Advanced Foundation Engineering

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Lecture - 64
Well Foundation - V

So, this class I will solve one numerical example or one example problem related to Terzaghi's analysis. So, in the last class I have discussed what is Terzaghi's approach to determine the maximum bending moment or soil bearing pressure for well foundation?

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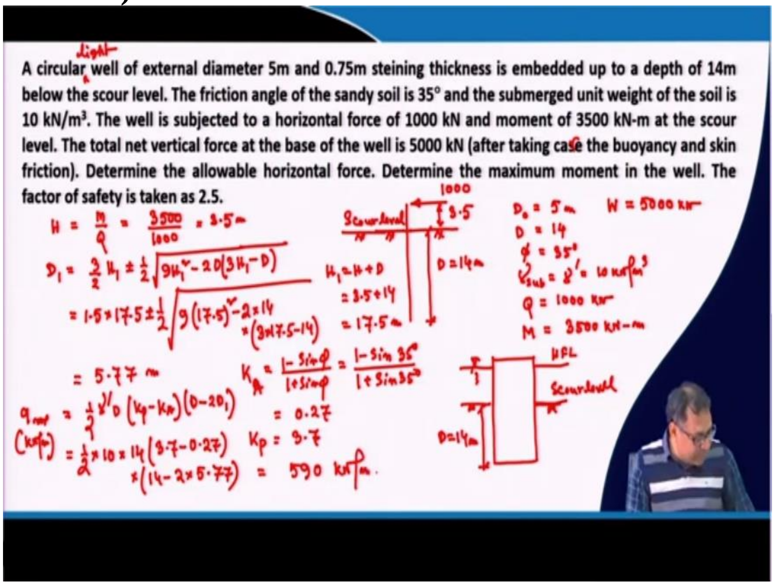

So, today I will solve one example problem. So, in the example problem it is given a circular well of external diameter. So, it is given, the external diameter D_o is given, how much? 5 m and the depth of embedment is 14 m below the scour level. So, D is 14 m because depth is below the scour level, so that is D. The friction angle is given, ϕ value is given 35° and submerged unit weight or γ' is given as 10 kN/m^3.

Because here submerged you have to use because water level is or above the soil level the well is subjected to horizontal force, so that Q is 1000 kN and the moment is 3500 N-m at the scour level. So, these both are applied at the scour level suppose this is the well, so this is your say HFL, this is the scour level and this is the grip length or the depth D which is 14 m, this is scour level, this is the HFL.

And moment is acting at the scour level. So, it is acting or the forces also acting on the scour level, now, the total net vertical force, so that means the W, vertical force is 5000 kN after taking care the buoyancy and the skin friction. So that means this buoyancy is being neglected, skin friction is also taken care, so total net vertical force which is acting at the base of the well is 5000 kN determine the allowable horizontal force, determine the maximum moment in the well with a factor of safety is taken as 2.5.

So, actually horizontal force or the moment is acting here or horizontal force is acting here. So, a moment is also acting, so we can determine what is the H value, so I can determine what is the H value. So, H value is nothing but this is M/Q. So that M is 3500 and Q is 1000, so this is 3.5 m. So, now, if I apply this moment, suppose this is now the well scour level, so this is scour level, initially it was applying here the horizontal force.

Now, we are applying it here this 1000 kN, but H value is 3.5. So that means, now it is providing a moment of 3500 kN-m at the same time the horizontal force 1000 kN is also acting. So, now this is H value is 3.5 m. Now, this is scour level it is acting at a height of H and now this is the grip length D which is equal to 14 m. So, now this is the problem.

So, now we know that how we can calculate the D_1, D_1 is the diameter or the point of rotation from the base of the well and this is for the light well. So, this is circular light well. So, we can calculate this D_1. D_1 will be $\frac{3}{2}H_1 \pm \frac{1}{2}\sqrt{9H_1^2 - 2D(3H_1 - D)}$. Now, what is H_1 here? So, $H_1 = H + D$, so H is 3.5, D is 14 m, so this is 17.5 m.

So, now, if I put these values this is $1.5 \times 17.5 \pm \frac{1}{2}\sqrt{9 \times 17.5^2 - 2 \times 14(3 \times 17.5 - 14)}$. So, this D_1 is 5.77 m from the base of the well. So, now it is Rankine's K_A or K_P where $K_A = \frac{1-\sin\phi}{1+\sin\phi}$, this is $\frac{1-\sin 35°}{1+\sin 35°}$. So, this is equal to 0.27. So, similarly, we can calculate K_P which is $\frac{1}{K_A}$ which is 3.7, remember this is as per Rankine.

So, my $q_{\max}$ which is kN/m as for light well equation is given. Equation one $q_{\max} = \frac{1}{2}\gamma' D(K_P - K_A) \times (D - 2D_1)$, this equation I have already derived. So, this is $\frac{1}{2}\gamma'$ or γ' is 10, D is 14 then K_P is 3.7, K_A is 0.27 then $\times$ D is 14 - 2 $\times$ D_1 is 5.77. So, this is 590 kN/m.

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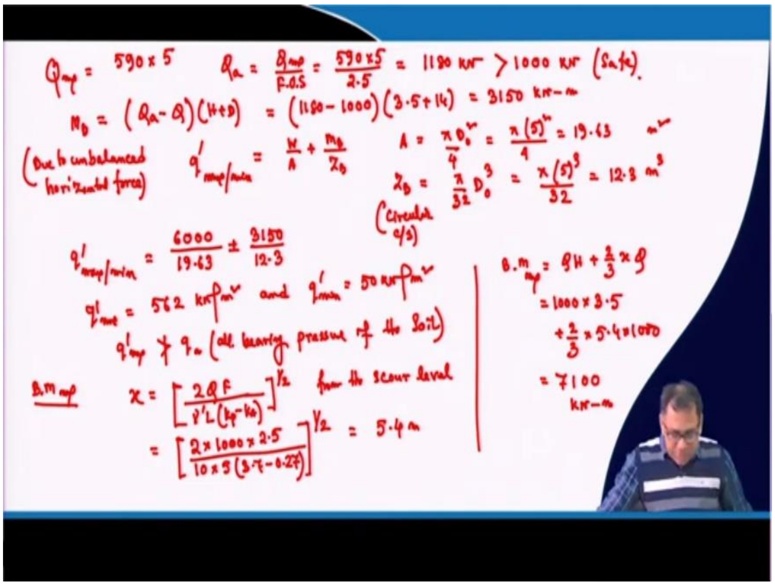

So, now the $Q_{\max}$ will be how much? Will be only 590 ×, here it is circular cross section, so we are taking length is equal to the diameter. So, diameter, external diameter is 5. So, I can write the Q_a that will be $Q_{\max}$ divided by factor of safety, so this is $590 \times \frac{5}{2.5}$, so Q_a is 1180. So that means we can allow to apply horizontal force is 1180 but we have applied 1000 kN, so it is safe.

But at the same time there will be an unbalanced horizontal force and due to that unbalanced horizontal force a moment will develop at the base of the well. So that moment M_B, this is due to unbalance horizontal force or the lateral force. So that is equal to $(Q_a - Q)(H + D)$. So, Q_a is 1180 and Q is 1000, so H is 3.5 and D is 14, so this is 3150 kN-m, so unbalanced force is developed.

So, due to the unbalanced force there will be a moment, so that mean the $q'_{\text{max,min}} = \frac{W}{A} \pm \frac{M_B}{Z_B}$. Now, how we can calculate the Z_B, so we are taking the total outside area of the well. Because we are taking total outside area of the well, so A will be $\frac{\pi D_O^2}{4}$, D_O is 5 m. So, this is $\frac{\pi \times 5^2}{4}$.

So, this is 19.63 kN/m^2 and Z_B for circular cross section is $\frac{\pi D_O^3}{32}$, Z_B as I mentioned, I have discussed how I am getting these values, so in my previous lectures. So, this will be $\frac{\pi \times 5^3}{32}$, so this is 12.3 m^3. So, here you can say that this is a hollow cross section but we are taking the outside diameter because here once the construction is over then this hollow portion will be filled first the bottom portion will be filled.

It will be sealed then it will filled by the sand or the concrete then it further concreting will be done, so then it will become a solid kind of structure. So that is why we are taking the total outside area and for *Z* is also circular cross section. So that means here finally, I can write that $q'_{\text{max,min}} = \frac{W}{A}$ is equal to, *W* is 6000. What is *W*? *W* is given actually 6000; *W* is taken as 6000 because I have done the calculation by considering *W* as 6000.

So, this is 6000, if it is 5000 you can use 5000 but, in my calculation, I have done considering 6000, so that is why I have just done the change, you can put 5000 and you will get a different value. So that means here I am getting 6000, so this is 6000 divided by *A* is 19.63 $\pm M_B$ is 3150 and this is 12.3. So, q'_{max}will be 562 kN/m^2 and $q'_{\text{min}} = 50$ kN/m^2.

So, your q'_{max} should not be greater than q_a or this is the allowable bearing pressure or allowable bearing pressure of the soil. So, here this allowable bearing pressure of the soil is not given. But if it is given you can check it that this is fine or not otherwise you have to redesign this. And then again we have to calculate the maximum bending moment.

So, to calculate the maximum bending moment we have to determine the *x* value and then this *x* value is $\left[\frac{2QF}{\gamma' L(K_P - K_A)}\right]^{\frac{1}{2}}$. This *x* is from the scour level. So, now, if I put these values, this is 2 *Q* is 1000, *F* is 2.5 then γ' is 10 and *L* is again 5 which is diameter then 3.7 - 0.27 then to the power $\frac{1}{2}$, so this is 5.2 m from the scour level.

So, the maximum bending moment $BM_{\text{max}} = QH + \frac{2}{3}xQ$. So, *Q* is 1000, *H* is 3.5 + $\frac{2}{3} \times x$ is 5.4 × 1000. So, this is 7100 kN-m. So, this way we can calculate what is the position of the maximum bending moment which is 5.4 m below the scour level and that value is 7100 kN-m. And another thing I want to say that I have done the calculation by considering 6000. Because, if I consider the 5000 then your q'_{min} will be negative.

So that also you have to take care, suppose if it is coming negative then you have to again redesign because here, I have shown you the example problem, so I have taken the 6000 kN, so both are as positive. But if you want to avoid that negative stress which is generated at the base then you have to change the dimension. But that dimension you can change in the same way you can do the calculation and that is same. So that is why I have done just to considering

6000, so for your case, you can change the design accordingly to avoid the negative stress at the base of the well. So, this is Terzaghi’s approach.

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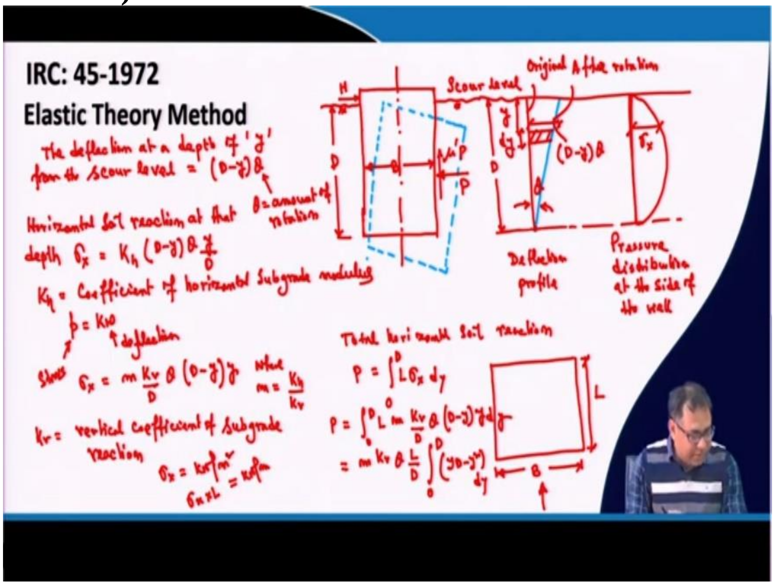

So, next one that I will discuss is based on the IRC code recommendation IRC : 45-1972 that is the elastic theory method. So, this elastic theory method is applicable for noncohesive soil and will not apply if the depth of well below the scour is less than 0.5 times the width of the foundation. In the direction of the lateral force that means the direction of the lateral force, if the width of foundation we can calculate and if the depth of well below the scour level is less than 0.5 times of the width of foundation then this method is not applicable.

So, in this method there are different checks we have to do, but I will show you how we can consider those checks, at the same time I will also show you how these equations are coming, how these conditions are coming? So, these things also have been discussed in the code. So, I am explaining those things again here. Suppose if we have a well foundation of this shape, so this is the well foundation and this is the scour level and where H is acting at this level, suppose H is acting at this level or I should draw something in different form.

So, H is acting here. So, this is the well and this is the center line and this is the total one is the grip length which is below the scour depth or this is the scour level. So, now, this is the width of the well for rectangular cross section, now because of this horizontal force H this well will rotate. So, what is the rotation form? So, the rotation is something like this, so rotation will be, this is the rotation of this well. So that means this is the rotation. So that means here, once this will rotate, so what are the forces that will be developed?

So, now I can write this is the scour level or it will go along this line and this is the base of the well, so there will be original position then it is rotated. So, this is the rotated position of the well. So, there will be the rotation or the new position after rotation. So, this is after rotation and this is original position, this is deflection profile. So, if I consider a small segment dy, at the depth of y from the scour level and amount of rotation is θ. So that means the amount of rotation at this point that will be equal to this $R\theta$.

So, what will be the R value? So, this is y, this is the total one is D. So, this small arc this will be $R\theta$. So, R is how much? R will be $(D - y) \times \theta$ because D is the total one, y is the depth from the scour level, so from the point of rotation to that small strip that distance is our $D - y$. So, total rotation will be or total deflection will be I should say, this rotation is θ and deflection will be $R\theta$.

So, R is $(D - y) \times \theta$. So, this is a small segment and the rotation is also small. So that means, we can consider it as a straight line, more or less. And the pressure distribution diagram because of this rotation, there will be a pressure distribution and that pressure distribution is assumed like this. So, at that level the stress or the pressure is σ_x. So, this is the pressure distribution diagram, pressure distribution at the side of the well, so this is at the side of the well.

This is the side of the well, so where the pressure distribution is like this. So, I can write from this equation of this figure that the deflection at a depth of y from the scour level will be equal to $(D - y) \times \theta$. Theta is the amount of rotation. What is θ? It is the amount of rotation, now, the horizontal soil reaction will be, so now the horizontal soil reaction at that depth σ_x and that will be equal to $K_h(D - y)\theta \times \frac{y}{D}$. So, let me explain what is that? So, here K_h is the coefficient of horizontal sub grade modulus.

So that means, we know that for the sub grade modulus if it is $p = K \times w$, if this is the stress or I should write these things here. That we know that $p = K \times w$, if this is the deflection and this is the stress, so that means this is the amount of stress and K is the modulus of sub grade reaction. So, here also K_h is the modulus of sub grade reaction and $(D - y) \times \theta$ is the amount of deflection.

So, deflection × modulus of sub grade reaction or coefficient of horizontal sub grade reaction or you can say that if I multiply that then I will get the stress, but here the stress distribution we assume like this, at the top it will be 0 and the bottom also it will be 0. So that is why this term is added, $\frac{y}{D}$. So, now, if $y = 0$ then the stresses will be 0 and if $y = D$ then also stress will be 0. So, this is the distribution that is assumed, so that is why this term is introduced.

So, now next one is that, so now the σ_x is given as, so we can write that $\sigma_x = m\frac{K_v}{D}\theta(D-y)y$ So, where $m = \frac{K_h}{K_v}$ where K_v is vertical coefficient of sub grade reaction. So, I have discussed this vertical sub grade reaction, coefficient of vertical sub grade reaction and horizontal sub grade reaction during my discussion in shallow foundation as well as the laterally loaded pile.

So, K_v is the coefficient of vertical sub grade reaction, K_h the coefficient of horizontal sub grade reaction and m is K_h/K_v. So that means, we can replace K_h by $m \times K_v$, so that we have done. So, this is σ_x. So, now the total soil reaction, this is the σ_x is at any depth which is *y* from the top from the scour depth. So, I can write that the total soil reaction that is *P* that we have to integrate.

So, again if you look at the σ_x whose unit will be, this is a K_v is kN/m^3 and then $y \times L$, so this will be kN/m. So, this stress will be this σ_x because this is dimensionally, so now $\sigma_x = K_v$ is kN/m^3 × *D*. So, this will be kN/m^2. So, now to make it because we are now calculating the force, so we have to multiply it with the length then it will give you in terms of, this is now kN/m.

So, in per m if I convert this one then this will be $\sigma_x \times L$, so then this unit will be kN/m. Now, what is *L*? Now, this *L* is the cross section of the well. So, if this is the *B* and this is the *L*. Now when we are looking this well from the front, so this is the front side, so we are looking this from this side. And this is the view where this is the width. So, perpendicular to this figure, so this is the length of the well. So that we have to multiply with σ_x.

So, then it will give you kN/m and that we have to integrate along the length or the depth of the well then you will get the total soil reaction. First, we are getting σ_x which is kN/m^2 we multiply it with the length. So that will give you the kN/m, but we have to calculate in terms of kN then we have to integrate it along the total depth of the well, so that we are doing here.

So that means we are integrating it 0 to D because D is the total depth of the well and then L and σ_x and that is dy. So, now, we can get from here that P is equal to, so if I now put $\int_0^L L\,\sigma_x dy = \int_0^L L\,m\frac{K_v}{D}\theta(D-y)y\,dy$. And finally, we can take that $mK_v\theta\frac{L}{D}$ outside and then we put the integration $\int_0^L (yD - y^2)\,dy$.

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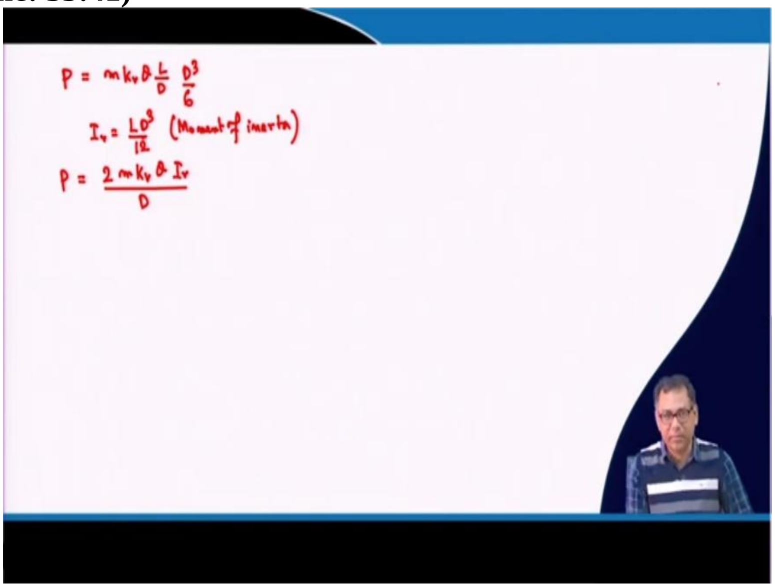

After integration we will get that $P = mK_v\theta\frac{L}{D}\frac{D^3}{6}$. So, now I can write that $I_v = \frac{LD^3}{12}$, so which is the moment of inertia about the horizontal axis. So, now I can convert $P = \frac{2mK_v\theta I_v}{D}$ P is equal to this is 12, so this will be 2, $2mK_v\theta$, and this is $\frac{LD^3}{12}$. So that is why this is 2. So, this will be I_v and then the total is $\frac{2mK_v\theta I_v}{D}$.

So, this is the total force or total soil reaction. So that mean this is the total horizontal soil reaction. So that total horizontal soil reaction will act where? So now, it will act here. So, this is the total horizontal soil reaction that is acting here because now, this is the total stress distribution, now P is the total force and this force is acting here. So, because of this force and there will be a friction shearing will occur along the depth of the well and in that friction is between the soil and the wall or the soil and the well.

So that we can write as $\mu' \times P$, so P force is acting and there will be a friction between the soil and the wall of the well, so that is $\mu' \times P$. So, where μ' we can write as coefficient of friction between the soil and the side wall. So, I can write here. So, later on I will write there. So that means, in this class we have determined the total soil force. So, the total horizontal force due to the soil reaction because the well is rotating and then when it is rotating the soil will give the reaction.

So that total reaction force of the soil is P and that P we have determined and because of that P there will be a friction between the soil and the sidewall and that friction is $P \times \mu'$. So, next class I will discuss that here now the side wall soil reaction we have determined, but there will be a soil reaction from the base of the well also. So that also I will determine, we have to determine, so that I will determine in the next class. Thank you.