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Lecture – 62
Well Foundation - III

So, last class I have discussed how we can determine the thickness of the seal for open well or the thickness of the concrete seal for the open well and I was discussing one particular example problem.

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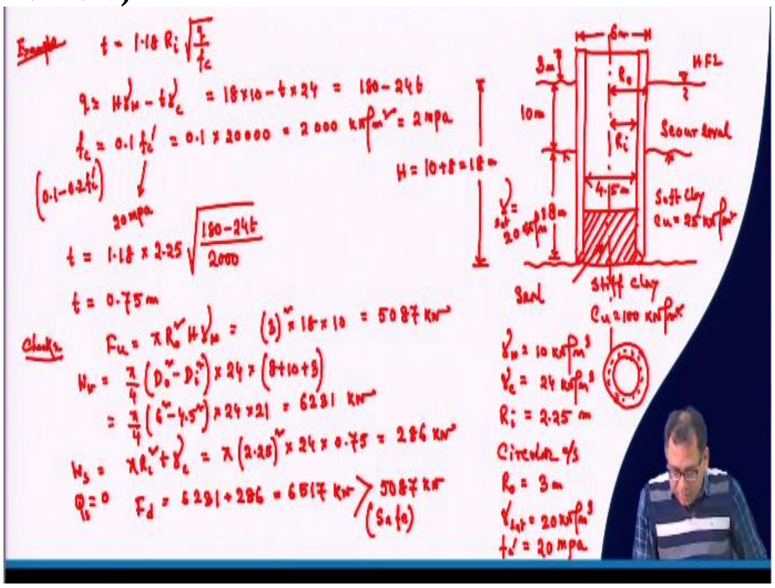

So, in the example problem it is a circular cross section and then the grip length is 8 m and the well is passing through soft clay layer whose C_u value is 25 kN/m^2 resting on a stiff clay layer whose C_u value is 100 kN/m^2 and inside radius is given as 2.25 m and we have to determine what would be the adequate thickness of that seal.

So now, that outside radius is also known and that is $R_o = 3$ m, so the total outside diameter is 6 m and inside diameter is 4.5 m. So, R_o is 3 m, R_i is 2.25 m, so we have to determine the thickness. So, it is a circular cross section, so t will be $1.18R_i\sqrt{\frac{q}{f_c}}$. Now q is roughly we can calculate by $H \times \gamma_w - t \times \gamma_c$. Now, this is unit weight of the soil that unit weight is given as 18 kN/m^3.

So, that unit weight of the soil is given 18 kN/m^3, so unit weight of the soil or saturated unit weight is 18 kN/m^3, this is γ_{sat}. So, this is γ_{sat} which is 18 kN/m^3 and obviously, the soil is saturated because it is below the water level. So, that means we can write that this is 20 kN/m^3.

So, γ_{sat} is 20 kN/m^3. Anyhow that unit weight may not be required, but it is given that γ_{sat} is 20 kN/m^3. So, now what is the stress or the pressure due to the buoyancy the H is 18 m total height of the water level from the base because buoyancy is acting at the base.

So that is equal to 3 m that is equal to 10 m + 8 m, so this is 10 + 8 that is 18 m, so total height H = 18 m. So, that means this is 18 × unit weight of water is 10 - t I do not know and this is 24. So, this will be $180 - 24t$, this is 24 kN/m^3 is the unit weight of the concrete. And then f_c we have taken as $0.1f_c'$, because the range is $(0.1 - 0.2)f_c'$, so we have taken $0.1f_c'$.

So that means here this is equal to 0.1 and the 28 days compressive strength of the concrete is also known and that is 20 MPa. So, 28 days compressive strength of the concrete that is known, so that is 20 MPa. So, this side all the properties are given and this side we are calculating the unknown and in the side all the known properties are given on this side we are calculating the unknown.

So that means the f_c' is given as 20 MPa, 28 days compressive strength of the concrete is 20 MPa. So, this is 0.1 and 20,000 kPa, so this is equal to 2000 kN/m^2 or 2 MPa. So now, if I put these values then I will get t = 1.18 then R_i, R_i is 2.25 × $\sqrt{\frac{q}{f_c}}$, where, q is $180 - 24t$ then f_c is 2000. And then if I solve these equations, because we have t in this side and t within the root also say we have to take both sides square.

Then if I solve this equation then t is coming out to be after solving is 0.75 m, so the thickness of the seal is coming out to be 0.75 m. Let us see whether that thickness is sufficient or not? And that we have do by two checks, so first check that I will do for the buoyancy and we know that $F_u = \pi R_o^2 H \gamma_w$ and this is $\pi \times 3^2 \times 18 \times 10$, so this is 5087 kN. So, that is the amount of buoyancy force which is acting.

Now we have downward forces and that is the weight of seal and the force due to the friction and the weight of well equal to these shafts that mean if this is a circular cross section. So, this weight of this shaft will only be considered at this stage because at this stage, no other components are present only the shaft and the seal at the bottom, so these two weights have to be considered.

So, weight of the well means this is D_o^2, this is we have taken $\frac{\pi}{4}$. So, this will be D_o^2 and this is D_i^2 that is the area of this solid portion and then the unit weight of the concrete is 24 and then the width or length of this shaft. So, what is the length of the shaft? This is 8 + 10 + 3. So, that the length of the shaft is 8 + 10 + this 3, so this is 21 m will be the length of the shaft.

So now, if I provide this D_o and D_i value, this is $\frac{\pi}{4} \times (6^2 - 4.5^2) \times 24 \times 21$, so that is equal to 6231 kN that is the weight of the well. Now, weight of the seal that is inside radius $\pi R_i^2 \times t \times$ unit weight of the concrete this is $\pi \times 2.25^2 \times 24$, where, 24 is the unit weight of the concrete and thicknesses is 0.75 m that is the thickness. So, this is equal to 286 kN.

And now for this case we are neglecting the friction force. So, if it is safe against this weight of well and weight of seal, then if I add the friction force then it will increase the safety. So, now we are checking considering friction force contribution is 0. Let us see, whether it will be safe or not, so that mean the total downward force F_d is 6231 + 286. So, that is 6517 kN which is greater than 5087 kN. So, it is safe.

So, even without considering the Q_s it is safe even if we consider theQ_s then definitely it will be over safe. So, but right now, it is safe against that buoyancy, let us see whether it is safe against the shear or not.

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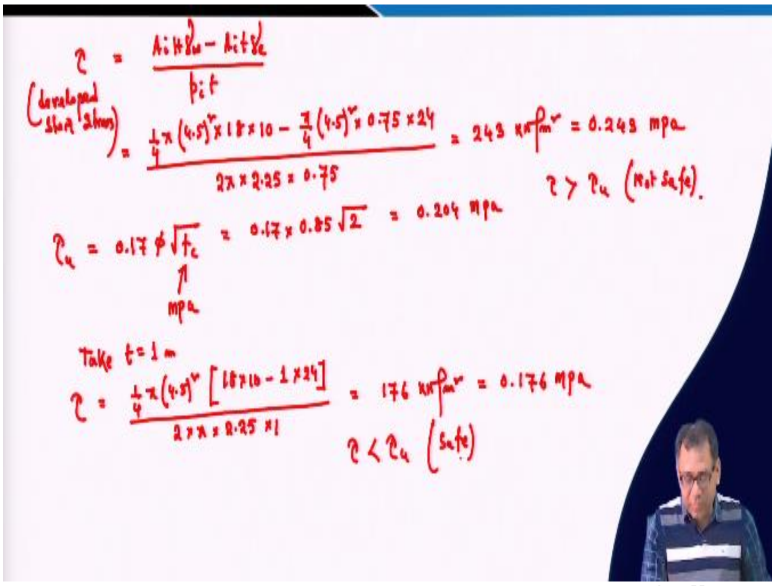

So, the second checks that the shear stress that is developed is $\tau = \frac{A_i \times H \times \gamma_w - A_i \times t \times \gamma_c}{p_i \times t}$. Now, if I put all these values then A_i is $\frac{\pi}{4}$, this is inside area for the well that means is 4.5^2. Then H is 18, unit weight of water is 10 again $\frac{\pi}{4} \times 4.5^2$ then thickness is 0.75, unit weight of concrete is 24 then divided by inside perimeter this is a circular section $2\pi \times$ inside radius 2.25 then the thickness is 0.75.

So, this value is 243 kN/m^2 or 0.243 MPa. So, the shear stress which is developed is 0.243 MPa. Now, the ultimate or the permissible shear stress $\tau_u = 0.17\phi\sqrt{f_c} = 0.17 \times 0.85 \times \sqrt{2}$ because, f_c value is 2 MPa, and that is coming out to be 0.204 MPa.

So that means you can see that $\tau > \tau_u$. So, it is not safe because the amount of shear stress which is developed is greater than the permissible shear stress. So, now we have to go for this next trial. Now in the next trial we are taking the $t = 1$ m, we are increasing that because other conditions are set only set against this shear. Now that τ which is developed is if I take this $\frac{\pi}{4} \times 4.5^2$ outside, so then this will be $18 \times 100 -$ now it is 1×24 then divided by again $2\pi \times 2.25 \times 1$ because now it is 1 m.

So that means it is coming out to be 176 kN/m^2 or 0.176 MPa. So, now $\tau < \tau_u$, τ_u you cannot change so τ_u is 0.204 MPa is greater than 0.176 MPa. So, I mean it is safe against shear also. Now, the question is that why we are calculating the shear between these well and that shaft because when we apply the concrete for the bottom seal then initially, so that strength of the soil this strength which is gained in the 28 days that we have considered.

So, there will be shear between this sealed concrete and the shaft, so that is why that shear stress we are checking here and there will be a buoyancy also that we have already checked. So, these two checks, we have to done and then based on that we have to provide what would be the thickness of that bottom seal. So, here initially by calculation it was coming 0.75 m, but when we did that checking for buoyancy it was fine, but for the shear checking it was not safe.

So, we have to increase it and we have provided 1 m now, all the conditions are satisfied. So, we will provide the 1 m thickness or 1 m thick concrete seal or bottom seal for this particular case.

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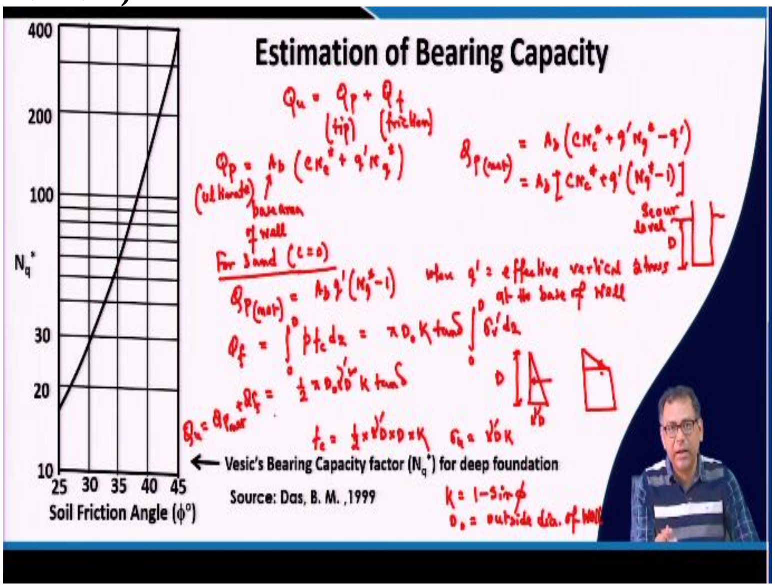

So, next one that I will discuss the estimation of bearing capacity, so we have the checking for the concrete seal for the open well, next one how we can determine the bearing capacity for well foundation. So, for estimation of bearing capacity, which is also same to the pile foundation that means the ultimate bearing capacity or load carrying capacity of the well is Q_P that mean tip + Q_f the friction contribution. So, this is the tip contribution, this is the fiction contribution, so summation of these two under compressive load.

So, now $Q_P = A_b\left(cN_c^* + q'N_q^*\right)$ where, A_b is the base area of well, c is the cohesion of soil at the base of the well, N_c^* and N_q^* are the bearing capacity factors and q' is the effective vertical stress at the base of the well. So, we have neglected the third component because we did it for the pile foundation also which is small compared to the second component. So, we have considered first for the cohesion part and then the second component. If the c is 0 then there will be only the second component.

So, now, this is $Q_{P(\text{ultimate})}$, if you want to determine the $Q_{P(\text{net})}$ or net ultimate then that will be again $A_b(cN_c^* + q'N_q^*) - q'$ that will give us the net. So, this will be $A_b[cN_c^* + q'(N_q^* - 1)]$. Now for sand or granular soil where $c = 0$ then $Q_{P(\text{net})}$ will be equal to simply $A_b q'(N_q^* - 1)$ where q' is effective vertical stress at the base of well.

So, this is for the Q_P part, similarly for Q_f friction part, so that will be the same as the pile foundation. So, that is 0 to D that means the total depth of the well then this is the fictional resistance × perimeter × dz. So, that will be same as πD_o that is the perimeter then K and then $\tan\delta$ and then the vertical stress that we have to integrate $\sigma_v' dz$, the same way that we did it for the pile foundation.

So, now, we can put the value and finally, we will get, so this is equal to $\frac{1}{2}$ then πD_o which is the perimeter $\times D^2$ where, D is the depth of the well below the scour level $\times K \times \tan\delta \times \gamma$. So, that means here the same way we are doing it, so that mean this is changing, so here you consider $\gamma' \times D$ if the depth of the well is below the scour.

This is the scour level and this is the well foundation base, so this is the depth or the grip length. So, this is equal to D, so along that there will be friction between the soil and the well, so this is the scour level and below that this is D, so this is $\gamma' D$. So, then the horizontal force that will act σ_h that will be $\gamma' D \times K$. So, that is the horizontal stress $\gamma' D \times K$. And then that we have to multiply with $\tan\delta$ that will give you the frictional resistance along the shaft, so that is we are doing here.

And then if I take the total force and that you have to take the average, so that will be $\frac{1}{2}\times$, so total force will be $\frac{1}{2} \times \gamma' D \times K$ and that will be again into $\tan\delta$. So, this is $\frac{1}{2}$ and this is perimeter $\gamma' D^2 K \tan\delta$ and that is acting along the perimeter. So, this is basically the f_c. And then if I multiply with the perimeter, then I will get the total friction resistance which is same as the pile calculation, pile friction resistance calculation.

Remember that again I am telling that these equations directly we can use if unit weight is uniform or same but if there is any water table, then this will be the distribution. But in this case this is the common distribution because it will be always below water. So, this type of distribution will not occur, so because the grip length portion of the well will be always below the water.

So that means here we can directly use this equation by considering our triangular distribution and this is the effective unit weight we have to consider that means, if it is below the water then you have to consider the submerged unit weight which is γ'. So, these ways we can calculate the friction resistance and the tip resistance for the well and N_q^* value I can get from this chart.

So, this is for different friction angle for sand and then from here I can get what is the N_q^* value and that N_q^* value we can put here. So, that means finally we will get another thing that is how we can calculate the K where δ is the friction angle between soil and the pile or the well and the K is taken as $1 - \sin\phi$. And then delta we can take as $\frac{2}{3}\phi$ for this particular case if no information is given.

Otherwise, I have discussed that what will be the δ for concrete and different condition for the pile foundation. So, that means here we know that K will be $1 - \sin\phi$ and δ I have discussed, so this way we can determine the frictional resistance and the tip resistance, so D_o is equal to the outside diameter of well. So, next one that I will discuss that how we can calculate the bearing capacity if the well is in clay.

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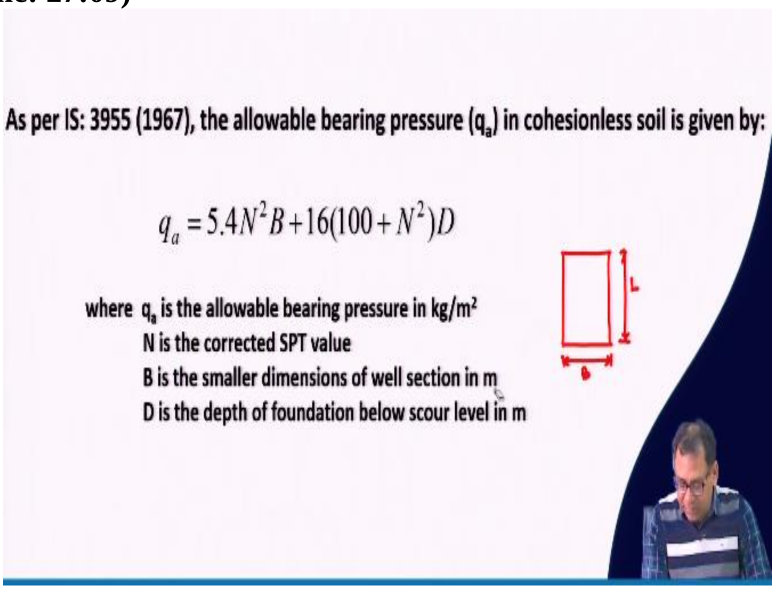

So, it is in clay, before I go to the clay, so here we can calculate the ultimate bearing capacity that means the Q_u which is equal to $Q_{P(\text{net})} + Q_f$, so I will get the ultimate bearing capacity.

And then if I apply the factor of safety of 2.5 to 3, then I will get the safe bearing capacity that you know. But IS code has recommended allowable bearing pressure.

So, allowable we know that here the settlement consideration is also incorporated. So, that means, here bearing and the settlement consideration are incorporated and minimum of these two will give you the allowable bearing pressure that means your settlement is also incorporated. So, this IS code has given the allowable bearing pressure in terms of N value. So, this is the equation where this is in kg/m^2 remember here N is the corrected SPT value at the base of the well.

And B is the smaller dimension of well section for smaller dimension of the well section means suppose, if it is a rectangular well, so this is B or this is L. So, among these, B is the smaller, so that is why B will be the dimension of the well, so that can be nearly any direction and D is the depth of foundation below the scour level and that is in meter. So, remember that this is kg/m^2, this B is in meter and d is also in meter and it is a circular well. So, B you can consider is equal to d diameter of the well. So, using these equations we can directly get the allowable bearing pressure.

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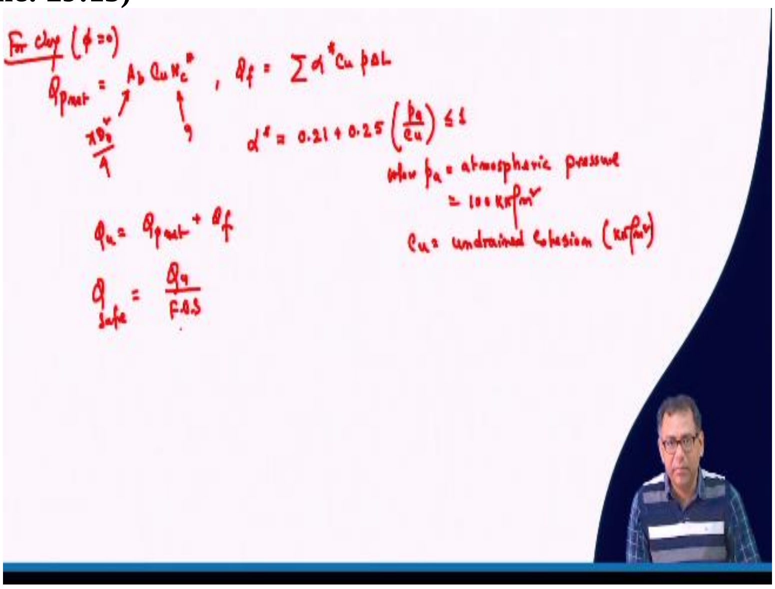

Now, for the clay ultimate bearing capacity we can determine as I remember that this is applicable for sand cohesionless soil, this equation is applicable for cohesionless soil. So, for the clay where $\phi = 0$ then $Q_{P(\text{net})} = A_b c_u N_c^*$ and Q_f is equal to again the $\sum \alpha^* c_u p \Delta L$ that we are doing for the pile. So, we are taking the summation because for different layer we have to determine the Q_f and then you have to add.

So, then here the N_c^* is taken as 9 like the pile foundation and A_b you know that it will be $\frac{\pi D_o^2}{4}$ and α^* is suggested as $0.21 + 0.25\left(\frac{p_a}{c_u}\right)$ and that should be less than 1. So, where p_a is equal to atmospheric pressure which is actually basically 100 kN/m^2 and c_u is the undrained cohesion which is also in kN/m^2.

So, if I know the cohesion of the soil and then we can put this value here p_a is always 100 kN/m^2 then we will get the α^* value and that should be less than 1. So, this way we can calculate the α^* for different layer and once we get the α^* we know that you have to multiply it with c_u then you have to multiply the perimeter and the length of that segment of the pile or the well. And then similarly, in the tip also you can calculate in this way.

So, finally Q_u will be $Q_{P(\text{net})} + Q_f$ and Q_{safe} will be $Q_u/\text{Factor of safety}$ which you can take as 2.5 to 3. So, this way we can determine the unit bearing capacity of the well in sand as well as in clay and IS code also gives equation based on the SPT value by which also we can determine what would be the allowable bearing capacity of the well. So, in the next class I will start with another section of well foundation which is the lateral stability of the well.

The well is subjected to lateral load also because it is generally subjected to large lateral force. So, we have to check the lateral stability on that well also, so that I will start from the next class. Thank you.