Geotechnical Engineering - II

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Lecture No. 31

Analysis of Completely Submerged Retaining Wall

So far, we have discussed a few cases of finding out the earth pressure by using the trial wedge method and remember that we have talked about only Rankine's wall. That means the wall is smooth and vertical. There is another interesting application of the trial wedge methodology would be when we talk about analysis of completely submerged retaining walls and the backfills.

So, I am going to discuss this about today and this is the retaining wall and there is a surcharge on this. So, this is the surcharge, and this happens to be completely submerged. So, the water table is up to this point. The height of the wall is H, and we want to analyse it for, let us say active earth pressure case. Now, this P could be P_a or this P could be P_p. We will complete the trial wedge.

So, this is at angle of θ A, B, C and because of the submergence what is happening is, I can find out the weight. So, weight will be equal to half into γ. Now, the question is which γ I should be taking? Because it is the case of submergence, so this gamma gets replaced by γ_t, that is the total unit weight. And this is multiplied by H^2 into cotθ. So, weight is known.

$$W = \frac{1}{2}.\gamma_t.H^2.\cot\theta$$

Now, let us draw the free body diagram. The free body diagram would be, there is a normal stress acting over here and why effective because it is a case of submergence. So, we have to superimpose here the pore-water pressure in the force form, not the pressure form and then there is a component of the force which is acting in the form of shear stress. So, this is the free body diagram of the system.

Now, rest of the things remain as it is what we have been doing since long. The only question is how to obtain the $\overline{U}$ and remember N will be equal to $\overline{N}$ plus $\overline{U}$.

$$N = \overline{N} + \overline{U}$$

So, $\overline{U}$ is the pore of pressure which is getting developed in the system because of the submergence.

So, a simple way to do this would be, if I find out the pore-water pressure at point A and pore-water pressure at point B. Do you remembers the previous course, if I want to find out the pore-water pressure at point B, what I have to do is, I have to insert a piezometer and if you insert a piezometer over here, what is the height of the water column? 0, so pore-water pressure at B is 0. And what is the pore-water of pressure at point A, this will be equal to, if I put a piezometer over here the height of the rise in the water tube or the piezometric tube would be H.

So, this will be equal to γ_w into H. So, the variation of the pore-water of pressure from B to A is triangular. Starting from 0 attaining a value of γ_w H. So, if I want to define U as the force, now this U as the force would be, you need not to write it as a prime, U will be equal to average of U_A and U_B. So, this is equal to half into γ_w into H. This is in the pressure form.

$$U = \frac{1}{2}\gamma_w.H$$

Now, if I am trying to find out the U, if I say U, let it be u, force now this will be equal to this pressure is acting on this surface AB. So, this will be equal to half γ_w H and what is the length of the surface? If this is H, this is θ, so this is equal to H by sinθ, correct? Multiplied by 1 perpendicular to section. So, this is equal to H by sinθ into 1. So, this comes out to be half γ_w H^2 by sinθ.

$$U = \frac{1}{2}.\gamma_w.\frac{H^2}{\sin\theta}$$

This is the pressure pore-water pressure which is acting on the slip surface AB because of the submergence. Is this part, okay? Now, rest of the things are simple mechanics. For this condition, $\sum F_x = 0$ and $\sum F_y = 0$ and solve this function. So, this is θ, this will be T cosθ, this will be T sinθ. Now, we have here the two components like this and then we can compute the values of, if this is θ, this is 90-θ so this is also going to be θ.

So, if you solve these two functions and one more thing which we require is we require a relationship between T and $\overline{N}$. So, T and $\overline{N}$ can be written as T equal to $\overline{N}$tanϕ'. Is this part okay? Yes, sorry, I am sorry. This is going to be ϕ, so this is going to be ϕ'.

$$T = \overline{N}.\tan\phi'$$

The major unknown is $\overline{N}$. So, what we have to do is from these two equations we have to obtain $\overline{N}$ and one of the ways to get rid of this would be, I can substitute for the T value when I am taking the components equal to $\overline{N}.\tan\phi'$.

$$T = \overline{N}.\tan\phi'$$

So, you will be getting two equations and you can solve those two equations and hence you can derive the relationship between the P because the first equation would be, F_x=0

$$\sum F_x = 0$$

So, this will be equal to, P plus Tcosθ equal to $\overline{N}$ plus $\overline{U}$ sinθ.

$$P + T\cos\theta = (\overline{N} + U)\sin\theta$$

This is fine and simply by using the resolved components of the weights I can take this also into account as q_s into H into cotθ. So, both the components would be qs into H cotθ plus W, W is known, and this will be equal to this component, cosθ. Now, you solve this expression.

So, ultimately what we should be getting? If you solve these two equations, what is that we are going to get? We are going to get the values which are known as the earth pressure P which can be obtained. You have to just do simple mathematics to obtain the pressure functions. Anybody in the class what will the final expression? We have filtered out the effect of water so the P will be equal to half γ_w into H^2 plus when you are filtering out the effect of water, what about the surcharge and the weight which is going to come?

So, this will be half effect of buoyancy γ_bH plus q_s, is this fine? H cotθ this has been so far the normal expression which we have been using in all this trial analysis and what is the component which is missing? The tan component, hope you can realize what are the different components which have been presented over here in the form of mathematical terms.

So, because of submergence we have the buoyant weight though we started with the total weight of the block, the pore-water pressures have been taken out from the component. So, when you do this type analysis what is going to happen? This will be the pressure because of the water, surcharge plus buoyant weight of the material.

Now, suppose if you want to find out the maximum pressure which is acting on the system, maximize this function, that is it, all right? So, when you maximize what is that you will be getting? The known terms that is half $\gamma_w H^2$ plus the effect of buoyant soil mass. So, this will be half $\gamma_b H^2$ into K_a plus the influence of surcharge which is acting on the system that is q_s into H into K_a. Is this okay? Without doing all this analysis also you would have been able to obtain this function just by using simple principle of superimposition. Three pressures which are being taken into account 1, 2 and 3 and that you are aware of.

Now, this analysis we can easily extend to the cases when we have partial submergence. In that case, what is going to happen? Any guess? The block or the trial wedge which we have considered is now going to be a composite of two sections. Now, rather than having water table here, the water table has moved down to this place. So, what will happen to the weight? If I had written here A, B, C, D and E the weight will be having now two components. So, this is W_1 and this is W_2 and we have discussed enough about the state of the soil mass in this block, all right?

In the first course of soil mechanics. So, depending upon whether you have a sandy soil, compacted clays, salty soil or whether I assume a variable saturation in this zone above the water table or completely dry mass, long-term, short-term stability, if you remember we can attribute γ values to W_1. So, this γ could be dry, this could be $\gamma_{\text{partially saturated}}$. I can include the effect of capillary action also here. So, if I include the effect of capillary action what is going to happen? There will be going to be a zone of capillarity.

So, we have now W_1 getting divided into W_{11} and W_{12} that can be taken care of. There is no other difference, rest of the things are almost similar. So, this is another situation which normally we come across in the real life. Now, partial submergence could be because of several things. This could be you are basically pumping out the water during construction and maintaining the water table over here. It could be because of the drainage which is going to take place and hence the water table does not remain up to the top of the backfill.

Under any circumstances the analysis can be done very easily. It is an example of how you would extend simple analysis which is being used, the trial wage analysis for finding out the earth pressure on the system. If you remember, the way we computed the stress acting on the soil mass, I can also use the principle of superimposition over here, how? I know the pressure which is coming because of the entire system of height H and then I have water dropped up to this level. So, I know what earth pressure because of this is.

So, in that case H gets divided into two parts, we can have the H_1 as the height of the free water table. And then we know the pressure distribution because of this and then from this point onwards what has happened? The water table is only up to here, so this is the earth pressure because of the soil mass. The water table is coming only from this point onwards so this will be equal to γ_w into H_1.

So, this also you can do. By all circumstances what is going to happen? The P will be equal to half K_a γ H^2. Subtract the effect of H_1 height, so minus 1 K_a into γ H_1^2 and then what is there the buoyant force plus half K_a γ_b into H_1^2. Try to prove this function by using the simple mechanistic laws. Any questions, any doubts? Fine.

Now, there is another condition of purged water table in the system. So, when we are dealing with these types of situations, the question is how would you construct the retention schemes or the retention system, retaining walls? Which is going to be beneficial and suppose if I take a case that this is the retaining wall, we know that the critical failure surface is going to be like this, idea is to minimize the earth pressure which are going to act on the wall.

And suppose there is a rainfall which is taking place, so because of this, a situation like this or this might develop. Now, what you want to do is, we want to minimize the earth pressures which are going to act on the system during rains, submergence. I have two options with me the one is, I will create this $\overline{U}$ or the U value as 0. What is happening because of this? If you take moment about this point of all the forces you will realize that the water which is present in the retaining wall in the form of the pore-water pressure has a toppling effect, correct?

That means this U has a tendency to topple the wall. The more this pressure P is going to be higher because then you require more reactions to balance this. So, in real life the best thing would be if you can create a situation so that the pore-water of pressure becomes 0. How will you do that in real life? pore-water pressure can be maintained 0 along AB which happens to be a slip surface when I provide a filter overly there.

So, suppose if I create a layer of filter like this, filter media. Sometimes, you also call it as a drain. You have done these things in your first course where we had talked about the non-homogeneous earthen dams where we had provided a filter layer to act as a toe filter. Now, because of this what is going to happen? If I ask you to draw the flow net for this situation which you have already done in your first course, seepage analysis. What is going to happen here? Draw the flow net, this is the flow line and this is how the flow net will look like.

These are the flow lines, what about the equipotential lines? Equipotential lines are supposed to be cutting them perpendicular to each other. I am sure now many of you will be unhappy to see this type of flow net. Why? We are defining the conditions of flow lines intersecting the equipotential lines. At most of the places in the system.

Look at this point, at this point by virtue of being a filter media the pore-water pressure is 0. So, this happens to be an equipotential line. This is a exposed to the atmosphere, this surface. So, this is also an equipotential line. So, exponential lines are cutting each other not correct, flow lines you are seeing the ambiguity. Equipotential lines are also intersecting the filter layer line. So, it is a rough flow net which we have drawn just for the sake of understanding. It is not the correct flow net.

Another issue is when we are creating a filter media layer like this, it is extremely difficult to execute this type of a filter drain in real life during execution. On black board you can draw this very easily but it is not very easy to execute this type of a filter drain in the field but still what people do is they go for layer wise construction and then by maintaining the geometry they provide this type of filter drains but I hope you can realize, it is not going to be very easy situation.

So, if I create this type of a filter drain and if I ask you to find out the pressure. This is pressure 1, coming from the wall onto the block. What is the another way of providing a filter drain in the retaining walls which is normally done. The second situation would be which is rather easy to execute in the field, the filter layers are provided in the form of a vertical chimney and this is how they are connected to the outside atmosphere. Even this can also go outside the atmosphere.

So, this becomes a vertical filter drain and suppose if I ask you to find out the pore-water pressure, sorry the earth pressures acting on the system, this is going to be P_2. Each point along this drain is exhibiting the pore-water pressure equal to 0. But not along the surface of the slip so AB, the pore-water pressure is still acting as U, what we have shown over here. Agreed?

So, for the sake of construction feasibility this system is very good. Now, if I ask you to draw the flow net over here, this is an equipotential line because it is attached to the atmosphere. So, you have flow lines you know coming and intersecting like this and what about the equipotential lines? Now, this becomes a difficult situation but the equipotential lines are also going to intersect somewhere like this perpendicular to the flow lines.

So, this is how the flow net has to be completed and then you can find out what is the pore-water pressure acting at each and every point along the slip surface. You can still use this function to average it get the value of U and do the analysis. The common sense says, in second situation because the pore-water pressure is acting, the P_2 value is going to be higher than P_1. So, you have to design the system accordingly. This is fine?