Advanced Foundation Engineering
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Lecture - 28
Design of Sheet Piles (Contd.)

In the last class, I have discussed about this sheet pile design. So, I have discussed of cantilever sheet pile. Now I was discussing about this anchored sheet pile. And the fixed support method that I was discussing.

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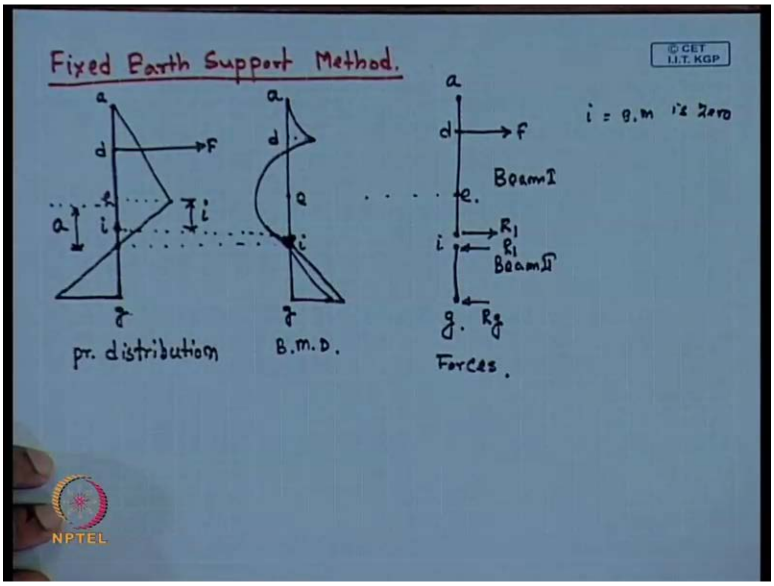

Now in the fixed support method or fixed earth support method that is discussed here; actually the proposed earth pressure distribution that was taken here. And then that was simplified; and we consider two different beam during the design, that means, this was the simplified form of earth pressure distribution. So, if this is sheet pile; this was the simplified earth pressure distribution; this is the position of the anchor f; this is, a is the top; d is the position of the anchor; e is the dredge level; i is the point of, point of fiction where moment is 0; and g is the point where this force is, this stress is maximum.

So, these are the assumed, these were the simplified earth pressure distribution that was considered. So, these things were discussed in last class. So, now here, if I draw the bending moment diagram of this portion; then this is the, here it is maximum; then at i point this value is 0; then this will follow this path.

So, this is the g; again this i point; this is e point; and this portion, this is where it is maximum d point; this is a point. So, this is the pressure distribution; and this is BMD. Then two different beams were considered: one from a to i, this is a to i; this is the same e point; and this is same d point where the force f is acting, this f is the anchor force. And another one is from i to g.

So, this is beam 1; and this is beam 2. Now, what are the forces which are acting here? That is the reaction force R 1 is acting; the same force in opposite direction R 1 is acting in beam 2; and then R g is acting in the g point. So, this R g is the reaction for at g point; R 1 is the reaction force at the g i point for the beam 2; then R 1 is the reaction of the i point in for beam 1; and f is the anchor force. So, these are the forces.

Now we have to start design of this method. Now one thing that we can notice, that here these value where this is, this point is 0, sorry this is the i point where bending moment is 0. So, this will be the i point. So, this is i point, not this one. So, this point is where value is a, and the i point is the point where minimum it is 0. And then this distance is a, where the stress is 0 from the dredge level; and i is the point where B M D is 0 from the dredge level. So, i is the point where bending moment is 0.

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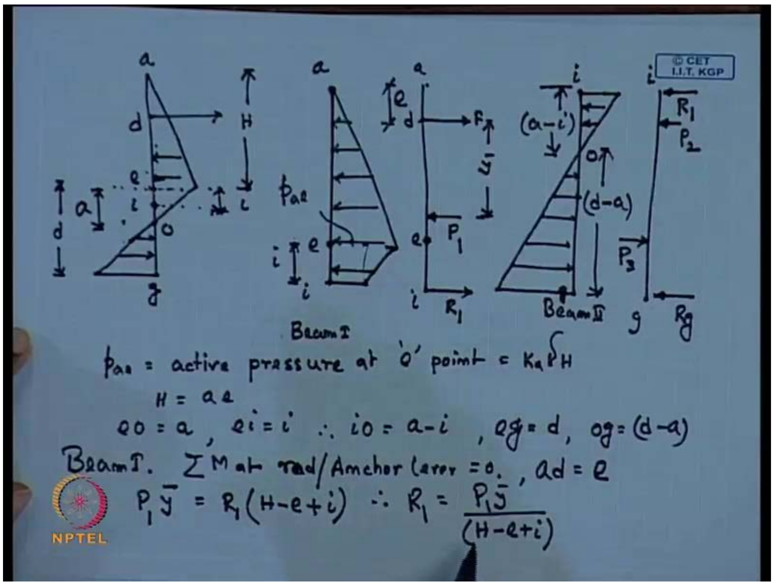

So now, if I consider these two things, and then we simplified how to calculate this forces. Then first, if I take that this is our again if I consider the that same distribution, that is this is dredge level; then this is the diagram g; this is may be the i point; this is e point; this is the anchored force is acting d point; this is a point. The same force diagram we are considering here. The forces are acting is in this direction; here it is acting in this direction. Now if this distance of stress is 0, this, then this is a; and this i point from the dredge level is say i, distance of the i point from the dredge level is i.

Now, so, if I take two beams, then we have this is our first beam, this is beam 1, and this is from a to i. And that beam if I draw the diagram, so, this is the dredged level is here say, this is say e point; and then this lower part portion. So, this is the pressure distribution diagram for beam 1, from a to i. And what are the forces is acting here? So, one is force which is f acting at d point, this is a; this is e; this is i; this is f. Then the reaction force is acting here R 1; then the p force which is the force due to this pressure is acting here; this is P 1. So, these are the forces which is act, this P 1 is the external force which is acting.

Say this P 1 is at a distance of y bar from d point. Now this P 1 can be calculated. The P 1 is the total force acting due to this zone, from a to i. So, we can divide it, one triangle then another triangle, here in this one rectangle; and then we can calculate, what are the forces here? So, this p a e is a, suppose this portion p a e, so, p a e is equal to active pressure, at e level or e point. So, that we can determine, so, for this one this will be the p a e will be K a into gamma into H, if H is the height of this point i, point e from the a, so H is equal to a e, distance. Then, this is i point; and these are the forces.

Now for similarly for beam 2, which is i to g, where the force diagram is, this i to g; so, this small portion and this one; so this is a small portion and this one. So, here forces are acting this direction; here forces are acting in this direction. So, now if, consider the forces which is acting for this i to g, then this is a reaction force R g is acting; this is the same R 1 is acting opposite direction; and then this P 2 that will act for the small portion, stress, this P 2; and here for this one another force P 3 will act. So, these are the pressure distribution and forces in beam 1 and beam 2.

Now, we have to determine the values of these forces. Suppose this distance is from here to 0 point is a; e to this point, suppose this is o, similarly this is also o, so, e to o is that means, e o is equal to a; and e i is equal to i; then you can write that i o is equal to a minus i. So, this distance is a minus i. Similarly, total distance if I consider that from e to g is d, that e to g that is equal to d; and this d, so we can write that this total one e to d is g; and this e to o, e to o is a. So, you write o to g is equal to d minus a, so this distance also d minus a.

Now, what are the forces that will act? So, first if I consider that beam 1, consider this beam 1, and taking the moment at anchor level or odd level that is equal to 0. So, if I consider in that form, then we can write that P 1 into y bar that is equal to R 1 into H. And if this distance from e a to d is e, so this distance a to d that is equal to e. So; that means, this distance total one is, from upto e point, it is H minus e, H minus e then e to i, e to i is i, so plus i. So, we can write that R 1 value is P 1 into y bar divided by H minus e plus i. So, we can write this is this R 1 is P y bar h minus e plus i. Now, here if P is known; P 1 is known; y bar is known; H is known; e is known because the, we know the position of this anchor; but i is unknown. So, how to calculate the i? So, that first we will decide. So, to calculate the i we have to take the help of one graph.

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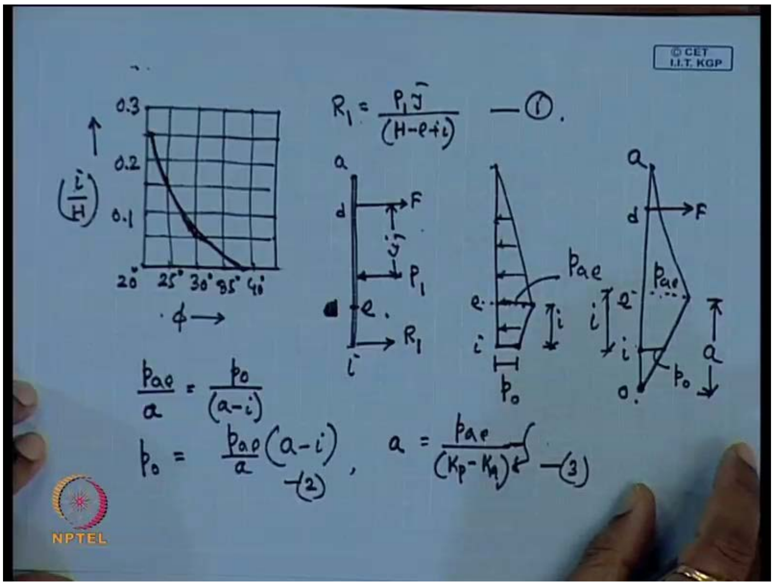

So, that graph you can draw here. So, this is 20 degree; this is 25 degree; this is 30 degree; this is 35 degree; and this is 40 degree. Similarly, this is 0.1; this is 0.2; this is 0.3. Now in this axis, this is phi is in this direction; and i by H is in this direction. Now this, if I draw the graph, this will be the graph. So here, if I know the value of phi, if I know the value of h, then from this graph we can determine the i. So any problem, where phi value is known for a particular site; H is also known. So, we can determine this i value. So, that means, the expression that we have derived that R 1 is equal to P 1 into y bar divided by H minus e plus i. So, in this expression, now i is known from this graph; then e is known; H is known, so we can determine R 1. So, that is known.

So, now from this beam 1, so that means, what are the forces that is, so, this is the beam 1. Again if I draw, this is the F force acting at the d level; this is a; and then the P that will act for this external pressure; so this is y bar; this is P 1 and then will act this R 1. So, here this R 1 is known; P is known; now this f we have to determine. So, from this expression we will get the R 1; P 1 is known; we will get the distribution.

Now, so this way, what will be the pressure? Similarly if I draw the pressure distribution diagram of this beam 1. So, at this point; this is the diagram; so, this is d may be in this; e point is this one; and this is i point, so at e point. So, this is the diagram. So, as I have discussed that at the e point, this is p a e; similarly this value at the i point we can determine that is p 0. So, now, we can determine p 0, linearly interpolating this value that is p a e divided by i, so, this is, this is p a e this is divided by total a, that is equal to p 0 divided by a minus i.

Because the total distribution, if we see this is up to i distance. So, now, if I draw the total distribution, this is e point. So, this will go up to here, so, at this point this is p 0, at i point. So, this is the point where the stress is 0, that is o point. So, this is e point; this is d point; and this is a point. So, now, if I linearly interpolate this thing, this is p a e. So, p a e this total distance is a; and this upto i is i. So, p a e divided by a, that is equal to p 0 divided by a minus i.

So, from this expression we can determine p 0 value is, p a e divided by a, into a minus one i. So, for this expression p 0 is also known. So, once we get this i value. So, what we have to do? That our p a e is known; then a is known; and how you will calculate this a? a is simply that expression p a e into divided by K P minus K a into gamma. So, that thing is, that thing we have already discussed, that we can determine this point, where the distance of the point where, the stress value is 0 from the dredge level that is a. So, that that a, we can determine this p a e, the active pressure at dredge level divided by difference of two coefficient of the earth pressure in passive earth pressure minus active earth pressure into gamma.

So; that means, from this expression the a, we can determine if I put this a; and if I determine this value of i from this graph. So, we will determine the i from this graph;

then we use, by determine the a value from this expression. So, all the quantities on the right side are known. So, we will get this a value; we will get i value from this graph. So, we will put these things in this expression, we will get the p 0 value.

So; that means, this is our expression 2; this is our expression 3. So, we will from this expression 2, we will get the p 0 value. Once we get the p 0 value, then we can determine, what is the total force P 1 is acting, due to this pressure diagram. So, then we can determine the P 1 as well as the y bar. So, once we get the P 1 and y bar, then from equation 1 we can determine the R 1. So, now these are the values that we know. So, from this when you go for the second beam, that R 1 should be required, because R 1 will act this in the second beam also, as a reaction force.

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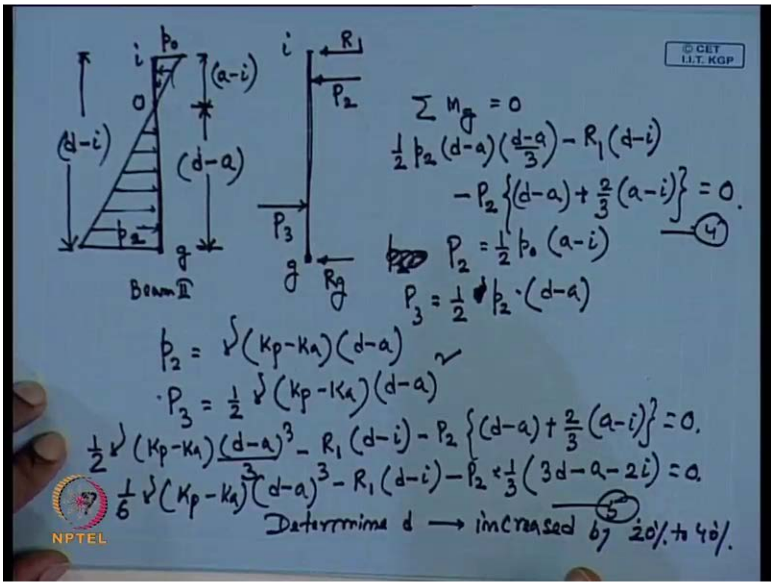

So, now in the second beam R 1 and p 0 will be required. So now, if I go for the second beam, so this is the second beam or beam 2. So, this is the expression; this is p 0 at i point; this is o point; and this is g point; this is a p 2 or stress. So, now, forces that is acting in this beam that is R g reaction force; similarly R 1, is coming from the top beam 1; and then the P 3 total force; and then the P 2 for this triangle, small triangle; and this is P 3 for this bigger triangle.

So, this will act in this direction; and this stresses will act in this direction. So, distance is here, as I have mentioned, that is a minus i; and this distance from o to g is d minus a.

So, now, for the second beam, if I write the expression that moment at g level is 0, if i take the moment at the g level that is 0.

So, now if I take the moment then the p 3 value is the area of this triangle; that means, half into p 2 into d minus a; and that will act a distance of d by, d minus a by 3, this is also d minus a divided by 3. So, that is equal to minus R 1 into d minus I, because the total one for the beam 2 is d minus i. So, this is d minus i; then minus P 2 this is the force. So, that is acting the distance of d minus a; then plus 2 third of a minus i. So, that is equal to 0; so two-third of a minus i of this small triangle.

Now, from this expression your d is unknown, which is I have to calculate; a is known then; R 1 is known from the expression 1; then i is known. So, P 2, we can determine, the P 2 value, the stress P 2 we can determine that, if this is P 0 and the stress P 2 from this two similar triangle we can determine that, P 2 force, I mean this value we can determine that capital P 2, this P 2, capital P 2 is equal to half into p 0 into a minus i; so half into P 0 into a minus i.

Similarly, P 3, capital P 3 is equal to half into gamma into small p 2 into, small p 2, half into small p 2 into d minus a; half into small p 2 is this value. Now small p 2 is gamma, in this value is gamma into k p minus k a into d minus a. So, that this value, how to calculate small p 2 that is also been discussed in the previous classes.

So, that is gamma of this level into difference of the two coefficient into that height d minus a. So, if I put this value the capital P 3 value is half into gamma into k p minus k a into, d a, d minus a whole square. So, in the this previous expression number 4, if I put this value in expression 4, then there is value is half into gamma into k p minus k a into d minus a to the power 3 divided by 3, minus R 1 into d minus i minus P 2 into d minus a plus 2 third of a minus i, so that is equal to 0.

So, this expression we will get, by putting all this value in expression 4, and final expression that we will get, that 1 by 6 gamma k p minus k a into d minus a to the power cube minus R 1 d minus i minus P 2 into 1 third into 3 d minus a minus 2 i that is equal to 0.

So, then we will get this final 5 th expression. So, in this expression were only unknown is t; because i is known from the graph; a is known from the expression; then P 2 is known from this expression, capital P 2; where p 0 is known; a is known; i is known; then R 1 is known from the previous beam 1; i is known. So, all this expression in this, all the parameters are known except this d. So, by using expression 5 we determine this d value; so using expression 5 determine the d value. So, determine d value, then increase it by 40 percent to 20 percent. So, we will increase this d value by 20 to 40 percent. So, now this depth, required depth we have calculated. Now, we have to calculate the forces which is acting here.

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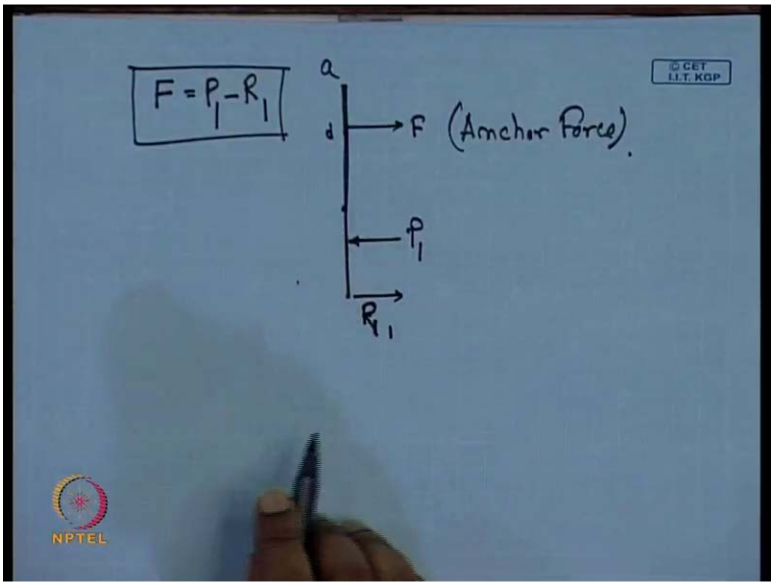

So, the F forces, F from this beam 1 we can determine, if I see the beam one; so, this is our d position which is F for anchor force; this is a position; this is the F 1 or R 1 position; and this is the force P 1 with act. So, F we can determine is equal to P 1 minus R 1. So, from this P 1 is known that is the forces; and R 1 we can determine by equation 1. So, once we get this value we can, so, 1 is R 1 is known; P 1 is known; then we can determine the F force also. And we can determine by using the expression 5, we can determine the depth required for this sheet pile. So, these are the two different methods: one is free earth support method, another is fixed earth support method. So, with these two method, we can determine the required depth of the sheet pile.

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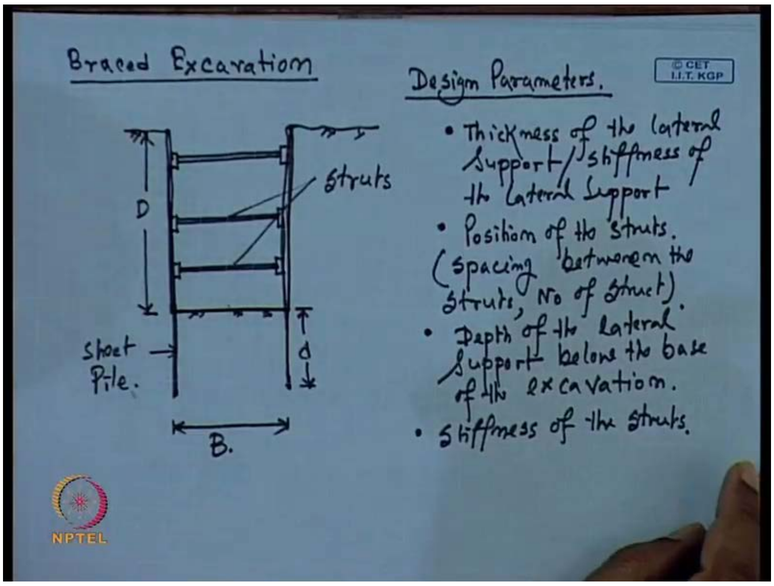

So, in the next section, that I will discuss that, one another important thing, that is our braced excavation. By using these sheet piles, we can construct one very important geotechnical structure that is our base excavation. So, these type of base excavation is required for the excavation purpose, or a deep excavation purpose. Where these lateral support are provided by sheet pile, and in between the sheet pile we can provide some additional component, that is called start to give additional support to the system.

Now, what you see base excavation? Suppose if we have one excavation level in this form; this is a existing round level, and here this is the bottom of the excavated area. So, this portion is excavated where soil is taken out. So, now, for this lateral support we can provide the sheet pile here, for this base square, base excavation. So, we can provide the sheet pile; we can provide the sheet pile this side also; and this is the existing, this is the ground base excavation, ground excavated. And then in this area we can provide a lateral support or that is this horizontal components.

So, depending upon the depth of these excavation areas, we can determine how, what is a number of this horizontal support will be required. So, these type of, this is the sheet pile; these components are called compressive member or this is called struts. So, these struts are providing additional support to this sheet piles. So, that they can sustain or they can take the load laterally which is coming from this two sides.

So, now what are the things that we have to determine, during the design of this base excavation? One thing that is very important, that first we have to decide the depth of the excavated area. So, this is suppose the depth of the excavation; this is the width of the excavation. So, now, the very important 4 parameters that we have to, so, these things this is the width of the excavation B width; D is the depth.

So, these things, suppose these D and B are fixed before the design; so; that means, we have to provide these B and we have to provide this D, that is fixed. Now what are the very important things or design parameters? So, design parameter we can say, that what would be the thickness of the sheet pile? That is the thickness of the sheet pile, so that means, what is the thickness of the sheet pile or support lateral, I should say that what is the thickness of the lateral support; that means, based on these thickness or what is the stiffness of this lateral support, or the stiffness. So, this is one design parameter.

Another design parameter, the position of this strut; so where we will place this strut; what is the spacing between two struts. So, this is the another very important design parameters. So, these are the design parameters we can say; so that means, the position of the strut, position means the spacing; then the number of strut. So, these are the very important another design parameter.

The next one is, this depth of the lateral support, below the base of the excavation. So that means, the small d below the base excavation; and another one is the stiffness of the struts. So, these are the things we have to decide before the, during the design. So that means, what would be the position of the struts? What is the spacing between two struts? What would be the number of the struts? So, that depends upon that this depth d. Depending upon this d, what would be the, we can design the number of struts; we can design the spacing of this, between the struts.

Then the next one is the, what would be the thickness or stiffness of the this lateral support? What would be the stiffness of these struts? And what would be the depth of this lateral support below the base of the excavation? So, these things we have to decide when during the design of this excavation.

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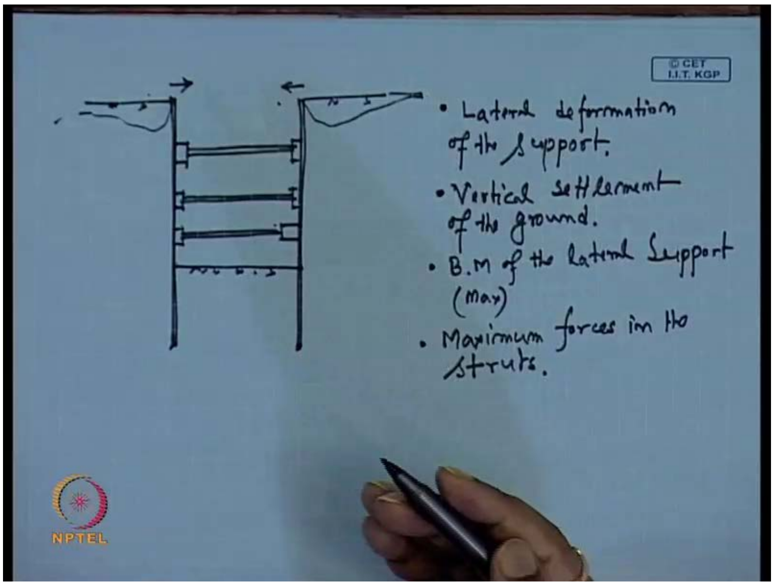

Now, what is the basis of, on what basis we can decide these parameters? So, one thing is that, when we are talking about this base excavation, suppose if I draw the same figure here. So, if I draw this same figure here, this is the strut. So, now, the thing is that we have to observe that should be within permissible limit that this support will reflect. So, there is a lateral deformation of the support. So, lateral deformation. So, that should be within permissible limit; that means, we cannot provide the huge lateral deformation of this system, that should be within permissible limit. So, these things we have to check.

So, then next one is, due to this lateral deformation or this thing this ground surface will deform; in this pattern this ground surface will deform. So, vertical deformation of the ground; so, we will get this type of ground surface deformation. So, this ground surface deformation or vertical settlement of the ground; vertical deformation of the ground and that is also important because if there is an existing structure is there. So, we have to design this system such that, there is no such influence of this excavation on that existing structure; then there should not be any deformations.

So, for that this lateral support, lateral deformation of the support, then ground surface deformation, these are very important things. So, that we have to taken care, during the design. The next one, what is the B M - Bending moment of the lateral support. So, we will choose this section; then, what is the maximum bending moment of this lateral support?

Then, what is the maximum force or forces in the strut? So, strut will be subjected when these two wall is deforming in this direction; now this is also deforming this direction. So, this will give a compressible load, or force to this struts so; that means, this maximum force in the strut. So, these things we have to check during this design; that means, there should not be a huge lateral deformation; that lateral deformation of the support should be within permissible limit; vertical settlement of the ground within permissible limit; the maximum bending moment what will be the maximum bending moment of this lateral support; then what is the maximum struts of this forces acting in the strut.

So, these things we have to take check during the design; and based on that we have to design we have to decide those design parameters; that means, the what will be the stiffness or thickness of lateral support? Then the position of the struts; and depth of the lateral support, below the base of the excavation; then stiffness of these struts; and then of course, the, this is the section of any base excavation.

So, there is, if I draw this, another view. So, this side this another, so, this struts are provided certain interval. So, that interval one is as vertical space in between the two strut; another is that, where this is continuous, where this struts are not continuous. So, these are placed with certain interval in the longitudinal direction also. So, this is the spacing between, in the vertical spacing and another is the horizontal spacing between the this struts. So, that that thing we have to also taken care, during the design. So, now, these are the design things that we have to decide. Now for this simplified analysis of this type of system.

So, now we have to go for the rigorous analysis. We are taking all these parameters during the design; and then we first we have to check every time that, if I consider this type of configuration; then what will be the our design, design steps. So, what will be the our settlement, in the lateral direction, in the vertical direction. So, every time we have to check all this things.

So now, then our aim of the design is that, you should design at the systems such that, that the lateral deformations should be minimum; the vertical settlement should be minimum; and maximum bending moment is minima can be minimize; that strut force is also can be minimized. So, all this things we can minimize. So, that, that is our design should be a economical one.

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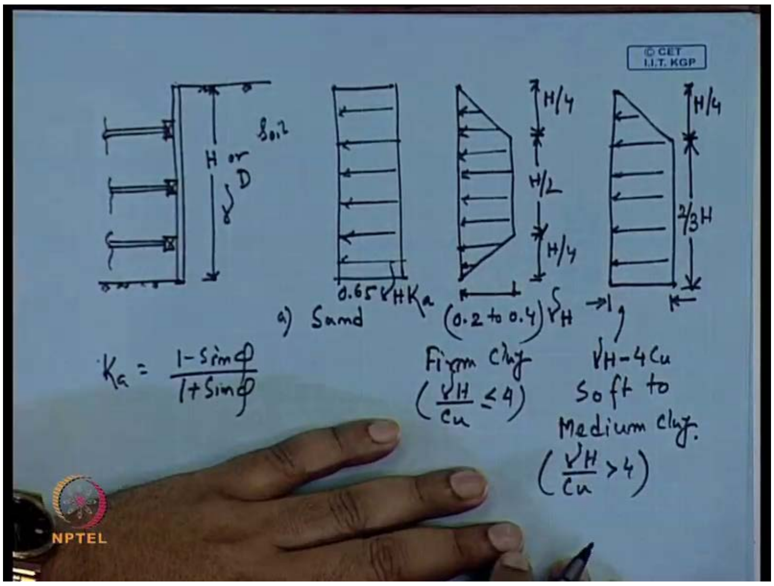

So now, for this one, first we will discuss simplified method, of reading this design. Suppose if this is our lateral support; and this is base excavation; then this is our sheet pile; and these are the struts. So, we are taking the half portion of this thing. So, then this is the base of the excavated ground; and we consider this value is H or d.

Now, for this different types of soil condition, we can draw the pressure distribution; that means, that this pressure because this side is soil; the soil is giving pressure to this lateral support; and then this lateral support is giving pressure to this strut so; that means, that will be the force that will develop in this struts. So that means, we can, for the different type of soil we have some different stress diagram. So, that depends upon the speed at which excavation is advance; and then the type of the soil. Suppose if I, we have a soil that is sandy soil. So, first soil is sandy soil. So, here we can get, this is the distribution pressure 0.65 gamma H k a. So that means, this pressure diagram, this pressure, this is 0.65 gamma, gamma is the unit weight of this soil; gamma H into k a that is the lateral pressure distribution which is acting here. Suppose here this will be the direction. So, that depends upon the type of soil and the speed at which the excavation is going on.

So, here k a we can write 1 minus sin phi divided by 1 plus sin phi. Now if the soil is firm clay or stiff clay, then the distribution will be different. So, then the total distribution pattern will be different. So, this is the, this value is 0.2 to 0.4 into gamma H. So, this is for your firm clay or stiff clay whose gamma into H then c u is less than equal to 4, this is another condition.

So; that means, here this value is H by 4; this is also H by 4; so; that means, this one is H by 12. So, this force will also, this stress will also act in this direction. Now if the soil is sub clay, then the distribution will be different. So, this is the stress that will act; that means, here 0.2 to 0.4 gamma into H; and here the distribution value, this is gamma into H minus 4 c u.

So, this is for soft clay to medium clay, so; that means, gamma H divided by c u greater than 4. So, this is another distribution; this is H by 4; and this value is 2 third of H by four. That means, these are the three different distribution for this different type of soil, one is this is if it is purely sandy soil; then this is for the firm clay; and this is for the soft to medium clay.

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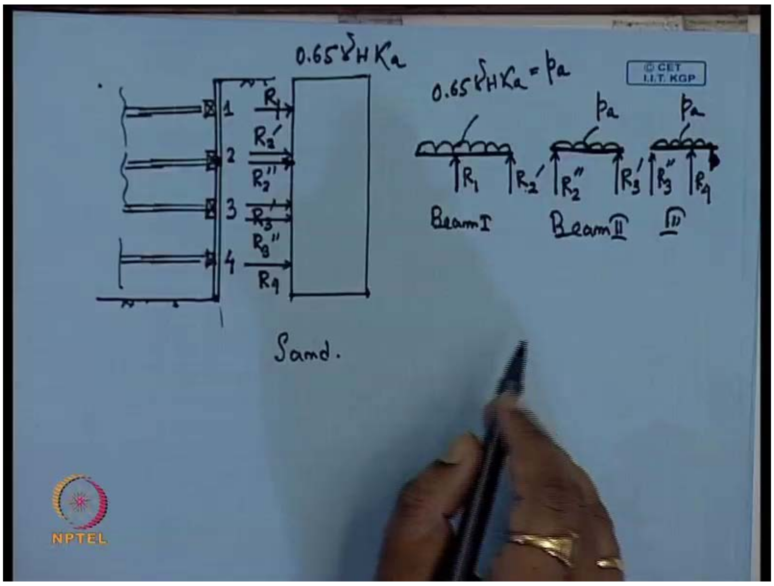

Now, how to analyze these things to determine the forces in the strut, and this pattern, suppose we have a base excavation system like this; this is our ground level, this is the base of the excavation, this is another side. And then we are taking the number of strut is 4, at 4 different level; these are now suppose if it is sandy soil, so, we will get this type of distribution; this is the sand. So, this is 0.65 into gamma into H into k a.

Now, we can divide this total diagram, or total this sheet pile lateral support in different number of beam or segment, where so; that means, here if I consider one beam from up to the second support; and then from second to third, this is first strut, this is the second strut, this third strut, this is the position of the forth strut.

So, we are taking one beam from top to second strut; and then another one second to third; another one third to bottom. So, there is a three beam, we have decided; one is from top to second strut position, another is second to third to the bottom. So, we have the reaction for this second, first strut that is 1; and the reaction, some reaction of this second strut that is R 2 dash; and then the second beam, there is another reaction for the second beam, that is R 2 double dash; some portion of the R 3 dash, for the second beam; and for the third beam that is R 3 double dash; and then for this beam R 4.

So, these are the forces is acting. Now if I get one by one this beams. So, this is the first beam or beam one. So, where we can draw the distribution or u d l with densities 0.65, value is gamma H into k a, and that is equal to p a. So, what are the reactions? So, this is the reaction that is R 2 dash; and then here this is R 1.

Similarly, for the second beam, we consider this is p a again the same stress is acting; then the reaction is R 2 double dash; then R 3 dash, this is for beam 2. Now for the third beam, the same p is acting; then this is R 3 double dash and then the R 4 is acting here. So, these are the, this is beam 3. So, this we are taking three beams in this way, we can we can take the more number of beams if the number of struts are more; and you have to take different diagram for different stress distribution.

So, now, we have to take this 3. Then we have to solve this determine this R 2 dash R 1 because this u d l we know, this distance between this two stars and this value that is also known. So, now, we have to take, determine the, these reactions separately, by considering this beam. So, this is, one beam whose this distance between two strut is known; this u d l is known. So, you can determine these two reactions. Similarly for this beam 2 also; similarly for the beam 3. So, once we get all the reactions that the then the force of the first strut will be R 1; force of the second strut will be R 2 dash plus R 2 double dash; force of the third strut will be R 3 dash plus R three double dash; and force of the fourth strut will be R 4.

So, then we can determine what is the forces of different struts? This is one method. And then we can determine, what would be the moment, maximum moment at this lateral support also. So, those things, so, we will discuss. And for this is, for u d l sand for the clay you will get different type of variation. So, those things I will discuss, how to calculate these forces in the next class, with some example problem.

Thank you.