Advanced Foundation Engineering
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Lecture - 25
Design of Sheet Piles

Now, today I will discuss about the design of sheet pile, or basically in this lecture, I will explain how to determine the depth of the sheet pile, because this sheet pile is very important structure in geotechnical engineering. This is another type of retaining structure. Now, this structure is very flexible, and the difference between the retaining wall and the sheet pile is, said that the depth of the retaining wall, or the foundation depth of retaining wall, is very less compared to the depth of the sheet pile, because the resistance of this sheet pile is getting from the soil pressure itself, that is why the required depth of the sheet pile is more, as compared to the retaining wall.

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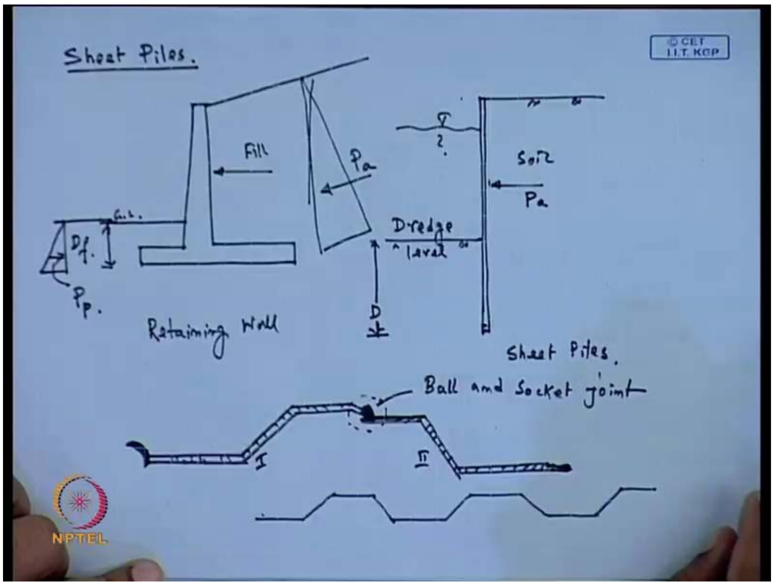

Now for example, if I first, explain that what is sheet pile. Now the basic difference, if this is our retaining structure, so this is one cantilever retaining wall. And this is say the dredge level, or this is the existing ground level, and this is your fill material. Now, here if we consider this is the depth of this retaining wall, and similar type. So, here this portion is void, and this is the soil, exist fill soil. And similar type of retaining wall for the sheet pile if I consider. So, this is the sheet pile, and here the ground surface. Here we can say this is the dredge level. And here if I consider this is the D is the depth of the retaining sheet pile. So, this is the retaining wall, and this is sheet pile. Now here we can see that, this type of structure is very flexible; that is why it is used for this excavation purpose, it is used.

This type of sheet pile can be used in excavation purpose. So, then after the excavation one place is over, then this can be used or this can be taken out from the soil, and this type of sheet pile, can be used for any other location for the excavation purpose, even in for the waters, in offshore structure, or in for retaining the soil near the sea course, that sometimes use this sheet pile. Now, here this is also the soil, and this portion it can be the, this can be the void or this can be the water. So, now, here we can see, that here also the lateral pressure is acting on the retaining wall. Here also lateral pressure is also acting on the retaining wall, and here. So that means, when we are designing the retaining wall tradition and retaining wall, then we consider that this side is active, pressure is acting, and this side this is the passive resistance is acting. So, this side we can say, this is the passive resistance P p, and here, this is the active resistance P a. Now this active pressure is acting from this side, and passive pressure is acting from this side.

So, as during the design also, as the depth of this retaining structure, foundation is very small compared to the height of the retaining wall, then sometimes we neglect this passive resistance, and we design by considering this active resistance only. But here; that means here, this resistance is, this passive force, which is coming from this side, is active force; that is registered by this retaining wall itself; that means, this retaining wall is, if it is a gravity retaining wall, then the size of retaining wall is huge. If it is a cantilever retaining wall, then to resist this moment, this reinforcement is used. So; that means, that that is why the required depth of the retaining wall, is less compared to the sheet pile. Whereas, in sheet pile here also, this lateral force is acting this side, and this side also soil pressure is acting. But here, the force which is coming from this side.

Suppose this is the active pressure is acting this side in here also. The passive pressure is acting this side; that means, the load which is acting from this side; that is resisted by the load, which is or the stress which is active pressure acting from the bottom of the wall. So; that means, the. So, the most of the resistance, this sheet piles is getting from the soil itself. So, that is why, the required depth of the sheet pile is more, as compared to the retaining wall. As the resistance from the soil below this dredge level, the soil resistance is giving the stability of this retaining of this sheet pile wall. So, that is why here, we cannot neglect this passive resistance, because that resistance is not small, as the depth of the sheet pile is more as compared to the retaining wall.

So, that passive resistance, we have to consider in the design. So, now So, first if I consider that, how this sheet piles are joined. Suppose this is our one sheet pile segment, which is joined with another sheet pile segment, similar sheet pile segment, by this ball and socket joint. So, this is your first pile, this is second pile, which is joined in this portion by ball and socket, and then next one is placed here. So; that means, the shape of the sheet pile structure may be in this form. So, this is the plan view of the sheet pile structure. So, that is why, and then this side is the elevation or cross sectional view, and this is the plan view of the sheet pile structure, and then if I take the (()). So, in the design purpose, you consider this is vertical and which is very flexible.

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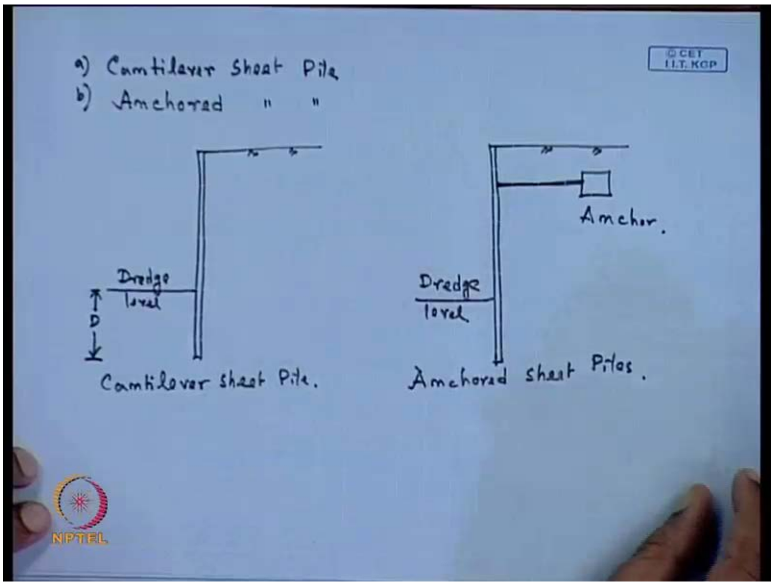

So, next one we can consider the different types of sheet pile. So, that the sheet pile can be; one is cantilever sheet pile, another one is anchored sheet pile. So, this may be the one type of cantilever sheet pile is. Suppose this is the sheet pile structure. This is dredge level, and this is the foundation, or this is the existing ground level. So, you can call this is our cantilever sheet pile. Then another one, this is ground level, where one anchored is attached with the sheet pile, this is anchored sheet pile. Now use of these anchor as for the cantilever sheet pile, the required depth of this is this is the depth of the sheet pile, required depth is more. So, that is why, to sometimes reduce these required depth, this anchors are used in the sheet pile. So, this type of sheet pile is called anchored sheet pile. Sometimes this retaining wall, there is a free cantilever sheet pile also. So, this is the cantilever sheet pile, and sometimes this is free cantilever sheet pile. So, that this portion top portion is free. So, that basically these are the two types of sheet pile; one is cantilever sheet pile, one is anchored sheet pile. In the first, I will discuss about the cantilever sheet pile, then how to determine the depth of this sheet pile, all this things.

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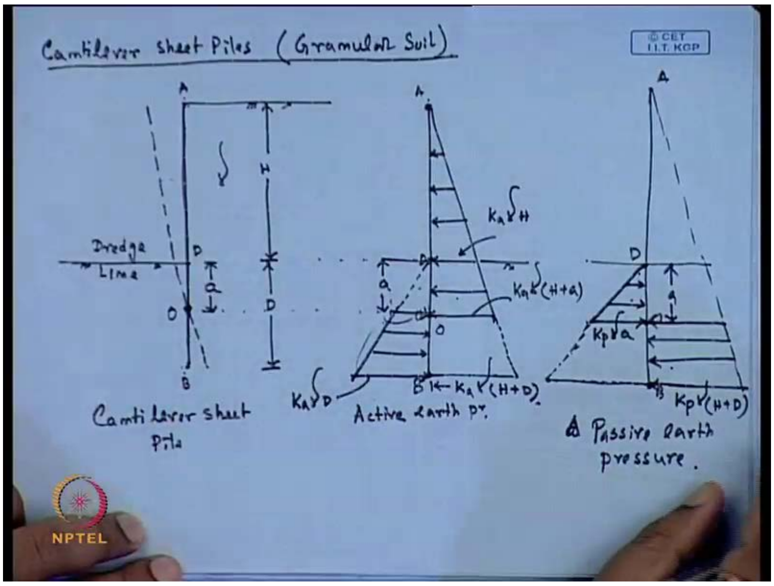

So, first problem, or first discussion with cantilever sheet pile, piles wall with is in granular soil. So, that means, this sheet pile wall can be in the granular soil, it can be in the cohesive soil. So, first we will discuss about the sheet pile is in the granular soil. So, suppose if this is the sheet pile wall, and this is ground surface, and this line is a dredge line. So, this portion is may be in the void, or this is water this side, and soil this side. So, this one is the height of the sheet pile, above the dredge line, and this one is the depth of the sheet pile, which is up to the base of the sheet pile. Now, as mentioned that here this depth of the sheet pile is not negligible one. So, when this, due to application of this lateral force, it will deflect. So, that means, the deflection pattern of this sheet pile, will be something like that. So, that means, rotate it within point below the ground level, so; that means, this is the deflection pattern of the sheet pile.

So, now from this deflection pattern, if we can say this is the a, this distance is a from the dredge level. So, you can see you can say, that up to this point, from the top of the sheet pile, there we have passive, there we have active pressure that will act, and in the this side. So, if I consider the two sides of the retaining wall; one is this side, or this is the right side, this is left side. So, that means, right side, from the top to this point O say. So, this portion active resistance will act, and from this O to the base of this retaining wall, can say if this is A this is B. So, from A to O in the right hand side, active resistance will act, because the active resistance, this is deflection is towards the direction of the force. And from O to B in the right hand side, this passive resistance will act.

So, that from A to O from the right hand side active resistance, and from O to B the passive resistance will act. Similarly, from this left hand side, this side, from D to O this passive resistance will act, and from O to B active resistance will act. So, now if I draw the active pressure diagram. This is the cantilever sheet pile, and if I draw the active pressure diagram, so this is the retaining wall. So, as I have mentioned, this is the sheet pile wall. As I have mentioned that from A to O. So, this is O, this point is D O A, this is base B. So, from A to O the active resistance, active pressure will act. So, this is the active pressure that will act from A to O. So, this value we can calculate, this form that, at this level the active pressure will be K a into gamma into H, if gamma is the unit weight of the soil. Similarly, at this point, because this distance is a, this will be K gamma H plus A. Similarly in this portion, the right hand side here, if I extend this pressure diagram.

So, here also the active pressure will act in the left hand side from O to B. So, this will give us the active pressure. So, the value of this active pressure, if I write this value here, this is K a gamma into H plus D, so this value. But at this point, this is gamma K gamma H plus A. Similarly here this side, this value is K a gamma into D. Now if I draw the passive resistance of this same of passive earth pressure. This is A point, this is same as D point, this O point, this is B point. So, if at this side, this is active resistance. Then, similarly this side, this area that will be passive resistance. So, this is the passive pressure diagram, when this side is active definitely the opposite side will be passive. So, this is the passive resistance. So, this value is K p into gamma into a, because this value is a, where K a is the coefficient of active earth pressure, K p is the coefficient of passive earth pressure.

And similarly if we extend this value, had extend this line, this will be in this form. Similarly, when this side is active; that means, definitely this portion will be passive. So, now, if we extend, so this portion will be passive. So, this value is K p gamma into H plus D. So, now this is the net diagram, is that, this is active from A to O, the right hand side. Similarly in the opposite direction, because this portion is void or so that soil is not present here. So, the passive resistance will act from this point to D to O, so the D to O is the passive, opposite to this portion. Here, this is active from O to B, and definitely passive will be in other hand side, this is passive. Now this is the passive and active pressure diagram for this cantilever retaining wall based on from this deflection and also we can see.

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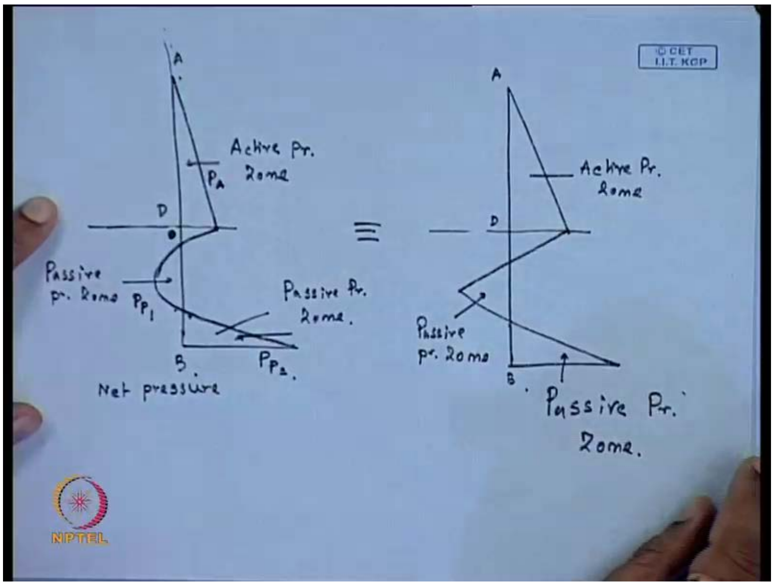

Now, if we draw the net pressure diagram, considering the active and the passive. So, this is retaining wall. So, this is the dredge line O, this is A, sorry this is D A and B. So, we can draw, this will be the net pressure diagram, because we can see from this figure, that here this is passive, and this side is active, as the net pressure; that means, the passive minus active, as passive pressure is more compare to the active pressure. So, this side, the pressure, net pressure diagram, this side the pressure will exist. And similarly here; that means, up to this point, here active pressure is increasing, and then up to this point there will be active pressure. So, this is the line straight forward we can draw. After that the net pressure diagrams, means this active and the passive both will act. So, that means, when this will start going from right to left, and that means, when this pressure, active pressure and then the passive pressure, if I take the name. So, at that point where this line will cross this sheet pile; that means, from here it will start, and then it will go this side and cross this diagram, and then again it will cross, so two portion it will cross.

So; that means, the final diagram if I draw, so this is up to this point is active, then the net pressure diagram, this passive will start acting. Then it will go this side, then again the passive force is more in this portion, then it will go this side, and then it will follow this pattern. So, this will be the net pressure diagram. So, here we can see this is active pressure zone, this portion is passive pressure zone. Again this portion is passive pressure zone. So, from this figure we can see, so this is active pressure zone, then again this portion is more this is passive force, passive pressure zone. And then it will go in this side, so this passive force will act, so this is also passive pressure zone. So, there is a three parts; one is active pressure zone, then passive pressure zone, then again passive pressure zone. So, that means, this forces that will act P A P p 1, and then another force that will act P p 2.

Now during the analysis. So, this is the actual net pressure diagram in cantilever sheet pile wall. Now, during the analysis, if we consider this pressure, this type of pressure diagram, then it is slightly complicated. Now to simplify this things, we can consider one passive pressure, one net pressure diagram, or this net pressure diagram, where same sheet pile if I consider A D and this is B. Then this portion as it is active pressure zone, then instead of taking this circle or non-linear, this non-linear variation, or the. Then we consider, we take one linear type of variation. So, the same net pressure diagram is representing in this form, where which is in same two points is crossing, but it is in linear form. So, that means, here also this is, active pressure zone, this is passive pressure zone, and this is also passive pressure zone. So, these are the net pressure diagram. So, this is the converted net pressure diagram. Now based on this net pressure diagram, we will do the analysis.

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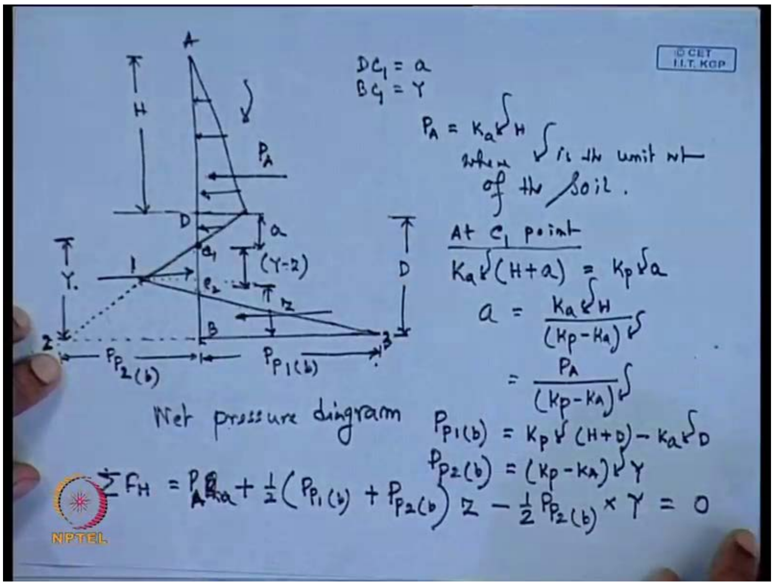

Now, if we start this, draw the net pressure diagram again. This is dredge line. So, this is the net pressure diagram. So, we can see that this force is acting this side. So, this P A is active force will act in this side. Now here, so further simplify what we will do. We will extend this line, and you consider that this is P p 1 and this is P p 1, this is 2, or we can say suffix B, because this is acting at B. Now, this distance is A from the base line, where this is passing first crossing this sheet pile, this diagram. So, this is A, now we consider this distance is Y, capital Y. And this one is this is y 1, y and this is a Z, so this one is y minus z. So, this distance, where this is point one point. So, this is a this point is, this is B, this is C 1, and this is the C 2. So, D 2 C 1 is a B 2 B 2, this point where the edge of this triangle is Z and then this one is y minus z, so total from C 1 to b is. So, we can write the D to C 1 is equal to A, then B to C 1 is equal to y, and this H point from the B point is Z.

So, now if I write this expression this is P A, P A will be K a, because this distance say height is H, and total is the depth is the, D is the depth of the sheet pile below the dredge line. So, this P A is K a into gamma into H. So, if this gamma is the unit weight of the soil, where gamma is the soil, and K is the coefficient of active earth pressure. Now, this point at this C 1 point, point that net pressure is 0; that means, the active pressure is equal to the passive pressure. Now if I write in this form; that at C 1 point what will be the active pressure. At C 1 point the active pressure will be K a gamma in to H plus a, because at C 1 point is active pressure is equal to passive pressure, because at C 1 point is, because this is net pressure diagram.

So, that means, at this point active pressure will be H plus a into gamma into K a; that is equal to the passive pressure, which is K p gamma into small a, because this is the passive and active pressure. So, now, if I draw the previous figure; that means, at this point, that this point, any point, the active pressure is equal to passive pressure. So, passive pressure at this point is K p gamma into a, and active pressure will be K p gamma K a gamma into H plus a. So, if we equate this two, because at this point this passive pressure and active pressure, this is equal to, this is equal; that means, net pressure is 0. So, if I simplify this thing, a value will be K a gamma H divided by K p minus K a into gamma. So, K a H K p K a gamma is that is equation to P A divided by K p minus K a into gamma. So, we will get first, now we will get the a value. Now, next one we will determine this P b 1 P p 1 b. Now this P p 1 b this value, that will be the net pressure that this P p 1 b; that is K p gamma H plus D minus K a gamma D. So, we can see from this figure; that at this point the passive force is K p gamma H plus D, and here the active force is K p gamma into D.

So, if we take the net, then this will be K p gamma H plus D minus K a gamma D. So, this is K p gamma H plus D minus K a gamma D. So, this is the net pressure diagram for this P p 1 b. Similarly P p 2 b, that is equal to. Because that a this P A into K p minus K a into gamma. So, we can write this value, that P p b, that will be K p minus K a into gamma into y. So, this is y the net pressure is K p minus K into gamma into y. So, this is the net pressure for this P p b 2. Now, we will start to calculate the forces F H. What is F H, because what are the forces those are acting here. So, now if I consider this things in three parts, that this is the P A, is the net pressure, this is the total pressure for this portion; that means, from A D C 1, this total pressure is acting as a P A. And then if I consider this triangle, this triangle this is say 1 2 3. So, if I consider 1 2 3 triangle, and subtract from this triangle C 1 2 and b.

Then ultimately; that means, you have first considering this total triangle, then we are subtracting this triangle C 1 2 b, then what will happen this portion will be cancelled out, so this thing minus this thing; that means, this are acting opposite direction, because this force is acting this side, and this force is acting this side. So, these are the three forces for one for this portion lower portion, one for this triangle middle triangle, one for lower triangle which is acting this side, one for the middle triangle, which is acting opposite side, and one for the upper portion. Now, what we are doing that, we are taking this triangle 1 2 3, and then subtracting from this 1 2 3 triangle, forces with C 1 2 and b. So, ultimately this portion is cancelled out, and this is acting opposite direction. So, now if I do in this form, then F H will be R A, then this triangle plus half into P p 1 b plus P p 2 b into this Z. Z is the height of this triangle 1 2 3 into Z, then subtracting this other triangle, so that height is y half into base is P p 2 b into y. So, that forces will be 0, for the equilibrium these forces will be 0.

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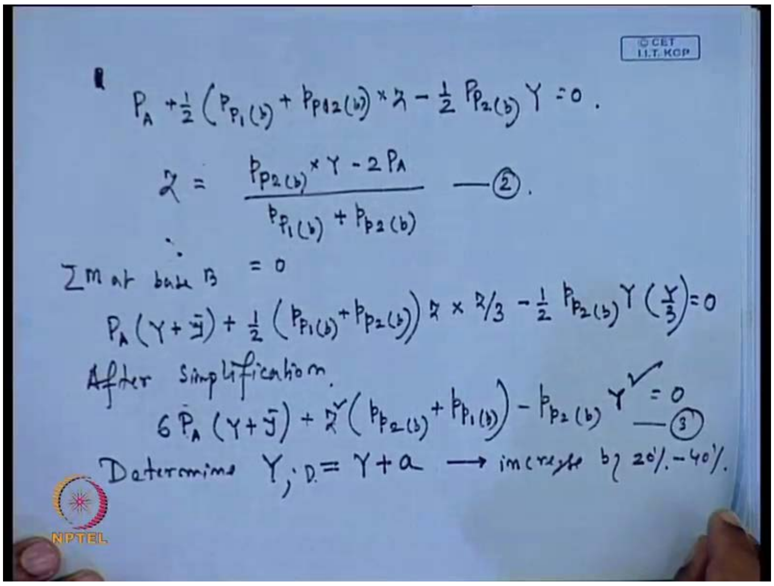

So, now from this forces. So, if I write that again that is R A, or we can write this force, this is P A, P A, because here this is P A. So, you can write this is P A plus P p 2 b plus this triangle. This P A is the total force for this upper portion. Now, we can write, if I write this expression again P A plus half P p 1 b plus P p 2 b into Z minus half P p 2 b into y, this is equal to 0. So, now from this expression we can write, Z will be P p 2 b into y, P p 2 b into y minus 2 P A divided by P p 1 b plus P p 2 b. So, from this expression we can also calculate the Z. Now we will take the moment, at base capital B, that is also equal to 0. Now, if I take the moment, and we can say that from this center point, from this point C 1, the distance of these forces, that is acting at the top portion is y bar. So, that distance is, from the C 1, where the net pressure is 0. So, that from the C 1 point, this force P a is acting at a distance y bar, so that we can easily determine, and this is the capital Y.

So, from the base b, the distance of P A in b capital Y plus small y bar. So, and so you can write this P A, if you take the moment into capital Y plus small y bar, plus for the first angle; that is half into P p 1 b plus P p 2 b into Z; that is the area, into that will act as the distance Z by 3 from the base. Then minus, the area for the mixed angle is half into P p to b into y, and that will act y by 3 from the base. So, that is equal to 0. So, ultimately after simplifying, so after simplification we can write 6 P A into capital Y plus y bar plus Z square P p 2 b plus P p 1 b minus P p 2 b y square, that is equal to 0. So, in this expression what are the unknowns, that unknowns is Z, that will get from this expression, and then P p 2 b P p 1 b this will calculate, and P will calculate, and then y that will also calculate, and ultimately we will determine the value of y. So, from this expression, we will determine capital Y, then if we add a, then D will be capital Y plus a.

So, we have to calculate capital Y from this final expression, last expression. Then if we add the a, the a calculation that we will do from this expression number one. So, now, if I give the M, this is number one. From here we can determine a, then this is equation number two. From here you will determine z, this is equation number three. From here we will determine the capital Y. So; that means, and this Z we will put here, so D we will get capital Y plus a. Now once we get this things, then we have to increase day D by 20 to 40 percent for give a additional factor of safety. For this factor of safety purpose, you have to increase this D by 20 to 40 percent that is a factor of safety. Now, this fashion will get the depth of sheet pile, based on this calculation, from this three expression, and this is for the sandy soil.

Now for the clay soil, what we will do, that if the same thing we calculate for the cohesive soil, that where phi u equal to 0, and same sheet pile. This is ground level. This dredge level. So, now for the cohesive soil, so this will be the pressure diagram for the cohesive soil. So, this is minus, this is plus, and from here we will get this type of pressure diagram. So now, why you will get this type of pressure diagram. First we will explain this is H, this one is D, D this is the depth of the sheet pile.

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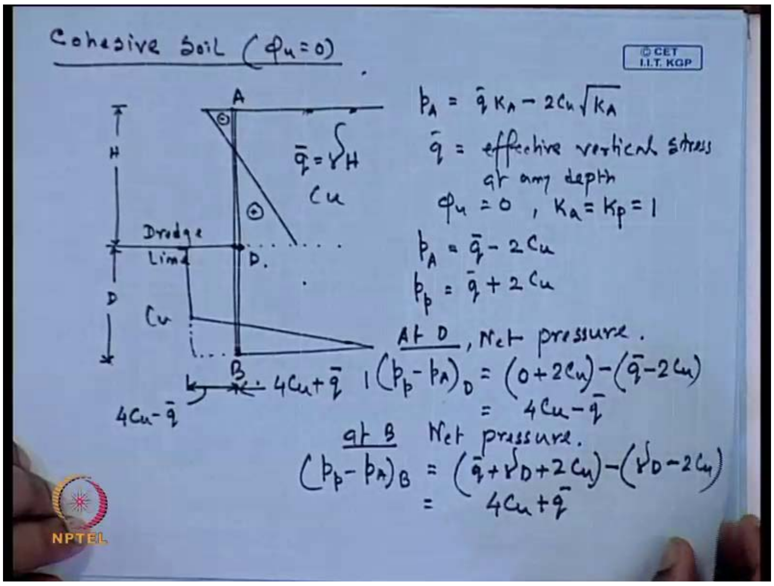

Now, here first expression of P A; that is equal to q bar into K a minus 2 Cu root K a. So, q into K a minus 2 Cu into root K a, K a is the coefficient of active earth pressure. Now where q bar is equal to effective vertical stress at any depth, and here phi u is 0, so your K a that is equal to K p, that will be equal to 1, as phi u equal to 0 for this expression, so K a equal to K p that will be 1.

Now, we can write that P A; that is equal to q bar minus 2 Cu, where Cu is the undrained cohesion of the soil. And P p that will be q bar plus 2 Cu, so P A will be q bar minus 2 Cu P p will be q bar plus 2 Cu. So, now at e point, or at say D point this is A D and this is B. So, at D your passive, the net force, net pressure, the net pressure will be that P p minus P A at D; that will be P p, because at this. Here the P p that passive resistance that will act in this side, and active will act in this side. So, but at this point, at this D point, if I consider the passive, that q is 0, because in this side, this is, it is no soil, so q u we can consider this is 0. So, at this side, this is 0 plus 2 Cu minus q bar. This is the q bar will be, this q bar is gamma H. The gamma is the unit weight of the soil, q bar minus 2 Cu, if it is a same soil, Cu is here also, and Cu is also here.

So, that net force that is 4 Cu minus q bar. So, at this point, this value is 4 Cu minus q bar. Similarly, at B point the net pressure is P p minus P A at B, that will be equal to. So, at this point B, here this side, at right hand side there will be passive pressure, and the left hand side there will be active pressure, because at this point this right hand side is active pressure, and left hand side is passive pressure, but at the base right hand side is passive pressure, and left hand side is active pressure. So, passive pressure if you write that is q bar, plus this load; that is gamma into D plus 2 Cu, this is minus, then this q bar will be gamma into D into minus 2 Cu. So, now net pressure will be 4 Cu plus q bar. So, this value is 4 Cu plus q bar.

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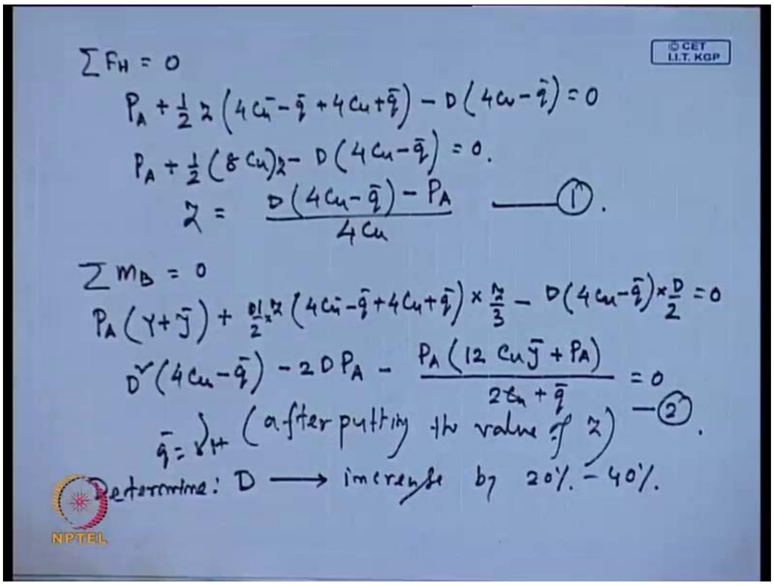

So, again we have to take the forces so; that means, if I take this F H, summation of the force, and we can write that this force is P A at total active force, and which is acting at a distance y bar from the D point. Similarly, we can write that this distance is Z; that means, where this is taking a, this distance is this. So, what we are doing by taking this force, this force is acting, so there is another force is acting this side, and another force is acting this side. So, we are taking adding this force, and then adding the force of this triangle, then you are subtracting this force, which is acting opposite direction. So, ultimately this portion will be cancelled out. So, in this way, so if H we can write; this is F H is 0 this is P A total force of the upper portion plus half into Z into half into Z; that means, this triangle half into Z into 4 Cu minus q plus 4 C u plus q bar.

So, we can write this is 4 Cu minus q bar plus 4 Cu plus q bar, then minus D is the depth into 4 Cu minus q bar is equal to 0, and 4 Cu means this D, then for this rectangle this portion is 4 Cu minus q bar into D; that is the area. So, from this upper portion force, plus this triangular force, when minus this rectangular force. Then ultimately we can write this is P A plus half into 8 Cu minus D into 4 Cu minus q bar that is equal to 0. So, Z will be D into 4 Cu minus q bar minus P A that is divided by 4 Cu. So, this is one expression one, from which we can determine the Z value. Now, next one, we will take the moment with respect to this B; that is also 0. So, moment that will be P A into capital Y plus y bar, then minus that D is half this triangular 1 plus; that is Z half into Z, and this one will be here also, this is Z we missed that Z 1, this is half 8 Cu into Z Z with Z then we can determine the Z from this expression. So, half into Z into again 4 Cu minus q bar plus 4 Cu plus q bar and that will act at a distance Z by 3 from the base B. Then minus this D into 4 Cu minus q bar, and that will act distance D by 2 from the base, because this is the rectangle, that is equal to 0.

So, after simplifying this we will get D square 4 Cu minus q bar minus 2 D P A; that is minus P A 12 Cu y bar plus P A into 2 Cu plus q bar that is equal to 0. So, after putting the value of Z here, so this is expression two. So, this is the final expression, so where this Z value is replaced by this expression one. So, we put the Z value in this expression, and then after simplifying this, we will get this final expression. So, from, again this q bar is equal to gamma into H. Now, again from this final expression, expression two we will determine the value of D, and then increase, we determine the value of D, and then increase it by 20 percent to 40 percent for the factor of safety. So, these are the two, this is the determination of the depth of the sheet pile for two different cases, for cantilever sheet pile; one is for the granular soil, one is for the clay soil cohesive soil. So, next class I will solve few example, and then we will find how to determine the depth of this sheet pile wall for different soil condition, need for the cantilever sheet pile. Then later on, I will discuss about how to determine the depth of the anchored sheet pile also.

Thank you.