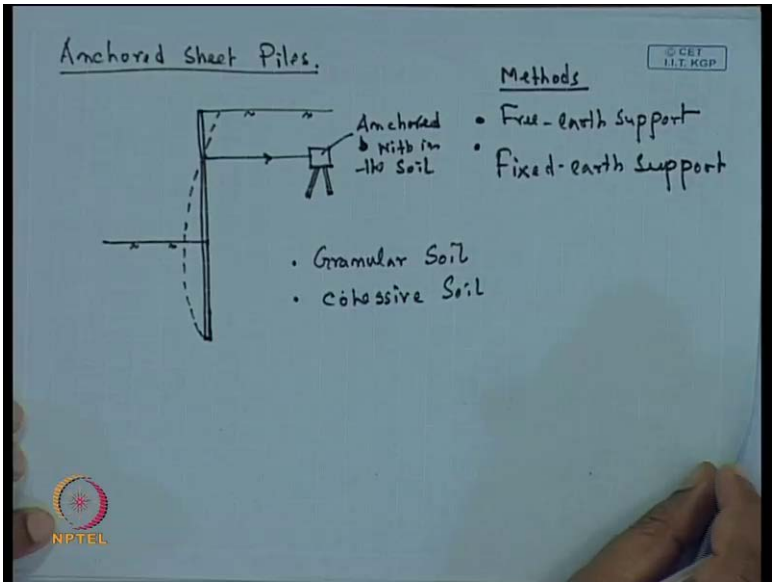
Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 27
Design of Sheet Piles (Contd.)

In last class, I have discussed about the cantilever sheet pile. Now in this class, I will discuss about the anchor sheet pile. Now the idea of this use of this anchor in a sheet pile is that, as I have already discussed that the difference, a main difference between the or normal retaining wall and the sheet pile is; then the retaining wall the depth of foundation is less compared to the sheet pile, where the sheet pile the most of the resistance is coming from this foundation depth. So, the required depth is very high as compared to the retaining wall, but sometimes to reduce this required depth is anchor is used. So, in so this type of sheet pile is called the anchor sheet pile.

(Refer Slide Time: 01:07)

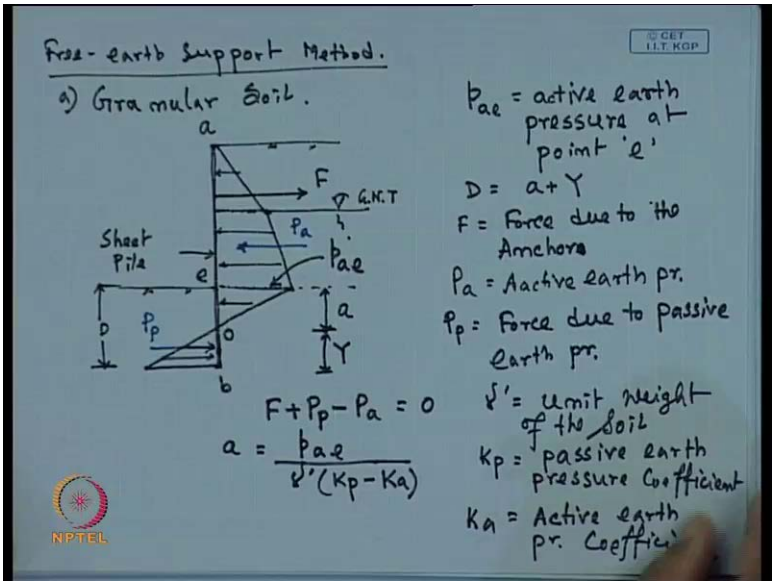


So, now first, if I go for this anchored sheet pile condition, similar to that this is the top ground surface; this one is the dredge level; and this is the cantilever sheet pile. Now here sometimes to reduce this required depth, one anchor is used here. So, this is this that means, this here apply tension is applied with the, this is the sheet pile, where this tension is applied through this anchor; then it is anchored in the ground.

So, now here this type of in sheet pile that is called anchored sheet pile. Now, where this is basically the anchor; this is this one is anchored within the soil. Now, that means, additional tension or force is applied. Now here when we do the analysis; that means, ultimately here also similar to the cantilever sheet pile you have to determine the required depth of this sheet pile, below the dredge level; this is the dredge level. Now here two methods, that is applied; one is our free earth support method; this is the, these are the analysis methods; one is free earth support method, another is fixed earth support method.

So, two type of analysis that we can do; one is free earth support method another is fixed earth support method. Free earth support method here we assume that surface this end is free. So now, if I consider the first free earth support method, then the deformation safe of this sheet pile is considered like this. So that means, it will deform in this form, and then this will be the shape. Now if I consider two different types of soil: one is, first will go for the granular soil; and next we will do for this for the clay soil or cohesive soil. So, we need do this analysis for this free earth support method in granular soil; and we will do the analysis in the cohesive soil also.

(Refer Slide Time: 04:49)



Now first that we will do this analysis, for the free earth support method. So, first we will go, do for, this is for the granular soil. So, if I consider one anchor sheet pile in the granular soil. So, this is dredge level; this is the sheet pile; this is the ground surface; this

is dredge level where this sheet pile, this applied force is applied here, that is the F force which is applied, due to this anchor. And this is the required depth of the foundation below the dredge level.

Now, the water table condition; suppose this is the position of the water table; this is the ground water table, position of the ground water table. Now the load distribution diagram that we can do, that this would be the expect diagram of the, see this is the earth pressures diagram corresponding to the active passive combination. So, here F is applied here; then this force we will act in this direction; and this we will act in this direction, opposite direction.

So, this is the earth pressure diagram of the sheet pile. So, this is sheet pile. Now these are the different position, if you, this is a; this is base is the b; then this is dredge level this is e we can consider. So, first these are different, components here we consider this one, this distance where earth pressure is 0, is at a distance of a form the dredge level.

Now, this earth pressure, at this level is p a is the active earth pressure at e level. So, p a e is the active earth pressure at point e or at level e; e is this point. Now, distance of this remaining part, if I consider capital Y. So, we can write that d is equal to a plus capital Y. So, the forces, so; that means, here what are the forces; we can consider this as the two parts: one is this portion is this is active zone, and this is the passive pressure.

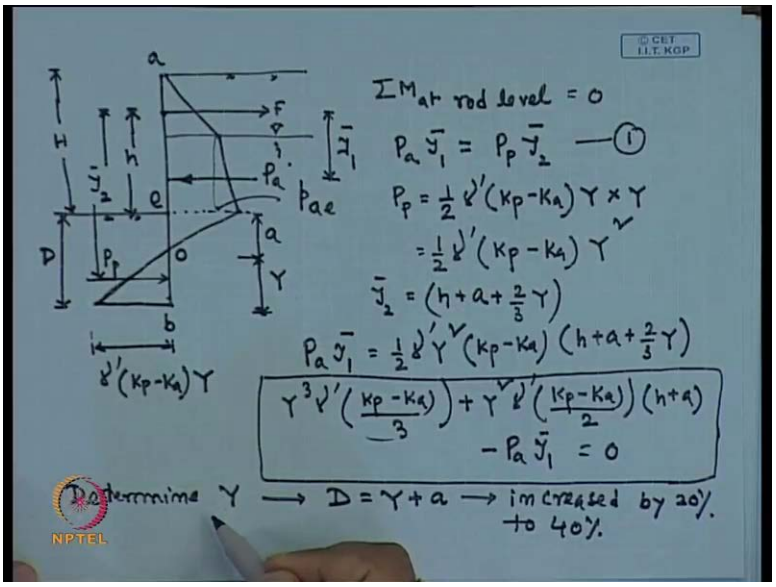
Now, if I take this two different force; that means, what are the forces that is acting? One is F due to this anchor force; and another is the P active and another force which is acting p passive, so, the forces, those are acting here. So, first one is F is the force due to the anchor, anchor; and then P a is the force or you can say active earth pressure, force due to active earth pressure; and P p the force due to this passive earth pressure. Actually this is the net pressure we can say; so now, these three forces that will act in this total. This three forces means if I consider this is o. So, one region is a e o, this region that is P at a; another is o b in this region this is P p.

So, now if I write this is, this anchor rod of force due to the anchor. And now we can write that this F plus P p minus P a that is equal to 0. So, this, among this three forces: F plus P p minus P a equal to 0. now as I have discussed already, in previous class in, during this are cantilever sheet pile, we can determine this a value with this expression that is p a e divided by gamma, at this level below the dredge level if I consider gamma

dash, into k p minus k a. Where p a e we have this is the pressure at this e level; gamma dash weight of the soil below dredge level; and k p is the passive earth pressure coefficient this is passive earth pressure coefficient; and k a is active earth pressure coefficient.

So, these are the things. So, in this expression, by with the help of this expression, we can determine the forces, this distance a. So, this is our expression; and this is our general force equilibrium expression. Now if in this other, if I draw the same figure here.

(Refer Slide Time: 13:02)



So, this is sheet pile; this is the top level; it is the dredge level; now this is the ground water table position. So, forces that is acting, this is the F anchor force; this force is p active; and this is p passive; this distance is D or depth. So, this is the a e o and b; and this point, this is the p active at e level; this distance is a, remaining one capital Y.

Now, if I check the moment at anchor rod level or anchor level that is equal to 0. So, now, this force P a say is acting at a distance of y 1 bar form this rod level P a; and P p is acting at distance of y 2 bar from the rod level. So, y 1 is from the rod level this is P a; and P p is acting y 2 bar from this rod level. Now we can say that our P a into y 1 bar that is equal to P p into y 2 bar. So, this is the expression if I take the moment at the rod level.

Now, how we will calculate this P a or P p. Now P p we can calculate because this P p value, this value is given by this expression that gamma dash into k p minus k a into

capital Y, because this things I have already discuss in during the cantilever retaining wall calculation. So, this one, this is the net force a net pressure this k p minus k into gamma dash into capital Y as this is the distance capital Y.

So, P p will be half into gamma dash k p minus k a into capital Y into, so this is capital Y into capital Y. So, this will be the half gamma dash k p minus k a into capital Y square. And y 2 bar will be, y 2 bar that will be, that if total height is h say; and the distance from the dredge level to the rod level is small h; total height of the sheet pile above dredge level is say capital H; and how position of the distance from the rod level to the dredge level is small h; then we can write capital Y 2 bar will be small h plus a plus 2 third of capital Y. So, this is Y 2 bar. Similarly we have to calculate the Y 1 bar by taking different components, this small triangle; then this rectangle; within that again this triangle; and then the remaining triangle.

So this how to calculate this Y 1 bar? There, as already explained in example in the last class. So, that thing already mean explained. So, in this way we have to determine the Y 1 bar and the P p also. Now putting this Y 2 bar everything in the this expression, is about this expression 1, if I put everything in the expression 1; then we can write that P a y 1 bar that is equal to half gamma dash capital Y square k p minus k a into h plus a plus two third of Y.

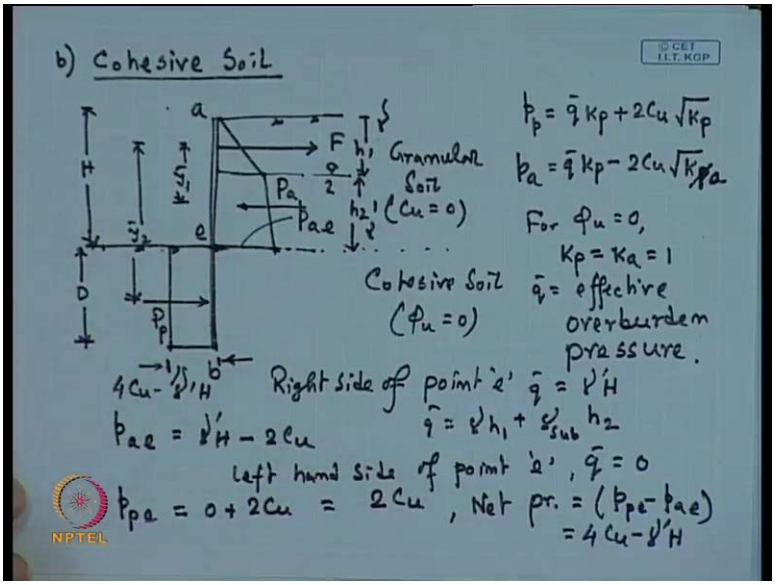
So, further if I simplify these things, so we will get capital Y cube gamma dash k p minus k a divided by 3 plus Y square gamma dash k p minus k a divided by 2 into h plus a minus P a into y 1 bar that is equal to 0. So, in this expression, this final expression, if I look, if we look this to this final expression, then the, what are the unknowns here. gamma dash is known; soil property k p k is also known; then this a is known, a we can calculate the expression which is soon; h is, h has to be known because we should know the position of this rod level from the dredge level; then P a we can calculate, y 1 bar also we can calculate. So, only unknown is Y, so this capital Y.

So, first we have to determine the capital Y form this final expression. Capital Y, once we get the capital Y, next step we will get the D that is capital Y plus a. And once we get this D, this is increased by 20 percent to 40 percent by providing this factor of safety. So, once we get this D value or capital Y value, then what we can do? We can, this P a we

can calculate, because this P a is the top portion, where a we know we can determine P a we can calculate and if I know Y, capital Y value, then we can also calculate the P p.

So, once we know the P a and P p then we can calculate this F force, anchored force that is P a minus P p because that force is equal, so, we have to design this anchor such that it can sustain under this if low. So, in, and so, this way we can determine, how much depth, required depth we can provide for this anchor sheet pile, and what is the required anchor force? So, this analysis is valid for granular soil. The similar one we can do for the cohesive soil also.

(Refer Slide Time: 21:50)



So, next one is for the cohesive soil; how to do this analysis for the cohesive soil. So, again this, thus next one is for the cohesive soil. Then, so, we will do this analysis for the cohesive soil. So, will consider same sheet pile, but the soil is different. This is the top portion; this is the dredge level. So, required depth is D. So, here the same, this is the position of the water table; this is the anchor force that applying F. Now here, the difference is that, here we consider, in the previous one granular soil we consider that our foundation soil and the field soil, because this is field soil and this is the foundation of both are granular soil; here we consider that this is the field soil is granular soil.

Where we consider c u is 0; and the soil below the dredge level of foundation soil that is cohesive soil that is phi u is 0. So, you can consider the both in c phi soil also there the pressure distribution diagram will be different. So, now, here we can consider similar

diagram for the, but here for the granular soil we will get this type of distribution, instead of this triangular one. So, how will calculate these forces?

So, this is also again, this one P active at e level. So, this is a; this is b; this is e. and here the forces that is acting again, this if, then this P active and again this p passive. So, again this F anchor force, active force and passive force. So, these are the forcers that will act against a distance between this anchor force, from this rod level, to this active force this y 1 bar. And this is up, for the passive force, this is y 2 bar. This y 1 bar; this is y 2 bar.

So, now in we try to calculate the, what are the forces at different level. Then we can get this value, this way that, for this passive pressure, if I go passive pressure diagram that is q bar k p plus 2 c u root k p. So, this is the common expression to calculate the passive pressure at any point. Similarly this is p active that is q bar k p minus 2 c u root k p; where k p is the passive pressure coefficient, and for that c u is the cohesion, undrained cohesion.

Now, for phi u equal to 0, this k p equal to k a, here this one is k a active. So, this is the k p is the passive earth pressure coefficient; and k a is the active earth pressure coefficient; this is not the k p this is k a. So, k p minus k a that is equal to 1. So, at the dredge level, now this q value, we can calculate the q is the affective overburden pressure. So, q bar is effective burden pressure. Now if I want to calculate, what is the active earth pressure and passive earth pressure at this point e, at dredge level. So, there is a two parts: one is the left part, another is the right part.

So, now, if I consider that dredge level, the right point; the right side of point e, the q bar value is, if this is H, again H is the height of this sheet pile from the dredge level. Then that will be gamma into H this is your, this is effective, this gamma into H; or as this water table is here, then we can calculate in other form also. that is if this height is, this is H 1 capital H 1, if it is capital H 2, then we can consider this densities, if it is gamma and this is gamma dash; then this will be gamma into H 1 plus gamma sub or gamma dash into h 2.

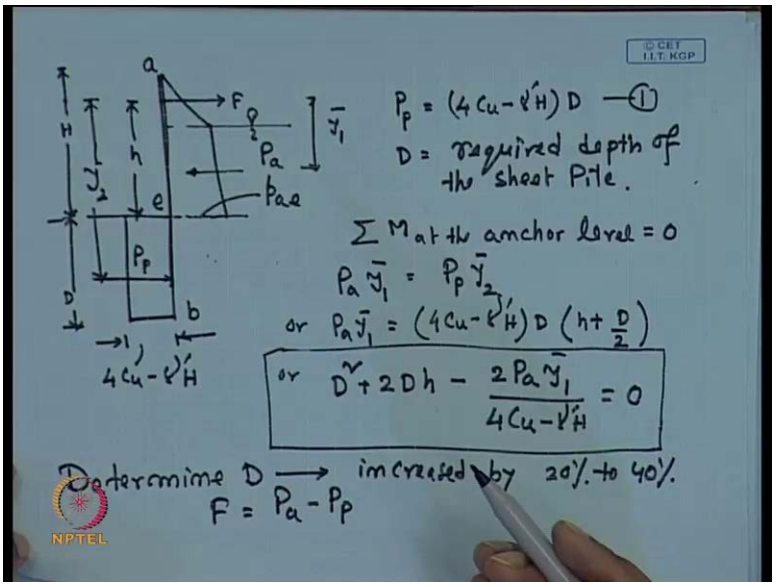
So, this is the unit weight; this is the sub margin unit weight of the soil; and this is the unit weight of the soil its natural condition. So, in this o a we can determine, but it is gamma dash h, for this calculation you are considering. So, now, we can put that p a e;

this p active at e level that gamma dash is equal to q is equal to gamma dash into H. As for this dredge level below this dredge, this portion, this phi u equal to 0 where considering that phi u equal to 0 for this portion.

So, at this level, the stress that we are taking that phi u, and if I consider this phi u equal to 0; so k p will be 0 for this level. So now, we can write that k a is equal to 1; as if phi equal to 0 then k p equal to k a equal to 1. So, this is gamma dash into H minus 2 c u. Similarly at the left hand side, at the left hand side of point e, q bar is 0. because here no surcharge is there. So, q bar is equal to 0. So, we can write that p p e, because here the passive earth pressure p p e, that is equal to 0 plus 2 c u. So, that is equal to 2 c u. So, at this point, dredge level the right side, the active pressure is gamma dash H minus 2 u, 2 c u; and the passive pressure is 2 c u.

So, net pressure, you can write that net pressure that is equal to p p e minus p a e. So, that is equal to 4 c u minus gamma dash H. So, p p e at e and p p a e. So, 4 c u gamma dash H; so the net pressure that we are getting at this level that is 4 c u. So, this is the net pressure. So, that is 4 c u minus gamma dash H; that is the net pressure.

(Refer Slide Time: 31:46)



So, now, if I draw this same figure. So, we can draw this is the sheet pile; this is dredge level. So, this is water table position is here; this is anchor force F. So, here net pressure we have calculated this one is 4 c u minus gamma dash H. And this is the p a e that is e position; this is a; this is base b; and this is the rod level.

So, forces which is acting that is p active; and this is p passive. So, this distance from the rod level to p active base y 1 bar; and this distance from the rod level this is p y 2 bar to this point. This is D is the required depth of the sheet pile; H is the height of the sheet pile, capital H.

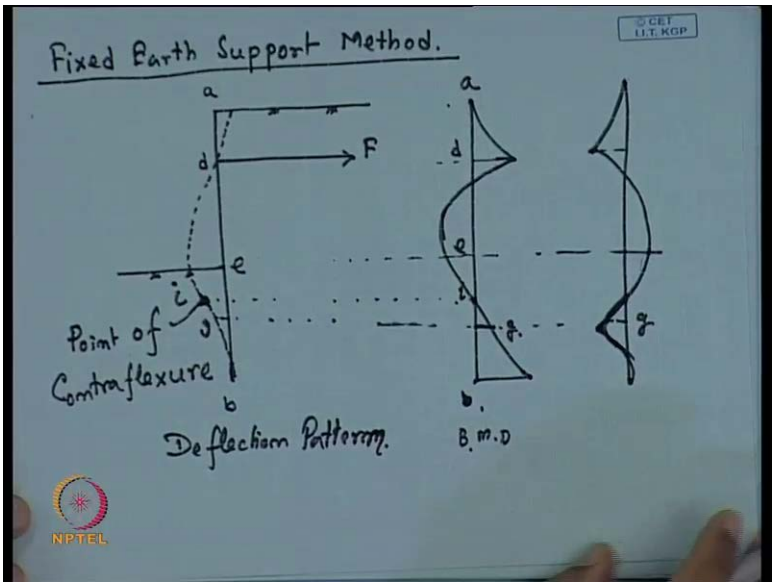
Now, again if I want to find the p p first because p a; again we can calculate p a and how to calculate this y 1 bar that is also been explained. So, that part is fine; but we have to calculate this P p; that P p is here 4 c u minus gamma dash H into D, where d is the depth of the sheet pile. D is equal to required depth of the sheet pile.

So, now, we can write this is, this is expression say 1. And then summation or of the moment, it is taken at the anchor level that is equal to 0. So, if I take the summation of this anchor level, that is P a into y 1 bar that is equal to P p into y 2 bar. So, we can finally, or we can write P a y 1 bar that is equal to P p is 4 c u minus gamma dash H into D; and the lever arm is, if this is the small h from rod level to dredge level the small h plus D by 2; because it will act at the center, it is rectangle. So, this is D by 2.

So, finally, you can get this type of expression D square plus 2 D h minus 2 P a y 1 bar divided by 4 c u minus gamma dash H that is equal to 0. So, the final expression is this one, where, which are the unknown? Unknown P a we can calculate which as total force due to this active pressure; y 1 bar also we can calculate; c u and gamma is soil property; h is known. So, only unknown is D. So, what you have to do? When we have to determine the D from this final expression, then increased by 20 to 40 percent due to the factor of safety. Then once we get this D we can calculate the P p. Then the finally, F will be determine by P a minus P p like the previous case. So, these two are the different two cases where previous one is a granular soil and it is cohesive soil; as it is in the cohesive soil then this phi u is 0.

So, k a is equal to k p is equal to 1, that we are using. So, in this way we can analyze this anchor sheet pile for the granular soil and the cohesive soil. But here, we have taken the free earth surface support method, where the next one that I will discuss, where this is analyze we consider the fixed earth support method.

(Refer Slide Time: 37:18)



So, for next we will discuss the fixed earth support method, in that method that the next one is support method. So, that means, here we consider this is our sheet pile; this is dredge level; this is the top surface. So, that is the dredge level. here, this is the anchor; this is the force, anchor force; and this is a; this is e; this is base b; this is the rod level d. here if I go for this, for this deformation pattern, then this will be the deformation pattern for the sheet pile. Here; that means, the difference is here one point of contra flexure will appear.

So, here this point is, say this is the point of, point of contra flexure. That means here, the bending moment, if I draw the bending moment diagram that bending moment is changing its sign; or here this will go from positive two negative or wise versa. So that means, here bending moment diagram, if I draw the bending moment diagram, this type of case. So, this is the total sheet pile we can consider.

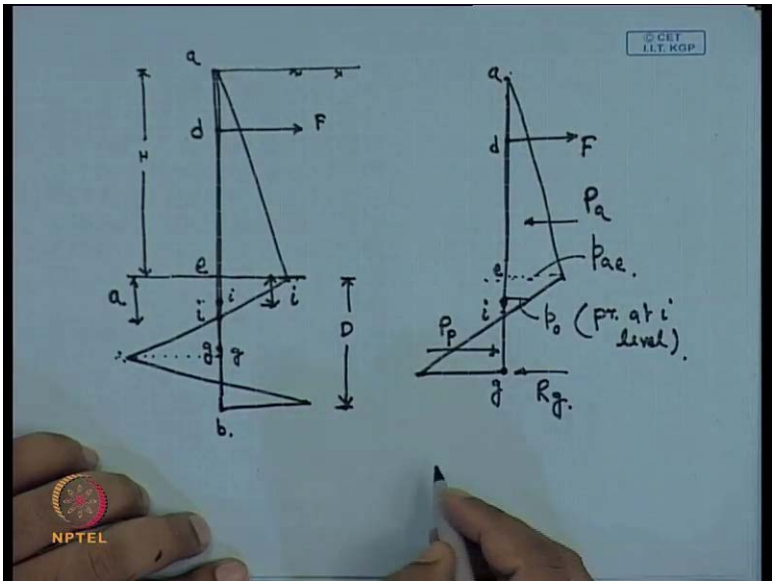
So, these are the same points. So, this is, suppose this is i point of contra flexure. And then we can draw this type of bending moment diagram, say here, at a; this is at d; this is at e; then next one is i point, this point say i point; and this is b point. So, we can get this, we may get this type of diagram; where, so, here this is the bending moment is changing is sign at this point of contra flexure; and then we get this type of diagram of the sheet pile. So, this is our fixed earth support method; or this is the different position or you can

say, so, this is I; and this is the diagram of different points. So, we can say, and here also we get different points where we will get say this another point g.

So, they also we will get this g point. And then we can get this type of diagram also. So, that is our, the same this is a friction force, that you are getting in opposite direction if I draw this diagram. So, this is our anchor position; and this is the dredge level at the i; this is the point of contra flexure; then we will get at g level, this value; and also we will get some, this type of pattern also. So, that means, we will get this type of bending moment diagram for the soil, for this fixed in anchor pile.

So, now, so, this is the our B M D. And this is also deflection pattern, deflection pattern. So now, we will discuss how to analyze this system? Because here this is, if this is the different type of, this is the point of contra flexure where this forces are changing; this is the g is the another point. So, now if I get, so, this will be the g value is somewhere here; and then you can get this type of diagram also.

(Refer Slide Time: 42:43)



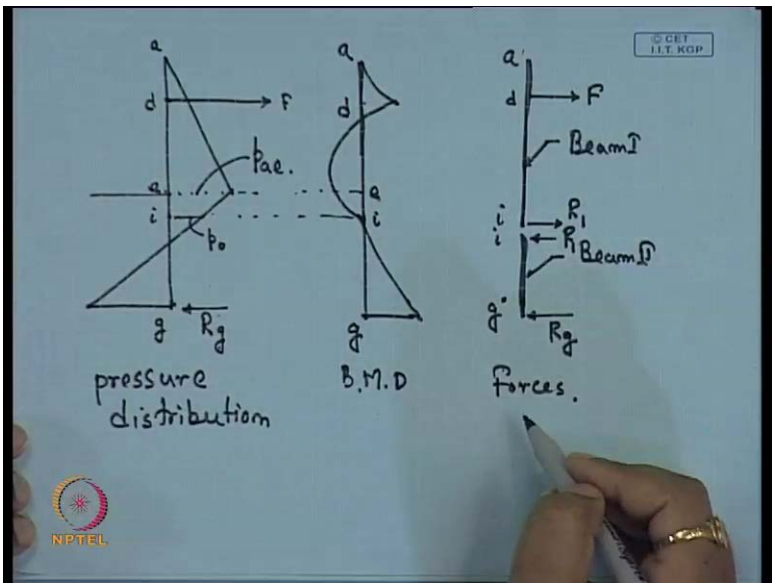
Now if I go for the pressure distribution diagram for this type of sheet pile, then we will get, suppose this is the sheet pile; this is dredge level. Now, the pressure distribution diagram, we are considering there is again, this is a; this is the anchor point d; this is e; and this is b; then one position is i which is point of contra fiction; then below that this is say g.

So, now if I get this diagram, we will get the granular soil. So, this is the diagram where the g, suppose this is the maximum; then we will get another change, then we will get this type of diagram in the analysis. So, here this i is somewhere, here say this is i point, this is the where this is maximum; this is g point. So, this is g point; i is somewhere here. So, this is the diagram, suppose this is H is the height of the i sheet pile.

Now, here somewhere F is acting which is the force of the anchor force; and then this is the required depth below the dredge level. So, we will get this type of distribution. So, the pressure distribution in this case; so here also this is say a; this distance is i say. Now from this total system we are considering only this, upto g portion; and if I draw this diagram for the g portion, only up to g, then we will get, so, this is the g value, g point; this is say i point; this is the e point; this is the d point; this is the a point; this is the i point. So, we will get this type of diagram. So, this i point is here somewhere. So, when, as your taking this portion, then you we will get another reaction that we will act is R g; and this is the force we will act at s.

So, then what are the other forces. Then similar to this is the p active for this region; that means, this is a d e i in this region; this is the total force a active; and then the net forces then this force in the opposite direction; this force p passive or p 2 that we will act. Now, here suppose at i 0 point, this force is p 0. So, these are the, and this pressure is p a e, at the pressure at e level; this is the pressure, p 0 is the pressure at i level.

(Refer Slide Time: 46:48)



So, once we get this forces then we will get basically two, if I consider two different beams of this total portion, then this, again if I take this, if I consider the, draw the same figure, figure up to a to g; then this is the dredge level e; this is the d level where force we will act f. So, this is g level; this is i level. So, here this force is p 0 at e level p a e; and g level one reaction, R g will act. Now for this one, if I draw the bending moment diagram, this is the pressure distribution. Then if I draw the bending moment diagram of this total portion; so this is the, at d level; then it will follow at i point; point of contra flexure it is 0; then it will go at g point, it is maximum.

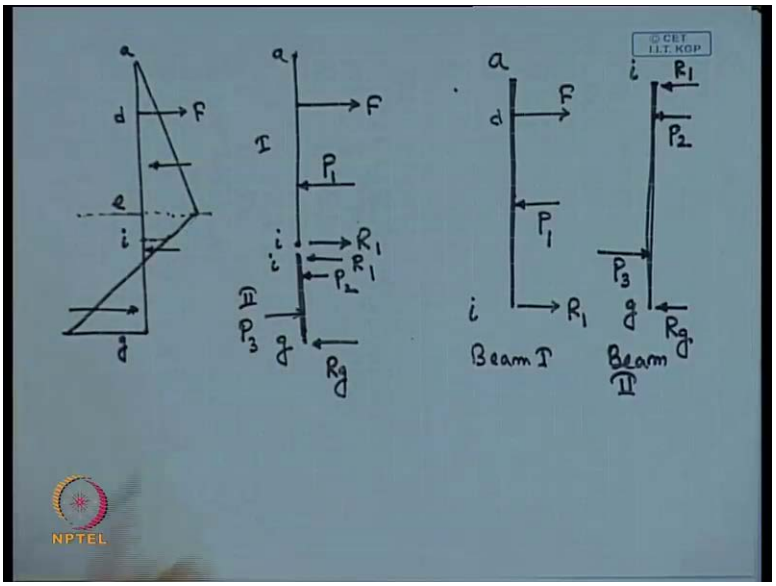
So, this is a point; this is i point; this is e point; this is d point; and this is g point. So, this is the bending moment diagram. Because this is, this bending moment diagram is a similar diagram that I have previously drawn, that mean this is the forces; then i it is 0; then g where taking up to g portion. So, this is the point. Here also we are taking up to g portion.

So, that means, if I consider only up to g portion, so, this will be the bending, is the just in the mirror image, you can opposite side; so this in the g portion. So, we will get this is the bending moment diagram. Now we consider this total portion is taking to, divided into 2 parts; and 2 different beams. So, you can consider one beam is form a to i; another beam is form i to g. So, we consider these two beams. One beam is form a to i. So, this is our beam number 1 and this is our beam number 2.

Because this sheet pile, you are considering this is two beam. This is, one is a to i; another is i to g. now what are the forces in the first beam? So, that force, if at d level that force we will act is anchor force; then this reaction R 1 that we will act at the i level. In the beam to opposite reaction i R 1 will act at beam level; and this reaction R g that will also act at g level.

So, these are the forces. then additional to that, in beam 1 and beam 2 the force will also act due to this earth pressure. So, that means, this is F R 1 R 2 and R g. Now due to the, if I consider the forces, this is the forces and beam, this beam two; then in addition to or other force that will act; if I consider earth pressure also because, because of this additional earth pressure some forces we will act.

(Refer Slide Time: 50:50)



So, what are that this forces that we will draw here. so that means, the forces that we are talking about. So, first we will draw the earth pressure diagram, of this a to g portion. So, the forces, this is the dredge level e. So, we will take this is the fourth earth pressure diagram. Here, so then it is here maximum then it will follow this path. So, this is the diagram we have drawn. So, this point is, say i, where moment is 0; and this is g point; and this is d point where is f is acting. So now, we have taken two beams; one is from a to i, a to i; another is from i to g.

So, now what are the forces that is acting here? So, from the h y, so for the first force from this beam 1, one is acting f anchor, another force is acting R 1 reaction, the similar opposite reaction is acting here, R 1, and here R g is acting. So, now the forces that is acting for this for a to i beam. So, this force, from this acting, so, this will act as p 1. So, p 1 is the forces due to this areas pressure. Similarly this beam, so, one pressure will act here because of this small triangular pressure; this is in the second beam. So, this is our beam one; this is beam 2. And so, that means, p 2 will act here; and this side, for the this triangular opposite direction one pressure p 3 will act. So, if I take separately this beam one, what are the pressure?

So, this is the beam 1, the pressure is acting, this is beam 1. So, one pressure is acting f at a d level; then this reaction R 1 that will act; and this force p 1 that will act. Force for this earth pressure, now for the beam 2, so, this is a to i. Now for the beam two, what are the

forces that we act? This is i to g, this is beam 2. So, this reaction R 1 also we will act here; one reaction R g is also act because this, as the reaction because we are taking the some segment, not the total beam. So, this is some segment. So, this is R 1 is these R 1 because this is beam 1, beam 2. Then additional force this p 2 will act, this p 2 is due to the small triangular force which is acting this side; this is also acting this side; and this is acting on the opposite side, so, another force p 3 that will act here. So, these are the forces that will act.

Now we have to calculate all this reactions, all this forces, then we can determine how, determine this D value. Now, these are the forces diagram for this force, this diagram on the different beams. What are the forces acting? What are the reaction forces? What are the external forces acting here? Now with the help of these forces, we have to determine the required depth of the sheet pile and anchor force. So, how to determine this depth of the sheet pile and the anchor force that I will discuss in the next class.

Thank you.