**Advanced Foundation Engineering**
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**Lecture - 26**
**Design of Sheet Piles (Contd.)**

In last class, I have discussed about the design methodology for sheet pile in granular soil and cohesive soil. Now design methodology means, I have discussed about how to determine the depth of the sheet pile, as the most of the resistance that sheet pile is getting; that is, because of the high depth that we have to provide for the sheet pile. Now, today I will solve a problem, so where I will find the required depth of sheet pile, which is in the granular soil. Now if I start this example on the sheet pile.

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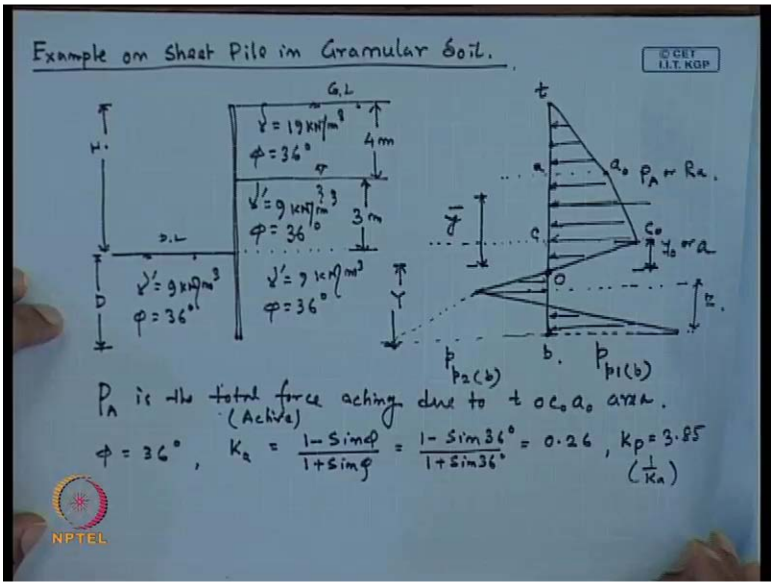


Now, for this example, I have taken, that is a sheet pile, whose required depth we have to calculate, and suppose this is the dredge level. So, this will be the D in required depth of the sheet pile, and this is the height of the sheet pile H, above the dredge level. Now, we have considered that the location of the water table, and this is the ground level, and this is dredge level. Now this properties of this soil above this ground level water level. Now this water level is 4 meter below the ground level, dredge level is another 3 meter below the water level, and this depth we have to determine. This depth is unknown, that we have to determine. Now, the properties which I have taken that gamma for the this soil, above the water level, is 19 kilonewton per meter cube, and phi I have taken is 36 degree, and below the water level as soil is saturated, we have taken the unit weight is 9 kilonewton per meter cube, and phi we have taken a same phi 36 degree.

So, here I have taken only the homogeneous soil, but that can be layer soil. So, depending upon the type of soil, we have to calculate the lateral earth pressure, which is coming on the sheet pile. Now here also same soil properties we have considered. This is, that means, here also gamma is equal to 9 kilonewton meter cube, phi is equal to 36 degree. Here also gamma dash equal to 9 kilonewton per meter cube, and phi is 36 degree. So; that means, all are the same properties we have taken, but that can be different. So, depending upon the type of properties, we have to take that consideration in the design calculation. Now for this sheet pile, if we draw the pressure, earth pressure diagram. This is the dredge level, this is the ground water table level. Suppose this is the top point, if I consider this is this ground water table, is a point, and this base is at b point, and this dredge level is c point.

Then the first we will consider, this will be the earth pressure diagram up to the water table level, then it will further increase. Then it will go this side, and then from here it will go this side, because that pressure distribution diagram, I have already explained in previous class. Now, here the force will act in this direction, but here the force will act in opposite direction, here also it will act in this direction. Now the resultant force, that will act here that is P A or R a. Now, this is point O point say, and now if I extend this triangular part. Now here we can say this one is passive pressure, passive pressure 1 at b point. This is also passive pressure 2 at b point, but this is at the b we have considered. Now, we have considered that the, this edge is at a distance of, z from the base of the sheet pile.

And this resultant is acting at a distance of y bar, from the O point, where the pressure is 0. And this O point, is also distance of y 0 or a from the dredge level, and this distance of O point, from the base is Y, capital Y, and this is y bar, small y bar, this is capital. So, if I, further if I explain what are the different components. So, this is the pressure distribution diagrams. Now, the P A or R a is the total force, for this active earth pressure zone. This active earth pressure zones means, if I this consider this is top t and this is c, and this is c 0. So, this P A actually, this P A capital P A, is the total pressure or total force, acting due to this t o c 0, and if we consider this is a 0 c 0 a 0 area. We can send total active force, that is active. So; that means, total t o c 0 a 0 and t, this area due to this total area, this is the active pressure or active force, which is acting.

Now, and this force is acting at a distance of small y bar from this o point, and o point is at a distance depth of y 0, or small y 0 or small a from the dredge level, or c level. And y and this o point is at a distance of capital y form the base of the retaining wall, as sheet pile, and z is the distance from the b to this edge of this triangle. Now, first now we have to calculate, from all this things we have to calculate the, this depth D required. Now first we consider if phi is 36 degree, and what will be the coefficient of active earth pressure; that is k a is 1 minus sin phi by 1 plus sin phi. So, that is equal to 1 minus sin 36 degree 1 plus sin 36 degree, it is 0.26. Similarly, we can write k p will be 1 by k, so this value is 3.85; that is 1 by k a. Now we will calculate, what are the forces says that is acting at different level. So, that part we will first calculate.

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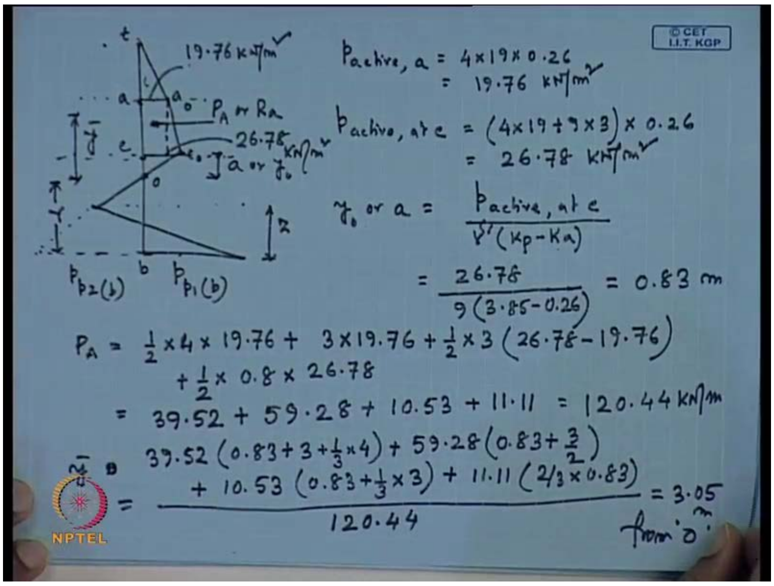


Now, if I further draw this diagram for, and to show what are the forces, that is acting at different level. Then you can see, if I draw this diagram again. So, this is water table level, this is dredge level, this is base level. So, these are the forces, here it is 0. So, you can. This is the diagram the same diagram I have drawn here again, to show the different force components. So, this is t point top, this is a point, this is at the, this is o point, this is c point, this is c 0, this is a 0, and this is p p 1 b, because this is b point, and this is p p 2 b. And this is the point, where this distance is z. Now these are the total force which is acting P A or R a, that is the distance of capital y small y bar on the o point, and o point is at a distance of a or small y 0 on the dredge level, and this distance is capital y on the base of the, o point is at a distance of capital y, on the base of the sheet pile.

Now, first if I calculate what is the pressure, active pressure at a point. I mean at this level, then this will be as we have considered, that the properties of the soil this is 19 for top and kilonewton height is 4 meter. This is 9 and 3 meter, and then we can write that this active point, this will be 4 into 19 into the active coefficient of the earth pressure; that is 0.26. So, force at this level will be 19.76 kilonewton per meter square; that means, at this level. So, here the force is 19.76 kilonewton per meter square. Similarly, what if the pressure, active pressure at c level, small c level, when this pressure, because this distance from this is 3 meter, water from dredge level to the water level, this is 3 meter and top is 4 meter. So, we can write this will be 4 into 19 plus 9 into 3, as here that gamma is 9 and height is this area is 3, and in the top is 19 is the gamma, and this whole and then into active earth pressure that is 0.26. So, this pressure, this point is 26.78 kilonewton per meter square.

So, the pressure at this level, it is 26.78 kilonewton per meter square. And next one, we have to determine the a value or y 0 value. So, y 0 or a; that is equal to p active at c point divided by gamma dash into k p minus k. This expression I have already derived in the last class, so previous class I have already derived this expression. So, from that expression, if we use that expression, then we will get the a value. Now, here a value will be, because p active at c pressure, active pressure at c is 26.78. Then the gamma dash, this is the lower portion, gamma we are considering below the dredge level, because this a or this a dash point, is below the dredge level. So, here the gamma value is 9. So, that is gamma into k p is 3.85 minus 0.26. So, this a value is coming out to be 0.83 meter.

So, a fellow; that means, o point is 0.83 meter below the dredge level. Now, we will calculate this P A or R a value, this P A total active force due to this area, is we can calculate. The total force, first we consider this triangle t a a 0. So, about this triangle, total force is half into height is 4 meter into the force that is 19.76. Then we will consider, the force of this rectangular area, I mean between a to c only this rectangular area we are considering. So, this rectangular area means; that is 3 is the height and into 19.76. Then we will consider this triangular area between a to c. So, this rectangular area we have already considered. Then we will consider this triangular area between a to c.

So, this triangular area will be half into 3, and then the total pressure is 26.78 from the 19.76 we have already considered. So, rest will be 26.78 minus 19.76.

Then; that means, this is the area. So, we have considered this triangle, then we have considered this rectangle, then we considered this triangle, then rest only this triangle c c 0 o, that we have considered c c 0 o. So, that triangle means plus half into the distance is c to o is a that is 0.83, so into 0.83 into, the total stress at c level that is 26.7. So, that will be 26.78. So, these are the four components of this area; first this triangle, then this rectangle, then this triangle, and then the lower triangle. So, summation of this area of this forces, for this total four areas, that will give you the total active force acting in this area. So, we can, if I segment, if I write, so first one will give 39.51. Then next one will give 59.28, and the third part will give 10.53, then the last one will give 11.11. So, total force; that is 120.44 kilonewton per meter. So, it is considering in terms of per meter, so this is 120.44 per meter. Next we will consider the. So; that means, this P A or R a value is known.

Next we will determine the, what is the value of small y bar. So, small y bar, that we will consider the area we will take the, this with respect to o point we will determine this y bar. So, the distance of the force, that is acting at different areas, from the o point, that we have to multiply with the force of each area, and they have to divide it by the total force. So, in that cancels if we consider the first one, then the for the first triangular portion, this t a a 0 portion. The total force is 39.52, and which is acting as one third of this triangular area from the base. So, the distance will give that o c 0 plus c a plus one third of a t. So, o c is 0.83, and c a that distance is 3 meter, then a t is 4 meter. So, one third of a t, that it will be one third of a t is 4 meter. So, that is the lever arm, and this is the force, so taking basically the moment with respect to this o point.

Then the next one is, next 59.28 for this rectangular area, now which is distance of this it is acting, this half of this rectangular area. So; that means, 0.83 plus, this is 3 meter, so 3 by 2. Next one is, this 10.53 which is the force, due to this triangular area only. So, that will act also one third from the base of this triangle. So, that is 0.83 plus one third of 3 meter. So, this height of this triangle is 3 meter. Then the last one, this 11.11 and this angle, so that is also acting one third of the base, but from the o point; that will be two third of the height of the triangle. So; that means, here we can write, into two third into height of the triangle is 0.83, and this total is divided by the total force, which is 120.44.

So, this total, all the segment and then the total force. So, ultimately the y bar is at a distance of 3.05 meter from o. So, y bar we have calculated, here it is at a distance of 3.05 meter from o point. So, now we know the total force of this area, now we know the y bar. Then we will calculate the rest foundation the things.

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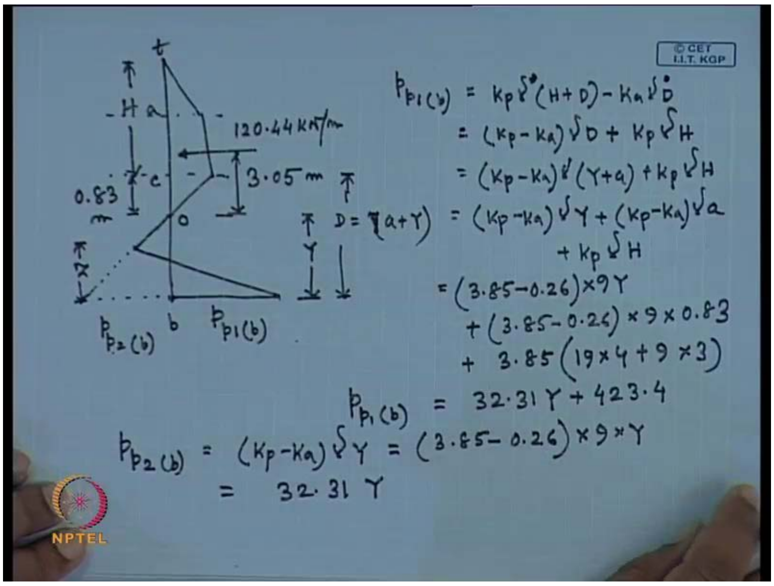


Now again if we consider or we draw this diagram, again if I draw this diagram, so this is the water table level; that is dredge level and these are the diagram, and then this is the base level. So, here the total force of this area, which is total force, is 120.44 kilonewton per meter, and which is at a distance of 3 point, the distance is 3.05 meter from o point. And this o point is at a distance of 0.83 meter from the dredge level. So, this is o point, a point, t point, and c point, d point. So, this things, this is the area force for this area, this is P A. Now again if I write, this is p p 1 b, this is p p 2 b. Now this distance is o point, is at a distance of capital y from the base of the sheet pile, and this edge of this triangle is at a distance of z from the base of the sheet pile. Now, first we will calculate what is the value of p p 1 b.

That value we can calculate this is the, because that thing I have already calculated in the previous class. So, this p p 1 b, this is the net force, or net pressure acting due to the passive and active. This right hand side of the sheet pile, this p p 1 b, and the net pressure and this is the pressure at the base, acting on the left side of the sheet pile; that is p p 2 b. So, p p 1 b, last class this has been already derived, so this will be k p into gamma dash, into h plus d minus k a into gamma dash into t. Now, we will this is first we will consider this is gamma, then we will apply it according to the here, because as here it is D, so it will be gamma dash. So, now, you considered, that this k p h and D, if I replace this D, and if I take this D also, then we can write, that k p minus k a into gamma D plus k p gamma H.

So, if first, for the general case we consider both are gamma. So, this is the way we can determine this is, ultimately k. So, this thing as previous class, it has been already derived, so; that means, k p minus k into gamma d plus k p into gamma into H. Now, from this figure we can see, that this D is basically a plus capital y. This is a or y 0 that is 0.83, so a plus capital Y, so this is the value of D. Now if I replace this value here. So, this is k p minus k a into gamma into y plus a plus k p gamma H. So, further if I simplify, this is k p minus k a into gamma y, then plus k p minus k a into gamma into a plus k p into gamma into H. So, here there are three parts and three gamma. So, here gamma, as this is y, y is below the dredge level, so gamma will be 9 kilonewton per meter cube.

And here also gamma, and that is into a, and a is also below the dredge level, where the gamma is 9 kilonewton per meter cube, but here gamma is H, and we multiplying with H, and here gamma is not throughout this height of, because H is this one, which is not always gamma is equal to 9 kilonewton per meter cube, because in the from top 4 meter gamma is 19 kilonewton per meter cube, and rest it is 19 meter per meter cube. So, if I put this value according to that, so k p is 3.85, k a is 0.26, here gamma is 9 into capital Y. Then there is the next part is plus 3.85 minus 0.26 into capital into 9 is the kilonewton per meter cube is gamma into a is 0.83. Then the third part k p is 3.85, now here gamma into H; that part will change, so we can first, we can write first gamma is 9, and there H is 4 meter, then plus gamma is, this first part gamma is 19 into 4 meter, then next is 9 into 3 meter. So finally, we can write this expression, is 32.31 Y capital Y plus 423.4.

So, this is the value of p p 1 at base level, or b level. Similarly we can write what would be the value of p p 2 at base level. So, p p 2 at base level; that is also explained or derived in the last previous classes; that is k p minus k a into gamma into Y capital Y. So, here this gamma will be 9, as it is multiplying with y which is below the dredge level. So, this will 3.85 minus 0.26 into 9 into y. So, that value is 32.31 y. So, now we know this p p 1 at base level, and p p 2 at base level. So, now, these things will put in our general expression. So, general expression, I have already derived in the last class. So, all these things we have, which we are calculating here, that will put in the general expression, and then we will determine the value of D.

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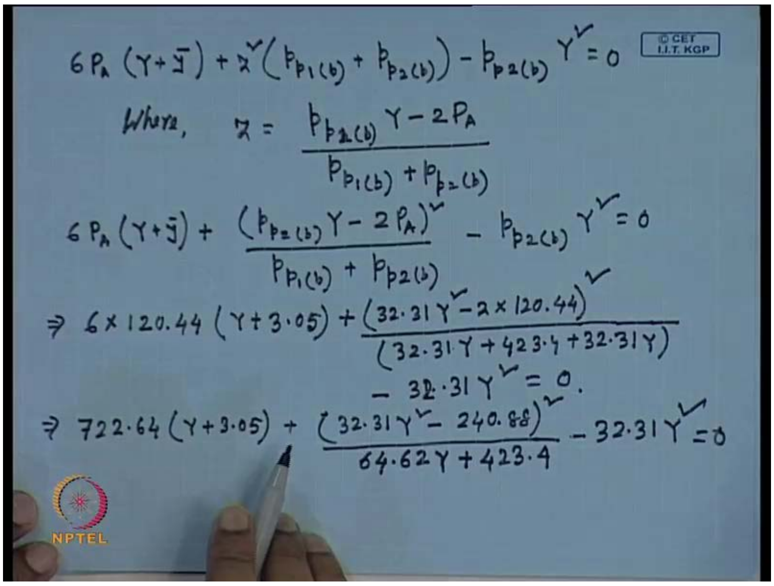


Now, the general expression which we got in the last class is 6 P A into capital y plus small y bar plus z square into p p 1 b plus p p 2 b minus p p 2 b into capital y square; that is equal to 0. So, this was the general expression or final expression that we got in the last class, for a sheet pile, cantilever sheet pile in granular soil. Now, where z that expression is got p p b p p 2 b into y minus 2 P A divided by p p 1 b plus p p 2 b at the base level. So, now, if I put this value in the general expression value of z, in the general expression, then we will get 6 P A capital Y y small y bar plus p p 2 b y minus 2 p A that is whole square, and then this is p p 1 b plus p p 2 b whole square into p p 1 b plus p p 2 b. So, 1 from the lower part, this p p 1 b plus p p 2 b that 1 will cancel. So, we can write this whole square divided by p p 1 b plus p p 2 b minus p p 2 b capital y square is equal to 0. Now, we will put this value 1 by 1. So, here this is 6 P A, that we have calculated is 120.44 capital Y is unknown, small y bar is 3.05.

Then plus this p p 2 b that we have calculated, is 32.31 y, so then y into y, so that will be 32.31 y square minus 2 into p is 120.44; that is whole square, divided by this p p 1 b is 32.31 y plus 423.4 that is p p 1 b plus p p 2 b that is also 32.31 y. Then minus p p 2 b is 312.31 y square; that is equal to 0. Now if I further simplify this expression, this will give us, that if we multiply this 120.44 with 6; that will be the 722.64 into y plus 3.05

plus 32.31 y square minus 240.88; that is whole square, and divided by 32.31 y plus 32.31 y. So, that is 64.62 y capital y plus 422.4 and that is minus 32.31 capital y square that is equal to 0. So, now we have to solve this expression. Now if I further simplify this expression, then we will get this expression. In further simplification, if I simplify this expression, and that means, from this expression we can see, that this expression is 722.64 y. So, this will be y 4, and then 1. From here the y cube term will come, I am sorry this is these expression, we can say this is p p 2. Here this expression this is p p 2 b is 32.31 y. So, this is 1 y square. So, this will be y 3. So, similarly this one will be y cube so; that means, y into y square, so this will be y cube. So, y to the power 4, then y cube, y square y, and sum then this form, if I further simplify this expression, then we can write that this expression in terms of.

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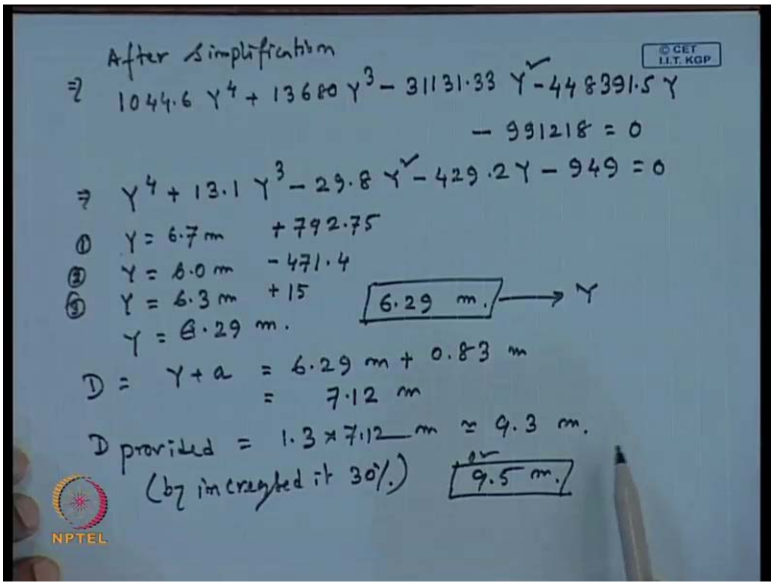


After simplification, we can write it is 10446 to the power y 4 plus 13680 to the power y cube minus 31131.33 to the power y square minus 448391.5 y minus 991218 that is equal to 0. Now, if I write and divide these all the terms by 1044, then we will get y to the power 4 plus 13.1 y cube minus 29.8 y square minus 429.2 y minus 949; that is equal to 0. So, now we have to solve this simplify expression, and from we will get the y value. So, this is y to the power 4 terms. So, we can solve it by trial and errors method, so that is one option. So, if I try with trail and errors method, so here I start with 6.7, so first trail is by consider y is equal to 6.7 meter, then we are getting, that the term, we are getting the extra term is 792.75. So, actually form the trail and errors method, this if I put the y value exactly, then this is left hand side should be equal to 0, but here if I put y is equal to 6.7 meter, the left hand side is coming plus 792.75. So, we have to reduce this y value. So, next trail we consider y is equal to 6 meter. So, then the left hand side we are getting force minus 471.4. So, that means, it is in between 6 meter to 6.7 meter.

So, in the third trail we consider y is equal to 6.3 meter, then we are getting which is plus 15 only. So, that means, it is closed to 0, so; that means, in this we have considered that our y value is 6 point, so we have to further reduce this thing, so we consider, this y value is 6.29 meter. So, we consider 6.29 meter, is the value of y by trial and error method. So, our D is y plus small a. So, y that we have considered is 6.29 meter, then a is 0.83meter. So, finally, the value that is we are getting, which is 217.12 meter. So, this is the D that we are getting, from this, so after solving. So, this will be the required D of that sheet pile, which we have considered. Now, here also, once we get the y value, then we can determine what is the value of z, then we can determine what will be the value of p p 2 b or p p 1 b; that means, the stresses at different level. Then one thing, once we put this t value, then we can check by taking summation of all the horizontal force, whether it is getting closed to 0 or not. If we are not getting 0, then we have to again check this calculation; that means, there is some mistake, and that means.

Once we got this y value, then we have to check whether all the horizontal or lateral force is, that summation is closed to 0, or if it is 0, then all close to 0, then it is otherwise we have to take the calculation. Now, here this D we will provide, this D we are getting from the calculation, but as the last, I mean previous lecture I have mentioned, I have to reduce it by 20 and 30 percentage, we have to increase this a d by 20 to 30 percent, because of the factor of safety. Then, if I increase this D by 30 percent, so D provided; that will be 1.3 into 7.12 meter. So, this is closed to 9.3 meter. So, we can provide D which is closed to 9.5 meter, or 9.3 or 9.5 meter, that will ultimately provide, by increase it 30 percent. So, from the calculation we are getting 7.12 meter, and we are providing, this is 9.5 meter.

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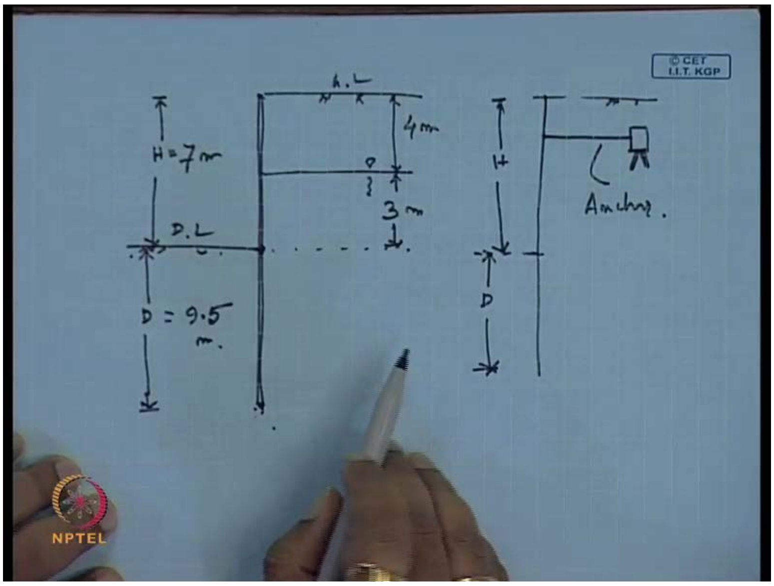


So, we can see that our H value; that means, if I again draw this figure of the sheet pile. So, this is the sheet pile, so this is dredge level, this is ground level. So, H value that we are getting, because this is the position of the water table, and from this ground level; that is dredge level, and this is the H, and this is D that we will provide or we will calculate. So, this is dredge level line. So, here this is 4 meter, and this is 3 meter. So, H will be 4 plus 3 7 meter, but D that we are providing is 9.3 or 9.5 meter. So, we can see, the depth of the sheet pile, below this dredge level, this D value is much higher than the H value. So, that means, here that is the difference between this sheet pile with the combinational retaining wall, because here the most of the resistance, this sheet pile is getting from this depth only.

So, that means, here required depth that we are getting is 9.5 meter, whether the height of the sheet pile above this dredge level is 7 meter. So, that means, the required depth is much higher than the height of the sheet pile. So, that means, this is, the one thing is that, we have to go for very higher depth for this type of flexible structure, and that means, here in the next section, that I will discuss that how to design this anchor sheet pile, because sometimes these required depth is very high. So, that means, because here all the resistance is coming from the sea depth, because of this depth of the sheet pile, that resistance is still getting form the soil. So now, get providing this higher depth, is sometimes very difficult. So, in that case, we have to provide the anchored sheet pile, to reduce these depth required depth further.

So, we can reduce that depth, required depth by providing anchor here. Suppose here the same, this sheet pile we can reduce the depth, if I suppose this is ground level. See if I provide one anchor here, and then fix it is with anchor this one, and then; that means, basically this is holding the, this pressure is acting in this direction, and this anchor is basically holding this sheet pile. So, in that case, we can reduce that required amount of the depth, below the dredge level if we provide the sheet pile here, if we provide the anchor. So, this is our anchor, and this is our flex cantilever retaining sheet pile, and this is anchored sheet pile, so where we can reduce the required depth. So, that how to design this anchor sheet piles, what are the different types of design methodology.

Thus, those things we will discuss in the coming classes or so in the today's class if I summarize this application part, so here I have discussed only the design of or determination of depth of the sheet pile, which is in the granular soil. So, now one thing, is that this sheet pile can be in the cohesive soil. Now in that case, in last class, I have already discussed that, in the cohesive soil what would be the expression, because in that case we considered the soil is purely cohesive. So, that means, we have considered that soil is phi value is 0. So, in that case, the final, then in the similar process, in that case a different; for example, if I consider the same sheet pile in granular in the cohesive soil, and then we will get a different value of the, this different diagram, then from that diagram we can get different value, and then we can try to.

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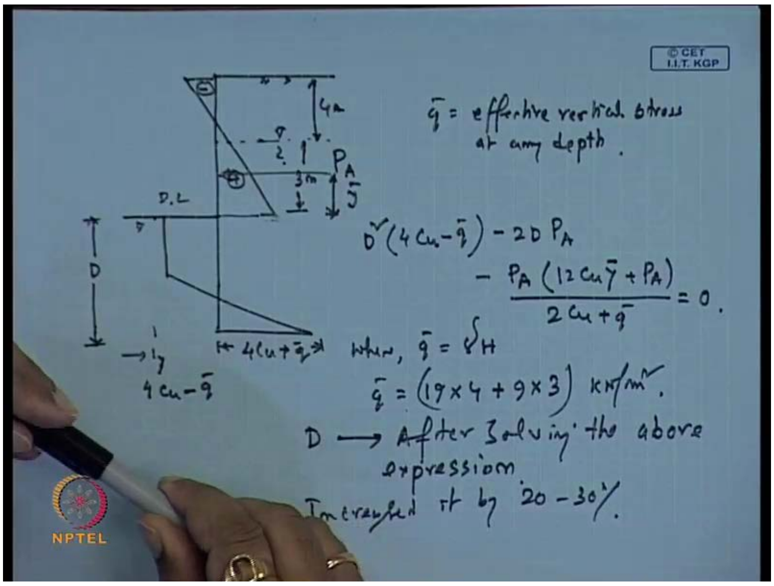

First suppose if I solve this same problem in the cohesive soil, then what will happen. So, this is your dredge level, this is the same water level, and this is the distances, height depth, this is 3 meter, and then this required depth we have to determine. So, I have mentioned that, in that case, our this diagram will be, this is negative, this is positive. Then this will start from here, then it will go in this form. So, here we know that this is our dredge level, this is the ground level. Here this value will be 4 c u minus Q, and here this value will be 4 c u, this is plus Q bar, this is minus Q bar.

Now, first Q is the undrained cohesion of the soil, and Q bar is effective vertical stress at any depth. So, and this finally, if I consider this things, and then finally, the final expression that we will get. So, similarly here also, this Q bar from these two pressure we have to calculate, then the final expression, then if I consider only the positive part. Then finally the expression that we will get, that is D square 4 c u minus Q bar plus 2 D p a. So, this is the force, which is acting that is P A then minus P A 12 c u small y bar plus P A divided by 2 c u plus Q bar that is equal to 0, where this Q bar will be gamma into H. So, from this if I consider same density, same unit, weight and height, then the Q bar for this case will be 19 into 4 plus 9 into 3. So, this will be the Q bar for this case.

Now, the p A, if I consider this p A, is the force only the positive part, and this y bar again which is acting the force from the dredge level. So, that means, we consider this triangular part if actually, if this is the rough triangular distribution, if it is the layered soil or different. Even in this case also, if I consider in the different level, because this is, water is here, you know this water table. So, that means, if it is layered soil, then we will get the different distribution, but here just we have taken a simple distribution of that, to show how to calculate in case of cohesive soil, but in case of layered soil we will get the different distribution. So, that in the negative part in the top thing different distribution in the positive part. So, that both things we have to consider. So, here we have drawn only the simple distribution, and then in case of water table if we have to consider, just. And then, if I consider only this negative or positive part and then the total force, that I have already calculated this example in the granular soil.

Similar way we have to calculate that P and then y bar. So, first we will calculate this P here and then y bar from the dredge level. Then these things, other things are known; that means, P A we will calculate, Q bar we will calculate in this way, and c u that is the undrained cohesion; that is the property of the soil. Then all the other things we put in this expression, then we will get a simplified expression in terms of D square. And then when we will solve this expression, then we will get the value of D, from after solving the above expression, d we will get after. So, once you get the D from this above expression, then we will increase it by 20 to 30 percent, because of the factor of safety. So, in this way we can design this cantilever sheet pile in cohesive soil also. In the next class, I will discuss about the design of anchored sheet pile.

Thank you.