Geotechnical Engineering II / Foundation Engineering
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Lecture – 21
Settlement of Foundation (Contd.)

Once again welcome to this lecture series of in Foundation Engineering and we are discussing on settlement of footing and we have also mentioned that settlement would be consisting of 3 parts and this is actually immediate settlement, consolidation settlement and secondary settlement. Immediate settlement we have done, then consolidation settlement we have discussed, we have derived or you have shown 2 method of calculating consolidation settlement one is M v method another is your or C c method. And again while you will do C c method you may have normally consolidated and over consolidated and I have discussed both of them.

I have shown one application also normally consolidated cases. Now you might have learned and from the soil mechanics that, the immediate settlement from the name itself it is clear that is immediate; that means, elastic there are immediately after the application of the load that settlement take place. Whereas, your consolidation settlement will take place over the long time period and that is now question actually I have shown some problem application that if a this much thick layer is there if we apply this much load then what will be the total consolidation settlement. Now question arise that what will be the time taken to the consolidate that much amount of settlement.

So, that is the next question actually we have to find out time. How much time it will take for consildate consolidating the soil under particular loading?

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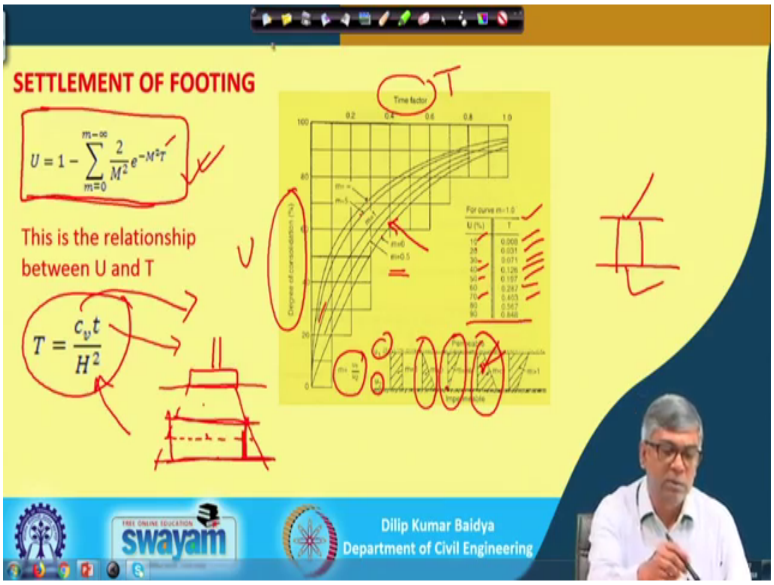

So, for that in soil mechanics you perhaps learned that one dimensional consolidation theory for the given by Terzaghi and finally, one expression U versus T was derived this has several assumptions actually that it will be compression it will be one dimension then it should has to be saturated that is is law valid so many other assumptions are there and based on that one such equation was derived. And finally, this is a mathematical expression and this in this actually T is there M is there what is this these are all known and basically the T is a term that is called time factor and which is related to soil properties like coefficient of consolidation C v and thickness of the consolidating layer and time T ok.

So, this T C v this two things actually one is time factor another is degree of consolidation. So, ultimately by handling the complex mathematics this is the expression and then using this expression people actually finally, obtained the value or valuation variation of U versus time factor T, U verses T. And in the in the any soil mechanics book if you see will get this type of curve actually and they are actually you can see that this is degree of consolidation that is nothing, but U and this is time factor nothing, but T.

And you can see while plutting putting this one they have given number of M value, M equal to infinity M equal to 5, M equal to 1, M equal to 0, M equal to 0.5, what is the meaning of this the M actually see the M is nothing, but ratio of U 1 and U 2 suppose if there is a soil layer what is the pressure at here and what is the pressure here. So, if this is called U 1 pressure at this point U 1 and U 2, then U 1 by U 2 actually equal if there is a ; if there is a if you apply load in such a way that our pressure distribution over the layer is same throughout at a top whatever the pressure bottom also the same pressure.

And if that happens then M become 1 and for M equal to 1 there is a curve this is a central one M equal to one is the central curve; that means, this is the throughout the layer there is a average pressure equal average pressure. And it can happen that at the surface pressure a power pressure is 0 whereas, at the bottom it is maximum then it become M become 0 and for that M become 0 this is the curve. And similarly a surface maybe a significantly high value and at a particular depth it will be 0, then it M equal to infinity and you can see M equal to infinity the extreme right that is M equal to infinity.

Similarly, M less than 1 and M greater than 1, that two more curve. So, M is 0.5; that means, less than 1 so this is the curve and M equal to 5 M; that means, greater than 1 so this is the curve. So, for different values of this U 1 and U 2 this curve represented, but in most of the practical work there are some evidence where this type of things happens in that case you may use that, this is also may happen. This is also most natural one, but all those things happen, but to avoid the complexities we generally simplify that and we take that the when we apply load the pressure is uniform average within the layer.

So and how we can simulate or visualize this one? When we apply a suppose there is a footing and when is a there is a footing and you apply load and suppose clear layer is somewhere here. And then because of these dispersion you can see that pressure whatever value of pressure here and at this pressure are different then, the logical will be using this one, but instead of that what we are doing we are considering at the middle of the clay layer; that means, we are taking average of these two and that can be; that means, I can imagine the pressure is uniform like this value ok.

So that means, in practical work we use M equal to 1 and corresponding T versus U curve is this and that value if I the read from the curve then U versus T, so U is 10 T is 0.008 is, 20 0.031, 30 0.071, 40 0.126, 50 0.197, 60 0.0287, 70 actually 0.0405, 90 percent is 0.848 like that values also the available in the tabulated form or in the form of curve. So, whenever you require either you refer the curve or a for the table or I will show you the subsequent slide that how this can be approximately estimated at different if you know the U how to estimate the value of T.

So, this is the one otherwise this is the things available in the literature for different values of M also, but will be using for M equal to 1 only.

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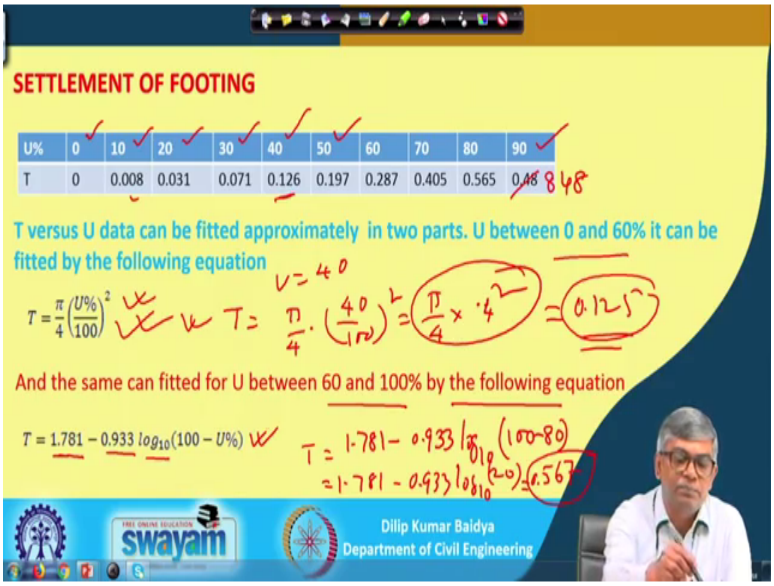

And you can see as I have mentioned that U versus so U equals to 0 and 10 it is 0.008 and 20 0.031, 30 0.071, 40 0.126, 50 0.197 like this alright this is not 4 8, 0.848 90 percent it will be 0.848. So, this is the error anyway. So, now, this data we have and this data is of course, obtained from that equation U versus T that mathematical equation, but sometime to use in the practice if you can feed this data in some convenient form the sometime it will better and someone did it and you can see this that since this plot is such that it cannot be fit in the single curve.

So, because of that based on trial and error process it is fitted in 2 parts; one part is up to 60 percent, if the U is greater than 60 percent sorry 0 to 61 up to 60 percent this is the equation is given T equal to pi by 4 U in percent by 100 U percent by 100 percent means what if it is 40 percent the T suppose U equal to 40 percent then T will be equal to pi by 4 multiplied by 40 by 100 square or equal to pi by 4 multiplied by 0.4 square, this is the way one can find out.

So, this is one equation and then another equation between 60 to 100 another equation is treated that is 1.781 minus 0.933 log 10 100 minus U suppose is it is again 70 percent suppose then I will this equation will be written as T will be equal to 1.781 minus 0.933

log 10 base 100 minus suppose 80 suppose then it will be 1.781 minus 0.933 log it is 10 base and it will be 20.

So, one can using the calculator one can find out this value suppose I will find out log 20 multiplied by 0.933 and then 1.781 minus this value become 0.567 and this one will be 0.4 square multiplied by pi divided by 4 this comes 0.125. We can see I have used 40 percent again see 0.126 given it is 0.125 you can see I have used 80 percent 0.565 is 0.567; so, they are quite accurate. So, one can use this instead of remembering or referring that. So, frequently and sometime we need to remember this equation actually because this is very useful quickly you can calculate by using this one. So, let me go to the next slide.

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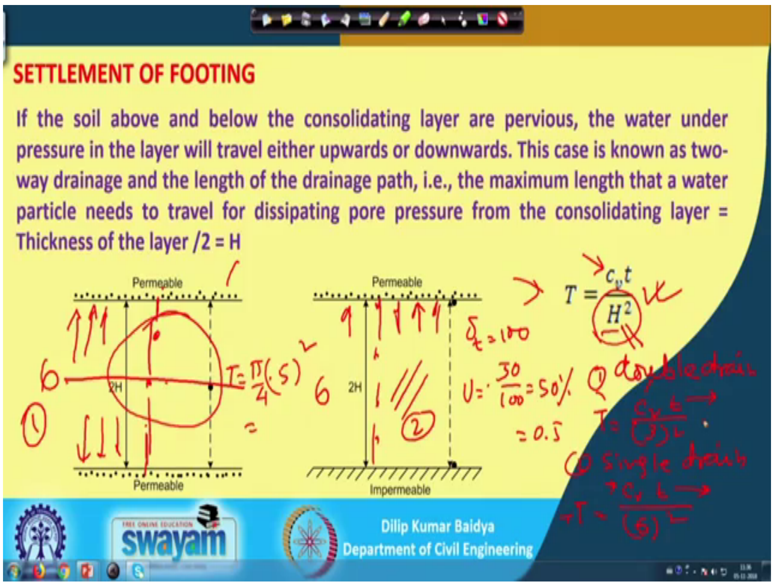

And then you can see this that your to calculate the time if you know the U suppose you know the U is 70 percent suppose, total settlement is 100 total settlement is delta t is suppose 100 suppose I want to find out time required to find out 50 millimeter settlement. Then what will happen the U become 50 by 100 so, it is 50 percent or 0.5, U become 50 percent then what is the T? Then T will become T equal to pi by 4 multiplied by 0.5 whole square, so, that become T.

Now, once your T is known and suppose C v soil properties coefficient of concentration of the soil is known and then I can find out t if I know the thickness of the layer. Now in this while finding out the thickness of the layer one has to remember one important point that, if there is a consolidating layer; if there is a consolidating layer and if both side is permeable. That means, if I apply load water can go this direction also water can go in this direction if they both are permeable layer ; that means, it is called two way drainage; that means, a layer between two permeable layer a compressible layer between two permeable layer.

In that case that water when will be adding load then, water will go which direction it will go to the nearest permeable layer suppose if water is here it will move this direction it will move this. So, water here it will move this direction so; that means, similarly at the middle of the layer at when water is middle of the layer it can go either this direction or this direction. So, the H will be calculated based on that the water moves maximum distance so; that means, when that were both were permeable then there will be a maximum trouble path for the water to come out will be half the thickness.

So, that is why when there is a doubled drainage then, your in this equation you have to use ; in this equation will be used half the thickness ; half the thickness whereas . So, the for this case actually your use if the thickness is 2 H the in this equation has to be used H.

Similarly, if that is another permeable; another permeable layer sorry another consolidating layer and thickness is 2 H, but if soil can water can water can come out only in this direction ; water can come out only in this direction. That means, water from here it has to go this side, water from here also has to go this side, water from here has to go this side, water from here also has to go there; that means, maximum distance water has to travel is the 2 H distance. So; that means, when single drainage; when this single drainage in this equation you have to use whatever the thickness of the layer as it is.

Suppose, here it is 6 meter, here also it is 6 meter and in this equation the case 1 that is doubled drain and case 2 of a single drain. So, case 1 doubled drain then you T will be equal to equal to C v t divided by actually 6 meter so, it would be 6 by 23 square.

This is the equation and 2; that means, single drain; that means, your T will be that means, this case your C v multiplied by t divided by H here or 6 meter, but entire 6 meter has to be taken here. So, this is the thing one has to remember to calculate the length of the drainage path for calculating the settlement sorry calculating the time. So, here actually this is known if this is known and this is known then we one can find out T, similarly if this known and this is known one can find out the time T and T how to find out if I know U I can find out T by this.

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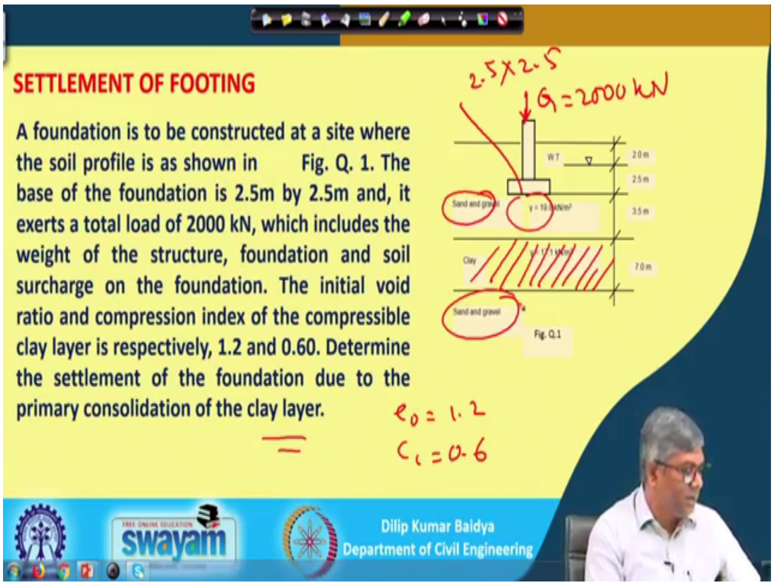

Next actually let me see one problem, the problem was like this a foundation is to be constructed at a site where the soil profile is as shown in figure this one. And the base of the foundation is 2 meter by 2 meter, this is 2 meter by 2 meter 2 meter 2.5 meter by 2.5 meter the square footing, it exerts a total load of 2000 kilo Newton that is Q become 2000 kilo Newton and which includes the weight of the etcetera. The initial void ratio and compression index of the compressible clay layer is initial void ratio e naught equal to 1.2 and your C c equal to 0.6. Determine the settlement of the foundation due to the primary consolidation of the clay layer only.

So, if it is so the consolidating layer is this only. So, load is applied here this soil, this soil also settle because of immediate settlement, this soil also will have immediate settlement that is different which we have discussed before. But I want to find out because of this loading only consolidation settlement for this layer and one more thing to be noted here actually above this clay layer sand and gravel, below the clay layer also sand and gravel; that means, it doubled drainage, but of course, time has not hours. So, we need not raise that need not use that one observation, but I have to find out consolidation settlement only for this layer.

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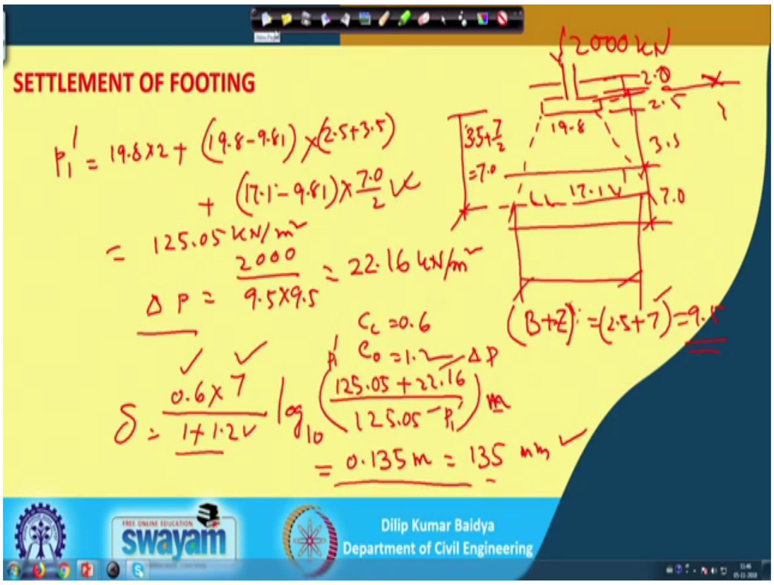

So, for that let me see the calculation, if I draw the fluid footing here and then this is actually your 7 meter and this is 3.5 meter and here this is actually your 2.5 and this portion is 2 meter. And here actually gamma 19.8 and here gamma is 17.1 and water table is somewhere water table somewhere here. And if I do the dispersion at the middle of the clay layer this would become so this distance become; this distance become 3.5; this distance become 3.5, this become 3.50plus7 by 2 so, that is equal to 7 these distance7.

So, you are footing width become this is actually B plus Z which is nothing, but B is 2.5 plus Z is how much 7, so, it become 9.5. So, you have to find out the p 1; p 1 will be how much? Assume that same unit weight water table also. So, 19.8 multiplied by 2 plus 19.8 minus 9.81 multiplied by actually from here to here soil is same and water table is there and that distance become 3.5plus 2.5. So, 2.5 plus 3.5 plus this much soil is how much?

This is 17.1 minus 9.81 multiplied by it is half the length of the thickness of the 7.0 by 2. So, if I calculate this one it comes 125.05. Now your del P comes your delta P comes it was 2000 divided by 9.5 multiplied by 9.5. So, at this point what is the pressure deltaP. So, that gives you 22.16 kilo Newton per meter square and this is also kilo Newton per meter square and your C c is 0.6 and e naught equal to 1.2.

So, delta will become 0.6 multiplied by thickness of the layer is 7 divided by 1 plus e is a 1.2 multiplied by log 10 divided log 10 base; log 10 base p naught actually 125 point, 125.05 plus delta P is 22.16 divided by 125.05. So, this is the one actually you have delta and if we apply the formula then, if you calculate then you will see that should be in meter and that value comes out to be 0.135 meter or 135 millimeter.

So that means, whatever problems are given based on this the footing was 2.5 loading was 2000 kilo Newton; 2000 kilo Newton and then because of these and the 7 meter thick clay layer was at a depth of it is 8 meter depth; at 8 meter depth 7 meter thick clay layer was there and water table is at a 2 meter depth. So, because of that what is the initial over water pressure p 1, p 1 dash sometime we have to write because it is effective stress only and delta P is because of this loading using 2 vertical one horizontal if you take this percent actually two vertical one. So, that we have shown that will be B plus Z at this level and B is 2.5, Z is7.

So, it will become total is 9; that means, footing at the middle of footing size at the clay layer will be 9.5 meter by 9.5 meter. And then if I put all those values now C c is 0.6 thickness of the layer is 7 and 1 plus e naught is 1.2 log 10 this is p 1, p 1 dash and this is del P divide by p 1 dash. So, those values if you put and finally, you calculate then become 0.135 meter and finally, you convert into millimeter then it become 135 millimeter.

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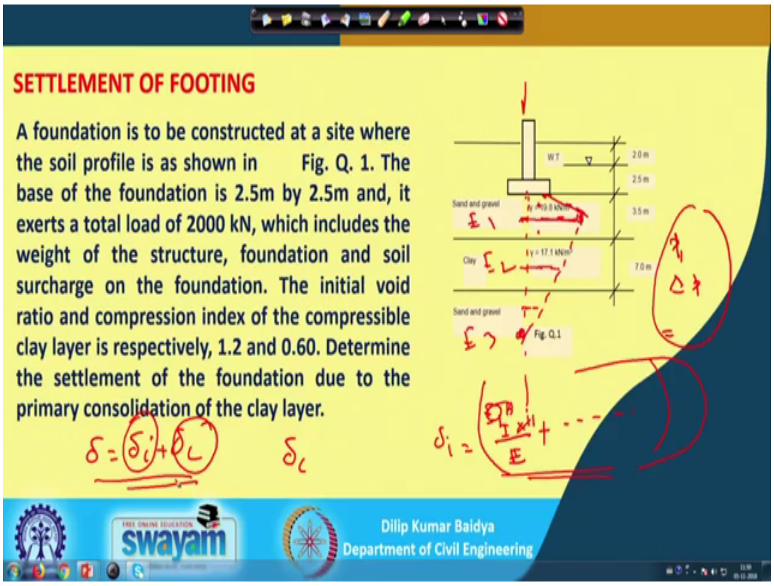

So, this is the problem actually we have only calculated your consolidation settlement now, if this same problem was if the same problem if this problem if it is asked that what is the total settlement sorry; what is the total settlement? I have shown that what is the delta consolidation settlement how much I have shown, but; that means, total settlement will be suppose delta will be delta i plus delta c.

So, now, I have shown this problem delta c calculation, but how to find out delta i; i could have done this one once again whatever Schmertmann method I have discussed, I could have plotted the for a corresponding to square footing what is the influence factor diagram and then based on that I could have taken this is E 1, this is E 2 and this is E 3.

So, I could have calculated what is the average I for this layer, what is the I for this layer, what is O for a this layer and then delta i could have been E I H I by no I multiplied by H divided E divide like that plus whatever for 3 layers I could have applied and I could have got at the immediate settlement and that immediate settlement if we add with this consolidation settlement I could have got the total settlement of the footing.

So that means, this is a very practical problem loading is there and consolidating layer details are given and then if in addition to that the E value of each layer is given and if it is asked you to find out what is the total settlement then problem has to be solved in two parts; one is for elastic settlement another for consolidation settlement.

Consolidation settlement already we have shown you have to find out what is p 1, then you have to find out what is del p and then by using the formula e naught, C c everything I can find out delta consolidation already have shown. And second part or this in fact, it can be first part for this footing corresponding to the particular footing type that Schmertmann influence chart I could have prepared and I know what is the value here; I know what is the value here.

And then I know the what is the depth here and then this diagram influence diagram within different layers and from this different layers I could have I can divide in 2 parts for this, I can divide one part I can divide one part and then I find out influence factor in each layer and then applying the equation whatever is given by the Schmertmann method and using the corresponding E value. I could have in addition get this elastic settlement also and this elastic settlement plus whatever consolidation settlement I have got this can be added to get the total settlement of the footing ok.

So, this in addition though I have this problem is only for consolidation settlement, but this problem could have been that find out the total settlement. In that case what you have to do I have to give actually Young’s modulus value of the respective layers and what you have to do? You have to in addition to the consolidation layer using log formula you have to use Schmertmann method and find out these 3 components or 4 component and add to them then to get the total settlement. And with this I will stop here.

Thank you.