Geology and Soil Mechanics
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Lecture - 34
Consolidation - D

Welcome back. So, in the last lecture we were discussing about the consolidation phenomena and we have derived the consolidation equation the 1D consolidation equation and the solution yields in the last lecture we have seen the solution yields this thing this expression.

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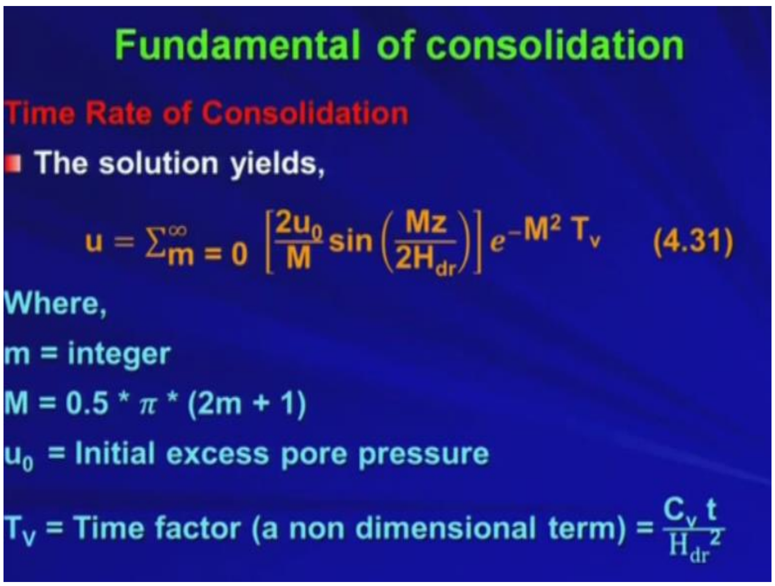

So, equation 4.31 we have established in the last class right or the last lecture. So, basically in this from this equation I mean what you are getting you are getting the excess pore water pressure at any point of time and at any location along the depth of the or along the thickness of the deposit right. So, and we introduced one new term that is T v that is a non-dimensional term and this is equal to your C v into t divided by H dr square right. So, where C v is nothing but your coefficient of consolidation, t is the time and H dr is the half of the thickness of the deposit.

Now this time factor is very important parameter. We will see later on I mean for calculation of your excess pore water pressure and particularly to calculate the settlement and degree of consolidation and other things okay. So, this equation is my backbone equation you can say by which we can determine the excess pore water pressure due to 1D consolidation okay. So, once you know the excess pore water pressure and how it is getting dissipated you can get other information like how your effective stress is getting enhanced and effective stress is getting built up right.

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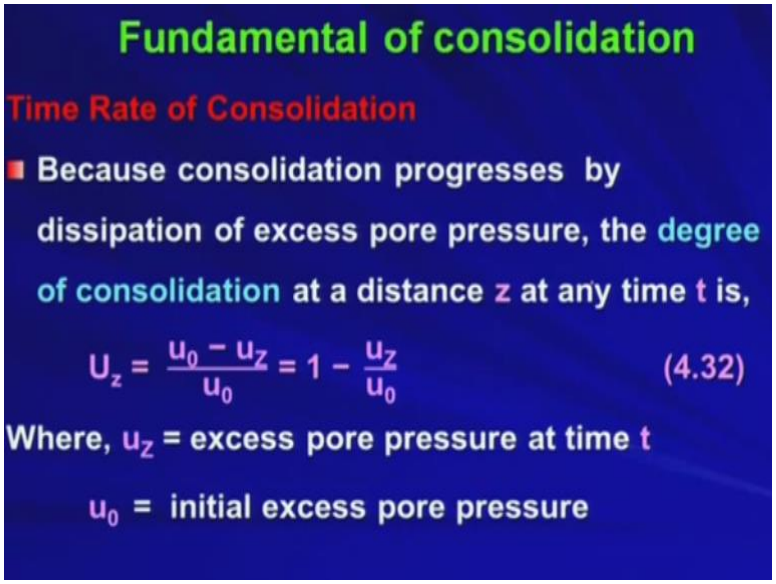

Now because consolidation progresses by dissipation of excess pore water pressure the degree of consolidation at a distance z at any time t is given by say U z capital U z is the degree of consolidation. That means I mean if I say my degree of consolidation is 100% that means the soil is completely consolidated okay. So, it is the progressive process right. I mean starting from t equal to 0 so you are I mean continuously I mean with the same amount of say I mean increment of stress or the stress total stress increment.

So, you are getting gradually the dissipation of pore water pressure excess pore water pressure and you are I mean getting enhancement in the effective stress. So, that is the progressive or the gradual process right. So, in that process you need to know at any point of time or any at any location say z okay so I mean now you recall that z is defined from the bottom of the I mean layer of concern and then basically at any depth at any location z if you want to find out what is my degree of consolidation how much the consolidation happened.

So, that thing basically will be obtained by this equation. So, what is U z that is the degree of consolidation is nothing but u not minus u z divided by u not right so where u not is nothing but the initial excess pore water pressure and u z is nothing but the excess pore water pressure at time t. So, you are trying to find out the degree of consolidation at any depth say z and basically you find out u z that is the excess pore water pressure at that location at any point of time t okay.

So, once you know u z that means that is the excess because the I mean u z will be of course your will be less than u not right.

The initial pore excess pore water pressure will be always higher and gradually it will be dissipating out and that thing already we have seen. So, u not minus u z so the initial whatever you had and now at any point of time say t whatever say excess pore water pressure you are having that is u z the difference between these 2 with respect to the initial excess pore water pressure will be giving you the degree of consolidation okay. So, this much will be the consolidation happen at any point of time. So, that is nothing but 1 minus u z by u not. So, that equation is very important equation so we will see later on.

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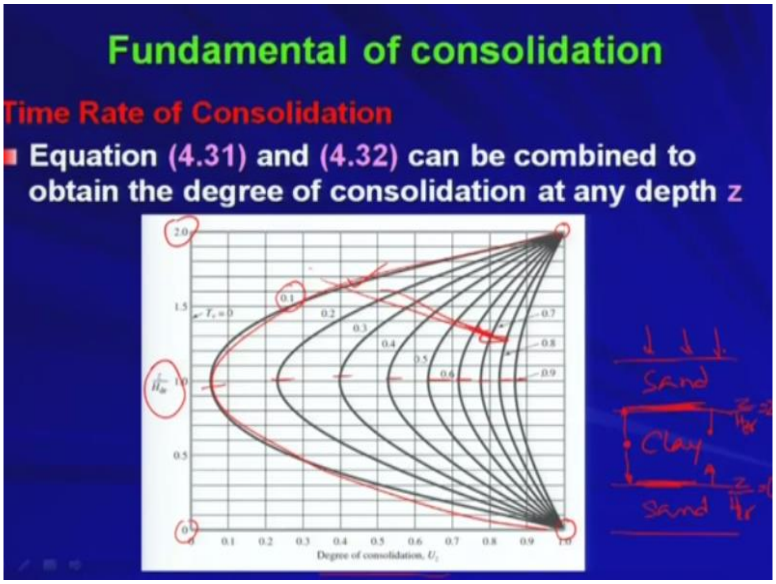

So, equation 4.31 that means the equation what was giving me the excess pore water pressure in terms of say initial excess pore water pressure and say time factor all those things that is the fundamental equation. So, that equation 4.31 and just now whatever we have seen equation 4.32 can be combined to obtain the degree of consolidation at any depth z am I right.

So, now it can be combined to obtain the degree of consolidation because the equation 4.31 will give me the information about the excess pore water pressure at any point of time at any depth z and the equation 4.32 will give me the information about the degree of consolidation at any depth z at point of time t right and if you combine these 2 equations you will be getting the idea or getting the say I mean information about the degree of consolidation at any depth z.

Now if you look at this problem so basically along y axis we are plotting z by H dr that is the normalized depth okay with respect to H dr and along x axis you have degree of consolidation u z. Now the what was the total depth of the I mean whatever the total thickness of the soil sample rather. So, that was twice H dr. So, that means basically z is varying from 0 to 2H dr right. So, that means the normalized factor z by H dr will be varying from 0 to 2.

So, within that you have the soil or the clay deposit saturated clay deposit. Now if you recall that saturated clay deposit is getting sandwiched between 2 sand layers on top of the clay layer you had the sand layer and at the bottom of the clay layer you had one more sand layer right. So, those sand layers are basically facilitating the drainage right. So, I mean in other way if you look at so basically those along those surfaces the interface between the clay layer and the sand layer at top as well as at bottom basically your pore water excess pore water pressure will be immediately zero.

That means if you increase the load okay immediately you will be getting 100% consolidation or the degree of consolidation will be 100% at those locations am I right? because that at that location so this is this was the deposit right so if you recall this is your this was your sand and this was your sand and this was your clay which the layer which is a matter of concern right. So, along these surfaces and this is basically at that location your z by H dr was 2 and at that location z by H dr was equal to 0 right. So, this is varying from 0 to 2.

Now at these surfaces basically at the interface between sand and clay layer basically you if you see that drainage is not a problem so if you load the soil immediately the drainage will be happening the water will be expelled out at that location. So, that means once you are applying some excess pressure or the excess load and immediately if water or the excess pore water pressure is getting dissipated then the consolidation will be happening as 100% am I right.

So, at that location whatever excess or pressure or extra load or extra load you are applying because of that you will be getting 100% consolidation always at these locations right because immediately water will be expelling expelled out from the clay layer. Now as you go deep and deep so you have 2 different say conditions. One is that as you move from say from this boundary to the middle of the layer and as you increase the time so there are 2 things one is the time another one is the how you are getting the getting the distribution of the excess pore water pressure.

Now for example say if T v equal to I mean 0.1 that is the time factor is 0.1. At some time because T v is nothing but C v into t divided by H dr square right. C v and H dr both are say I mean for a particular deposit so that will be a that will be kind of constant right. So, now basically at certain time what will happen so this will be your say at T v equal to 0.1 say this will be your excess pore water pressure distribution at the degree of consolidation the plot of degree of consolidation right.

Now that I mean degree of consolidation is nothing but I mean it will give you the impression about the excess pore dissipation of excess pore water pressure. Now what does it mean? See if you see this curve will give you the degree of consolidation. Now at z by H dr equal to 2 you are getting 100% degree of consolidation. That means u z equal to 1 right. Similarly, you will be getting u z equal to 1 at H z by H dr equal to 0 because water is immediately draining out so you will be getting the excess water pressure will be immediately becoming 0 and you will be getting 100% consolidation at those location as I told you.

So, whatever may be the case or whatever time you consider right or whatever say time factor you consider so always at the interfaces you will be having 100% consolidation okay degree of consolidation will be 100%. So, that is what the u z is equal to 1 at the interfaces. Now as T v increases right so this is the as T v increases you are getting the higher degree of consolidation but if you look at as you are at the surface of the clay layer that means surface of the clay layer means either on the top surface or on the bottom surface your degree of consolidation is 100%.

However, this degree of consolidation is reduced right at the so at the middle you will be getting minimum degree of consolidation right. So, at the middle you will be getting minimum degree of consolidation. So, at any point of time if you look at the distribution of degree of consolidation along the depth along the thickness of the layer so basically you will be getting the maximum degree of consolidation at the interfaces.

That means at the drainage face okay and you will be getting minimum degree of consolidation at the middle of the layer because at the middle of the layer if any water particles if you consider this water particle will take some time to go either on the top or towards the bottom say interface to drain out from the I mean soil or the clay deposit right. It will take some time. So, that is why the degree of consolidation will be minimum at that location because degree of consolidation is directly related to the how the water is getting or the excess pore water pressure how it is getting dissipated right.

So, as T v increases your degree of consolidation is increasing that you can say if you move in this direction as I showed by this arrow so if you move in this direction as T v increases that means as time increased basically your degree of consolidation also increases but at the same time your degree of consolidation will be maximum at the interfaces but it will be minimum at the middle of the deposit right and gradually it is increasing right.

So, you have 2 different parameters. One is the time another one is the I mean thickness of the deposit, clay deposit right. I hope that you have understood this thing. So, now this is the distribution. Now in that way basically your degree of consolidation will be varying as well as your excess pore water pressure will be also varying.

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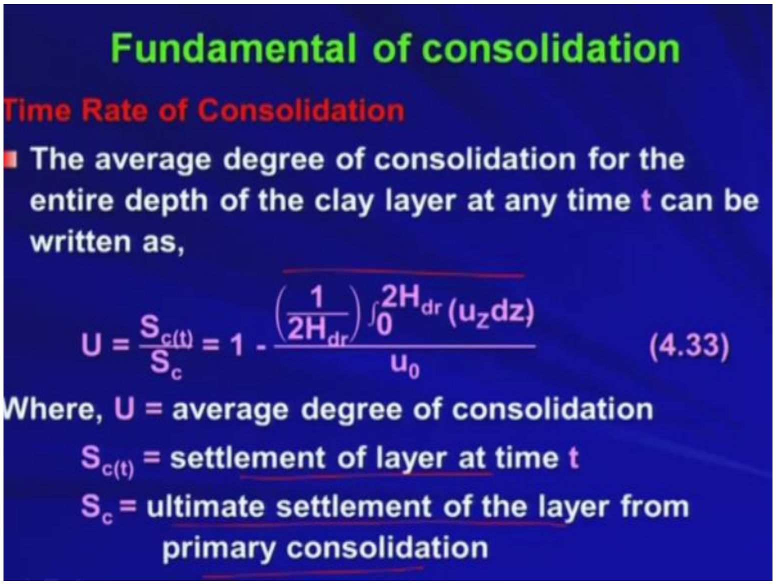

Now the average now basically you have seen that degree of consolidation is varying with depth right. So, degree of consolidation is not a constant for the whole deposit. So, if I consider this is my soil deposit or the clay deposit, saturated clay deposit, I cannot say my degree of consolidation is at a particular time my degree of consolidation is constant for the whole deposit no right. Already we have seen.

It will be maximum at the boundaries and it will be minimum at the center of the deposit. So, we can think of some average kind of degree of consolidation because I need that to talk about the degree of consolidation for a particular deposit. So, the unless until you go for the real distribution you always think about the average kind of degree of consolidation. What is the average degree of consolidation for that particular deposit.

So, the average degree of consolidation for the entire depth of the clay layer at any time t can be written as U equal to S c t divided by S c. What is S c t? S c t is nothing but settlement of layer at time t okay and S c is nothing but the ultimate settlement of the layer from primary consolidation. Am I right? So, after I mean at the end of the primary consolidation what is the ultimate settlement.

That means when your degree of consolidation is 100% at that time what is your ultimate settlement. So, that is the maximum settlement you can have from the primary consolidation. Now S c t is in between. As time progresses you are getting higher settlement and slowly it will be equal to S c right. So, S c t at any point of time S c t divided by S c this ratio will give you the degree of consolidation which is nothing but 1 minus now what is this I mean if you see the equation 4.32 so 1 minus u z by u not that was there right.

That means what is u z? u z is nothing but excess pore water pressure at time t that is the average kind of excess pore water pressure for the whole depth say if I consider. Then basically this expression the numerator will give me this average kind of excess pore water pressure right. So, that means u z into dz u z is the excess pore water pressure at any depth z okay into dz which is integrated over 0 to 2H r.

2H r means the total depth of the clay deposit you are considering. So, you are integrating over the whole thickness of the clay deposit divided by the 2H dr will give you the average excess pore water pressure so at any time t divided by u not is nothing but your degree of consolidation right. If you come back from equation 4.32 this will be the expression okay.

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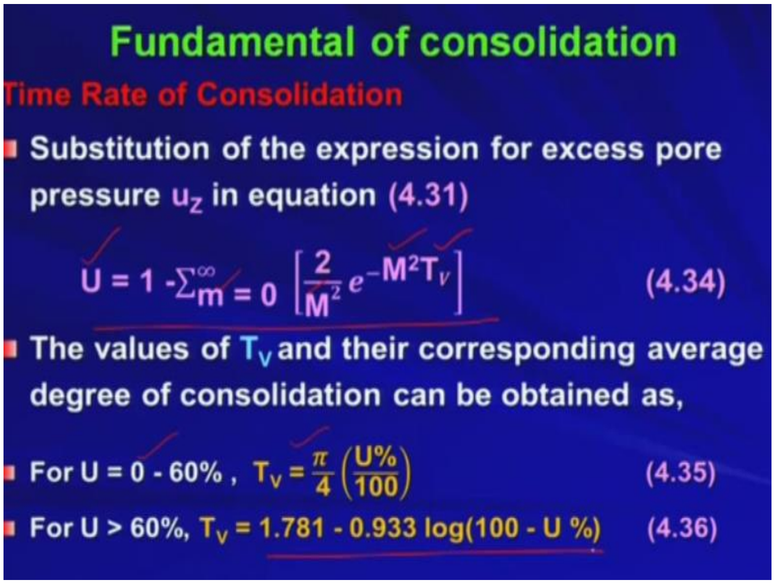

So, now substitution of the expression for excess pore water pressure u z in equation 4.31 that is the fundamental equation whatever we have derived for 1D consolidation then we will be getting the degree of consolidation average degree of consolidation rather is U capital U is equal to 1 minus m equal to 0 to infinity into 2 by M square capital m square into e to the power minus M square T v. So, these terms capital M, T v these terms already we have defined right and small m is already defined that is an some integer okay. So, if you know these things or if you put all these values you will be getting the magnitude of average degree of consolidation at any point of time t okay.

Now the values of T v that is the time factor and their corresponding average degree of consolidation can be obtained as if U equal to that is the average degree of consolidation if it is 0 to 60% then your T v can be obtained or T v can be calculated as pi by 4 into U in percentage of course divided by 100 or if U that is the average degree of consolidation if U is greater than 60% then T v will be calculated from this expression okay. So, that means if you know the degree of average degree of consolidation capital U then you can calculate T v that is the time factor. So, once you know T v you can find out other parameters. We will when we will be taking some numerical problems you will appreciate that how these equations are getting used okay.

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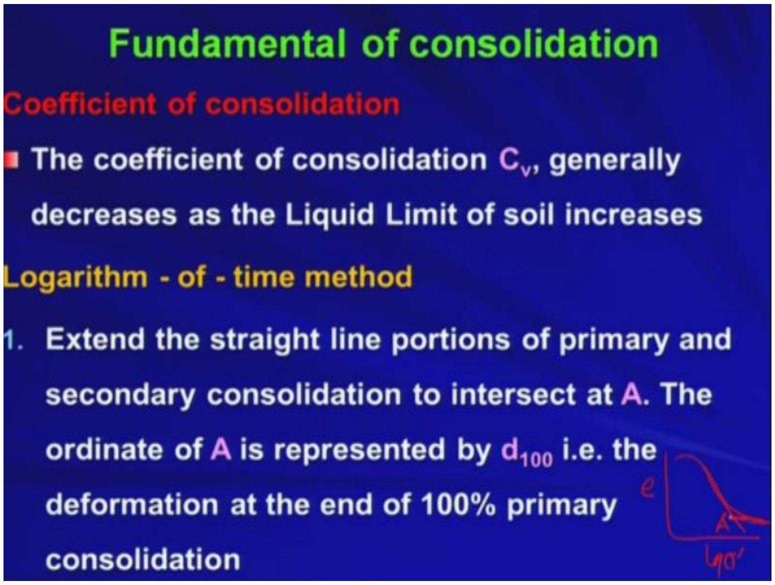

Now the coefficient of consolidation C v because that is another important term. So, C v you can remember, I hope you can remember right. The coefficient of consolidation C v generally decreases because I need to find out coefficient of consolidation right. So, if know the coefficient of consolidation then other parameters I can find out. So, how to obtain coefficient of consolidation from your consolidation curve or the e-log I mean e-log sigma prime curve so that is nothing but my consolidation curve.

How I will get the coefficient of consolidation from the consolidation curve. So, let us find out that. So, before that the coefficient of consolidation C v generally decreases as the liquid limit of soil increases. So, this is true for any kind of say plastic soil that means clayey type of soil. So, generally it decreases C v generally decreases as the liquid limit of soil increases okay. So, anyway.

Now there are now 2 methods by which you can find out the coefficient of consolidation C v. One is the logarithmic of time method another one is the square root of time method. Now first one I will discuss. So, logarithmic of time method, what is that? Now in the consolidation curve basically extend the straight the straight-line portions of primary and secondary consolidation to intersect at A right.

So, you remember you have say e-log sigma prime curve so basically you are getting something like that right. So, basically what it says you this is your primary part and this is your secondary part you extend this part and this is the point say A. So, extend the straight-line portions of primary and secondary consolidation to intersect at A. The ordinate of A is represented by d 100 okay. The ordinate of A is represented by d 100 that is the deformation at the end of 100% primary consolidation.

That means this point A will tell about the separation from primary consolidation and the secondary consolidation. That will separate it out right. So, just on the left side of A you will be getting primary consolidation and just on the right side of A you will be getting secondary consolidation. So, that means at point A whatever deformation is happening that deformation is happening due to the 100% primary consolidation and that is nothing but your you can say that my degree of consolidation is 100%, average degree of consolidation is 100% at that point okay.

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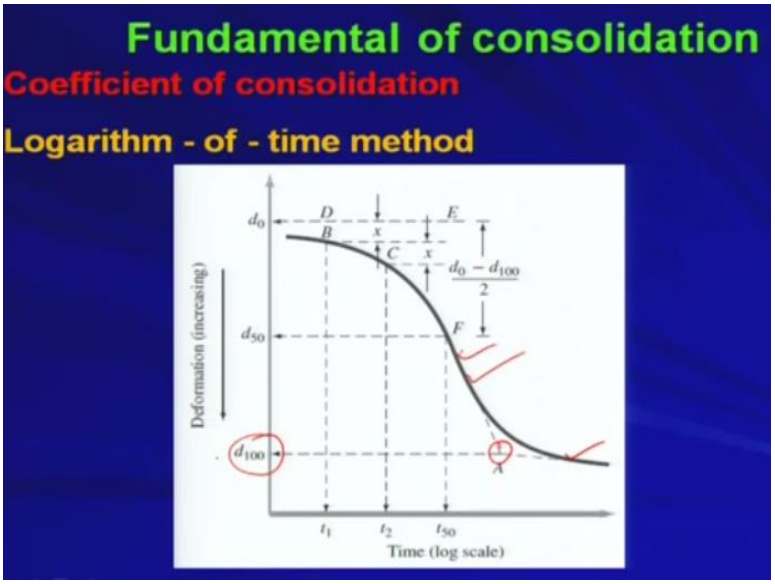

So, now basically if we look at the figure whatever I said you so this is the curve okay so this is your E or the deformation so E nothing but proportional to deformation right. So, deformation versus time scale okay. So, now basically we are plotting that thing with time scale okay, so deformation versus time. Now I mean as deformation increases right your as time increases rather the deformation also increases.

Now basically this is your primary part, this is your secondary part whether you are plotting with e-log sigma prime or sigma prime plot or E I mean deformation versus time slot. So, it will be looking like more or the same right the consolidation curve because the I mean consolidation is a function of time right anyway. So, this point once you establish this point, at point A, A will correspond the deformation of d 100 where you can say that 100% primary consolidation is happened okay.

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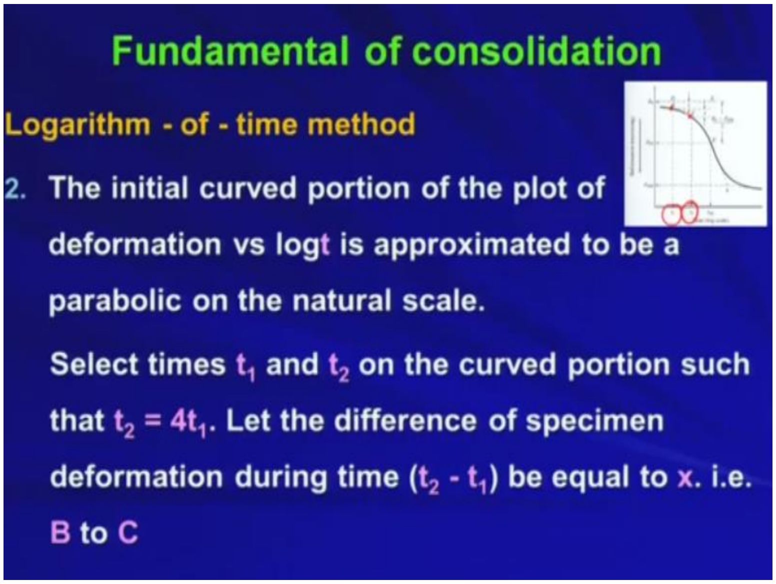

So, now what we are doing? Now the initial curved portion of the plot of deformation versus log t is approximated to be a parabolic on the natural scale okay. So, that is nothing but I mean we are approximating that thing as a parabolic plot okay. Now select times t 1 and t 2 so we are considering we are I mean selecting 2 times t 1 and t 2 on the curved portions such that on the curved portion such that t 2 is always equal to 4 of t 1. That means t 2 is nothing but 4 of t 1 right. Now let the difference of specimen deformation during time t 2 minus t 1 be equal to x. That is nothing but B to C.

So, at t 1 the deformation was here. At t 2 your deformation is here. So, I mean the difference between these 2 points B and C is nothing but x and which is nothing but the difference of specimen deformation during time t 2 minus t 1. So, at t 1 the deformation was at point B and at t 2 the deformation has reached point C so the difference between these 2 points that is small x will be the difference in deformation in the soil for time t 2 minus t 1. This within this time this is the difference in deformation okay.

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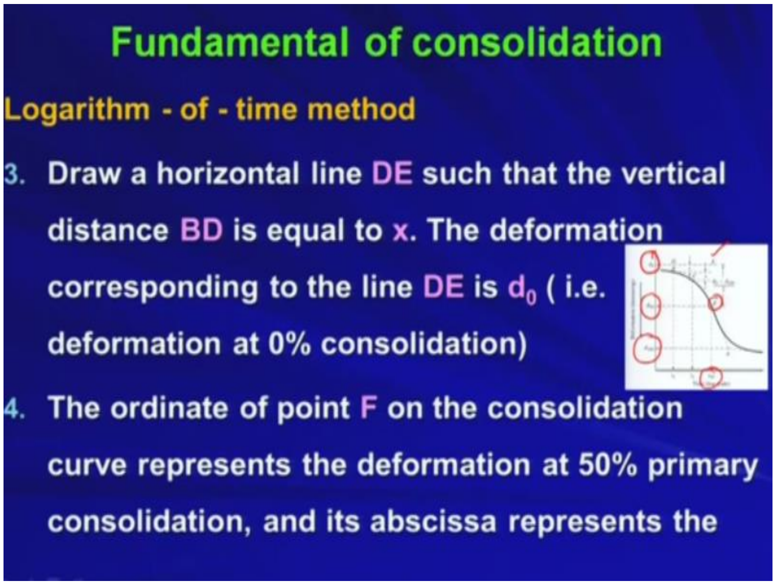

Now draw a horizontal line DE okay. So, draw a horizontal line DE such that the vertical distance BD is equal to x okay. So, BC the vertical distance between B and C is x and we are plotting another horizontal line DE such that the BD the distance between B and D point is x same amount okay. The deformation corresponding to the line DE is say d not that is deformation at 0% consolidation okay.

So, this is very important. So, this is something like this is this is observed from the experience and as well as from other techniques that this DE will represent the 0% consolidation line that is d not. So, now you have got d not that means 0% consolidation. You have got the point d 100 that is 100% consolidation. So, that means you are in between these 2 points. So, 0% to 100% consolidation.

Now the ordinate of point F on the consolidation curve represents the deformation at 50% primary consolidation okay. So, now we are choosing one point F on the consolidation curve such that it will be representing the 50% consolidation okay and its abscissa represents the time required for 50% consolidation right. So, t 50 is nothing but that is t 50 so I have written t 50 here. So, the 50% consolidation will be happening at point A and for that how much time is required say t 50.

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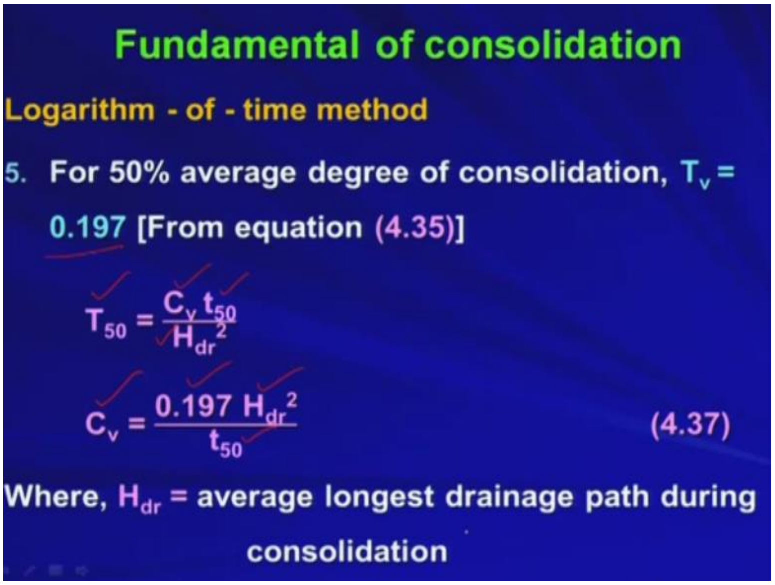

So, for 50% average degree of consolidation T v that is the time factor can be calculated as 0.197 from equation 4.35. So, if you go to your equation 4.35 you can calculate T v right because I mean from 0 to 60% for degree of consolidation you have got some expression for T v and from when U is greater than capital U is greater than 60% then you have got some another expression for calculating T v right. So, that hope that you can remember, just now we have seen. So, from equation 4.35 we can calculate T v and which will be coming as 0.197 for 50% average degree of consolidation.

So, once we know T v that means I know this t 50 that is the time factor at 50% consolidation. C v is not known to me, I am going to find out that; t 50 is known to me just now from the curve we have established that what is my t 50. I know the thickness of the deposit so that I mean if I know the thickness of the deposit which will be consolidating then I should know the what is my magnitude of H dr. So, once I put all those things basically I will be getting C v where H dr is nothing but the average longest drainage path during consolidation right.

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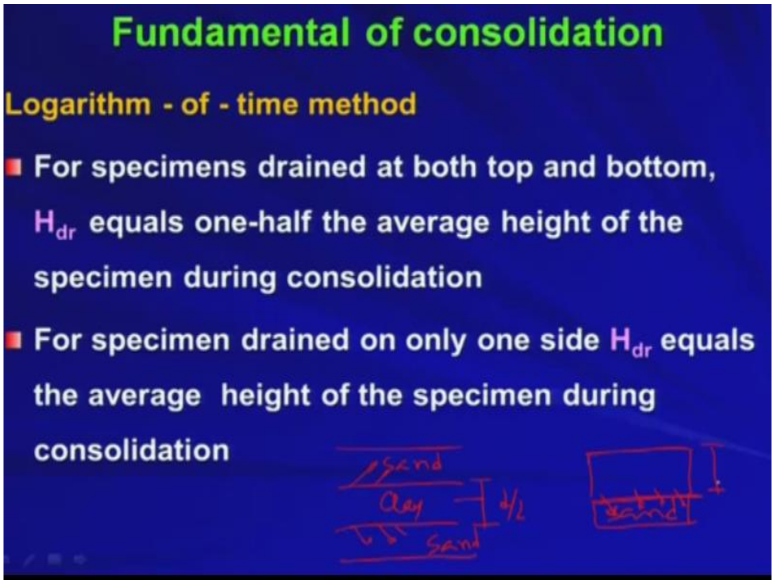

Now let us talk about the H dr. Now for specimens drained at both top and bottom H dr equals to one half the average height of the specimen during consolidation okay whereas for specimen drained only one side H dr equals the average height of the specimen during consolidation. So, what does it mean? So, you can have this kind of situation. So, this is your clay, this is your sand. That means the water can move in this direction or water can move in this direction if it is also sand. That means you have got double drainage system. That means you have got the top I mean surface that is also that will be also facilitating drainage as well as the bottom surface that will be also facilitating drainage. In that situation, the H dr equals to one half of the average height of the specimen okay I mean one half of this average height okay.

So, if this is my total height so average height will be one half of that. But if you have this kind of situation. This is your say clay deposit okay and you have some sand deposit at the bottom okay. So, in that situation water will be only allowed to go out through this bottom surface or it can have on the top surface if you have the sand layer on the top. So, that means you have the single drainage system. So, in that situation the total depth will be considered as the drainage path or the specimen will be drained out only on this path okay.

So, I hope that you have understood this thing. So, in the next lecture we will be talking about the next I mean another type of procedure by which we can calculate C v and then we will be taking a couple of numerical problems. Thank you very much.