Advance Foundation Engineering
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Lecture – 48
Pile Foundation: Under Compressive Load – VIII

So, this class I will discuss that how we can determine the group load carrying capacity of the pile and then how we can determine the settlement of a pile group in clay?

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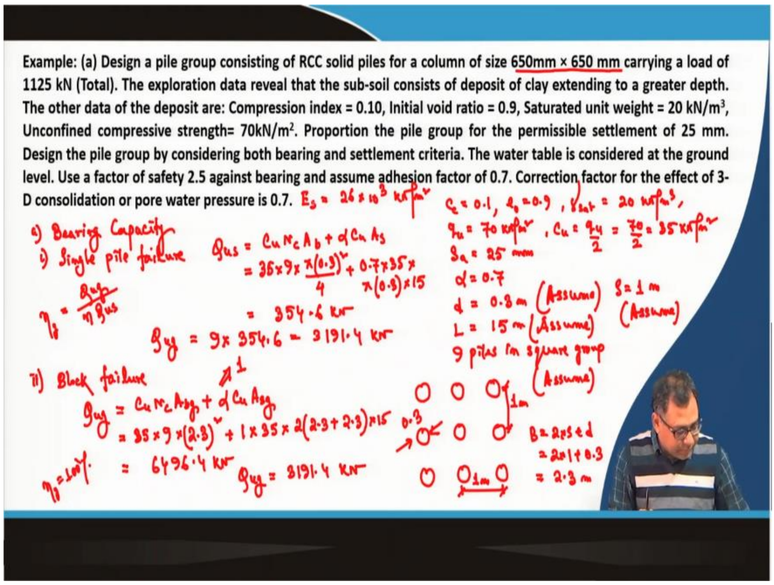

So, this is the problem which is given here that designing a pile group consisting of RCC solid piles for a column of size 650 mm × 650 mm carrying a load of 1125 kN and then the soil data that is given it is a clay extending to a great depth and other data of this soil deposit are the C_c value is 0.1, then initial void ratio e_0 is 0.9, saturated unit weight of the soil is 20 kN/m^3, then unconfined compressive strength that means q_u is 70 kN/m^2. So, the undrained cohesion, C_u value will be q_u divided by 2 and that is $\frac{70}{2}$ and that will be 35 kN/m^2, then permissible settlement S_a is 25 mm for the pile group and design the pile group by considering both bearing as well as the settlement criteria.

The water table is at the ground surface, factor of safety is 2.5, α value is taken as 0.7 and correction factor for the effect of 3D consolidation or pore water pressure is 0.7, which is given. So, now we have to design the pile group. So, this is not the pile size, this is the size of the column, for this particular column we are designing the pile group.

So, the total load that is coming is 1125 kN. So, now for the pile group, first we will calculate the bearing capacity. So, first we will consider the single pile failure. So, for single pile failure, $Q_{us} = C_u N_c A_b + \alpha C_u A_s$, we know this equation and here first one is the tip resistance, second one is the frictional resistance for the clay.

And C_u is given as 35, $N_c = 9$ and A_b is $\pi \frac{d^2}{4}$, d is the diam. So, first we are assuming the diam is 0.3 m. So, diam of the pile is 0.3 m. So, this is for the first trial it is assumed, so first trial it is assumed as 0.3 m, so that is $\pi \frac{d^2}{4}$ then α is 0.7, C_u is 35 × πdL, d is 0.3 m, L is taken as 15 m. So, for the first trial L is taken as a 15 m, so here also L is not given.

So, what are the things you have to determine? You have to determine the diam of the pile, length of the pile and spacing between the piles. So, diam and length we are assuming for the first trial and length is assumed as 15 m. So that means here this value is 354.6 kN and we have assumed again that 9 piles in square group that is also assumption for the first trial.

So that means the number of piles we have to assume for the first trial, then you will check whether that assumption is correct or not, if it is not correct then you have to redesign this. So, 9 piles are assumed in square pattern. So, the group load carrying capacity based on the single pile failure will be 9 × 354.6, so that is 3191.4 kN. So that is for the single pile failure consideration and then we have the 9 piles in square group.

So, these are the 9 piles and the diam is 0.3 m, again we are assuming for the first trial the spacing between the piles is 1 m. Here also because as per IS code the minimum spacing is 3D. So, we are taking 1 m, so the spacing between the pile that is also 1 m and that is also we are assuming for the first trial. So, the B value will be $2S + d$. So, $2 \times 1 + 0.3$. So, this will be 2.3 m.

So, previous one was single pile failure, now we are considering the block failure. So, my group capacity the same as the single pile failure case that means this will be also $C_u N_c A_{bg}$ that is for group + again also we are taking $\alpha C_u A_{sg}$, where, C_u is the average undrained cohesion along the shaft of the pile or along the pile group and A_{sg} is the area of the pile group. Now there is a question that in single pile the interaction is between pile and the soil.

So, we are taking the adhesion factor but now when the group piles, so it is a block, so this block is basically interacting. So, but here the difference between the pile is more. So that means here more soil will interact compared to the pile. So that is why here the adhesion factor for group pile is considered as 1. We saw here basically the interaction between soil versus soil in case of group pile, so that is why adhesion factor you are taking 1.

So that means here C_u is 35 again $N_c = 9$. Now this is a square pile group, B is 2.3. So, this will be 2.3^2 + adhesion factor is 1, C_u is 35 then the area that means the perimeter is 2 × (2.3 + 2.3) and length is 50 m, perimeter × the length that will be the surface area. So that is equal to 6496.4 m^2. So that is the load carrying capacity of the pile considering block failure. So, the minimum of these two we have to consider as the load carrying capacity of the pile block.

So, these will be 3191.4 kN that is the group load carrying capacity. And remember that suppose as I mentioned in my previous lecture the efficiency of the pile group is these pile load carrying capacity considering the block failure of the group and then the number of pile × the load carrying capacity of the single pile. So, now if I consider this condition then this is the 3191 this is 6496.

So, that means group efficiency is greater than 1, no this is not the case group efficiencies 1 here. So, as I discussed in my previous class this spacing is sufficiently large then that block failure will not occur and the pile will fail as single pile and in that case your efficiency will be 1. So, here this is the case so that means here the block failure is not occurring and a single pile failure is occurring that is why that is the lowest value compared to the single pile and the block pile failure.

So, here efficiency will be 1. So, you cannot say this is the efficiency when there will be a group pile failure suppose this block failure is given then lower amount of load carrying capacity compared to the single pile failure, in that case you can use this expression and put the value will get the efficiency less than 1. So that will be the efficiency of your pile group. But when the single pile failure is giving lower value compared to the block failure that means this spacing is sufficiently large that is why we are getting a single pile failure.

So, in that case efficiency will be always 1. Efficiency cannot be greater than 1 except in one case that I have discussed for the loose and driven pile in that case also will get the efficiency greater than 1 but that case also during the design, consider efficiency as equal to 1. So that is why these minimum spacing recommendations are given. So, if we take more than 3*D* in case of piles we will get efficiency close to 1. So, there will be a single pile failure. So that is why here efficiency is always 1. So, in this case pile group efficiency is 100% because it is a single pile failure and then but group value is 3191.4.

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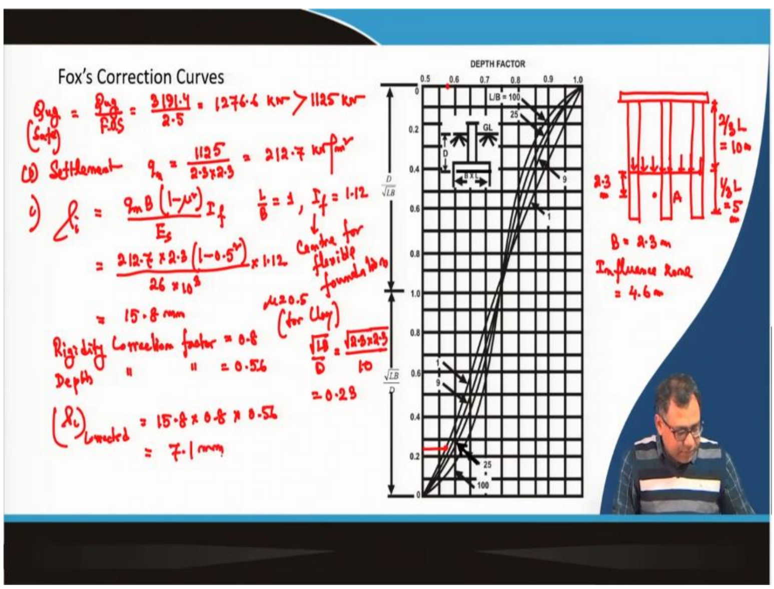

So, what is the factor of safety let us determine that. So, factor of safety will be your safe load, or Q_{ug}(safe), safe load will be how much that Q_{ug} divided by factor of safety and factor of safety we are taking 2.5 to 3. So, here we are taking 2.5, so 3191.4 divided by 2.5. So, this is 1276.6 kN. So, how much load is coming? The load is coming 1125 kN and the pile can carry safely, or the pile group can carry safely a load of 1276.6 kN.

So, the design is safe for the bearing capacity consideration. So, this is greater than 1125 kN. So, in terms of bearing capacity consideration design is safe what are the values we assumed? Number of piles, spacing diameter, length that is absolutely fine for the bearing capacity consideration, now we will check it for settlement consideration. So, for the settlement consideration, so this is the pile group.

And we have mentioned here in the question that the soil is in greater depth the extension of the soil layer so that means here we consider a homogeneous soil. So, we will put it at the $\frac{2}{3}$ from the top of the pile. So, here we will place the raft and that means this is $\frac{2}{3}L$ this is $\frac{1}{3}L$, so L is 15, so $\frac{2}{3}L = 10$ and $\frac{1}{3}L = 5$ m and then our B value is 2.3 m. So, influence zone will be twice B for the settlement calculation and that will be 4.6 m from the raft. So that is within the pile group itself for this particular case.

So, this will be 4.6 m, so we will take A point for our settlement calculation which will be half of that 4.6 m that mean 2.3 m from the base of the raft because this is similar as the sallow foundation design or raft design. So, now the q_n which is coming at this level, I mean net stress, which is coming, so load is 1125 kN and dimension of the raft is 2.3 m × 2.3 m. So, this load is 212.7 kN/m^2.

So, we will calculate the immediate settlement which is $\frac{q_n B(1-\mu^2)}{E_s} I_f$. So, for the square foundation $\frac{L}{B} = 1$, I_f at the center for the flexible footing is 1.12. So, this is for the center of flexible foundation but here we are considered it is raft, so it will be a rigid foundation. So, now, $q_n = 212.7$, B is 2.3, μ is 0.5 this is 0.5^2 value is given in the problem no it is not given.

So, for the clay we are assuming that μ value is 0.5, this is for clay. So, elastic modulus of the soil is given in the question, but I should write that thing also. So, elastic modulus of the soil is given as 26×10^3 kN/m^2. So, it is given if it is not given during design purpose, I have given you a number of correlations based on C_u.

So, in my previous raft design problem I have used one of those correlations. So, you can use those correlations and you can determine the E_s value but in this particular problem it is given. So, this is given $E_s = 26 \times 10^3$ kN/m^2 but here I am doing a design problem. So that is why you can assume few things but when you solve a problem in exam or in assignment, I will specifically give every data.

I will give μ value because otherwise you will not get a particular answer. But I can assume during the design but actual when you do it assignment problem or exam problem data will be given. So, I can write that E_s is given which is 26×10^3 kN/m^2 then I_f value is 1.12. So that means the value is coming as 15.8 mm then we have to apply the corrections.

So, we have to apply the rigidity correction factor of 0.8 because we are taking the I_f for flexible foundation at the center and the depth correction factor for the immediate settlement and for the consolidation settlement there will be pore water pressure correction also this correction factor, so what will be the depth correction factor? Now here in my shallow foundation design I consider the upper part of this chart that was $\frac{D}{\sqrt{LB}}$.

So, this chart was given in the IS code. So, I use the same chart with this $\frac{D}{\sqrt{LB}}$ for the shallow foundation design but for the deep foundation design, that upper part is not sufficient you have to use the lower part with this $\frac{\sqrt{LB}}{D}$. So, $\sqrt{LB}$ is $\sqrt{2.3 \times 2.3}$ and the depth of foundation, D is 10 m.

So, we can write this is 2.3. So, for $\frac{L}{B} = 1$ and this is $\frac{L}{B} = 1$ and it is 2.3 this is the value. So, this value will be around 0.56. So, the correction factor is 0.56, so the $\rho_{i(\text{corrected})} = 15.8 \times 0.8 \times 0.56$, so that value is 7.1 mm. So that is the corrected immediate settlement.

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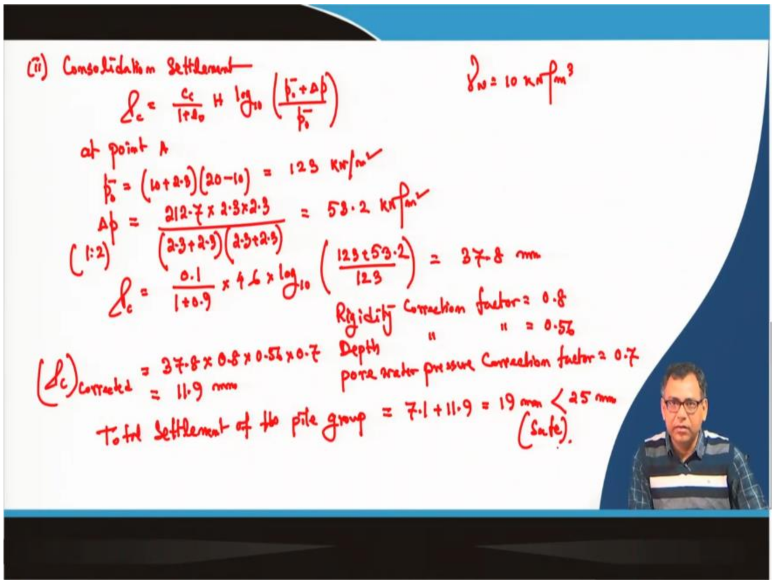

Now we will calculate the consolidation settlement. So, consolidation settlement is $\frac{C_c}{1+e_0}H$ because here it is a single layer, so I will take the single layer values and this is $\left(\frac{\bar{p}_0+\Delta p}{\bar{p}_0}\right)$. So, at point A this is the point A which is 2.3 m from the base of the raft.

So, what actively is here, so all you need to do you have to consider the submerged unit weight and at point A which is 10 + 2.3 = 12.3 m from the ground surface. So, it will be 10 + 2.3, so this is 20 - 10, so we are considering unit weight of water as 10 kN/m^3. So, 12.3 × 10 kN/m^2 and then we are considering 1 : 2 distribution then this will be 212.7 × 2.3 × 2.3 then this is 2.3 and the depth is also 2.3 then 2.3 + 2.3.

So, this 1 : 2 distribution we already discussed. So, then it will give you 53.2 kN/m^2. So, the uncorrected consolidation settlement C_c is 0.1, e_0 is 0.9, γ_{sat} is 20 that is why I have taken 20 here, so 1 + e_0 is 0.9, H is the thickness and H is 2B and 2B is 4.6 m, this is influence zone. So, 4.6 × $\left(\frac{123+53.2}{123}\right)$. So, this is 37.8 mm. So, what are the corrections you have to apply?

So, again the rigidity correction factor which is 0.8 then depth correction factor which is 0.56 we have already determined the pore water pressure correction factor, which is given 0.7. So, now if I calculate the corrected consolidation settlement that will be 37.8 × 0.8 × 0.56 × 0.7. So that will give 11.9 mm. So, that total settlement of the pile group will be equal to the 7.1 + 11.9 = 19 mm.

So, 7.1 + 11.9 which is equal to 19 mm, so it is less than 25 mm which was the permissible settlement for this particular design. So that means the design is safe in terms of bearing capacity as well as the settlement. So, this way we can determine the bearing capacity of the pile group and the settlement of the pile group. So that I have done for the clay similar way exactly by using that single pile bearing capacity equations you can determine the bearing capacity of the pile group in sand also and the settlement of the pile group in sand also.

Because I have already discussed the settlement of the raft resting on sandy soil a settlement of the shallow foundation testing on sandy soil. So, same equations you can use because I have used the similar type of equation here for settlement calculation of the pile group or the raft for clay. So, in the next class I will discuss the last topic of this pile foundation under compressive load that is the negative skin friction. So, next class I will discuss the negative skin friction then I will go for the next topic that is lateral loaded pile. Thank you.