Advanced Foundation Engineering
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Lecture – 55
Pile Foundation: Under Lateral Load and Uplift – V

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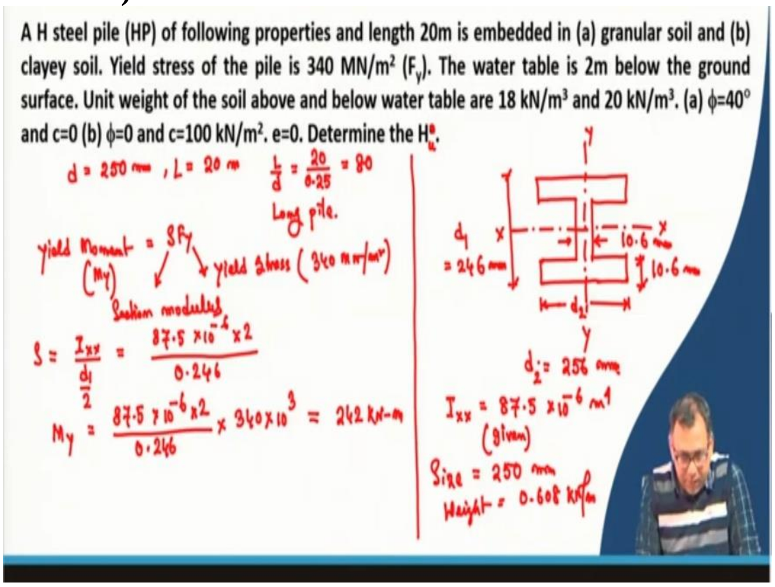

So, last class we are discussing about one example problem where steel pile section was taken and the soil properties were given and there are two soil conditions were given, one is the granular soil and another is the clayey soil. And the diameter or the size of the section was 250 mm. So, diameter was taken as 250 mm as the size was given. So, these values are available for a particular section and for this section these are the values.

So, and this is d value is 250 mm, L value is to 20 m. So, L/d is 80. So, definitely it is a long pile. So, we have to determine what would be the value of yield stress, yield moments because yield stress is given. So, based on that you have to calculate the yield moment at the two points below the ground surface and then moment of inertia about the X-X axis, d_1, d_2 value thickness of the web and the flange. So, all are given.

So, now we will get the yield moment. So, yield moment is equal to $S \times F_y$. What is F_y? F_y is the yield stress and S is section modulus and in most of the cases this yield stress and section modulus are given. So, we have to calculate the yield moment, directly yield moment will not be given, but if yield moment is given then you can use that yield moment directly. But in most of the cases the yield stress and the section modulus are given.

So, for the section modulus how we can get that. So, yield stress is given that is 340 MN/m^2. So, section modulus, $S = \frac{I_{xx}}{\frac{d_1}{2}}$. So, $\frac{d_1}{2}$ that means half. So, section modulus I_{xx} is given as 87.5×10^{-6} and this is $\frac{d_1}{2}$. So, d_1 is how much? d_1 is 0.246.

So, this is the section modulus. So, $M_y = S \times F_y$. So, $S = \frac{I_{xx}}{\frac{d_1}{2}} = \frac{87.5 \times 10^{-6} \times 2}{0.246}$ and $F_y = 340$ MN we are converting it to kN. So, this will be 10^3. So, M_y is 242 kN-m. So, yield moment for this particular section is 242 kN-m. Now, for different sections what would be the section modulus?

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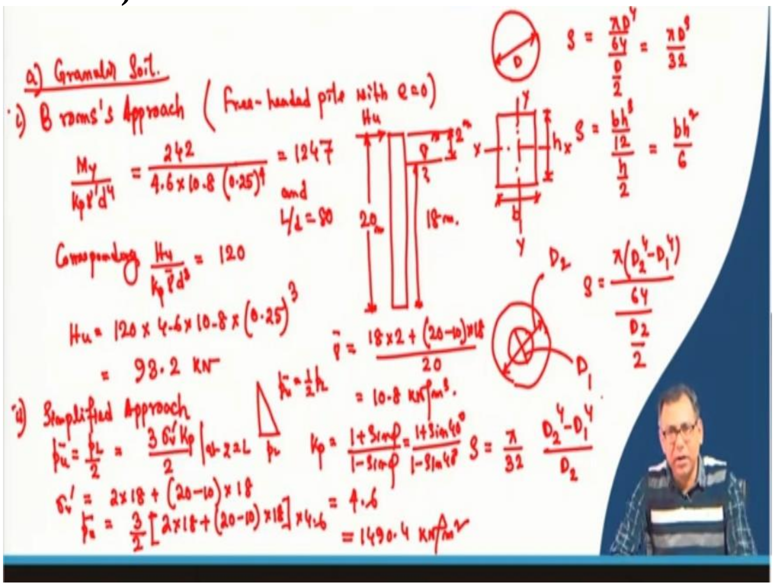

So, quickly I am giving that idea because this is each pile section. But suppose if that is a circular section, then what will be its section modulus? So, suppose the circular section of diameter D then the section modulus will be $\frac{I_{xx}}{\frac{D}{2}}$. So, this will be $\frac{\frac{\pi D^4}{64}}{\frac{D}{2}}$. So, this will be $\frac{\pi D^3}{32}$ for the circular section. Now, if it is a rectangular section if this is b and this is h, then the section modulus will be what? $\frac{\frac{bh^3}{12}}{\frac{h}{2}}$. So, this is the XX axis.

And now this is YY axis, for a circular section it is the symmetric case. So, this will be $\frac{bh^2}{6}$. Now, what will be the section modulus for the hollow circular section? So, outer diameter is D_2 and the inner one is D_1. So, $S = \frac{\frac{\pi\left(D_2^4 - D_1^4\right)}{64}}{\frac{D_2}{2}}$. So, for this case S will be $\frac{\pi}{32}\frac{D_2^4 - D_1^4}{D_2}$.

So, these are the section modulus for different sections. Now, for our case we have determined the M_y value and that value is 242 kN-m and different section modulus we have determined by using these equations and the same equations we have used for this particular section and we have determined its section modulus.

Now, first we will consider the Broms's approach. The first case is the granular soil. I should say that I should write the granular soil first then for the granular soil first one will be Broms's approach and then the second one will be the simplified approach. Now it is a free-headed pile with $e = 0$ because e is given as 0. So, for this particular case either we can use those equations

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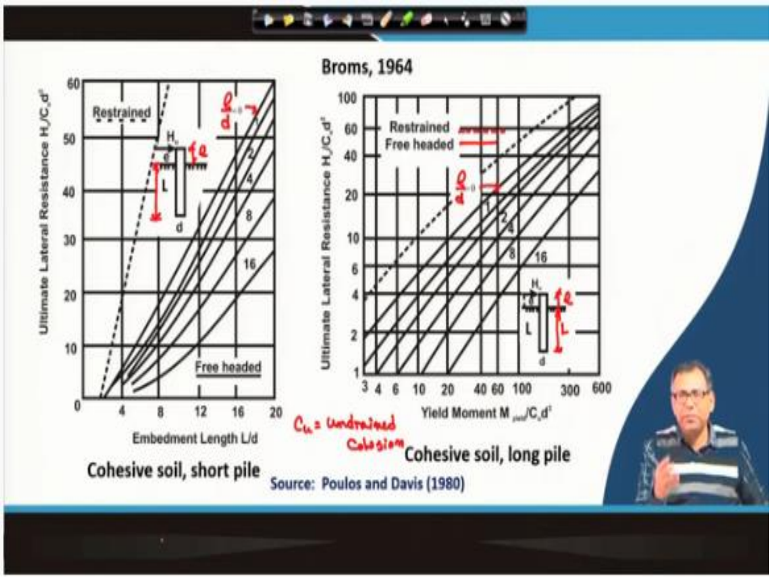

But I will use the charts, because those charts are developed based on those equations. Our first case, it is a gramular soil.

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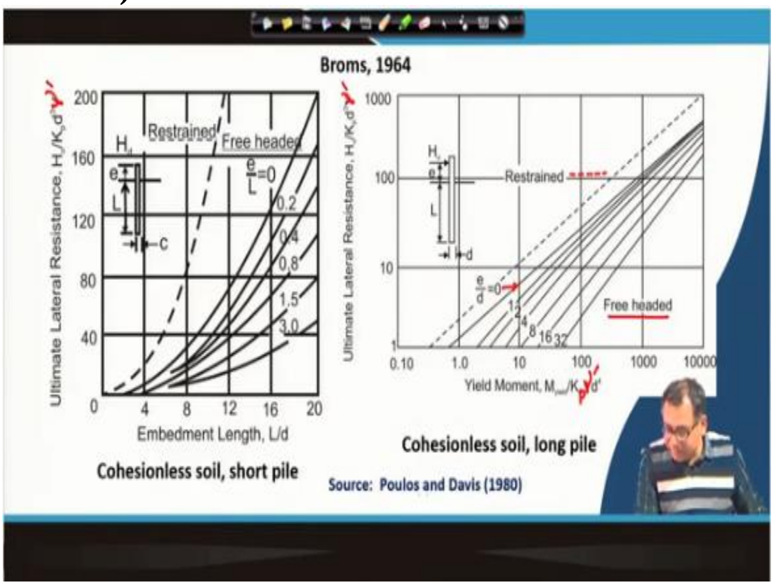

So, it will be the cohesionless soil and it is the long pile. Long pile and so, we have to calculate yield moment, M_{yield}, K_p, γ', d^4. So, let us calculate that. So, you have to calculate $\frac{M_{\text{yield}}}{K_p \gamma' d^4}$. Now which γ we will consider because the water table is 2 m below the ground. So, if this is the ground surface and H_u is acting here, H_u because e is 0.

And what is the length of pile here which is 2 m and rest of the pile is 18 m. The total is 20 m. And 18 m below the water table and 2 m above the water table. So, here I am taking the weighted average unit weight and so that means that it will be $\frac{18\times 2+(20-10)\times 18}{20}$. So, take total unit weight above water table and submerged unit weight below water table.

It is a saturated unit weight. So, this is definitely this will be a saturated unit weight, γ_{sat} because it is 20 kN/m^3 and submerged unit weight is 20 – 10 = 10 kN/m^3. So, that means, here we have taken the weighted average $\frac{18\times 2+(20-10)\times 18}{20}$.

If the water table is at the ground surface. Then directly we can use the $\gamma' = 10$ kN/m^3, if it is at the ground surface. So, that is why you have taken the weighted average value. And that value is 10.8 kN/m^3 and $K_p = \frac{1+\sin\phi}{1-\sin\phi}$. So, this ϕ value is 40°.

So, $\frac{1-\sin 40°}{1+\sin 40°}$. So, this is equal to 4.6. Now, I will put these values here. So, the yield moment is how much? 242 then K_p is 4.6, unit weight is 10.8, d^4 is 0.25^4. So, this is 1247. Now, let us go to that chart and $L/d = 80$. So, let us go to this chart. This is for the cohesionless soil, cohesive soil, long pile. So, this value is 1247. So, this will be somewhere here and $e/d = 0$.

So, this value will be somewhere here. So, from here I can take this value as 1247, so 1247 you will remember that this is in log scale. So, 1247 will be somewhere here, 1247 and this is the value corresponding value is here which is roughly 120. So, this is 1247. So, roughly this value is 120. So, the value that we are getting that $\frac{H_u}{K_p d^3 \gamma'}$ is 120 from the chart.

Because that is the value. $\frac{H_u}{K_p d^3 \gamma'}$. So, $H_u = 120 \times 4.6 \times 10.8 \times 0.25^3$. So, this is 93.2 kN. Now, if I use the simplified approach, then this soil pressure variation in granular soil is linear.

So, in that case $\bar{p}_u$ will be $\frac{p_L}{2}$ and p_L is nothing but $3\sigma_v' K_p$ and that σ_v' we have to calculate at $z = L$. So, what is σ_v' at $z = L$.

So, σ_v' at $z = L$ will be how much? So, σ_v' will be $2 \times 18 + (20 - 10) \times 18$. So, now, if I calculate the $\bar{p}_u$. So, I will get $\frac{3}{2} \times [2 \times 18 + (20 - 10) \times 18] \times 4.6$. So, this value is equal to 1490.4 kN/m^2. So, $\bar{p}_u$ is 1490.4 kN/m^2.

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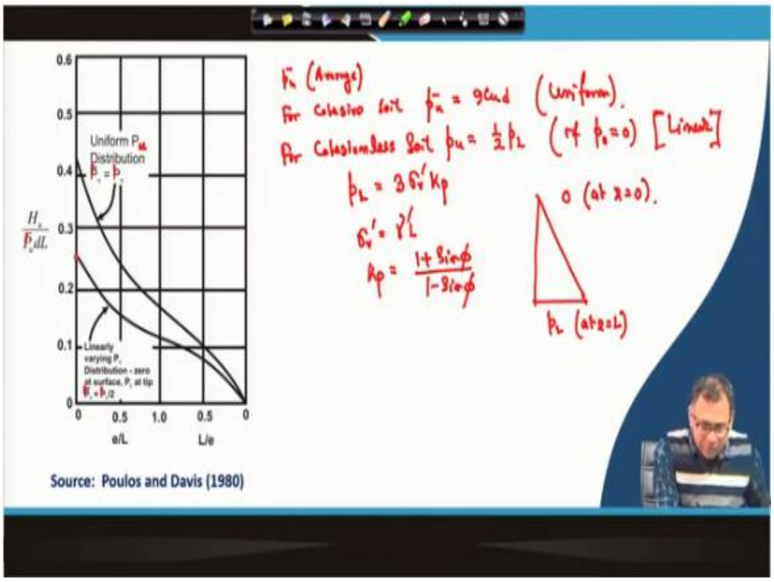

So, this is the linear variation this curve and $e/L = 0$. this value. So, $\frac{H_u}{\bar{p}_u dL} = 0.25$. So, this is 0.25.

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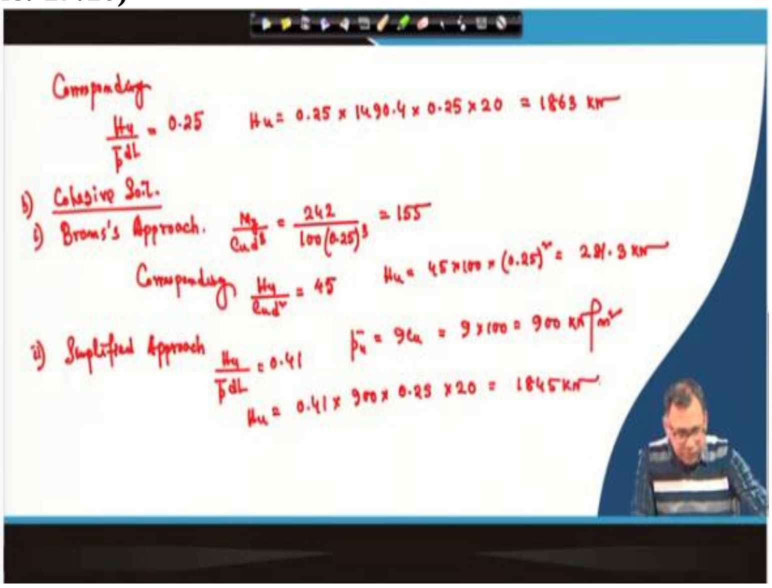

So, I can get here the value of H_u corresponding to $\frac{H_u}{\bar{p}_u dL} = 0.25$. So, you can see this linear variation for the granular soil. So, this value is 0.25. So, once we put this value. So, I will get that $H_u = 0.25 \times 1490.4 \times 0.25 \times 20$, because, $\bar{p}_u = 1490.4$ then $d = 0.25$ then L is 20. So, this value 1863 kN. So, Broms's approach is giving a value which is 93.2 kN and the simplified approach is giving a very higher value.

So, that is why? I will recommend that you use this Broms's approach because it is giving a lower value to be in the safer side. So, that simplified approach as I discussed is the linear variation. So, it is a linear variation. So, this is p_L. So, my $\bar{p}_u = \frac{p_L}{2}$. So, that is the case and p_L is nothing but σ_v' at $z = L$ that we have calculated that means at the pile tip. And then we put this equation and we will get the $\bar{p}_u$ value is like that 1490.4.

So, now we will go for the second case that is for the cohesive soil. So, previous one is for the granular soil and this is cohesive soil. So, by Broms's approach. So, this is the equation. So, and it is a long pile. So, this we have to calculate $\frac{M_y}{C_u d^3}$. So, here by Broms's approach, M_y is 242 and C_u value is 100 kPa, d^3 is 0.25^3. So, this is 155.

So, corresponding what value I will get from the chart? So, this is chart, this is $\frac{H_u}{C_u d^2}$. So, corresponding $\frac{H_u}{C_u d^2}$ that is coming how much? Because this is 155. So, this 155 will be somewhere here and then this is free-headed pile equal to 1. So, this will be here. So, it will be around 40 45 around this is 155. So, 155 means, this is 155 means log scale this is 2345, somehow here.

So, if I extend that, so it will be around here. So, this value will be around 45 46. So, I have taken this value is 45. So, this is 45 remember one thing that when you are taking some value from the chart. So, that may change depending upon the person who is taking that value slightly there may be a variation. So, this type of problem for the assignments. So, I will try to give these values directly or I will give the equations you have to use the equations.

So, there will not be any difference between the results of different persons. So, that means here this is 45. So, I can write that $H_u = 45 \times 1000 \times 0.25^2$. So, this is 281.3 kN. Now, by simplified approach, this is the chart. So, this value will be around this is equal to 0. So, these values around 0.41, this is 0.41. So, this is $\frac{H_u}{\bar{p}_u dL} = 0.41$.

So, now $\bar{p}_u$ for cohesive soil is $9C_u$. So, this is $9C_u$. So, that is why it is 9 × 100. This is 900 kN/m^2. So, H_u will be $0.41 \times 900 \times 0.25 \times 20$. So, this is 1845 kN. Again, higher than the Broms's approach. So, this way we can calculate the ultimate lateral load capacity of a pile depending upon its fixity condition whether it is a free-end or the fix-end or it is within the granular soil or the or the cohesive soil.

So, for the Broms's approach either you can use the equation that I have given or you can use the charts because those charts are developed by those equations. Moreover, you can use the simplified approach. But I would recommend that you use Broms's approach to determine the ultimate lateral load carrying capacity of the pile. So, now next class I will start the settlement response of the lateral loaded pile.

Because this section, I have discussed the ultimate load carrying capacity of the laterally loaded pile. So, next class I will start the settlement response of the lateral loaded pile and then I will discuss that how you can determine the settlement response of the single pile as well as the group pile and one more thing before I finish this to the lecture the group pile capacity for ultimate lateral load carrying capacity of group pile because I have discussed all single pile.

So, group pile capacity is the same as we are using the same approach but only in that case the diameter will be the width of the group or equivalent diameter of that group. So, we have done it for the pile under compressive load how to calculate the width of a group. So, that width we can use for or we can take an equivalent area or equivalent diameter of that rectangular or the square section we can convert to an equivalent circular section then you will get an equivalent diameter of that group.

So, that diameter also we can use once you get that data. So, there need to be a single pile analysis that when that group section you convert it to equivalent circular section. Then you determine the equivalent diameter, then after that the analysis is same for the group section that are discussed for the single pile. So, in the next class I will discuss the settlement response of the pile and then I will give you the next week that how we can generate the simplified or the generalized *p-y* curve for the lateral loaded pile. Thank you.