Concrete Technology

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Lecture -27
Creep of Concrete

Welcome to module 7 and module 6. We looked into the strength properties or related strength related properties of concrete, and this in this module 7; we shall be looking into creep and shrinkage of concrete. Other two other important properties in or other behavior of concrete and in the first lecture will start with creep.

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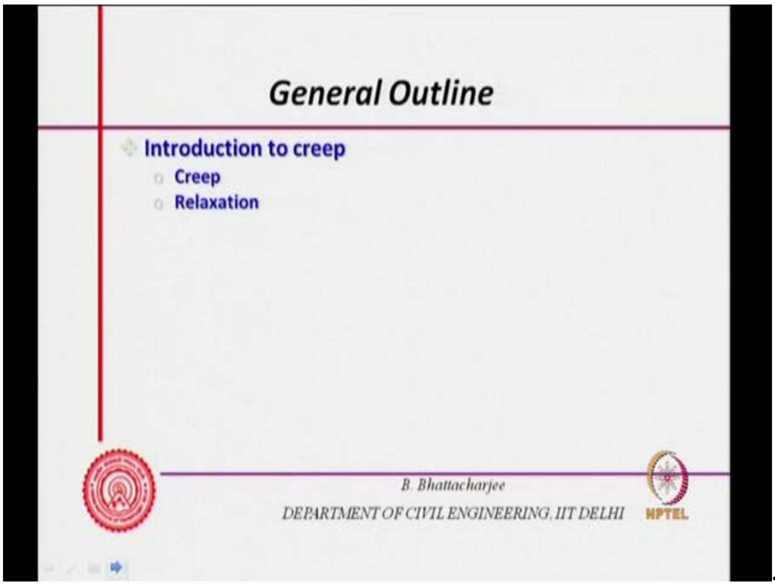

The outline of this lecture is, first we will talk about or other we will introduce creep, the some creep call relaxation. We will also talk about that mechanism of creep as much as possible. Effect of various factors aggregate modules of elasticity, temperature and etcetera and we will look into part of the prediction, which would continue to the next lecture as well.

So, let us see what is creep? Now, you know in material science, creep is the tendency of the solid or if any solid, material to move slowly or deform permanently under the influence of stresses. You know, so basically, it has you know most many materials have tendency to move slowly or deform permanently under influence of stress.

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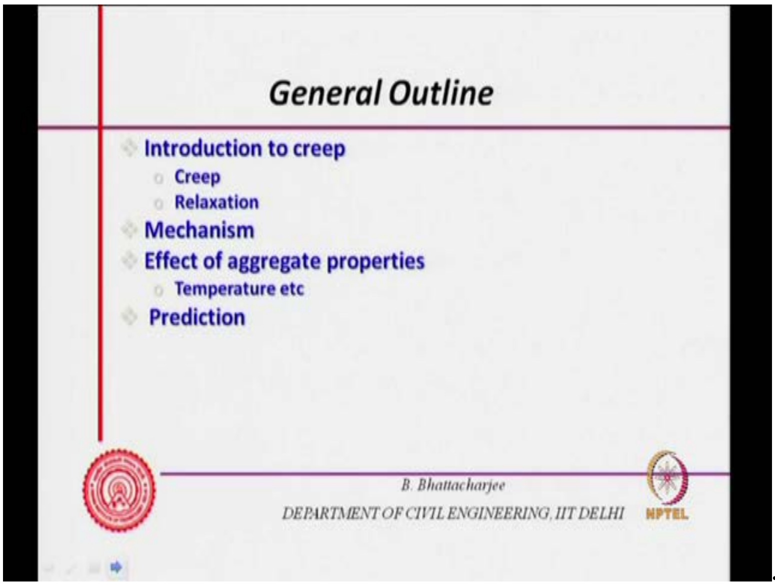

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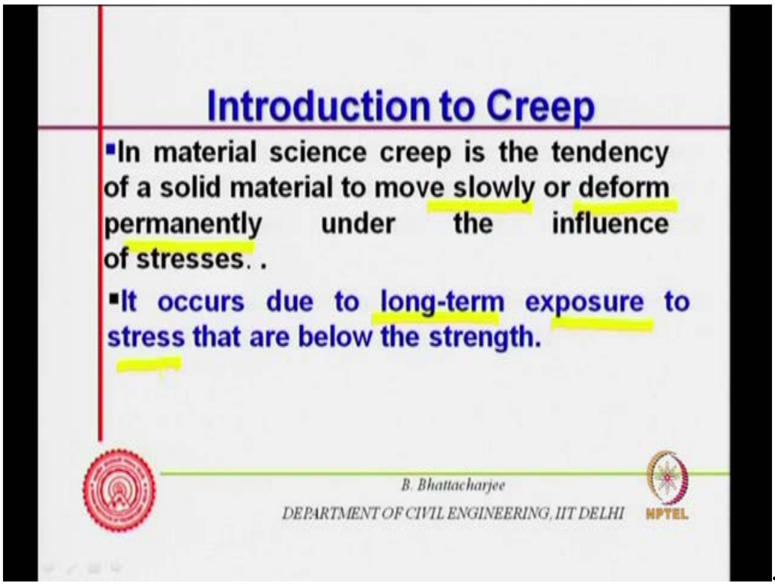

Now, metal exegetes this under certain conditions. Polymers also exegete this, and of course concrete does. Therefore, it what it is means is that it occurs due to long term exposure to stress and obviously, they will below the strength because you know it will not fail, so below that, they will delta deformation. Long term, if you expose them to long term stress, that means stress you have and you keep it, maintain the stress, it would show deformation moves slowly or deform permanently.

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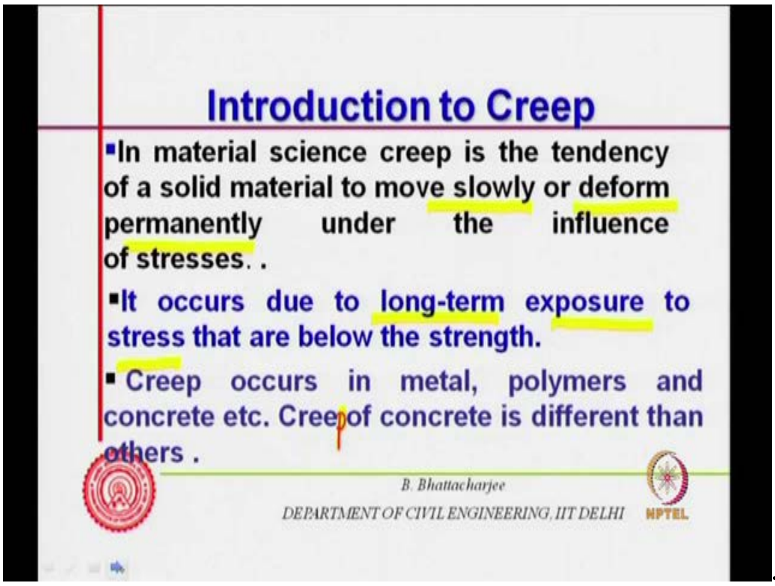

So, therefore that is what creep is. Creep occurs in metals, polymers and concrete. Creep of concrete is different than of course others you know creep of concrete is different than others mechanism are different because the materials themselves are quite different.

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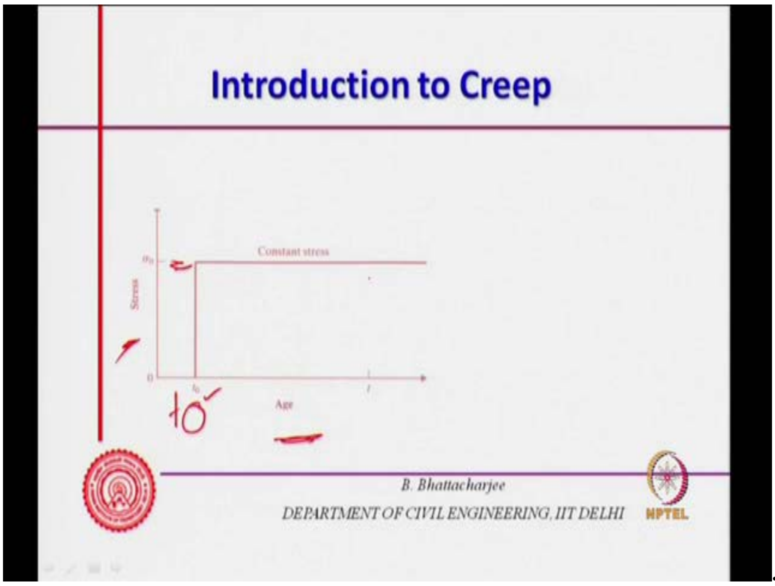

So, let us see supposing I have a concrete, and I apply if stress as some times t 0 as shown here. This axis is stress, this axis age and put it to some value of sigma 0 the stress level, and maintains the stress constant. Therefore, sustain loading, you know kind of sustains stress, so expose it continuously, continuous exposure to a stress. Let us see what happens sustain stress as we are applied.

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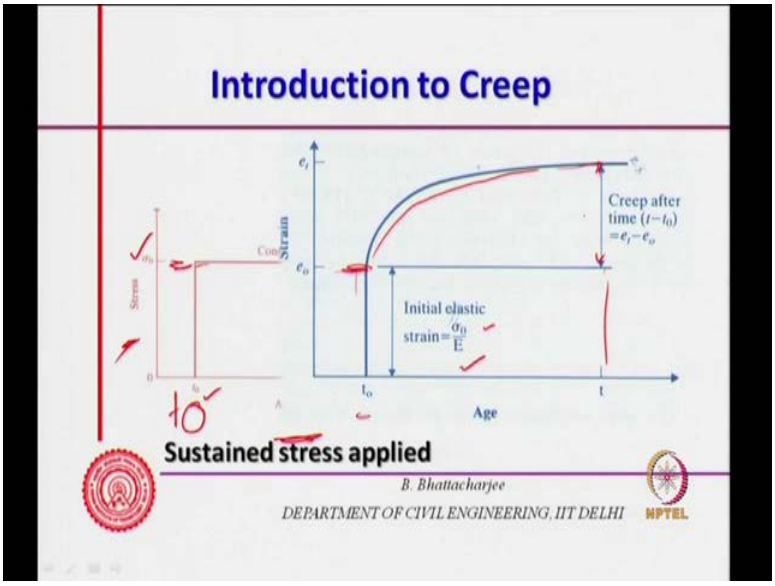

Then, at this, you know same time t is 0, the strain would be elastic strain because instantaneously, there will be elastic strain due to this. So, there will be some elastic strain because I have applied this stress. So, initial elastic strain will be given by this sigma 0 divided by module of elasticity of the material. As the time progresses, you find there is some form of deformation occurring. If you consider the time t, you know when I have sustained the loading as we have seen; we have sustained the loading t n beyond. So, upon t, you find some additional deformation under this constant or additional strain under the constant, sigma 0 is been observed. Sigma 0 you have not changed, but in time you find there is additional deformation strain.

Therefore, the creep at these point would be defined as strain at e t, which is the sum total of this. At t, it is sum total of e 0 plus the creep. So, therefore, e is e t minus e, so that is what creep strain is after time t minus t 0. So, that is what is creep concrete exhibits is behavior many other material does, but concrete does. That is what is of our interested movement. So, that is what it is. So, this resulted in strain.

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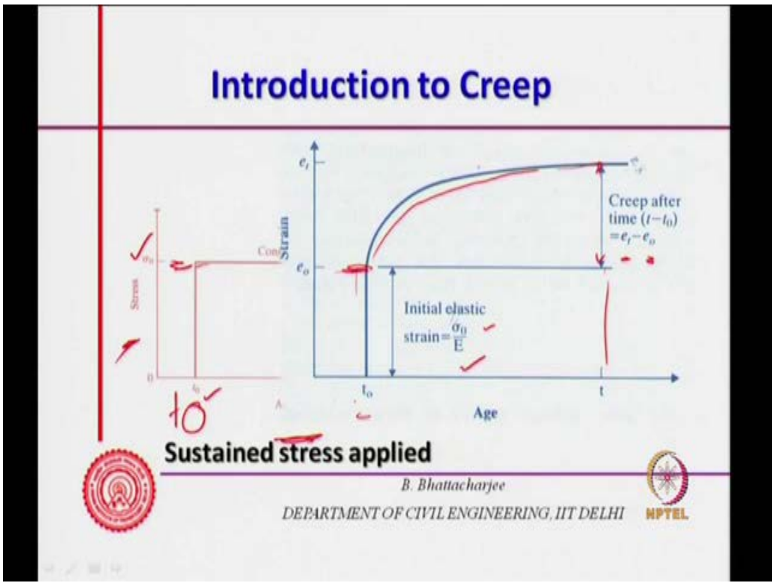

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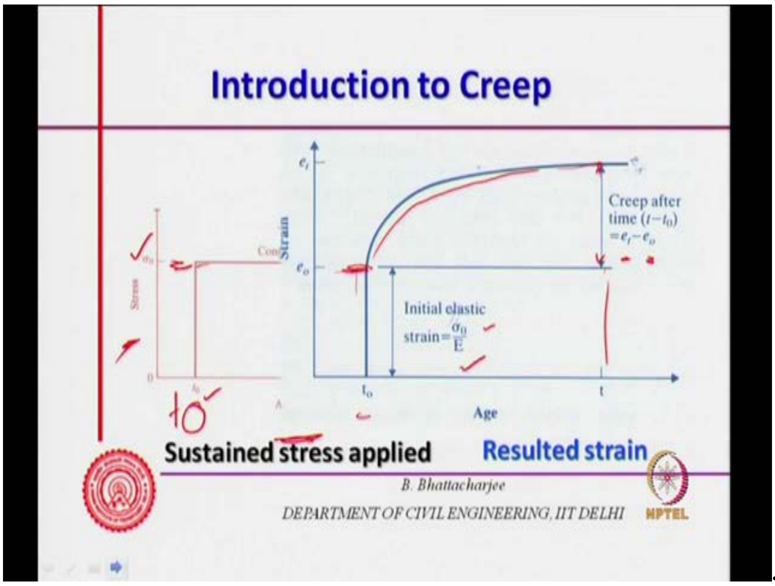

Sustained stress, resulted strain, we find there are two components, instantaneous elastic strain and with time, there will be some more strain, which is of course a semiotics to same line. The difference between these two, we call as creep strain or creep simply.

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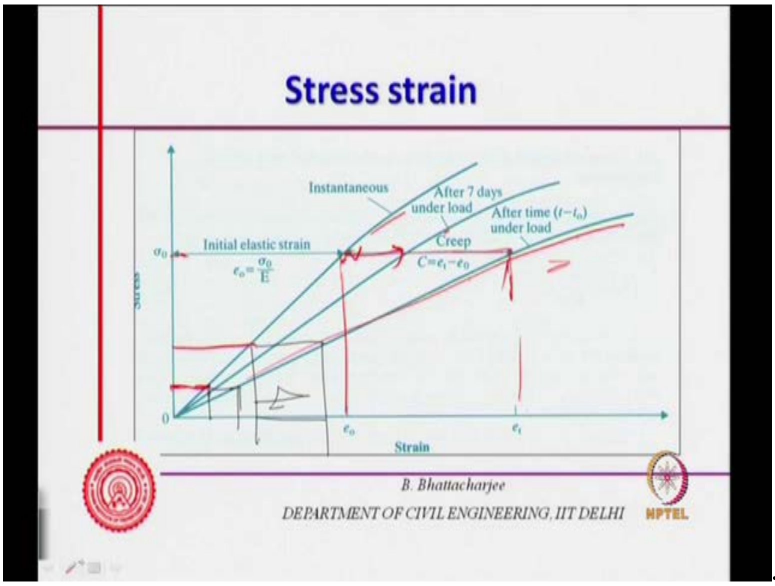

If we look at this stress strain diagram, write epsilon t stress is sigma 0, same stress is sigma 0. So, instantaneous at e 0 is this much. So, this is my you know initial elastic strain, stress strain, so this is the stress, this is the strain. As an increase in my strain stress, it reaches to this strain. Let me keep it there; do not increase it further as this shown here.

Then, what will happen after 7 days of loading? You will find there is some increase and further increase at any time; you will find the strain is increased further at e t. So, therefore, creep is e t minus e 0. So, this is e t minus e 0, this is creep. So, some days and 7 days under load up to entities load 100 days under load. So, at any time after t minus the 0 under load, stress strain behavior will change.

In other words, effective module has also changed. So, if I am considering some later time, I find that actually you know, for example, if this is my stress level, instantaneous will be this much and this will be the creep, this should be the creep. So, instantaneous is this much, this will be the creep.

If I consider this stress level, this is the instantaneous, this is the creep level, and this is the creep strain. So, at any point of time, any level of stress, this occurs below the fallers below the strength level and you find there is always creep. So, that is what is creep; we have defined. We define creep like this.

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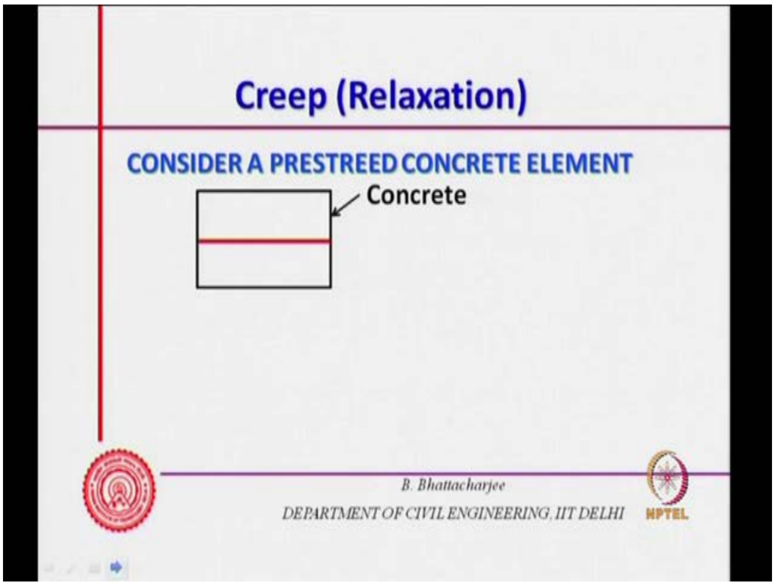

Now, a related aspect is relaxation. To understand relaxation, let us consider this, you know, pre stress concrete element, an element of concrete just hypothetical element of concrete something like this, just an element of concrete. I have, you know put pre stressing bar there. So, I have put pre stressing bar, it is stress tensioned, pre tensioned. Then, I have just you know so pre stressing bar.

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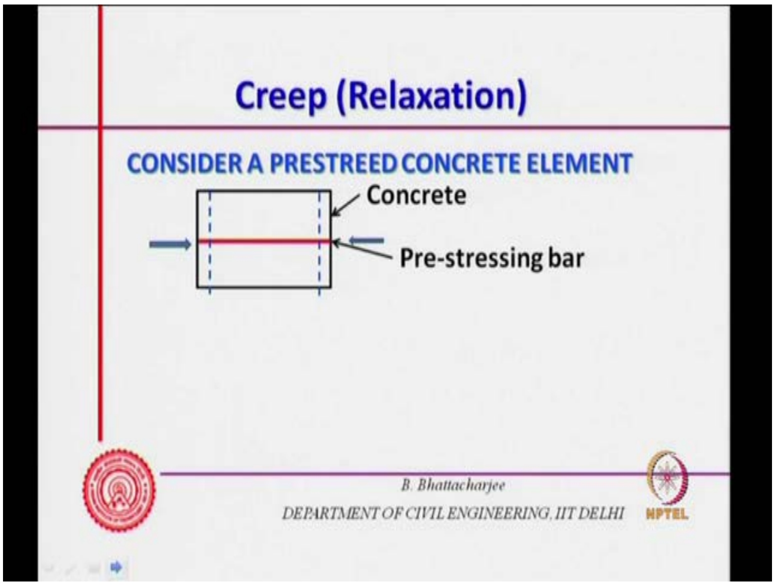

This is what I have done. So, I have just pre tensioned it. This will result in a compression in that concrete; you know through this bar, there will be resultant compression in the concrete. So, concrete will get compressed and therefore some elastic deformation will occur.

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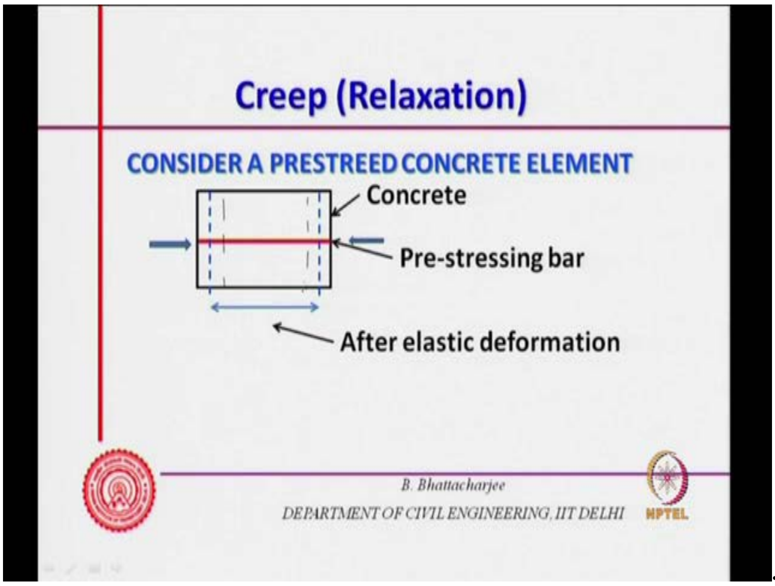

So, it is reached to this level, this is the after the elastic deformation. It would have, you know it will actually short term. Now, if I allow it allow this continuously for a long period of time, actually I will find some deformation, which I have not shown here, which I have not shown here. You know finally over quantity long period of time, I might end up getting further release of you know, further compression of this whole thing if I just kept this material in the long rams.

So, this will be my creep. This will be simply creep, but then that is what we have explained earlier. Now, let us look at relaxation that. So, the creep was something like this. Now, what I do? Now, I take this same after elastic deformation, take this specimen.

Then, provide some restrained to this. Do not allow it to shrink as I say in due to creep, it will have gone to this deform to this level, but I decided that I will restrain it and I not allow it to go to this level. So, what will happen? Net effect would be because it is you know after creep its dimension should been some here, but I have restrained it. This restrained means I am effectively applying a tension in this restrain means I am applying a kind of tension and this tension neutralizes the compression.

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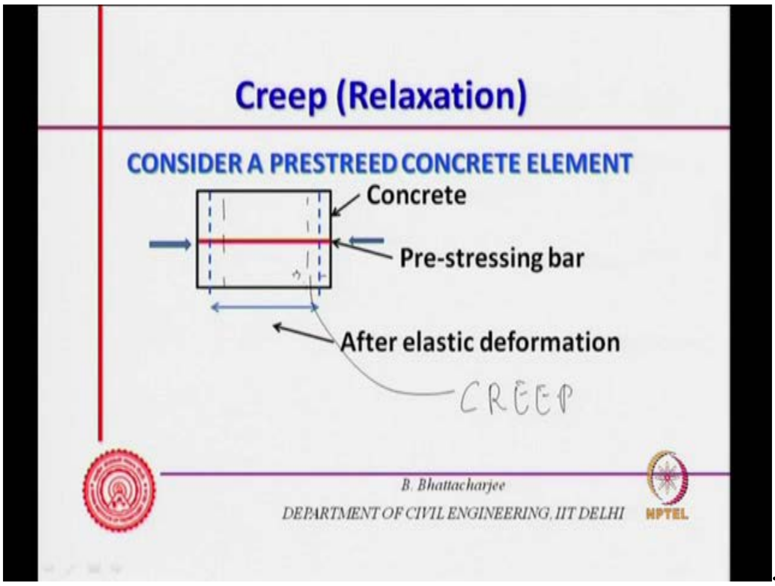

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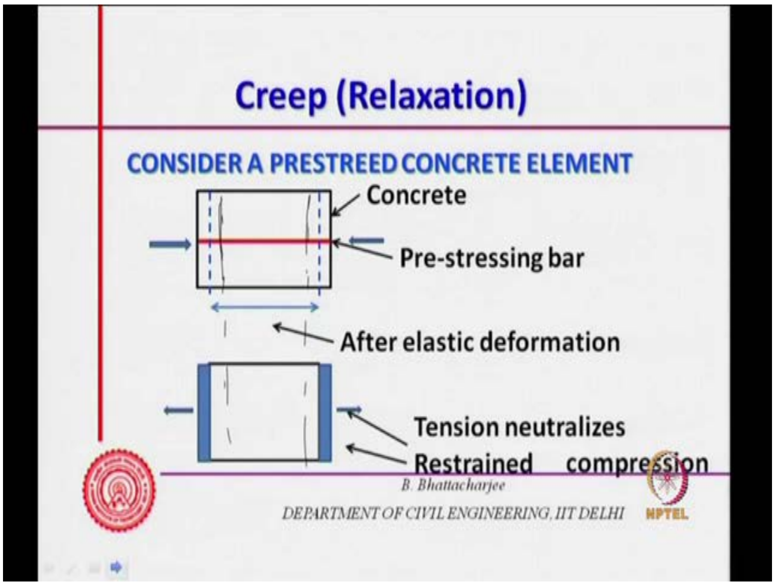

So, the original compression, which I have provided through pre stressing is actually getting reduced. It will get relaxed and this is called relaxation.

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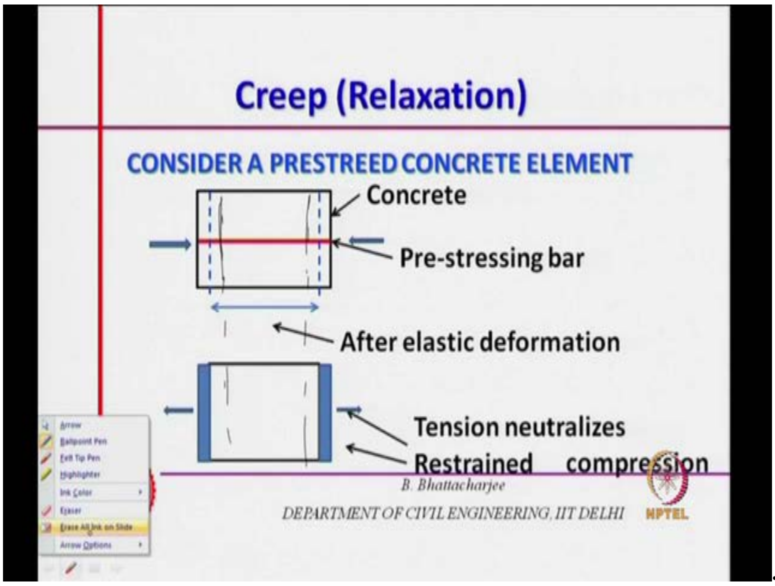

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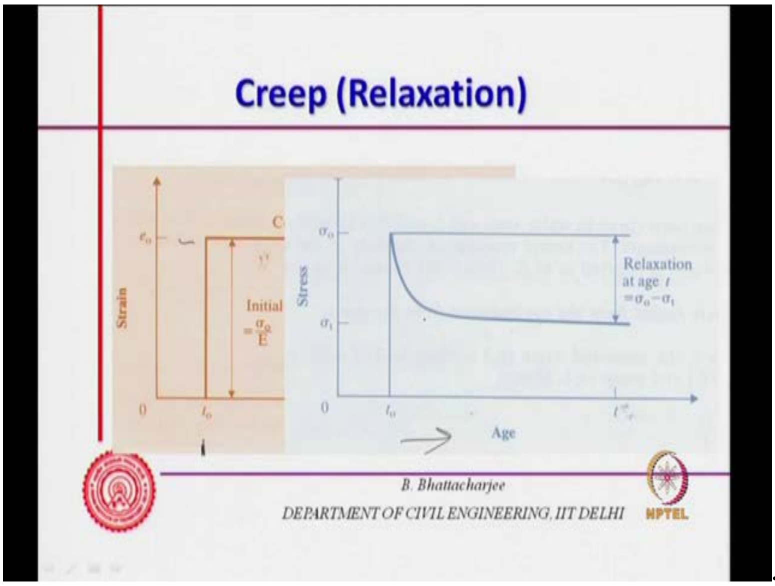

So, therefore, if I diagrammatically try to look at it, this my age, and then a t 0, I have provided sigma 0 like this before and elastic strain is like this. But, instead of allowing it to deform further or a strain to increase, what I have done is I have restrained it. So, as I restrained it, the stress will get utilized by the kind of tension that comes in because I have restrained it. It is natural position will have been some more different. So, it enough this as we said there will be a kind of, since it is restrained, there will be a kind of tension, which will actually the neutralized this sigma 0 value.

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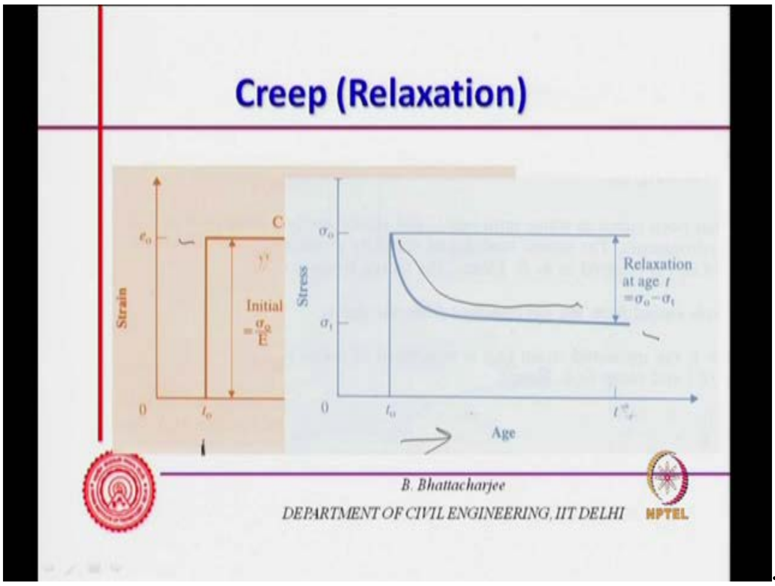

Therefore, this is a reduction in the stress and this is what we call as relaxation. So, relaxation, since the creep varies it is time, relaxation will also vary with time. Since, creep was you know it something of this kind, creep was something of this kind.

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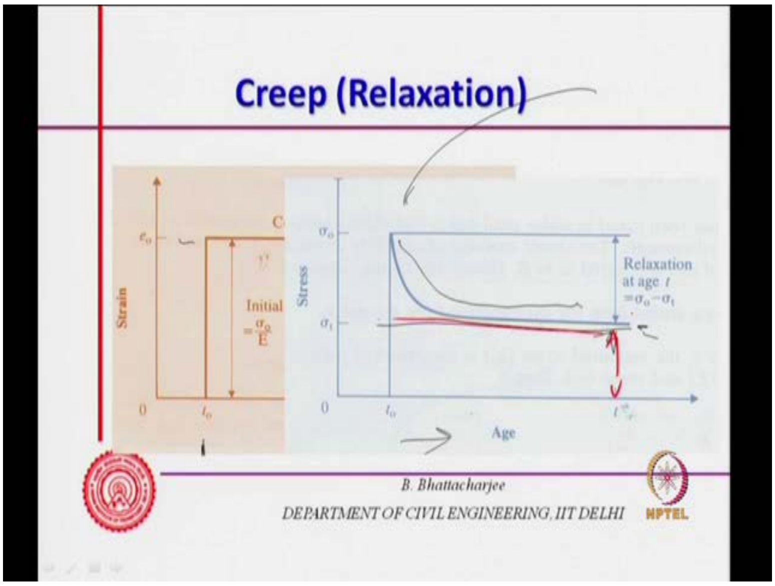

Relaxation will be in the opposite direction of the source. Here is the stress, not the strain. Here is the stress, gets reduced and relaxation at any age will be given as sigma 0 minus sigma t. So, this is your sigma t, so this is the sigma t, so sigma 0 minus sigma t. So, you see this if it is restrain specimen, creep gets actually reduced, and through this pre stress concrete element that I try to show you actually what I am implying is that is very important in stress concrete. We will just discuss about that some time later on, where creep is important, very important certain you know type of structure is where in the situation where creep is important.

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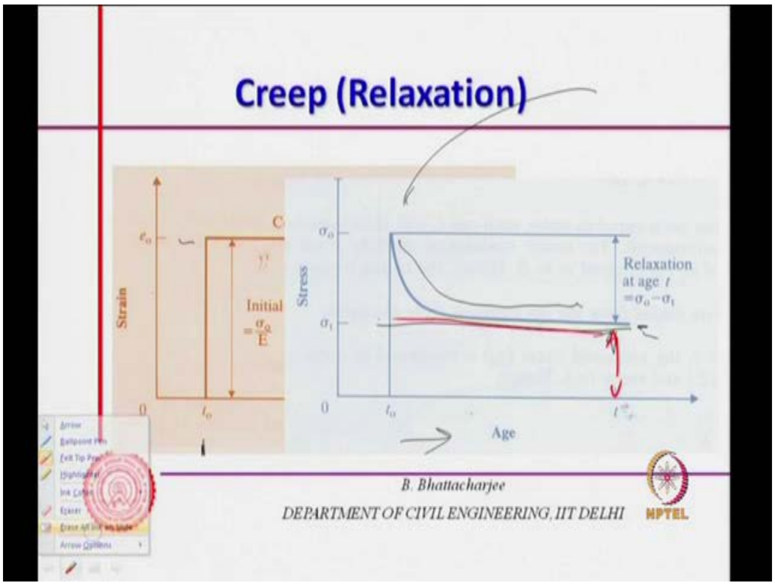

So, this is what relaxation is. So far, we have defined creep and we have also defined what is called relaxation.

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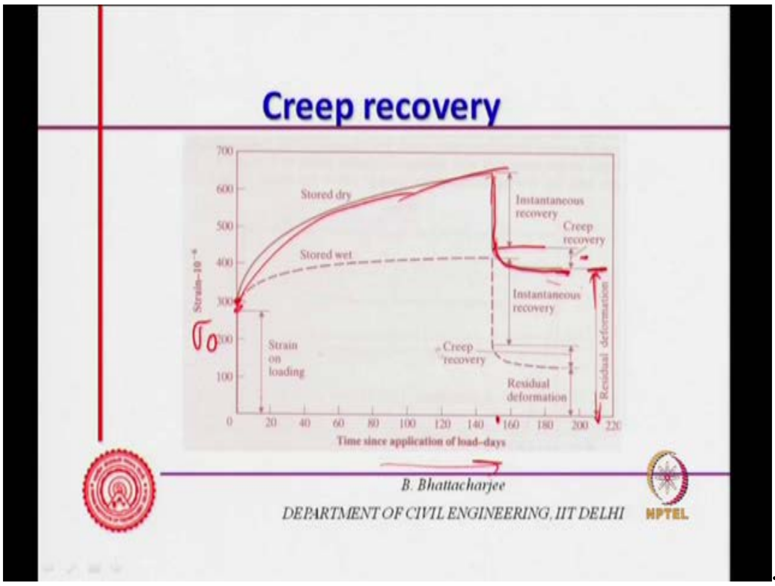

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Now, let us see if I withdraw what happens, if I withdraw this stress you know this is my strain original and I withdraw the stress. So, times in since application of the load, so this is your t and I withdraw this stress. Now, what you find this strain it actually comes down, it comes down. So, this is button.

It does not come back to the 0 level. You know I have applied stress. This is the elastic strain at sigma 0, elastic strain, and then this is the creep strain. Then, I will just withdraw the load completely, so it comes back. So, this is actually instantaneous recovery kind the sounds of elastic strain will be recovered. But, then it does not come back to the original straight. It stops here only. So, this is creep recovery, which time some amount of recovery occurs, this is called creep recovery. Some were residual deformation is here.

So, there is creep recovery. This residual deformation is still remaining and which it does not come back to zero. So, this residual deformation and recovery will have two components. One is instantaneous recovery. As soon as I remove the load, you know somewhat like elastic strains, so instantaneously recovery of the strain, but after that gradual decrease, you know gradual recovery of the strain will occur. That we call as creep recovery where you can see that this is in two states.

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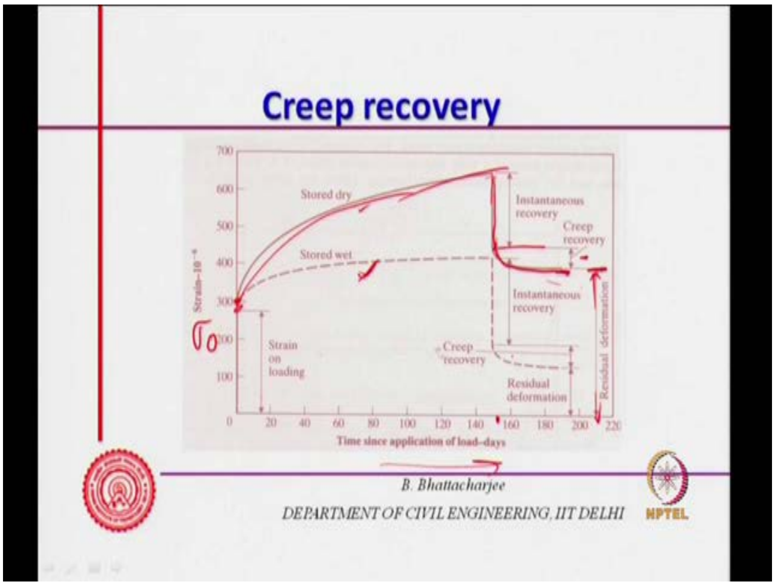

If it is to dry and if it is to do it in wet condition, of course, creep is somewhat will less. It is too wet. Completely, it is less actually and then creep recovery is but the behavior as per as further you know after unloading the behavior is almost similar to whether you stored it dry or stored it wet. So, this is creep recovery. So, what we have seen? We have seen so far what is creep relaxation related phenomena and how the recovery occurs.

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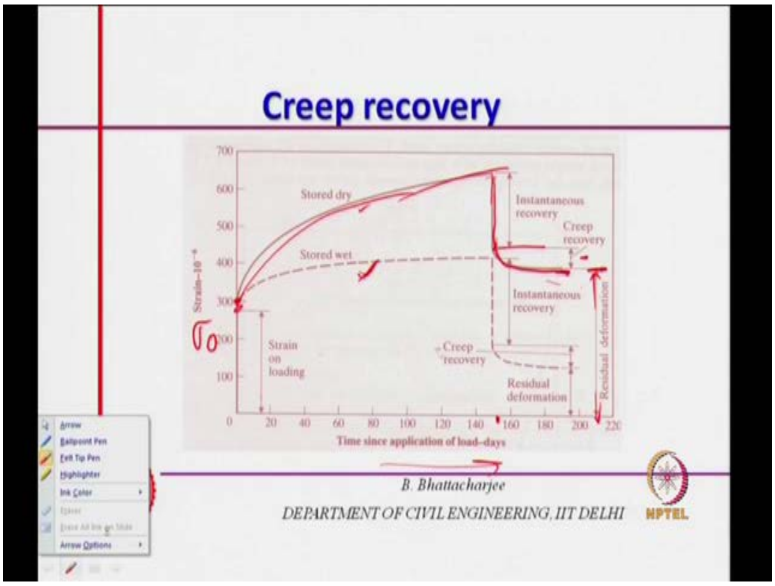

So, you can proceed further. We can proceed further and by proceeding further, we can look into mechanism occurs. So, you can proceed further and then we can look into mechanism of creep. Now, what is mechanism of creep?

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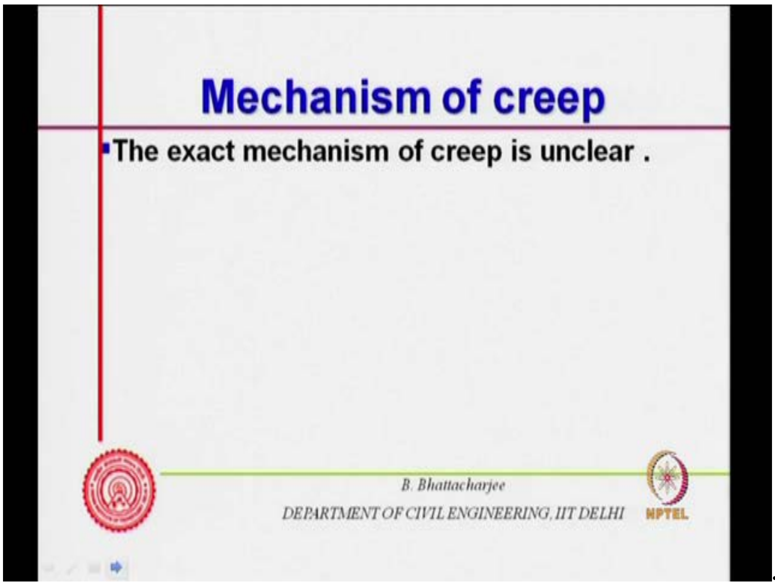

What actually the problem is exact mechanism of creep is still unclear, it is not well understood as yet. They of course some kind of theoretical modeling being attempted, but there is lot of devote on it. You know there are debates available on it. So, at the movement, exact mechanism of creep of concrete is not not clear. Creep in cement paste is not clear. But, it is one thing is understood that it is related to the gel and gel water. You know it is related to gel and gel system, you know is capillary, you know the poor system of the concrete, so gel pores, related to the gel pores.

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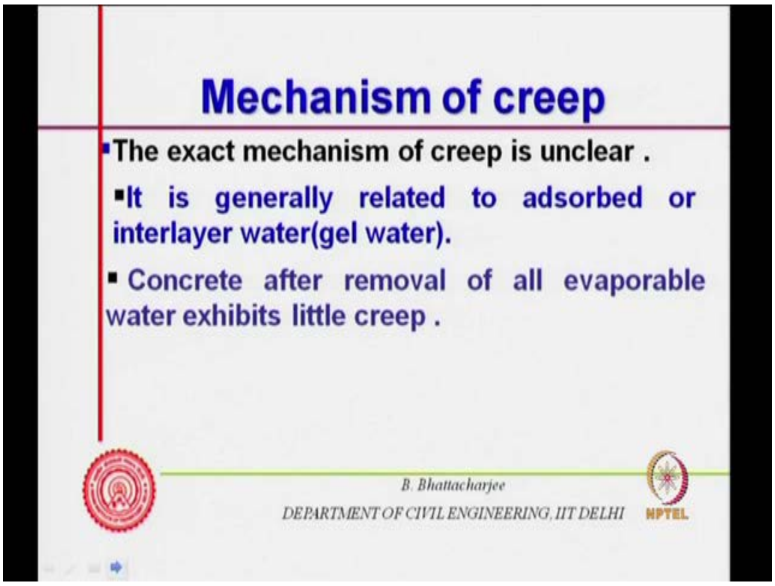

Generally, it is related to adsorbed or interlayer water. One thing has been observed. The concrete after removal of all evaporable water exhibits little creep, you know exhibits little creep. Basically, if you remove water, then it might confuse your limit. It is because we said creep in wet situation.

You know if it is fully saturated, completely wet situation, if you keep there is no movement of water actually, but if you are removed all the evaporable water, then you know, then try to study the creep. It shows that the creep is relatively less. Therefore, it is something to do that evaporable water or the water, it present.

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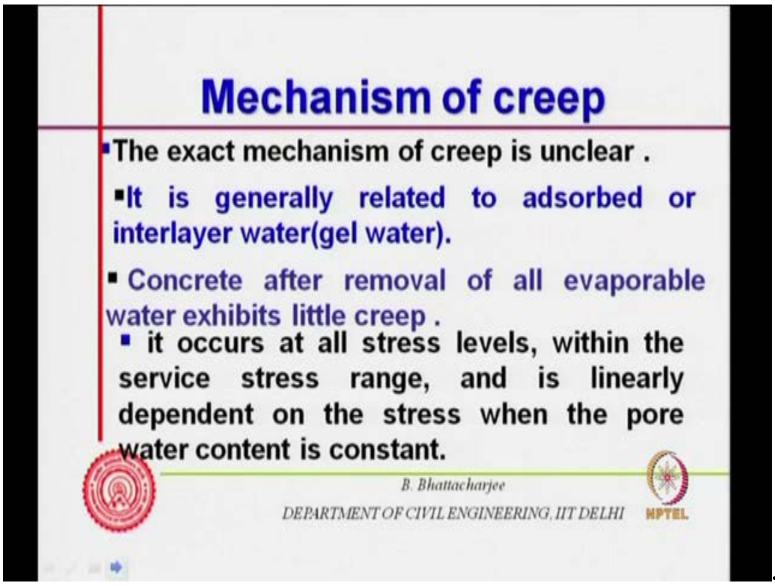

As I said earlier that it occurs set all stress levels, within the service stress range that means before failure, if has been absorbed that is linear dependent on the stress, when the poor water content is constant. So, if you are not allowing to dry or anything of that kind seeing the poor water content is constant, then it is linearly related to the stress level, you know when poor water is content is constant.

So, it occurs at all stress levels. So, there is something to poor water level that is what we understand, you know, if you remove the water, and then you do not get creep. Clearly, it does not exhibits creep, therefore it is related to absorbed inter layer or you know water present in the cement high grade system that is that can be understood.

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When drying occurs, I am inform saturated. See, one issue is, one case is dry written. Then, studying the creep completely drying, but if you are looking at during the drying process, drying creep occurs when water moves out. Of course, shrinkage also occurs. Simultaneously, this is very difficult separate out shrinkage from creep because many cases, both are related to water movement and the gel water gets involved in both the cases. So, it is difficult to actually separate them out, especially even when you are studying the drying case.

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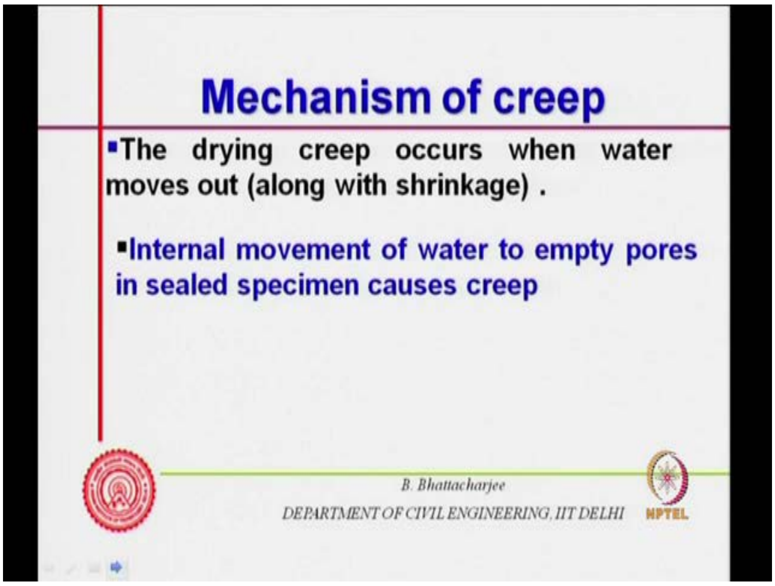

Internal of water, internal movement of water to empty force in sealed specimen causes creep. So, in sealed specimen, movement of water to empty force causes creep. See, you can understand there are some sorts of there are the statements I am making. It is not, it does not stress way get into the mechanism straight forward.

There are more complexities involved and the understanding is not yet clear. Certain observations are, one can list a huge number of observations there has been seen in the laboratory, but generally, it is attribute to movement of water and this you know absorbed water and so on so for.

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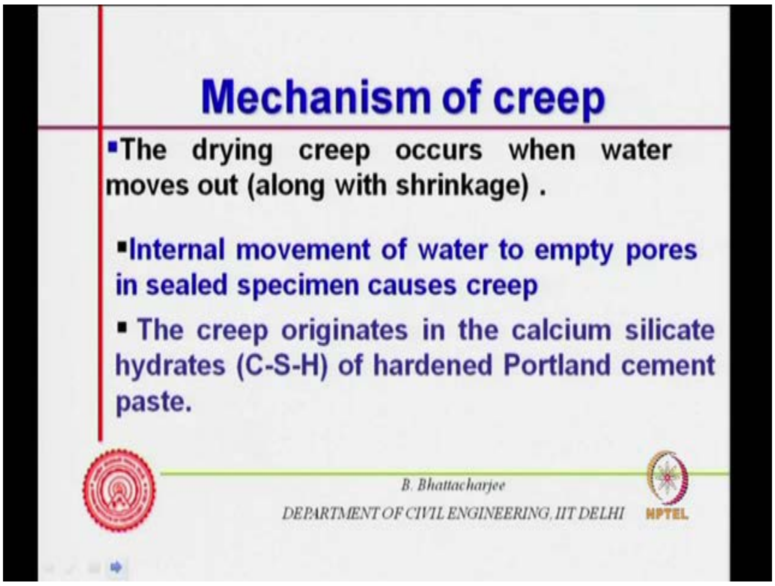

Basically, it is a calcium silicate hydrates CSH of hardened Portland cement and that there it originates. In case of dried or when we have removed the water, so that has been said that creep is caused by slips, due to bond rupture along the bond, along with bond restoration at the adjacent sites, when water is removed. So, when you removed the water, C H S has got bender was kind of bond. This rupture of these bonds is causing actually some source of further deformation and then of course the bonds restores. Also, bonds get restored has get.

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So, movement of water from one place to other actually causes from gel to some other place from some gel to other place, causes rupture of some other bond, which are associated with the water. Actually, the bonder can be bond, we talked of in case of CHS gel, you know it is a cross dose internally water. That is what we mentioned in the beginning. When you remove the water, there come into some kind of slippages can occur due to bond rupture, but then, water moves into some more else and they are the bond actually restores.

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So, these are some kinds of ideas there have been put forward, but one has to remember the cement past of concrete, you know I am talking about cement base its concrete as hydration process is continues. It does not occur instantaneously and it goes on occurring. So, this is what is actually you can say aging, you know the material changes with time. In any case, you have large specific surface of the gel, and these ones have some roles to play creep. So, continuous hydration process, the change that occurs the aging of concrete and of course large specific surface associated gel, the water is getting absorbed there and this is, these have all some roles to play in creep.

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So, concrete under goes actually gradual changes in response to stress and environment because hydration is also occurring. If you are putting some stress, this is an interaction with the stress, and the changes that is occurring, it will also depend upon the environment related humility and so and so for. There is actually an extremely complex thermo mechanical behavior. You know this exhibits extremely complex thermo mechanical behavior and creep is no exception.

So, that is why, this is so difficult to actually predict, but one thing we have understood from our discussion so far is this is related to the gel water and its movement. Gel water in its movement may be related to porosity and so on so for. So, as we see, we will see the factors effecting will have some idea, but exact mechanism so still is not very clear.

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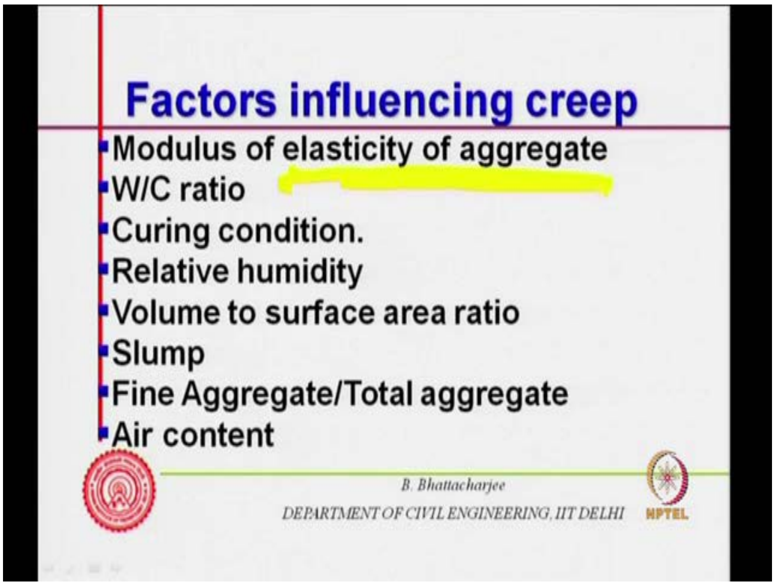

So, now we can look into factors influencing creep. Let us see what are the factors related to influence the creep. First of all, modulus of elasticity of aggregate, we will see more of it, but we can understand you know because the deformation of the concrete, if you are looking it, it would be the affected by modulus of elasticity of all material. In the overall, material aggregate modulus of elasticity plays a role.

Therefore, modulus of elasticity of aggregate is an important one. Water cement ratio has essentially governed the porosity and pore structure of cement base material. Therefore, water cement ratio of will also you know is plus fact is a factor that influences the creep.

Curing condition, then nonmetal condition whether it is fully saturate or how what it the water movement you know finally it is water movement. Therefore, curing condition and it is also complex, interaction of hydration process, which continues our long period of time. So, therefore, curing condition becomes important. Relative humidity and environmental condition, we just mentioned before.

Volume to surface area ratio is important because depending of on volume to surface area ratio is operation rate in the movement of water outside the specimen or outside the element would be governed by volume to surface area ratios. The slump is the flow of the concrete, the concrete characteristics and find to total aggregate. They are content all these factors. So, these are the factors. We will see how do the effect? How one can then we look into, how one can use this for predicting creep, for predicting creep. So, this is, so these are the factors lets individually some one of them how to the effect.

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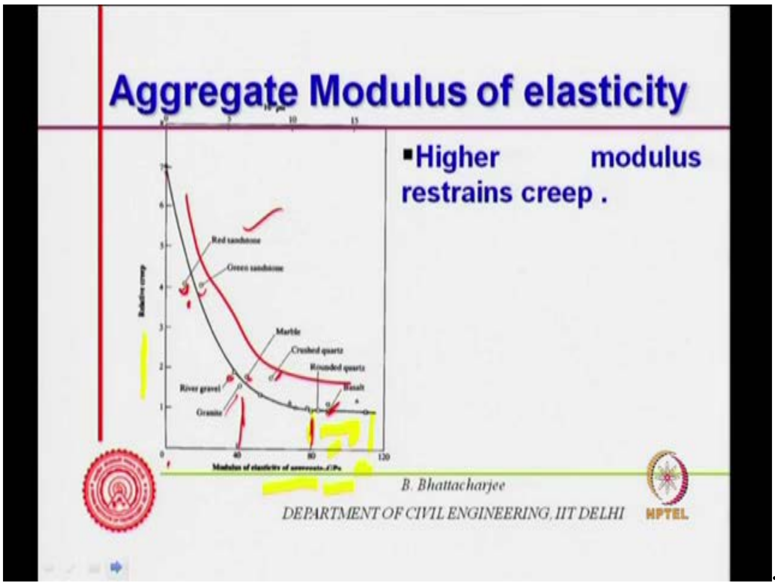

Aggregate modulus of elasticity, this is an important part and you find that as the modulus of elasticity of aggregate increases, the creep reduces. The creep actually you know relative creep reduces. So, higher modulus of elasticity, these are all in g p a, let us say something like hundred g p a or 60 g p a, you know 60 g p a or 100 g p a. So, 60 g p a 40 g p a and relative modulus the very little is high, you know space sold of very little.

So, as the modulus of elasticity increases, creep will decrease. So, this is somewhere is red seems stone, these is green since to stones some over there, marble, reparable, granite and crust codes, basalt and so on, so forth.

So, as you increase, as the modulus of elasticity increases, creep reduces. So, higher modulus reduces stress strain creep. You can understand this very easily. Actually, creep means more deformation, but deformation, but if is higher modulus stiffness of the aggregate is more; it is not going to deformation.

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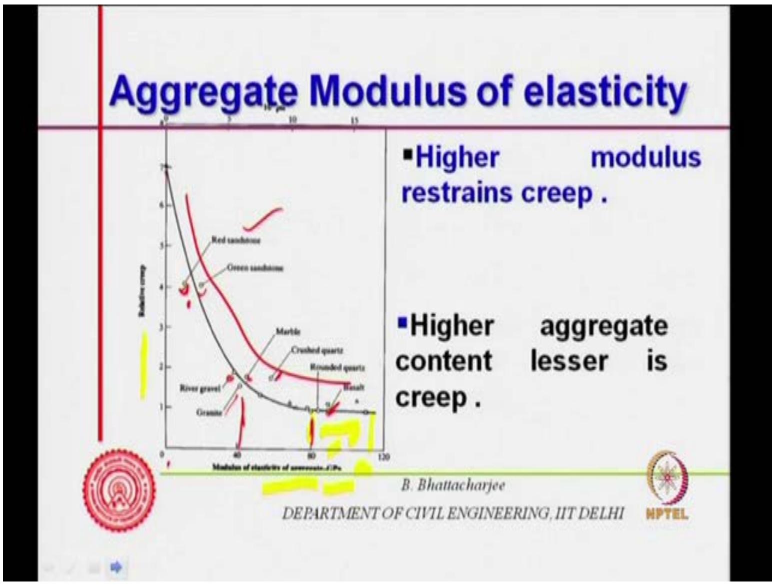

So, it will not allow creep to occur. It will restrain the creep some want, it will just restrain the creep, some water because you know the deformation would be restrained by higher modulus aggregate. Higher aggregate content of course will also result in less creep, is related because aggregate does not creep it is the cement paste, which shows exhibit you know, which is responsible for creep of concrete. Therefore, more the aggregate content, less then will be that creep. This we can see in the diagram.

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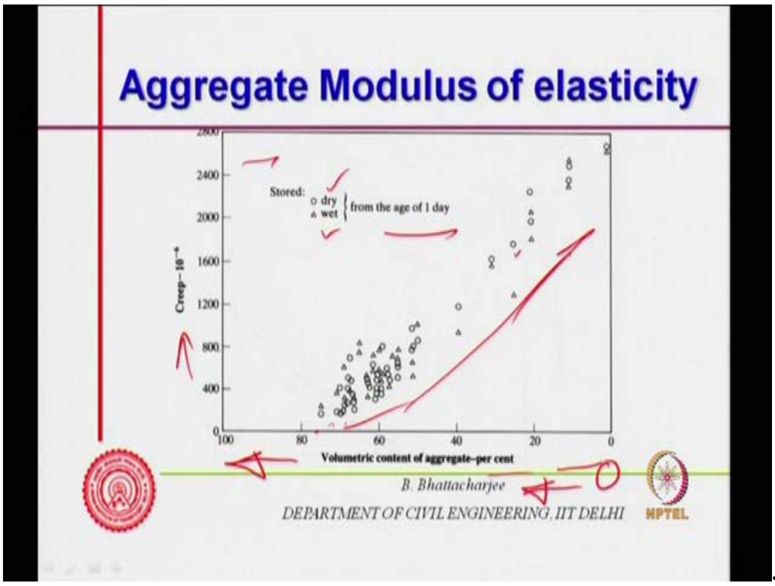

More the aggregate content, more the aggregate content, lesser will be the creep, is a volumetric content of the aggregate percent. So, this is the 100 percent here, 0 percent here. So, it increases along this direction and creep in micro strain sort of, so this some of them also dry specimen the round at one. These are for wet specimen and this is creep from the age one day. You can see as you have lesser aggregate, more creep; more aggregate the creep.

So, if we have more aggregate, less creep and this is understandable because aggregate do not creep, so it will not contribute to creep while paste will do. All it is not really related to modulus elasticity, but this is related to the aggregate content. Finally, it is affecting the stiffness of the system because more aggregate means most if this is more you know more will govern is, stiffness will be the governed by the aggregate modulus.

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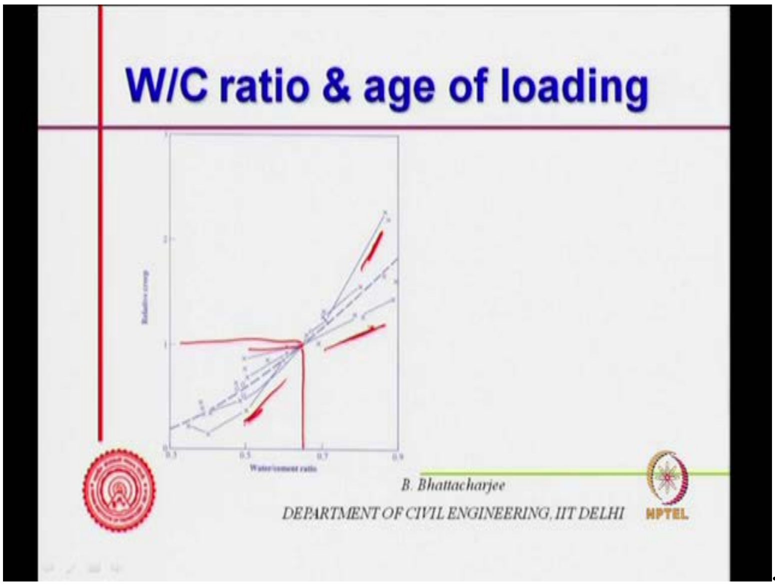

The next factor is water cement ratio and age of loading. If you look at water cement ratio and relative creep, some around 0.65, I am saying creep is let us say 1 or dividing all creep by that is later on 0.65 or so. Then, what we will find is that higher water cement ratio, more creep, and lower water cement ratio, less creep. I mean this is you know related to porosity. This is largely related to porosity.

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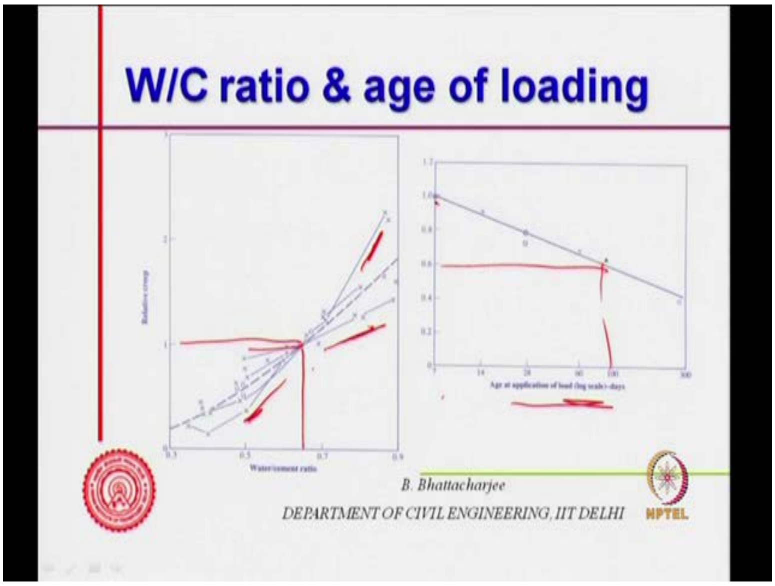

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So, what it says, if I have age of loading increases, creep should decreases. So, age of application of the load if it is 7 days, if this is 1, then at 100 days, this will be some relax 60 percent of that. So, relative creep is on this axis, and therefore he can understand. More water cement rate ratio means more pores.

So, if scope for water to move from water field pores, all pores are unlikely to be saturated even if we have some water content unnecessary fully saturated. That is separate situation may be you know within see for the wet specimen, the creep will be very less. That is what we have seen in the earlier, when we said dry specimen and wet specimen; it is not fully dried, if evaporable water was there. But, at the same time, wet specimen fully you know it is fully saturated situation.

The movement of the water will be relative very less. If it is fully dried, there be some creep, but keep this is much less because you know because of it can continue because of slips that we talked about between gel, water and a gel particle viscose elastic behavior of the gel system that means still call sums, but it is relatively less. Any way coming back to here, back here that higher water cement ratio means more pores. It is unlikely to be fully saturated, some pores will be empty, and some will be fielding more. That phenomenon, it will be more here.

So, water can move from field spaces to un field space, while in low water cement ratio, lesser the overall pores and you know the movement, this kind of movement will be restricted besides through gel poor. It has to move only because capability segmentation and all will occur. So, movement, so also would be relatively difficult.

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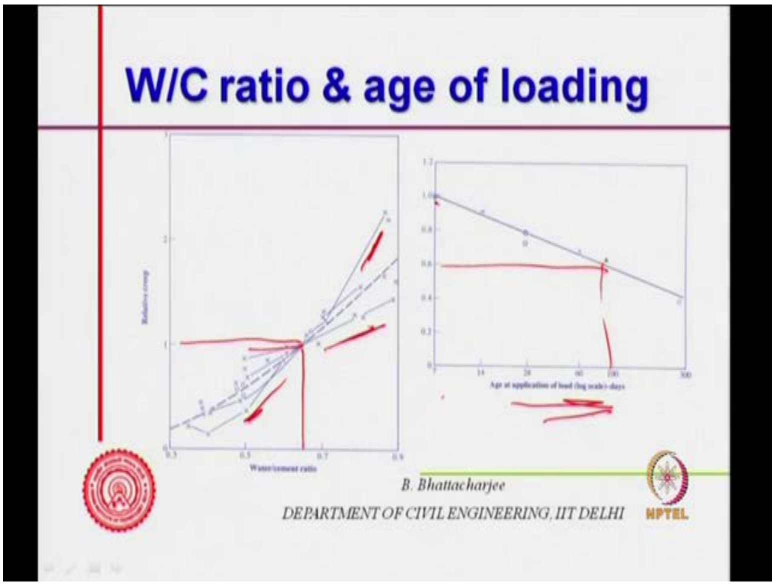

Now, this same thing follows. As hydration progresses, obviously the gel structure or segmentation occurs and gel structure becomes very solid. So, if you apply load later, you are likely define less creep. If you are applying load later, you are finally likely to find you know you are applying load. Now, on a system, which is more mature, therefore you are likely to find less creep relative creep as shown here.

What about relative humidity? Well, it is a percentage relative humidity, 50 percent, 70 percent, 100 percent. So, you see if you are 50 percent, the creep is more 100 percent is relatively less creep absolute values in micros strain and you can see that it is 50 percent it is more, and this basically time t since loading 5 years 28 days. So, times is loading, so after loading 28 days after loading, 10 days after loading and so and so forth. So, you after loading, you find 10 years. Now, relative humidity, higher the relative humidity, less again same movement of water, relative humidity gel should be more or less saturated.

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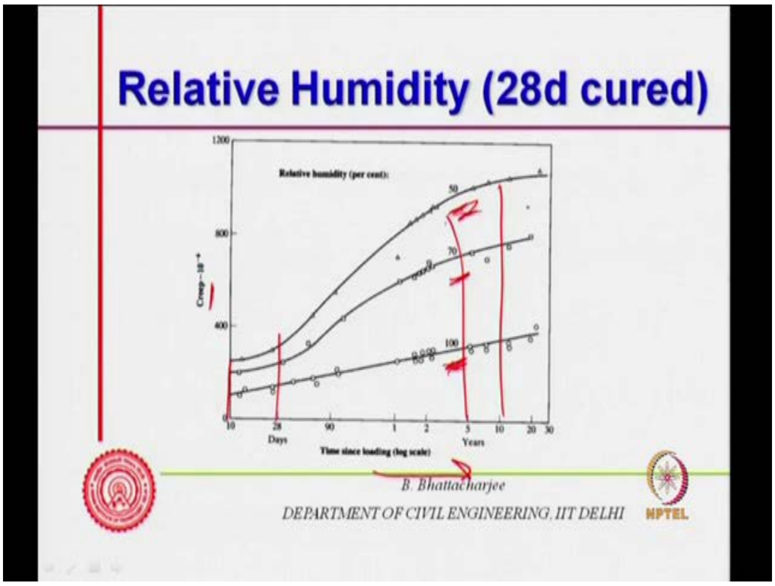

So, movement of water from gel pores to other gel pores that is will be relatively less, and in saturated in case 100 percent relative humidity. So, gel pores also be saturated, therefore absorbed water movement will be relative less. Capillary force hold absorbed water section, capillary section the gel force hold absorbed water. You know weeper also can come get absorbed in the surface because it has got environment mass surface area. That is what we say that it is got very high specific surface, earlier we mentioned that. So, therefore, relative humidity higher relative humidity, lesser will be the creep.

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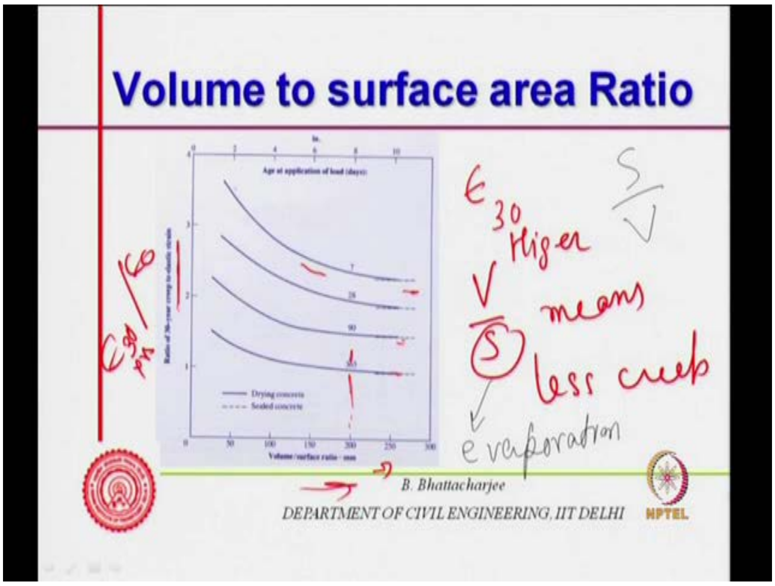

Volume to surface area ratio, if I look at volume to surface area ratio, you know so ratio of 30 year creep to this side is 30 year creep to elastic strain, 30 year creep strain to elastic strain, you know and volume to surface area ratio. So, what you are looking at is epsilon 30 years on the y axis epsilon 30 years by epsilon 0 elastic strain. So, this ratio you know, so the creep would be more. If this is of course drying concrete, this side is sealed concrete.

So, if you see so basically you know this is a sign is finite creep. Creep at infinity divided by this, so c 65 days at the age. Now, volume to surface area ratio more, less is the creep. Volume to surface area ratio greater higher by higher v 2 surface area ratio means less creep. Why? So, well, it is through the surface, it is through the surface through the surface evaporation occurs. So, higher volume or if I say S by V more as by V more surface area per unit volume means more evaporation possible, drying is possible. So, moisture movement is more, moisture movement is possible.

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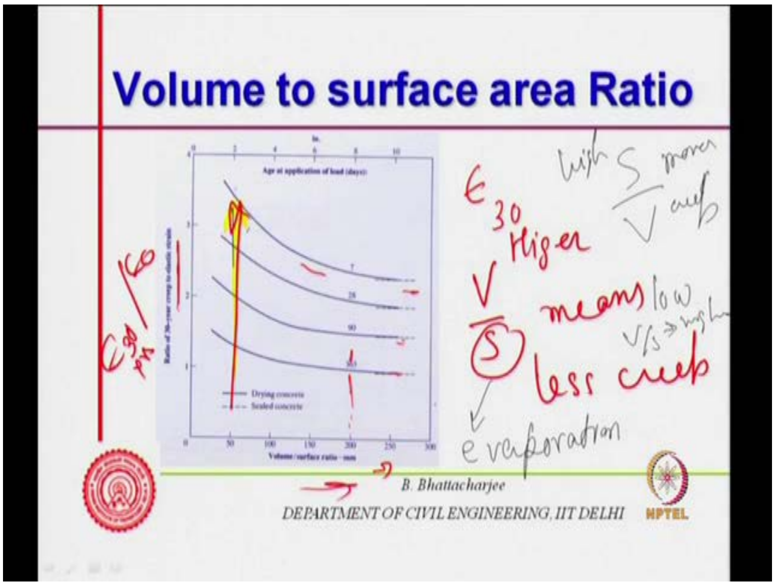

So, in other words, you know less V by S is more creep. So, high V S by V more creep, so low V by S higher creep, higher, so that is what it is. So, we see that you know lower values; you get high lower V by S get creep lower V by S on gets higher creep, lower V by S you get higher creep and this reduces. So, because of the evaporation losses, the water movement gets restricted etcetera.

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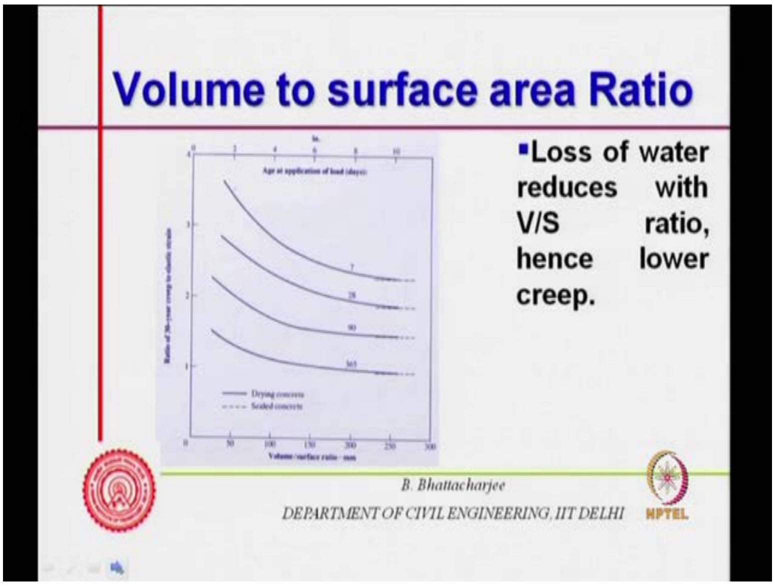

Therefore, you know the, so loss of water reduces is V by S ratio, hence lower creep. Loss of water reduces is V by S ratio, hence lower creep. So, this is the explanation for this one, V by S.

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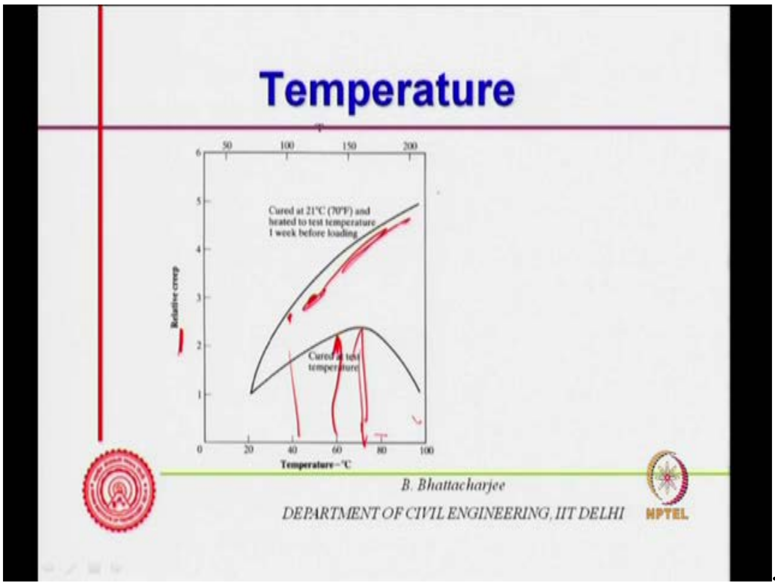

Now, what about temperature? Temperature also affects the creep. Supposing I have 60 degree centigrade cured at the test temperature, this is the relative creep. So, higher the temperature there is some sort of pick and beyond that there is a relaxation, but if you cure at 20 on degree centigrade and heat to the test temperature that is 40 degree centigrade 1 year 1 week before loading, and then do the loading, you find that creep actually increases with the temperature.

So, what you are doing? You are actually cured at 21 degree centigrade and heated to test temperature there, so what you do? Then, you heated to 40 degree centigrade or 60 degree centigrade and keep that sustained loading under the same condition.

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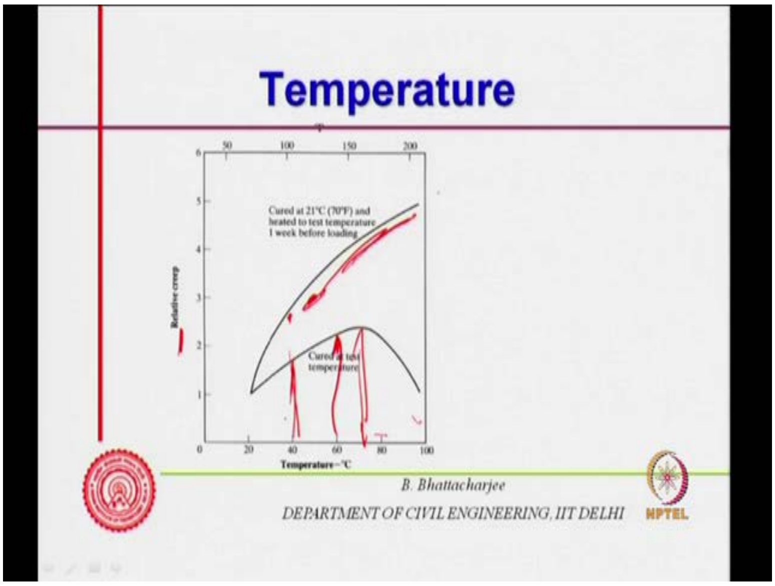

Now, what us, what happens is does not increase in the creep, so you have 21 degree centigrade cured and this situation, but here cured and tested at this temperature. So, you do curing at 40 or 60 degree centigrade. Now, the problem is you are doing as curing at 80 degree centigrade. Curing will not be you know the pore structure will not be uniform and beyond that when you are curing at 100 degree centigrade practically by evaporable water has all gone.

So, most of the evaporable water vanishes actually. So, this will not help beyond that you know, of course you have non into uniform structure. At the same time, the most of the evaporable water will vanish as you go close to 100, the most of good lot, and therefore creep end to reduce.

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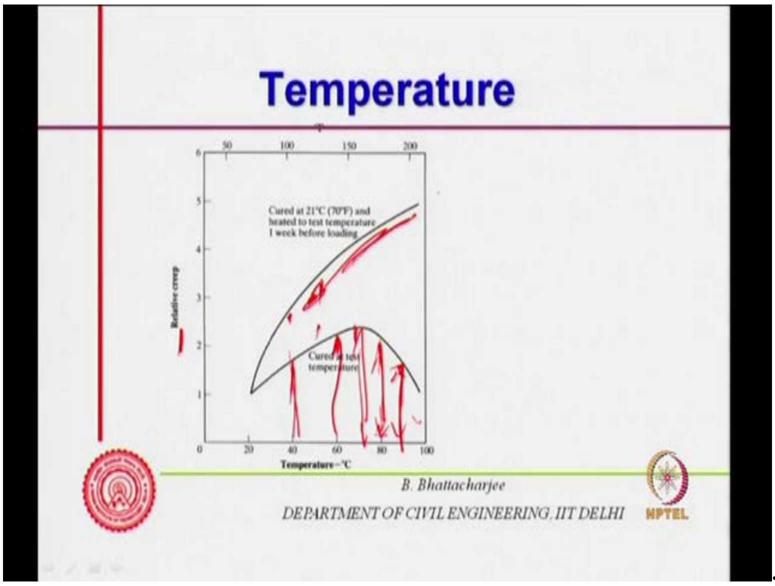

So, that is what we are saying when you a actually, removing some of the evaporable water during curing because you are curing at 90 degree say, here you are curing at 90 degree centigrade, and then applying the load. So, curing at 90 degree centigrade and then applying the load, so this at this point, the water has evaporated. Therefore, but up to this point, still there is an increase in the creep, but this creep is less than this because some water has moved out.

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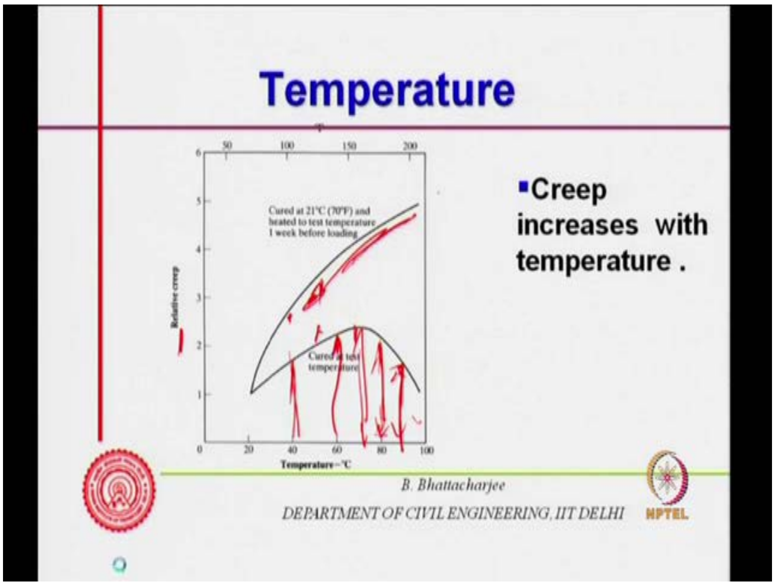

So, creep increases with temperature that of course we have seen, but then it is something to look the movement of water. That is what explains the situation.

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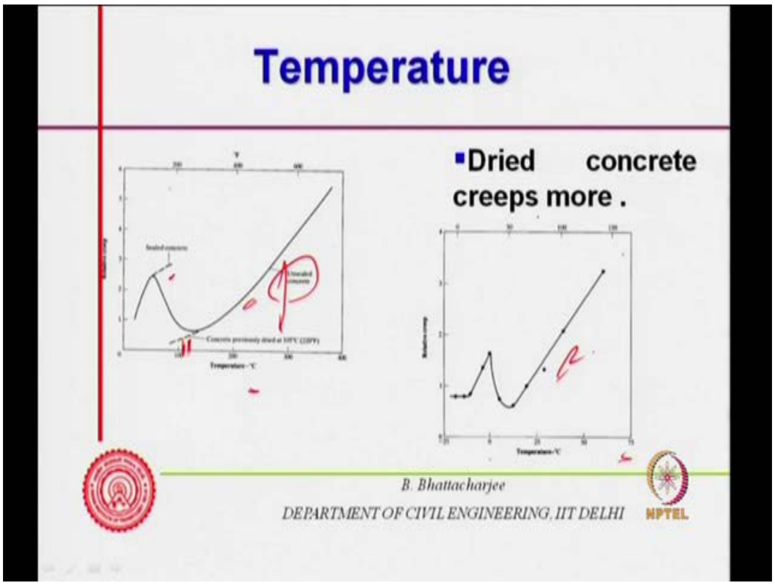

For example, this is again temperature; concrete previously dried up to 105degree centigrade seals specimen. This is unsealed concrete. So, you have dried it goes to a very low level. You know previously it dried to 105 degree centigrade. The relative creep is less. So, dried concrete is relatively, but if you are dried to 500 degree centigrade or so, 300 degree centigrade unsealed concrete, and then obviously creep seems to be more, creep seems to be more.

This is also the case you know, so relative creep tends to increase at 0 to 75 degree centigrade in the higher, so higher temperature its related to you know more since as related to moisture movement. This is what is happening.

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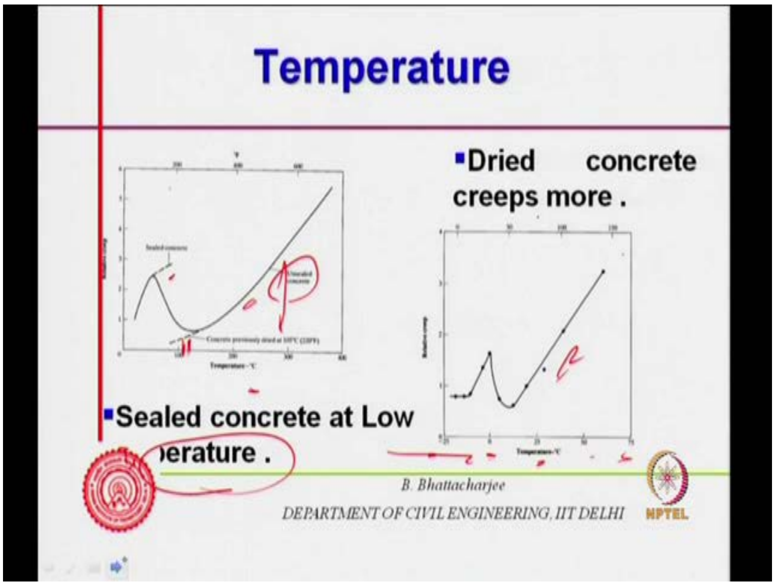

Sealed concrete at low temperature shows low temperature you know at low temperature sealed concrete at lower temperature and dried concrete obviously creep more, so this at sealed concrete at low temperature. So, this is what it shows the behavior minus 25, 0, and 25 and so on. So, if it is sealed, the moisture is still retained. So, if you increase the temperature actually below it tendency show high creep.

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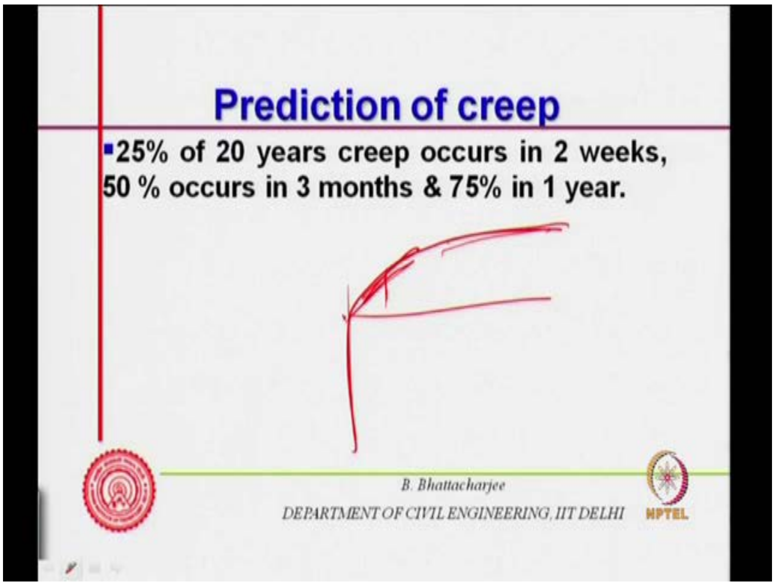

So, with all these factors, one can think in terms of predicting the creep. Roughly 25 percent of 20 years creep occurs in 2 weeks. So, it is you know as we have seen creep behavior, we have seen that elastic strain and then from this is follows like this. So, you know initial rate is very high. So, 25 percent of 20 years creep occurs in 2 weeks, 50 percent occurs in 3 months and 75 percent in 1 year. So, most of the creep seems to occur within the first 1 year, 75 percent of 20 years its asymptotic behavior or later on. Therefore, creep is creep with time you know a gradually creep with time creep will actually a reduced down.

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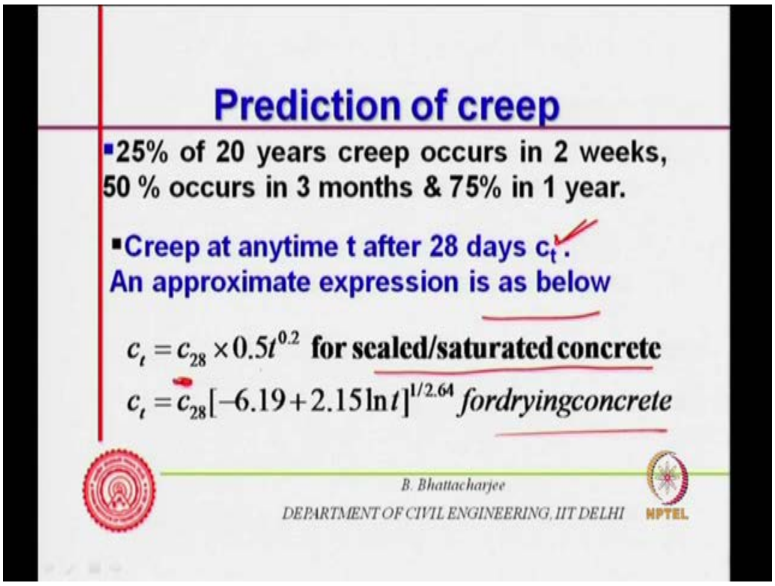

Now, there are guidelines are through which we can actually estimate creep. An approximate expression will be given like this. Creep at any time t after 28 days let us say that may call it as c t, and the approximate expression is that if I know c 28, then for sealed and saturated concrete will be 0.5 due to the bar 0.2. For drying concrete, this will be given as minus 6.19 plus 2.15 l n t to the power 1 by 2.64. So, this is some imperial equation. As t increases because it is t increases creep reduces, you know creep I means time for drying concrete the relationship is like this.

So, as t increases, creep reduces. t increases, creep reduces or rate of creep actually reduces. That is what it shows you know rate of creep actually reduces. So, as t increases, rate of creep reduces, asymptotic curve and this is why it is like this. So, as t increases, this 0.2, so you know if you differentiate these, you will get 0.2 t to the power 0.2 minus 1. You can see that as t tends to infinity, it will tend to go to that constant value. So, whatever it is basically the like to you know this is like to one, it is an asymptotic.

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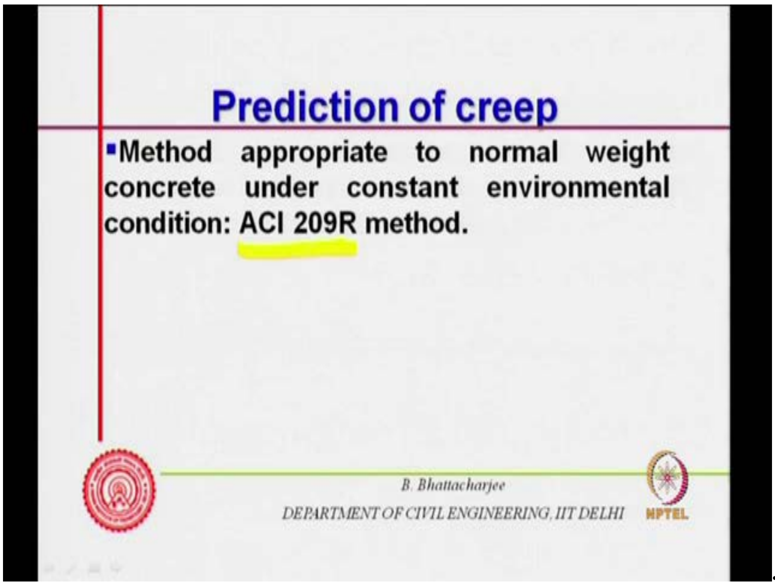

So, the formulas are fit acting in this manner. But, better way would be to predict through some of the guideline some like some using some guideline like ACI 209R method. So, this is method appropriate to normal weight concrete under constant environmental condition. So, approximately one can actually predict, but remember these are for design purpose or estimation purpose for practical uses. So, they would like to it should be a it should be for practical purposes. Actually, environment may not be as constant though but still this is could applied this could be you know, one can use this for estimation.

So, let us define something called specific creep, there is defined something called specific creep. Specific creep at time c t t 0, where t is the time at which I am trying to find out this specific creep, t 0 is the time of an application of the load is the creep due to units stress applied at t 0. So, if you apply sigma is equal to is equal to 1, then the creep that you get c, at time t, and t 0 is a time when you have applied that I call as specific creep. So, a specific creep at any time is the creep at that time due to unit load due to unit stress, not unit loading unit stress applied at t 0 due to unit stress applied at t 0.

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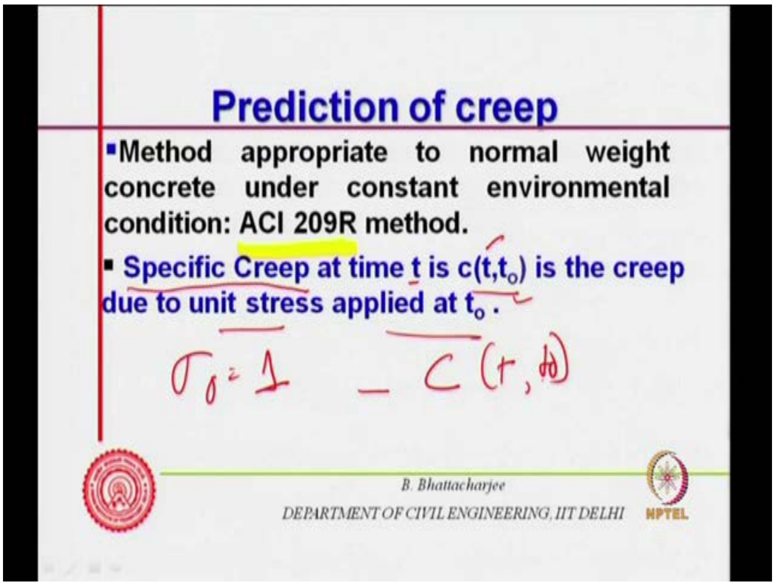

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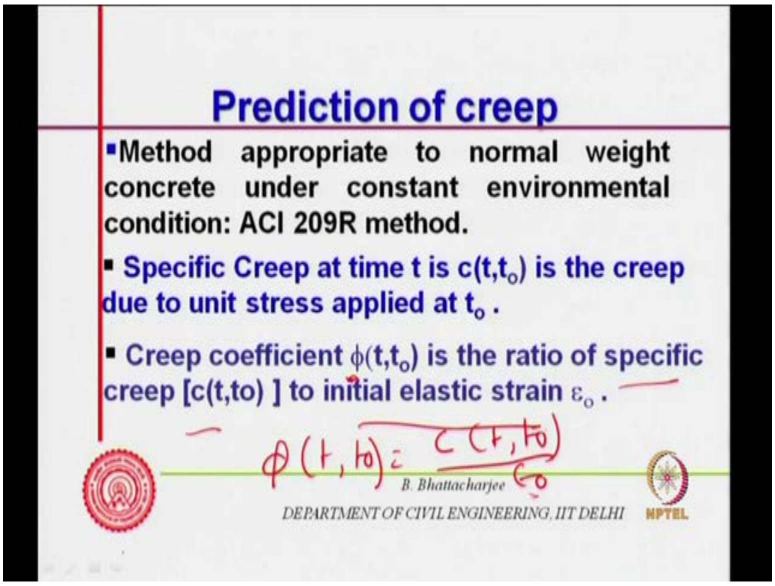

Then, another terminological creep coefficient, which is denoted by phi is a ratio of specific creep to initial elastic strain. So, phi t t 0 is nothing but c t t 0 divide by epsilon 0. So, this is basically related to elastic strain. So, creep coefficient is the ratio specific creep. So, this is for unit load. This is for unit load, and this is the initial elastic strain.

So, elastic strain if you want to find the creep specific load multiplied by epsilon 0, it will give me the specific rate. So, scrip coefficient multiplied by elastic strain will give me specific creep. It will give me specific creep. It will give me specific creep.

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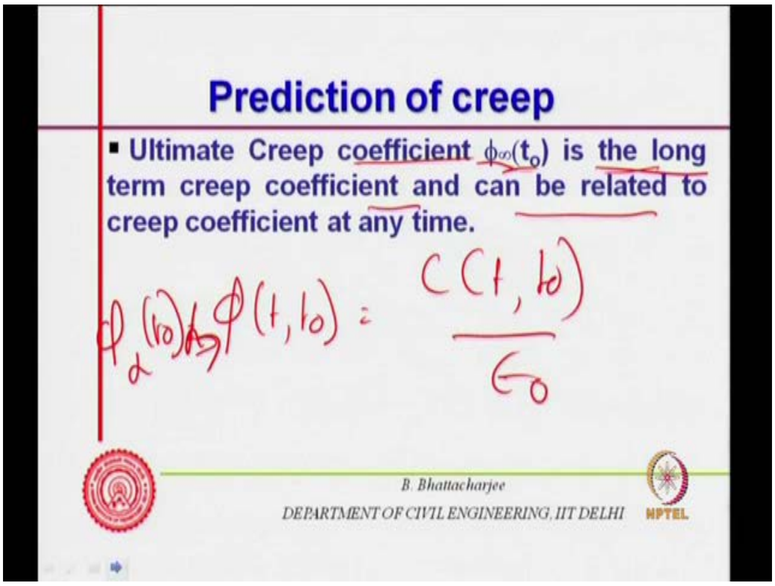

Ultimate creep coefficient is the long term creep coefficient and we can be related to creep coefficient any time. So, creep coefficient we have defined as phi t t 0, we have defined as c t t 0 divided by epsilon 0, but ultimate creep coefficient that is the long term, this is the long term. So, long term, this ratio of creep coefficient can be related to creep coefficient at any time. So, this can be phi infinity t 0 is a time of application load can be related to can be related to this; that is what we are saying.

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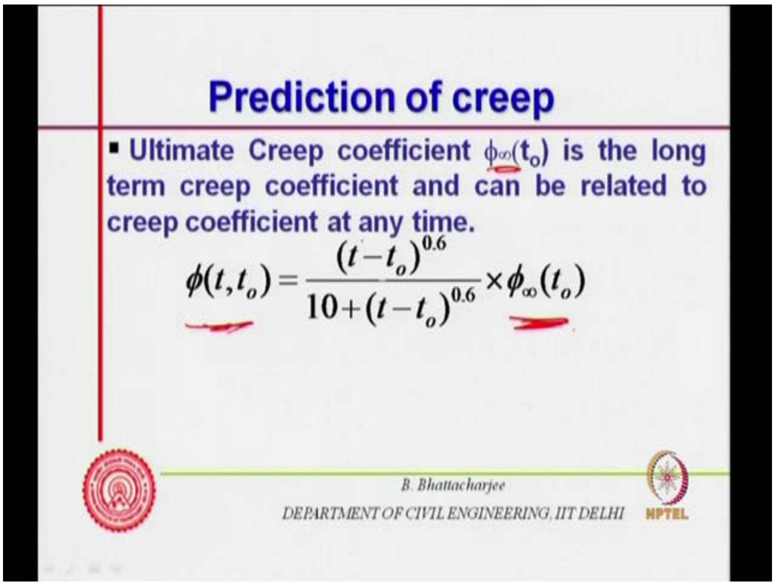

In other words, phi t t 0 at any time is t t 0 to the power 0.6. So, these are relationship between this and this. So, this is related by an empirical formula and this is a guideline. It is actually t minus t 0. t 0 is the time of a application of the load t is the time, which you are finding out the creep coefficient, and t minus t 0 to the tip of 0.6 10 t minus t into the 0.60 into the tip 0.6 into phi infinity.

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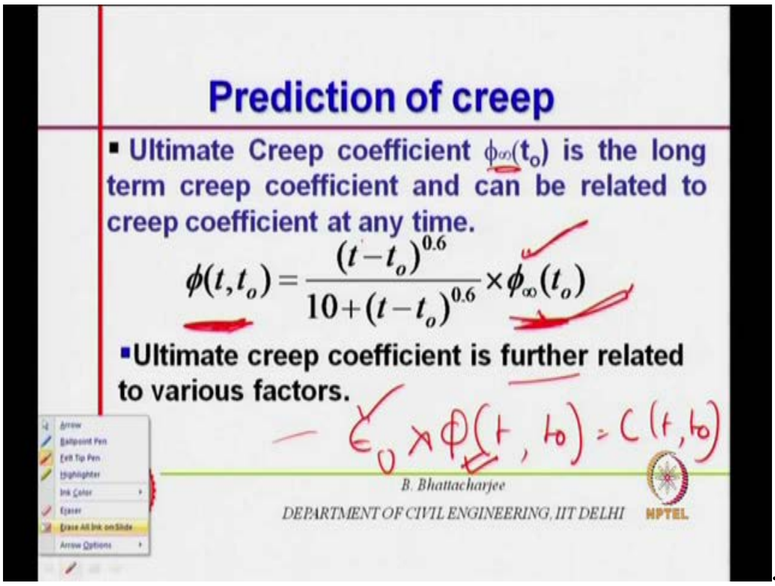

If you are applied the loaded t 0, so if you have applied loaded t 0, ultimate creep coefficient is further related to various factors. So, this I can relate to various factors, if I can relate this to various factor, I can find out days and multiplied this by epsilon 0 into phi t t 0 that gives me c t t 0. So, creep at any time, I can find out. First of all, I must find out this. This will be known to me first, find out this and to find out this can be found out and this is related to various factors.

So, let us see how the related phi t 0 is given by 2.35 k 1, k 2, k 3, k 4, k 5, k 6 some factors. Factor six factors some fix six factors. Simply phi this is k 1, k 2, k 3, k 4, k 5, k 6. So, there are six factors to which you can relate. Now, remember these factors are what we have seen earlier like aggregate to modulus, aggregate content, then water cement ratio, volume to surface area ratio and so on, so forth. So, this we can estimate in this manner. This is very this of course, so complexity of mathematics involved here, but one can, one may not be able to remember this, but using a procedure simply because these are all empirical equations.

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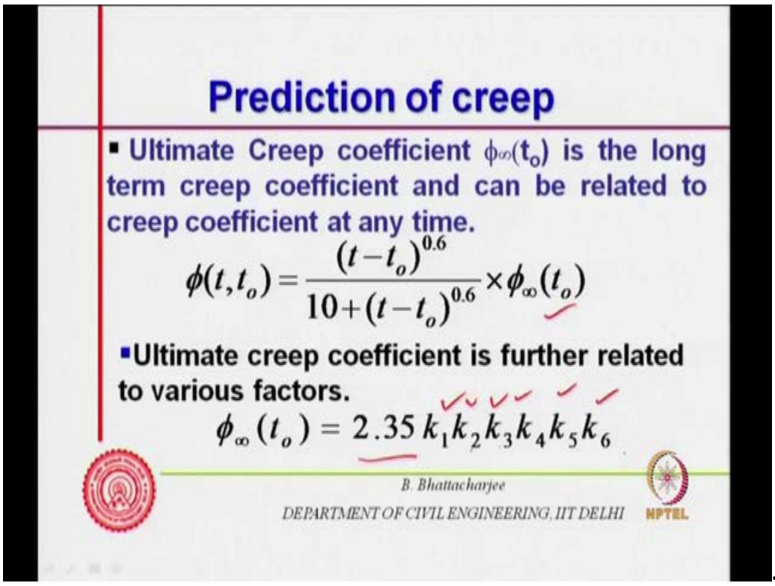

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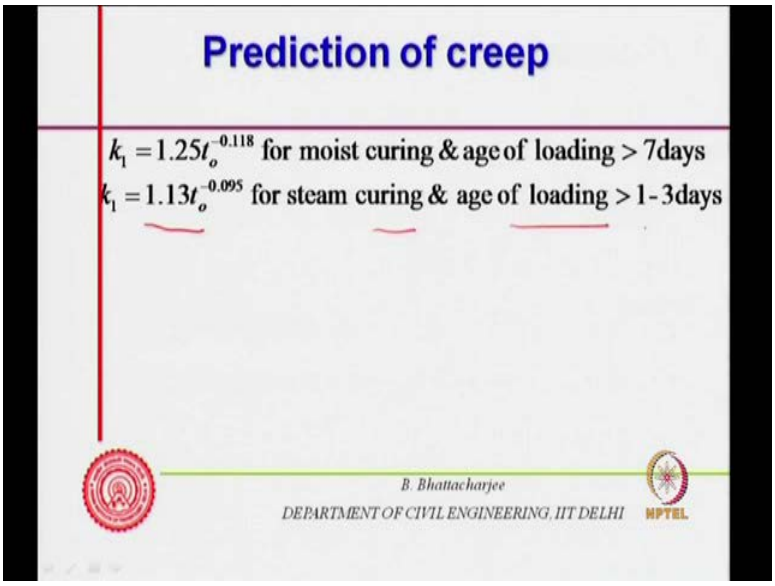

k 1 is given as 1.25 t 0 to the per minus 0.118 for moist curing and age of loading greater than 7 days. So, these guideline are given or it is is equals to 1.13 t 0 to the power 0.095 for steam curing and age of loading is 1 to 3 days.

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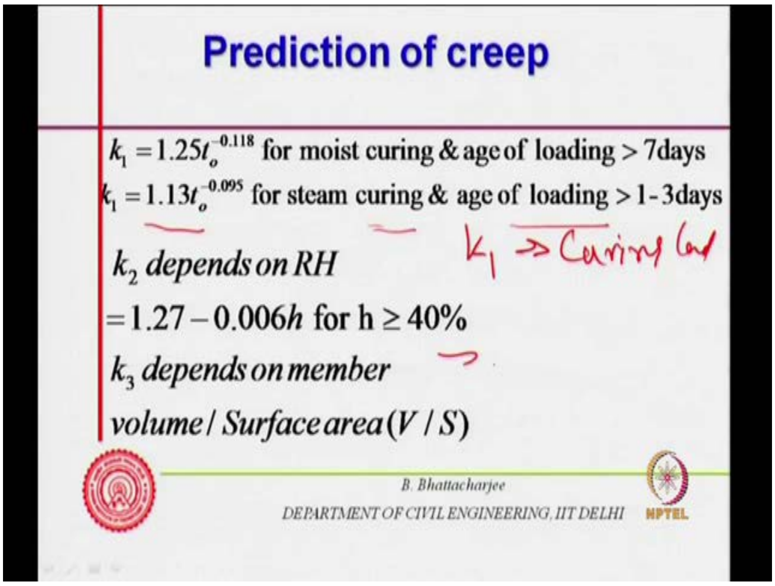

These are more practical situations. See age of loading would be most of time more than 7 days. It is rarely would be less than 7 days because the shuttering etcetera after that even construction load most of them will come. But, if you are doing steam curing, then load can come very early because its steam curing is done to at in higher earlier strength.

So, load can be applied easily. So, this again a kind of a empirical or guideline available. So, k 1 was what was the k 1? It is for moist curing in the type of curing. k 1 is the factor related to curing condition, so k 1 curing condition, k 2 is related to relative humidity and this more about it, but I think I have picked the only one portion. If one is interested in calculating for various conditions, various relative humidity situations, one may go back to ACI, you know the document data he mentioned just now ACI guideline 209R are a part of it time just mentioning here.

For example, I am mentioning here the related to relative humidity. If it is more than 40 percent, the equation is given like these, but each stands for relative humidity in percentage. So, h stands for relative humidity in percentage. k 3 depends on the member volume to surface area ratio, you know we seen that this is a factor.

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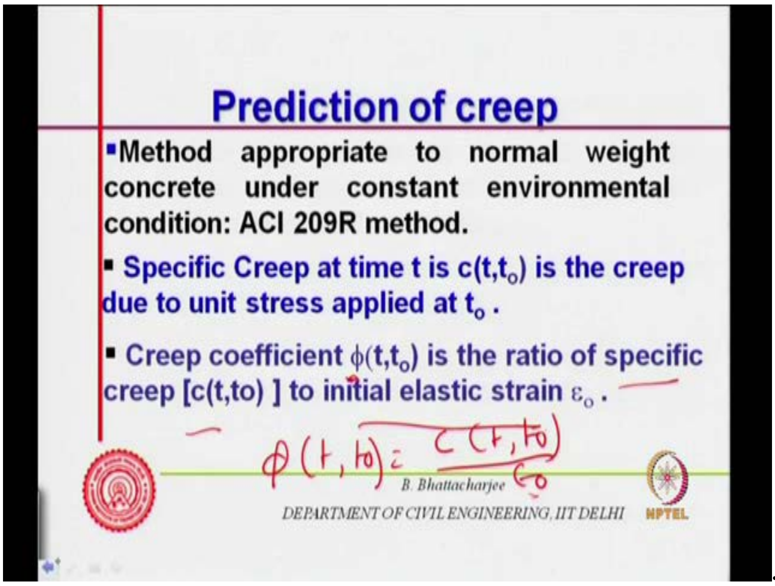

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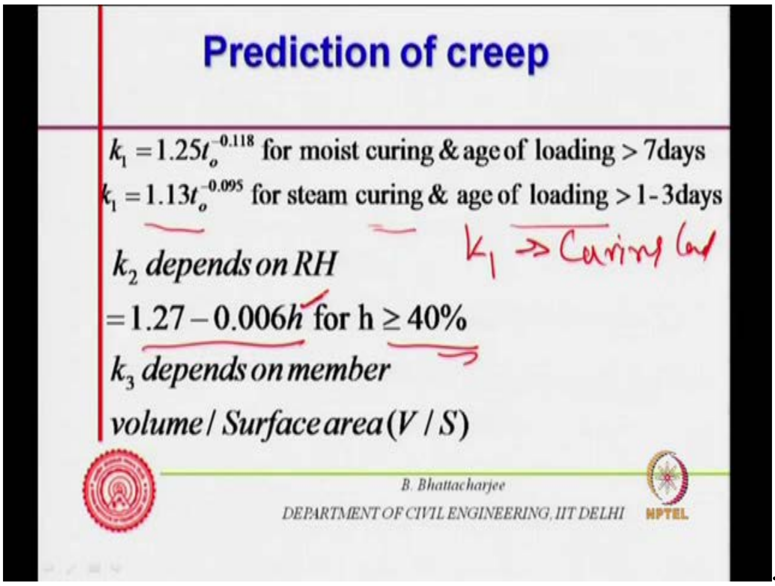

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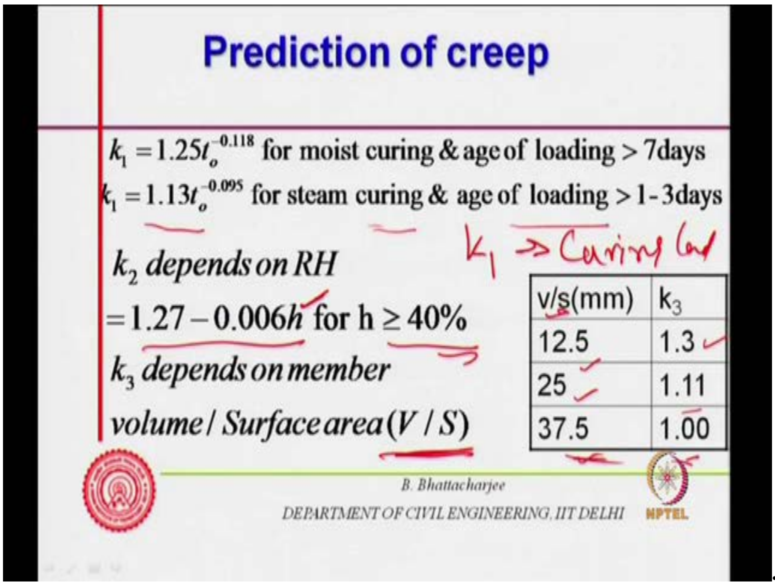

You have a table, part of the table reproduce here. Part of the table, it not really full table. Volume to surface area ratio 12.5, it is 1.3 25. It is 1.13, 7.5 it is 1 0 0. Now, we have seen that more surface area means more creep likely to be. So, lesser this value is you know this lesser this more surface area means lesser this value, creep will be more. This is V by S all in millimeter V in millimeter surface area also in millimeter, so volume to surface area ratio in millimeter.

Apart of the table actually, I have just reproduce you know table is much wider, so one can use this. We have understood why this actually, why this occurs because drying on moisture movement can be easier when you have more surface area. Therefore, when you more surface area, this value is less, this factor is higher. You know remember that we said it is 2.35 k 1, k 2, k 3, etcetera k 6. So, phi infinity at t 0 this is given as you know ultimate coefficient it is a function of k 1, k 2, k 3. So, higher the values of the k 1, k 2, k 3, more will be the ultimate creep coefficient. In other words, more will be the creep.

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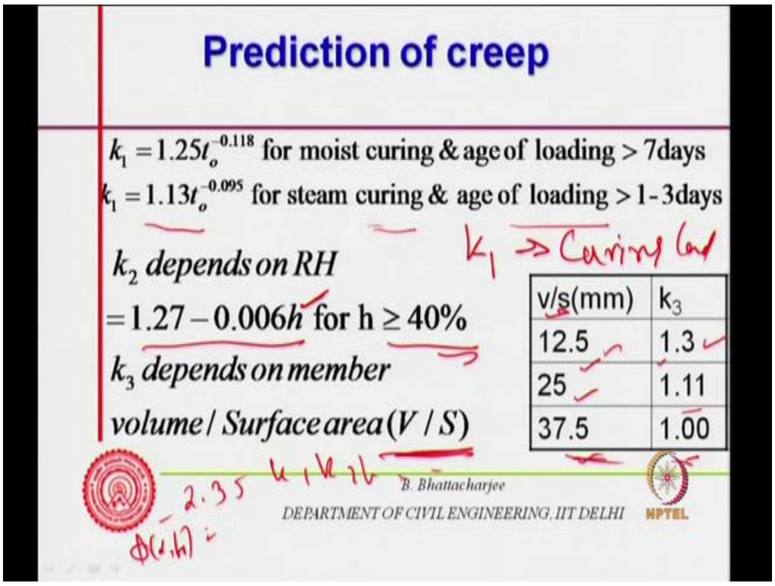

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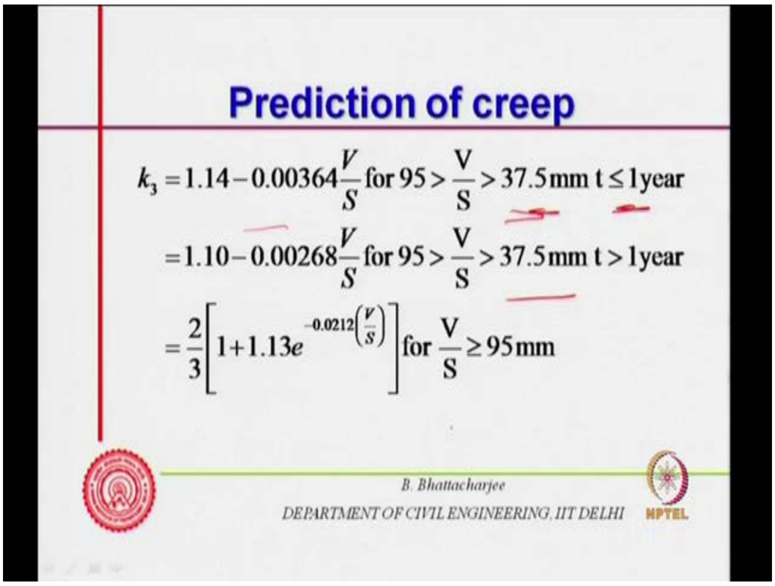

Then, we have k 3, which we said that was related to V by S and V by S you know k 3 is k 3 k 2 was related to relative humidity k 2 was related to this. So, values of k 3 are given and in some cases, it is related to the period of creep also given by this kind of formula.

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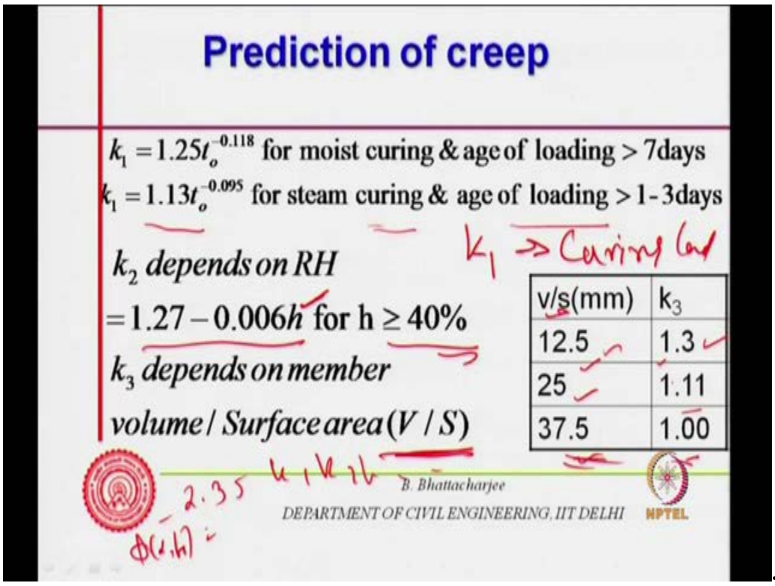

This kind of formula for up to 37.5, this table was good enough up to 37.5; this table was good enough and 12.5 to 37.5. For other values, for other values this formula also given.

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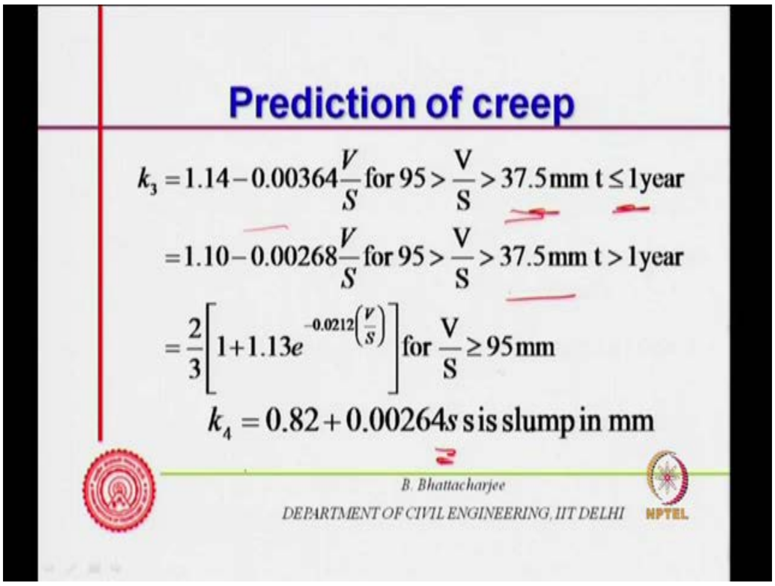

t is more than 1 year, t is less than 1 year. Two formulae are given and V by S is greater than 95. So, greater than 37.5 95 mm, you know those values are given. Now, k 4 is related to the slump of the concrete, in other ways, compaction and you know fallibility concrete or compaction of concrete.

So, a possibility related to water content, so higher water content is higher slump as this slump. k 4 is related to slump of the concrete, which is in terms of higher water content.

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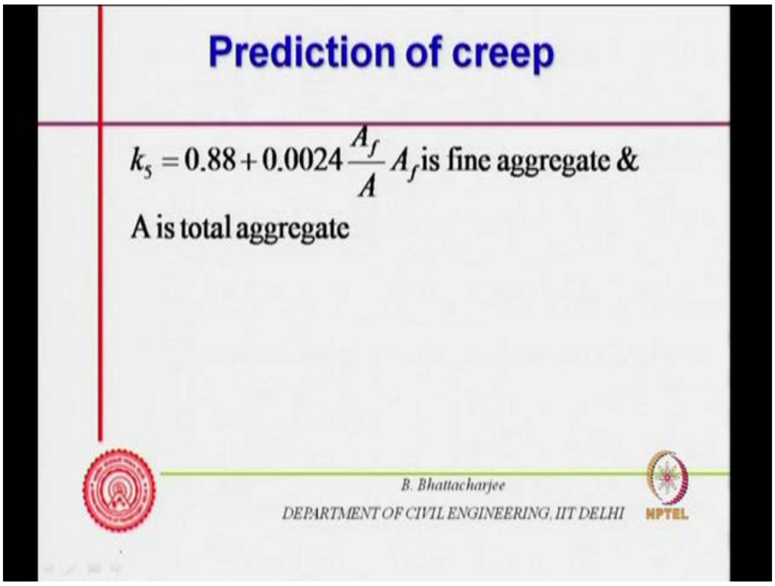

Then, k 4 was related to slump k 3. So, what we seen just repeat it for just repeat it k 1 relates to their very first factor, relates to curing condition. The second factor relates to relative humidity. The third factor relates to volume to surface area ratio. The fourth factor relates to slump of the concrete and the fifth one relates to the aggregate content.

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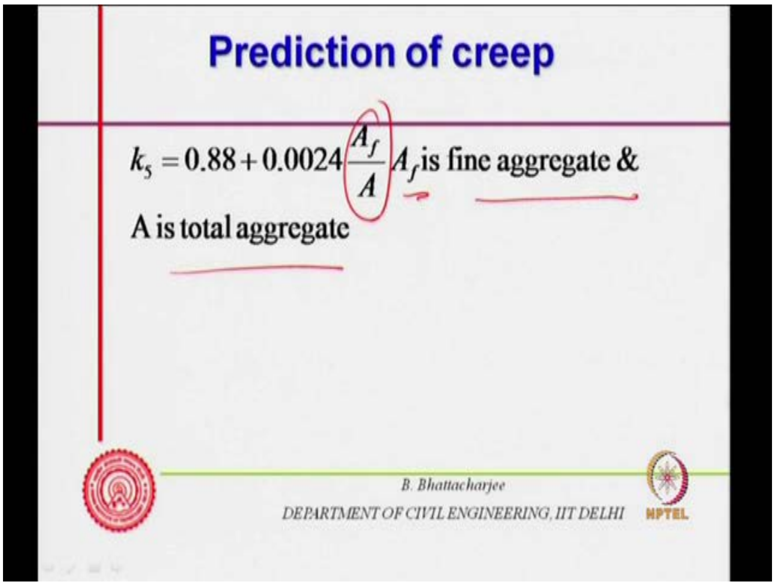

So, A f is the fine aggregate content and A is the total aggregate. So, relatively this ratio is more of the pores aggregate content less will be the creep that is what we have seen. So, because it will be the actually restrain and then for k 5 is related to the proportion of force aggregate in the system. k 6 is related to real content. k 6 is related to real content. Higher real content high will be possibility of more you know water movement. So, therefore, A is the is the air content, so higher the air content, k 6 is higher.

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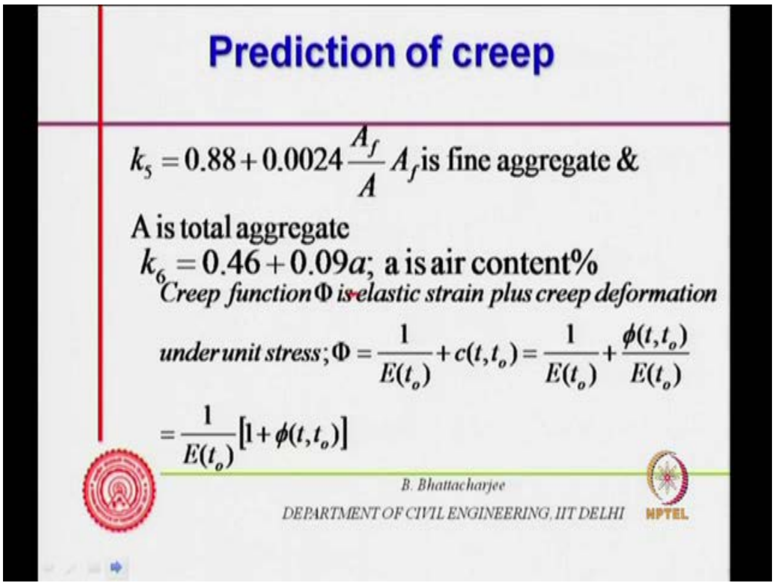

So, what we see is that it all depends upon all this factors and then we defined a term can so what we have seen k 1 curing condition, environmental condition like we can say k 2 relative humidity again environmental condition, k 3 volume to surface area ratio, k 4 slump, k 5 fine to course aggregate ratio, k 6 is there content. So, this is the factors, which is related to then 5, what we have got is five, we got actually 5 that is ultimate creep coefficient, which I can multiplied by multiplying factor, which is a function of t minus t 0.

I can get this the creep coefficient at any time. If I know the creep coefficient at any time, I can find out actually creep at any time multiplied by elastic strain, for unit stress. Creep function 5 is elastic strain plus creep deformation. So, creep function is elastic strain plus creep deformation.

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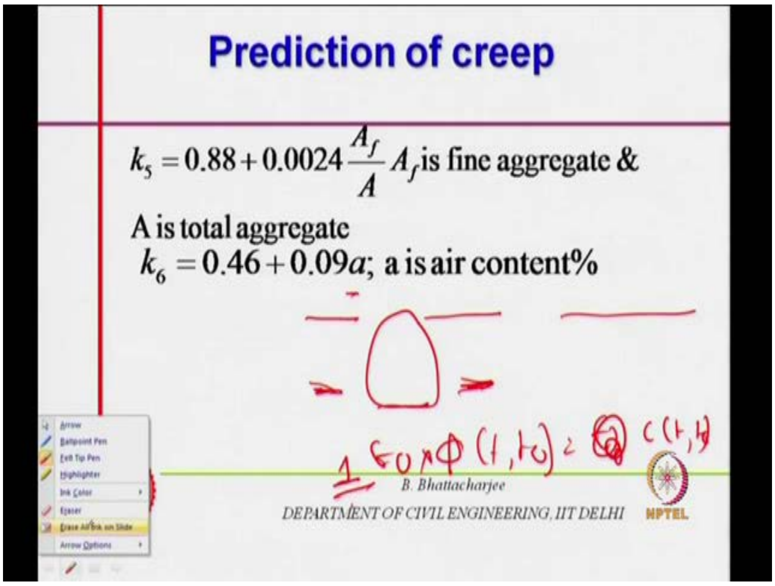

So, under unit stress 1 divided by this is epsilon 0 under units stress and this is creep. Now, this is can be related to units stress because which said you know phi t t 0 was nothing but epsilon 0, epsilon 0 multiplied by c is equal to c t t 0. So, therefore, this can be you know this is epsilon 0 is nothing but this is nothing but 1 divided by E. So, this can also be let me just rewrite this let me just rewrite this separately, what we said was creep function is 5.

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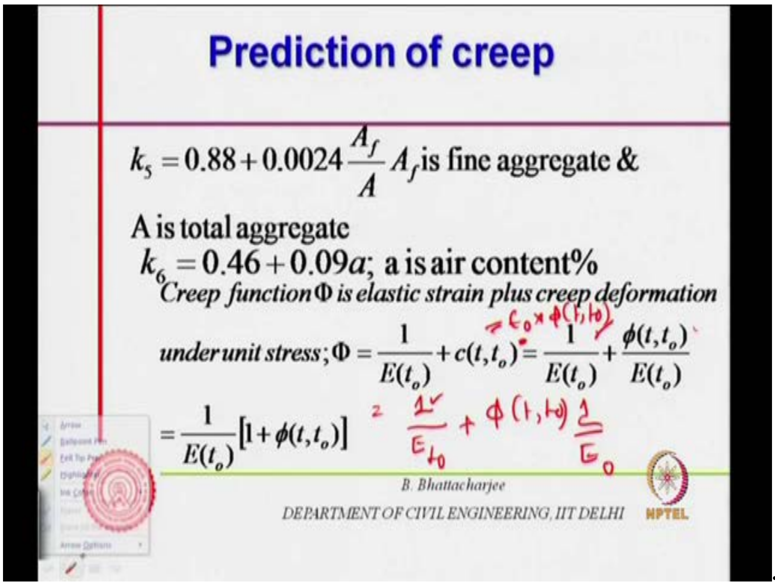

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It is given as 1 by you know this is c plus, this I can write as 1 for unit stress, all is elastic strain plus creep for unit stress. So, epsilon t 0 unit, so this is elastic strain plus this can be written phi t t 0 multiplied by 1 by E 0. So, therefore, you see that this is one. What is this is basically, you know c can be written as a epsilon 0 multiplied by phi t by t 0 and epsilon 0 is what 1, our E 0, so I just can replace it like this.

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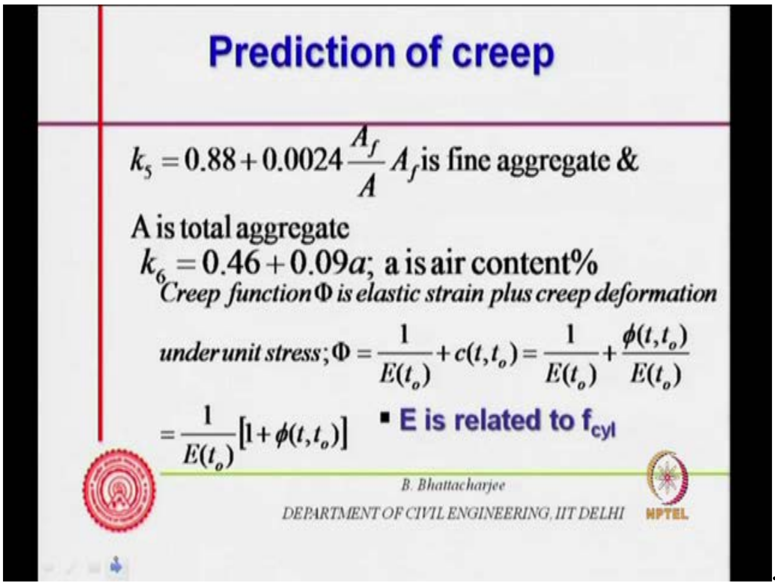

So, therefore, I can write, I can write this whole thing, the creep function as 1 by E T 0 1 plus phi you know this E T 0 can be taken common modulus of elasticity at that time and this is what it is 1 plus creep. So, this is for unit stress creep function unit stress and that is how I can estimate. So, E is related to cylinder stress, this E is can be related to cylinder strength because we know it is 5000 and cube strength was 5000 under route of c k. So, E related to cylinder strength by a formula and one can obtain this.

So, that is how we can predict the creep function, which is for unit stress at any time t. So, that is prediction of creep will have more of the prediction in the next class. In this class, therefore, what we have understood is this lecture? We understood is creep and relaxation, we have looked into mechanism and we have looked into factors effecting creep, and some part of the prediction. Rest of the prediction, some more of the prediction we look into the next class and then will look into measurements and so on.

Now, as per as prediction is concerned, just I like to mention one more thing at the moment, we have come up to creep function through which I can predict the creep 4for unit stress. So, with these, we conclude our lecture.

Thank you very much.