Admixtures And Special Concretes

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Lecture -64

Special concretes - Mass concrete - Design guidelines, temperature differential measurement

Typical guidelines to avoid cracking:

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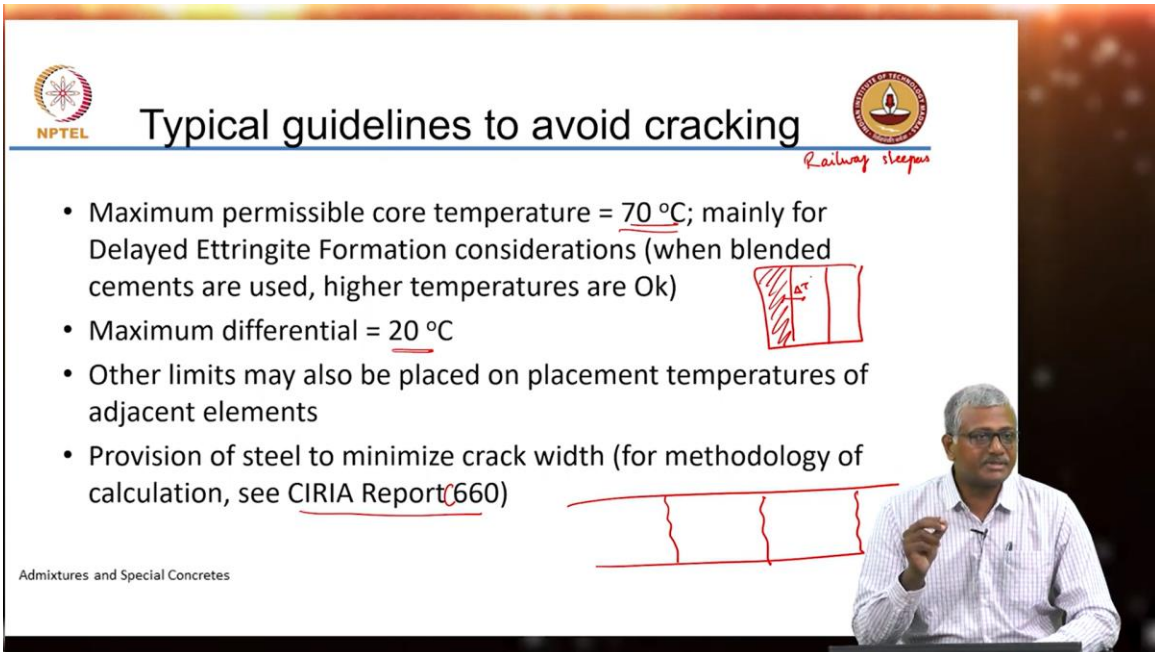

Typical guidelines to avoid cracking

- Maximum permissible core temperature = 70 °C; mainly for Delayed Ettringite Formation considerations (when blended cements are used, higher temperatures are Ok)
- Maximum differential = 20 °C
- Other limits may also be placed on placement temperatures of adjacent elements
- Provision of steel to minimize crack width (for methodology of calculation, see CIRIA Report 660)

Admixtures and Special Concretes

So, again as I said typical guidelines that are undertaken in most concrete specifications to avoid cracking involve keeping the core temperature in the concrete down to less than 70 degrees Celsius. It is mainly for the consideration delayed ettringite formation. Now what is delayed ettringite formation? Ettringite you know very well is formed at the early stages of cement hydration. Ettringite has a structure which is causing expansion. In sulphate attack, that is what happens long-term sulphates from external environment interact with the aluminates in the system to form ettringite. But early formed ettringite is even though it is expansive does not affect the concrete because concrete is still plastic it is able to accommodate the strains because of that expansion. Now in normal course, this ettringite gets converted to monosulphate and then it is subjected to external sulphate attack causing the ettringite to reform in normal sulphate attack cases.

But in delayed ettringite formation what happens is the early formation of ettringite does not happen. It does not happen because the temperature during the early stage of the concrete is so high that the ettringite decomposes and the sulphates basically simply go into the CSH. Later on when sufficient quantity of water is available this ettringite reforms and leads to cracking and this was actually discovered by accident for railway sleepers in England. Now railway sleepers you know are typically made in a precast unit- concrete railway sleepers and usually they are heat cured.

They are cured at high temperatures right to ensure that the productivity increases you can release the pre-stress early and get the sleepers ready in a short period of time. So, in this pre-stressing heat curing that you do for railway sleepers there is a good potential for suppression of ettringite formation in the early stages and when these railway sleepers are out in the open when they are exposed to the environment moisture is easily available. The railway sleeper is not a very massive structure you know it has got a fairly large available surface for a limited volume of the system. So, more surface available moisture can penetrate, reform ettringite and cause cracking. So, this was discovered by accident in the UK where they were looking at damage of railway sleepers they thought it was the problem due to alkali-silica reaction but they ended up understanding that the aggregate was not really reactive something else was happening and then they started looking at the microstructure of the concrete they found that massive ettringite formation had happened in the system and this ettringite is what led to the cracking of the concrete.

So, from that perspective at the early stages if the temperature is kept down to less than 70 degree Celsius you can have stable ettringite in your system. If the temperature goes beyond 70 your ettringite has a chance of becoming unstable that means the formation of ettringite may be suppressed. Now when blended cements are used like slag or fly ash this really does not happen at such a low temperature. So, this is still a point where the specifications are not really moved forward most people want to adopt this conservative spec of 70 degree Celsius in the interior but please remember for delayed ettringite formation to occur you need significant amount of moisture to really reform the ettringite and cause the cracking without moisture you would not have that cracking at all. So delayed ettringite formation in blended cement concretes is mostly avoided to a large extent.

So, there are several reasons why that happens but I am not going to go into the discussion of that right now. But yes, DEF (Delayed Ettringite Formation) is the primary reason why highest temperature in the concrete is kept to less than 70 conservatively in most codes. Maximum temperature differential between the core and the surface of the concrete which is exposed to the ambient conditions should be within 20 degrees Celsius. You may also want to place other limits on placement temperature of the adjacent elements. So let us say you are making a massive raft and you are deciding to pour it in 3 segments.

So, you finish casting this one segment when you are placing the next segment next to it you may want to again have a restriction of the difference in temperature between this segment and this segment. So, which means that you will have to time your placement of the next concrete appropriately. So, wherever you are going to be causing a restraint to the movement of the concrete you have to see how well you can avoid that restraint or minimize the restraint because restraint only will cause cracking. If concrete is able to float in the air in zero gravity it can expand or contract without any problems. Even then internally it may still crack because the aggregate will not change volume easily the paste only changes volume.

So, aggregate will still restrain the paste and cause cracking internally. But there is no other structural restraint if the concrete is floating in the air. Now there is a very well-written document called CIRIA report C660 and this is the standard guideline which people use to design mass concrete structures. So let us assume that cracking will happen because of temperature differentials or because of the restraints that are there to the movement of the early age concrete. See restraints can happen also in pavements you put a concrete pavement the pavement is resting on the ground.

The ground is the one which is causing the restraint to movement because of shrinkage because of all the other effects the slab is going to try to move inwards. So, if you lay a continuous concrete slab because of the restraint so let us say you lay a continuous concrete slab on the ground because of the restraint offered by the ground you will see that the slab nicely splits itself. To avoid the splitting at undesirable locations you are jointing the slab you are creating those cracks yourself. You lay a continuous strip of concrete then you calculate the length over which the shrinkage will be dissipated and you simply groove a joint into the concrete. So, jointing of the concrete is done to avoid cracking in other places and then you can protect the joint by sealing and so on.

So, cracking is inevitable in thermal stress conditions however crack width can be minimized by providing appropriate amount of steel in the system. You can provide appropriate steel in the system to minimize the crack widths and that is what is typically done in the design methodology proposed by this CIRIA report C660.

Calculation for temperature differential allowed:

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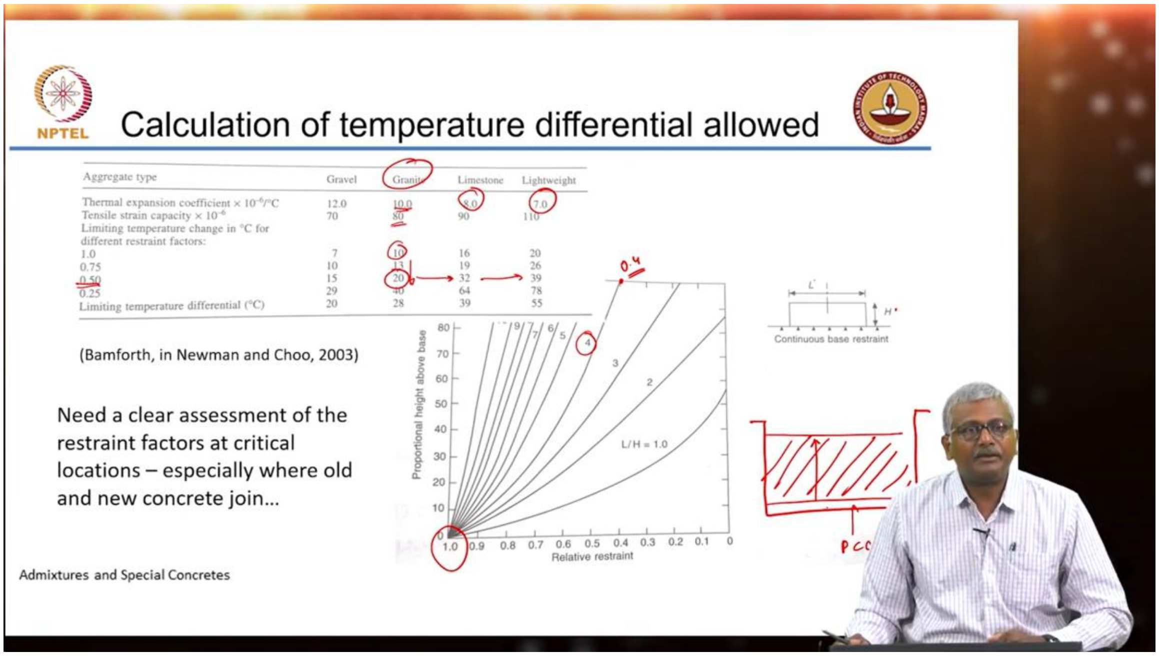

Calculation of temperature differential allowed

Aggregate type	Gravel	Granite	Limestone	Lightweight
Thermal expansion coefficient × 10^{-6}/°C	12.0	10.0	8.0	7.0
Tensile strain capacity × 10^{-6}	70	80	90	110
Limiting temperature change in °C for different restraint factors:				
1.0	7	10	16	20
0.75	10	13	19	26
0.50	15	20	32	39
0.25	29	40	64	78
Limiting temperature differential (°C)	20	28	39	55

(Bamforth, in Newman and Choo, 2003)

Need a clear assessment of the restraint factors at critical locations – especially where old and new concrete join…

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Now this temperature differential that is allowed this 20 degrees temperature differential that I talked about is keeping in mind a certain aggregate type. If the aggregate type changes if it is able to accommodate more temperature differential because of its low coefficient of thermal expansion then you can increase this allowable temperature differential. For instance if you are choosing granite which has a thermal expansion coefficient almost equal to that of concrete and assuming a tensile strain capacity of concrete of 80 micro strains that means your thermal stress cannot exceed 80 micro strains or thermal strain cannot exceed 80 micro strains otherwise there will be cracking.

So, if the restrain factor is 1 that means allowable temperature differential is only 10. If the restrain factor is less than 1 then you go to higher allowable temperature differences for instance if the restrain factor is 0.5 you can have a 20-degree temperature differential. Now if you change the aggregate from granite to limestone you can go up to 32 degrees temperature differential at the same restrain factor. That is because limestone has a lower coefficient of thermal expansion and because of which it is able to help the concrete take up a greater temperature differential.

Lightweight concrete lightweight aggregate has even a lower coefficient of thermal expansion and that will again lead to further increase in the allowable temperature differential. So, you can choose material that is available which can be beneficial to the cause of mass concrete if you have that choice in many instances you may not have a choice. You may not have one location where you have both granite and limestone available at plenty as aggregate. So, you have to be careful about how you choose this. The other aspect is let us say you have a slab sitting on a base like a raft.

When you make a raft what do you do typically? You do the excavation and then you put a plain concrete layer typically a lean mix which has very little cement or at least not something which is beyond about 30 MPa grade of concrete and 30 is max you will use for a plain cement concrete and then you put your raft on top of it. Now what happens is this raft is sitting on this plain concrete base. So there will be obviously some restraint to the movement of the raft from the base that is offered. So that restraint will change from the base to the top. At the base the restraint is going to be maximum, at the top it is going to reduce and that will depend on the size of the member.

So, length to the depth ratio of the member will govern the drop in your restraint at the top. Where are we concerned about cracking? At the top. So we need to choose a configuration of the slab so that you can minimize the restraint at the top. So for L by H equal to 1 which is like a cubical concrete block you do not really have much of a restraint at the top there is no problem. But when the dimension of the concrete at the top keeps on increasing you have a potential for increased restraint.

For instance, even at an L by H of 4 let us say your raft is 3 meters thick that means the length of 12 meters is able to still generate 0.4 restraint here. The more the length of your slab the greater will be the restraint on top for a given thickness of the slab. So you have to take into account this calculation also it is just restraint multiplied by the factor K multiplied by alpha times delta T to determine your strain that is a very rough quick calculation that you can do. To ensure that strain level keeps below the tensile strain capacity.

So, for instance you may have a raft which is massive you want to place a raft that is huge. But then concreting wise it is easy to place a raft altogether which is very huge. But differential thermal strain wise you want to minimize the length to which you pour your raft. So, you have to decide on your strategy of pouring based on this aspect also.

52 x 52 x 4m raft for high rise building

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52 x 52 x 4 m raft for high rise building

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So, this was a case where as I said I think I have described this before the erstwhile capital of Andhra Pradesh that is Amaravati that is where lot 5 high-rise buildings were coming up and these 5 high-rise buildings were supposed to be on raft footing which was 52 by 52 by 4 meters. So more than 10000 cubic meters of concrete in this footing.

So, this is the details of the raft footing you see the form work for the periphery and you can see the extent of reinforcement inside the raft. So, the plan was to continuously pour concrete without any gap continuously pour self-compacting concrete.

NPTEL

52 x 52 x 4 m raft for high rise building

Admixtures and Special Concretes

NPTEL

52 x 52 x 4 m raft for high rise building

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So, again more details of the reinforcement are given here.

52 x 52 x 4 m raft for high rise building

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And you can now see the reinforcement most more closely there is absolutely not much space at the top reinforcement to really put the chute inside. So, you have to pour the concrete from the top and expect it to completely fill up.

52 x 52 x 4 m raft for high rise building

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Now you get a much better view of the top mat of reinforcement.


52 x 52 x 4 m raft for high rise building

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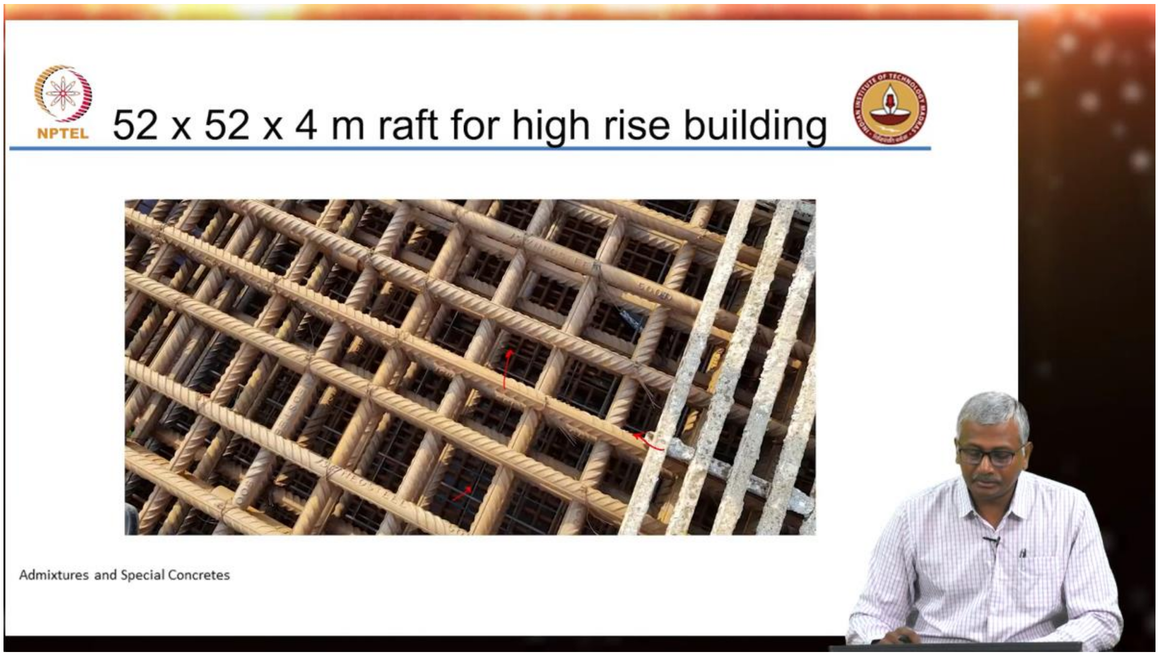
And you can also see the bottom reinforcement from here.


52 x 52 x 4 m raft for high rise building

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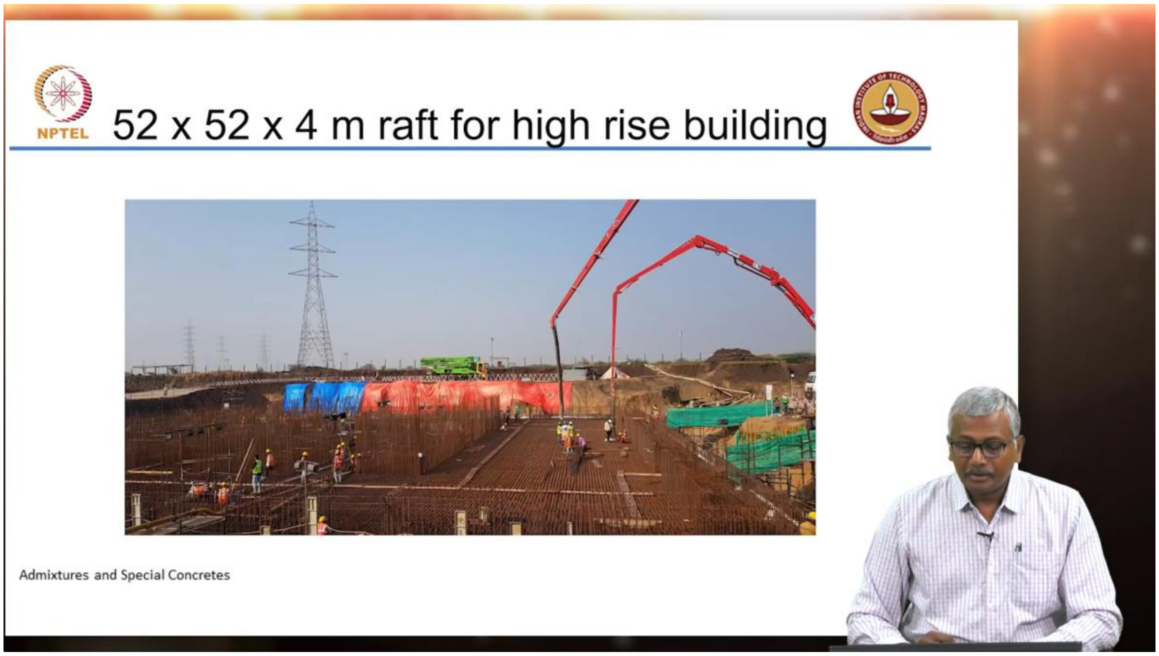
The boom placers are in location and I will show you that I think there were 6 boom placers attacking the periphery of the concrete and there was also, you are not able to see it here but there was also a concrete pipe which was carrying the concrete to the center part of the entire structure. So, all these were operational continuously to supply concrete and do a continuous placement.



52 x 52 x 4 m raft for high rise building

Admixtures and Special Concretes

52 x 52 x 4 m raft for high rise building

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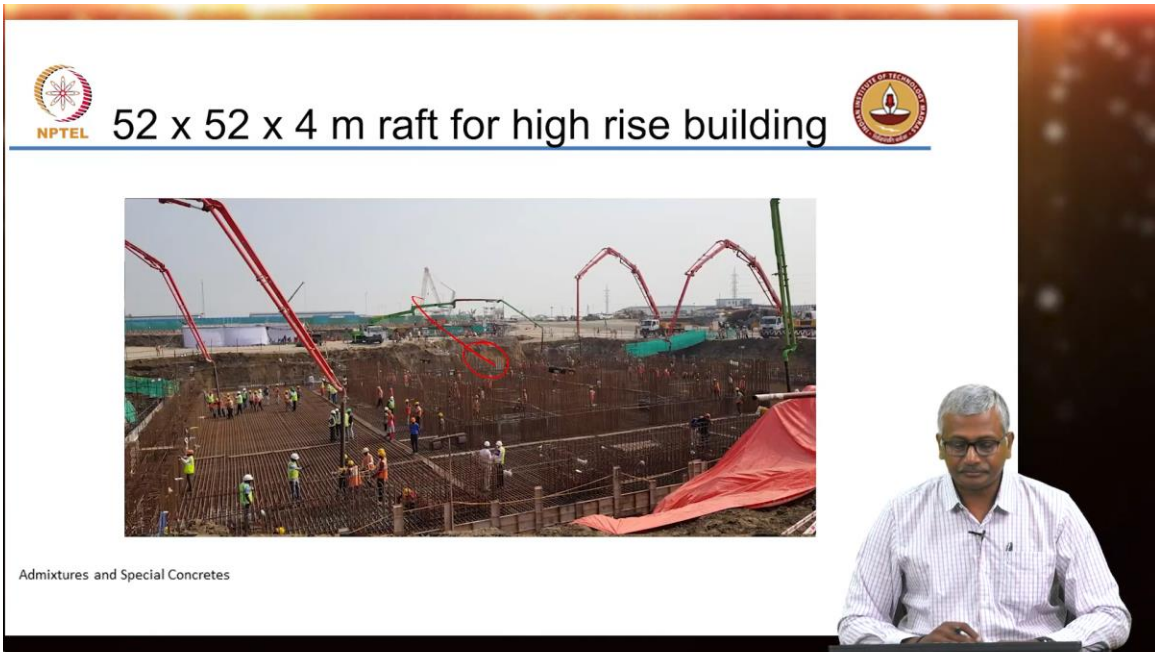
You can again see all the boom placers that is 1, 2, 3, 4, 5, 6 at least are visible in this picture. Now of course to ensure that the concrete compacted well at the base level also there were some locations in which workers could actually go down with vibrators just in case the SCC was not getting fully compacted they did some minimal vibration to ensure that the SCC had completely encapsulated the reinforcement.



52 x 52 x 4 m raft for high rise building

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Temperature measurement in raft:

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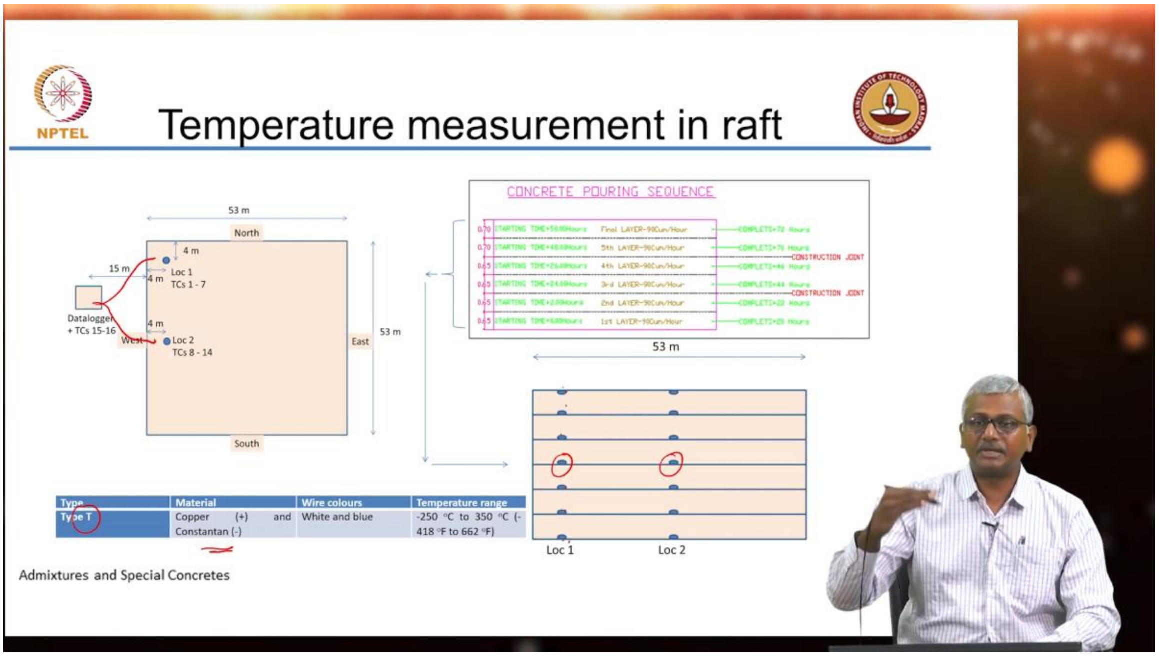

Temperature measurement in raft

Type	Material	Wire colours	Temperature range
Type T	Copper (+) and Constantan (-)	White and blue	-250 °C to 350 °C (-418 °F to 662 °F)

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Now we needed to understand what is the temperature development inside this raft to try and figure out the overall temperature rise of the system so you could calculate whether your concrete is in danger of cracking or not. So there are 2 locations chosen one was close to the corner about 4 meters from the corner, second one was 4 meters from the edge more towards the center. Now this was chosen in such a way that the lengths of the thermocouple cables could still be managed from the location where the data logger was located. You do not have to do this nowadays there are temperature data loggers that are like capsules which can be attached to the steel directly and you can read the concrete temperature using a mobile app itself right on top. You do not need to have thermocouple cables running out, but in this case, we were using a slightly older system.

So, cables had to be embedded different locations and these cables were taken to the data logger which was located 15 meters away from the entire structure. So, this thermocouple that was used was a type T thermocouple which has copper and constant and wires and temperature range of operation in which the thermocouple is stable that means it is able to give the strain versus change in temperature as linear that is very important for thermocouple to do in the range of operating temperatures. It should have a linear variation of strain with respect to temperature and that is what helps us read the temperature differential or extent of temperature. So, the entire concrete here was placed in six layers continuously. It was placed in layers to ensure that the entire structure came up as one rather than some segments getting completed first and then moving and so on.

So, what you can see here is the extent of concrete placement, the speed of placement 90 cubic meters per hour. So, at each of these locations the thermocouples were embedded at different depths. One was close to the bottom, one was close to the top, this one as the core and then every 670 millimeters was the approximate height at which thermocouples were embedded.

Results:

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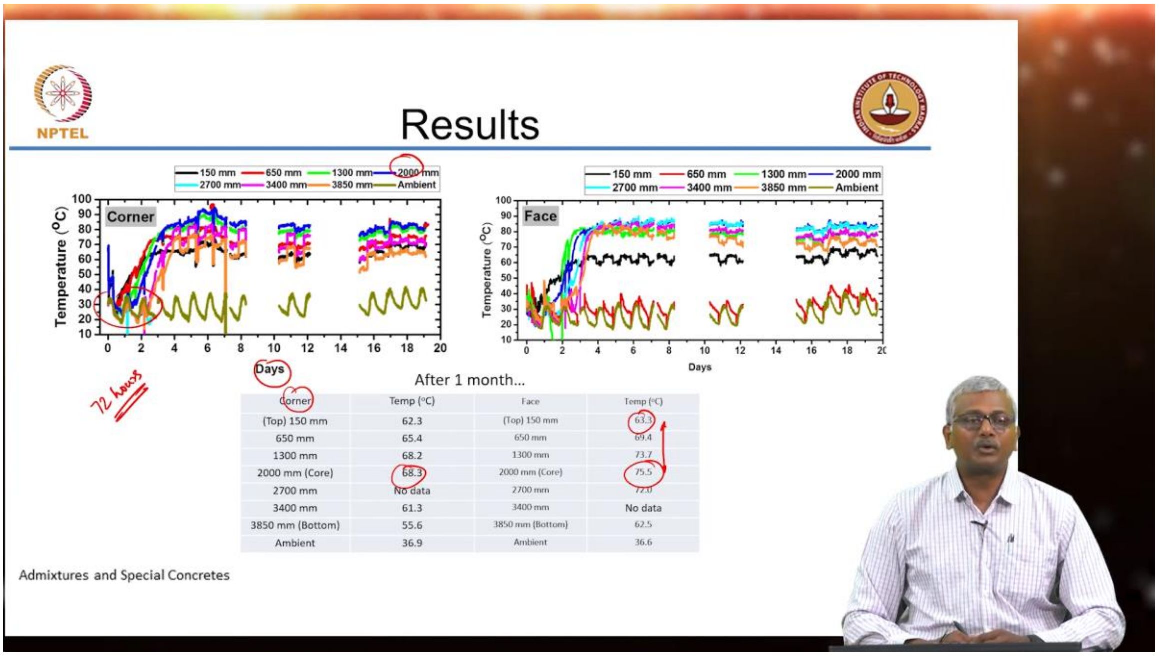

Results

After 1 month...

Corner	Temp (°C)	Face	Temp (°C)
(Top) 150 mm	62.3	(Top) 150 mm	63.3
650 mm	65.4	650 mm	69.4
1300 mm	68.2	1300 mm	73.7
2000 mm (Core)	68.3	2000 mm (Core)	75.5
2700 mm	No data	2700 mm	72.0
3400 mm	61.3	3400 mm	No data
3850 mm (Bottom)	55.6	3850 mm (Bottom)	62.5
Ambient	36.9	Ambient	36.6

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So, these are the results of the temperature measurements of these systems. Now what you can imagine is because of the type of concrete pouring sequence the thermocouples which are located at the bottom will start measuring the data almost immediately.

All the other thermocouples will be only measuring the ambient data. They will start measuring concrete data only when the layer gets completed. So, there will be obviously some delays which you are not able to see here because this is in days. The entire concrete was placed in a total time period of 72 hours. The entire raft concrete was placed in a time of 72 hours.

So, what you do see here is that the core temperature which is exactly at the center which is denoted by the blue line went all the way up to nearly 85 to close to 90 degrees Celsius. It is a dark line so you are not able to make out. So here for instance this is after one month but anyway, the core temperature went up to about close to 90 degrees Celsius at an age of nearly 6 and a half days. 6 and a half days it has gone up to 90 degrees Celsius. That means from the point of placement may be the placement would have happened on the second day.

It has gone up over a period of 4 days to maximum temperature and you can see that even after nearly 20 days the temperature is still high nearly in the 80s and after one month you can see the temperature in that core is still 75.5 degrees Celsius. Now this is at the corner level location 1 as I showed you in the previous picture. At the corner there is some more dissipation so temperature has gone down to about 68 in that case but still quite high after one month. What about the surface? It is at 63 degrees Celsius so temperature differential is still controllable.

It is only about 12 degrees not much but the ambient conditions at this time were in the 30s. So, if you expose the top surface you are going to cause some level of shock especially if you expose the surface and pour water is going to cause a major thermal shock. So in this case a decision was taken to put insulation on the top surface.