Advanced Concrete Technology

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Lecture - 32
Creep: Mechanism and Behaviours

So we were talking in the last lecture about why creep occurs; primarily because of rearrangement of your gel structure by the dissipation of water from outside the gel. The water tends to move from the zones of higher stresses to the zones of lower stresses. Essentially you have a movement from the gel to the capillary pore spaces and if there is an extra effect of drying you also get this water going out of the concrete that adds to the overall creep strain that you have in the system right.

But apart from the negative effects which primarily relate to the quicker approach to failure strain for structural members you can also get some positive effects in terms of reduction of stress concentrations and when you have combination of creep and relaxation happening together you can also get resistance to the stress concentrations induced by shrinkage, temperature changes and also support movement.

So there are some positive effects, but on the whole the negative effects really need to be looked at prior to designing the concrete for the structural member and also understanding how well we can incorporate that into the design process. Currently how do we actually incorporate creep in the design process? The definition of what is called a creep coefficient.

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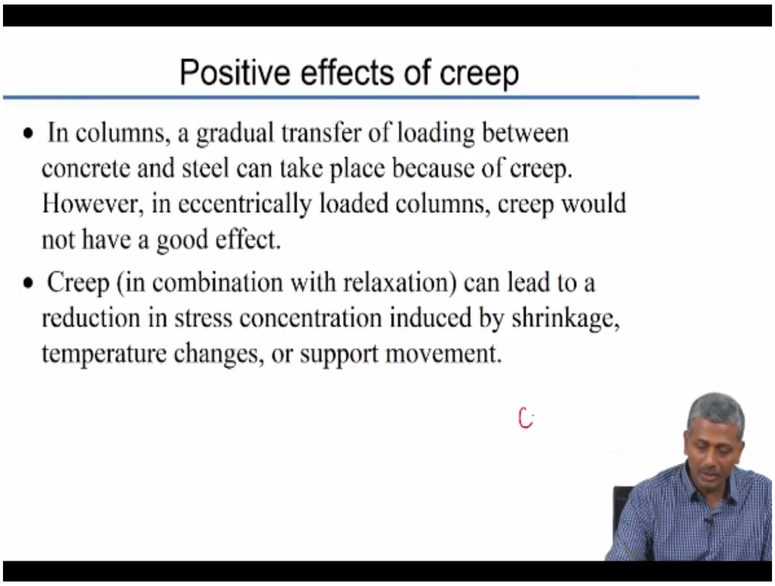

So your creep coefficient is basically a ratio of the permanent or built up strain divided by the original elastic strain, okay, and based on the concrete mix design that were used in the past there is a statistically valid value of the creep coefficient that has been incorporated in the design process, okay.

However, what we are increasingly finding is that for the modern blends of concretes that we prepare these days with different mineral admixtures, different grades of concrete, sometimes incorporating very microfine additives, the creep coefficients that are existent in our present design codes are probably not accurate. So there is always a need for additional research to understand how is the creep coefficient getting altered when we change the design of the concrete significantly.

Especially with a new philosophy of the particle packing approach there can be a lot of changes to the creep coefficient and we have to be more realistic in terms of the design when we incorporate creep coefficient because that input can actually change the kind of parameters that we get for design significantly, okay. Anyway that is part of your design process we are not really looking at that specifically here.

Our aim is to look at what factors contribute to increasing creep and what factors contribute to controlling the creep.

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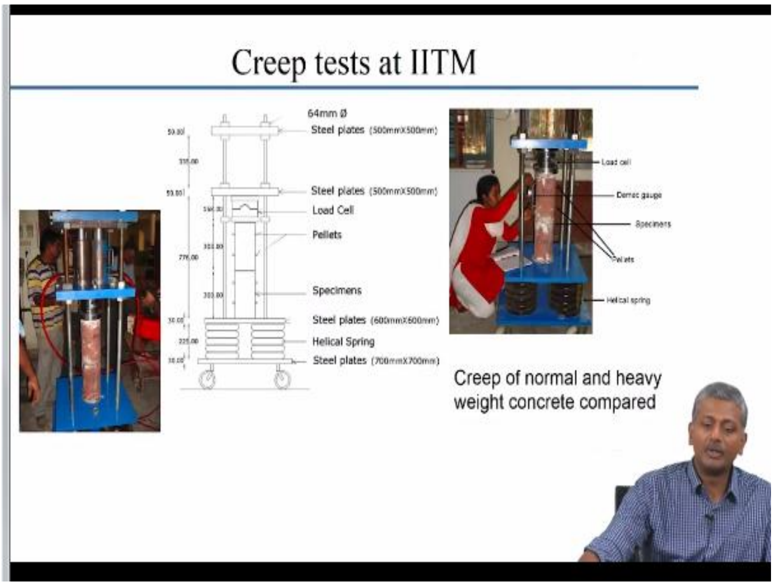

So here we also have tested creep of concrete through a specially fabricated setup in our laboratory. So in this setup what we have done is, there is a loading frame, with 4 steel rods. There is a top steel plate and there is one more steel plate on the top of that and, between these 2 top steel plates you apply the load okay.

Load is applied hydraulically so that it pushes this bottom plate down and that compresses the concrete to the extent that you want to. So again please remember we talked about this earlier that concrete will be assumed to have elastic response up to about 30 to 40% of the load.

So you decide on the ultimate load that you want to exert in this process fixed at about 30 to 40% of the strength of the concrete, and that stress level needs to be maintained throughout the duration of the study. Because creep is the response to sustained loading. So we maintain the same level of stress and measure the strain that is there in the system with respect to time.

So again hear this strain is measured with respect to pellets that are embedded in the concrete and we used a DEMEC gauge to actually measure the distance between the pellets. As the concrete gets compressed the distance between pellets will keep reducing. So the setup in our lab takes 2 cylinders at the same time, okay, one on top of the other and you can see that the ends have to be properly ground or alternatively they have to be capped to ensure that you have a perfect transfer of the compressive load without any eccentricities and without any deformations on the top surface which may alter that kind of loading that is coming on to the cylinder. Now when this entire system is getting compressed, you can imagine that there is some deformation that is happening in the system that needs to be accumulated and for that this deformation is actually accumulated with the help of these helical springs which you see at the bottom here.

On the right side picture, you see the helical springs at the bottom and these are accumulating the deformation that is happening because of creep. Now these are extremely stiff springs that are actually used for the railway axles, okay and we actually purchase this from the Integral Coach Factory in Perambur. So for each frame we have 4 springs, 2 in the front, and 2 at the back.

So that these can actually accumulate the deformation that is happening in the concrete specimens. There are also other designs available for creep cells where instead of springs people use compressed nitrogen gas cylinders where the accumulation of the deformation is because of the displacement of the nitrogen gas, okay. So here the load is being measured on top of the concrete cylinders using a load cell, okay.

And that helps us understand whether the system is maintaining the load or not. So right after the application of the hydraulic loading in the beginning of the experiment, you see these nuts on top, these are tightened to the right extent. But what will happen is as the deformation continues to happen there will be some movement that may actually lose some of that load that is being maintained by the place. So you need to monitor that load constantly with the load cell and keep tightening the nuts until you get the same consistent level of the loading.

So that way you can actually maintain the constant loading condition and after that you need to measure or monitor the displacement between the pellets and plot that as a function of time in terms of the strain and what you get is something like shown below.

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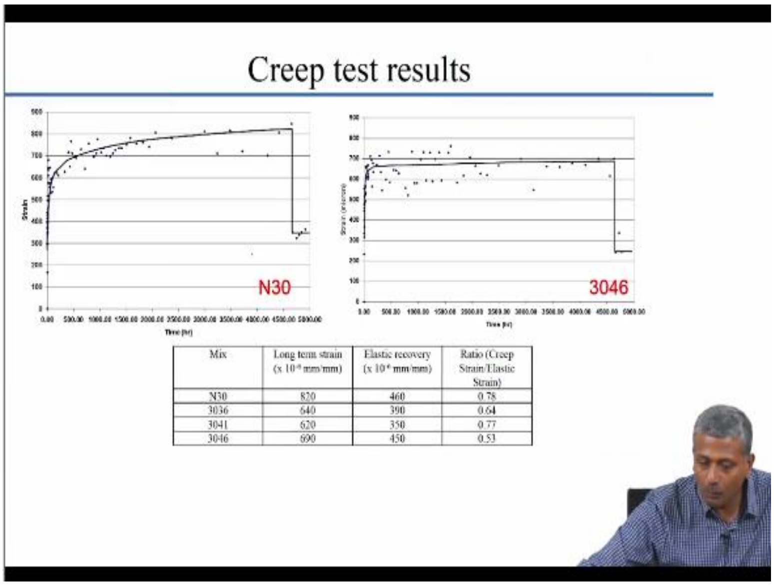

You have the strain versus time being plotted on this graph here and this is again for a set of high density concretes that we talked about earlier, when I explained how modulus of elasticity of high density concrete does not necessarily follow the IS relationship. So here this is for 30 MPa grade high-density concrete and N dictates that this is normal concrete, not high density; 3046 is high density concrete with 4.6 g/cc density.

So that is very high density concrete, okay. So you see here that up to a certain load or up to a certain strain you get an almost instantaneous sort of an accumulation of that strain and that is because of what? that is the elastic response. This curve is the delayed response that you get which is composed partially of an elastic response and partially of the creep response.

And this constant rise that you see slow but steady rise of the strain with time that you are seeing here that is because of the creep response. So as soon as you unload at this location this load was removed and you saw an immediate recovery which is basically because of your elastic response, that is the elastic recovery and this will be the permanently built up strain.

So here the creep ratio is presented in terms of the creep strain divided by the elastic strain and this ratio is generally between 0.5 and 0.8 for all these concretes that we study, okay. There seems to be some suggestion that the high density concretes are having somewhat lower creep ratio as compared to the normal weight concrete, but there is no clear or clinching evidence to show that this is actually the case.

Now one problem with this set of results is the extent of variation. You see the data points are all over the place, what is plotted inside is somewhat of a not really a best fit, a best appearing fit. This is not a statistical best fit, this is actually drawn by visual appearance, because it was very difficult to get some sensible best fit plotted through this system, okay.

Now this set of results was actually taken by a temporary staff who was working in our laboratory at that time. So the temporary staff was actually using the DEMEC gauge to measure the readings between the pellets. We had another set of concretes which was a 45 MPA concrete and in this case we had a PhD student, who had finished his PhD doing these readings and you can see the difference.

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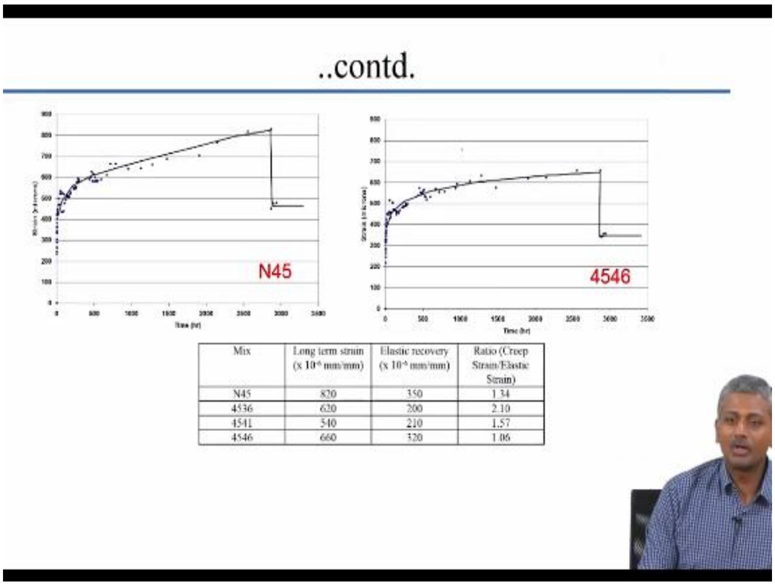

Mix	Long term strain (x 10^{-6} mm/mm)	Elastic recovery (x 10^{-6} mm/mm)	Ratio (Creep Strain/Elastic Strain)
N45	820	350	1.34
4536	620	200	2.10
4541	540	210	1.57
4546	660	320	1.06

The quality of the readings is much better with the PhD students. I am not saying PhD students are better than project staff to take the readings, but probably some extent of commitment comes in when you are actually doing a degree in the institute and probably that makes your data collection capabilities much better or your interest in collecting the right data much better.

So you can see here the variation is much smaller and you do not see the kind of zigzag pattern that is observed in the previous set of data. So this is the 45MPa concrete, normal concrete and the one with 4.6 g/cc density. So you can really imagine as the density goes up, you expect the deformation capability also to reduce because the stiffness will be higher for the same strength.

And you can clearly see from here that, in general, you get response at high densities which indicates a smaller creep ratio as opposed to the normal density concrete. But then at intermediate levels of densities 3.6 and 4.1 g/cc especially at 3.6 you actually get a higher ratio of the creep strain to elastic strain. So again we could not really have a conclusive or clinching evidence to show what really happens when you use high density concrete.

But at least what we presented was a way forward to actually do this experiment and get some realistic estimates which can suit your design, okay. At this stage I think we should understand that concrete mix design when it is undertaken for a project needs substantial mode of time because it is not just the 28-day compressive strength that we are designing for, it is for a long term performance.

And that long term performance obviously includes resistance to creep and shrinkage as well as durability aspects of the concrete. Now very often when we do mix designs for construction projects at least in the Indian scenario, the primary emphasis is just to obtain the workability in the strength as long as you do that the project actually takes in that input and the concreting process is started.

But nobody really thinks deeply about choice of alternative materials and different design procedures will actually effect the long-term capability of this concrete. So it is always essential that when we go for a special grade of concrete or a special type of concrete in this case of course high density concrete, we do a thorough investigation of not just a short term strength gain characteristics, but also long term development of the deformation capabilities, the durability and so on and so forth.

So again this was a step in the right direction because it showed the way forward for people to adopt these long term tests also as part of the concrete mix design process.

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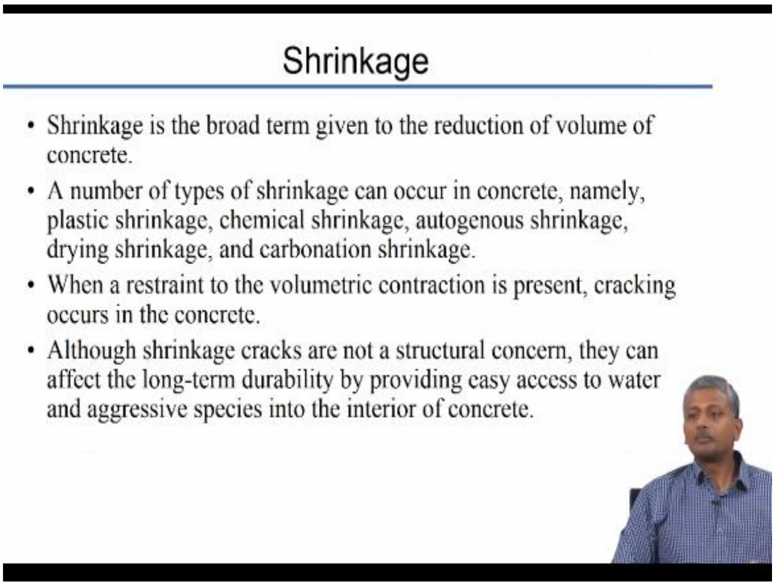

Now from creep we move on to shrinkage which is a lot more easier to understand because we are here talking mainly about the removal of water because of drying okay, or reduction of volume of concrete because of drying. But the problem is this term shrinkage is associated with the number of different phenomenon that happen during the process of early age of concrete as well as the long-term performance of concrete.

So in general there are different types of shrinkage that can be defined, you have plastic shrinkage, chemicals shrinkage, autogenous shrinkage, drying shrinkage and carbonation shrinkage. So there very many types of shrinkage that can be defined for your concrete depending upon when it actually occurs, what is the main cause and so on and so forth. Now of course when there is a restraint to the volumetric contraction.

When shrinkage happens there is a volumetric contraction, whenever there is a restraint that leads to cracking in the concrete and of course shrinkage cracks in general are not a structural concern, but they can lead to other problems for example durability and so on.

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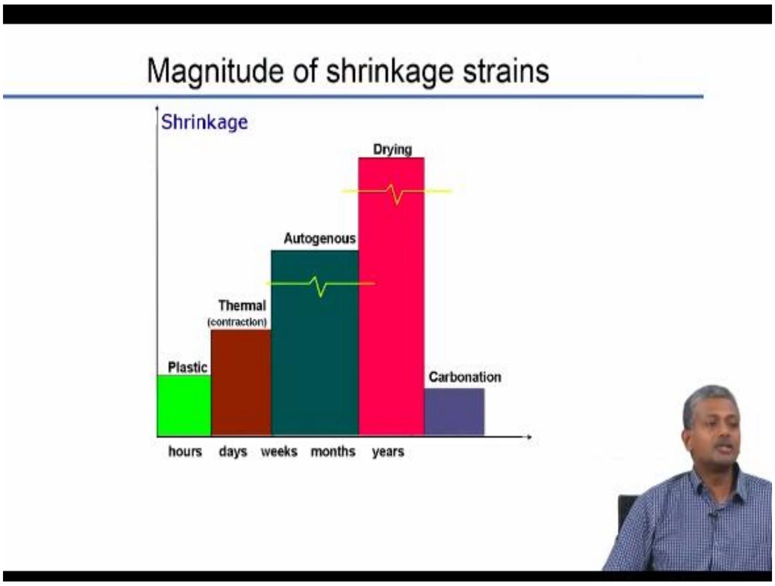

Now in terms of magnitude of these shrinkage stains, if you compare the different types of shrinkage processes there is quite a bit of difference in the way that you can damage the concrete. For example, plastic shrinkage happens very early after the laying of the concrete, but in terms of magnitude the extent of plastic shrinkage is much lower than what you have for drying shrinkage, okay.

Thermal contraction, because the concrete after cement hydrates goes to a higher temperature and then it starts contracting when it approaches the ambient conditions, that extent of strain also can be significant especially when your concrete is made with very high cement contents, right, in those cases you can have lot of heat development leading to very high temperatures in the interior and the extent of contraction could be substantial and definitely more than plastic shrinkage. But in terms of others shrinkage types, autogenous and drying, the extent of contraction which happens because of thermal effects may not be significant. The main shrinkage or main components of shrinkage would be autogenous shrinkage and drying shrinkage. Now what is autogenous?

Without any external drying the concrete still shrinks, that means there is some internal drying happening in the concrete, that is what is called autogenous shrinkage. Drying shrinkage typically is associated with the drying of water or losing of water to the external environment, okay. We look at the mechanisms which cause these shrinkage problems a little bit later.

In terms of carbonation shrinkage, this happens after several years, that means the substantial amount of carbonation or attack by carbon dioxide of the concrete should have had happened before we see any significant increase in the level of shrinkage caused by carbonation. So the time period over which this happens is also significant from the point of view of understanding how this concrete will perform in the long term.

Now in terms of early ages, plastic and thermal shrinkage are the most critical, but in terms of the long-term performance we are talking primary about autogenous and drying shrinkage and probably to some smaller extent the carbonation shrinkage because the extent of carbonation shrinkage is much smaller as compared to drying shrinkage or autogenous shrinkage.

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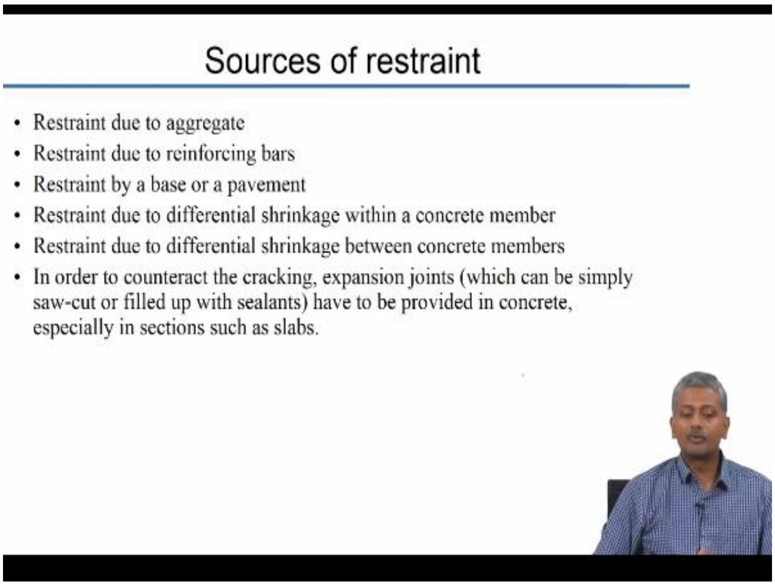

Now of course there are several sources of restraint which may happen inside the concrete. The aggregate itself maybe a restraint because it is only the paste that is undergoing shrinkage, right,; and then the reinforcing bars are a restraint; and then you can have differential shrinkage within the member, you can have the soil or a base which is actually restraining the concrete from expanding or contracting.

And because of all these aspects we know that in the construction process we need to accommodate these shrinkage strains by providing expansion joints, okay. Especially for large slabs of concrete or for long slabs of concrete we need to provide joints at regular intervals to ensure that the shrinkage cracking does not happen at random locations, okay, and also in some cases we can use alternative methodologies to reduce the extent of shrinkage or control the shrinkage cracking like use of fibres and so on.

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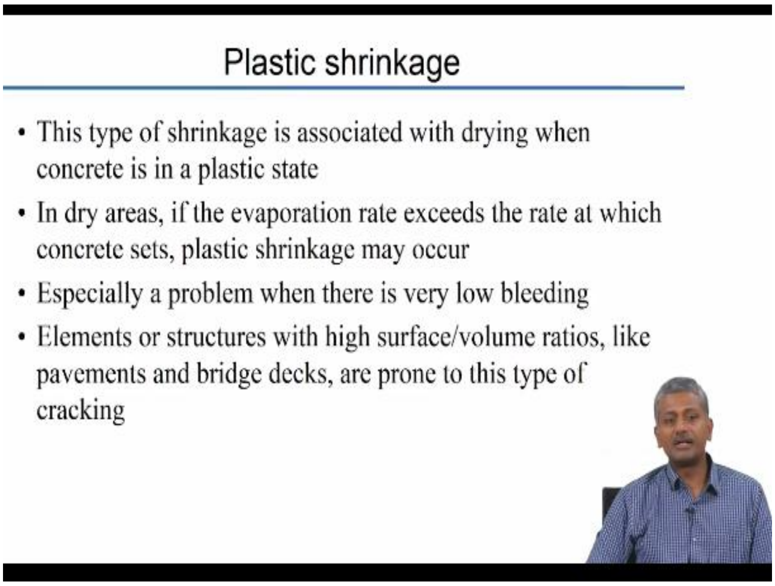

So let us look at these different types of shrinkage in more detail. Plastic shrinkage is what happens in the early stages of the plastic state. Plastic state implies that concrete is still not hardened completely, it is still mouldable, not completely mouldable, but it is still subjected to easy deformation if there is any loading on it. So if the evaporation rate that is happening from your typically slab type component, because those are very high exposed surface area.

So the typical concreting operation involves final finishing of the slab and then after that the curing is only started after one day, right, in the most construction sites. But because of that what really happens is if the concrete does not completely set at that point and the rate of evaporation of the concrete is exceeding the rate at which the bleeding water is rising up to the surface then the concrete at the surface starts drying, okay.

So since the concrete is drying at the surface it is volumetrically contracting. But the concrete underneath is not subjected to any drying and that acts as a restraint which causes cracking in the top concrete okay. So what type of concretes do you think will have this problem? especially the ones which have very low bleeding. Of course bleeding is not something that we want in the concrete, but some level of bleeding helps to control the drying from the top surface.

We do not want the water in the concrete to dry out before it participates in the reaction with the cement and causes the hardening of the concrete, okay. If that happens much before that then we lead to these plastic shrinkage cracking type problem. Now what do you think what type of concretes will lead to plastic shrinkage cracking? we discussed this earlier, concretes which have fly ash for instance.

Why because fly ash concretes would set at a very slow rate, first of all setting is very slow, second because of the optimized powder composition of the concretes, the extent of bleeding is going to be minimal. So already your concrete does not have sufficient green strength because it is setting very slow, so cracking can be quite easy if the stresses generated are large enough.

And that can be large especially because there is no bleeding in the case of fly ash concrete. Silica fume concrete we talked about that previously also, the extent of pressure, the capillary pressure that gets generated up on drying when you have extremely fine pores because of silica fumes usage, that can really cause a lot of cracking in your concrete. So silica fume concrete can be especially prone to plastic shrinkage problem.

Of course not all structural members will have plastic shrinkage issues, only the ones which are exposed or which have large exposed surface areas like slabs will have this issue.

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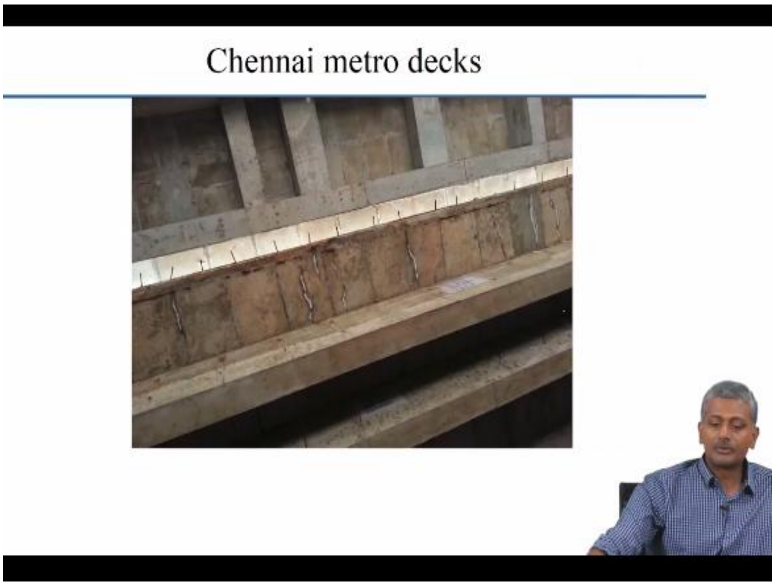

So this is actually a live example from the Chennai Metro project where several of the slabs that where laid actually ended up having plastic shrinkage problems. I am not showing you the top of the slab, I am showing you actually the bottom of the slab. So these cracks actually started from at the top, came all the way to the bottom and people actually noticed it only after water was seeping out of these cracks.

The water that seeped out of the cracks also leached out some lime and you can see the white deposition of lime transformed to calcium carbonate, right, because of atmospheric carbon dioxide. So the crack started at the top, penetrated all the way to the bottom and then led to water seepage from the bottom that was also leaching out the line, okay.

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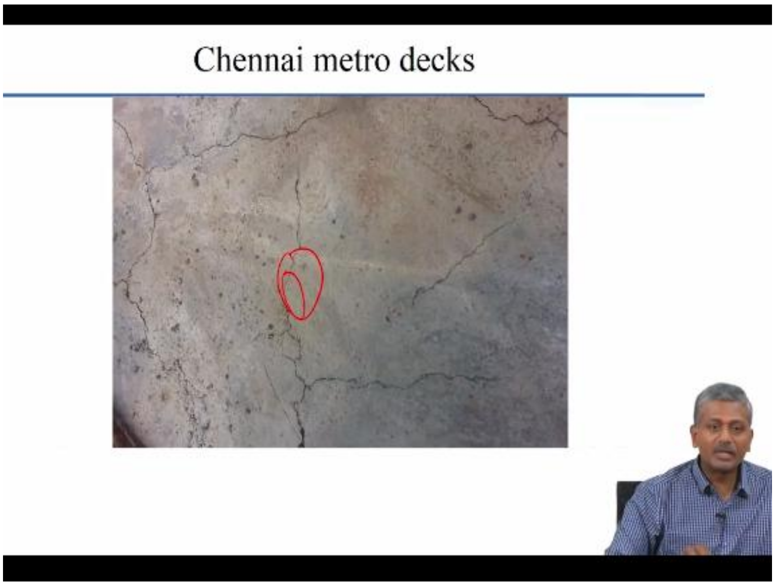

So for that of course we need to observe the top and the top of the slab is showing this kind of a cracking, this is what is otherwise known as map cracking pattern, that means random cracking. So you can see the nature of cracks are quite random and most of these cracks start off as being hairline cracks and if you are not paying attention to it, many of these cracks can start progressing further because concrete is not going to resist cracking.

Once crack starts or originates in concrete it is quite easy for the crack to propagate. So the same crack, which is started on the top surface propagates all the way to the bottom and then it causes a clear pathway for the water to flow through. So these were identified in several of the slabs. Now it turned out that these slabs where actually made with silica fume concrete and that too it was self-compacting concrete, okay.

The slabs were made with silica fumes based self-compacting or high flowability concrete and to ensure that they were not casting it during the hot times of the day. The casting was started in the middle of the night, typically around 3 to 4 a.m. as when they were doing the casting, but because of the length of the process sometimes it went up to about 9 to 10 a.m. and during this time; this was actually being done in August, okay.

Chennai in August is quite warm and there has been no rain typically in August. So usually in those hot temperatures especially if it is accompanied by winds you can have a lot of drying that happens from the surface and that will lead to plastic shrinkage related problem. Unfortunately, because we do not really worry about surface appearance of the concrete and we come back only the next day and start curing nobody ever reported these kinds of problem.

In many situations it is actually quite easy to get rid of these cracks if you are present at the site after the concrete is completed. Once you do the initial finishing and if there is no bleed water rising to the surface, if the crack start appearing at that point of time, all you need to do is take a float and simply rub the cracks, that will make it go away, that is the simplest solution to plastic shrinkage cracking.

Just use the float and rub the cracks and they will go away and once you remove that tendency of cracking, the shrinkage cracks should not appear. But then just as a precaution it is always better if you are there early enough to start curing process as early as possible. Essentially prevention of drying of water from the top surface of the concrete should be done as early as possible.

And there are easy ways to do that, you can as well cover the top with an impermeable membrane, just use a polyethylene sheet for instance, which maintains the moisture inside and does not allow it to go out. So there are several ways in which you can reduce the extent of plastic shrinkage.

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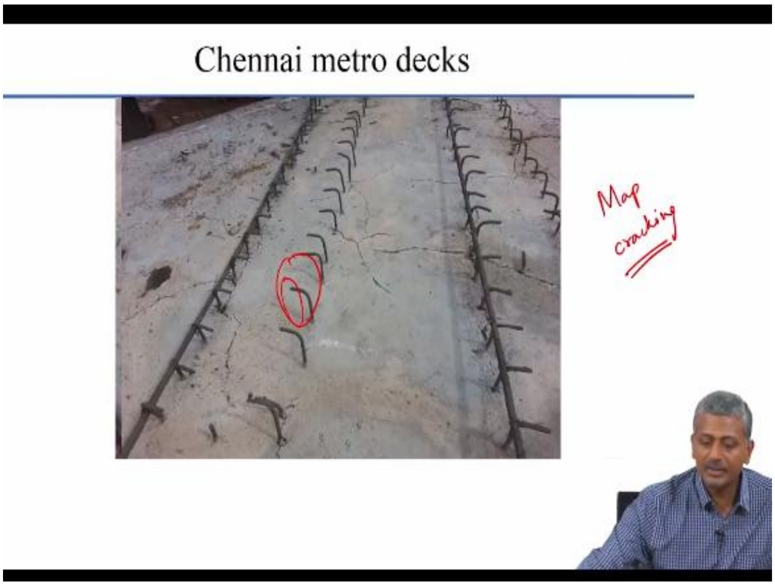

This is again the same Metro deck, these are where the rails are supposed to come, right, now of course this section is completed. These are where the rails are supposed to come, so these are the steel inserts within the concrete which are going to be holding the rail in position. You can again see there are several cracks here, some of them have become very wide, which is what cause the entry of the water through these cracks, leaching of the lime and then it was detected at the bottom.

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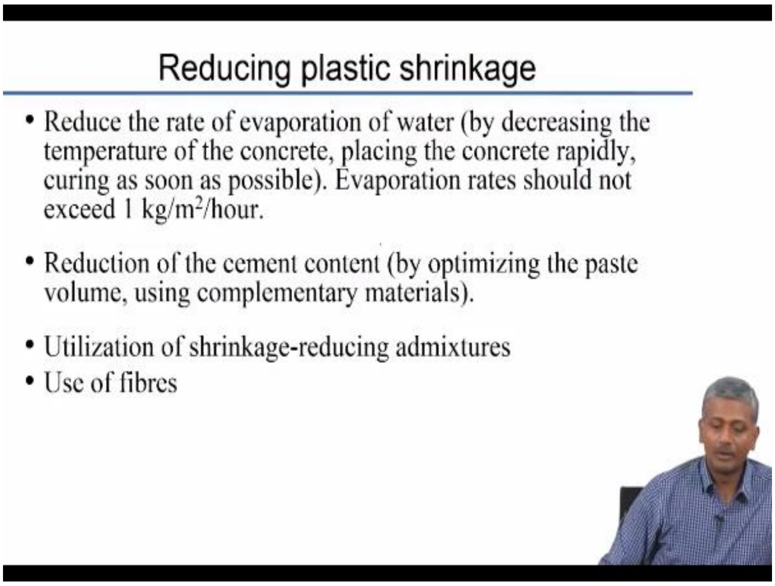

So of course reduction of rate of evaporation of water is very important. It is generally seen that when the evaporation rates from the top surface do not exceed 1kg/m^2/hr, plastic shrinkage is not really a problem, okay. But then very often especially in dry and windy days we can have this combination causing excessive drying from the concrete.

How do you estimate this $1kg/m^2/hr$? It is easy, just place a bowl of water in the same environment and see the mass of the water with time, okay. You know the surface area over which the water is evaporating, you can calculate the amount of evaporation rate, right. So reduction of the cement content is also important. The problem is when you often use supplementary materials as a replacement for cement your paste volume generally increases.

When your paste volume increases your tendencies to shrink also has to go up and secondly since most of these pastes cause the retardation of the setting process there is a greater tendency to have a plastic shrinkage cracking wherever you use mineral admixtures. So although I have said this, by optimising the paste volume using complementary materials this may not always work in your favour, okay.

So you have to be very careful whenever you choose different cementitious combinations you need to evaluate for plastic shrinkage. I will show you a methodology later on. You can go the costlier away and use shrinkage reducing admixtures in your concrete. We talked earlier about how shrinkage reducing admixtures reduce the surface tension of the water, which reduces the capillary pressures when the drying actually occurs.

But then these are quite expensive, much more expensive than doing a simple control of the evaporation from the top surface or you can use fibres. Fibres can, especially the low modulus fibres like polypropylene fibres or polyester fibres can reduce the extent of shrinkage tremendously okay. But then there is an added cost because you are adding an extra material.

And then your concrete becomes more difficult to handle when you are adding fibres, right workability goes down, you need to control it again by addition of more superplasticizers. So overall your cost will be much higher than doing a simple treatment of the plastic shrinkage at early stages by identifying the kind of membranes or coverings that you need to provide to ensure that evaporation does not take place.

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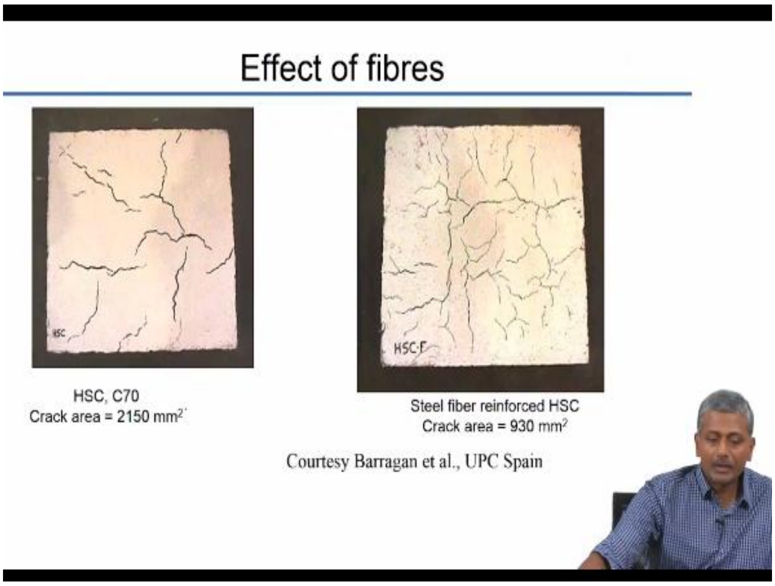

Again this is just some research study showing the effect of fibers. This is plain concrete without fibre of course this is high strength concrete, 70MPa concrete and this was subjected to an extremely dry and windy environment in the lab which was simulated and controlled quite nicely. So 70MPa concrete, the total crack area for normal high strength concrete is 2150mm^2 okay.

Of course to calculate that crack area, image analysis was done to actually figure out what is the length of the crack and average width of the crack so that you could get the area. The same type of slab when it was cast with fibres or steel fibres, the overall crack area came down to 930 square millimetres, but what you see on the right side? You see more cracks. So what is basically the steel fibre, what is it done, it is basically distributed the fibres over larger area.

So you have more number of smaller cracks, but the overall crack area is much lesser and you can also imagine that the crack width would have got significantly reduced. So if the crack width is low then your dangers of water and other aggressive chemicals entering is also lowered.

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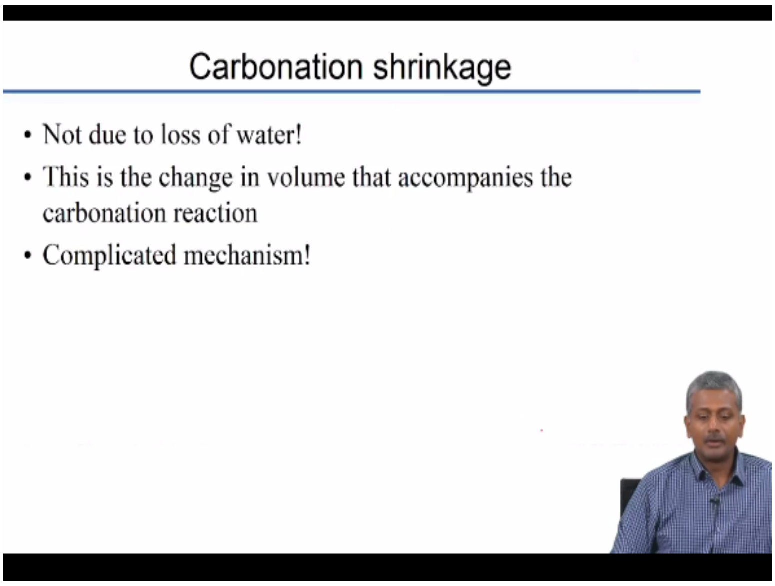

Now carbonation shrinkage I did not want to treat in much detail because there is a lot which is still unknown about this kind of shrinkage. Carbonation shrinkage does not happen due to loss of water, it happens more because of the reaction itself which leads to carbonation, that is your calcium hydroxide combining with carbon dioxide to give you $CaCO_3$ plus water.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

It appears as if water is produced in this system but actually if you really go through this process in detail which we will do in the durability part. Water is actually an ingredient in the reaction itself because it needs to convert the CO2 into carbonic acid for this reaction to proceed forward. So this reaction is associated with the volume change.

When you convert lime to calcium carbonate there is a volume reduction which is basically your carbonation shrinkage. In other words, what you are doing is you are forming a denser product, okay, for the same mass you are occupying a lesser volume. So the mechanism is rather complicated as far as shrinkage is concerned, but we will try to treat it in conjunction with the study of concrete carbonation in the durability chapter.

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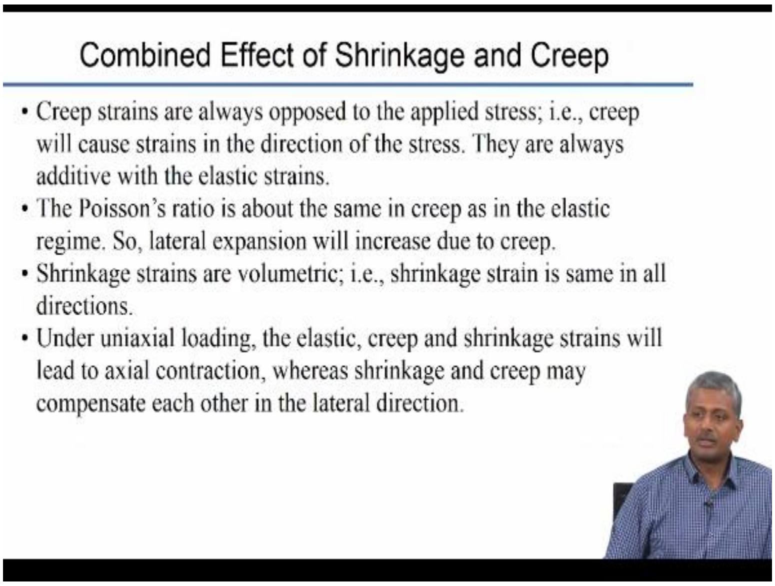

There are different ways in which creep and shrinkage can act together. Now it depends on the kind of structural member and the kind of loading that is happening inside it. Consider the example of a beam we talked about this earlier. When you have the tensile stress in the bottom fibres of the beam the shrinkage strains are actually acting in the direction opposite to it.

So very often when you have shrinkage and creep acting in a different direction you can actually get a positive result from it, but in the case of a column you may actually have a negative effect because both shrinkage and creep are happening in the same direction, okay.

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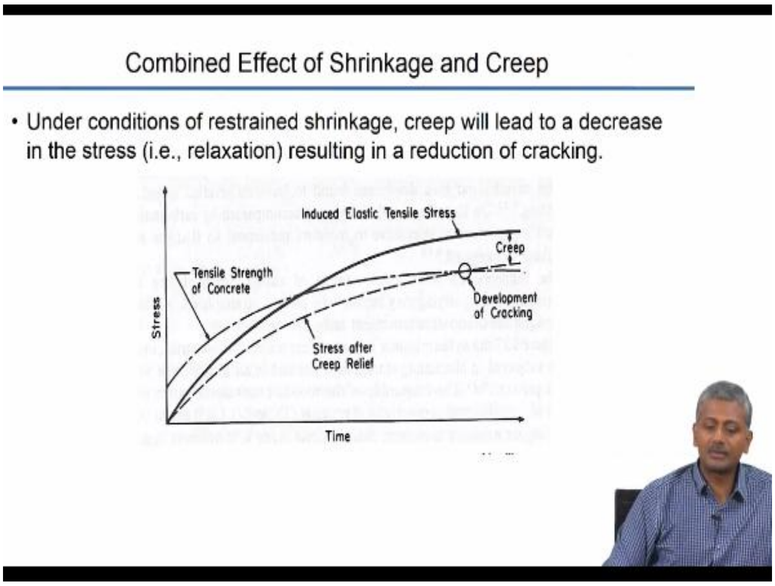

So if you look at example of a flexural member, the shrinkage and creep acting in combination will actually produce a more positive effect. So what will happen is, if this is your development of the tensile strength of the concrete, okay and that is your induced elastic tensile stress, because of the cracking that is accompanied by shrinkage or rather because of the creep relief that is happening because of shrinkage your actual stress, in the material will actually be much lower okay.

And this lower stress will cause an extension of the time it takes for the development of cracking. In normal circumstances the crack should have developed when the induced elastic tensile stress exceeds the tensile strength of the concrete, but because of this combined effect of shrinkage and creep you are actually getting an extension over which your cracking actually occurs in the system. So this is a positive response of the combination of shrinkage and creep.

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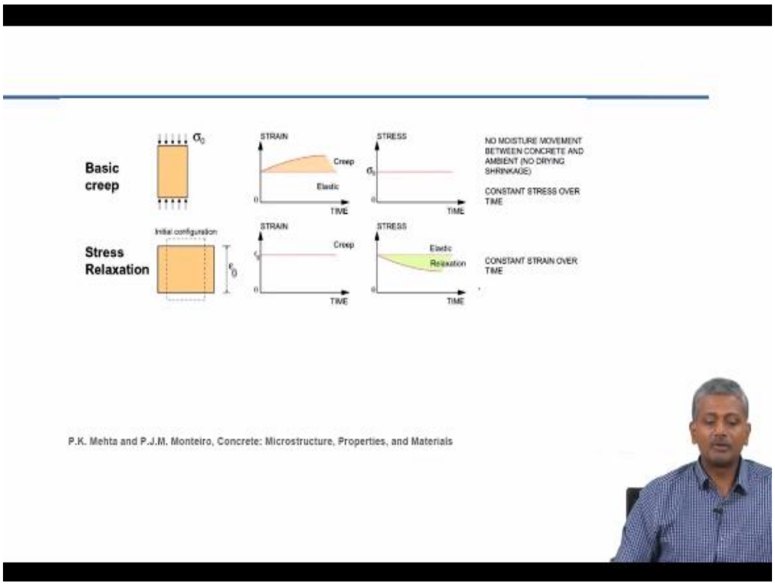

Now if you look at how we study these phenomena in the laboratory, basic creep is basically when there is no drying associated with it. You have your concrete, which is subjected to a constant stress condition. So stress against time is constant and here your strain, there is an elastic strain and there is going to be a creep strain okay, and the difference between the creep and the elastic strain is what accounts for the permanent deformation in your material, okay.

The stress relaxation experiment is performed with a constant strain and monitoring the drop in stress with respect to time. So stress relaxation and creep can both play a significant role in the loss of prestress in prestressed concrete members. Creep and concrete and stress relaxation in the steel both will lead to reduction in the amount of prestress that the concrete has.

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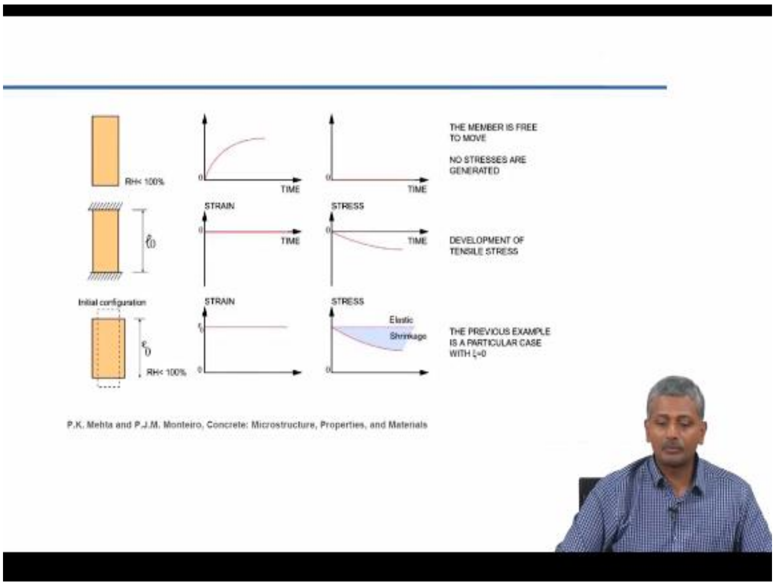

Now in the case of shrinkage, if your member is free to move, right, then obviously the strain keeps on developing with time, but there is no stress, because there is no restraint at all, right,? But if you have a restraint which is preventing free movement of the concrete the strain is 0, in this case restraint is at both ends obviously, and the stress keeps on developing in the material and of course when the stress exceeds your tensile capacity there will be failure or cracking in the concrete will be initiated okay.

Now in this case what we have is a constant strain and the extent of loss of reduction of stress that will be caused because of relaxation as well as shrinkage will be more than what is just caused because of relaxation alone. So here this is a combination of relaxation experiment done with drying, okay. So your overall stress reduction is going to be much greater with shrinkage in this case.

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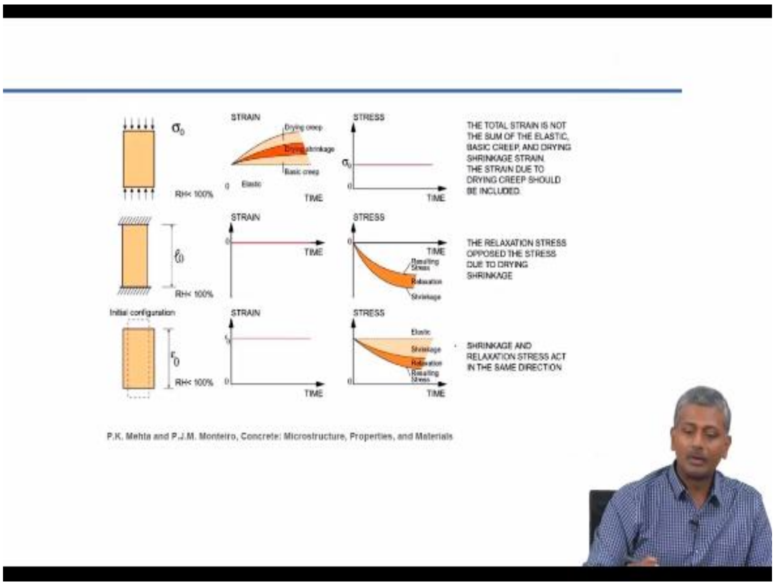

But what we are primary looking at is the case of a loaded concrete member which is also subjected to drying, okay. So here we have a constant stress condition, but you have 3 different mechanisms which will cause an increase in the strain including basic creep, drying shrinkage and drying creep. So overall deformation of your material will be significantly high when your material is loaded and is also drying at the same time.

Of course you can also have other conditions where your material is restrained at both ends in which case you can actually get; of course your strain is 0, but your stress continues to develop. But because of the relaxation that has caused your resulting stress will be much lower in this case, okay. So you can look at various different ways in which creep and shrinkage can act together depending upon the type of structural member that you are looking at, okay.

And your response that you determine should be based on the conditions that the member is subjected to whether it is drying, whether it is of member that is free to move, whether it is a member that is restrained on both sides or not, okay. So all that has to go into your design process and the thinking forward to select the best materials that can help you restrict the extent of damage that will happen to the concrete.

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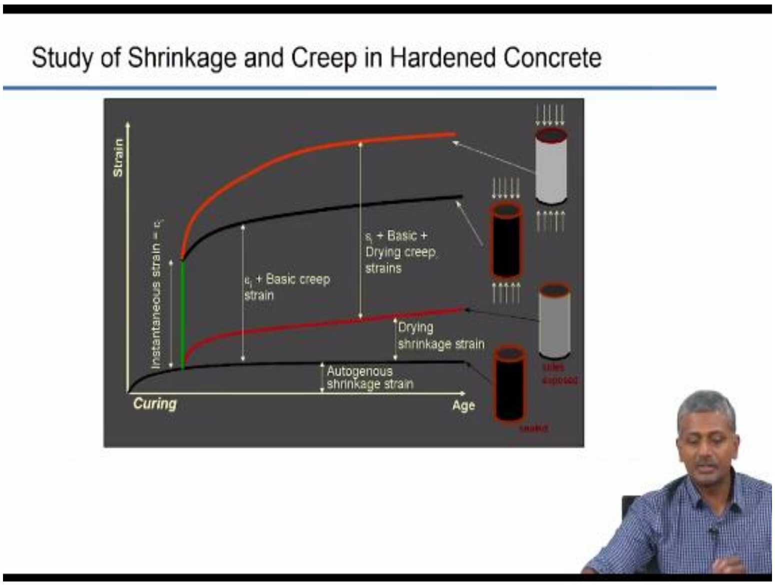

So this is how we typically study creep and shrinkage in hardened concrete. For basic creep and for autogenous shrinkage, that means the shrinkage that is happening within, we are trying to study the materials in a sealed condition because we know that autogenous shrinkage happens when there is no drying in the system itself. So for basic creep and autogenous shrinkage, we study the change in strain with time for a member that is completely sealed.

For something that does not have any loading but are subjected to drying we can actually measure the total shrinkage which is composed of both drying shrinkage and autogenous shrinkage. Even when drying is happening there will be some autogenous shrinkage also. The most important loading case is obviously the case where the concrete is subjected to load as well as is shrinking.

So there will be total shrinkage that is composed of drying and autogenous shrinkage and there will be total creep composed of basic creep and drying creep, okay. So there are different ways in which you can actually test your concrete depending upon what you really want to find out.

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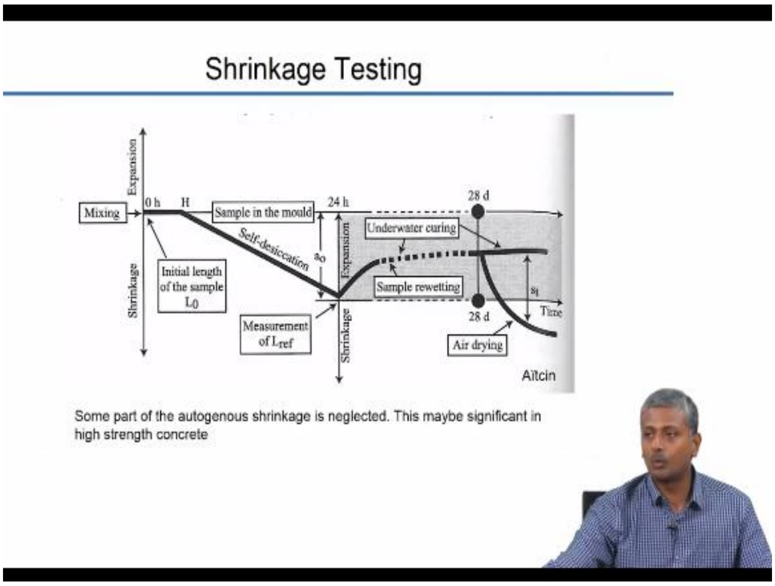

Again this is just showing you a typical schematic as to what we do with respect to shrinkage tests. The concrete is first setting inside the mould okay. But we know that within the mould itself some level of internal drying may actually happen which is causing the concrete to actually shrink, okay. But only at 24 hours we remove the specimen from the mould and measure the reference length of the specimen, right.

Because before 24 hours we do not want to remove from the mould because concrete may not be sufficiently strong enough to maintain the specimen dimensions, it may start breaking or cracking. So we removed it at 24 hours and measured the initial length and with respect to the initial length only we are measuring the strains later.

But in most cases what we do is, we do underwater curing after we remove it from the mould to have a normal development of the structural part of the concrete. Because without the underwater curing your cement hydration reaction will not proceed the way that you want. Even in normal structure you cure for at least 7 days to ensure that there is some sufficient development of your structure right.

So whether you cure for 7 days or 28 days what this curing process will obviously do is push in more water into your system and lead to some expansion upon rewetting. Because here it has been drying. Part of that drying can be recovered by simply rewetting okay. And beyond a certain period of time you are then going to be exposing your concrete to drying environment because you want to study the shrinkage, right.

So at this point of time your concrete starts shrinking because you are subjecting it to a drying environment. So what you need to be careful about is, how you define your reference length for your measurement of the shrinkage. You can either define a reference length here or you can define it at that location okay. So when you measure shrinkage you need to be careful about these issues.

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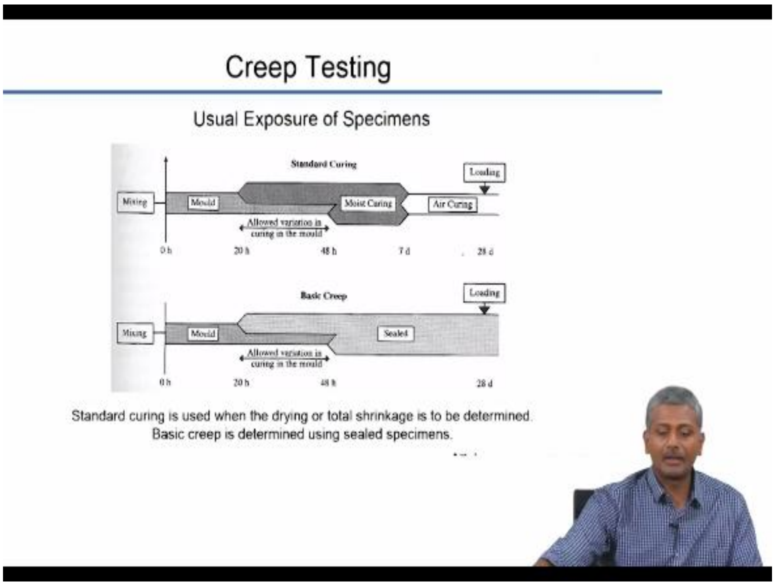

Again there is also some methodology suggested for creep testing. I am not going to go into that in detail here.

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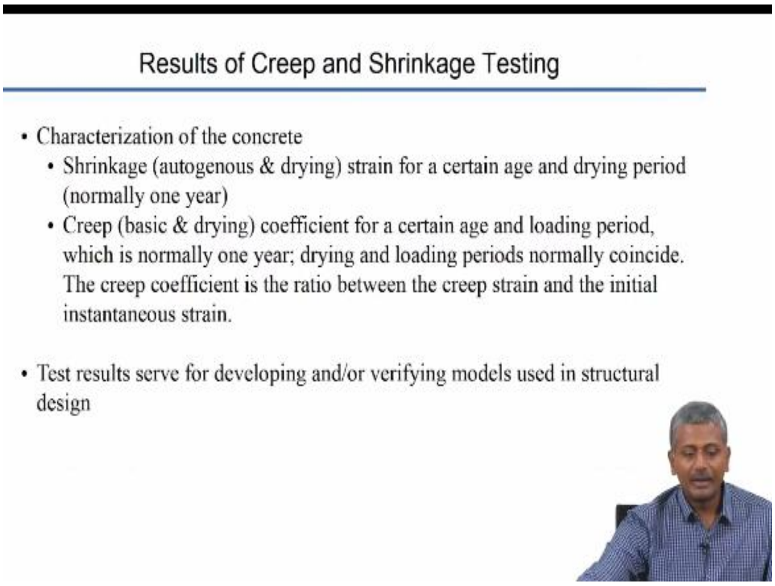

Essentially what we look at from the testing of creep and shrinkage is the characterization of the concrete in terms of shrinkage and the different components of the creep itself and what these help with is to develop and sometimes verify the existing models in the structural design. Because, ultimately the inputs from creep and shrinkage can lead to significant changes in the way that you design a concrete for the structural purposes.