are having adjacent successive lifts one above the other coming up, the restraint is maximum along the joint between the two slabs.

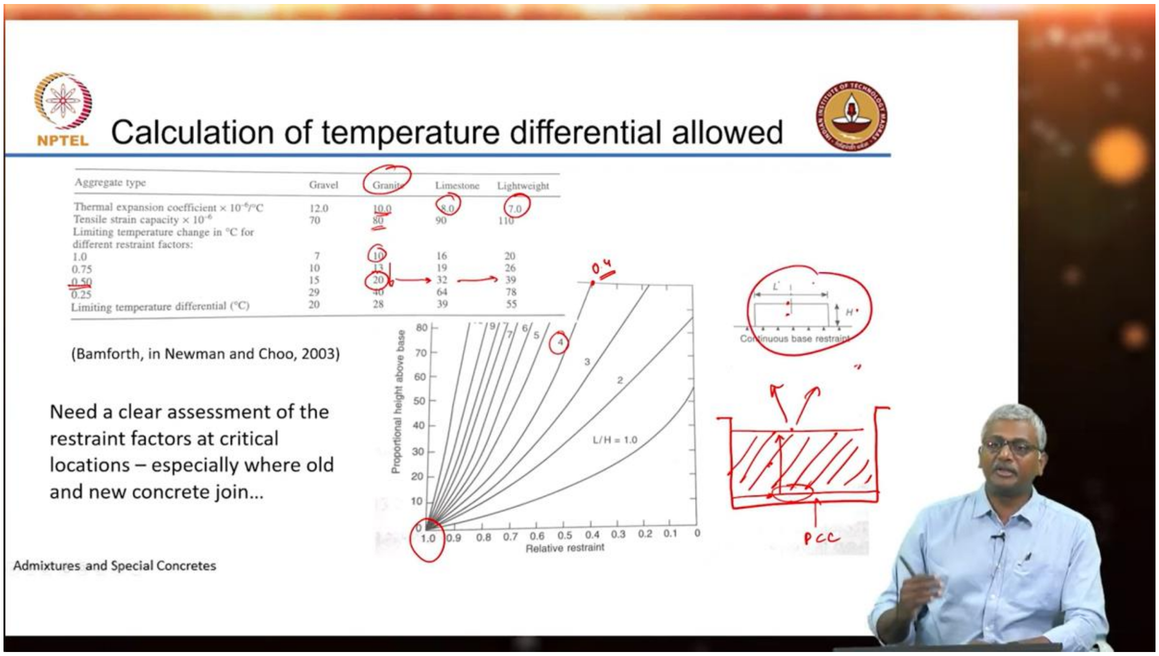
There will be the direction of the maximum restraint. Alternatively if you have adjacent bays one sitting next to each other the restraint is in the long direction, maximum restraint is not in this direction, it is in the long direction. So, you need to ensure that you are minimizing this restraint. This looks more or less like a regular concrete pavement slab. So to ensure that you do not have cracking you will be creating joints at regular intervals to ensure that the cracking does not happen in any other location and then you protect or seal the joints appropriately so that no water actually gets into the concrete.

So you have to ensure when you are doing mass concrete construction to have square shapes as far as possible because otherwise if one direction is much longer than the other the restraint in that direction becomes substantially large. So, you want to use as far as possible square shapes. Construction joints can be used in areas close to high restraint. For instance here in the case of a pavement slab you can have construction joints to ensure that whatever stresses are created are contained within that space. You would not get any more cracking within the construction joint and then you can treat the construction joints after the entire construction period is over.

So that is why when you do industrial slabs you go at about 24 to 36 hours and cut grooves in the slab. Now this groove cutting cannot be done very early. If you do it before the initial set the concrete will just close. If you do it too late if you use a saw to cut the groove too late what will happen? There will be concrete cracking which may propagate too much because concrete will be too hard and stiff it will resist this grooving. So you want to do a groove when strength is relatively low but at the same time not extremely low that the concrete simply closes the crack again.

So groove cutting is a strategy that you need to think about and decide properly before doing the concrete. Now with thick sections which are more than 500 mm thick or may be more than 1 meter thick I would say you do not have that much of a problem of external restraint. So let us say your slab is sitting on a base which is providing restraint to the movement. If the slab becomes thicker and thicker the extent of the external restraint comes down you have mainly the problem of internal restraint which is caused because of temperature differential between the core and the surface. Mostly internal will happen from temperature differentials but if you have thin slabs like a concrete pavement the restraint from the base is much more than the internal restraint it may have because of any temperature difference.

So here in such cases when concrete sections are thin there is no need to take precautions to reduce the internal differential temperature. You can proceed with construction as usual you do not have to worry about because when you start doing that your cracking risk of the structure may go up when you start paying attention to the internal restraint effects like providing insulation and things like that. Those things you need to take care of only for larger concrete members like mass concrete members. So just to give you some examples here this is a case of external base restraint dependent on the length to height ratio. The restraint goes down as you reach the top, we saw this already in the slide here.



Base restraint is maximum at the base and goes down to the top but in the cases where your height or length to height ratio is too large you can get significantly large strains at the top also.

In this case gives you an idea about internal restraint from vertical temperature variation across the slab the maximum restraint will be at the top and bottom where the temperature differential is maximum. This case internal restraint from temperature variation through thickness of wall again because if the wall is very thick the exterior periphery of the wall will have large tensile strains, restraint will be maximum there. Now what we will have to do is obviously get a combined restraint of your entire segment by looking at all of these aspects external base restraint and internal restraints which may appear because of the temperature differentials. In reality you can actually separate out the 2 effects and concentrate on what is going to be dominant.

So, in a pavement you forget about internal temperature differential and concentrate only on the base restraint. In the case of a mass concrete like a raft you forget about all the external restraint and you can try to minimize the temperature differential. So, what could be a good strategy for instance for an industrial floor? How thick is an industrial floor? Is it a mass concrete structure or not? Industrial floor. How thick typically is flooring used for industries? 500 would be very thick typically it will be of the order of 250 to 300 mm. So in which case the same conditions as in the case of a pavement will apply.

In many of these instances industrial flooring you can minimize the base restraint by putting a polythene sheet at the base also. That could be also a solution that many people use. Put a polythene sheet something to reduce the restraint from the bottom. So that is another strategy that is typically followed because their base restraint is much more important than temperature differential.

Surface Insulation:

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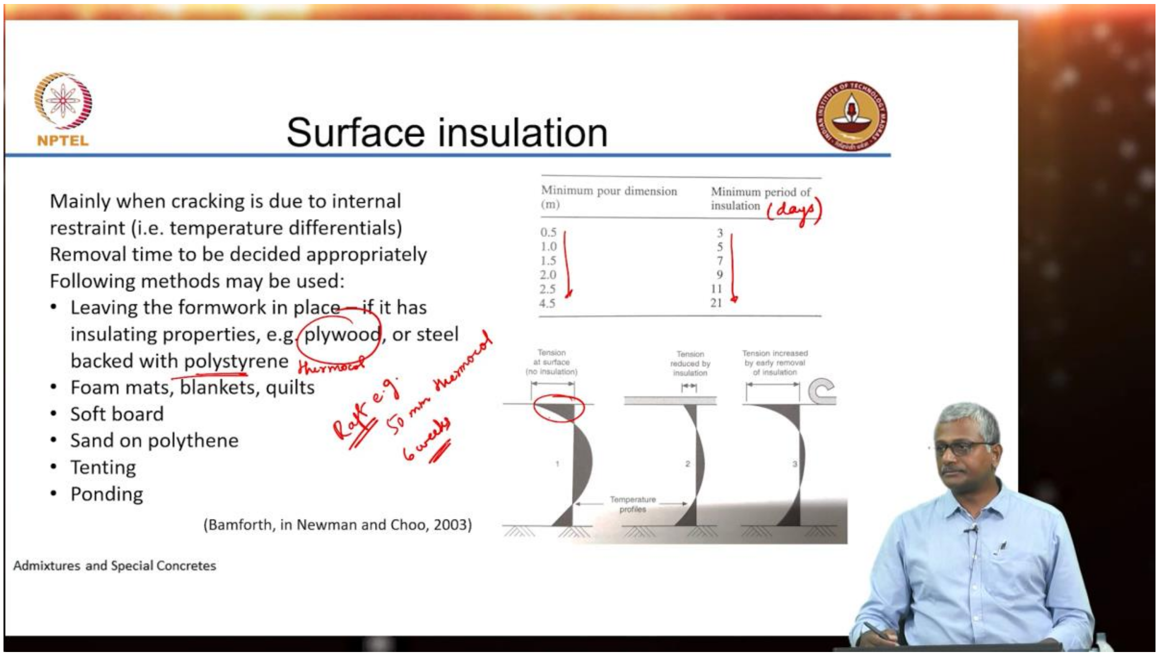

For instances where you want to reduce temperature differential insulation strategy is quite good.

Insulation can be done by several different ways. One is leaving the formwork in place. Suppose you have formwork on the sides you can leave it in place for a longer period of time without removing it. Only thing is if it is a steel formwork, steel is highly conductive so heat will come out quite fast. If it is a plywood formwork your heat will be retained for much longer time because wood is not a good conductor of heat.

So, for mass concrete structures it is preferable to have plywood. Wooden formwork is preferable for mass concrete. If you are using steel, it is good to have a backing of polystyrene or thermocol as we call it. So, the back of the steel formwork plate you should have a pad of thermocol or polystyrene to ensure that the heat dissipation does not happen very quickly. This was a case we saw in one of our recent CMRL projects where the pier was nearly 2.5 by 2.55, very large massive concrete pier and they were using steel plates or steel formwork and without really paying attention to the core temperature development their strategy was to remove the formwork at 24 hours and spray water.

So, this resulted in cracking. We told them to go ahead with keeping the formwork in place for at least 7 days and they were able to see that very clearly there was no cracking happening because of that. But again, if they had used a plywood formwork for 7 days it may have been better because the heat retention would be much better with the plywood formwork. If it is a horizontal surface like a slab, you can put the styrofoam or thermocol right on top just like what is indicated here.

Let us say this is a slab. So, without any insulation you are creating a lot of tension at the surface because of temperature differential. When you have the insulation the temperature differential is minimized. The raft that I showed you, the example of the raft the top surface was insulated with 50 mm thick thermocol boards. So that is why when you see the data for the slab that I showed you previously the differential temperature between the core and the top surface of the concrete was always maintained to less than 10 degrees Celsius because of the presence of the thermocol board on the top and as a result you are minimizing this temperature differential. Problem is if you remove this thermocol too early you are probably going to cause an increase in the tension that happens.

Very rapidly you will dissipate the heat from the top. Because of that depending on the size of the member there are some thumb rules with which you maintain the insulation for a long period of time. For instance, in this book by Bamforth it is given as if you are increasing your pore dimension size of thickness of the raft pore from 0.5 to 4.5 your period of insulation is going up from 3 to 21 days.

You maintain your insulation for 21 days if your pore dimension is 4.5 meters. In the case of this raft that I showed you previously we used 50 mm thermocol boards which were kept in place for 6 weeks. Because we saw that at 28 days also core temperature was nearly 75 degrees Celsius. So, we kept it in place for 6 weeks only after that the core temperature came down to between 60 and 65 Celsius.

So, the structure will continue to dissipate the heat outwards even after you remove the insulation after 6 weeks there will still be some outward flow of heat that will happen very slowly. So, you have to keep all this in mind.

Example from raft pour:

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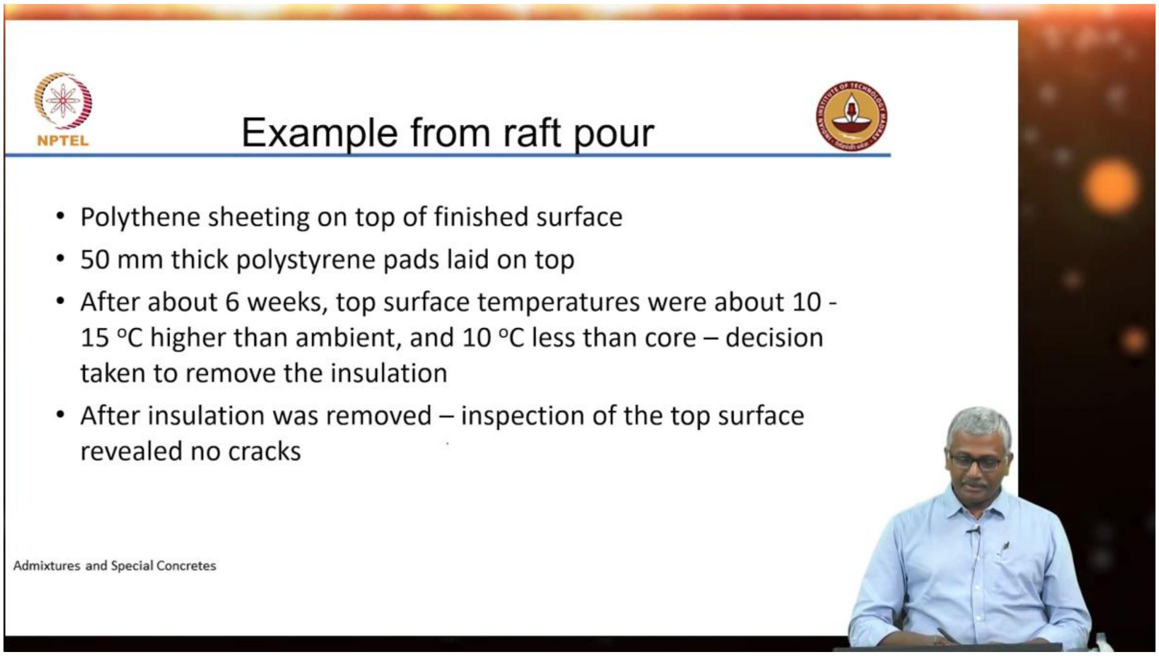

Again, just to round up that example from the raft pore polythene sheeting on top of the finished surface what is the purpose of that? No not polythene sheet. You want to prevent evaporation of the top surface and on top of that 50 mm thick polystyrene pads were laid. After 6 weeks as I said top surface temperature is about 10 to 15 higher than ambient.

Ambient was 35 degrees the top surface temperature the concrete which was measured just about 100 mm below the top surface that was around 50 degrees Celsius and the core was between 60 and 65. So at that point it was decided that yes, we can remove the polystyrene because now your gradation of temperature is much more controlled and the concrete also has gained sufficient strength by that time. So, the possibility of cracking is quite less. We did this and we found that the concrete was indeed safe from cracking. Finally, we did the same thing in another construction project but the concrete cracked.

So, I do not know what the reason was because we followed exactly the same strategy. Temperature monitoring was done. In fact, here the core temperatures did not reach to the level that it reached in this raft. It reached only about I think 75 degrees Celsius because placement was done at 20 degrees not 30 but here adopting the same strategy concrete actually cracked. So, you can design, you can do a lot what happens at the site is left to the people who are actually dealing with the concrete on the site.

So, you never know what has actually taken place. I mean as a consultant I cannot go and stand on site for 28 days to see what is happening with the concrete. Unfortunately, many a times what you design and what you actually get constructed can have differences and the way things are executed on site is not always on par with what you expect in terms of the design. So, you have to pray. Prayer goes a long way. Prayer adds that factor of safety to your construction projects.

This cracking is not debilitating from structural view point because it is a foundation, it is going to bear the load, it is going to be mostly in compression. So, any cracks that do appear are bound to close after sometime. It is not like it is in tension and then cracking is going to further damage the concrete but still if a crack is there it is a pathway for water, CO_2, chloride to enter the concrete and damage the reinforcing steel. That is something we need to avoid at all costs. Thanks.