Geotechnical Engineering II / Foundation Engineering
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Lecture - 20
Settlement of Foundation (Contd.)

Welcome once again, let me continue with consolidation settlement and I have just I have discussed in the previous lecture about normally consolidation, over consolidation and what they are and how to. If it is a over consolidation soil then how to find out the over consolidation pressure and now we have discussed one method of calculating consolidation settlement. Now we are we have discussed about the e log p curve and slope; that means, compression index. But by using that how to find out the consolidation settlement let me discuss that part and that is more useful we frequently use that.

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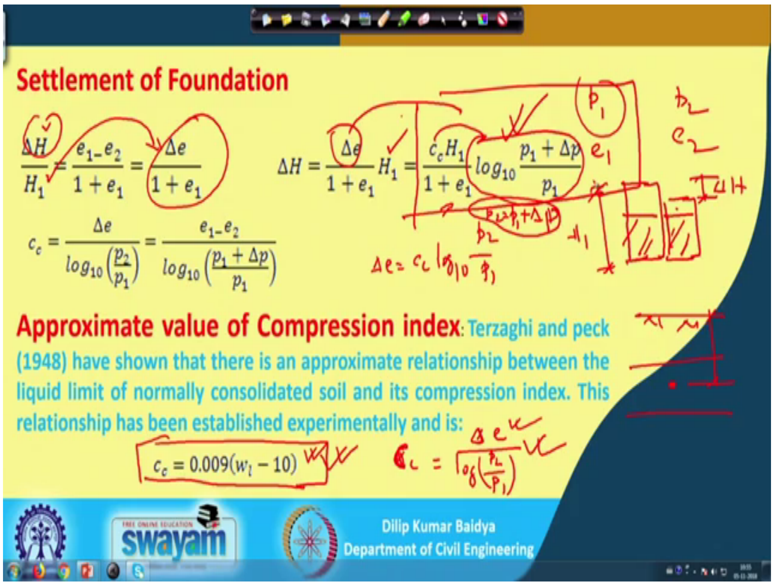

So, you know that we have soil mechanics you might have learned that when there is a layer suppose something like this initially and this is solid and this is void and then because of the consolidation. So, it happens like this become void and this is solid, solid will remain unchanged.

So, this is actually your delta H. So, delta H and this is H, this is one dimensional consolidation we consider. So, delta H by H 1; that means, delta H by original thickness which will be nothing, but delta e by 1 plus e. This is soil mechanics you might have learned I will not go in detail derivation of this. So, e 1 minus e 2 is nothing, but delta e suppose initial pressure was p 1 and final pressure is p 2 under this p 1 it was e 1 and under this pressure it is suppose e 2.

Then under this 2, the pressure change your void ratio change from a e 1 to e 2. So, e 1 minus e 2 is the delta e and if you say from definition this is original volume is nothing, but 1 plus e 1 or original initial void ratio. So, delta e by 1 plus e is nothing, but the change in volume by a original volume and change in thickness by original thickness they are equal, the soil mechanics you might have learned.

So; that means, I can utilize this equation and if I use this equation I can see now delta H is nothing, but delta e by 1 plus e 1 multiplied by H 1 ok. So, if I take from here delta H will be equal to H 1 multiplied by this quantity. So, that is the thing is done and now delta e, delta e is what actually we already we have shown that delta e is previously we have done delta e is nothing, but c c into log 10 base p 2 by p 1 and p 2 is nothing, but p 1 plus delta p; p 2 is nothing, but p 1 plus delta p ok.

So, because of that you can see I have substituted delta e by c c multiplied by this quantity. So, and that means, your equation become now c c multiplied by a thickness compression index of the soil multiplied by thickness of the layer divided by 1 plus e 1 and multiplied by a log p 2 by p 1 and p 2 is nothing, but p 1 plus change in pressure divided by p 1. So, this is the equation that is very well known formula the log formula called, that consolidation to find out the total consolidation settlement by using log formula.

And we can see that as I have explained how to find out c c and c c actually is nothing, but here actually this one. So, just inversing this one I can find out c c equal to del e divided by log p 2 by p 1; that means, if I have the e versus pressure data then if I plot in a semi log from a particular normally in consolidated soil, then I can get the this is not del t this is c c say sorry c c I can get the c c like this. And that is that is one unknown to find out calculate settlement H 1 will be thickness of the total consolidation layer thickness will be known.

Initial void ratio also will be known can be determined and p 1, p 1 is what? Nothing but initial overburden pressure; that means, the if there is soil layer something like this, suppose this is the ground surface and soil layer is like this. So, I if I want if there is a consolidating layer here then present overburden pressure at this point we have to find out. How to find out this one? I will find out weight of the soil above this. So, that is your nothing, but overburden present overburden.

So, gamma 1 H 1 plus gamma 2 H 2 and when there is water table then you have to use effective unit weight; obviously. So, by this way we can find out p 1; that means, if soil unit weight and all the profile soil profile is given then I can find out what is the present overburden pressure in the middle of the clay layer and delta p that is the only unknown now delta p. So, delta p is actually I will discuss separately so; that means, suppose delta p is known suppose, then I can find out this.

And if by using c c from here, but many a times that calculation of cc from the e log p curve actually it is good to use, but there are also several other alternative and people lower the time given many empirical equation and one such equation given by Terzaghi. And if you know the liquid limit of the soil then you can approximately find out c c by using this equation. That means, c c is nothing, but 0.009 liquid limit minus 10 and liquid limit suppose if it is 40, then 40 minus 10 then it become 30, 30 multiplied by 0.009; that means, 0.27 ok.

So; that means, if you know the liquid limit of the soil then you can also find out approximately the compression index by using this empirical equation. There are so many also in the literature, but different types of soil, different c c formula also available one can use it, but the for the time being in our course if e versus a pressure data is not available. And, if you have the a liquid limit then we can use by using we can use this equation to find out the c c for calculation of consolidation settlement by using this. So, the ultimately your consolidation settlement equation is this one. What is this? c c into H by 1 plus e log 10 base p 1 plus del p by p 1. So, this is a important one, one has to remember; next one.

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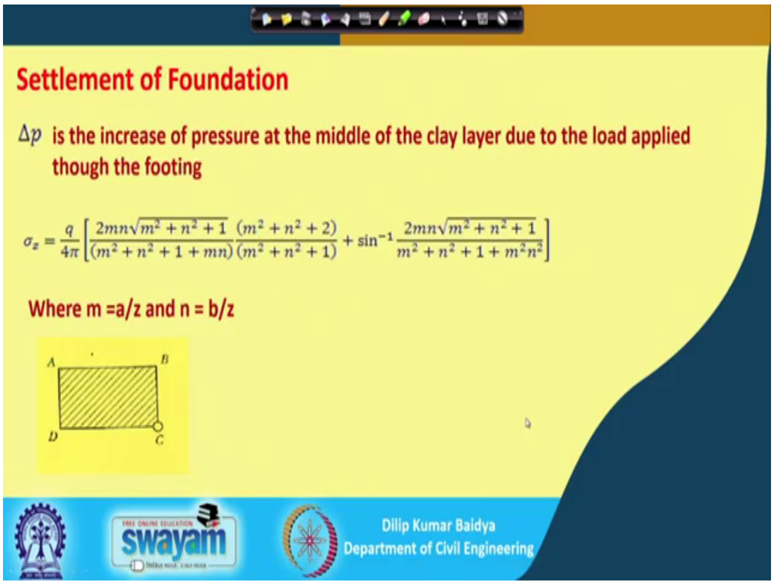

Actually you can see the next part I have told that your equation was like this, your equation was delta was c c multiply by H 1 divided by 1 plus e 1 log 10 base p 1 plus delta p divided by p 1. So, p 1 how to find out if there is a this is the ground surface and clay layer is somewhere here and suppose water table is here itself. Then what I can find out this is the 1, this is the our 2 and present overburden pressure how to find out?

Suppose this is h 1 and this is suppose h 2. So, it will be gamma 1 minus gamma w multiplied by h 1 plus gamma 2 minus gamma w multiplied by H 2 that gives you p 1. That means, at the middle of the clay layer what is the present overburden pressure because of the self weight of the soil. So, that is your p 1 and that means, p 1 is known, but if the soil data or unit weight etcetera is given then what is the del p? That del p has to be estimated.

So, del p is the increase of pressure at the middle of the clay layer due to the load applied through the footing; that means, what actually this one, let me. So, suppose this is the footing and suppose the clay layer is somewhere here. Then because of this suppose this Q load is applied here if it is Q and if the footing is B by B then at this point what is the pressure? At this point q will be equal to Q divided by B square.

I know the below the footing what is the pressure, but I do not know what is the pressure here and we have discussed or you know also in through soil mechanics that the when if you apply a load at a particular point when you go deeper and deeper the pressure will be decreasing ok. And there is Bossiness formula is there some other method also there, we will discuss one by one. That means, what actually if you go deeper and deeper then whatever pressure was here that pressure intensity at this level will be reduced that has to be obtained.

So, how to find out that pure analytical method is there by integrating bossiness formula that if you have a say rectangular footing like this A B C D and if you want to find out suppose at any point at any corner. So, somewhat corner d if you want to find out; so, this is a integrated like this only and so at this corner if you want to find out this is the expression for pressure, suppose the footing is here and this is the below the corner.

So, in at any point suppose I want to find out this is suppose z at any z below, but vertically below the corner if you want to find out the pressure then. So, footing may be or so something like this. So, this is the expression analytical expression and you can see this expression contains only m and n and what is the m and what is n? m actually a by z, if I say this is a and if I say this is b then m equal to a by z and n equal to b by z. And z is what? At; that means, if this is the footing located and from the footing base two the point where you will be calculate settlement so this become z.

So, the footing base to the middle of the clay layer that distance become the z. So, if you know the z and if you know the dimension of the footing then you can find out m and n and then by using this formula I can find out what is the pressure at this point. Now also we have discussed and we have shown before particularly by using or calculating settlement also that if there is a rectangular footing. And then the pressure variation at the allowing the center particularly for flexible say footing, allowing the center of the footing actually pressure will be maximum and corner will be comparatively less ok.

So; that means, if I find out a corner of the footing; that means, we will be using lesser value of pressure. So, what you have to do then? You have to find out at the middle of the footing. So, if you how to by, but you can utilize this equation and find out the set pressure increase at the middle of the clay layer. How to do that let me draw a phrase if I, if I have a footing something like this then I can divide easily by 4 parts.

Now, I will apply through this equation I will find out for this at this corner; that means, and again I will apply this equation for this footing and this corner. Again I will apply this equation for this footing at this corner I will apply this equation for this footing and at this corner so; that means, I need not do 4 times since it is similar. So, what I will do I will find out pressure increase by this equation once, and simply I will multiply by four that gives you pressure along the center line of the footing ok.

So, so along the central of the footing so that means so if there is a footing. So, the while applying this equation what I have to do then, if the length is suppose 6 meter and width become 3 meter then what I have to take a I have to take 6 by 2; that means, 3 and b I have to take 2 by 2; that means, 1.5 meter. So, based on that now if suppose z equal to 5 meter. So, z equal to 5 meter. So, now our a by z become 3 by 5 and that is nothing, but m and n become b by z, that is actually 1.5 by 5.

So, this m and n if you apply in this equation we will get a value and then whatever value I will get multiply by 4 that will give you the pressure increased because of this rectangular loaded footing along the central line of the footing. So, that is our expected that that we will need to find out. So, this is the way if you want to find out let it is actually lengthy calculation and the expression was also, expression is also quite lengthy and generally in practical work we generally do not do by this method of course, if you use computer program and all simply this expression can be programmed and this can be done in no time. But when you do grand calculation, hardly we use may this method there are other simplified method which can be utilized.

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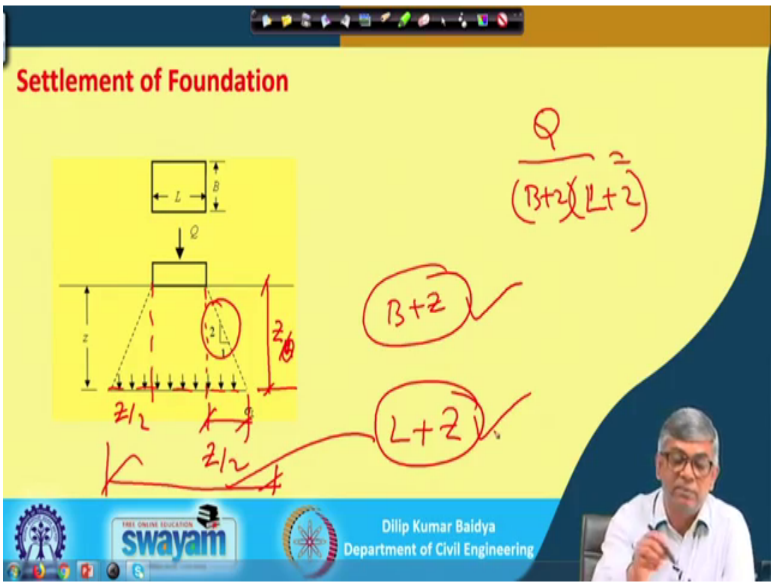

So, what other methods are there actually we can see. that if there is a footing like this as L length and width B then we know that when we will go different deeper the pressure will be decreasing; that means, I can imagine that this footing width or length is increasing. So, lengthwise also increasing and widthwise also increasing; that means, if you go deeper and deeper the area of the footing is increasing.

So, if you can find out the area of footing different-different depth load divided by area you can get directly the pressure. So, to find out that how much it is increasing footing size generally this dispersion we take 2 vertical, 1 horizontal. That means, if I go, that mean if I go 2 vertical 1 horizontal; that means, if this become z this become z vertical z then horizontally if the how much it will go? It will go z by 2 horizontally will go z by 2. So, if this height is z then a horizontal movement this portion will be z by 2.

Similarly, this side also a z by 2, then entire width will become your l plus z. Similarly width also in the other direction it will also 2 vertical 1 horizontal it will be if it that way this part. Then what will happen both side will be z by 2, z by 2 ultimately this width also become new width will become b plus z if I know this and if I know the loading of the q loading. So, q divided by b plus z multiplied by l plus z by this way I can find out what is the pressure at this point.

And this pressure actually very much approximate, but many a times if it is a little deeper soil then we can find out that by using that whatever expression we have shown by that way whatever value you get and the by this way also value will be by and large similar. So, that means, one can use this, but frequently when calculation when you do then automatically it is our tendency to quickly assume a dispersion sometime. If the soil is this soil is deeper as sorry stiffer, little better soil this dispersion can be little bit we can change different values also.

But most commonly used dispersion is two vertical one horizontal, but this can be according to the soil type this can be different values can be taken, but generally we take two vertical one horizontal. And if you take 2 versus 2 vertical 1 horizontal then at a depth z from the footing base what will be the width and what is the length of the footing? Width will be b plus z length it will be l plus z, that I will show in the next figure you can see.

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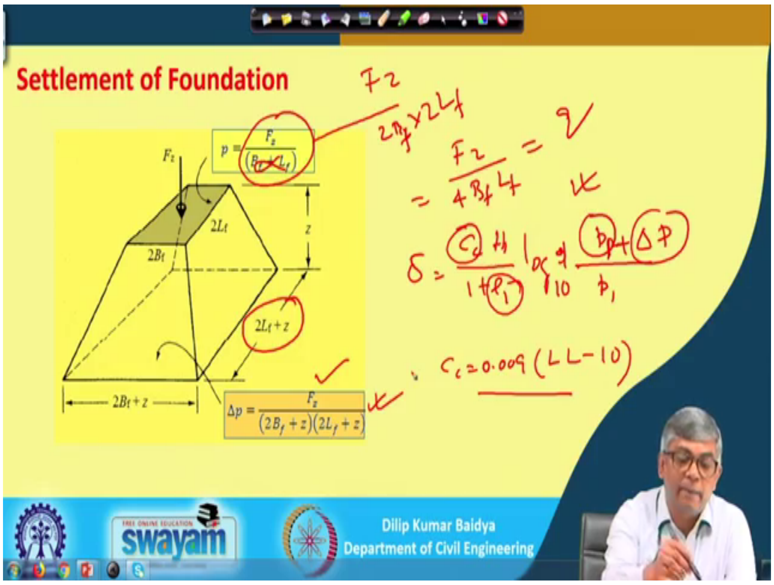

So, this is the figure suppose both length and width is shown here, sorry here there is a error I will just correct it and you can see when it is a footing F z is applied this equation since it is taken length is taken as 2 L f and width is taken as 2 B f. So, this equation will be corrected as F z divided by 2 B f 2 B f multiplied by oh sorry this totally wrong, this is 2 B f multiplied by 2 L f or it is nothing, but F z divided by 4 B f L f.

This is the way so; that means, that is nothing, but actually q pressure at the below the footing and you have to find out pressure at some depth z suppose this is at depth and you can see at depth z as I have shown in the previous slide your length become 2 L f plus z and width will become 2 B f plus z. So, F so, your del p will become F z divided by 2 B f plus z multiplied by 2 L f plus z. So, by that actually by using this equation one can find out quickly the value of delta p.

So, now if your if your equation is delta will be equal to c c into H 1 divided by 1 plus e 1 log 10 base and log 10 base p p 1 p 2 by p 1 or it is p 1 plus delta p. So, p 1 calculation I have shown del p calculation I have just shown like this and c c to be either used from the slope of the compression curve, e log p curve or from the empirical equation like c c equal to 0.009 liquid limit minus 10 by this way can be obtained and e 1 initial void ratio can be obtained from the initial measurement. So, you once you get this then we can find out what is the total consolidation settlement.

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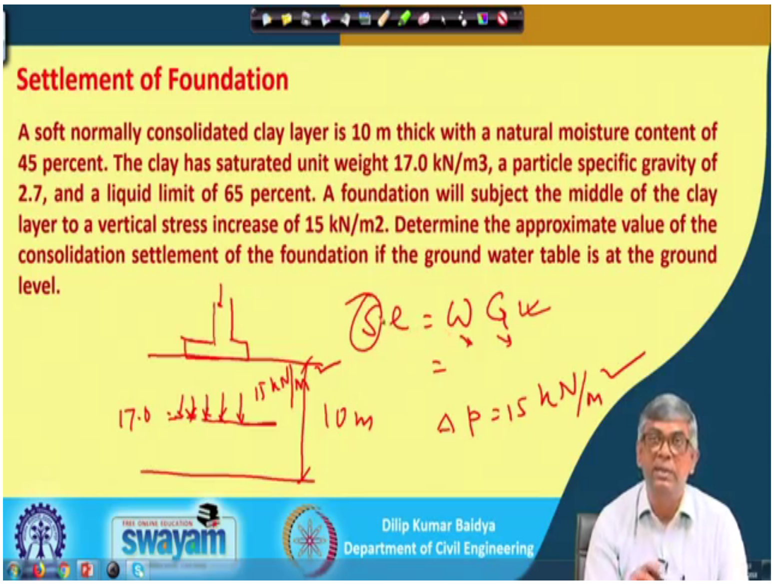

So, now one problem a normally soft normally consolidated clay layer is 10 meter thick and with a natural moisture content of 45 percent the clay; that means, natural moisture content is given. Why it is given I will show you how it is actually the initial instead of giving your initial void ratio and we know that your S multiplied by e equal to water content multiplied by G.

And since it is saturated soil so this become 1; so, e become natural water content multiplied by G. So, that that way actually you will get the e value, the normally consolidated clay layer is 10 meter thick with the natural moisture content of 45 percent the clay has saturated unit weight of 17 kilo Newton per meter cube. A particle specific gravity of 22.7 and a liquid limit of 65 percent, a foundation will subject the middle of the clay layer to a vertical stress increase of 15 kilo Newton per meter square determine the approximate value of the consolidation settlement of the foundation. if the ground water table is at the ground level; that means, your footing was something like this.

And it is suppose resting on this and this is suppose 10 meter and 10 meter and unit weight is given 17, the saturated unit weight and loading is your pressure in kilo degrees instead of pressure instead of loading here directly it is given it at the middle of the clay layer, what is the pressure what is the pressure actually it is given 15 kilo Newton per meter square. So, the; that means, del p is given 15 kilo Newton per meter square.

So this is the problem all details are there and you can see the approximate value of the and c c is not given since liquid limit is there. So, we can find out cc also and what else you required c c and thickness is 10 meter is given and initial void ratio I can find out from here. So, like that everything is given. So, I can find out the consolidation settlement, let me go to the next slide.

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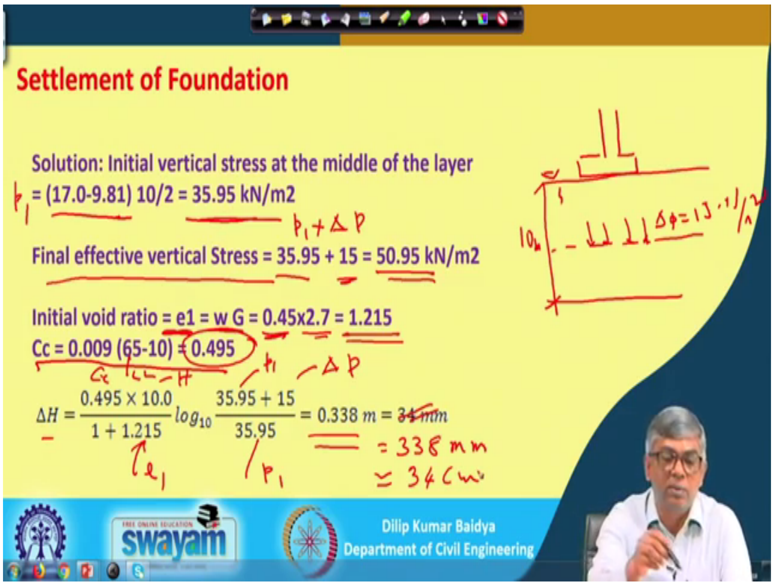

It is shown here you can see that, 1 second I will draw the problem and suppose clay layer is 10 meter and delta p equal to 15 kilo Newton per meter square. You can see that initial vertical stress at the middle of the clay layer so; that means, I have this is nothing, but p 1.

So, 17 minus 9.81, 17 the since it is saturated ground water table is here. So, I have to find out 17 by 9.81 and a middle of the clay layer you have to find out overburden pressure. So, will be 10 divided by 2. So, if I do this value comes 35.95 and final effective vertical stress will be this will be p 1 plus del p. So, since del p is already given no calculation is required. So, 35395 plus 15 become the del p. So, it become 50.95 kilo Newton per meter square and initial void ratio as I have told you that e 1 is nothing, but w into G, this is 45 percent and 2.7 is the specific gravity. So, it become 1.215.

So, your delta H become and c c become you can see 0.009 65 minus 10 this is liquid limits 65 is the liquid limit minus 10. So, it comes 0.495. So, this is actually c c and this is actually H, this is actually e 1, this is actually p 1, this is actually del p and this is also p 1. So, if you put all those values then if you calculate it comes 0.338 meter. So, approximately sorry it will not it will be it will be 338 millimeter.

So, if you convert into millimeter a 338 millimeter. So, it is nothing, but actually 3 you can say approximately 34 centimeter also. So, this is the way actually one application I will just show you, shown you next thing is as I have told you that the soil can be this is actually whatever calculation we have done. This is based on normally consolidated soil.

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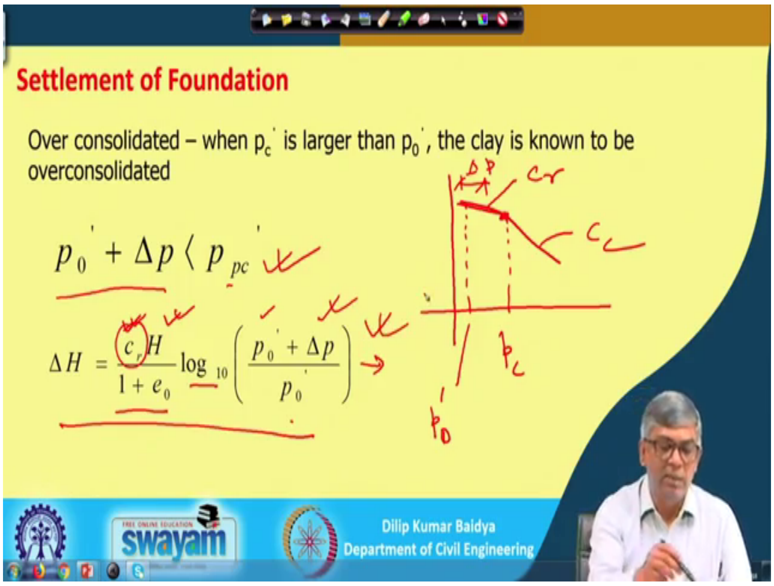

But if the soil is over consolidated then your as I have explained that when there is a soil is over consolidated generally we use a model. Model means what I find out suppose p p consolidation pressure here this portion curve this is also curve. So, I put which we generally take from up to pre consolidation one straight line and from here to here another, a straight line. Though it is actually curve, but up to this we will p this is p c pre consolidation pressure, beyond that one curve and this is so another curve.

Now, suppose your p naught is somewhere here or p 1 was somewhere here or p naught suppose naught dash is here and you have applied del p in such a way that it did not cross the this p c. That means, suppose your del p is somewhere this much, if it is show then p naught plus del p p naught plus del p is less than p c. So, p naught plus del p; that means, it did not cross the over consolidation pressure; that means, your this portion is nothing, but recompression.

Pre consolidation pressure means what before that whatever we are getting that is once it was consolidated now it is recompression. So, this slope is actually is c r and this slope is c c. So, now, this portion consolidation I will consider like a consolidation settlement, but with a c r value we can see c r multiplied by H divided by 1 plus p log 10 base p naught plus del p by p naught this is nothing, but our normal log formula I have used. With what I have done I have changed only instead of c c because it is compression taking place in this zone recompression zone, I have used only c r.

So, different soil will have different c r values actually it is related to c c also sometime one fifth one fourth. So, that value can be taken and otherwise c r can be obtained from the laboratory and then p naught can be obtained from the calculated and del p also can be calculated and based on that one can find out the consolidation of the, over consolidated soil when your p plus del p is less than p c that is the formula. If it happens at otherwise that is.

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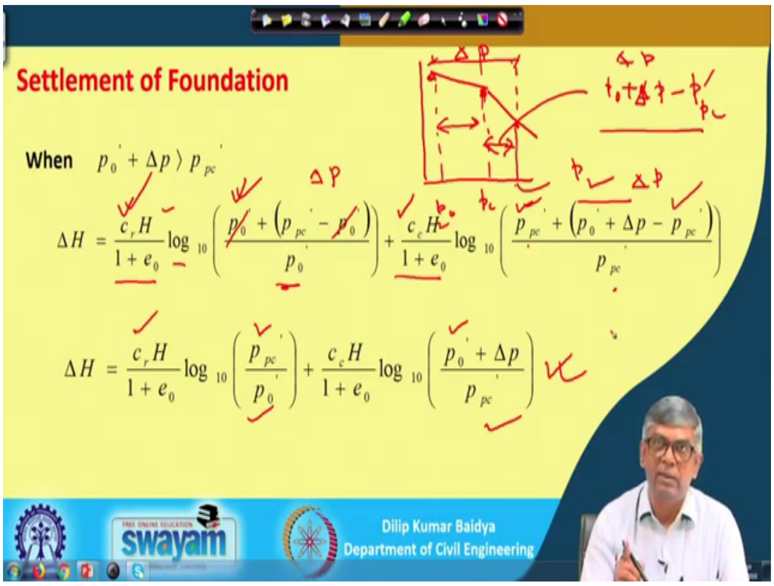

If your p the plus del p as I have shown the model let me draw once again let me draw the draw once again the model is something like this. This is suppose p c and this is suppose p naught and your del p suppose applied in such a way the it is going here, this is suppose del p. If this is del p then we can see p p naught plus del p is crossing the del p c; that means, it is crossing this one and the settlement will be linear from here again linear from here. So, because of that what I can do instead of using formula 1 so I can use formula twice actually.

I will consider p naught to p c ones calculation and p c to this 1 p c to p 2 p c to p p 2. So, for that actually you can see if when I will calculate from here to here; that means, c r will be used I have use c r and H 1 plus e naught log and you can see p naught already there plus del p is how much here? I actually it is not del p so it is p c minus p naught. What is del p here actually? P c minus p naught, p c minus p naught this is nothing, but del p for this when I will calculate this portion, when I will calculate this portion del p is nothing, but p c minus p naught and divided by p naught.

So; that means, I have consider consolidation for this zone. Now I will calculate for calculation for this to this portion and here when your consolidation taking place in this zone I will be using c c and again same thickness 1 plus e will be there log 10. Now I will calculate from p c and you can see if p naught plus del p I am once your p naught plus del p that I am reaching here and already we have taken effect of p c. So, p naught plus del p minus p c. So, that become this one will be nothing, but from here to here it will be nothing, but p naught plus del p p naught plus del p minus p c pre consolidation pressure.

So, so that so that is that become del p and this become initial pressure. So, initial pressure this become del p in the formula p naught plus del p by p naught, now if you simplify this one little bit you can see this equation this p naught p naught get cancel. So, p c by p naught plus c r and here actually c c 1 plus e log p naught plus del p by p p c and. So, when this is a over consolidated soil and p naught plus del p is summation is greater than the p c then this is the formula, if two components will be the 1 will be c r component one will be c c component. So, by this actually one has to calculate the total consolidation settlement when it is over consolidated soil. So, now, I think I will stop here with this.

Thank you; I will take some more application maybe in the subsequent slide.