Soil Structure Interaction
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Lecture - 8
Design of Shallow Foundation (Continued)

So in the last class, I was discussing about the design of a raft foundation on the clay. So, I will start from there in this class and finish that problem in this class okay. So I will continue the same problem the design of a raft foundation on clay okay.

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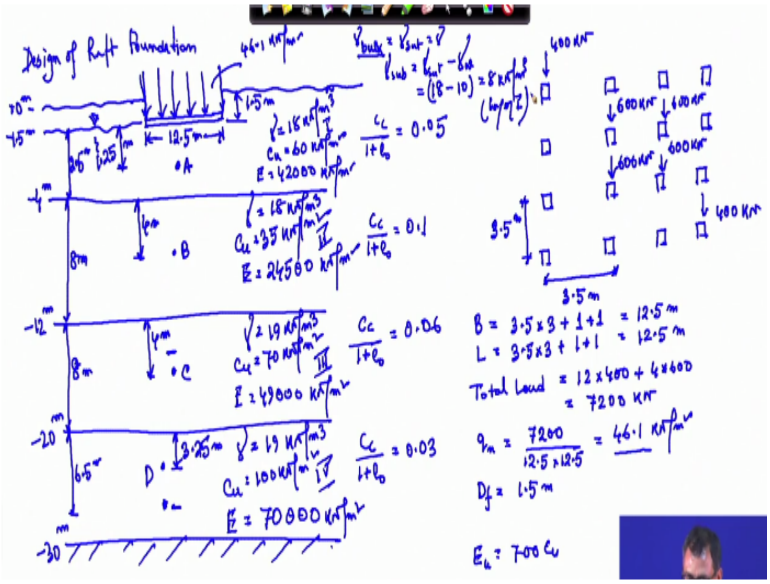

So this was the problem that I was discussing and then the dimension for the first trial is taken as 12.5 meter is B value and L value is 12.5 meter. Depth of foundation for the first trial is taken as 1.5 meter and these are the soil properties okay.

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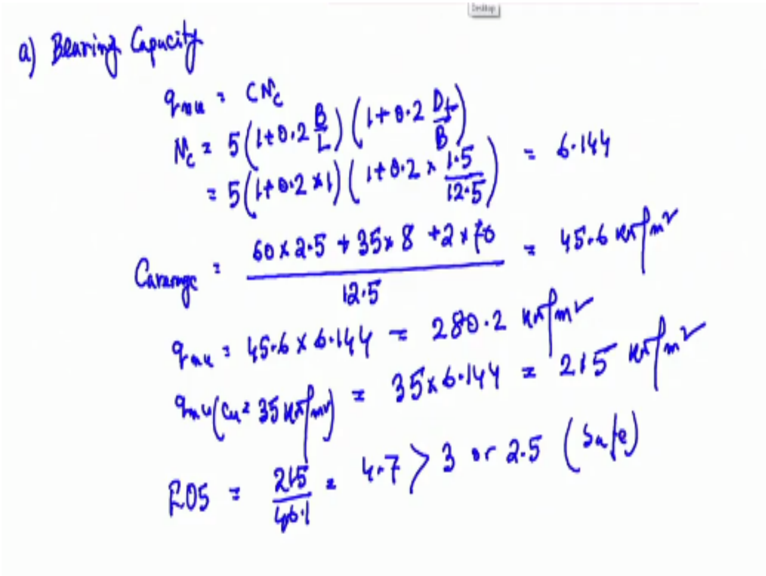

So now for the bearing capacity calculation purpose, as I mean mentioned that here it is a problem of clay, so I will use the Skempton bearing capacity equation, because that is applicable for clay and generally the bearing capacity okay, and the Skempton net ultimate bearing capacity cN_c, I am using Skempton one okay, net ultimate bearing capacity which is cNc and Nc it is your square footing. So, for the rectangular footing, the common or the general equation is 1+0.2 B by L into 1+0.2 D_f by B okay.

So, B is the width of foundation and L is the length of foundation. So, this is 5 1+0.2 and that is a square footing, B by L will be 1, then 1+0.2 and D_f is 1.5 and B value is 12.5 meter okay. So, this value is coming 6.144. Now, here as I mentioned in the last class that the influence zone is B that is 12.5 meter from the base of foundation. So, for the first layer, it will be 2.4 meters, second layer it will be 8 meter, and third layer it will be 2 meter. So, if I take the average value.

So, now if you look at the variation, so first layer C_u value is 60, second layer 35, and third layer is 70 okay. So, we are taking the average c, C_u average that is 60 for the first layer and 2.5 meter okay. Second layer the Cu value is 35 and that will be 8, then 2 meter into the 70, C_u is 70, and total is 12.5, that is the total depth. So that is coming out to be 45.6 kilo newton per meter. So, if you look at these values, so there are three C_u values within the influence zone. One is 60, one is 35, one is 70 and average one is 45.6.

So, some people recommend that you use the 35 one because then you will be in the safe side okay because 35 is the lowest value okay, so to be in the safest side you can use 35. So, that is the designer's choice which value he will use, either you can use 35 or you can use 45.6 okay. So I will use 45.6 kilo newton per meter square, but if you want, you can use the 35 also to be in the safe side okay. So, now I will use the q net ultimate, the C_u is 45.6 average value, then Nc is 6.144, so that value is to 280.2 kilo newton per meter square okay.

And if you use the 35, then it will be so q_{nu} if you use, if C_u is taken as 35 kN/m^2, then it will be 35 + 6.144, that is equal to 215 kilo newton per meter square. So, your load is coming on the soil is this one, your 46.1 kN/m^2 okay. So the factor of safety will be that if I use the lowest one 46.1, then it is 4.7 okay. So that is more than 3 or 2.5, so it is safe, so, even if I use the lowest value of C_u.

If I use the 280, then it will be more than 5 or something okay, but I will recommend you to use the 280, but here that means your design is over safe. So, that means the dimension that I have chosen is over safe, so I can slightly reduce the dimension, but I recommend not to reduce, this is the minimum dimension that I have taken because 1 meter from the centre of the outer column is the minimum recommendation you can choose, otherwise if the column is very very near to the edge of the footing, then it is not good.

So, that means here, I have taken the minimum one even if it is safer as bearing, I have not checked the settlement one, let me check the settlement one, then we will see whether it is over safe or not, but now in terms of bearing, it is was safe. So, it is safe against bearing. Now let us go for the settlement calculation okay.

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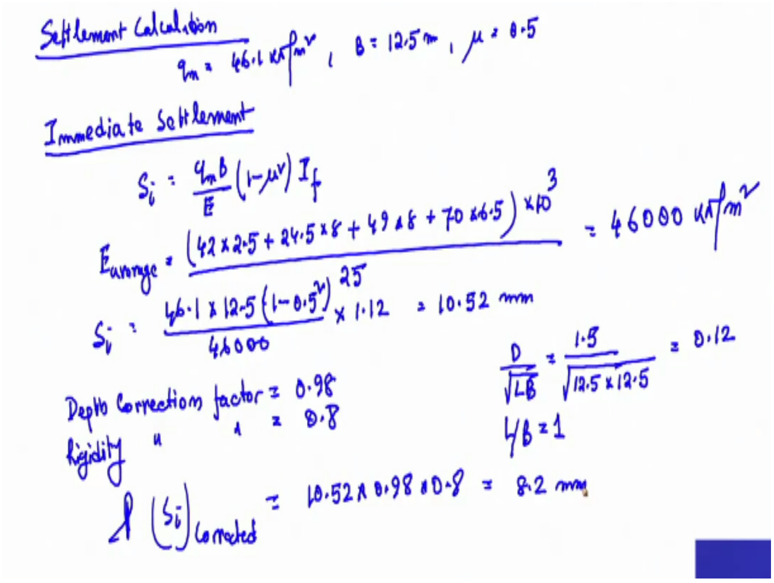

So now the next one, I will go for the settlement calculation. So here our q_n is 46.1 kN/m^2, that means that stress is coming on the soil and B is 12.5 meter, μ is taken as 0.5 as it is a clay soil and for the immediate settlement, your equation of S_i, immediate settlement is q_n B E_1 minus μ square, then If okay. Then it is If, If is the influence factor. Now B we know that is 12.5 meters, then q_n is 46.1. Then again for the E value, again it is the settlement, so the influence zone will be 2B, so 2B we will use, now influence zone is 25 meter okay.

So, influence zone is 25 meters, so it is up to 31.5 meters, so it will be up to here something. So, influence zone will be 25 and then +1.5 from the top, it will be 26.5. So, 26.5 maybe something here, so this will be the influence zone. So, for the settlement one influence in first layer will be 2.5, second layer will be 8 meter, third layer will be again 8 meter and it is 26.5, so for the fourth layer it will be around 6.25 okay. So, (6.25 + 8 + 8 + 2.5). So, this is the total influence zone for the settlement calculation.

So now for the first layer it is 4200, second layer is 24500, third layer 45000 and fourth layer 70000 okay. So I will go for the average E value calculation, E average is 4200, I have taken (42 X 2.5) okay first layer. Second layer is (24.5 X 8). Third layer it is (49 X 8) and the sixth layer it is 70 X 6.5 okay and that is we are taking into 10^3 and that divided by 25. So that value is 46000 kilo newton per meter square okay. So finally the $S_i = \dfrac{(46.1 \times 12.5 \times 1.5)}{46000}$.

Now what is the If value? Let me check what is the If value okay. So first check the If value, this is the table. As I mentioned for the rigid foundation, it is the raft, so it will be a rigid foundation. For a rigid foundation also we will take the settlement value, influence factor of the centre of the flexible foundation. So, it is a square footing. So, for the square footing, our flexible foundation, the influence factor is 1.12 okay at the centre. So we will take 1.12 okay. So, we are taking 1.12. So, this will be 1.12.

So, this value is 10.52 millimetre okay. Now, this is the uncorrected immediate settlement, now we have to apply two corrections. So, the corrections one will be the depth correction and then the rigidity correction. Now for the depth correction what will be the value? So depth correction factor will be, so for that we will use the Fox chart. So there we need to know $\frac{D}{\sqrt{(L \times B)}}$. Now D is here 1.5, now root over L is 12.5, B is 12.5. So that value is 0.12 and L by B will be 1.

So let us go to the depth correction factor chart and then determine corresponding to L by B equal to 1 and D root over L by B equal to 0.12, what is the correction factor okay. So let us go to that chart okay, this is the chart. So here your L by B, this is the L by B is 1, that means this chart we will use okay. So if I use this chart and = $\frac{D}{\sqrt{(L \times B)}}$by root over L by B is 0.12, 0.12 means here okay and this is the $= \frac{L}{B}$ is 1, this chart and 0.12, so I will go here, so this is the value. So this value is almost 0.98 okay because this is 1, this is 0.9.

So this value will be 0.98 because it is a very shallow depth, so that is why depth correction factor is very close to 1. If I go to higher depth, then the correction factor will be less than very, I mean around 0.6, 0.7 or and even for the pile foundation it will be very low value. So now the depth correction factor is 0.98. So we will go to our problem. So, depth correction factor we are getting 0.98 and rigidity correction factor is 0.8. So, S_i corrected will be 10.52 into 0.98 into 0.8, so that is equal to 8.2 millimetre. So, immediate settlement is coming out to be 8.2 millimetre.

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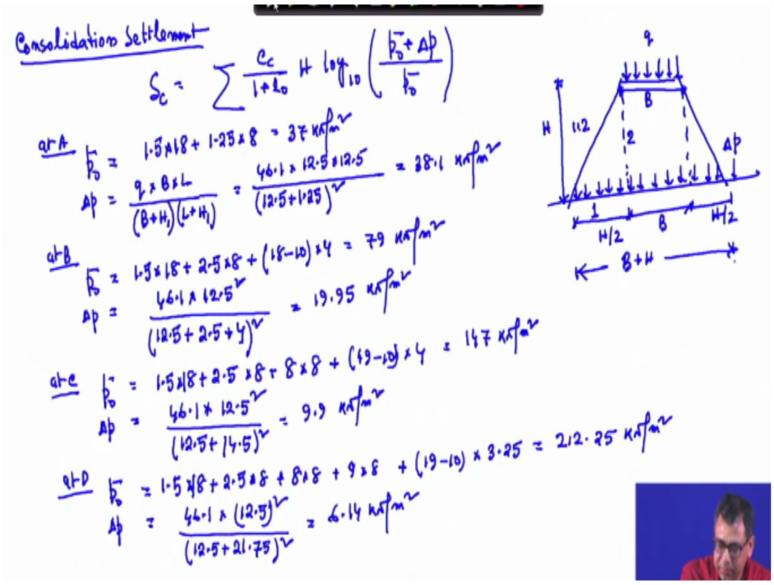

Now, I will go for the consolidation settlement okay. The consolidation settlement the equation is given C_c 1+E_0, then H log $_{10}$ p_0 bar plus δp divided p_0 bar okay. Now how I will calculate, in which point I will calculate p_0 bar and δp because we have now four layers okay and influence zone is 25 meter from the base of the foundation, so which point we will calculate? So, let us go to the figure.

So, this is the figure and one thing I want to mention that suppose here there is a rigid base and here in this case influence zone within the soil, not in the rigid part, but if the influence zone is within the rigid part, then consider only the soil part property, not the rigid part because you do not have the point, that may be the rock, where we would assume that there will be no settlement. So, you consider only the soil part even if influence zone is within the rock. So, that rock portion influence zone you neglect, you calculate the settlement within the soil part only.

But in this case, the total influence zone is within the soil, so there is no problem, but at which point you will calculate the δp or the p_0 bar? So I will calculate the centre point of each layer. So this is from the base, centre point from the each layer means from the base it will start, so from the base, this is your 2.5 meter. So I will calculate here. A point is 1.25 meter from the base. Then I will calculate at B point which is at 4 meter from the first layer, because this is 8 meter.

Then I will calculate at C point which is also 4 meter from the third layer because this is from the second layer, this is 4 meter, this 8 meter. Then I will calculate at this point, which is, this is because this is your 6.5 meter, so this point will be half of that, this will be 3.25 meter okay. So, at A, B, C, D these four points, I will calculate the stresses and these four points is centre of that particular layer okay. So now I will calculate those stresses at these four points. So at point A okay.

So $p_0$effective, so p_0 bar effective means if you see that that here water table, so when you calculate the stresses I have to consider from the ground surface because that stress will also act at point A. So, I will consider at the ground surface. So, at the ground surface, this 1.5 meter unit weight will be the bulk unit weight that is 18 kN/m^3, but below the water table, all the unit weight will be the submerged unit weight. What is submerged unit weight, that means this is saturated minus unit weight of water.

Saturated unit weight is here for the first layer say 18 kN/m^3 minus unit weigh of water is taken as 10 kN/m^3, so this will be 8 kN/m^3 for layer one okay. So submerged, so we are taking unit weight of water is 10 kN/m^3. So, if I follow that process, that means at 1.5 will be 18,/kN/m^3 then it is 1.5 and then 1.25 is below water level, 1.5 meter, that means point A is 1.5 + 1.25 meter from the ground surface and among that layer depth 1.5 is above water table and 1.25 is below water table okay.

So, I will take that is 1.5 is above water table and 1.25 is below water table and that is 8. So, that was case, sigma 0 bar will be 37 kN/m^2. Now δp, how I will calculate the del p. For δp calculation, suppose this is the width of the foundation and where your q is acting, this is your B, this is your distribution of the stresses at any say height H okay. So, what would be the stresses at this level that is δp okay. So stresses at this level is basically δp. Now here, I will follow 1 is to 2 distribution method.

So, that means if this is 1, this will be two 2, or if this is 1, this will be half okay, and here also I will consider 1 : 2 distribution method. So, now that means if this is B, this is H. If this is H, this will be H by 2 okay, this is B, this will be again H by 2, so the total width will be B + H okay. So, that will be the point where I can calculate the δp. So, here δp I can calculate, first you calculate q into B into L, then this will be B + H or H1, then L + H1 okay because it will distribute in the length direction also.

So, that means the area of the point where I am calculating the del p will be B + H into L + H. So, here for the first layer, it will be your q is 46.1, B is 12.5, and L is also 12.5. So, this will be your B is 12.5. Now, your H value is, how much is H value. For the A point, H value will be 1.25 because your stress is distributed from base of the foundation. So, H value is 1.2. So, I can write this is 1.25 okay, so that is square. So, that value will be 38.1 kN/m^2.

Now similarly, I can calculate at point B. At point B, p_0 bar will be, what is the p_0 bar, I will show you only two points, then rest of the thing I will write directly. So, point AB, the depth is 1.5, then 4, then 4 okay. So 1.5 of the first layer above ground level and 2.5 of the first layer below ground level and 4 meter from the second layer which is definitely below water level okay. So, that means, here I can write that is 1.5 into 18 + 2.5 into 8 and for the second layer the unit weight for the second layer is again 18 kN/m^3, that is saturated also.

So I can write for the second layer also 18 minus 10 into 4. So, that is 79 kN/m^2 and δp again I can write 46.1 into 12.5 square. Now this point, its depth is 12.5 then + 2.5 for the first layer from the base + 4 okay. So that is square, so that will be 19.95 kN/m^2. Similarly at point C, directly I am writing that value, at point C it is 1.5 into 18 + 2.5 into 8 + 8 into 8 + that is your 19 minus 10, now, here it is 4 meter again, that is 147 kN/m^2.

Now del p again here 46.1 into 12.5 square, then this is 12.5 + 14.5 square. So, that is 9.9 kN/m^2 okay. Now similarly at point D, your p0 bar you can calculate and that value will be 1.5 into 18 + 2.5 into 8 + 8 into 8 + 9 into 8 + again 19 minus 10 into 3.25, that is equal to 212.25 kN/m^2 and your δp value is equal to 46.1 into 12.5 square divided by 12.5 + 21.75 square okay and so this is 6.14 kN/m^2 okay.

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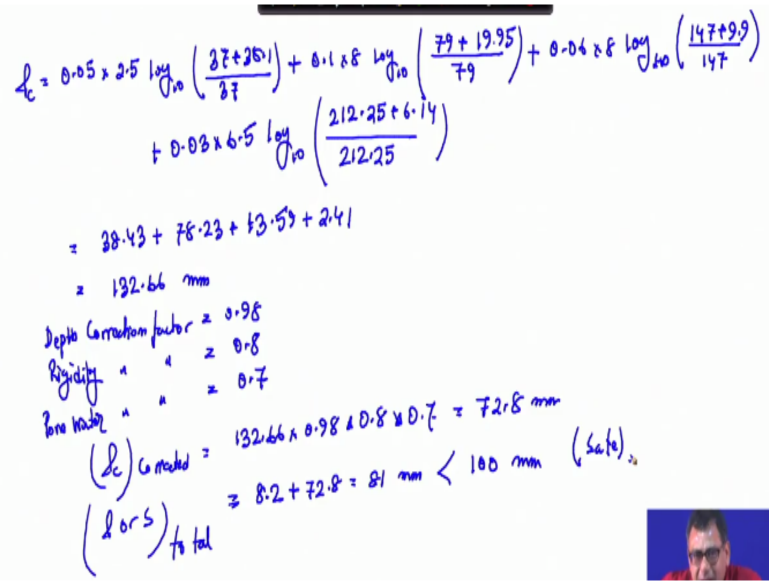

So, now finally, if I put those values for the first layer, the C_c for the first layer if you see that value, first layer C_c $1+E_0$ is 0.05 and thickness will be from the base, so this will be 2.5, second layer thickness will be 8 meter, third layer thickness will be 8 meter, and fourth layer thickness will be 6.5 meter, not the total fourth layer because total fourth layer is not within the influence zone, we will consider the thickness of those layer that is below depth of the foundation within that total influence zone okay.

So, I can put this value. So this is your 0.05, thickness of first layer is 2.5 meter, this is locked in, this is 37, δp_o bar + 38.1, δp 1, then 37 okay, then plus, this is 0.1 into 8 into log 10 79 + 19.95 divided by 79 then plus for the third layer 0.06, again 8 locked in it is 147 + 9.9 and this is your 14.147. Then for the fourth layer 0.03, 6.5 meter, then locked in it is 212.25 + 6.14 divided by 212.25 okay. So the final value will be thirty 38.43 + 78.23 + 13.59 + 2.41. So, that is 132.66 millimetre.

So, this is the uncorrected value and we have to apply 3 corrections here, one is rigidity correction, one is depth correction, one is pore water pressure correction okay. So, the depth correction factor, again it will be 0.98 okay, rigidity correction factor will be 0.8 and as I mentioned if nothing is mentioned, you can take pore water correction for normally consolidated case 0.7. So, here pore water correction factor we are taking 0.7. So, our corrected value will be 132.66 into 0.98 into in 0.8 into 0.7.

So, that value is 72.8 millimetre. So, the total S or ρ or S settlement total will be your 8.2 that is immediate settlement corrected, then 72.8 that is equal to 81 millimetre. So, now as per IS code what is the permissible value, so it is on clay that is plastic clay and it is raft and RCC foundation, so, permissible value will be 100 mm/sec , so it is less than 100 millimetre, so, it is safe and it is not over safe also, but the dimension that we have chosen it is the minimum requirement.

So, we will not change it again, so even if is not over safe because 100 is the required value and we are getting 81 millimetre. So, that is safe against bearing and safe against the settlement also. So, the dimension that we have chosen that is appropriate okay, and as I mentioned previously also, your design means the dimension, the depth of foundation and the dimension of the foundation. So, I have discussed two cases, one is the isolated footing on sand and one is the raft foundation on the clay.

So, now here the same way, you can design the isolated footing on clay also, the only difference will be here rigidity correction will not be applied in case of isolated footing, but other design procedure is same as the raft foundation, but that means that will be only individual column. So, remember that if you are designing on the sand, then try to use the available field test data, in if it is clay, then you have to use the laboratory test data to design your foundation. So, these are your basic or normal design guidelines for the shallow foundation.

So, in the next class, I will start the soil structure interaction part. These eight lectures were the kind of introduction type of lectures where I have discussed our traditional design methods for shallow foundation on sand and clay. So, next class, I will start the soil structure interaction part. First, I will introduce the modulus of sub-grade reaction concept, then how to determine the modulus of sub-grade reaction, what are the factors affecting the modulus of sub-grade reaction, and next week, I will discuss about the different available models to model the soil structure interaction problem. Thank you.