Admixtures And Special Concretes

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Lecture -57

Special concretes - High strength concrete - Stress: strain relationships, applications

Autogenous Shrinkage

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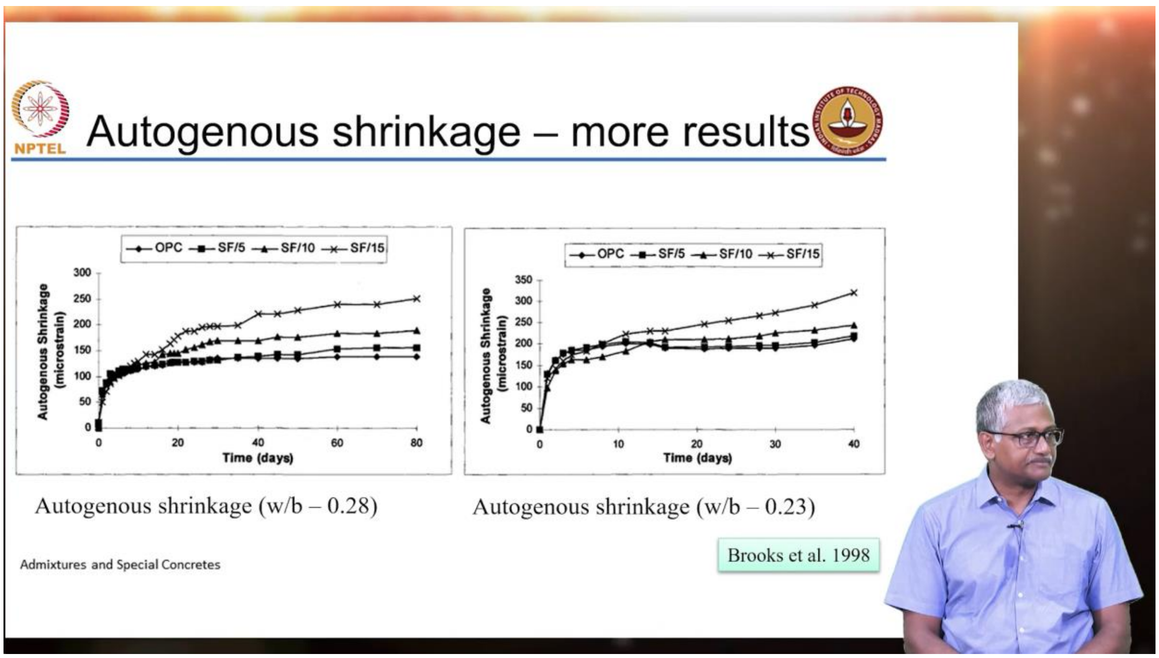

So, we were talking earlier about properties of high-strength concrete, primarily the fact that because of the extremely high cementitious material contents and the low water-to-cement ratios, we have possibilities of two kinds of issues which are not typically seen in regular concrete with lower cementitious content. One is thermal stresses and the other is autogenous shrinkage and autogenous shrinkage can be a big problem, especially for very high-strength concretes which have water-to-cement ratios much below 0.35. So, in such instances, it is very important for us to look at mitigation strategies for autogenous shrinkage. The only way to mitigate autogenous shrinkage is to ensure that you prolong your wet curing period. Because internal desiccation or drying is happening because of internal movement of water so if you are providing an exterior source of moisture it is likely that you will be able to overcome some extent of autogenous shrinkage.

But nevertheless, that is only true for the surface of the concrete. In the interior the desiccation will continue to happen because the exterior moisture just cannot make it to the interior of the concrete because in high-performance concrete already your water-cement ratio is low, the porosity is less, interconnectedness of porosity is also very low because of which you are not going to be able to get penetration of this moisture deep into the concrete. But nevertheless, at least in the surface zones you can to some extent avoid autogenous shrinkage-related problems by continuing moist curing. Now, the challenge comes when you have a mass concrete which is high strength. In a mass concrete, as I mentioned earlier, you want to prolong your formwork removal.

You want to delay your formwork removal because you want the heat inside to dissipate as much as possible to avoid large differential temperatures. We will look at that in detail in the mass concrete chapter anyway. But here just imagine if you keep your formwork for long you cannot start moist curing and in fact when you remove your formwork and you start spraying water you can subject the structure to a thermal shock. So, all this requires a close understanding of the material behaviour and because of this whenever you are planning mass concrete which is high strength you need to be particularly careful and have appropriate models to figure out what the extent of temperature rise in the concrete is going to be so that you can decide upon your schedule of formwork removal whether you want to continue curing with water or should you use a curing compound and so on and so forth. So, it is little complicated it is not something that people can easily find a solution to and the solution may be variable depending upon the conditions at the site.

When you go into practice you will see that this is the most common problem that is being seen in concrete today especially because the use of high-strength concrete strengths of more than 45-50 megapascal is routinely increasing and the size of the structural members also is increasing especially when we go for high rise buildings or special structures which require very thick raft type construction you have to really be careful. So provision of reinforcement needs to be relooked at you cannot just think about providing reinforcement thinking about long-term shrinkage you also have to worry about internal drying that is actually happening in the system. And creep, creep is because of the effect of sustained loading on the system. So, if you let us say you take a column concrete column you do not have any load coming on top of it let us say. So the column is not subjected to any loading except its own self-weight.

So, it will creep somewhat under its own self-weight but it will continue to dry and shrink. So, shrinkage is in the absence of loading, creep is because of sustained loading but of course, both the conditions are not mutually exclusive you typically do not have a structure which is not loaded. So, you will have the effects of both shrinkage and creep together.

Autogenous shrinkage is because of the internal drying that is happening creep is because of the movement of water within the concrete. The idea is overall similar from the perspective of the fact that it is the movement of water which is causing the strain but creep is a response to a load that is sustained for a long period of time.

Autogenous shrinkage is because of the drying that happens when the water is pulled towards hydrating the unhydrated cement. So, while they happen maybe similarly but the mechanisms causing them are quite different.

HSC Stress- Strain relationship:

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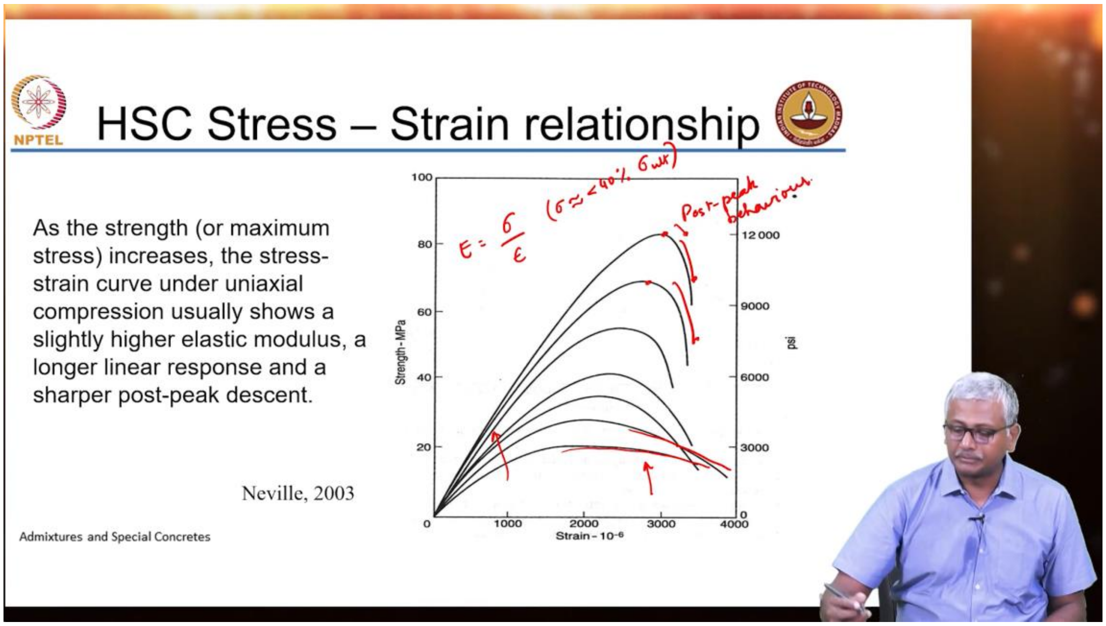

So, let us move on to other properties of high-strength concrete, one is the stress-strain relationship what is commonly observed is that when you increase the strength of the concrete the slope gets steeper of the stress-strain curve which is quite obvious because you are making the concrete more and more stiffer. So, slope is basically your modulus. Up to what load do we consider for calculation of modulus of elasticity for concrete? What level of stress? Less than 40% of ultimate. At a stress level less than 40% of ultimate.

$$E = \frac{\sigma}{\epsilon}\ (\sigma\ \approx < 40\%\ \sigma_{ult})$$

So, until then we can assume that there is some linearity exhibited by the stress-strain relationship. It may not be entirely linear because concrete is a complicated material you have two different phases aggregate and paste and then you have the interfacial transition zone which may have its own properties in terms of additional cracking more porosity and so on and so forth.

So, because of that, you may have trouble in trying to figure how best you can actually achieve stiffer concrete with the combination of dissimilar ingredients. So, the non-linearity basically exist beyond 33 to 40% of the ultimate load and you need to be so coming back to modulus of elasticity of high strength concrete is going to be extremely high and you can see that the curve basically gets steeper the higher the strength. What you also notice is that post-peak the fall in the strain is sudden or fall in the load is sudden and the material basically fails all of a sudden. Whereas, when you go for lower-strength concrete you have a very gradual failure it is almost as if concrete is exhibiting some ductility. Why is this happening? In normal concrete, as we discussed earlier the cracking is going around the aggregate this substantial amount of crack development which happens in the system and after the ultimate load level has been reached the system does not fall apart yet because there is a significant amount of interaction between the aggregates that sustains the deformation for some more time.

Whereas in high-strength concrete because the paste and the interface are now very strong the crack starts going right through the aggregate and you are now causing a very brittle failure because of which as soon as you reach the peak it is almost a sudden drop beyond that period. So, when you compare stress-strain curves that is what you will notice that overall, the curve becomes more and more steeper but the post-peak is significantly sharp. We call it the post-peak behaviour this part is called the post-peak behaviour.

Brittleness of HSC:

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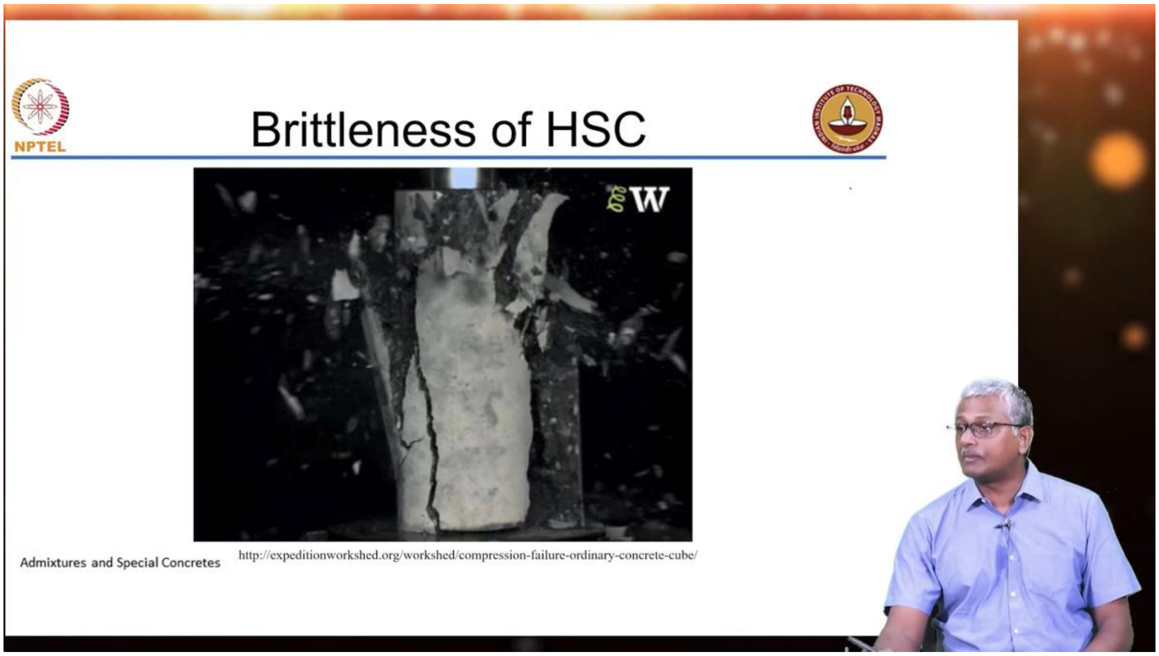

Of course, with respect to brittleness, I have already talked about the fact that because you are now having cracks that go through the smallest path right through the aggregate you have a sudden explosive failure of high-strength concrete. So, when you test high-strength concrete you need to be very careful you have to have an enclosure around the concrete because it will start splattering all across and then if you are too close in the vicinity you are likely to get hurt so you need to ensure that you have a proper covering to the concrete cube or cylinder to ensure that the explosive failure does not cause splinters to fly across all over the place.

So, this is what typically happens with the high strength concrete it is quite brittle because of this post-peak deformation being very sharp.

Applications in high-rise buildings:

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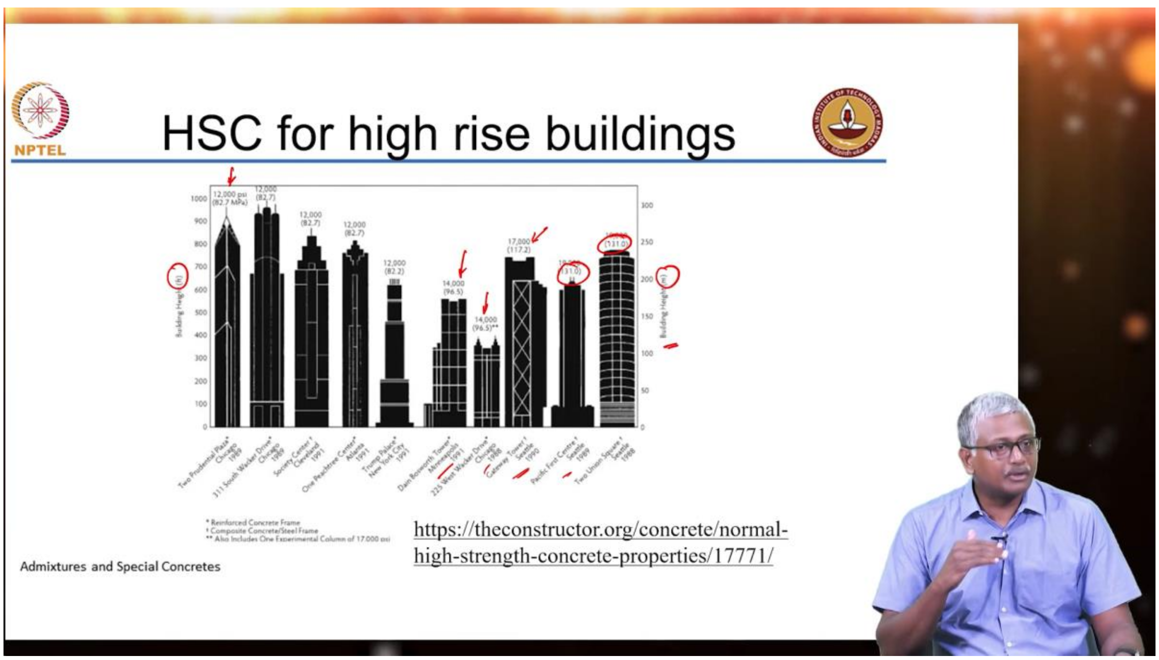

Now, high-strength concrete obviously finds a major application in high-rise buildings. Here some examples are given of different buildings and the kinds of strengths of concrete that they have used. So, the building height is on the right-hand side, this is in feet and this is in meters. So, you can see different buildings which were constructed mostly in the 1980s and 1990s these are buildings constructed in 1980s and 1990s and what it tells you is the strength of the concrete which was used in these buildings. So, you can see that the strengths were around 12000 pounds per square inch is about 82.7 mega Pascal.

Here these 2 buildings in Minneapolis and Chicago you can see that they are 14000 or 96.5 mega Pascal. Whereas the gateway tower in Seattle and Pacific First Centre in Seattle are okay gateway tower is 117.2 mega Pascal whereas the Pacific First Centre and 2 Union Square in Seattle are both 131 mega Pascal. So why do we need very high strengths of concrete in high-rise buildings? Why should you design concrete with very high strengths for high-rise buildings? You need more stiffness because of the lateral loading effects which will cause severe sways in the buildings.

So for that, the stiffness has to be very high at the ground stories. Secondly of course by using a higher-strength concrete you can reduce the overall member dimensions and that means you have more open floor area space. When you reduce the member dimensions you have more floor area space. So, obviously you want to maximize your retail space so you can minimize the member dimension like columns and so on. This increase in stiffness that you desire is typically obtained by increasing the strength of the concrete.

Now this is a challenge that has baffled many concrete engineers. How do we increase just the stiffness without really increasing the strength? That is a problem that people have not been able to solve in any big way because you do not really need that much strength but you need very high stiffness to counter this way. So, that is one challenge. People have looked at the use of nanomaterials and things like that to strengthen the concrete more from the perspective of making a cement paste phase that is quite stiff and overall increasing the stiffness of the concrete but very few have been able to achieve it with moderate to high strength concrete. They have to have a very high strength to really get the levels of stiffness that you want.

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Some examples are given here. This tallest concrete building in the US about 70 stories 82.7 MPa. This is one of these buildings. I think it is the South Packard Drive building in Chicago and again about 84,000 cubic meters of concrete was poured here.

Concrete had silica fume and high-range water-reducing admixtures. A high-pressure pump and special boom was used for placing the concrete. Of course, this you know very well in Malaysia, the Petronas Twin Towers. So, here again M80 concrete was used with water binder ratio 0.27, silica fume was used in this case and early strength was achieved in 12 hours which allowed early removal of formwork.

So, very often the needs of the concrete are quite stringent in these high-rise buildings. If you go to Mumbai when they are routinely using grades of concrete above M60 in high-rise buildings they combine that need for strength with the need for extremely long workability retention. In Mumbai, any concrete that you ask, so when you have have need for extremely long workability retention like in Mumbai the example is mostly 3 hours workability retention something that they need. So, 3 hours and providing that at water binder ratio of less than 0.3, it is quite a bit of a challenge and if you have ever made concrete with Mumbai materials you will see that the aggregates are really ridiculous, they are very bad.

The basaltic aggregates when you start crushing them to make sand or crush stone sand with basaltic aggregates they leave behind a lot of fines. So, controlling workability itself is a big thing. Meaning that workability over 3 hours can be quite challenging. So, when the demands for high workability retention and use of high-strength concrete come together it can be quite challenging. So, all this requires a very careful consideration of the mix design.

So, one example of course is the Burj Khalifa where concrete was pumped vertically to a distance of 600 meters. This is the world record for highest pumping and in this case not just high strength it was also self-compacting. So, again a further complication you need to have the self-compactibility maintained at the point of discharge which is 600 meters above. You are making concrete on the ground sending it up vertically 600 meters so lot of frictional losses will happen as the material is being pumped. You need to design the concrete adequately well on the ground so that when it reaches the top it still maintains self-compactibility and that is quite a bit of a challenge.

To achieve that you need to have a significant bit of testing done. In fact, what they did for Burj Khalifa to ensure that the concrete had that level of workability at the 600-meter level is that they created a network of pipes of nearly 2.5 kilometers on the ground, horizontal pipes with multiple bends and so on. And then they tried pumping their concrete through this because they realized that the pressures of pumping here would be similar to what you put for 600 meters vertical pumping. So, only after that, they were able to design the concrete appropriately.

They could decide on how the concrete should be designed. So, it requires a lot of work, tremendous amount of work to really get to that level.

Applications in bridges:

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Of course, one popular structure in India is the Bandra-Worli sea link. Again here M60 concrete with silica fume is used for the piers that you see. The piers of the bridge were made with M60 concrete with silica fume.

Of course, the main emphasis here was on the durability not just the strength because this is a channel that comes directly from the sea and then you have very high levels of chloride, you need to ensure that the concrete quality is extremely good. You may also have heard about the Mumbai Trans Harbor Tunnel Project. The Trans Harbor Tunnel basically is a very long tunnel that goes across the Mumbai Harbor and there to ensure that the concrete could have sufficiently good resistance against chlorides, they also had in the spec a condition to be met for the concrete for the migration coefficient, chloride migration coefficient which was supposed to be less than, so migration coefficient in the Mumbai Trans Harbor Tunnel Project, they had a value of less than $2 \times 10^{-12} m^2/s$. If you remember our discussion on mineral admixtures, you usually get this value with the use of silica fume and or ternary blended systems of silica fume and slag but we saw that even with low grades of LC3 one could achieve such low values in terms of migration coefficient. So, you have to have a proper understanding of what are the mechanisms of damage and how to actually test what kind of test to use and what limiting values to prescribe because you want a design life of 100 years, 150 years as the case may be and you need to connect that to the test parameters that you are trying to use and this has to be met by concrete which is supplied on a regular basis.

It is not just something that you show in the lab and continue to pour concrete, that is not the way it is done. For concrete quality to be ascertained, you have to take random batches from the concrete that is being supplied to the site and check strength and durability for concretes that have been supplied at various points during the project.

HSC Documents:

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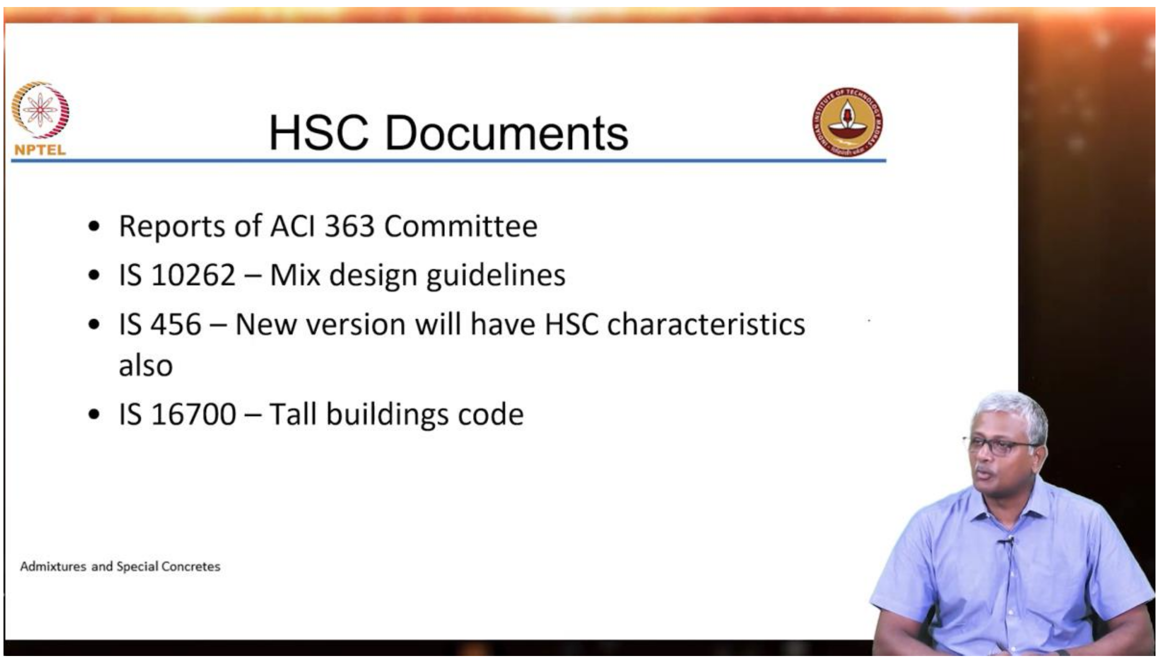

There are several documents of high-strength concrete which you should go through. One is the report, I mean several reports from ACI 363 committee which is essentially the committee on high-strength concrete. All of you are students so you can become free members of ACI, free student members.

So go to the website, I mean for those of you seriously interested in concrete I would suggest that, that you become free student members of ACI. You can download some documents for free, you get access to the journals and you can also download the reports, at least I think 3 to 5 reports are available for free download. Then of course IS 10262 is our IS mixed design guidelines. IS 456, the new version which is being promised for a long time now, I am hoping it will be ready within the next year. It will have high-strength concrete characteristics also and as I was explaining earlier IS 16700 which is a tall building code has a lot of information on high-strength concrete and what kind of tests are necessary to make high-strength concrete, to make high-strength concrete work for a tall building.

There conditions such as autogenous shrinkage, creep, all of these things are mentioned and there is also a requirement to actually do testing for these properties before you start using the concrete onsite.