Advance Foundation Engineering
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Lecture - 49
Pile Foundation: Under Compressive Load - IX

So, this class I will discuss the negative skin friction and what are the different cases and how we can determine the resistance or the load that we have to subtract from the pile load carrying capacity due to the negative skin friction.

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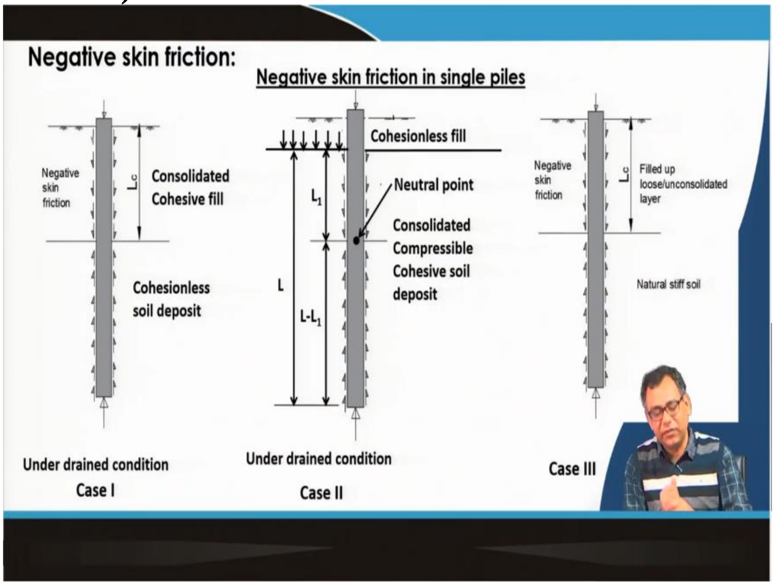

So, what is negative skin friction? Suppose we have a newly constructed fill so, that fill can be cohesive soil that can be loose cohesionless soil also. And if the pile is constructed before or after the placement of the fill but before the completion of the consolidation of the filled soil then what will happen? That filled soil will deform more compared to the pile deformation. So, in terms of relative deformation the soil deformation is less compared to the pile deformation.

So, relative deformation is the pile is moving towards the downward direction. So, frictional resistance is acting in the upward direction but if the relative movement of the pile is less than the movement of this soil then as if the pile will move in upward direction. So, the resistance will act in the downward direction. So that will basically reduce the frictional resistance given by the pile and overall load carrying capacity will be reduced due to this negative skin friction.

So, it is a negative means actual friction is acting in upward direction for compressive loading but it is for this portion because of the soil movement is more than the pile movement then the friction will act in the opposite direction. So that is why it is called the negative skin friction. So, this is the condition you can say the first or here this is the condition you can say so where this is the filled topsoil with thickness, L_c and then the bottom soil is the actual natural soil.

So, this you can see the filled soil movement is more compared to the pile. So, the friction will act in the downward direction but actual in natural soil deposit the friction is acting in the upward direction which is the normal. So, actually some portion of the pile friction is acting in the downward direction. So, overall the net friction will reduce. So that is called a negative skin friction.

So, we have to take care of this negative skin friction by measuring the amount of negative skin friction that the soil or the field is generating so that we can subtract that amount of load from our load carrying capacity of the pile. So that we can safely design this pile foundation so there are three cases that I will discuss. So, what are these three cases? The case number 1 that your fill is a consolidated cohesive soil which is resting over a cohesionless soil deposit.

So that means the lower portion of the soil is cohesionless soil and the fill is consolidated cohesive soil. So that means the fill is cohesive, but the natural soil is the cohesionless soil that is one condition. Another condition your natural soil is cohesive which is very soft or soft. And you are applying a fill over that and that soil is cohesionless soil.

So that the cohesionless fill is placed over the natural very soft clay and third condition is that you can place cohesionless or cohesive fill over a stiff soil. So, these are the three conditions and now let me explain how we can calculate the negative skin friction for these three conditions.

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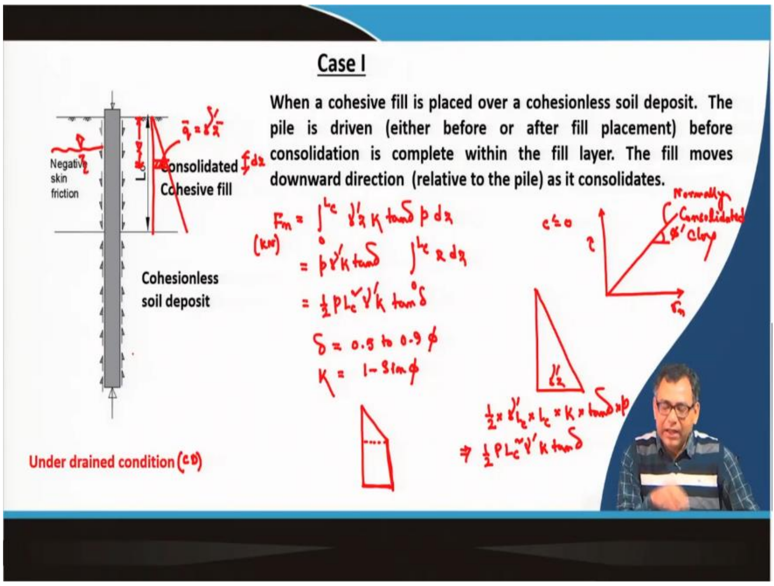

So, first condition what will happen that when the cohesive fill is placed over cohesionless soil deposit? The pile is driven before consolidation is complete within the fill layer that can be before or after the placement of the fill. So, in that case the fill that cohesive soil that will start to consolidate or the consolidation is already been started. So, but it is not finished yet.

So that means that is why the fill material fill cohesive soil will move in the downward direction and then the movement of that fill is more than the movement of the pile. So, overall this fill will move in downward direction as it consolidates. So, in such case how we can determine the load carrying capacity of the pile. So, in that case the load carrying capacity of the pile we can determine so that mean this is a consolidated soil and then there will be the distribution.

Now you can ask me that this is a clay soil then why I am drawing such distribution because it is under drained conditions. So, because your properties are given under drained condition so that means the all the properties are determined under consolidated drained test because we know that there are three types of triaxial tests UU unconsolidated undrained, CU consolidated undrained and CD consolidated drained so all the properties are determined under consolidated drained condition.

So now why it is under consolidated drained condition? Because soil is consolidating, and water is draining out that means it is flowing out and it is consolidating so it is under drained condition. So that is the actual condition because the soil is moving downward because of the consolidation. So that is why you have to consider the drained properties of the clay.

And you know that for the triaxial test if you do it under CD triaxial test if this is τ and this is σ_n then your Mohr-Coulomb failure profile will pass through the origin if the soil is normally consolidated clay so your c' value will be 0 if it is a CD test. So my c' value will be 0 and there will be only ϕ' value even if it is a clay remember that because that you should know because you have done the soil mechanics course.

So, for CD test normally consolidated clay the cohesion value will be 0 there will be only friction values and if it is over consolidated clay then there will be some cohesion value as well as the friction value. But here we assume that our fills as a normally consolidated clay. So, you will get this type of distribution and then we can calculate the frictional resistance or the negative skin friction. Suppose this is the $\bar{q}$ which is equal to $\gamma \times z$.

And γ will be the effective γ and z is any distance z. So the skin friction will be 0 to L_c this is $\gamma' \times z$ there will be K we have to multiply because $\gamma' \times z$ is the vertical effective overburden pressure if we multiply by K you will get the lateral stress, then there will be $\tan\delta$ and that total you have to multiply with the perimeter of this pile at this zone × dz because dz will be this small thickness.

So that is dz so this way we can calculate so that if I take perimeter out then γ' outside K out $\tan\delta$ also out so that will give us $\int_0^{L_c} z dz$. So, we can write so this will be the $\frac{1}{2}z^2$ so $\frac{1}{2}p$ is the perimeter then L_c^2 because z^2 mean L_c^2 if I put the limit then $\gamma' \times K \times \tan\delta$. So, here for this particular case δ is taken as 0.5ϕ to 0.9ϕ, ϕ is the friction angle of this soil or the fill.

And K you can take as $1 - \sin\phi$ which is equal to the K_0. So, this way we can determine the total negative skin friction and it is in kN how much amount we can calculate which is same as the frictional resistance calculation for the pile. So frictional resistance calculation for the pile we have done the same thing because in that case we have taken this average frictional resistance.

So, it will be $\frac{1}{2} \times \gamma' z$ because this is $\gamma' z$, I should write the L_c here directly $\gamma' z L_c \times L_c$ then the K then the $\tan\delta$ then the total resistance into the perimeter, P so same thing we will get that is $\frac{1}{2} P L_c^2 \gamma' K \tan\delta$, same thing we are getting by doing the integration we have done these things during the frictional resistance calculation. So, the same thing we can do here also you will get that.

But remember that if there is a groundwater table for example, then directly you cannot use this equation in such case this will be the distribution remember that. Then these integration you can also do the integration but that integration you have to get two limits one from the top to the water level, then from water level to the end of the negative friction zone.

So, if you want to calculate in this way then I have already discussed how we can calculate in such case the first you take the two parts, one above the water table and another below the water table and then take the average stress that is acting at the middle of the each segment. So, this way we can calculate this negative friction amount and remember that here this first case the negative friction will be due to the fill movement only the lower cohesionless soil will not give any significant effect on the negative skin friction value.

The lower cohesionless soil that will give the upward friction resistance as I have shown and that upward friction resistance will increase due to the application of this field because your effective overburden pressure will increase for the cohesionless soil. So that will be the only effect for the lower cohesionless soil but it will not give any negative effect it will give the positive effect as it was given before the placement of the fill.

But once the fill is placed that fill portion only give the negative skin friction and the cohesionless soil will give the positive skin friction and that skin friction will increase due to the placement of the fill as the overburden pressure will increase.

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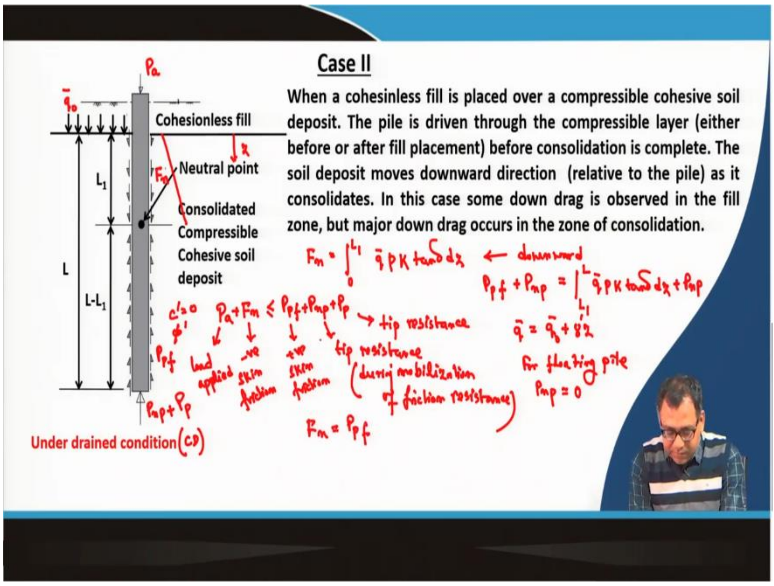

So, next one the second case which is very crucial so, in the second case that when the cohesionless fill is placed over a compressible cohesive soil deposit that means suppose a very soft clay because your pile is installed in a very soft clay where the consolidation is not completed yet soil is very compressible. Now we have placed a cohesionless fill over there. So that means you have placed some surcharge load over a very compressible soil whose consolidation is still in progress.

So, what will happen so it will further consolidate so consolidation is not completed yet. So, the consolidation will start for the lower soil and so that means the most of the positive skin friction the pile was getting from the soft clay only but now if the consolidation starts for the soft clay portion then there will be a downward movement of this compressible soil. So, the negative skin friction will generate in the compressible clay.

So the negative skin friction will not be considered for the cohesionless fill that will act as a surcharge on the compressible clay layer. So, negative skin friction will be generated for the clay layer only. So, the soil deposits move in the downward direction as it consolidates. So, in this case some down drag is observed in the fill zone but major down drag occurs in the zone of consolidation.

So, as I mentioned there will be a downward movement in the fill zone but that is not that significant compared to the down drag that will be observed in the compressible clay layer. So that will give most of the negative skin friction. So, you can see that this is the total pile length so here this is the cohesionless soil acting as a surcharge, $\bar{q}_0$ which is acting on the top of the existing your compressible cohesive soil.

And so that means the length of the pile is not large enough then the most of the pile friction will be negative skin friction because in this case so that is why to counter balance the negative skin friction there should be a sufficient length of the pile. So that there will be some portion or the top portion will be negative skin friction and the bottom portion of the positive skin friction so that we can counter balance this negative skin friction.

That means pile length should be sufficiently large otherwise most of the portion will be the negative skin friction and if we provide a larger length of the pile then these negative skin friction will be counter balanced by the positive skin friction if the length of the pile is large. So, now there will be a neutral point so above the neutral point there will be negative skin friction and below the neutral point there will be positive skin friction.

So that way we can determine what would be the length L_1 of the neutral point from the top of the compressible layer and total length of the pile is L because the fill portion we will not consider during the load carrying capacity of the pile. Because fill portion we will not consider we will consider only the natural soil where the pile is installed and the load carrying capacity will be calculated based on that portion length.

So, here the length is that this length so and now we have to calculate what is the L_1 value? So to calculate the L_1 value as we have mentioned this is the fill that is acting on this compressible layer. So again, this distribution is like this again this is a drained condition because clay soil under consolidation, so it is a drained condition. So drained condition means c'will be 0 and there will be ϕ' only under CD test condition.

So $F_n = \int_0^{L_1} \bar{q}$, $\bar{q}$ is the effective over burden pressure, then perimeter, p, then K, then $\tan\delta \times dz$, that is the F_n and F_n is acting here then this is the negative skin friction then there will be a positive skin friction. So that we are talking about P_{pf}positive skin friction and there is a tip resistance P_{np}.

And this is the P_a which is acting on the pile. So, this load P_a is acting and F_n is the negative skin friction, P_{pf} is the positive skin friction, tip resistance has two parts, one is P_{np} and another is P_p. So, what is P_{np}? What is P_p? That P_{np} is the tip resistance when there will be a negative skin friction. That means during the negative skin friction also the pile will have some tip resistance.

So that is considered as P_{np} and P_p is the normal tip resistance that pile is getting. So that means here as I mentioned that when there will be a mobilization of the frictional resistance some tip resistance will be there. So, I have already discussed that during the mobilization of the frictional resistance some tip resistance will be there. And once the frictional resistance is mobilized, then tip resistance will start mobilizing.

So that means this P_{np} is the tip resistance during the mobilization of this frictional resistance. And then P_p is the normal tip resistance that is developed after the mobilization of your frictional resistance. So, here I can write that so that means the actual design condition is $P_a + F_n \leq P_{pf} + P_{np} + P_p$. So, I should write what is the meaning of different terms. So, this is p is the perimeter so that I have not written here.

So, I should write that p is the perimeter then K I have given $\tan\delta$ I have given and L_c is the length of the fill zone. So, now here P_a and F_n are the downward forces and $P_{pf} + P_{np} + P_p$ is the total upward force, P_{pf} is the positive frictional resistance. So, this is the load applied this is the negative skin friction this is the positive skin friction this is the tip resistance and this is the tip resistance during mobilization of friction resistance.

So, these are the forces so ideally this downward load should be less than the upward load and you can apply a factor of safety also. So, now this is the tip resistance or the downward forces. So, I can write that this is the downward force so corresponding upward forces will be the $P_{pf} + P_{np}$ because during mobilization of the friction is changed there will be some tip resistance and then the positive friction resistance.

So that means the negative frictional resistance should be counter balanced by the positive frictional resistance + some amount of the tip resistance. So that is positive frictional resistance will be 0 sorry not 0. Because F_n is the negative friction resistance or negative skin friction so these terms I have already written so it is not required to write because it will only kill the space.

So, these things I can write so 0 to L_1 is the negative skin friction and L_1 to L is the positive skin friction and the equation is same $\bar{q}$, p is the perimeter Ktan $\delta \times dz + P_{np}$. Now what is $\bar{q}$ here? $\bar{q}$ is the surcharge $\bar{q}_0$ which is acting at the top plus the over burden pressure. Over burden pressure is $\gamma' \times z$ at any depth z.

So that is $\bar{q}$ now for floating pile we assume that the P_{np} contribution is 0 for the floating pile the tip pile there will be some contribution for floating pile I assume that $P_{np} = 0$ or we are assuming the contribution is tip during the frictional resistance mobilization is very small so, we are neglecting that. So, now we can write that because we have to determine a neutral point. So, above that there will be negative skin friction and below the positive skin friction.

So, we have to equate these downward and upward forces or which are counter balancing the skin friction. So, here we have written P_{np} that contribution is 0. So, only the positive skin friction will be equal to the negative skin friction. So that means here we can write that $F_n = P_{pf}$ which is positive skin friction.

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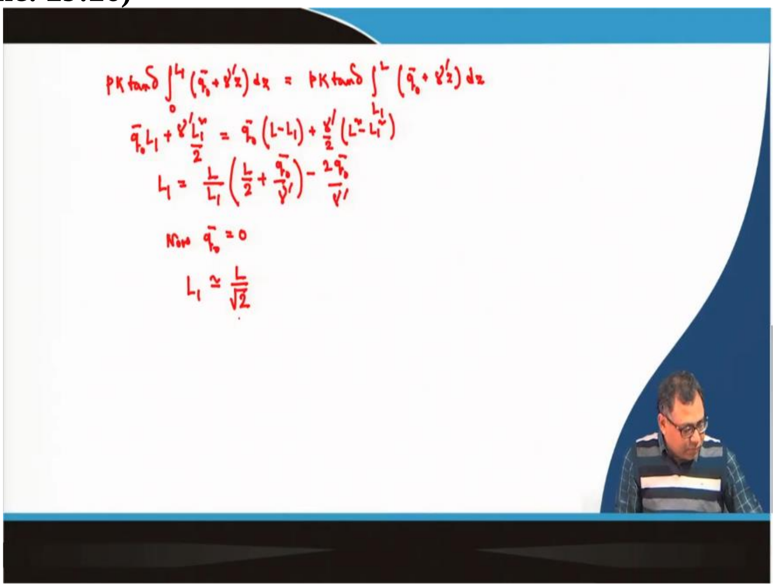

So, if I write that $F_n = P_{pf}$ so if I take this is outside F_n is $pK \tan \delta$ outside so this will be 0 to L_1 and there will be $\bar{q}_0 + \gamma' z$ that is $\bar{q}$ because this is the expression. This is $\bar{q} pK \tan \delta$ we have taken outside, and $\bar{q}$ is $\bar{q}_0 + \gamma' z$ that will be equal to $pK \tan \delta$. Now this is from L_1 to L again $(\bar{q}_0 + \gamma' z)dz$ we are equating that.

Because basically we are counterbalancing the negative skin friction by the positive skin friction and some tip resistance during that process but that tip resistance we have neglected. So that means we have to make the pile length sufficient so that developed negative skin friction can be counter balanced by the positive skin friction. So, if I cancel these both side and then we can integrate these.

So, this will be $\bar{q}_0$ then z if I put limit L_1 then + γ' this will be $\frac{L_1^2}{2}$ because it will be $\frac{z^2}{2}$ then this will be again $\bar{q}_0$ and z that means $(L - L_1)$ then + $\frac{\gamma'}{2}(L^2 - L_1^2)$ because z^2. So, $L^2 - L_1^2$. So, now we can write $L_1 = \frac{L}{L_1}\left(\frac{L}{2} + \frac{\bar{q}_0}{\gamma'}\right) - 2\frac{\bar{q}_0}{\gamma'}$.

So, this is the expression of L_1 and that we have to use for our negative skin friction calculation so we can determine what is the value of L_1. Now if I put $\bar{q}_0 = 0$ which is practically not possible just to get an idea about what would be the approximate value of L_1. So, we have taken $\bar{q}_0 = 0$ the L_1 is roughly coming out to be $\frac{L}{\sqrt{2}}$ but actually $\bar{q}_0$ will not be 0. Because if the $\bar{q}_0$ is 0 then this consolidation will not start if we do not place any fill then the consolidation will not start so that iL_1 is close to $\frac{L}{\sqrt{2}}$.

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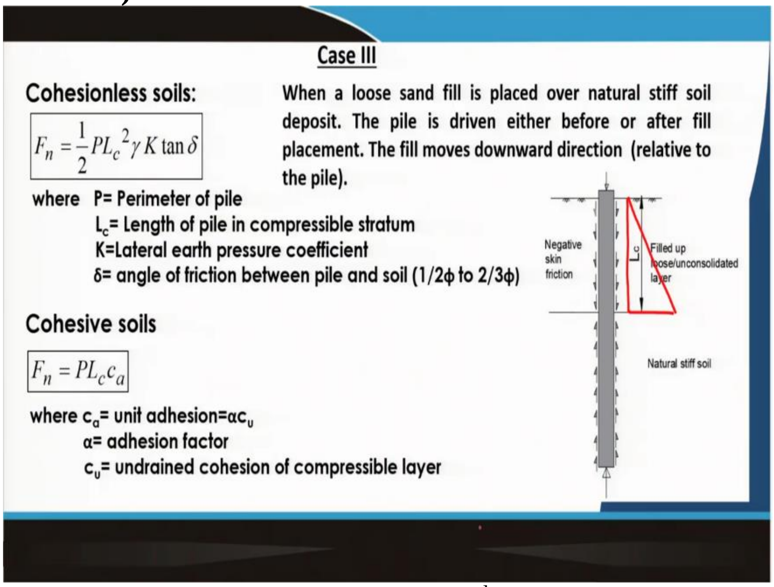

So, in the 3rd case quickly I am just explaining the 3rd case then I will finish today's lecture. So, in the 3rd case when the loose sand because in previous two cases we have considered that the fill is consolidated soil that is a clay. So, the reason is due to the consolidation of the clay in 1st case the fill and the soil is cohesionless 2nd case clay is the natural soil deposit.

And we have placed a cohesionless fill but there is a 3rd case where the natural soil deposit is very stiff soil above that we have placed a very loose soil. So, but here the natural soil there will be no consolidation effect because it is a very stiff soil it is not that much compressible so consolidation will not make any effect for the natural soil but as the soil is very loose so negative skin friction will develop for the top portion due to that loose soil that is also another reason.

So, in that case that will be under undrained condition because if it is a loose soil so with that drained properties you are considering so that even if you consider the CD test so loose soil also giving you the ϕ value for the sand CD test also. So, but the unconsolidated soil I am coming later on. So that means it is giving your ϕ value so that way you can determine in the same way that we did it for the 1st case.

But only difference in the 1st case it was clay but here it is sand. But here the same way we can determine the value of a negative skin friction for cohesionless soil but if there is a water table as I mentioned then you have to modify this equation or this diagram so that we can done but sometimes if the clay soil is placed so and if the undrained properties are given so in few cases you will find actually even for the first case also you should use the drained properties because that is the actual condition.

But sometimes you will find that you have the undrained properties and here also you can place the clay fill also over the stiff soil but that clay is very soft clay soft deposit but that will consolidate. So, here also ideally you should use the drained properties because that is a consolidated but if you have the consolidated undrained properties are given. So, in that undrained properties are these then you have to use this equation which is the same equation we use to determine the frictional resistance of the clay.

So, this is the equation to determine but if we consider that is the unconsolidated layer then only it is possible but so this is the special case where say, undrained properties are available then only we use otherwise straight forward three cases. 1st case consolidated clay over consolidated soil where you have to use the drained properties CD properties 2nd case cohesionless fill is placed over the compressible consolidated layer drained properties.

And the 3rd case where the very loose sand is placed over a stiff soil or very stiff soil then you have to use the cohesionless skin friction contribution but if for the clay is placed over the soil. And then the undrained properties are available then you can use these conditions but if the drained properties are not available then only you can use but otherwise you should use the drained properties.

So, in the next class I will solve one particular problem or to show you how you can determine the negative skin friction then I will finish these pile part under compressive loading. Thank you.