Geotechnical Engineering II / Foundation Engineering
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Lecture - 49
Anchor Bulkhead

Today again, I will continue with sheet pile wall and I have discussed different types of sheet pile wall. And I have discussed also, mainly cantilever sheet pile wall and cantilever sheet pile wall again can be of different combination of soil, above dredge level, below dredge level, both are actually sand then that is one case. Above dredge level, if it is sand and below dredge level if it is clay, that is another combination and if both are clay then another combination.

So, all those, out of all three cases, I have discussed mainly the first case actually; that means, the sheet pile driven through sand and also retained sand. And just we have tried to show how to find out the depth of embed pile required and to provide a particular factor of safety. And finally, I have taken without water table and most of the time it will be, there will be water table, because it is most of the times sheet pile wall will be the water fall structure and either the river bank or there will be jetty or there will be (Refer Time:01:52).

So, everywhere it is, water table will be there and we have what I have considered without water table. And if there is water table what will be the changes that also I have mentioned, that we are. For finding out the pressure diagram we are doing, what I have been doing? Gamma times, depth times, earth pressure coefficient. So, if the water table is there, so below water table instead of gamma you have to use gamma submerged, rest of the things are same. So, that is the thing which I have already discussed.

Also I have shown with the help of probably on application, on numerical example, the application of it how to do it. And next part of course, I could have done other two cases; like sand cohesive and cohesive, but I am not doing that, because it is too much for, perhaps in under graduate level, so I am not doing that. And next part I will do that is cantilever retaining wall, cantilever sheet pile wall, not returning wall, cantilever sheet pile wall. And a brief introduction I have given in the last lecture, but today I will try to show some more detail that actually the, what is cantilever, sorry anchored sheet pile wall not cantilever?

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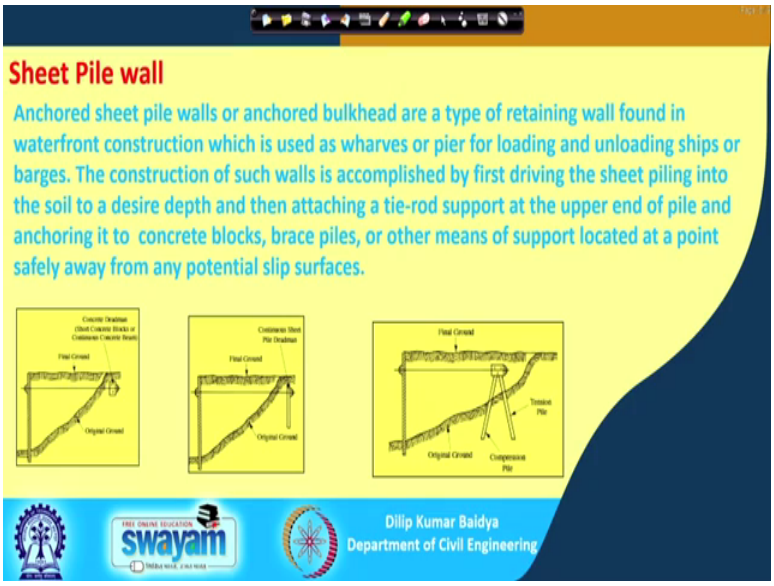

Cantilever already we have done, anchored sheet pile wall which is also known as bulkhead, anchored bulkhead are type of retaining wall, found in waterfront construction mostly, which is used as a wharves or pier for loading and unloading ship or barges and how it constructed actually. Generally this construction of this type of wall fast, it will be penetrate and desire depth.

And then from the top it will connected to a tie and it will be connected to, finally, to a dead weight or wall or somewhere where actually and that will be far away from the potential slip plain. So, I can show you here that you can see here, this is the continuous sheet pile wall and this is actually mostly a filled up material soft and this is actually original ground. So, here actually this anchor is connected to a dead weight. The dead weight is kept actually in the original ground not in this.

So, if you keep this one then it may pull entire thing and fall, so because of that it should be away from what I from, safely away from the potential slip plain. So, similarly here actually we can see this is also anchor is connected to some wall actually and this you can see this is also kept in original ground not in this ground. Actually this idea of this, this area has to be accessed. So, because of this vertical wall will be made and then this will be filled up and this area will be used for whatever service required. And similarly when this is kept you can see here the actual is load take by these two piles actually (Refer Time: 05:20) pile.

So, because of that instead of coming here it can be kept here or anywhere, but this portion, this connection is within the soft zone, loose zone or filled up zone, but actual support is there actually in the original ground. So, because of that is also another mechanism by which we can do anchoring.

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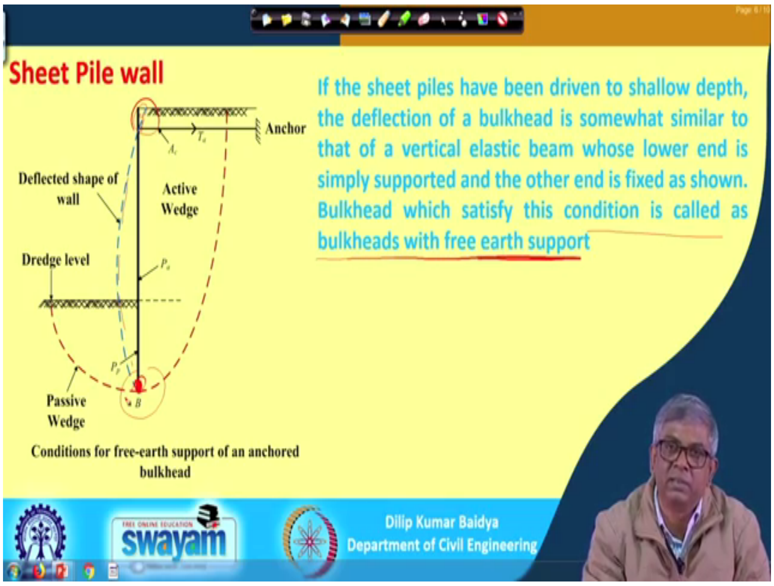

Next part is actually that anchor bulk head and if you see typically if it a, penetration is very deep and it can be deep or it can be shallow. When the penetration is shallow then your typically anchor bulkhead that deflection shape will be like this. It is shown here actually deflected shape will be like that and this portion will be keeping like almost like simple support ok.

So, and you can see and because of that this is called, at this point actually there is no fixity. So, because of that this point as if it is simply supported and it is just holding, like simple support. So, because of that this one is called free earth support. You can see that sheet piles have been driven to shallow depth and deflection of bulkhead is somewhat similar to that of vertical elastic in, which lower end is simply supported and the other end is fixed as shown basically, this looks like fixed and this is like a simply supported, and because of that the condition is called actually bulkhead with free earth support.

So, this is the one actually, another is there actually fixed earth support and mostly we will discuss this one, because again that is little more rigorous, so we will not discuss that for this level ah. So, we will discuss this, but what is actually fixed earth support that I will just tried to show in the. Of course, diagram is not there I will try to sketch. So, let it be, let me continue this one.

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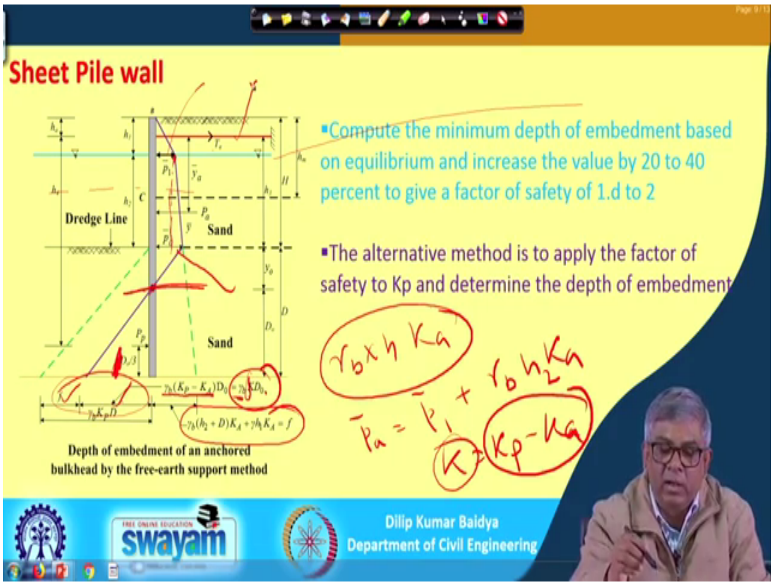

So, when there is a free earth support is there. suppose this is the wall actually, this is the wall and then what would be the pressure actually the behind the wall and in front of the wall. And you can see that typically the bending of the; bending of the earth was something like this, is it not, so it is like this. So, because of that you can ultimately, it will be 0 here.

So, you can see here that active wall pressure will be this side. And if it is continued, assumed that totally active then it cannot go this way. And if you construct that simply passive for then this diagram could have been this way, but the diagram will not be actually shown because of this bending and it will be 0 pressure somewhere. So, active pressure and then because of passive pressure it will become somewhere 0 and then it will become passive, net passive here.

So, ultimately so; that means, for anchored bulkhead under free earth support, that typical pressure diagram will be this side up to some depth below up to some depth of it will be active and from that point to beyond up to the bottom that will be passive. Now this for this equilibrium actually, so this minus this plus equal to this; that is the only thing to be considered. So, two things we have to do consider the equilibrium that to find out what is the depth required for particular height of wall and second thing we have to find out what is the force in the tie rods, this two things to be. And then finally, you have to find out bending moment also, to find out the thickness and all that is also there, but initially two important thing which; one is depth, because sheets are sometimes available in particular thickness.

So, we can choose it, but where how much depth to be given and how much rod ah, what size of the rod, anchoring is required to this design, so we have to find out that. And for that you have to take this is the effective pressure diagram actually, rest of the things actually for understanding these are all for understanding, but ultimately you have to take this portion of the diagram and this portion of the diagram and then you have to take this anchor post.

These three components you have to consider the equilibrium and then based on that we will get this D unknown D and you can find out unknown force in the rod. So, this will be I also in the subsequently later stage.

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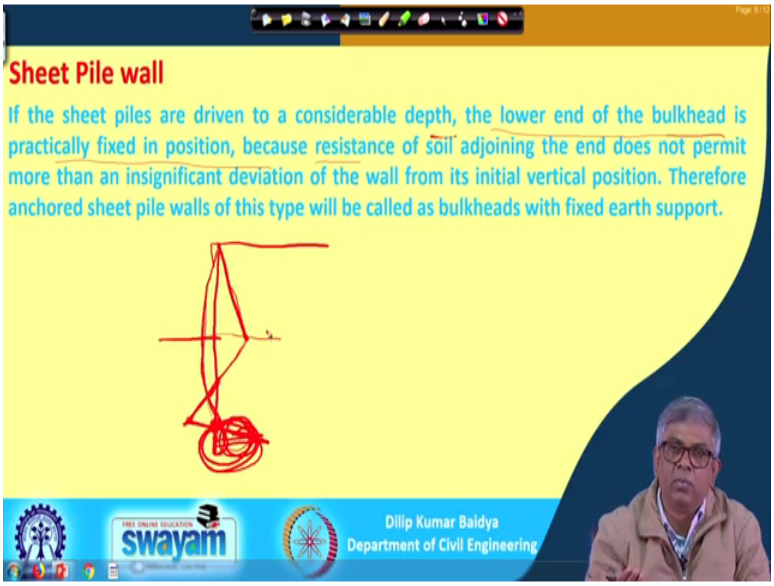

But next let me show if it is ah, what is fixed earth support? See that is the fixed earth support this is, if the sheet piles are driven to considerable depth, the lower end of the bulkhead is particularly fixed position because. So, that is what we have got something like that (Refer Time: 10:26) line and this is the one and we with typically the fixed earth support diagram will be something like this and like this. Instead of becoming 0 here it will be, diagram will be something. So, somewhere at this point at this point and beyond this, because of this pressure at this side it will give you some fixity ok.

So, instead of bending like this, this bending will be like this, this now will be like this, it will be like this if it is depth like this. So, I have not, if you see any book will get the typical diagram, but what is the difference I wanted to show here that it will go here, then it will become 0 somewhere, then it will be passive and then again from passive to again I it will become active that it, which will bend in the other direction. So, that is actually this portion almost like giving you the fixity effect.

So, because of that it is called fixed earth support. But of course, since lot of involvement is there in this analysis; of course, the if the time permits we can do, but because of the limitation of the time I will not do this, I will try to discuss in length in free earth support, how to find out the depth of embedment, how to find out the force in the anchor, how to find out the bending movement those things I will discuss ok.

So, let me go to the next slide. and you can see here the same diagram again I have taken here and as I have told you that your in sheet pile wall always there will be water table and water table will be, both side will be same because see if there is water table here, water table also will be expected almost same may be little difference, may be sometime, but most of the you can see water table will be here, because this is close to ground. If you go deeper then your water table may be something like that it will go, but in the very close to this it will be immediately behind the wall, water table will be same height and it can be instead of here it can be anywhere also.

So, we have taken some height actually water table at a depth suppose h 1, we have shown in the diagram and accordingly we have drawn the pressure diagram. So, this portion actually dry unit weight is taken. So, gamma dry multiplied by h 1 multiplied by K a, this will be the p a bar p 1 bar and then if I go deeper then what we have to do? I have to do that this part will be there and if I go deeper then what will be the increase.

So, below water table; that means, this zone you have to use gamma b multiplied by h and multiplied by K a if I do and from here if I start with 0 and with the increase of K it will become this value. So; that means, if p 1 at this point, at this point p a bar, p a bar will be equal to p 1 bar plus gamma b h K a h, instead of h, I can say this is h 2 gamma b h 2 K a. So, this p a bar to be calculated, so this diagram is complete. Now it will be; it will be decreasing because of this passive pressure here. So, at some depth it will become 0. And then further increase of the depth at this point this value will be equal to gamma b K p minus K A D naught or you can say gamma b K is nothing, but K p minus K a. Already I have since last 2 3 lecture I am using, difference of K p and K a as K without any suffix.

So, this is actually you can say, this portion at this point intensity of pressure will be gamma b times K multiplied D naught you can see that D naught from here actually. So, how it is there I have shown here if this diagram, if I continue as considering active then here actually could have been intensity could have been this one. And from here if I consider only passive then this could have been this one, this plus this ok, entire this portion ok. And because of that ah, so now, if I want to find out only this one. So, this one will become gamma b K p minus K A D naught or gamma b multiplied by K multiplied by D naught.

So, this is the pressure diagram. Now using this pressure diagram I have to analyse, considering equilibrium. And first I have to find out at what depth it will become 0 y naught, then I have to find out different other quantities and then from finally, I have to find out d naught and then at the end I have to find out T in the anchor naught. So, if I go to the next slide. And you can see that analysis procedure also there are two method of analysis; one actually based on equilibrium of this, based on this diagram consider the equilibrium and then find out D naught. And this D naught can be increased by something like 20 to 30 or 40 percent to provide some factor of safety; that is one approach.

And another approach is actually this side diagram then the K p itself while introduced one factor of safety 2 2.5, then this pressure diagram will become smaller or reduced and taking that finally, you can find out D naught that is another approach. But out of these two approach I will consider only this approach; that means, whatever diagram I have got this diagram I will consider the equilibrium and based on that whatever d naught I will get D naught plus y naught will be D required, then I will increase by 20 to 30 percent or even 40 percent to provide your factor of safety.

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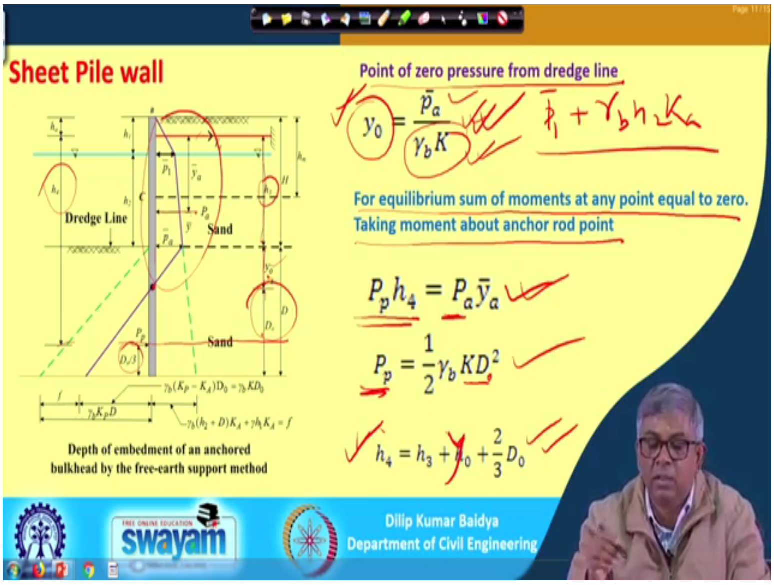

Now actually you can see step by step this is the thing already we have done before also, what will be the y naught. Y naught actually will be p a bar divided by gamma b K and pa bar is nothing, but p 1 bar plus gamma b gamma b h 2 Ka and divided by K gamma b, K means K p minus Ka, so this y naught can be obtained.

So, this is the point of 0 pressure from dredge line; that means, y naught is what? Point of 0 pressure from dredge line, this distance y naught, this is the equation. And how you have got that is the pressure should be equate passive pressure or active pressure, that become then only it will become 0. So, that from there actually this is done before, so I am not showing that.

Only directly equation I have written here and for equilibrium sum of moments at any point equal to 0 is it not. So, that taking moment about anchor point; that means, there will be one force, this will be another force and three force are there. If I take any other moment then there will be two unknowns ok.

So, because of that what I will do, I will take moment with respect to this then T will not come. So, to avoid that actually always you have to take the moment with respect to this. So, then P p, Pp is acting here, it is acting from D naught by three from the base. So, that is actually. So, if I want to take anchor rod then if I know this and then if I know this stand the, I can find out h 4 also. So, all that dimension unknown, this is known. So, from here what is the distance to up to anchor rod I can find out.

So, Pp multiplied by h dot h 4 this is giving moment in this direction and Pa into. This is the Pa, this entire diagram the acting Pa is acting here; this is giving this direction counter, so; that means, here there must be equality. So, Pa multiplied by y a bar. Y a bar is what actually, this is the point of application of P a and it is a distance from the anchor rod two this point of application, so, that to be equated. Now P p will be equal to area of this diagram half gamma b K D square, actually it will be D naught square.

And h 4 actually, you can see h 4 you can find out. H 3; that means, this is the one h 3 plus h naught h 3 plus h naught is shown here or it may be y naught, h 3 plus h naught is not there, this is Y naught must be, h 3 plus y naught plus 2 by 3 D naught; that means, 2 by 3 this is up, this is 2 by 3 D naught. So, then it will, you are getting h 3 means this one, h 3 means h 3 means this one plus this plus y naught; that means, this one plus two third of D naught. So, that becomes h 4 you can see, from here to here that is shown. So, here it will be a correction it must be y naught, not h naught

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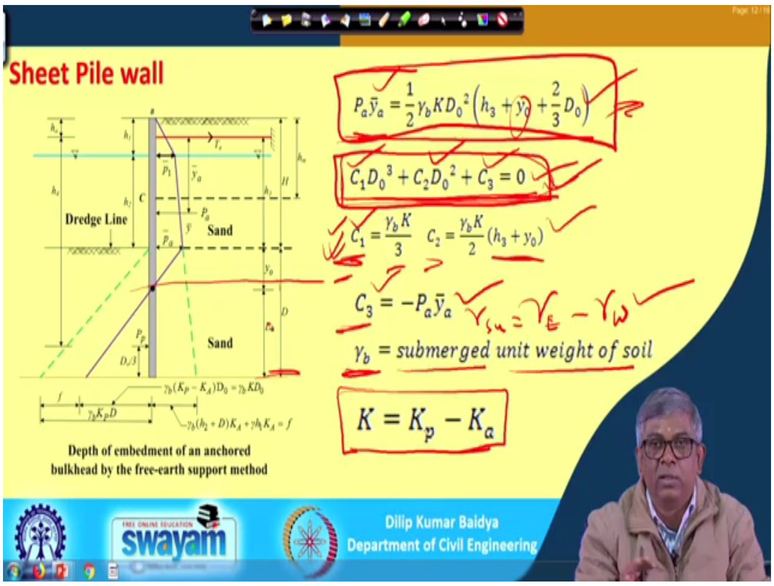

So, next one, you can see now P a y a bar, y a bar is this equal to so; that means, P a y bar equal to half gamma b K D naught square plus h 3, so this is written correctly here; h 3 y naught plus 2 y 3 D naught. And then this one if you simplify, this one if I simplify then it will reduce to equation C 1 D naught cube plus C 2 D naught square plus C 3 equal to 0.

So; that means, I have not done anything extra. What I have tried to express area of this and I have multiplied by h 4 and I have multiplied by h 4 and I have find out the area of this multiplied by y a and then I have equated as, equated and then simplified. And if I simplify and then finally, I can express D cube D square and D 0 with some coefficient C 1 C 2 and C 3 and then I can get a cubic equation. And this cubic equation C 1 is actually from this when you will expand this one and simplify, then you will see that C 1 become gamma b K by 3 and C 2 become gamma b K by 2 plus h 3 plus Y naught and C 3 becomes minus Pa ya bar y a bar ok.

So, these are the things C 1 C 2 C 3. Either you can do this way or you can directly you take this equation x plus y a also in terms of that and then simplify, then directly I will get equation in this form or if I know the all dimension I can take this equation first and then I can calculate C 1 by this, C 2 by this and C 3 by this then I will put there and then I can solve that cubic equation.

Now out, in these there are some more things are there that gamma b I have used constantly, that gamma b is nothing, but submerged unit weight of soil and which is nothing, but gamma total minus gamma w, gamma submerge equal to gamma total minus gamma w. And K I have taken everywhere which is nothing, but Kp minus Ka ok.

So, this is the one that I have got the equation from where actually what I can get D naught, D naught only from here, from 0 pressure to the bottom of the pile. So, that is D naught, but still you have not got actual depth of embedment. So, to get that one what you have to do?

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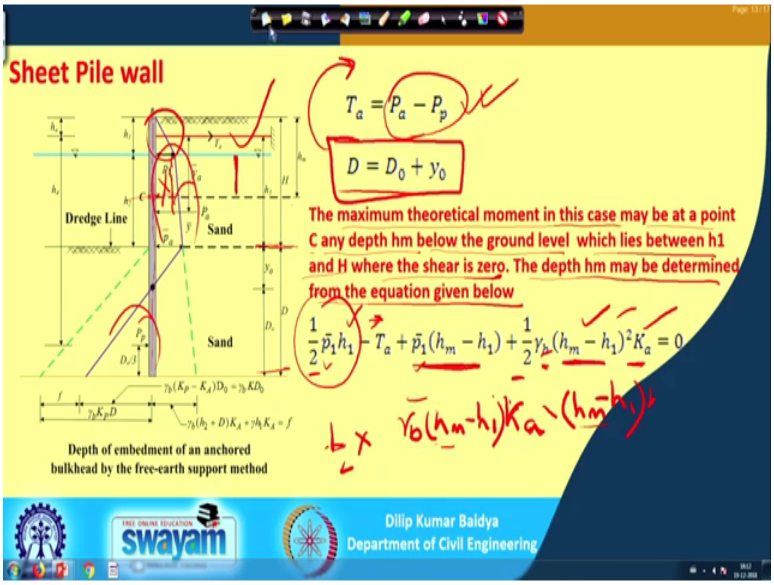

You can see that your D will be equal to, D will be equal to. This should have been, this should have come before D equal to D naught plus y naught, because D naught plus y naught is D . And then after getting that getting this then, here actually Pp is in terms of D naught here actually. So, now, I can find out once D naught is known I will get actual value of this and here all dimension known I will get actual value of this.

So, difference of these two Pa minus Pp is nothing, but tension in the; tension in the tie rod ok. So, this way we can find out force in the rod. So, this is done. And then in the last part actually that finding out the bending moment in the sheet pile wall. Then what we can do here, you can see that, you know that where particular beam if you consider loaded beam, where we get the maximum bending moment actually. The point where your shear force is 0 there actually you will get the bending moment maximum.

So, there actually, here actually if I consider this is beam actually then this direction is force, then the lateral force is nothing, but the shear force here and that is the concept used, then I will try to find out the point where actually lateral force is 0. If I can find out that point actually you have bending moment become maximum ok; that is the concept actually see. The maximum theoretical moment in this case may be at point C; that is C, any depth h m; that is h m from the top below the ground level which lies between h 1 and h. H 1 actually here h 1 here and h is here so, between h 1 and h where the shear is 0.

Shear means lateral force here. The depth h m may be determined from the equation given below. So, how I have got the equation actually? I have tried to get the, considering I have equated the force here, you can see half I have got the area of this smaller triangle; half p 1 bar in to h 1 that is one part, then there will be a trapezoidal part. And before trapezoidal part this forces D direction and T forces in the other direction, so it will minus plus this is trapezoidal part or rectangle part I can say, this is the rectangle part.

So, P 1 multiplied by h m minus h 1; h m minus h 1, h 1 is this one. So, h m minus h 1 becomes this depth, this depth. So, these depth multiplied by p 1 bar, we are taking the rectangular area this is the rectangular part this part. And then this triangular part will be half gamma b h m minus h 1 square K. So, pressure will be, so that means, this pressure actually I have told you that gamma b multiplied by h m minus h 1 multiplied by Ka this is the pressure. So, if I want to find out the force then I have to multiply by half, multiplied by this, multiplied by this, multiplied by this, multiplied by h m minus h 1.

So, if I do this one. So, h m minus h 1 becomes square and K point, this K a is there, gamma b is there and half is there. So; that means, now up to this, once again if I clean, I just clean and show you once again; that means, what I have to do? I have to take force up to this. So, I will be getting I will draw a vertical line.

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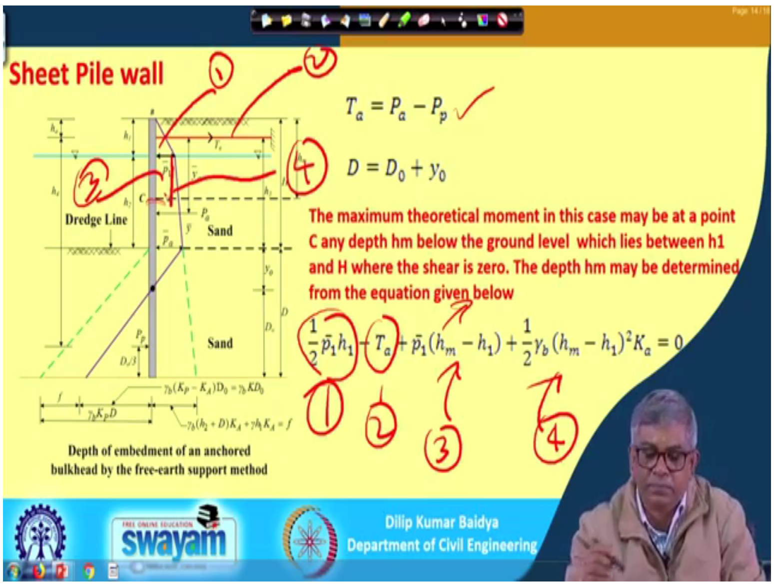

So, this is the triangular part, this is the tension part 1, this is 2 and this is this rectangular part 3. So, this is 3, this is 2, this is 1 and this is actually 4 this portion, this triangle is the 4, so this is also 4. So, 4 part if I do and their direction is known. All are, these are all actually this direction, but only T is in this direction. So, based on that always T a is known. So, if I put 0, from here actually only unknown is h m. So, once you know the h m from this equation, I can find out the bending moment at this point what is that it will be the maximum bending moment in the sheet pile wall and that will be sometime useful for desired purpose.

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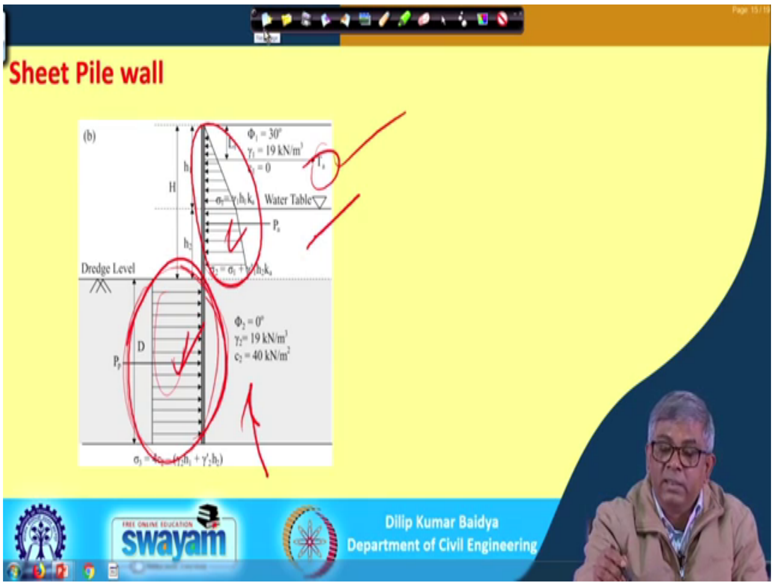

Now, I will go to next slide. So, this is the one I have told you that similar to your cantilever sheet pile wall, even bulkhead also it can be of combination of above dredge level, suppose sand, above dredge level sand and below dredge level actually your clay, then corresponding pressure diagram is like that. If this pressure diagram like this then your problem actually, again it becomes simpler, in that, I have not done this, but if you want you can do it, same way it can be done.

So, you can find out equilibrium, this pressure diagram and this pressure diagram and plus this should be equal to 0. And from there I will get K a actually or sometime I can find out if I know this dimension and I require, first I can find out what is the D required. Once you know the D required then from there actually I will get the unknown quantity here that become known, this become known.

So, difference of this two will become T a and similarly I can find out depth of bending moment, maximum bending moment, what is the maximum moment also. So, I am not done, it is actually simpler than the what I have shown, but you, one get the pressure diagram I have shown by equal, but other thing is, if you wish you can complete it by your own.

So, that means, this is actually your; this is actually your sand above dredge level; that means, sheet pile wall retaining sand, it is penetrated on the clay layer, then corresponding pressure diagram there is there, if this two pressure diagram is if known. And if you know how we have done actually calculation, similar way if you follow you will be able to do what is the depth of embedment required; what is T, what is that depth of maximum bending moment, all those thing can be similar way can be done ok. With this I will stop here.

Thank you.