Geotechnical Engineering II / Foundation Engineering
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Lecture - 05
Quick Review of Soil Mechanics (Contd.)

Good morning. Once again I welcome you to this lecture series Foundation Engineering. And as I have mentioned from the beginning, that I will be doing Quickly Review on Soil Mechanics. And today is for fifth part, and where I will talk about the compressibility of soil.

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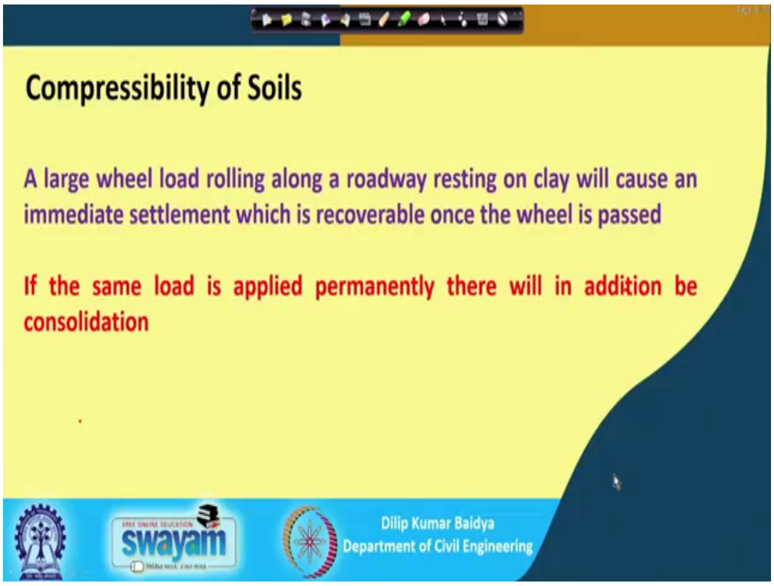

And this compressibility means what? Actually at the beginning I have told that any material if you apply load, then it will subjected to compression or elongation. Particularly if it is a elastic material like a rod suppose, and if you pull by load from the both end, then it will be elongated; or if you push from the both ends then it will be shorten. So, this is because of the elastic properties of the material. And when we will talk about the soil, the soil not only it behave elastically, but also will have another mechanism for compression of soil.

As I have mentioned you that the soil is consist of soil, consist of solid particles and voids. and these voids when is too much is there, then the soil will be having larger volume; and when it will be having less voids, then it will have minimum lesser volume.

So, as a result soil in the natural state will have both voids and solids. And when we will apply load, then there will be a chance of reducing the voids. And by that way, the volume will be reducing.

And this volume reduction can be done in the two different ways, one is actually by compaction that immediately we apply the load; and then force the particle to come closer, and then by that way reducing the void ratio that is one way of reducing the voids. And another in another thing happen in saturated fine grain soil, where when we apply a load, and then because of the incompressible nature of both soil and solid particles, then there will be development of excess pore water within the void spaces.

And this excess pore water pressure cannot stay for long, they will always will have tendency to dissipate and water will come out and pressure will be reduced. So, the soil mass and within the soil mass, there are number of voids and those interconnected void spaces will be acting as a as channel and through that water will pass when it will be subjected to a load. So, that is the another mechanism how the volume change take place, and another mechanism is elastic.

So, these two examples are here when a large wheel load rolling along a roadway resting on clay will cause an immediate settlement which is recoverable once the wheel is passed. That means, when if the on the you might have noted when there are all by trucks are moving on the road or even rail, your trains moves on the railway track, then you will see there will be depression immediately. And when move we will passed away then the place that then again it will be coming back almost in the original position this is because of the elastic nature of the material.

And where as if you keep that wheel load for a long time on a fine grained soil, then there will be another where the soil will deform that is actually consolidation, which I have just explained briefly. So, this consolidation means what actually that when you apply load, then pore pressure will develop and then slowly the dissipation of pore pressure and then change of volume that is the thing it happening in the soil.

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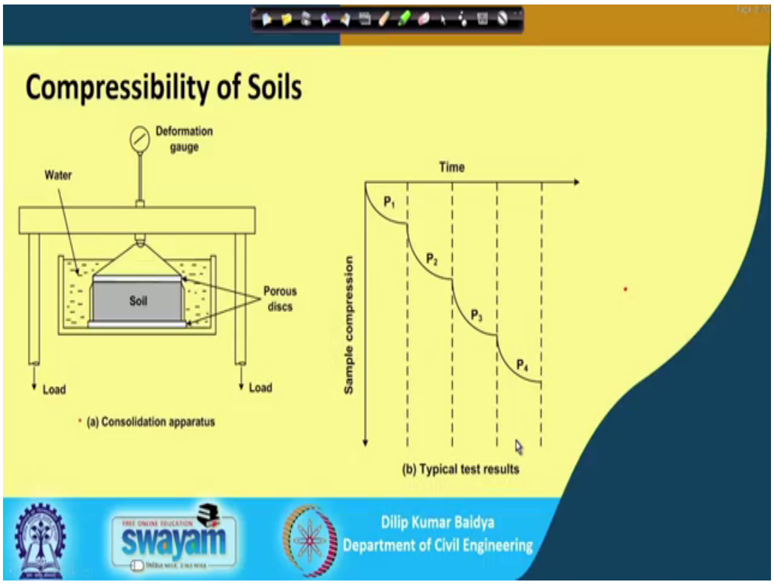

So, this is suppose a particular soil sample with carrier we generally conduct the test in the laboratory by preparing a sample. And we put it in the saturate condition and then we apply load. And when we apply load then immediately as I have mentioned that within the soil mass that if this is the soil mass suppose, there are number of voids, and those voids are filled up with water and that water will be pressurized when we apply load. And this pressure will not sustain for long because of this interconnected void spaces through that water will slip, and as a result is the pore pressure will reduce. And when pore pressure will reduce then whatever load we have externally applied, that load will cut the soil grain and that will cause you the compression of the soil.

And the compression is actually measured by void ratio that I will discuss subsequently. And again this consolidation again is not a is a onetime phenomena. Suppose, a soil is there, a saturated soil and you have applied 100 ton or 100 kilo Newton load. Then under these 100 kilo Newton load, whatever excess pore water pressure will develop, and if it dissipates that is the end of consolidation under that load.

And again after that another 100 kilo Newton load if we apply, again we will start consolidating, and of course, rate of consolidation may become less because soil already consolidated. Similarly, after second set of loading when the completely pore pressure dissipated, then that is the end of consolidation under second set of loading.

And then again if you apply another load, then again pore pressure will develop, again dissipation of pore pressure will takes place, then again consolidation takes place like that. If it that means, in the consolidation under certain load it is not a that means, I have applied a load and consolidated means that soil is ultimate consolidation is happening happened that is not true. Under certain load whatever possible that consolidation will lower.

Again if you apply more load, then again the consolidation will take place. But again second time, third time, fourth time, if you go subsequently the amount of consolidation settlement may reduce because already it is consolidated and got compacted. So, that is the way if we do that this can be visualised like that under that load P 1. Suppose this is a compression under at what time. Again if I put P 2 here, then under that there will be compression over time.

So, when you go that P 1, P 2, P 3, if this is same, then when you go towards end, the time taken by this same amount of compression will be more because of the soil getting compacted and interconnected path will be narrow and dissipation will be slow. As a result when you will go towards a later stage, your compression rate will be reduced.

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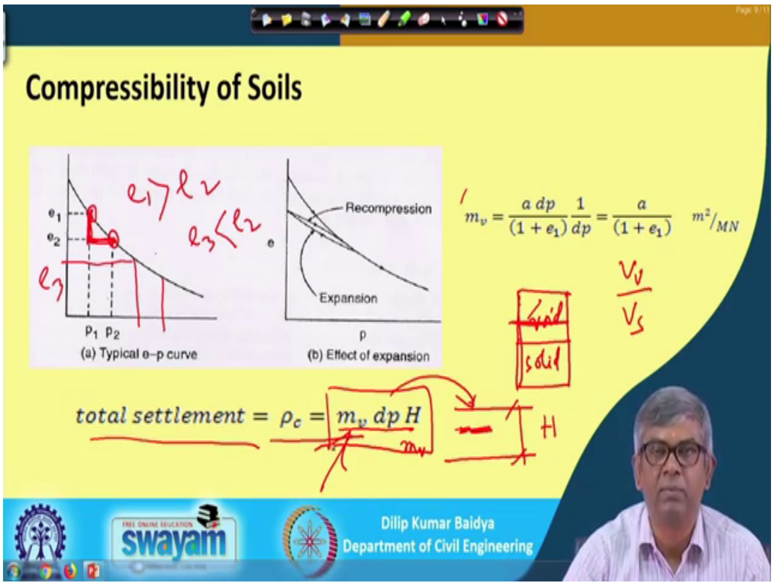

And the as I have told you that this compression will be measured by volume sorry void ratio change actually. Because as I have told you that if the soil is visualised like this in a particular condition suppose this is the soil total volume, and if this is the solid, and this is suppose void, this is void, and this is solid and this void will be reduced. And our definition of void ratio is volume of voids V v by V s. So, V s is unchanged. So, V v is changing. So, void ratio will be changing.

So that is what we generally this will help us to study some of the things because of that we the volume change we measure by change in void ratio. So, like that if you see the p 1, p 2 like that if you go on increasing like this, and then void ratio will be changing. And of course, at lesser void, lesser load, void ratio be high. And when we will be increasing the load, then subsequently void ratio will be reduced. So, this e 1 will be greater than e 2. Like that similarly if I say this is the one e 3, again it will be e 3 again will be less than e 2.

So, like that with increase of load, then void ratio will be slowly decreasing. And this actually sometime the e versus p curve it is called and slope of this curve that d by d p is a. And then from there I can get a parameter that is called a over 1 plus e and that is defined as m v. And if you know the m v of the soil, then we can find out the total settlement as m v d p into H. Suppose, this is a soil layer like this, and suppose the property of the soil or volume compressibility is m v, and suppose d p pressure is applied at the middle of the clay layer, and thickness is H.

If thickness is H, and pressure applied at the average pressure applied over the layer is d p, average pressure thickness is H, and m v of the soil layer is the this is given suppose, then we can find out under this d p pressure how much total compression will take place or settlement will take place, so that this is the expression. This is one way of calculating the amount of consolidation.

And for finding out this consolidation settlement, what you need to what you need to evaluate for the soil, you have to evaluate for the soil m v property. How to find out the m v? You have to you are you can apply a suppose p 1 load, and then you can see at the end what is the void ratio. Then you apply p 2 load, you can see at the end of what is the void ratio p 3 load at the end of this consolidation what is the void ratio. Like that number of loads you apply and corresponding void ratio you get.

And then e versus p if you plot and then you take two points suppose this is 1 and 2, and then you can see this is actually d e and this is d p. So, d e by d p is your a. And a by 1 plus e is actually your m v. And if you know this m v, then you can find out the consolidation settlement by this expression.

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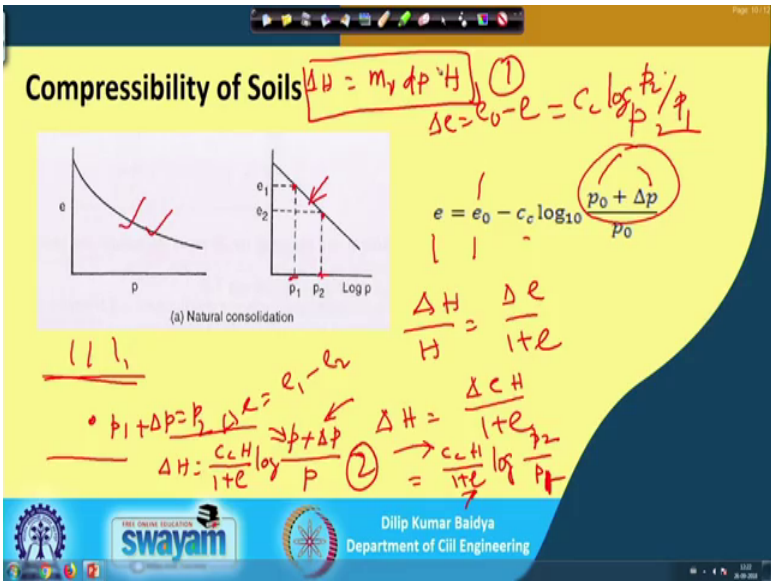

And then another thing is observed that when e versus p if you plot it is a curved. This is the one have shown in the previous slide. And your not linear. And some of the investigator observed that when e versus log p if plotted that mean the under application of the load p suppose whatever void ratio if you note, and number of them if you get and then finally, p if you express in log p and that means, that p if you plot in a semi log sorry log scale and void ratio in the normal natural scale, and then we see that this curve become a linear.

And once this become linear, then again from here also change of void ratio can be obtained, suppose this was e 1 and e 2. So, e 1 minus e 2 is nothing but delta e; and that can be obtained. And to obtain these, what I need to know, I need to know the slope and how to this slope is called actually c c or compression index sorry not compression index, yes compression index c c.

And you can see that suppose I want to find out initial void ratios e, and then final e naught, and final void final void ratio e, then e will be equal to original void ratio minus c c multiplied by log original pressure and increase pressure this is the p 2 suppose and this is suppose p 1. So, this ratio that is log scale, so that means, in this log scale actually you have to think off.

So, log p 2 by p 1 or here actually p naught you can say c c multiplied by this will be the actual change. So, because of that you can find out this original void ratio minus change, so that will be your void ratio.

And we know another thing actually del H by H equal to del e by one plus e. So, from there I can find out delta h that is nothing but consolidation settlement will be equal to del e by del e multiplied by H by 1 plus e. And I can see that delta e from here can find out delta e is nothing but e naught minus e will be equal to c c into multiplied by log p 2 over p 1. So, that means if I substitute here now that become delta if I say I will substitute then it become c c multiplied by H by 1 plus e log p 2 over p. That means, if a particular soil layer if there is a if there is a soil layer, and originally there was a pressure suppose p 1, and then because of foundation load etcetera, it become p 1 plus delta p which is nothing but p 2.

Then how to find out the consolidation? I need to find out c c of the soil. And I need to know original void ratio and I need to know that sorry this is actually p 2, this will be p 1 So, original pressure acting and after foundation what is the pressure so that is the formula; that means, I can write separately here delta H equal to c c multiplied by H over 1 plus e log p plus delta p over p. So, this p is original pressure, and this is the pressure applied because of the foundation load. So, this is the formula, another formula.

There were two formula we are getting. One formula delta H equal to m v d p and H, this is formula one. And this is formula two for calculating the consolidation settlement. And here actually what we need the coefficient of volume compressibility. How to get that? You have to plot the e versus p and then find out the slope of that that is a; a over 1 plus e is the m v. And then pressure applied to the layer and thickness if you know then you can find out this consolidation settlement.

And second way actually we can do that log formula it is called. And to apply log formula to find the consolidation settlement what you need, you need compression index. How to get the compression index: e versus log p you can plot which we will get a straight line. And from that straight line and we can find out the slope of that line which will be nothing but c c. And that c c if you get c c multiplied by H by 1 plus e log p is the original pressure class change in pressure divided by p that formula this is the formula one. So, two ways actually you can calculate the consolidation settlement. For that obviously, we require two different soil parameters, one is m v another is c c.

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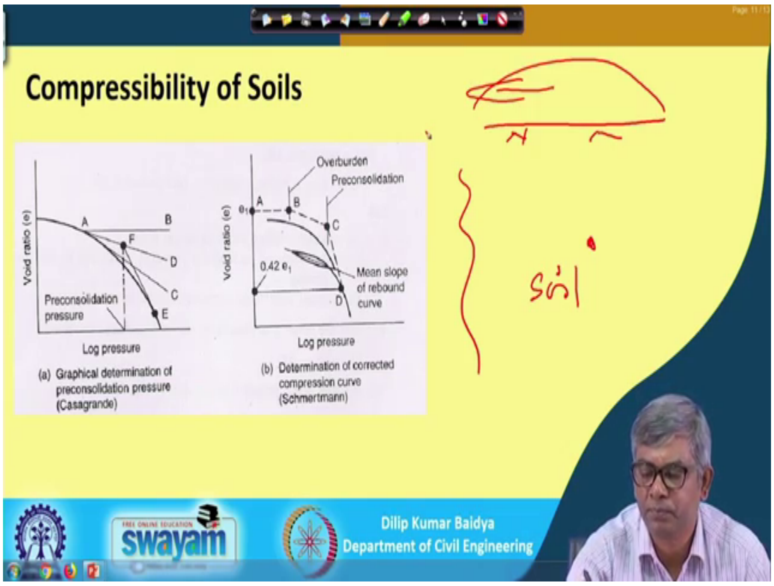

So, next sometime soil can be called normally consolidated, sometimes it is called over consolidated or pre consolidated. What is the meaning of it? Normally consolidated means it will in a particular deposit, now this is suppose ground and this is now this is soil. And if you know the history of the soil, and if you find that this soil layer never have been subjected to higher load than it is acting presently then it is called normally consolidated soil.

And if in some soil if you know the history of a particular site, then you can you may find that at some site, soil already subjected to a higher pressure than it is at present, that means, at under a certain pressure the soil already consolidated. So, because of that this soil may be called as preconsolidated or over consolidated soil.

What is the example I can give suppose at a particular site, suppose a because of for some construction excavated some soil and it is dumped here for suppose 5 years. And then after sometime, this dump is removed, then what happened that last five years the soil here was subjected to a higher pressure then after removal whatever it is, so that is the example of over consolidated soil.

So, that the when the soil is normally consolidated, some time consolidation behaviour something; and if it is over consolidated behaviour also different. So, because of that sometime we need to find out the preconsolidation pressures if it is a preconsolidated. So, so for that generally we do this you can void ratio versus log pressure we can plot.

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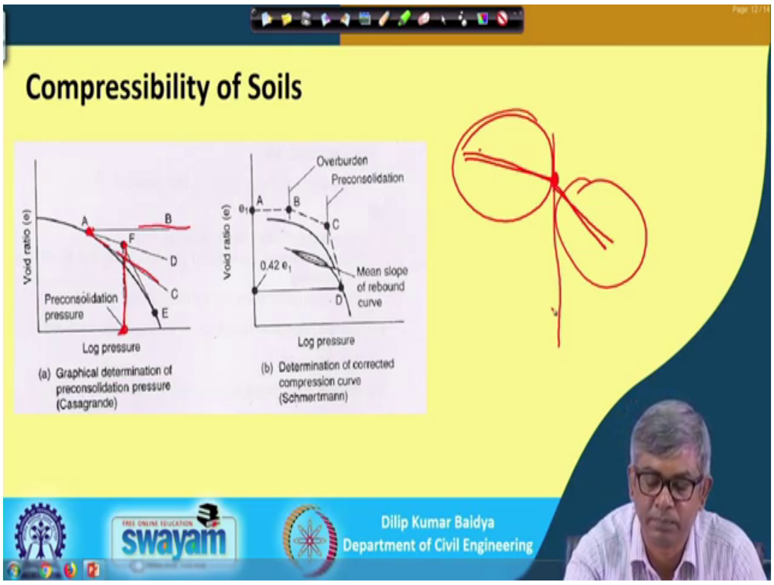

And then we can find out a point of maximum curvature. And from there we can draw on horizontal. And this curve actually and on from that point, you can draw a tangent. So, this point you have to select far from the curve portion, and you have to draw horizontal and you have to draw tangent, and then you have to divide this tangent. When you draw a tangent and draw a horizontal, then it will make a make an angle at this point a then you can divide this angle. And after dividing this angle and the you will get a line A D.

And then though the curve v log v curve towards the end almost like a straight line and that from end of the curve, you can again draw a tangent and produced back to A D intersecting A D then you get a point F. That if actually you can drop to x-axis. And this value if you read that is actually called preconsolidation pressure. So, this is actually a graphical method of finding out preconsolidation pressure which is suggested by Casagrande and still we use it.

And if the soil is preconsolidated, generally we generally we model it e p curve sometime suppose there is a preconsolidated pressure here, So, suppose this one curve and this is another curve. Though it is curve, but we can divide into two state part like this. And up to this we can consider preconsolidation, and this is normally consist of two segments, we can compute the total consolidation.

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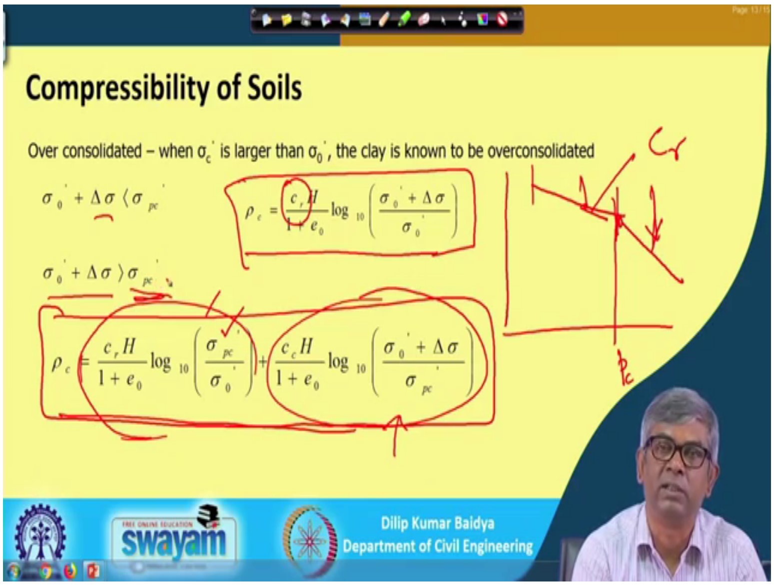

So, this is the one actually, say if it is a over consolidated soil, and over consolidated as I have told you that the curve it is over consolidated something like this curve is like this. And suppose see p c this is actually p c or preconsolidation pressure p c. And suppose you have you know the site what is the effect present pressure, and applied pressure is del sigma. And sigma naught dash plus del sigma the value if you calculate and if you find that it is less than p c, that means, the point comes somewhere here then we can use this formula. This is nothing but recompression actually this is the preconsolidated portion, so it is recompression taking place. So, because of that the slope of this line is called c r or recompression. So, c r into H by 1 plus e sigma naught plus del (Refer Time: 22:23). This formula is similar as normal consolidation.

Only instead of c c, we will be using c r; that means, slope of this portion. And then if you have sigma naught plus del sigma is greater than delta p c sigma p c, that means, if the point comes here then you can use this formula. And this formula how you will do, I can first find out using the c r between this to this what is the consolidation settlement, and then from between this to this using c c what is the consolidation. So, that is the thing done here. Using c r up to p c value this consolidation is taken. And beyond this use c c and use this formula this part this is actually actual consolidation and this is pre recompression.

So, this two components together will be the total consolidation settlement when it is a over consolidated. And that too sigma naught plus del sigma when it is greater than preconsolidation pressure ok.

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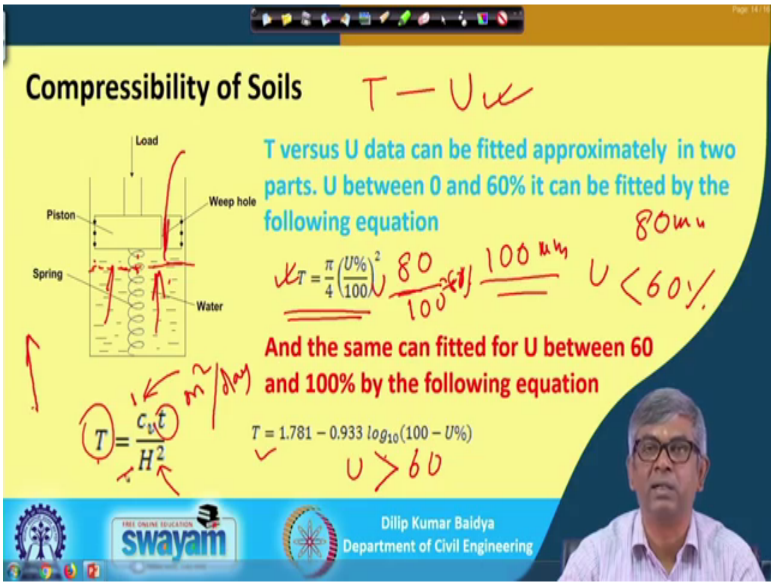

Now, that consolidation rate of consolidation, that is called another important aspect that you know that when it is a saturated fine grain soil subjected to load that it will be compressed, but at what rate that you can visualize this something like that. Suppose, there is a tank; and on that there is a piston water totally sealed. This piston supported by a spring. And what happen if you apply load here, and there is no leakage, then if you apply load and then so this soil is the water is incompressible here. So, soil will not water will not compress; as a result whatever load you apply this load is taken by the water has excess pour water pressure, and no load will be transferred to the spring.

But if you allow a fine opening here, and you apply load, then what happened due to this loading when this excess pour water pressure will develop, then water will try to come out from there and excess pour water will try to come to 0. And when it will be become 0, then what will happen, whatever external load you have then it will be then some water is going out to make pour pressure 0, then what happened the volume may reduce and come down here. Then as a result, then this load will be transferred to the spring, and spring will undergo a that compression, so that is the way actually soil compression takes place.

Now, if the this the opening is very very small then obviously, the compression rate will also will be very very small and if this opening very wide, then there it will be very high. So, because of that we generally again rate of consolidation or degree of consolidation we have another way that means, a particular site, we know if I build something which is over a saturated fine grain soil, it will consolidate by some amount.

But we then next question will be how long it will take? So, for that actually that there are some computation; so, we generally use there are time factor we use and the one term is time factor which is c v t by H square. And this time factor is a non-dimensional thing. And c v is a coefficient of consolidation which unit is metre square per time suppose day metre square per day. This c v unit is meter square per day. There are a number of methods to estimate this one. And H actually the travel path that means, water how much distance is travelling to dissipate, so that is the H. And t is the time.

So, if you know the time factor, if you know the c v, if you know the H, then you can find out the t that is one way. And T has a relationship with U; Y has a relationship with U. What is U? U is the degree of consolidation. What is degree of consolidation? Suppose I know that what is the total expected consolidation settlement suppose 100 millimetre based on that whatever method I have told that I can calculate the total consolidation settlement that is suppose 100 millimetre.

Now, I want to know suppose if at some time the settlement is 80 millimetre, then degree of consolidation is degree of consolidation U is 80 by 100, that means, 8 percent. So, like that suppose if the total settlement is a 100 millimetre. I may ask I may in my mind question may arise how much time it will take to achieve 20 percent or 30 percent or 50 percent or 90 percent or 100 percent, so that is some calculation or I can also find out what is the time required to completely consolidate 100 percent consolidation. So, that actually T versus U relationship we use. And T can be written in terms of U, U suppose 20 percent or 30 percent, 40 percent. So, T versus U relationship is like that this relationship valid when U less than 60 percent.

And another T versus U relationship when U greater than 60 percent. So, that means if I want to find out degree of consolidation suppose 60 percent or 70 percent consolidation how long it will take, then I will consider U is 70 percent. From there I will find out T, and then I will put T here. And if I know the c v of the soil and H of the soil, then I can find out the T of the soil. So, this is the way generally we find out the time, how long it will take to achieve certain degree of consolidation.

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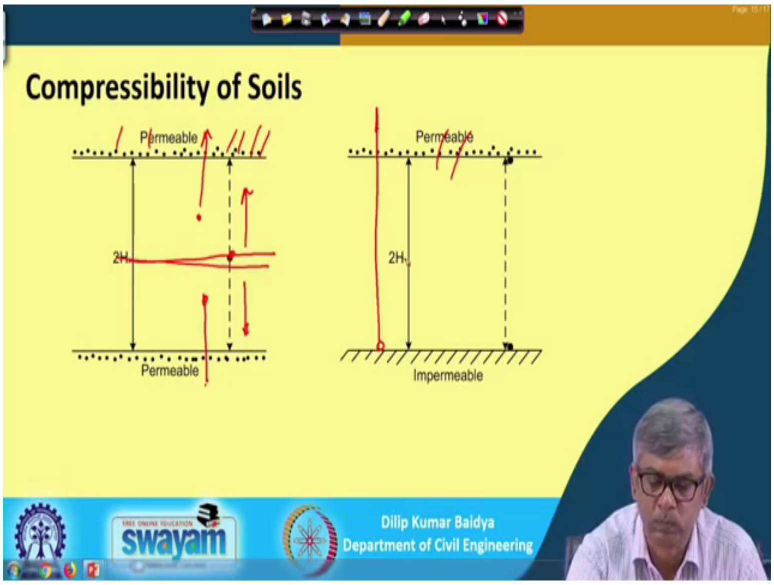

And that as I have told you that H is the maximum distance the water to travel for dissipation. When the both side are permeable, and if there is 2H, then water are actually at this point sorry water at this point either it can go this way or it can get this way. When water is here, always it will go this way because this is shortest path, will go by this path. Similarly, when water is here, it will go by this path, not this in this way. So, that is why maximum distance the water has to travel is this half the thickness. So, that means, when there is a two sides both sides your shipping possible, then your h will be half the thickness of the layer.

Whereas if the clay layer is like this, and it is impervious here and only permeable here, then water from here actually has to travel this much distance to dissipate. So, that is the longest distance. So, that means, for this case, you have to take the entire thickness as a distance travel distance and in that calculation.

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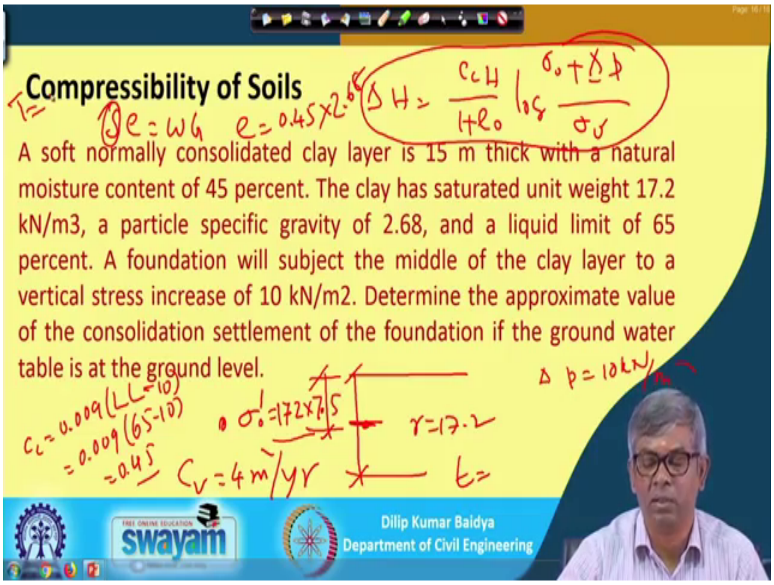

So, this is the application of this problem. So, this problem can be solved by anyone. So, I will not be able to take now this one, but I will just explain a soft normally consolidated clay layer 15 millimetre 15 metre thick like this and with a natural moisture content of 45 percent. Then saturated unit weight of 17, then gamma is 17.2. And the particle gravity is these, and liquid limit is 65. Foundation will subject to 10 kilo Newton pressure that means, delta p is 10 kilo Newton per metre square. And this is clay layer is 15 metre so that means before application of the load at the middle of the layer what is the effective stress you have to find out that is delta sigma naught dash initially. And this del p is this.

You have to find out that that this value will be 17.2 multiplied by seventeen 7.5. And del p is this. And we do not know c c; c c can be approximately calculated 0.009 liquid limit minus 10, so that will become 0.009 65 minus 10, so it will come around 0.45 or so. So, c c will be there; del p is here; sigma naught here. Then you can apply the formula, delta H will be equal to c c multiplied by H is 15 and 1 plus e naught actually void ratio a natural moisture content is 45 percent.

And if it is saturated I know that s into e is w into G so this become 1. So, e will be equal to 0.45 multiplied by 2.68 that become e and log here actually this sigma naught this value plus del p is this one divided by sigma naught dash. So, these formula if you use by this those are the values shown here then you will get the consolidation settlement.

And similarly if this consolidation suppose if I ask that how much time it will take 50 percent of this to achieve, then you require actually C v. And suppose the value of C v is around four meter square C v value is given suppose 4 metre square per year, then of course, using those formula we can find out how much time small t is required you can find out. For that what you will do you first find out since I have told 50 percent, then using first formula you have to find out what is the value of t. And then t related to C v T by H square that formula you use. C v is known; H is known and capital T is known, only small T to be determined.

So, this way actually both time and total consolidation can be obtained; so, like this there can be several types of problem. And I with these actually I will just close review of soil mechanics. And from next lecture onwards, I will start with shallow foundation and bearing capacity and all, and subsequently other topics.

Thank you.