**Geotechnical Engineering - II**
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**Lecture No. 39**
# Analysis of Sheet Piles- I

So, I have discussed in previous lecture about the sheet pile walls, introduction, different types, how are they used to construct infrastructure, what are the types of the sheet piles and what type of facilities you can create out of them. In fact, I showed you some videos also, so, that you can understand the philosophy of execution of the sheet pile, walls also. Now, depending upon the type of structure which you create this part also I discussed in the previous lecture.

I tried to show you the difference between a sheet pile wall which acts as a cantilever wall then we introduced the concept of the propping or using a tie bar with an anchor. Particularly if you want to increase the height of the retention. We talked about different types of cofferdams; we talked about different types of bracings, and which are used to stabilize the cuts we talked about the single cell cofferdam then we talked about the multiple assemblies of the cofferdam and so on.

Now, what I will do is I will introduce the concept of Analysis of the Sheet Pile. So, there are few concepts which you should try to understand. When you talk about the Analysis of the sheet piles, see this is a sheet pile and I am trying to retain the soil mass. So, this becomes the ground surface and if you remember, we have depicted this as the dredged level. So, up to here the dredging has been done and in the process I am achieving a height H of the wall.

Now, let us try to understand what the mechanics of deflection of this pile is. You are retaining this soil mass, active earth pressure is acting on the pile, pile has a tendency to get deflected on the left-hand side. Certain portion of the pile is embedded into the soil mass. So, if the tendency of the wall is to get deflected on the left-hand side, up to a certain depth on the left hand side below the dredge level the soil will have a tendency to resist this movement. What about this portion of the soil mass?

Now, this portion of the soil mass can be considered as a passive zone, why? Because if the pile deflects on the left-hand side this portion is trying to move into the soil mass and remember when we are discussing the earth pressure theory when we are talking about the retaining walls, we defined active and passive or precious as movement of the wall with respect to the backfill outside is active earth pressure and movement of the wall inside the backfill is mobilization of passive earth pressure.

So, truly speaking this pile is going to get deflected in the left-hand side and this portion is going to get deflected on the right-hand side. So, if I try to depict this pictorially, this is how it will look like. Now, you will realize that this point which we defined as O becomes a hinge because this is the axis of rotation of the pile. Now, if I ask you to superimpose the forces which are acting on the pile can you do that?

So, before we start doing this, we should understand that this portion of the pile let us say AOB, which is or let it be A', B' and this is A and B, this is experiencing Active Earth Pressure. Now, below the dredge line up to the point O if I draw a horizontal plane this much of the soil mass is resisting the movement of the pile. So, this happens to be a Passive Earth Pressure, above this line yes in between.

Now, what about the region below this, this portion is pushing the wall outside. So, this happens to be Active Earth Pressure and the retaining wall, or the sheet pile is trying to move into the backfill. So, the pressure which is going to get mobilized here would be Passive Earth Pressure. is this part clear? Now, when rotation is taking place at about point O what is the net pressure at point O this will be 0 this is part ok?

Now, we can compute A.E.P 1 let us say or the way I write it is mostly right-hand side right-hand side of the sheet pile this is P.E.P on the left-hand side this is Active Earth Pressure on the left-hand side and this is the P.E.P on the right hand side. Now, what you have to do is just compute these pressures draw the free body diagram and from that onwards we will start doing further analysis.

So, just to help you out, can you think of now developing the pressure diagrams. The simplest possible pressure diagram would be, and this is the tip this is where the sheet pile is point O happens to be point of rotation. So, that means this is the pressure diagram and this will be equal to $(A.E.P)_R$ have you followed this what about this portion from here to here the passive earth pressure is acting.

So, this we have defined as P.E.P left for the same soil suppose there is a transformation from passive earth pressure to active earth pressure what is going to happen to the pressure diagram. So, this is going to decrease you are right, this axis I was talking about. So, this becomes $(A.E.P)_L$ and what about the passive resistance which is coming from the right-hand side for the same soil what happens to this pressure axis for case of Passive Earth Pressure.

So, this is what is going to happen over here is this clear approximation of course. So, we have got now, $Pa_1$ the way we write it this is $Pp_1$, $Pa_2$ and $Pp_2$. Now, we have to do one more approximation, what? I can idealize the situation as, this is the retaining wall, or the sheet pile. We have gone up to this point. What I have done is I have taken the centroid of the $Pp_2$ and $Pa_2$ net effective. So, we call this point as point C. So, this becomes the point C.

So, a better way of drawing this would be I can get rid of all these intermediate pressures, and I can replace the $(P.E.P)_R$ - $Pa_2$, $Pp_2$ - $Pa_2$ with a reaction which is going to act over here and then continue with the pressure distribution.

So, this is the net pressure diagram where we have $Pa_1$, $Pp_1$ and R is equal to $Pp_2$ - $Pa_2$. Now, what is the significance of this? The significance is we have created an artificial point C within the sheet pile which acts as a pin joint, it is a point of rotation. So, at this point of rotation the moment is going to be zero and there is a reaction.

So, what we have done is mechanistically we have got a simple situation starting from a very complicated situation where we can idealize the whole pile system in such a manner that this point C beyond which the certain fraction of the sheet pile exists if I assume this as H this is the depth of embedment d the practice is to compensate for the bottom portion we augment d by 20 percent. So, that means the $d_{eff} = d+0.2d$ rest of things are simple if I take moment about point C you can solve this.

So, $Pp_1$ into d/3 and this will be equal to $Pa_1$ into this is H plus how much this would be H+d/3. So, this is the equation which I get what is the principle unknown here? The principal unknown is d, depth of amendment and H is normally a design parameter. So, we assume certain value of H we say that this is the height of the wall which we have to create for this height what should be the depth of embedment so that the sheath pile remains stable compute the value of d from here and the $Pp_1$ and $Pa_2$, $Pp_1$ equal to half gamma $H^2$

$$Pp_1 = \frac{1}{2}\,\gamma\, H^2$$

So, this will become a cubic equation. So, $Pa_1$ will be equal to half gamma $(H+d)^2$ into $K_a$

$$Pa_1 = \frac{1}{2}\gamma(H+d)^2.K_a$$

and this will be half gamma d square into $K_p$

$$Pp_1 = \frac{1}{2}\gamma d^2 K_p$$

what is the fallacy in this analysis which we have done. Now, if point $M_c= 0$ and suppose if I want to equilibrate the forces what is going to happen to the forces then. Now, if you say $Pa_1=Pa_2$. It is not correct because R is also acting over here correct.

So, truly speaking $Pa_1 \neq Pa_2$ are you getting this point? But what happens to the net pressure at point C, at point C the net pressure should have been equal to 0 because what we assumed is that the point O happens to be the axis of rotation where the net pressure is going to be 0. So, this is a paradox.

So, you may say when we are assuming this 20 percent of the d value which we are adding up that takes care of the uncertainties associated with the analysis. A simple way of analysing the whole situation. Another obvious thing which we would be interested in is as a civil engineer, geotechnical engineer draw the bending moment diagrams correct or the pressure distribution.

So, first let us do the pressure distribution and pressure distribution would be the actual pressure distribution and the idealized one. So, if you superimpose on this figure the pressure distribution graph also will draw this somewhere here let us say, yeah you try to analyze it how the pressure diagram would look like.

So, the pressure diagram would be, if this is the whole pile I can take it like this, this is the idealized one and then you will have somewhere here the pressure and then it becomes changes the direction and by the time you come at the tip this is what the pressure distribution would be. So, this is what is known as the Idealized Pressure distribution. So, this condition also tells you that $\Sigma M_c$ should not be equal to 0 you are defining the law of mechanics. Particularly if there is no R, the net resultant force.

Now, when we have discussed so much, we should also be discussing a bit about what are the possible modes of failure of this system. So, what are the possible modes of the failures? Your P.E.P is not sufficient enough the Passive Earth Pressure is not sufficient enough. So, what is going to happen? if passive pressure is not sufficient enough to stop the sliding of the wall, the wall will get slide because of the application of active earth pressure.

So, what normally we do is, we apply a factor safety to the Passive Earth Pressure which is getting mobilized and there is a very conservative way of doing the analysis. We augment the depth of embedment by 20% of the pile which we get as d and second thing is we apply a factor of safety, F.

So, this becomes factor of safety against sliding. We are very conservative. We do not want to take any chance what it also tells you is that there is a possibility when you are installing these types of piles either you have not reached the enough depth of embedment or even if you have achieved the depth of embedment the possibility is that the passive earth pressure might not get mobilized due to improper compaction or density state. Because this passive earth pressure is going to depend upon the friction angle of the material which is lying over here below the dredged line and then the chances are that if you are not compacting this material the friction angle may not get mobilized and hence the passive earth pressures might be lesser.

The second possibility is, excessive deflection and if excessive deflection takes place basically the sheet pile has yielded. That is what is known as the structural failure of the sheet pile. Excess deflection not the displacement. This is what the displacement we were talking about the sliding because of the Active Earth Pressure and the whole wall sliding on the left-hand side. So, due to the axis deflection there could be a structural failure of the wall. This can be corrected by assuming a proper section modulus because what you are realizing is that the moment function is cubic function.

So, if I can select a proper section modulus. So, if I know the bending moments, I can select the section modulus I know the axis of y value from the neutral axis and then I know the value of moment of inertia. So, the, this is the structural part of this element. The third thing is there could be a failure of suppose it is anchored. What we were discussing the previous lecture. So, this is the tie rod, and this is the anchorage. There could be the snipping of the tie rod. So, the failure of the tie rod or the anchors, both systems may fail.

So, these are the three possibilities in which the sheet pile might fail. So, this is what actually we analyse, and we make sure that the system is going to be safe against such type of failures. Now, one more thing which we have to discuss when we are discussing about this simplified diagram of the pressures the way they act over this there is an empirical solution which has been proposed by a researcher known as Henry and what Henry's relationship talks about is.

So, a simplified solution would be, particularly for the backfills or the soil mass which are pure frictional. So, there is a relationship like the value of $\phi$ and the value of d pure frictional materials. So, when it is 20° in degrees then this is 2 times H when it is 25° 1.5 H when it is 30° any guess what we are observing here the value of d is decreasing or increasing yes.

So, the denser the material becomes below the dredge line what happens the effective d value decreases. So, suppose if it is 35° this becomes 0.9 H and the maximum value is 40° heavily compacted soil mass. So, this will be approximately 0.7 H. This thumb rule is sometimes utilized for getting the values of d also. These are known as Henry's simplified solution.

So now, you can do analysis of any of the sheet piles usually the value of F is taken as 2.0. So, when we have done this analysis, there is one more thing which is remaining I hope some of you must have guessed it what we have done is we have done first condition moment at c point equal to 0, there could be another situation where I would say that let the shear force at a given point is 0 that is $\Sigma F_c=0$ and this type of situation is going to occur at $d=d_0$ let us say.

So, if I obtain the value of $d_0$ and if I substitute over here, I can get the moment at point c. So, what is going to happen there the moment at c will be equal to if I say that this is equal to A and this is equal to B. So, $M_c= A-B$ corresponding to $d=d_0$. Now, what is the definition of $d_0$ how will you get $d_0$ $F_c= 0$.

So, that means active and passive earth pressures are going to become same the shear force is going to be 0 or the total pressures are going to be 0, let us put it like this. So, at this point rather than taking the moment, what we will be doing is will be equilibrating the pressures and the pressures will be equal to $Pp_1 = Pa_1$. From this condition you obtain the value of $d_0$ and substitute this value of $d_0$ into this equation to obtain this. This is the most simplified Analysis for a Sheet pile wall. I hope you have understood this, thank you.