Admixtures And Special Concretes

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Lecture -59

Special concretes: Self-compacting concrete -Introduction, design requirements and plastic shrinkage

Introduction:

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So, today we will start on a different topic on self-compacting concrete. So, last chapter covered details about high-strength concrete and what kind of mix design approaches are required to look at development of high-strength concrete. So, more or less self-compacting concrete would also require an understanding of how well you can pack the granular ingredients, how best to actually design the rheology of the paste to ensure that flowability is introduced into the concrete system.

Outline:

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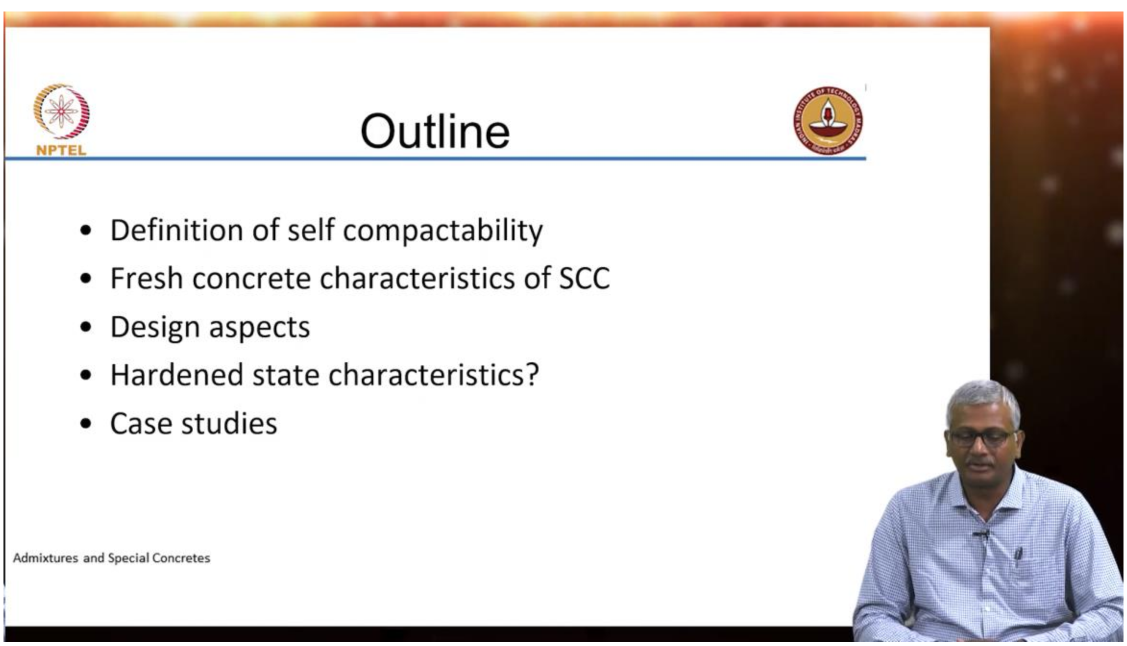

So, here we will go about defining what is self-compactibility first and then look at fresh concrete characteristics, some ideas about design of this concrete and some discussion on hardened state because technically speaking self-compacting concrete is special in regard to its fresh state properties but as far as hardened state is concerned it is more or less like a regular concrete and some case studies in the end especially with respect to how you can do a design based on particle packing and rheology.

Self-compacting concrete:

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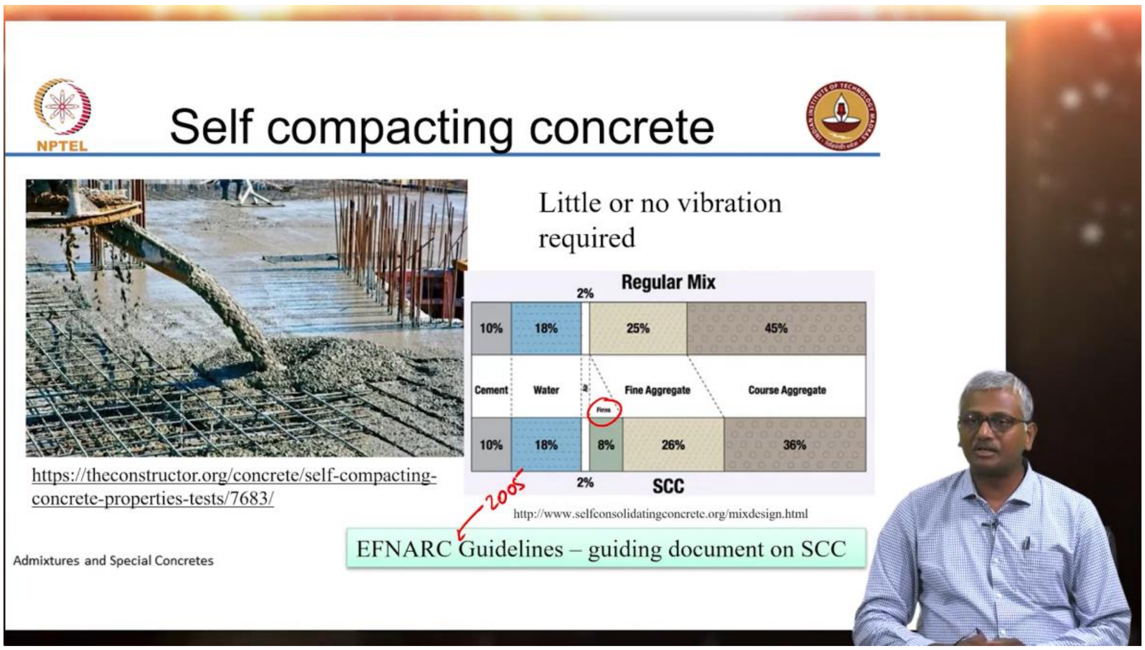

So, of course, self-compacting concrete is a technology that is now quite widely used in the construction industry. The idea is to have a compaction under the self-weight of the concrete itself without any need for external vibration.

There are guidelines available on self-compacting concrete. EFNARC guidelines basically came around in about 2005 or even before. The last version I think was in 2005. It gives a basic understanding of how one should design and test self-compacting concrete for utilization and construction.

Since then, of course many of the tests that were employed in self-compacting concrete were standardized also and today many of these are available as standard test methods. Now how does it differ from a regular concrete mix design? One is that you need to now work with a more optimized grain size distribution preferably with coarse aggregate that is smaller as compared to your regular conventional concrete because you want better flowability in the system but more than that it is the presence of fines in the system. The fines can be contributed in the form of inert fillers or you could have supplementary cementing materials in addition to the cement to increase the extent of the cementitious component to provide the self-compactibility. So, that is the primary difference between conventional concrete and self-compacting concrete. And generally, the ratio of the fine to coarse aggregate is also higher in the case of self-compacting concrete as compared to conventional concrete.

While in conventional concrete we are talking about 30 to 70 or 40 to 60 at the most in self-compacting concrete we are close to the 50-50 range of fine to coarse aggregate because if you have too much coarse aggregate in the system it has very high yield stress as we discussed earlier in our discussion in rheology. So, to avoid extremely high yield stresses you can cut down the proportion of coarse aggregate in your system and increase the fine aggregate content.

World of possibilities with SCC:

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There are of course a range of possibilities that you cannot get with other concrete because of the fact that self-compacting concrete is flowable. For most of the special concrete structures which have shapes that are difficult to achieve with conventional vibration self-compacting concrete is a top choice these days. For instance, if you have structures such as this where you have multiple barriers that concrete has to overcome while flowing and it is almost impossible to actually get a vibration done for such kind of structures SCC is a very good choice.

In fact, in most cases, if you can design concrete to be self-compactable it reduces the amount of energy that you require to actually place the concrete and put it in place and the high workability also ensures that you do not waste too much time in repairing defects that are caused because of poor workability like honeycombing and things like that which happens with conventional concrete. S,o I guess you can say that self-compacting concrete is one which is best suited to meet the demands of architects who have obviously conceived of structures such as this like a helical or spiral staircase which is not very easy to do with conventional concrete.

SCC applications:

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Now in terms of applications of course with the traditional mix when you are applying a concrete the RMC basically is dropping the concrete here there are these people who are raking the concrete to different locations and there are people with the vibrator on site you can see the number of people who are actually on site but here in SCC you have a single person who is actually operating the chute and simply depositing concrete wherever it is required in some instances you can just simply fill up in a single location and concrete will flow to all the corners of the formwork and compact itself without any need for even moving the chute around. So, you may actually not require as many workmen as you do with conventional concreting.

Pioneered by L&T-ECC in India:

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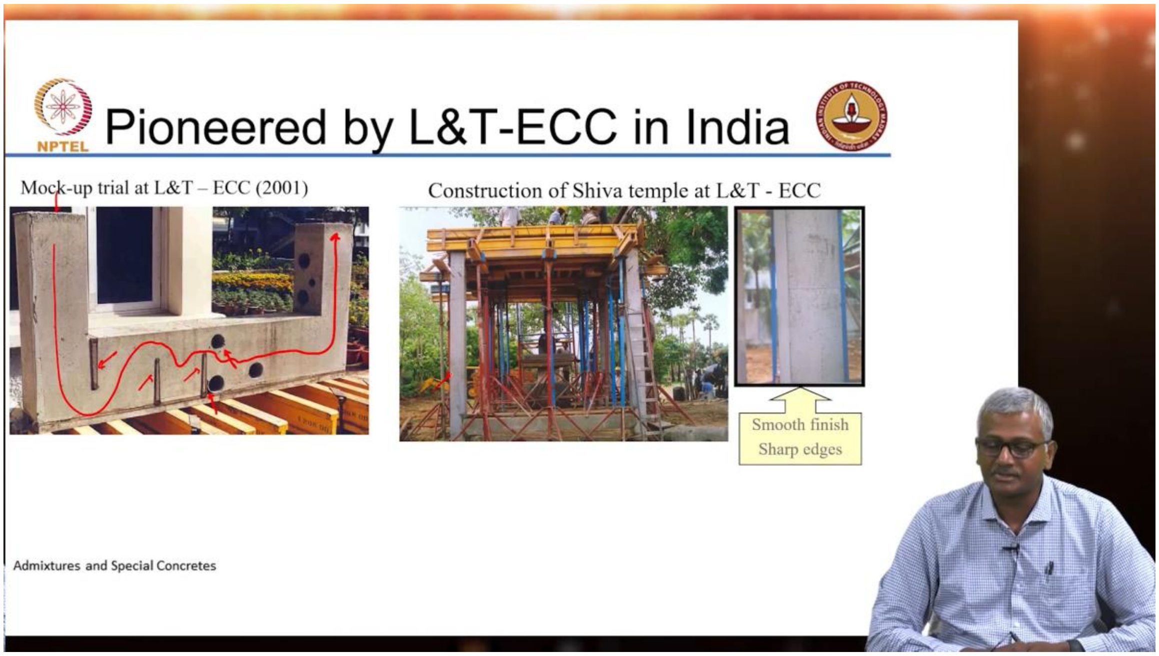

In India, L&T actually did the pioneering work on self-compacting concrete way back in 2001 in their research and development center at the Chennai campus.

So, this was one of the first mock-up structures that was done with self-compacting concrete where they had these baffles introduced at various locations these inserts in the form of pipes at some locations the idea was to pour concrete here so that it will go all around all these obstacles then come out on the other side. So, they just poured at one location until the entire structure was filled up until the concrete came out on the other side and then when they removed the formwork they saw that the locations were properly filled up and even here, of course, you can see that there are some locations where concrete simply cannot access and this is a realistic possibility in many structures especially today when we do reinforcement detailing for earthquake resistance your congestion with reinforcement may be so much that concrete simply cannot find its way through. So you have to be extra careful while designing concrete and ensuring that the strategy for placing concrete addresses that concern. It's almost impossible so you see here very clearly even a laboratory scale experiment resulted in a gap like this you can imagine what happens in real life but nevertheless of course they also used self-compacting concrete for the columns of this temple that they constructed on campus and the finish that they obtained on this temple is extremely good with smooth finish and sharp edges.

Famous applications:

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There are famous applications for which you can find several references in textbooks and in research papers and on the internet.

One of the earliest applications was in Japan, Akashi Kaikyo Bridge which has a very large volume placement of self-compacting concrete. Wall for liquefied natural gas tank in Osaka. Several Japanese applications because Japan was the first country to move with self-compacting concrete. You may come across in literature of the name of Okamura who was one of the scientists from Japan who first pioneered the concept of self-compactibility in the late 80s that's when it actually 80s implying 1980s because most of you are in the 21st century. So 1980s seems like a long time now but yeah end of 1980s was when self-compacting concrete was first introduced as a concept in the construction industry primarily because in Japan they were facing a shortage of skilled workers and so the demand for concrete that could make itself work without having the intervention of several other people was felt and that's where the need for self-compacting concrete actually came about.

Now since then of course there have been several projects across the world. In India, also there are number of projects where self-compacting concrete has been used. Today it is almost routinely used in many of the infrastructure applications.

Challenges with SCC:

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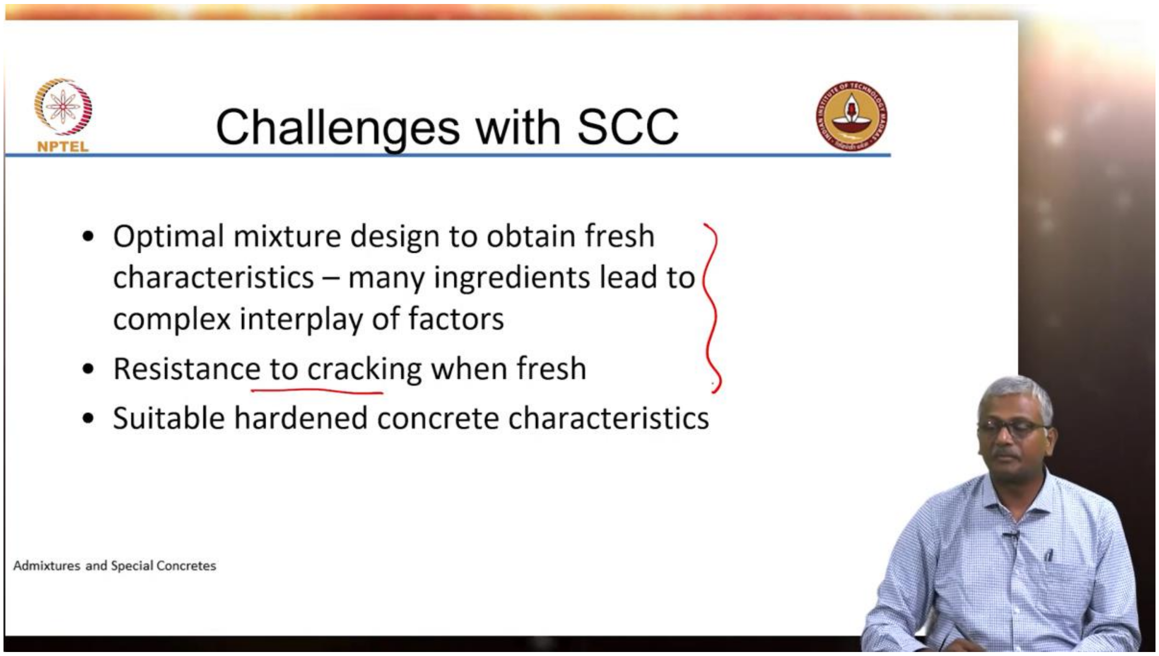

So, what are the challenges? We have talked about rheology, we have talked about high strength concrete design and so on many of the concepts are going to be applied here also but primary challenge is you need to optimize a mix design to obtain the required fresh characteristics. Now you want the concrete to flow but at the same time, you don't want it to segregate.

So, you want to have a judicious control of the rheology so that flowability happens when you are pushing it but when concrete is addressed segregation should not actually happen. So all those qualities that we talked about in terms of internal structural build-up because of the exotropy, removal of this internal structure by application of stress that is the pumping and the pushing of the concrete. So all of that concept basically applies directly to self-compacting concrete. Now because you are going to get flowability only with a high amount of fines in your mixture there is also the tendency for higher amount of cracking in the system. So, resistance to cracking when fresh is an important thing to design for with respect to SCC and of course ultimately you need to obtain the suitable hardened concrete characteristics in terms of the strength, in terms of your modulus of elasticity, in terms of durability and so on.

So, all of that still has to be achieved you need to meet the demands of the structure for which the SCC is designed for but keeping in mind these particular fresh concrete characteristics that you need to work through.

Sufficiently complicated concrete:

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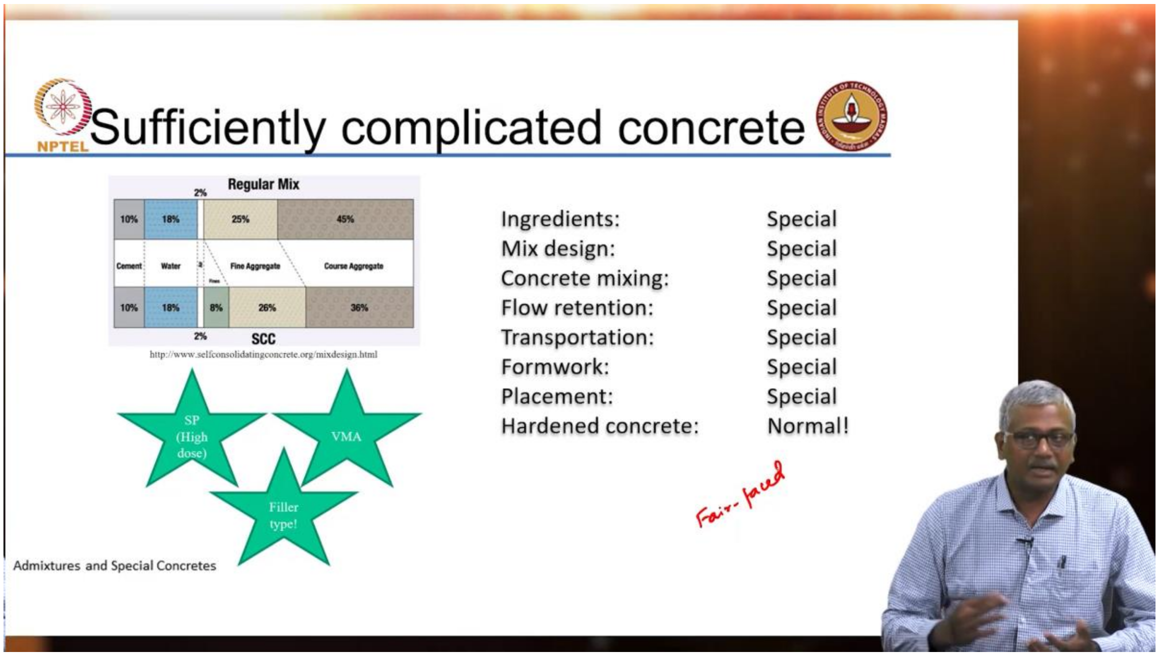

So, SCC can also be christened as sufficiently complicated concrete. Why? First of all because we are dealing with mixture ingredients that are not commonly used, mix design generally is special, concrete mixing has to be done properly to ensure that the super plasticizer's effectiveness is maintained. Flow retention has to be looked at because again giving you the example of Burj Khalifa where SCC characteristics were to be obtained at the point of discharge 600 meters vertically and so to control that flow retention it requires a lot of special strategies for concreting. Transportation has to be special because very often if you are transporting a flowable mixture without the right speed of agitation you can cause segregation in the truck itself.

Formwork has to be specially designed because you can imagine that when you are pouring something like water inside the formwork there will be a lot of leakage at the joints, slurry leakage will be there significantly if you do not design your formwork well. That is not the only thing. If you have formwork and you are filling up something which is as liquid as self-compacting concrete there will also be hydrostatic pressure on the formwork. I have seen this in real life where we actually try to do a mock up structure with SCC for about 2 meters height and when we started filling up the concrete, no 4 meters height sorry, when we started filling up the concrete after about 1.5 meters the formwork was not well supported on the sides, the pressure of the concrete was so much that the formwork just collapsed and the concrete simply came out.

You need to design formwork in this case. It is very important to design formwork. It is not just in regular concrete the concrete moves only when it is vibrated. Once it comes to rest it develops an internal structure that does not push the formwork too much. But when something is as fluid as SCC you need to look at that.

Placement is special because you want to avoid segregation while placement. Such a flowing concrete if you pour it from a large height what is going to happen? It is going to start separating. So that is why we have requirements of pouring heights. What are the typical heights of pouring that are typically followed on site? About 1.5 meters.

If you drop over a height of 1.5 meter generally flowing concrete will not tend to segregate. If you drop beyond that there is a good chance of segregation. So in such instances, you have to adopt special means like a tremie for instance so that you can actually push the tremie between the reinforcement, fill up the concrete and then move it up. We had this challenge in construction of IIT Tirupati.

The buildings there were designed to be fair-faced concrete. Fair-faced concrete implies that when you remove the formwork that is the finish. There is no other additional finishing to be done on the top. So, for this, you need to attain concrete that has very good characteristics so that it does not show up any major honeycombs or bug holes on the surface.

It has to be perfect. So in this case they were feeling some difficulties when they were actually pouring the concrete from a height. They tried pouring because the walls were about 4.3 meters high and the initial strategy was to pour from the top, self-compacting concrete from the top and they saw that when they were doing this the concrete was not getting properly compacted in the edges and close to the bottom and so on. Then they adopted the strategy that they would push some of the reinforcement at the center and push a tremie pipe down and then slowly extract the pipe up as the concrete is filling up in the entire wall and they got very good results at the end of it. So, you have to look at placement strategies that are special only to get hardened concrete that is normal.

It is not going to be any different as compared to any other hardened concrete but perhaps because of the fact that you are getting excellent compactibility it may have lesser permeability as compared to your normal concrete perhaps. But that is not what it is designed for. Hardened concrete properties we always assumed as a function of the water-to-binder ratio that you have in the system. The lower the water binder ratio the better the durability and water binder ratio obviously is related to the strength also. So all the special things you do to get concrete that is fairly normal.

That is why SCC is sufficiently complicated. We have to use high dosages of super plasticizer. We sometimes or most of the times need to incorporate also the VMA in the system viscosity modifying agent. Why? Because we want that characteristic that when the concrete comes to rest there should be no segregation and the VMA really helps in that purpose. And of course, we need to work with different types of fillers to try and get concrete that is suitable for self-compacting. So that is one aspect of complication with SCC.

Self-cracking concrete:

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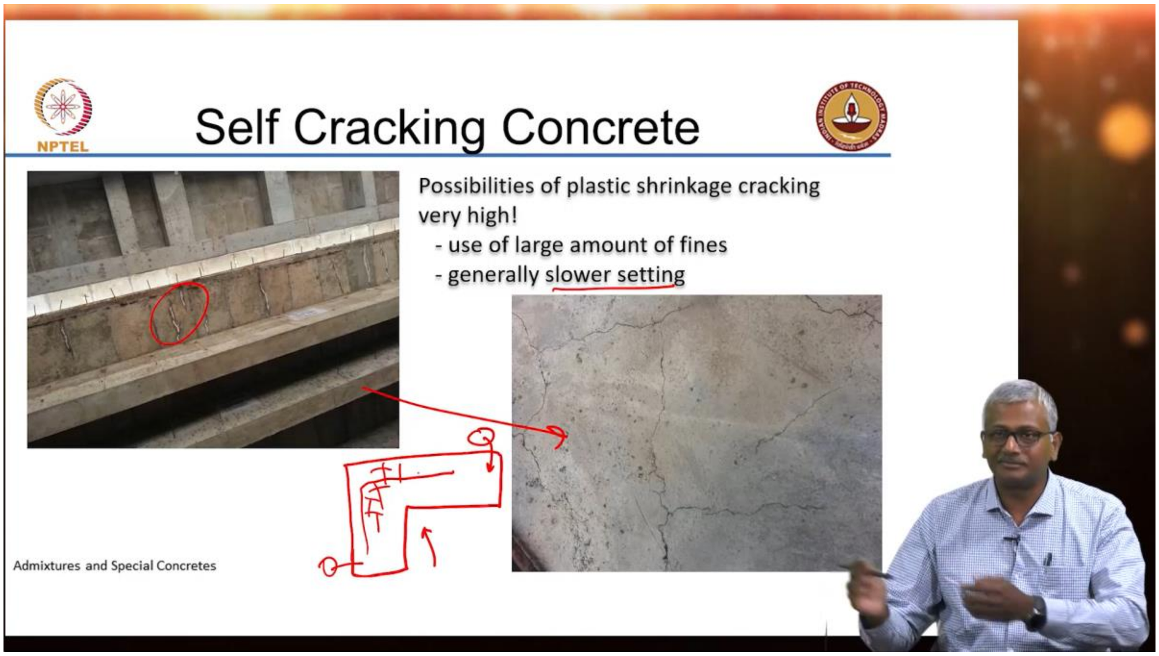

And then SCC could also be self-cracking concrete. And this is obviously because of the fact that it has a lot of fines and these fines can increase the tendency for cracks to appear in the plastic stage, in the early stages. We call it plastic shrinkage. The same thing as we discussed when we talked about silica fume.

Silica fume is an extremely fine component that increases the capillary pressure significantly. And this capillary tension increase whenever drying happens it can cause a lot of cracking in your system. So this is an example from a metro rail project where the deck slab of the concrete was found to be cracked severely after about 1 month of placement. Now why after 1 month? Because until that time nobody bothered to check. The cracks would have appeared, plastic shrinkage crack obviously appears very early in the life of the concrete maybe about 3 to 6 hours after placement.

Although the tendency to crack may start even after about 1, 1 and a half hours. So possibilities of plastic shrinkage cracking are very high because of the use of large amount of fines. And because we usually use fly ash as an ingredient of concrete because fly ash improves workability and it is good for self-compactibility. So when you use these materials in conjunction with a high dosage of superplasticizer you are bound to get slower setting. So concrete is not sufficiently able to develop the strength to overcome the cracking tendency that is happening at early stages because of drying.

So, that is one major reason why we want to protect self-compacting concrete as soon as it is laid. As soon as you lay compact and finish it we need to protect the surface from evaporation. So why is plastic shrinkage happening? If you remember our original discussion it is because the rate of evaporation of the water from the concrete is exceeding the rate at which your bleed water comes up to the top. And because these mixes will have very little bleeding since you have lot of fines in the system you will probably not have that protection on the surface. So again slow setting, high amount of fines is an ideal recipe for plastic shrinkage especially when the construction is done in conditions where you have exposed surface in low relative humidity and high wind type of situations.

So in this project, the construction work was undertaken in August. August is not really a dry season in Chennai of course and I mean it is not a wet season in Chennai in August. And secondly, the temperatures in August of course in Chennai temperature is always 30 plus. In August you have temperatures of around 30 to 35 degrees Celsius and to avoid these problems in most cases concreting is undertaken at night. Because in the night temperatures are lower you can have lesser rates of evaporation because sun is not directly shining on your surface and so on.

So that the rates of evaporation can be lower and workability retention also is more as the temperatures are low and so on. So in this case what happened was they started the placement of the slab at 3 o'clock in the morning 3 am. But the volume was large enough that they actually got extended all the way up to 9 to 10 am. They completed the top surface finish and then they left. Nobody was on the site to check what is happening.

They came back the next day and started normal curing without really paying attention to the surface. Because curing would have been done by labourers who are on site they would have started pouring water and curing and all that. After about a month they started noticing that the slab was leaking from the bottom and water was actually gushing through some of these cracks. You could see water dripping through these cracks and you see those white patches what are those? Calcium hydroxide that is leached out of the concrete because of the flowing water and converted to calcium carbonate on exposure to atmosphere. So you have clear signs of leaching happening through these cracks.

So, this was the original photograph that was shared and they wanted us to come and inspect. And so when we went up to the slab we saw this that the slabs were cracked significantly and these cracks have grown over time to go all the way to the bottom surface. And that is a dangerous thing because a surface crack that appears need not grow a lot but in this case it has grown all the way to the bottom at least in some locations they have grown all the way to the bottom and the water is able to gush through. So this has to be treated it is not a structural problem because structurally concrete is strong steel is there to take care of bending and so on but durability can be severely affected because of cracking. So, this is something that needs to be very carefully avoided in self-compacting concrete.

So, in other projects where we are involved the safeguard against cracking in self-compacting concrete is to ensure that as soon as placement happens you have a team of workmen on site. So whenever the cracks appear you take a wooden float and simply rub the surface wherever the cracks appearing cracks will go away and this has to be done actively in the initial period when the cracks are bound to appear that is that 2 to 3 hour period that is when cracks mostly appear and you start rubbing through these cracks and then these will disappear. Alternatively what you need to do is as soon as the surface has been laid and finished you cover the top surface with the plastic sheet prevent any evaporation from happening that would be the other strategy to adopt. This was also a problem when we were doing the construction of our NAC2 building. In NAC2 at the lower slab levels so there I think the structure of the NAC2 is they have large slabs like this very large slabs.

So, this is the front of the building and the building is shaped more or less like an L I am not getting the correct shape but that is so what they did was they had a concrete truck standing here and pouring the slab from here and one more truck pouring here and then they were moving around to ensure that the entire slab surface got covered. Now this entire process the slab is so large that the process took several hours. So when they were doing this concreting on the lower slabs they were actually getting a lot of cracking in these slabs all over the place plastic shrinkage cracking was appearing and they had to treat all those cracks to ensure that they do not become problems in the long run. So, once you treat the cracks you need to do water ponding to see whether the water is actually able to pass through the cracks or not and so on. So when they reach the terrace that is when we adopted the strategy that the contractor would call in at least 20 or 30 extra labourers on site who are ready with their wooden floats to ensure that when the cracks appear they will go and rub them.

So, we actually did this actively and the terrace came out quite nice. This was self-compacting concrete by the way and the terrace came out quite nice without any problems of cracking. I hope it will have to be seen when the building actually is operational but nevertheless, this operation really helped that they were able to restrict the cracking significantly. The other problem that can happen, so as I said cracks may go through depth also. The other problem that may happen is called plastic settlement.

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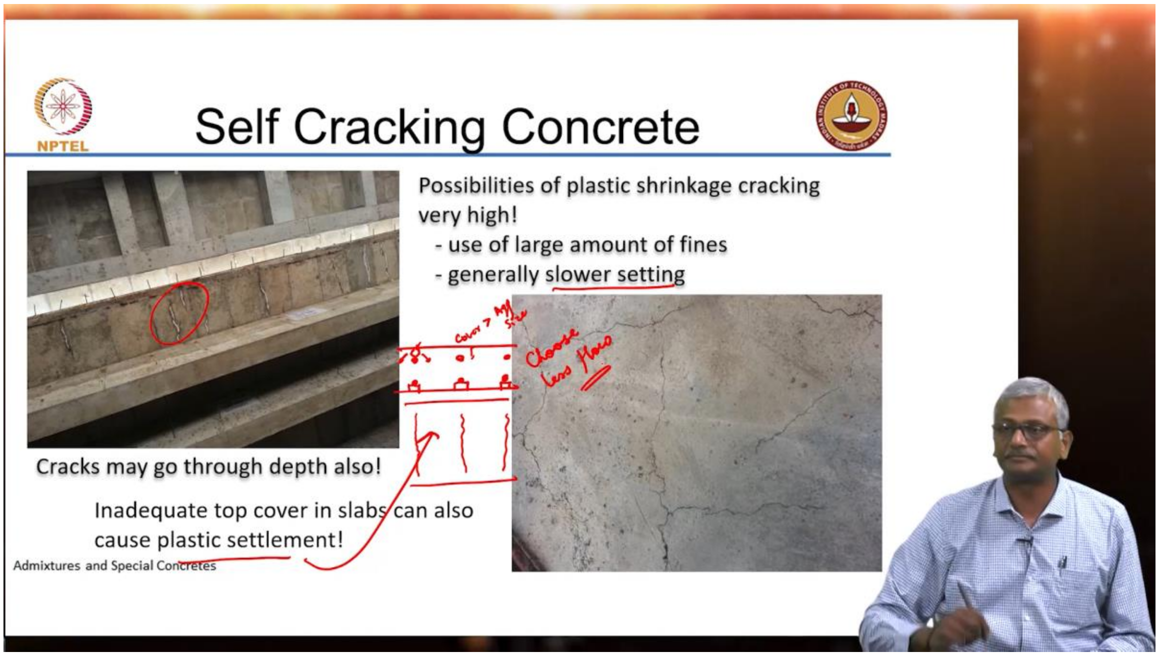

Now let me draw that separately. What is plastic settlement? So now you have a slab like this and you have reinforcement at the top of the slab. Now the bottom reinforcement we are able to maintain because of use of cover blocks. We maintain the cover in the bottom reinforcement with the help of cover blocks. For the top reinforcement we usually do not measure the cover correctly. We assume that we are providing the right cover, we do not really measure the top reinforcement cover in the slab.

In a column it is fine, the reinforcement cover is properly maintained on all sides but in a slab it is not the case. So when we do this self-compacting concrete which is highly flowable, the aggregates tend to move around when the concrete is still plastic. For instance, if an aggregate piece is somewhere here on top it may have a tendency to shift from the top of the reinforcement to the sides leaving behind a gap on top here which gap may more or less look like a crack. So if you have highly flowable concrete used in SCC this kind of problem may actually appear. So when you see the top of the slab, if I am seeing the plan of the slab wherever the reinforcement is I will see a crack appearing.

That is a traditional sign of plastic settlement. The concrete has subsided around the reinforcement leaving behind a crack on top of the reinforcement. The very purpose for which concrete was present that is to prevent the corrosion of the reinforcement now is lost because the crack is right on top of the reinforcement. So, plastic settlement cracking can be a realistic problem in self-compacting concrete. Professor Gettu who works in our concrete research group, he built his entire house in self-compacting concrete in 2005-2006. That probably was the first real large-scale application for residential construction of self-compacting concrete.

Now at that time, he learnt by experience that high-flow self-compacting concrete has this problem of plastic settlement cracking. A lot of his problems came in the terrace slab which was with high-flow self-compacting concrete. Since then we also noticed the same problem when we did SCC for a chiller unit in IIT Madras outside the library, the slab for the chiller unit was done with SCC and we noticed the same issue when we used a high-flow self-compacting concrete it was subjected to the plastic settlement cracking. This is not shrinkage, this is just settlement because of the subsidence of the concrete.

So, you need to avoid this also. How do you do this? You need to ensure that the top cover that you have should be greater than the aggregate size. Because if it is greater the aggregate will be stable otherwise the aggregate will subside or settle to the sides. But how often do we check the top cover? It is not physically possible all the time. So again working with small aggregates always helps but more than that when you start working with slabs you need to restrict the flowability of your concrete to a level that does not cause this problem.

So, choose less flow for slab. I will come back to this point later when we discuss how to decide on the characteristics of SCC for specific applications.