Concrete Technology
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Lecture - 28
Creep & Shrinkage of Concrete

Lecture 2 and if you recollect in module 7 lecture 1 we discussed about creep of concrete and at the end, we talked about prediction of creep by SEI formula. We will just quickly recap that, but today we will be looking into some issue related to creep and some related to shrinkage.

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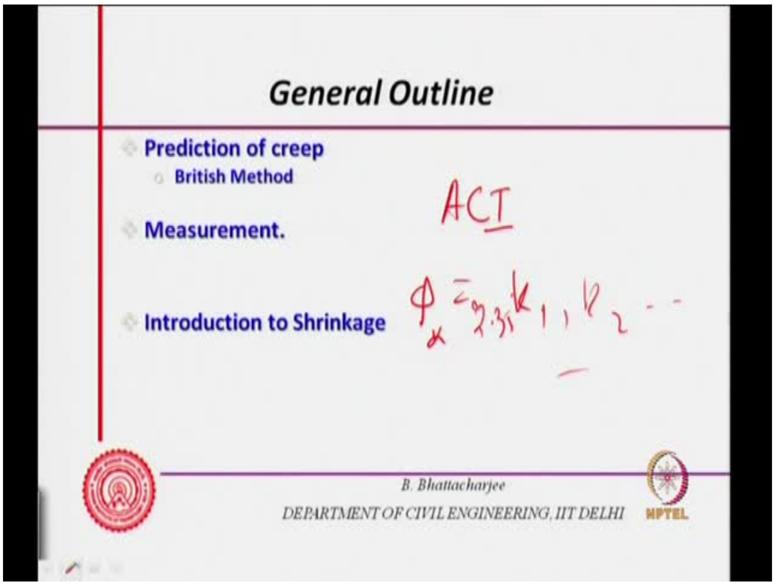

So, we look into creep, prediction of creep, what is being reaming. Also we look into where creep is you know relevance of creep in civil engineering, structural engineering and then we look into measurement of creep and lastly some introduction to shrinkage. So to start with we look into the British method of predicting creep, and if you remember we talked about the ACI method, ACI method in the last lecture, and where we said that a you know the phi ultimate you know ultimate infinity can be related to you know some factors 2.35, 2.35, 2.35, k 1, k 2, k 3 etcetera several factors. Today, we will look into the other method. Today, we will look into another method.

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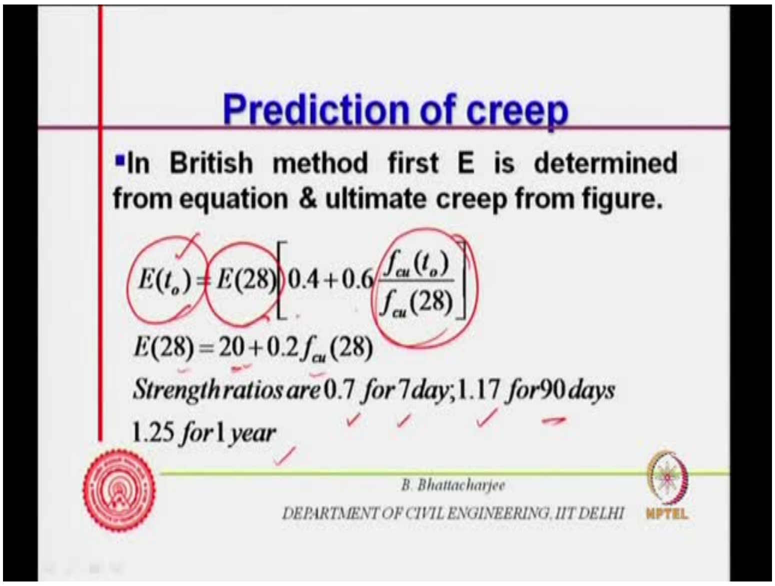

So, that is the British method and in this one what you do is first E is determined from equation and ultimate creep from figure. So, E is given as E t 0 that is at anytime. Modulus of velocity is anytime is important because you do not know at you know whatever time modulus of velocity is not known. So, it is actually related to modulus velocity at 28 days and then this ratio of the cube strength of at that time 228 days cubes strength. So, this ratio is important. So, this is related to 0.4 and plus 0.6 into this ratio. In other what is when this is high, this ratio is more than little bit more than 1, so 60 percent weight age to this one.

Multiplied by E 28 and this know this gets increased actually and 40 percent directly as this much. So, it is this relationship is of this form. Now, E 28 is found out from this relationship. E 28 is found out from this relationship, 20 plus 0.2. So, it is assumed a linear relationship with respect to cube strength simply with the intercept being 20, intercept being 20. So, it is put in as a linear relationship and this strength ratios depends upon age. It is 0.7 for 7 day, 1.17 for 90 days and 1.25 for 1 year. So, this; from this first you find out the E corresponding to year at that time.

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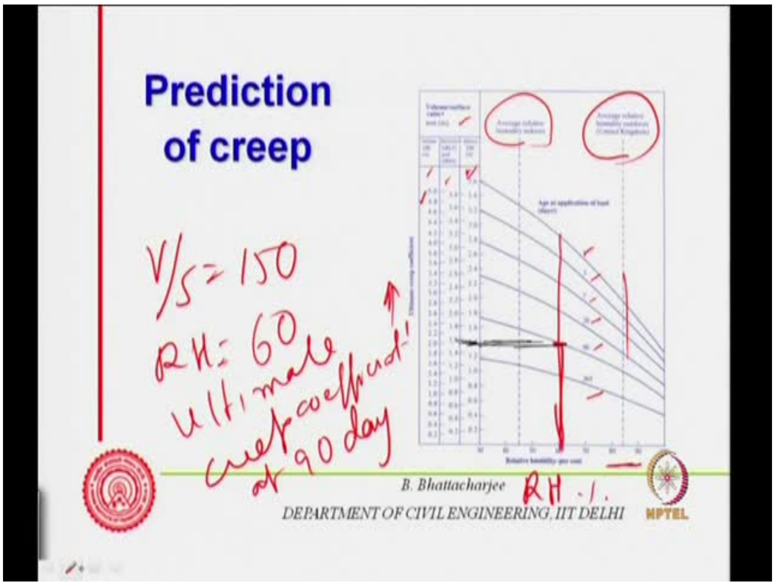

Once you done that then you can use this diagram. Now, if you look at this diagram in this diagram you have got relative humidity percentage here RH, RH percentage here. Then this is the ultimate creep coefficient, ultimate creep coefficient is given along this direction and this is for three conditions actually, three conditions of volume to surface area ratio. So, these are one, two and three. So, three conditions of volume to surface area ratio and millimeter, 1 millimeter or in bracket it will be in inch. So, whatever it is the its volume to surface area ratio is like this. So, up to certain value, up to certain value, up to certain value, up to certain value below 100 mm of, below 100 mm of volume to surface area ratio, this values, this values should be ultimate creep coefficient values can be obtained.

So, below 100 mm values volume to surface area ratio, below 100 mm values and this is the relative humidity. So, average relative humidity indoor, this is average relative humidity condition, this one is outdoor in United Kingdom and this is 1, 3, 7, 28, 90, 365 age. So, these are the ages. So, if you have age, say for example, it is a kind of nomogram, let us say I have got 60 percent relative humidity, 60 percent is the relative humidity and I am interested in the ultimate creep coefficient in 90 days then I come to this curve and then you know my volume to surface area ratio is let us say is between you know between I mean below 200, above 100, but below 200 and this is more than 200.

Let us say 150 mm. So, my V by S is 150 just hypothetically, RH is 60 percent and I am interested in ultimate creep coefficient, ultimate creep coefficient, creep coefficient at 90 days. So, what will I do? 60 percent relative humidity, go to 90 days, go to 90 days, go to 90 days come along this direction and it is 150, so it is somewhere in between. So, it will be given as 1.6. So, it will be in 1.6 ultimate creep coefficient will be given as 1.6. So, basically you can find out using this nomogram the values of ultimate creep coefficient, values of ultimate creep coefficient, all right?

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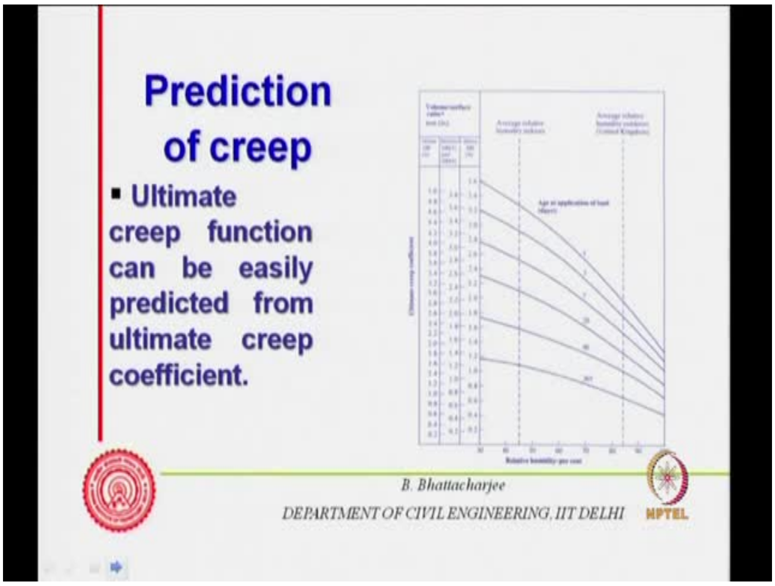

So, values of ultimate creep coefficient can be found out using this kind of a nomogram which is there. Depending upon the relative humidity age so the factor that has been considered here if you see it is the age, volume to surface area ratio and relative humidity, right? Relative humidity of exposure, so exposure condition, volume to surface area ratio and age, these are three main factor that was considered in this one to find out the ultimate creep coefficients. So, if you ultimate creep coefficient then you can find out ultimate creep function which you have seen in the last lecture.

The formula is same; it is the same because the definitions are same. Definitions are same; there is no variation in the definition to SCI method or other method. So, we find out creep function from creep coefficient. We find out creep function from creep coefficient, alright? So, ultimate creep coefficient can be related to creep coefficient at any age. Same, similar kind of formula, same basic concept that was there and then it can be related to creep function as we have done in the last lecture.

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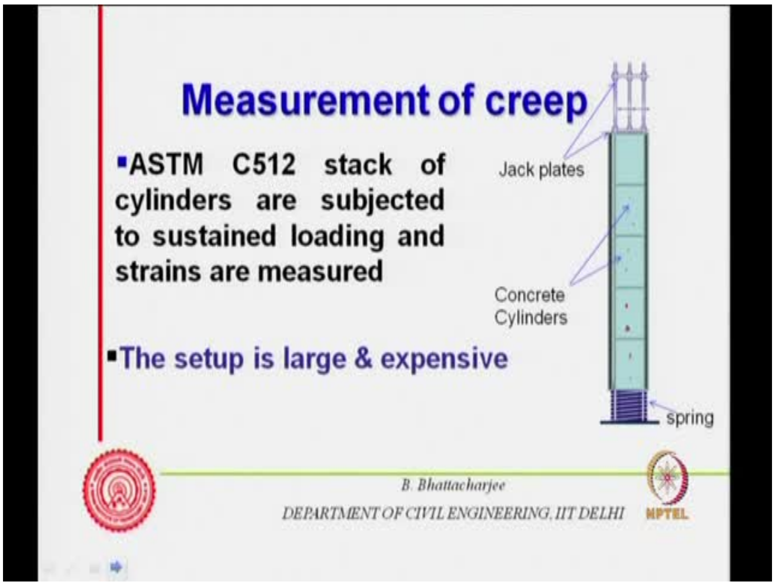

So, you can predict by using either of the method, but obviously with modern days with excel sheets available and all that, it is fairly easy to use the factors k 1, k 2, k 3 etcetera etcetera and simply multiply them by 2.35 to find out the ultimate creep coefficient which can be finally, related to the creep function in the similar manner as we have done in the last class. So, that is related to prediction of creep and now let us looks into measurement of creep.

Now, measurement of creep the standard that is main, the only standard perhaps is available is ASTM C 512 and it suggests is that you stack cylinders, four five of them and they are subjected to sustained loading and strains are measured, strains are measured it will look something like this. Like given a loading frame the loading frame is here, so that will have some sort of a you know, some sort of jack plates you know loading frame it will have some sort of jack plates, lower and the upper one and through which you apply actually load onto these are concrete cylinders, concrete cylinders and there is a plug in between gap. A main, but the main issue is this is almost cremating and there is spring below, there is the spring below.

So, you know you apply actually load, there is a spring below, there is a load of series load apply in series to set off cylinders and there concrete plug at the top and by now there is a plug between the cylinder and the jack etcetera and also between the spring and the concrete which I have not shown here and then you apply load like this and keep this load sustained. Now, the deformation that will occur will be absorbed by the spring will deform by this amount. So, there is no chance of load getting reduced because spring will provide the kind of kind of reaction that is required.

Now, how, what do you measure? You put actually strain gauges, you put strain gauge or any varieties of gauges actually is been suggested, you know you can have varieties of gauges here in the, you know gauges in the central portion. I mean you can actually put in gauges, strain gauges or you know all kind of gauges are possible you can insert them put it onto the surface or even embed them. So, all possibilities are given in the code and if you look at that there is all available and that is how creep is measured, that is how creep is measured, alright?

Now, this is costly, is large and expensive especially when you are trying to do a number of such cylinders because of loading frame. So, it is expensive, but possibly the, you know the only standard method available for measurement of creep. Now, you have to also do one thing. You see this there will be other factors which would be affecting the creep. So, therefore you have to have concrete control specimen which will be subjected to similar environmental and such other condition and the strains there also change in strains there also will be measured. So, the comparison will eliminate out you know all the other other factors, effect of other factors. So, difference between the strains will be activated to creep actually under the sustained loading, under the sustained loading. So, this is one of the setups that has been used.

For researcher they have tried to actually adopt somewhat simpler way to subject you knows that that would mean that you know if you look at this particular dimension of this one this will be very large, enough at least something like 2 meters to you know 1 1.5 2 meters the specimens etcetera etcetera plus a loading frame, the loading frame through which you can apply constant load. So, this is a large specimen and you large setup and costly also. Simpler way is to subject to concentric cylinders, right?

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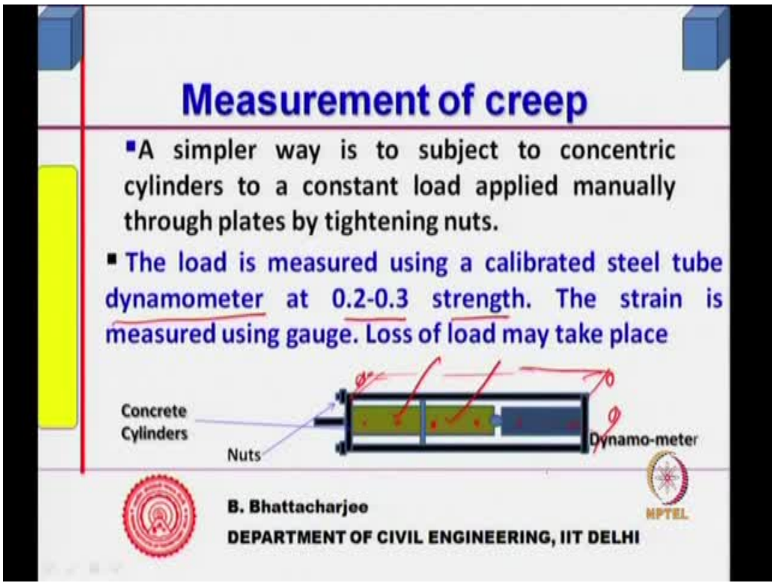

To a constant load applied manually through plates by tightening nuts just we will see that. So, earlier one you have a jack through this actually you apply the load and maintain that load and you can test a number of cylinders in one go, you know so stack them and put them together to study. Now, in this one when you have, so number of samples becomes large in particular case in fact a minimum is suggested in the code again that you must cross check at least five, six of them, one or two as control, rest are for testing and so on and so forth. So, it is relatively large, but as I said earlier there is this mostly.

These are only one, possibly only type of code that is available or guidelines available. So, it is the best, the best way to do is through that only, but simpler way is to subject the concentric cylinder to a constant load applied manually through plates by tightening night, nuts as we shall see. Then load is measured using calibrated steel tube dynamometer at 0.2 to 3 20 to 30 percent of the strength and then strain can be used, measured using gauge like DEMEC gauges, you know DEMEC gauges etcetera etcetera, but loss of load may take place because there is no spring support system like that is there earlier. For example, we will look like these are the concrete concrete cylinders. These two are the concrete cylinder, this one and this one there is the concrete cylinders.

These are four rods, maybe two of them are seeing, other two will be somewhere there and there other two will be somewhere there you know. So, four rods are there and there are plates here, there are plates here and this can be there are nuts here which can be tightened. So, this is of course the dynamometer and this are the nuts, this are the nuts actually which you can tighten to actually stress this. This is fixed here. So, this is a dynamometer, there is a ball joint point joints, so as you stress this as you tighten up this, so this will be stressed.

So, it is stressed to around 0.2 to 3 percent of the, may 20 to 30 percent of the strength and then then then allow the, you know allow the the formation to occur and you can measure this deformation again by putting the DEMEC gauges here, the DEMEC gauges here will all, dynamometer is essentially for measuring the force, the load or the stress, you know finding out the stress that will come into. So, this is there are DEMEC gauges you know it is pre calibrated, this is very much pre calibrated. So, it is deformation if you know from that you can find out what will be the stress.

So, the stress level in this one can be found out, stress level in this one can be found out. So, because deformation is known, so strains in this one you can obtain. So, the stress level can be found out because same stress will be transferred through throughout. So, one can find out the stress level and the DEMEC gauges or kind of gauges you can actually apply in the concrete to find out the strain that would occur. At the same time you must have control specimen in order to obtain the variation due to temperature and any other aspects that would be there. So, this will we have four such, four such rods and through which there will some nuts there also and that is how you do it. Now, it is manually tightened essentially to, manually load is applied manually.

So, it is actually a simpler setup, but the problem is see there is no spring here. So, therefore the due to deformation because you do not have a way here, you do not have a way to unless there is a feedback system and you have a way to check that there is a, the load is same and this this will not tell you whether load is remaining same or not because of some of the deformation reaction might get reduced and in the process it might end up getting somewhat load deduction may occur. So, loss of load may take place.

So, these are basically creep measurement. Not too many facilities are available in many places. It is not a very common facility to have this, but those who are doing research may have to you know setup this kind of facilities or wherever people do this such creep research and creep this kind of facilities, the other one would be obviously better ASTM 512 type, but something simpler one can also device. So, this is what is creep measurement; this is what is creep measurement.

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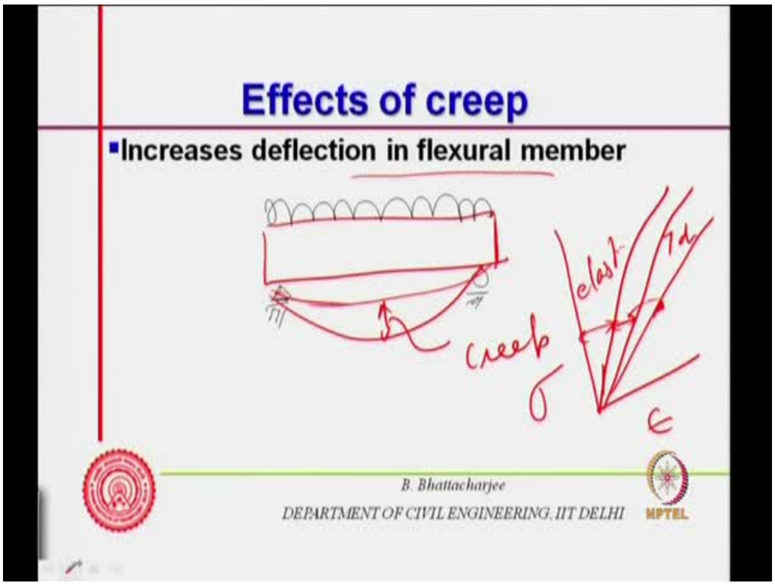

Now, let us see what is effect of creep? Effects of creep are let us see what are the effects of creep. First of all it will you know increase the deflection in flexural members. You can and imagine this, this is my flexural member and says simply supporter system and I have applied load here. So, what will happen? In the long run the deflection will increase. So, elastic deflection and later on deflection may increase further. So, elastic deflection and later on deflection manual. So, this could creep, this could be due to creep, this could be due to creep, so this could be due to creep. So, increase of deflection in flexural member that we have understood.

So, while taking account of you know like deflection control, the modulus of velocity value that you take must account for the creep as well because it is a long run behavior because what we have seen earlier was this. This is your epsilon, this is your sigma, this will be the elastic scenario, elastic and this is due to the creep at some 7 days or some you know like, so the creep will appear and then 128 days and so on. So, finally the modulus velocity is at this point. So, there is some effect of creep and it must take into account of you know it must take this factor into account. Therefore, deflection calculation must the modulus of velocity used for deflection calculation and the code actually does that, code takes those values into, (( )) codes takes those values into account.

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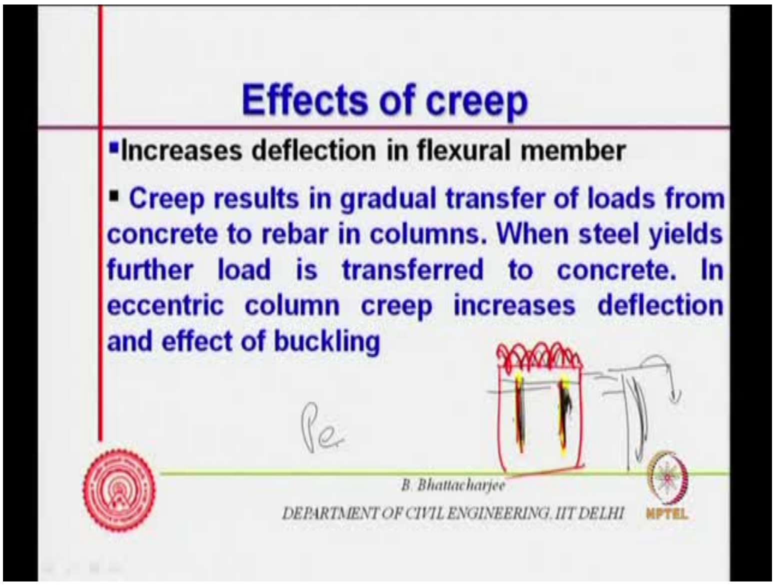

Now, you see the creep results in gradual transfer of load from concrete to rebar in columns, you know basically if you have loaded a column, loaded a column. Now, the load is coming onto the you know column. It is coming on to the column. Now, the bond exists alright, but you know more more this stress stress more, more the stress increases or this deforms more this will have a tendency to transfer this because they are under same deformation, you know this, this materials are in parallels. So, this is your rebar let us say this is your, this is your rebar, this is the rebar, this is the rebar, this is the rebar. So, they will have same deformation.

They will have same deformation, they will have same deformation, this two will have same deformation rebar and this will have same. This is your rebar this is rebar and they will have same deformation because you know they are acting in parallel. So, if you have load like this they will have same deformation you know same deformation. So, deformation will be similar. Now, when deformation is similar, the you know the deformation is similar and deformation increases overall deformation increases because concrete is creeping, concrete is creeping under creep concrete is getting additional deformation.

Actually, it would try to reduce that deformation or you know the deformation to the on the strain to the rebar as well, to the rebar as well. Therefore, with time there is gradual load transfer takes place from concrete to rebars. So, with time gradual deformation, you know gradual load transfer will take take. So, when steel yields further load is transferred to the concrete. So, only after steel, yielding of the steel the further load will be transferred to the concrete. So, in eccentric column creep increases deflection and effect of buckling. Now, obliviously in eccentric column where there is a load is coming here, this is your column.

So, actually this deflection would you know this deformation, downward deformation would actually increase the effect of buckling because this was bending, this was bending and at the moment we know eccentric column. So, there is a P e effect, P e and this would P u would result in bending of this one, but creep would tend to increase this bending and therefore, buckling will be you know increasing. And again you take in terms of the you know the E you take in calculation for all these. Modulus of velocity we must take account of all this factor into account. So, this is done while doing in design.

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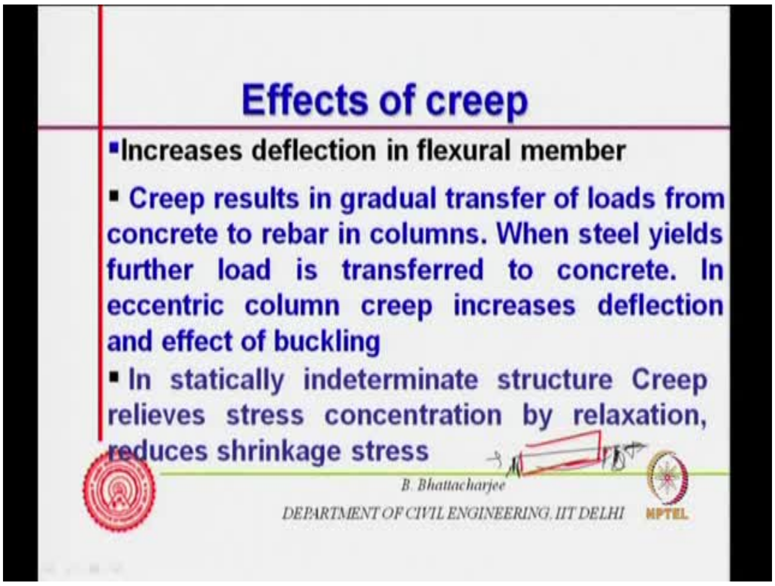

So, nothing to really specifically one good to look into, but the design E must take account of all this aspects. In the long run creep effect and so on so forth. In statistically indeterminate structure creep relives stress concentration by relaxation and reduces shrinkage stress. So, it is statistically indeterminate structure. Now, what is an indeterminate structures? You have actually restrains. Additional restrain. For example, a determinate structure you will have possibly roller and a hinge here. So, this can move, but you make again another hinge. So, two hinge here it becomes indeterminate. Therefore, it is actually restrained.

So, statically indeterminate structures are restrained, they are restrained. Now, we have seen when you apply restrain, when you put in restrain there is some amount of relaxation locker, some amount relaxation locker. Therefore, the stress in the concrete will actually reduce down; stress in the concrete will reduce down. So, it causes reliving, it causes some relives in the stress. So, when there is a you know like basically creep would have caused some short of defamation, but then this is restrained, no movement can occur.

Therefore, this horizontal movement, so additionally you will have additional force coming in. Therefore, this will neutralize the effect of, this will neutralite neutralize I mean this is just as an example, this will neutralize the effect of applied stress and relaxation will actually reduce and it will reduce stress concentration, also shrinkage stresses get reduced. You know shrinkage stress for example, if your shrinkage stress in a restrained element shrinkage cracks would be tensile because this actually, its natural position is here it you know after shrinkage it will (( )) discuss about shrinkage later on, but shirked position is somewhere there, but it is restrained. So, there is a tension.

Now, this tension gets actually relieved because of you know tension gets relieved because of relaxation. So, this actually relaxation has actually tendency to reduce all kind of stresses including in in you know in in restrained structures because relaxation occurs only in structures which are restrained, which are restrained where you know where you are not allowing any deformation to occur. So, they actually reduce down the stresses of all kind whatever their including shrinkage stresses etcetera etcetera. So, this is the first effect.

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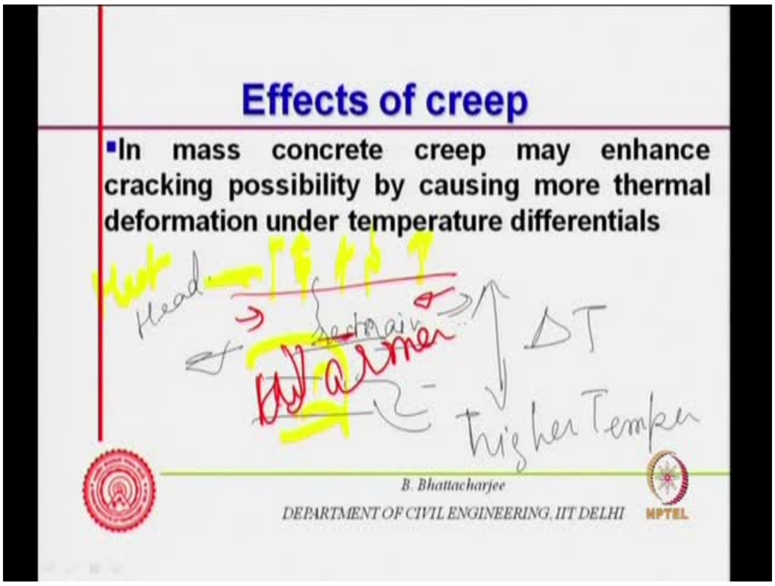

Then in mass concrete of course creep may enhance cracking possibly by causing more thermal deformation under temperature differential. Now, mass concrete the cracking comes because this is your top surface of the concrete and let us say this is your bottom concrete. Now, there would be a temperature differential if it is existing, if there is delta t, delta t exist between this one which can exist because if t could be higher, higher temperature, higher temperature in mass concrete temperature can be higher because heat may not dissipate from this portion, the heat may not dissipate from this portion, heat dissipation is difficult while heat will dissipate from this one, heat will dissipate.

So, heat dissipation would occur here, heat dissipations would occur here, heat dissipation, heat. So, heat dissipation would occur, so heat would dissipate from, dissipate from this portion while this may remain still hot. This may remain still warmer, warmer if I may put it so, warmer. So, this may remain warmer. Result is what? This will try to shrink, this will try to shrink, this will try to shrink you know this will try to shrink and if it just tries to shrink the bottom concrete will restrain it. So, bottom concrete provides a kind of restrain. So, restrain here there is a kind of restrain to that shortening.

Now, if this is happing net effect is a kind of tension, net is (( )) tension. So, the cracks can come like this. So, net effect is a tension. Now, what can happen? There is a temperature differential, there is a tension and the, there is no you know there is a tension actually occurring. So, thermal deformations under the same tension thermal deformation might try to increase. Thermal deformation might try to increase that means you know and it is again restrained at the bottom. Therefore, this might results in you know causing more thermal deformations.

So, it can cause more thermal deformation because these are it is trying to expand and you know this or rather this is trying to contract and this might try to contract further. This might try to contract further over the time period run. So, there is a contracting there as or if there is a tension it will try to, tension is trying to you know like cause deformation in a given direction. So, under same tension deformation will tend to increase, deformation will tend to increase.

Therefore, whatever the force is this is causing, this tension comes because it is restrained. So, basically this this this restrain still exists and because of the contracting forces, this may further you know like enhance the deformation. So, essentially depending upon the situation, deformation might you know this thermal deformation in case of temperature differential it might cause it to increase because crocking, cracking possibility might increase because of the thermal deformation. Now, it is actually trying to contract, I am holding it in position.

So, there is a kind tensile force acting. Now, since there is a, you know like tensile force acting which was a tendency to cause a deformation in the which is actually restraining the you know which is because of the restrained deform, restrain tensile forces there is a restrain. So, the tensile force comes and concrete can crack under those tensile loading.

Now, when you have the sustain this, condition is sustained and no crack has occurred. Actually, further contraction may occur because of the tendency of the contraction maybe there because of the, you know because of the, because of the creep itself, the it may actually cause under more tempt because sustain temperature differential this effect may get enhance and if it is not cracked earlier might crack later on. So, mass concrete this can actually.

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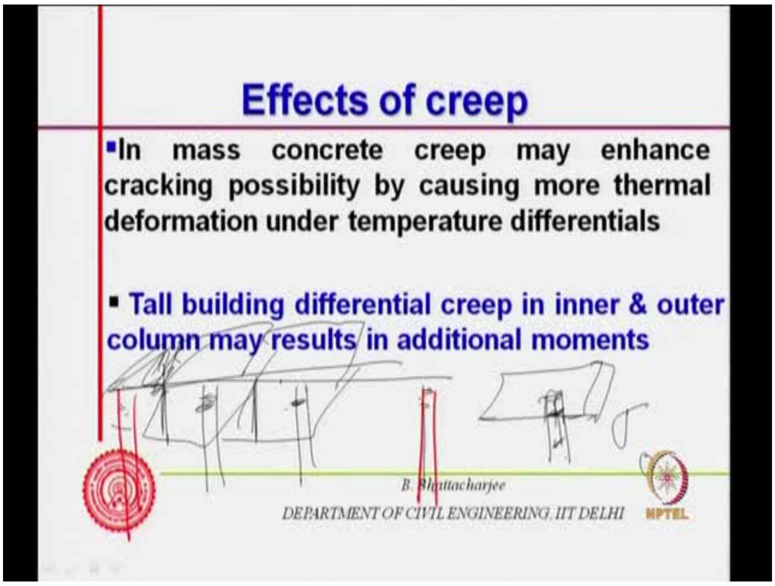

Tall building differential creep in inner and outer column may result in additional moments. How does it do? In very tall building this is your outer column and this is the inner column. So, outer column let us put it red, outer column is here by red, outer column here is red and this is inner column. So, this is, this is inner column you know this is actually inner column. So, if I look at it my slab is something like this. Now, the load that would be shared by this column would be coming from this portion of the slab. Load will come from this portion of the slab while this column will share more load, you know internal column actually shares more load.

The contributory area scattering to the inner inside column should be more, so here actually it has to share. So, this contributory area that from which the load comes into a inner column would be more you know it would have to support more whereas outer column only half of it comes, you know from one side. That means this is loaded at a higher level. So, sigma 0 is high and we have seen all our definition was for unit stress. So, if the stress is more creep strain, final creep strain will be more.

So, because our definitions were specific creep etcetera etcetera all were for unit stress, creep function though all for unit stress. So, you want to find out the deformation in the long run, more the initial stress level sigma 0 more will be the creep deformations. So, this will be deforming more. So, creep, differential creep. So, this will have more creep than the peripheral column, you know this will have more more load sharing therefore more creep than this one.

Now, what is this result? If it is a short structure not a very tall structure it it may not have any effect, but if it is a very tall structure, the column length is very very high. So, this might result in overall shortening of the column you know which may be appreciable, this effect is not seen in relatively shorter building. Only in tall building say 30, 30, 40 storey building and so on and so forth. One if calculates out the difference in the creep deformation over the long run from internal column and external column there will be some differences.

Now, when you have settlement, differential settlement between inner and outer column this settles more than this, this will actually induce some kind of stresses you know 6 (( )) over l square or whatever it is because of the settlement. So, delta 6 (( )) delta over l square so you know if the delta is appreciable it may induce additional stresses. So, this is one effect, in tall building this is taken into account 50, 60 storey building or similar building, 40 storey building one would like to take effect of the (( )) of 50, 60, 45, 50 buildings, so (( )) building where or similar kind of buildings this might affect might be there.

Thus, shrinkage also does effect in the similar manner, but we can look it, look at it in a different manner. Loss of pre stress is other effect; pre stress is lost in many ways actually. Pre stress loss occurs in many ways. First of all, first during slippage can occur you know, you are pre stressing post tension let us say the system where you have pulled the wire and anchored it. Now, there can some losses right here in the beginning.

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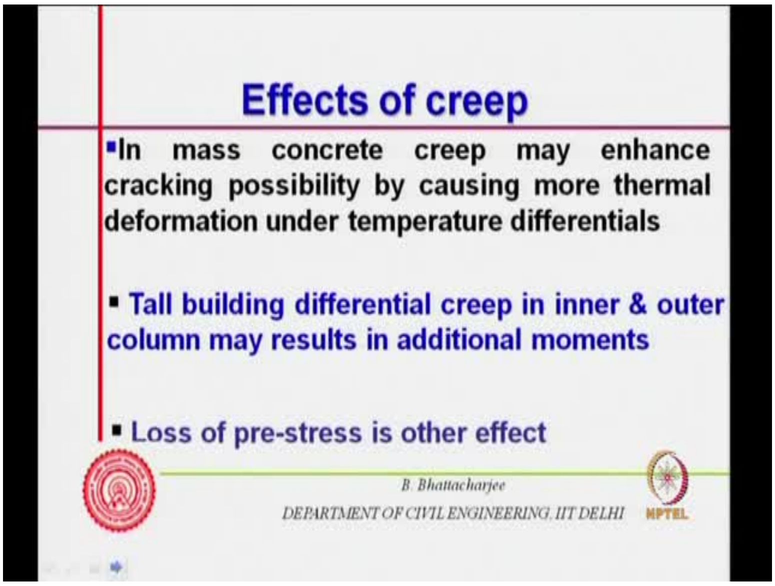

So, there can be loss of twisters because of slippage of the twisters in wire through the anchor and all that, but creep does cause loss of twisters due to relaxation that is what we have seen in the last lecture. Creep causes you know loss of twisters due to relaxation effect. So, therefore that is what we have seen. Even creep of steel is important here because creep is tension so, but it is restrained, its deformation you know its length is fixed. Now, due to relax you know creep its natural length will actually tend to increase, but you have restrained it from expanding further.

Therefore, there will be some amount of relaxation. So, creep of steel can result in loss of twisters, but we are talking of loss of twisters due to creep of concrete and that we have seen in the other day that relaxation will cause loss of twisters. So, these are the effects, some of the effects and some of the effect of some of the effect of creep on a structure. Now, creep is also related to fatigue which I just mentioned somewhere in the sixth module at the end of you know fourth fourth lecture, but let us see how it is related.

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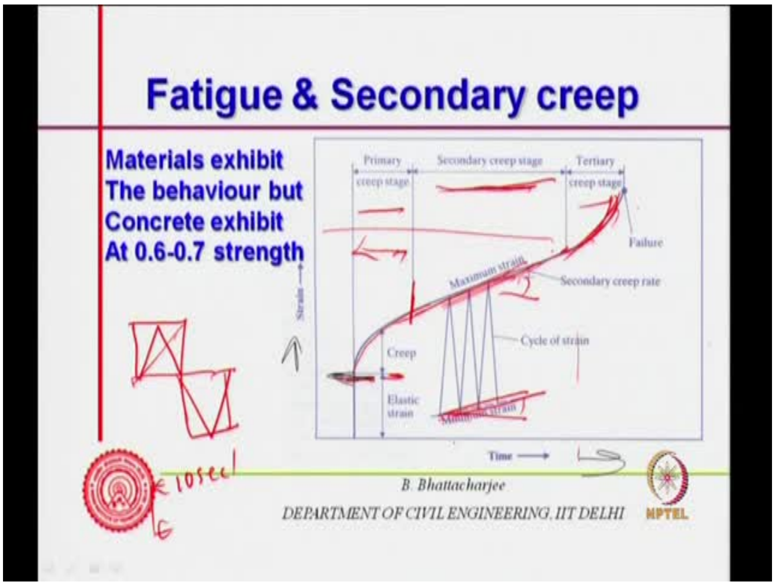

This is for almost all material, many material show this kind of behavior. What you said is if you see this is time, this is strain and after loading so you have loaded, this is elastic strain, this is elastic strain. So, this is your elastic strain. Remember, then this is the creep, but beyond certain stress level this goes on increasing, we have seen in case of concrete of course in normal lower load level it actually tries to be asymptotic, but anyway the slope has in many material slope will get reduced and it is like a linear constant rate increase and as you go further high, at high strain at very high strain you know long run at high strain it may actually result in, it may actually result in failure because suddenly there may be lot deformations.

So, rate my increase again. There is a high rate here which is tendency to reduce and here low rate tendency to increase and somewhere here it may, failure may occur. So, failure can due to creep at higher level of load. Now, this is called elastic strain, this is called primary creep up to this before the linear range starts this is called secondary creep and tertiary creep again it increases non linearly and the failure occurs. So, tertiary creep stress, secondary creep stress and primary creep stress and concrete also shows this behavior about 0.6 to 0.7 or 60 to 70 percent of the strength.

Therefore, you know where to operate on that is one thing. Therefore, primaries and secondary creep etcetera and tertiary creep that is how we distinguish. So, concrete also exhibit this around 60 percent to 70 percent of the strength, but interestingly you see this as you go repetitive loading after each step of loading because it is sustained, it is you know time it is also sustained, I mean you can assume, you can assume. Supposing my cycle time is very high, frequency is very low, frequency is low that means one case I apply, let us say 10 cycle per minute. Let us say for the just for the sake of understanding or 10 hertz, 10 cycle per seconds that kind of a reversal of stresses, stress reversal I have a cycle of stress and I just you know I have a cycle of stress and let us say one cycle of stress going to maximum compression to tension again this.

Let us say finishes in constant let us say or even (( )) or whatever. It is rectanglur I am showing, but it can be triangular, triangular or something of this kind some sort of cycle of stress I am applying. Now, you see this let us say is 10 seconds then think of this being 10 hours or let us say 10 years. Now, one cycle in 10 years means there is constant load is there, load is sustained, but the value is changing, value is changing. So, you know fatigue is a case reversible stresses occurs at a very fast rate, cycle time is low. But if the cycle is infinity it is actually sustained loading, if cycle time is infinity that is very long time to complete the cycle practically my load is constant. Therefore, that is actually a sustained loading. So, there is a relationship between sustained loading and fatigue. So, when I have reversal of stresses so it goes to a, you know it goes to minimum, but then the load is still sustained, it is not gone away.

So, when I come back I do not come back to, I do not come back to again this point, but I come back somewhere above because load has being sustained for certain period of the second cycle. So, cycle time is less here, small you know and so frequency is cycle time, time period is small. So, one over time period frequency is very high. So, very high, low frequency, extremely low frequency is 0 frequency is sustained loading. Low frequency 0 frequency is sustained loading, high frequency is kind of fatigue, so repetitive reversal of stresses. Now, next time it comes here.

Then again I go back, come back it comes here. It does not come back to its original strength of the strain actually. You know it will not come back to your original strength of the strain itself, so basically because it is under sustained loading. So, slope of this line is same as the secondary you know slope of this line you know it is somewhat related, the slope of this line is related to secondary creep strain. Therefore, one can relate the fatigue strength or number of cycle it can withstand, number of cycle it can withstand, number of cycle it can withstand you know to the secondary creep rate, secondary creep rate. So, this is the secondary creep rate strain per unit time if you look at this strain per unit time.

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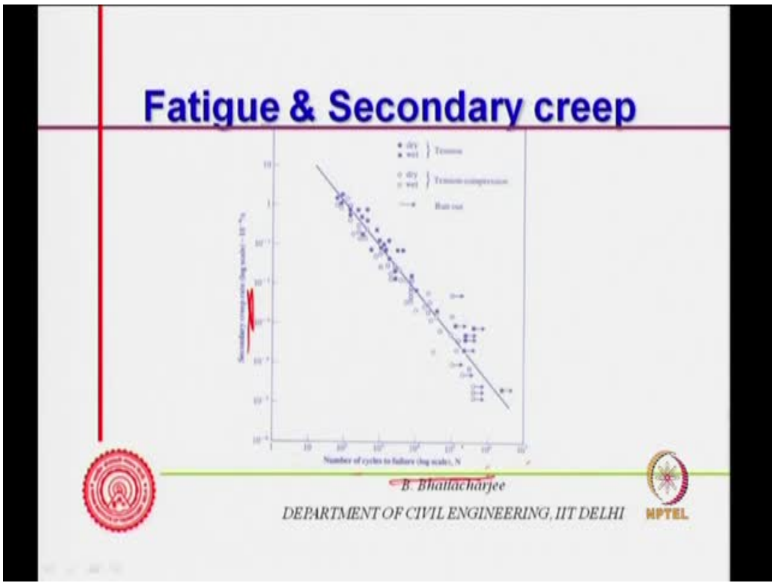

So, one can relate this and this is what has been done. Experimentally people have tried to find out for concrete as well tension or or tension and compression for various kind of materials one can think in terms of this. So, numbers of cycles to failure is in terms of log scale 10 to power 7, 10 to the power 6 etcetera etcetera that is related to secondary creep rate in log scale, in log scale again secondary creep rate. So, you know it is per unit time, it is per unit time. So, if it is seen that when your secondary creep rate is high secondary creep rate is high the number of cycle is the failure to the cycle is low. So, it is related to, linearly related to one can approximately linearly related to the number of cycles at failure, number of cycles such failure, so this is related the secondary creep rate. So, creep and fatigue are somewhat related.

We did not discuss this, there is something called Miner's rules in fatigue, although we are discussing creep, but I like to just come back and discuss about this. This you know it is a kind of damage theory, cumulative damage theory. So, let us say N 1 is the you know number of cycles to failure, number of cycles to failure, number of cycles to failure at certain stress level, at certain stress level you know reversal of stress level, certain stress level, stress level plus reversal. N 2 is the number of cycles to failure in another stress regime if I may say so. In the first one I am going to some level of stress and coming back, in the second one possibly I am going to compression and so on so forth.

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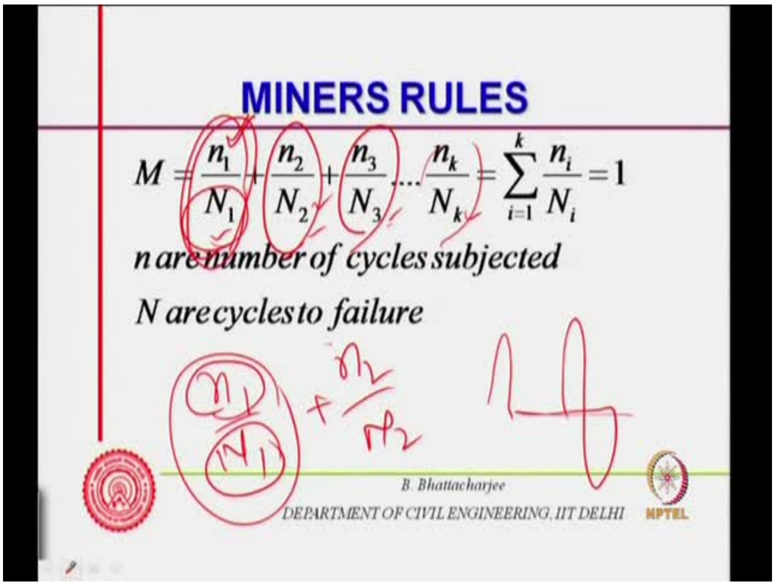

So, there is regime could be different and it requires N 2 failure, N 3 is similarly another regime of another you know cycle of stress, the the amplitude of the stress could be different, time period could be different and corresponding to failure is this. Now, I have subjected, so cumulative damage supposing the structure or element of the structure is subjected to N 1 number of cycles in a particular regime of stress reversal whose number of cycles of failure is capital N 1 then this is the damage. So, damage is n 1 divided by N 1 where this is the number of cycles till failure and this is the cycle actually I have applied. So, the fraction of damage is given by this. Now, the fraction of damage for another regime is this.

So, when this sum total of k such regime is equals to 1 we say that failure is occurred. So, therefore is you know this is Miner's rule. So, fraction we can cumulate the damages. This is the damage, this is another damage and this another damage in another stress and this is another damage and so on so forth. So, when sum total are all total of fraction of damage as slow, as soon as it become 1, if as long as it is less than 1 no failure, the moment it is 1 actually the failure would occur. So, you know this is my what is Miner's rules. So, when cumulative damage is equals to 1 you know the failure would occur. Now, what is relevance actually? What is relevance? How it is useful? Supposing, I know I have subject you know my my let us say in a bridge, let us say in a bridge you know, I know the vehicular load, it is patterned, was available now till date and N 1 number of cycles have actually has occurred under that kind of load.

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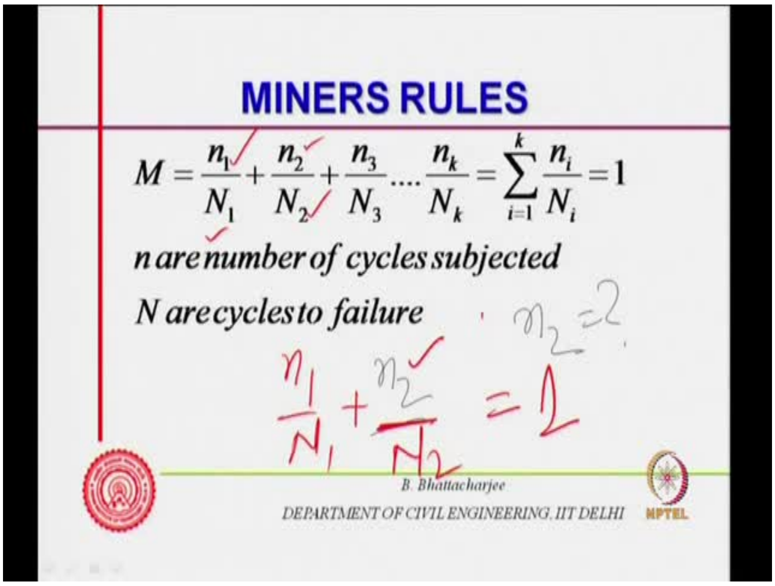

Now, the certainly the load has changed, the pattern as changed and you know corresponding to this failure number is N 2 and N 1 is a number of cycles for failure in the so far whatever has been happening. So, now I want to find out how many years or how many number of cycle it can be withstand. So, what I know is n 1 by N 1 is known to me and plus n 2 which is mine unknown n 2 divided by, divided by N 2; this must be equals to 1 for failure. So, n 2 is unknown, n 2 is unknown and that I should find out. So, n 2 is actually unknown. So, I can find out the number of cycles that it can withstand in future. So, residual number of cycle or residual life if I may say or residual damage that is possible you know or residual life that is possible under fatigue situation like I can really find out from this. So, this is Miner's rule which I thought should be important for us. So, this once can be Ns, this Ns values can be find out from S N curves, from S N curves from you know strength versus number of cycle curves which we have talked about. Alternative approach is to use secondary creep rate that is a measure of partial damage. So, this once can be Ns, this Ns values can be find out from S N curves, from S N curves from you know strength versus number of cycle curves which we have talked about. Alternative approach is to use secondary creep rate that is a measure of partial damage.

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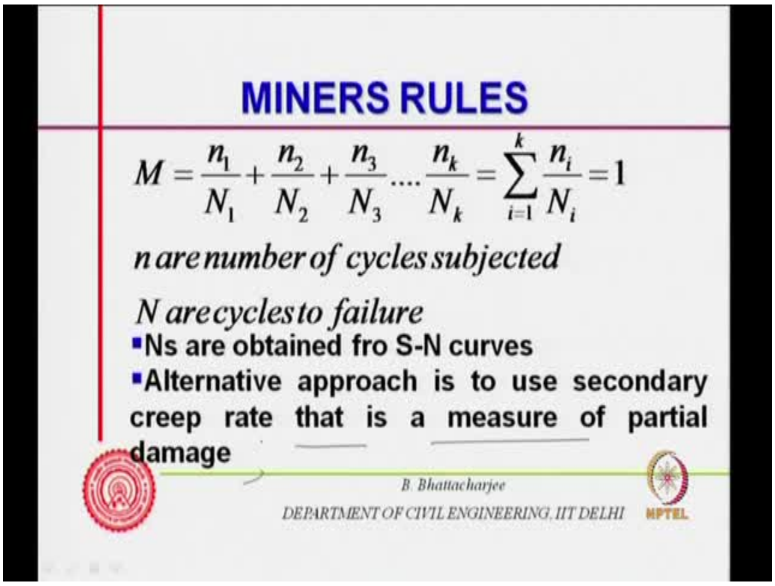

So, secondary creep rate we have seen where secondary creep rate if it is known then number of cycle depending upon the creep rate, the number of cycle it can actually withstand that we can find out. So, under a give load what is the creep rate that if I know under a given static sigma 0 what is the creep rate for that material if I know, secondary creep rate that can be related to N number of cycle N capital N that can be related to capital N and then one can find out. So, this is Miner's rule.

So, this is related to you know creep and some related aspects we discussed. So, this is all about creep. We can now just introduce the shrinkage for this class while we will discuss it in details in the next lecture, we will discuss it in detail in next lecture. Now, why does shrinkage occurs in concrete? So, so far we have seen deformation is increasing, so it is compression, it is compression the creep such under sustained loading it will further differ. Now, why creep and shrinkage is put together? You know both are related to gel force and perhaps mechanism one can look into movement of water from the gel force.

We have looked into creep and we said that it is essentially movement of water, inter layer water and so on so forth, either within inside relocating itself, therefore the bound can get disturbed and slippage of can occur and then it can reestablish itself and so on so forth. That is what we have looked into. Now, of course it is somewhat similar to you know long term consolidation in clay the creep because consolidation takes very long time. So, here the load immediately there will be some consolidation, but the water moves out and further some analogy, some analogy. Now, shrinkage is also movement of, related to movement of water from the gel system and that is why they are studied together, they are put in the same module.

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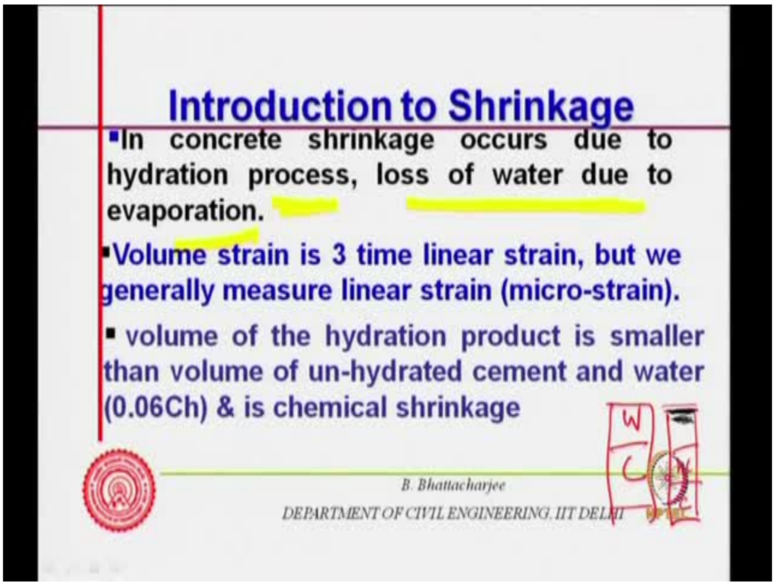

So, when does, why does shrinkage occur, when does shrinkage occur? First of all in concrete shrinkage occurs, in concrete shrinkage occurs due to hydration process loss of water due to and also due to loss water due to evaporation. So, hydration process causes some amount of shrinkage which I have, we have seen it somewhat we will be you know looking at it again and evaporation loss of water would occur both in plastic state of stage of concrete and later on the drying stage of the concrete as well. So, first is the plastic stage that would be some evaporation because the bleeding water, bleed water might come at the top and subsidence may occur, plastic settlement might occur and obliviously there is also a kind of volume change and then later on also your portion can occur. But right in the beginning because of hydration process itself the volume of the hydration product is lowered than the original volume, there is some shrinkage which occurs. So, that is what it is.

So, volumes, generally there is a volume strain. It is not actually linear strain, it is essentially volume strain, volumetric changes are occurring. But we measured the linear strain and you know the shrinkage when you talk of we talk in terms of linear strains that is in micro strain 10 to the power minus 6, order of 10 to the power minus 6. So, we measure it that way, that is what I said volume of hydration product is such very in the beginning, in the beginning volume of the, right in the beginning of the hydration process, right in beginning of the hydration process volume of the hydration product is smaller than the volume of the un hydrated cement.

We have seen that while we looked into the cement hydrated process and we actually calculated that as 0.059 C h or 0.06 C h if you remember. And that is what is chemical shrinkage. So, what is it actually? Volume of the, you know if you recollect, if you recall back this was your volume of un hydrated cement you know un hydrated cement basically C plus W and finally, there is a reduction in the volume, finally there is a reduction in the volume, there is some un hydrated cement, there is some hydrated cement and there were you know, all those put together, but there can be some loss of some volume reduction was very much there and when it you know what we have seen earlier.

There is some reduction in the (( )) volume and this volume reduction, this reduction in the small volume that is actually chemical shrinkage, that is chemical shrinkage. So, there are several components of shrinkage. This is chemical shrinkage. So, chemical shrinkage actually one can estimate how stressimatically, using the stressimetry you can actually find out the product that would be formed from different compounds of cement C 3 A, C 2 A, C 3 S, C 2 S. All major compounds of cement or you can have other smaller (( )) formation and so on, which actually causes a volume expansion, right in the beginning you know within the structure. So, total volume change actually you can find out and original volume of cement and water is known because specific gravity of cement is known, water is known. So, therefore what is the reduction in volume one can find out because of the chemical reaction itself and that is called chemical shrinkage. So, this can be estimated, this can be estimated, this can be estimated, chemical shrinkage can be estimated.

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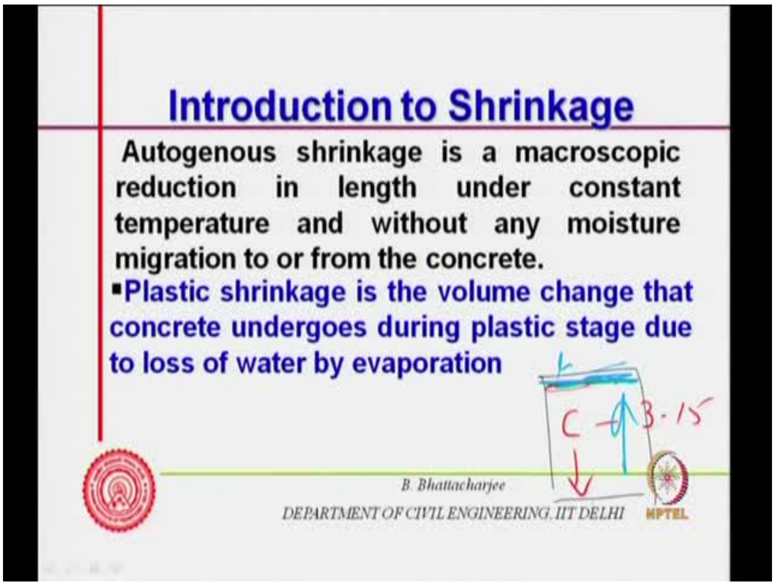

Then there is something called autogenous shrinkage. Now, so actually some volume change occur to the even even this is also relatively early stage in a macroscopic, is there a macroscopic reduction in length under constant temperature and without moisture migration to or from the concrete. So, if you seal a specimen so that no water can go out of it, no evaporation, nothing is occurring and it is maintained at constant temperature. Also then there is some amount of, you know volume change can occur, volume change can occur and that is called autogenous shrinkage because a plastic material is now changing into a solid material. So, there are some volume change associated with this and this is you know it is changing into a solid material. One is a chemical reaction, other is a plastic material changing into a solid state and therefore, there is some amount of volume change.

So, you have even if you seal it, do not allow water to go away, no (( )) loss, but these are these are more of you know, so this would, still volume change will occur in paste and they can result in some sort of cracking and all that as usual scenario. So, this is autogenous shrinkage and chemical shrinkage and plastic shrinkage is also a terminology used quite often because for practical use, practical point of view understanding point of view chemical autogenous shrinkage they are very useful. Then when it comes to practical point of view you see the volume change that is occurring during the plastic stage is the plastic shrinkage.

So, it is the volume change that concrete under goes you know plastic stage and usually that could be due to loss of water, loss of water by evaporation. So, what you have? You will have something like this. This is your concrete and you know because specific gravity, specific gravity of cement is 3.15, so it will have a tendency to come down and water has the tendency to come up. So, you will have water, water coming in you know you will have water, water coming in here, water coming in here and accumulating bleed water and if it evaporates or even otherwise there is no bleed water, but to some water evaporates from here, more water will tend to move upward and therefore, the solid will subside, settlement would occur.

Therefore, this there is a volume change associated with this because of loss of water by evaporation and quite often this is actually referred to as plastic shrinkage, plastic shrinkage. Now, the settlement had got a role in fact it can cause cracking. Plastic settlement can cause some sort of cracking, I think mentioned some day earlier, I mentioned some day earlier.

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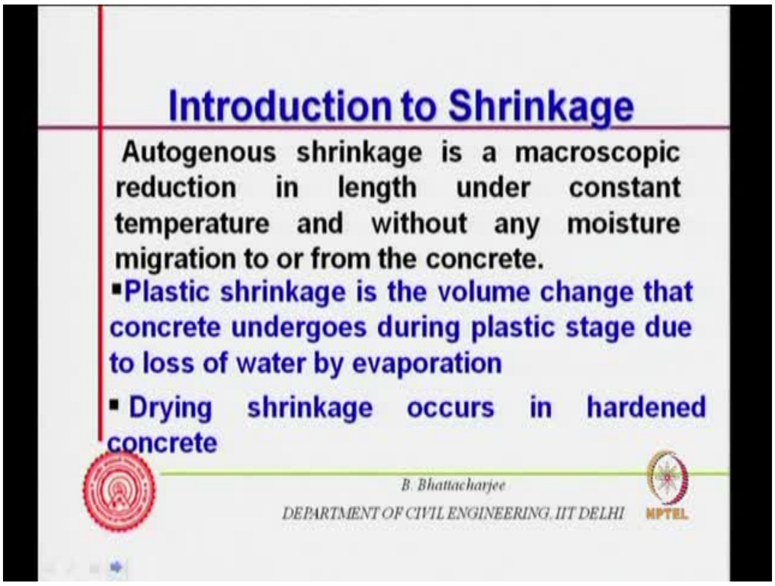

Then drying shrinkage, drying shrinkage occurs in hardened concrete as it is drying. So, once you are solidified and now it is hardening at this stage if there is evaporation loss the actually loss of water from the gel system can cause shrinkage and this is called drying shrinkage. So, later stages drying shrinkage would occur, drying shrinkage is occur because of the evaporation loss, you know loss of water due to evaporation and this can continue for months 1 or 2 months in fact and within 6 months of course by and large this will be complete and this is one of the reason, this is a reason for cracks in many thin sections. This is a reason for cracks in many thin sections.

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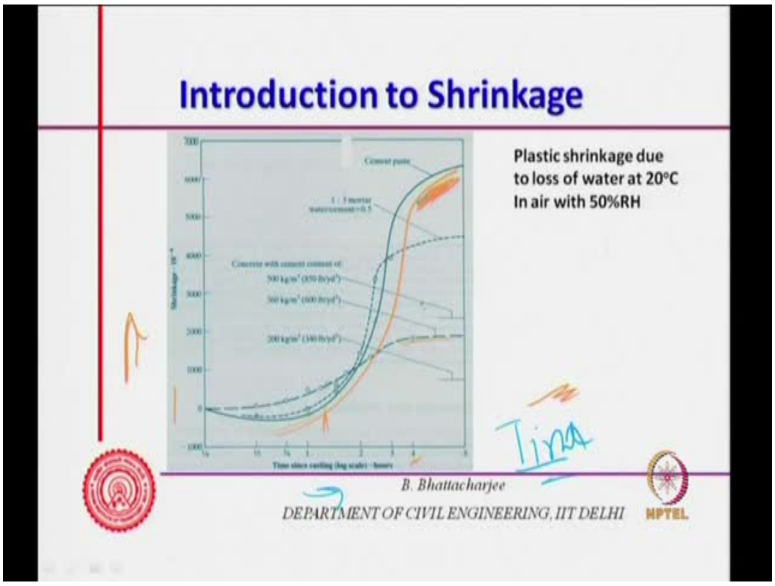

So, let us see plastic shrinkage more, plastic shrinkage more, plastic shrinkage is due to loss of water at 20 degree centigrade and 50 percent (( )) this diagram shows this. This for cement paste and you can see in the x axis is time in hours. So, time along this axis, time along this axis, time along this axis and time along this axis, okay? So, time is along, time is along this axis, alright? And time is along the x axis and y axis I have shrinkage, this is for paste, this is for cement paste. So, cement paste shows lot more you know it is about 3 4 hours, so lot of shrinkage it, it would show.

Initially it is not very much, in fact there can be small expansion also for a (( )) and all that formation and this dotted line shows large quantity of cement in case of concrete. Now, concrete with 500 kg of cement is somewhere there. This is for 1 is to 3 mortar. So, that means you have lot of cement here. So, cement paste need cement paste shows maximum, cement mortar shows somewhat lower and this is with 360 kg meter cube of cement. So, higher the cement content more is this you know shrinkage during the initial stages itself. So, this is plastic shrinkage stress test you know sub shrinkage as has been seen for paste mortar. So, aggregate has a tendency to cut it down. Aggregate has a tendency to cut it down. So, this is plastic shrinkage.

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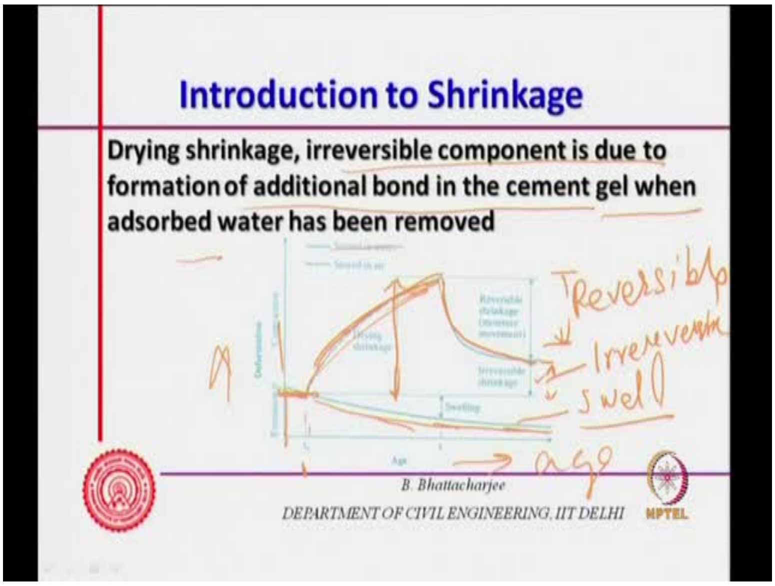

Drying shrinkage, there can be some irreversible component in this. Let us see what is drying shrinkage. See, if this is the, this is again the age, this is the age, this is age and this side is deformation, this side is deformation. So, you have you know like this is your t 0 and from this point you started drying. So, this is stored in air and you will find the strain deformation increases you know deformation shrinks. So, deformation has increased one, you know shrinking or reduction we are calling it as this side while swelling if you constantly keep under water this is, it will swell actually.

So, swelling would occur, you know swelling would occur under constant water condition while if you are drying it will go somewhere there. So, this is the drying shrinkage, this is the drying shrinkage and then supposing you put it wet again, so therefore, then it will come back. So, this is reversible shrinkage you know so you have moisture coming in, but it does not come back. So, this is the sum amount irreversible shrinkage. So, this is reversible, this is reversible and this is irreversible shrinkage, irreversible shrinkage. So, with age this is elongation, this portion is elongation, this is contraction. So, if you are dry, if it is dry then there will be so t 0 drying has started we find that it increases in this manner, but there is some amount of irreversible shrinkage, everything do not come up because you know reversible shrinkage moisture comes in and then reestablishes some of this.

So, irreversible component is due to formation of additional bond in the cement gel when adsorbed water has been removed. So, when you have removed the adsorbed water new bonds have been formed like we said when creep you know, so new bound would have formed, where water has gone the bonds have gone, Van der Waals type of bonds have gone, but some relocation would have occurred, a new bond would have formed. When you add water this is, this takes wherever there is some bond some bond might form, but some cases where new bound is formed that leads to irreversibility. This leads to irreversibility.

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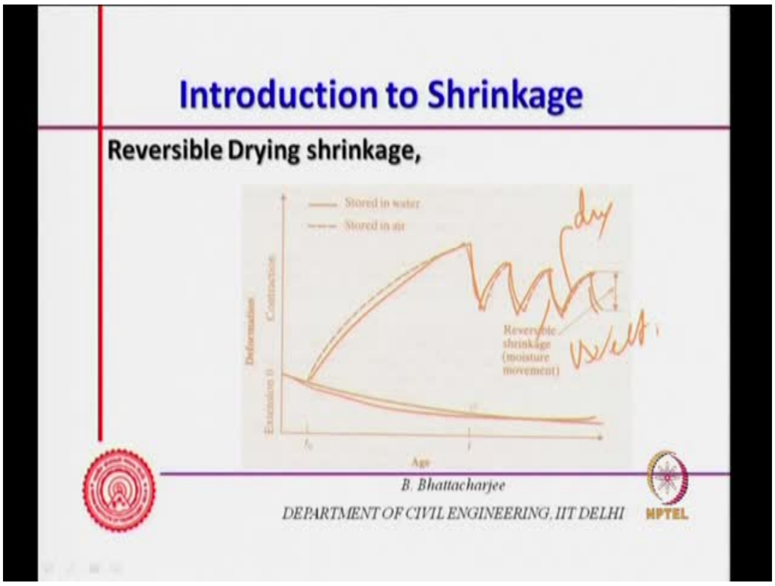

Then we have situations of reversible drying shrinkage, reversible drying shrinkage. So, you can see that this is the drying that is occurring, this is swelling, wet saturated and then again I have actually wetted, dried, wetted, dried you know and so on so forth. So, this is drying, this is wetting. So, it will show a cyclic behavior, it will show a cyclic behavior, it will show a cyclic behavior. So, this is what it is.

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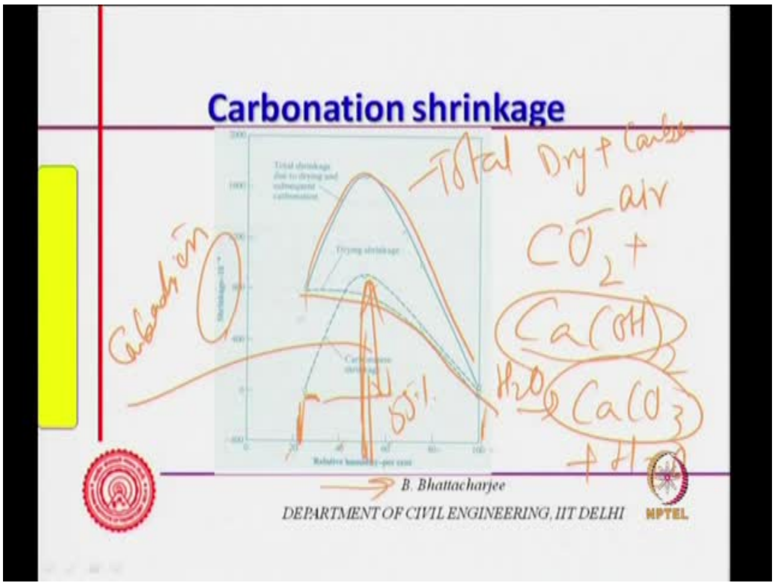

Now, carbonation shrinkage, carbonation shrinkage occurs. Carbonation is the phenomena where carbon di oxide from the atmosphere reacts with calcium hydroxide to form actually finally, calcium carbonate plus H 2 O, we will discuss this a little bit later, more in the context of durability and it is this product occupies less volume than the original calcium hydroxide. In presence of water all this happens, there is a shrinkage associated with carbonation process and you know if you have measured it total shrinkage is this one, total shrinkage this total, drying total, drying plus carbonation. And drying alone if one measures would be something like this.

Relative humidity percent is shown 20, 40, 50, 60. So, as you increase the volume change occurs like this. So, this shrinkage, so net difference is the carbonation shrinkage. Therefore, this is the difference, this difference is drawn here as carbonation shrinkage, carbonation shrinkage. So, carbonation shrinkage and you can say it is maximum around 55 percent relative humidity. So, carbonation occurs maximum at 55 percent relative humidity or 50 to 60 it is at very high level, low humidity does not occur, high humidity does not occur because presence of moisture is essential and presence of air is also essential.

So, at very high humidity presence of air is low, this reaction will not continue. In fact I should rewrite here H 2 O. So, in presence of H 2 O this will occur and this comes from air. Therefore, if it is fully saturated less of carbon di oxide will be available in the air and if it is fully dry again relative humidity is low, less of carbon di oxide. So, this is called carbonation shrinkage. We will discuss about this later. This is of course, not very important, it is just important while the other two are very, very important and we will look into those and one is to estimate them because shrinkage can cause cracking inside that type of structures.

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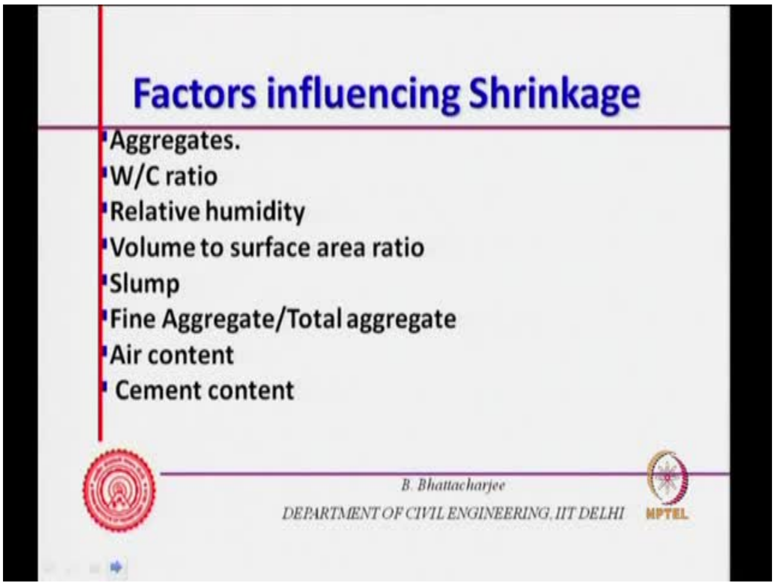

So, that is what it is, so we have introduced the shrinkage that is which are the chemical shrinkage, autogenous shrinkage, plastic shrinkage and then we talked about drying shrinkage, carbonation related shrinkage. So, next class we will look into factors which will affect the shrinkage aggregate, water cement ratio, relative humidity, volume to surface area ratio, slump, fine aggregate, total aggregate, air content and cement content. The amount of shrinkage due carbonation is relatively less.

So, we will not discuss much about it. I mean this is not universal, but the drying shrinkage really can cause problem. Carbonation shrinkage do not seriously cause problem, not really cause serious problem, the surface concrete might shrink, but depending upon the extensities it may cause cracking, but very rarely. This is not usually seen. Carbonation has got other issues, so we will look into this. But drying shrinkage and it is how, what factors affect it like this factors we will discuss in details in the next class.

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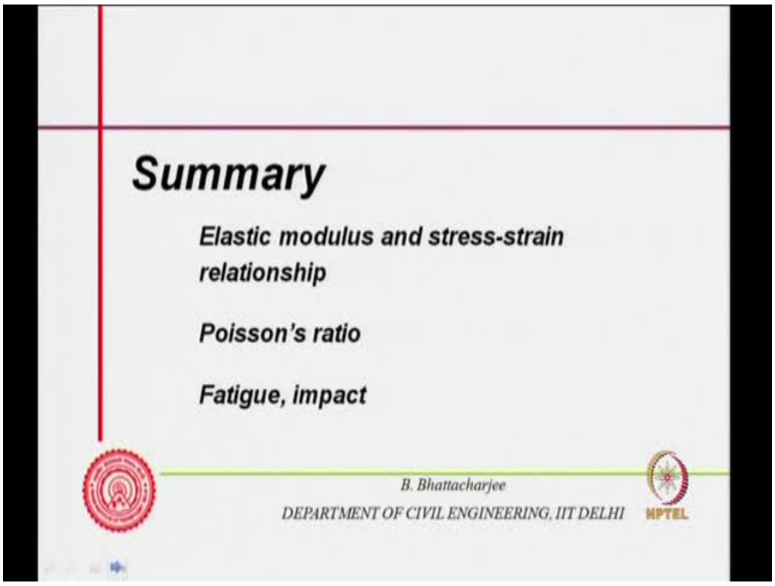

So, let us summary is this. What if, what we have seen in this class is, actually what we have seen in this one is summarized.

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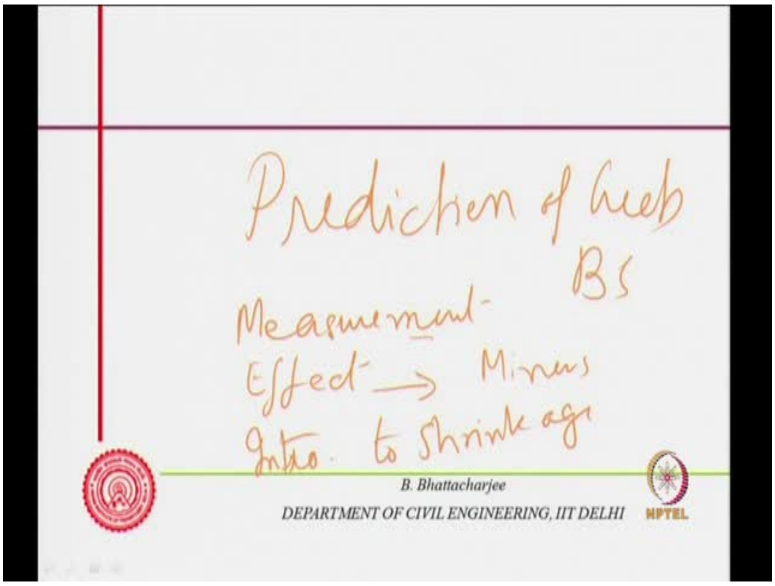

To summarize this actually, first of all we looked into prediction. Predication of creep B S, then we looked into measurement, then we looked into effect and in the process of course we looked into relationship to fatigue, Miner's rule etcetera etcetera, and lastly introduction to shrinkage, into to shrinkage. So, this is what was this class related to. So, this of course, will be our discussion on creep finishes, but we will continue to discuss shrinkage in the next class. That is for the day that is for the you know this lecture.

Thank you.