Advance Foundation Engineering
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Lecture – 66
Well Foundation – VII

So, last class I was discussing about the elastic theory method to check the stability of well and I have already discussed that one condition.

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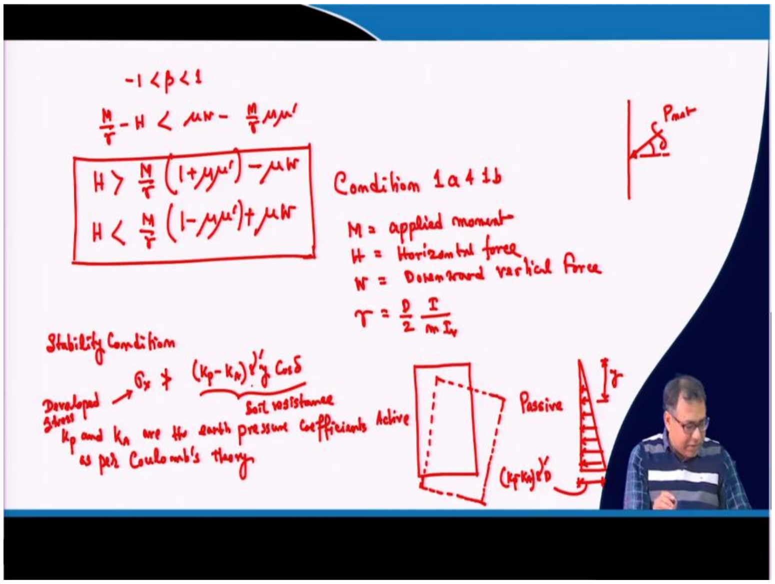

So that condition is this one that your H should be greater than $\frac{M}{r}(1 + \mu\mu') - \mu W$ or H should be less than $\frac{M}{r}(1 - \mu\mu') + \mu W$. Now these are the values and I have discussed what are these values. Now the next condition for the stability condition.

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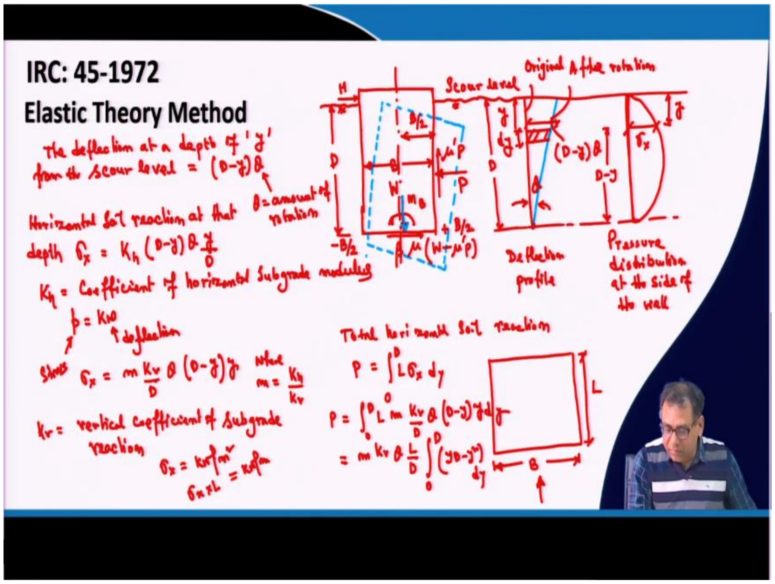

For example, that conditions so you can see that this well is rotating from left to right side or you can say it is rotating in clockwise direction. So that means that both side there are soil. So, one side will be passive another side will be active similar to that I have discussed during Terzaghi's analysis. So, here the right side will be the passive condition and left side will be the active condition. So, if I draw that condition suppose this is the original position of the well.

And this is the rotating condition of the well. So, this side will be the passive and this side will be active. So, and the total throughout the depth in the right side is passive and total left side is active. So, then net pressure that will act here is $(K_P - K_A) \times \gamma \times y$ or γ' I can say so $\times\, y$. So that means here if I draw the net pressure diagram, so this will be something like this and this value will be equal to $(K_P - K_A) \times \gamma$ and if it is D, so this is D or γ' means the effective. So, this will be the net pressure diagram.

And in the previous analysis when Terzaghi's analysis the K_P and K_A were Rankine's earth pressure coefficients. But here it is Coulomb's are pressure coefficients. So, K_P and K_A are the earth pressure coefficients, one is passive and one is active as per Coulomb's theory. Terzaghi's analysis was as per Rankine's theory but here it is as per Coulomb's theory. So, as for Coulomb's theory so we know that P value or the net pressure or the passive force that act at an angle of δ to the vertical plane, so this will act with an angle of δ.

So, this is net P_{net} so that will act with the angle of δ. So, for the stability condition so we have already drawn this pressure distribution diagram. So that means this σ_x expression is given so here σ_x is in kN/m^2. So, this σ_x that is acting that should not be greater than the net pressure. So, you can see that this is the σ_x or the horizontal stress at any depth y.

This is the horizontal stress at any depth y so that is acting at this point and there will be net soil pressure that σ_x should not be greater than that soil resistance, if that σ_x which is the horizontal pressure which is developed if that is greater than the soil resistance then this well become unstable. So, to make this well stable that the stress horizontal stress which is developed at any depth y from the scour level should not be greater than the soil resistance at that point.

So, in that condition the soil resistance at that point say at a depth of y will be $(K_P - K_A) \times \gamma' \times y$ and it is acting at an angle of δso the horizontal component will be $\cos\delta$. So, horizontal component will be $\cos\delta$ so σ_x should not be greater than this value that mean this is the stress developed and this is the soil resistance. So that means this should not be greater than this soil resistance, so if I put that condition. Now σ_x value is given so this is the σ_x which is $m\frac{K_v}{D}\theta(D-y)y$.

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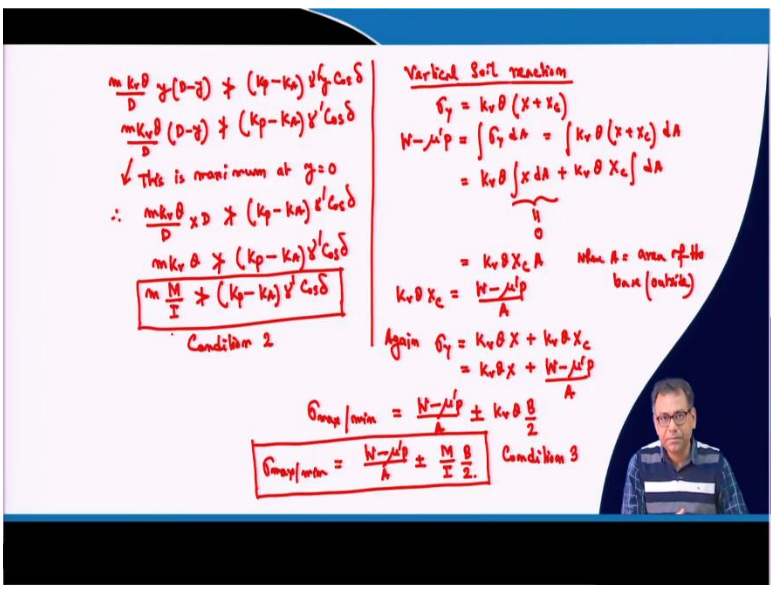

So, if I write that σ_x value, so this will be $m\frac{K_v}{D}\theta(D-y)y$ that should not be greater than $(K_P - K_A)\gamma' y \cos\delta$. So, further we can write $m\frac{K_v}{D}\theta$, so y y will be cancel out and $D - y$ should not be greater than $(K_P - K_A)\gamma' \cos\delta$. So, these left-hand side values will be maximum, so the maximum at $y = 0$ this right sign value this value will be maximum because y y has been cancelled out.

So, now this value will be maximum it is not the stress I am talking about now the current left side value, so this should be maximum at $y = 0$. So, I can write that $m\frac{K_v}{D}\theta \times D$ should not be greater than $(K_P - K_A)\gamma' \cos\delta$ or I can write that $mK_v\theta$ should not be greater than $(K_P - K_A)\gamma' \cos\delta$ or I can write that $K_v\theta$ is what? $K_v\theta = \frac{M}{I}$.

So, I can replace that $K_v\theta$ by $\frac{M}{I}$, so this $m\frac{M}{I}$ should not greater than $(K_P - K_A)\gamma' \cos\delta$, so this is another condition, condition 2. So, we have to satisfy this condition also to maintain the stability of the well. Now we have one more condition that is the vertical soil resistance or soil reaction I should say. So, this is condition 2. So, next condition is vertical.

So that means that the stress which is developed at the base that we have to also check. So, now we will take that, so the vertical stress at any point $\sigma_y = K_v\theta(X + X_C)$. So, vertical stress at any point $\sigma_y = K_v\theta(X + X_C)$, so this is vertical stress at any point. So, now we can write that $W - \mu'P$ that is the total vertical downward force.

So, that means what are the vertical force? W is acting in the downward direction and $\mu'P$ is acting in the vertical direction I mean upward direction these are two vertical forces. So, what this W which is acting in the vertical direction you can see this W is acting in the vertical direction and this $\mu'P$ that is also acting in the vertical direction but both are in opposite direction.

So that vertical force is $W - \mu'P$ that should be equal to the summation of the soil reaction which is acting at the base of the well to summation of the soil reaction only the vertical stress at that point σ_y and if I integrate it over the area of the base of the well then I will get the total soil reaction. So, this is the total soil reaction and that should be equal to the downward or the net downward force vertical force.

So, σ_y I can replace by $K_v\theta(X + X_C)$ and this is dA or further we can write that $K_v\theta \int XdA + K_v\theta X_C \int dA$. Now I have already discussed that this part will be equal to 0 because your center of gravity is the center of the base. So that means here $\int XdA$ will be 0. So, if this is 0 then this will be simply equal to $K_v\theta X_C A$ if I integrate the small area then that will be the total area of the base.

So, this is where A is the area of the base or this is definitely outside area. So, I can write that $K_v\theta X_C = \frac{W-\mu' P}{A}$. So, again I can write σ_y is $K_v\theta(X + X_C)$ and that σ_y is the vertical stress at the base of the well so that I can write that or I can replace this one this is $K_v\theta X$ and now $K_v\theta X_C = \frac{W-\mu' P}{A}$. I can replace.

So, I can write that $\sigma_{\max/\min}$ that will be equal to $\frac{W-\mu' P}{A}$ then $\pm$ why $\pm$? So, there are 2 ends this is the $+\frac{B}{2}$ point this is $-\frac{B}{2}$ point, so I should write this is $-\frac{B}{2}$ point this is $+\frac{B}{2}$ point because this is the width. So, if I put these two limits because definitely the maximum stress at the base and the minimum stress at the base will be at the two edges of the well. So that is $+\frac{B}{2}, -\frac{B}{2}$.

So, this will be $\pm$ now $\frac{B}{2}$ where I will write? I will write this is $K_v\theta$ in place of X I will write $\pm\frac{B}{2}$ because this is the X which is the distance from the center, so that I can write $\pm\frac{B}{2}$ or further I can write that $\sigma_{\max/\min} = \frac{W-\mu' P}{A} \pm K_v\theta \frac{B}{2}$ now $K_v\theta$ is what K v theta is $\frac{M}{I}$.

So, again I can write this as $\frac{M}{I}\frac{B}{2}$. So, this is another condition or by this we can calculate what would be the stress which is acting at the base of the well or I should write this is condition 3, there are two conditions if I put + there will be 1 if I put - there will be another but these are the maximum minimum stresses. So, these are the conditions, these three conditions we have to check as per the elastic theory method for the stability of well. So, this is condition 1, this is condition 2 and this is condition 3. So, this is 1 method that is elastic theory method.

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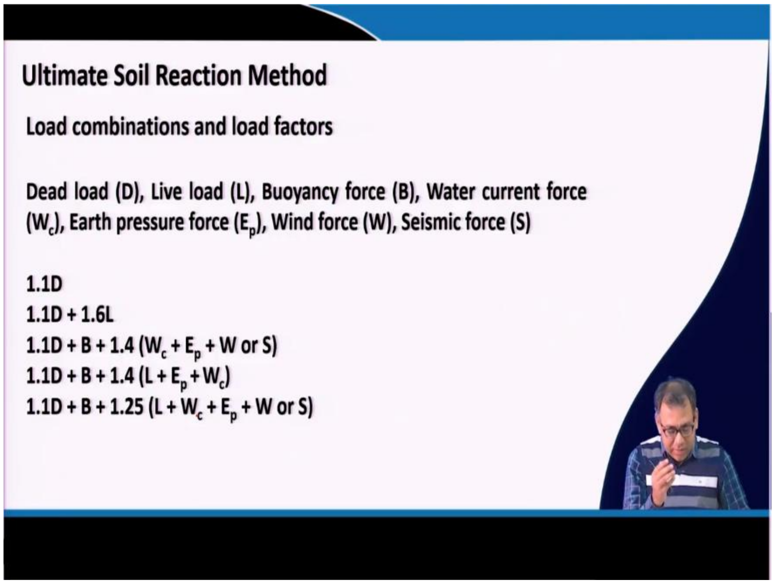

So, next method that I will discuss is the ultimate soil reaction method. So, ultimate soil reaction method is another method by which also you can determine or we can check the stability of the well. So, in this method, the load combinations and the load factors which are recommended are as follows. So, what are those load factors, so here the different loads will act on the well.

So, these loads are dead load, live load, buoyancy force then water current force, earth pressure force because both sides will be soil then wind force and the seismic force. So, then load combination that we have to consider during the design or during the check that dead load alone dead load live load, dead load buoyancy load then the water current force, earth pressure wind load or seismic load.

So, it is quite uncommon that the seismic force and the wind force will act at the same time. So that is why it is taking either wind load or either seismic load the next combination is 1.1 D + B buoyancy force then live load, earth pressure load and the water current. And then last one is considering all forces them dead load, buoyancy load, live load, water current, earth pressure wind or the seismic is force.

So, now here different load factors are recommended, so for the dead load this 1.1 is the load factor why because more or less dead load is a permanent type of loading. So that is why here load factor of 1.1 is suggested. Now when the live load is added to the dead load the second combination there with live load 1.6 load factor is recommended because that this is due to probable overloading.

So, now suppose if we add dead load and live load this is due to probable overloading, so this load factor is applied. Now when this live load is applied with the other forces that means you can see that for the last combination when this live load is added when is added with dead loads is 1.6 is the load factor but when it is added with the water current, earth pressure and wind load then it is 1.25.

Because it is very uncommon that when there will be a wind load or the seismic load then there will be maximum amount of live load will act. So that is why the reduced probability of occurrence of maximum live load when the wind load or the seismic load is acting. That means when the wind load or seismic load is acting then there is a very low probability that the maximum live load will act at the same time.

So that is why a lower amount of load factor is suggested but for the buoyancy the load factor is taken as 1 because of buoyancy the reduction in the density of the submerged masses is more or less constant. So that is why it is taken as 1 and when this live load is added with earth pressure and the water current but not with wind or the seismic in that time it is higher when the wind load and seismic load is considered that is 1.2 it is more than 1.2 but less than 1.6.

So, it is1.4 which is added because that is sufficient because all the cases this 1.4 is sufficient because this reduction of the load factor is due to that occurrence of all the maximum forces at the same time will reduce as you consider more number of forces at a time. So that is why these are the different load combinations that you have to consider during the design and these are the different load combinations and the corresponding load factors are recommended.

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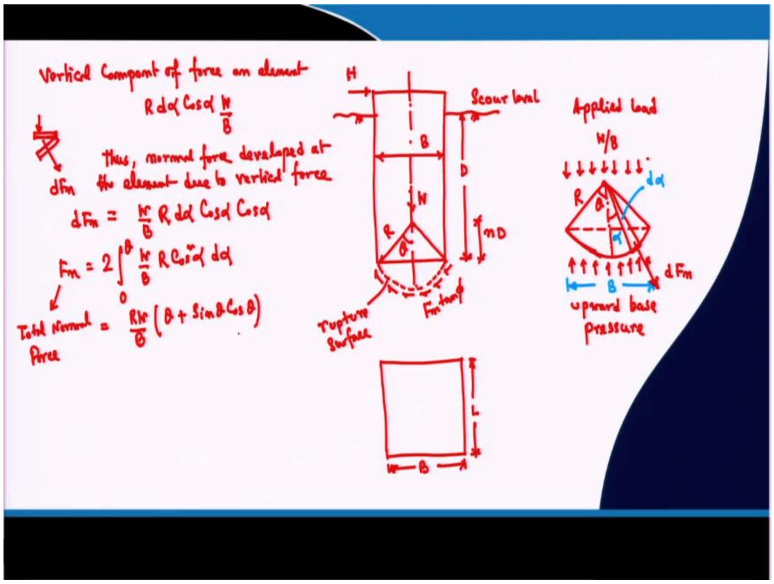

So, next one is that for this particular method that will consider that this is the well. So, this is well this is the scour level here the H is acting in this direction this is the center line, this is B and this one is the depth well below the scour level. And here this method assumes that this well will rotate with the point and say this point is this one, and that point is at a height of nD from the base of the well.

And when it will rotate then this well will rotate along this within the soil. So, a rupture plane will develop below the base of well. So, with a radius of R we can draw this rupture plane and this radius is making with the vertical line the angle that is θ. So, along this rupture plane a shearing will occur. So, this is the plane rupture surface.

And if you say this is the vertical force or the normal force along these rupture surfaces F_n, so shear force or shear stress will be $F_n \times \tan\phi$ because it is the friction between soil and soil because the rupture surfaces within the soil so it is rotating because of this rotation rupture surface will be developed at the base of the well and if the F_n is the force normal to the rupture surface then the shear stress that will develop along this rupture surface will be $F_n \times \tan\phi$, ϕ is the friction angle of the soil.

Now if the cross section of the well say or rectangular cross section then again this is B and this side is perpendicular to that sectional view that length is L. Now if I draw that rupture surface portion only. So, this is the point and this is that rupture surface which will be a circular part. So, this is a rupture surface, this is the center line and this angle is θ was a small segment is considered.

So, this small segment is considered at the angle of α and this angle is $d\alpha$. So, at the angle of α we have considered a small segment with angle of $d\alpha$ and this is the width of that well. Now the applied load is W, so here W is acting in the downward direction. So, here that applied load is acting at the base or at that applied load is this one. So that will be W/B is written here.

So that is the applied load and there will be an upward base pressure, so base pressure will also act below the rupture surface, so this is the upward base pressure. And as I mentioned there will be a vertical force along the rupture surface. So that vertical force for this particular small segment is dF_n. So, this vertical force is basically perpendicular to that rupture surface. So, these are the forces that are acting at this small segment.

Now let us determine that how we can do the stability checks for this particular condition. So, there will be a force which is acting dF_n. So, now we can write that the vertical component of force on the element suppose we have considered an element which is very small. So, like this, this is the element that we have considered. So, on that element that dF_n is acting.

What is the force which is acting on this plane suppose if I take say this element if I take horizontal and vertical and then how much what is the vertical component of force on that element, so that means the vertical component of force so this is the normal direction. So, vertical component of that force on this element. So that forces will be this R and $d\alpha$ so that is the element. So, what will be that that element length.

So, this is the R is the radius and angle is $d\alpha$ so the length of the small element will be $Rd\alpha$ and we are taking the vertical component of this element. So, we want to calculate the vertical component of the force on this element. So, horizontal component of this element will be $\cos\alpha$.

So, this is the horizontal component of the element on which the vertical force will act. So that horizontal component will be $Rd\alpha$ is the element and horizontal component will be $Rd\alpha \times \cos\theta$

then the vertical applied load which is acting W/B. So, this is the total vertical component of the force. Now thus the normal force because why you have taken vertical component because your W/B is acting vertical direction.

But your direction of the element that you have taken is not horizontal or vertical it is with a certain angle. So that is why the horizontal component of that element you can say on which this vertical force will act. So that is why we have converted this element with $Rd\alpha \times \cos\theta$. So, on that portion this vertical component of the force is acting. So that is why the horizontal component we can write directly and what is the vertical component of forces acting on that element.

So, this is the vertical component which is acting on the horizontal component of that element. So that is the normal force developed on the element due to vertical force will be equal to now this is the vertical component. Again, remember that this is the vertical component of the force on the element but we want to determine the dF_n. We want to determine dF_n which is the normal component of the original element.

So that means that dF_n we know the vertical component, now the dF_n is the normal component or normal force. So, again we have to multiply with $\cos\alpha$. So, then we can again convert it to vertical to normal. So, initially convert this to that why we have converted to vertical because our load is acting vertically. So you have taken the vertical component then now we are converting the vertical component to the normal component because that force we want to determine.

So that means again this will be $\frac{W}{B}Rd\alpha\cos\alpha$ this is the vertical component then again $\cos\alpha$ this is the normal component. So, now we can write that F_n will be the $2\int_0^\theta \frac{W}{B}Rd\alpha\cos^2\alpha$. So, F_n is the total force, this total normal force along the rupture surface. So that will be 0 to θ or I should write $\int_0^\theta \frac{W}{B}Rd\alpha\cos^2\alpha$. So, this is for the one half but we have other half also so that means this will be $2\int_0^\theta \frac{W}{B}Rd\alpha\cos^2\alpha$.

So, this is the total normal force along the rupture surface. So, if I integrate this then put the limit then you will get that $\frac{RW}{B}(\theta + \sin\theta\cos\theta)$. So, this is the total normal force that is acting along the rupture surface and $F_n \times \tan\phi$ will give me the friction force that is acting along the rupture surface. So, this next class I will continue this part.

And I will show you that how we can convert this θ with the other parameters like depth of the well or width of the well because these parameters depth of the well width of the well. So, these are known to us. So, we have to ultimately convert this θ to that parameter. So, those things I will discuss in next class. Thank you.