Geotechnical Engineering II / Foundation Engineering
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Lecture - 45
Pile foundation (Contd.)

Good morning. Let me continue on Pile Foundation, and we have discussed several aspects of pile foundation. Particularly, most important part is that estimation of pile capacity, and that we have done. And pile capacity means have one pile how many how much load can take, and also pile cannot be used in single most of the time it will be used in a group and because of that what will be the group capacity that also we have discussed.

And finally, another important aspect of pile foundation is that or any foundation not only pile foundation that you have to limit the settlement. And that also I have mentioned that for a single pile settlement is that settlement of group pile is much more than the pile group settlement. And again when a pile group settles, there may be of several components. And there may be elastic settlement, there may be compressible settlement or compare consolidation settlement.

So, all those things, we will discuss one by one. And particularly, since it is a pile used in the groups, so we will discuss more about group. And again group will be installed in different types of soils. So, accordingly the settlement calculation also will be different; so, we will show that one by one.

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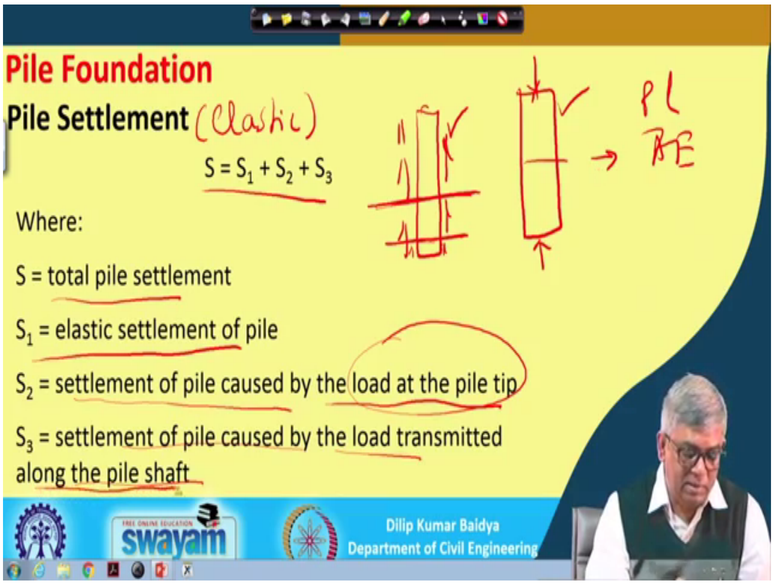

So, let me take the first slide that is pile settlement, and this that to this is actually you can say elastics. So, I have forgot to mention, this is suppose elastic settlement of the pile that means, pile itself will be set will set to a certain because of these compression loading. And it will have three components, actually can see here that is S equal to S 1 plus S 2 plus S 3; there are three components.

And this summation of these three components would be total elastic settlement. And they are explained one by one, S is the total settlement, and S 1 is the elastic settlement of the pile because of the loading pile directly settle some amount and S 2 settlement of pile caused by the lower at the pile tip.

And when there is a n bearing and friction pile, there because of the load transfer mechanism, the some load will be transferred to the tip, and some load will transfer to the surface. So, because the load transferred at the pile tip because of that whatever a settlement that is S 2. And settlement of the pile caused by the load transmitted along the pile shaft that means, if this is the pile, and then your this friction because of the friction load continuously, there will be some shortening that means, how to find out that shortening, so I will not go in detail.

But, if this is the one loading, and if I apply load like this, then this can be easily estimated settlement PL by AE, because stress at any point is constant, but this type of loading actually how to find out? We can imagine that this section, and at that sector this is a small section you can take suppose here.

And on that small section what is the load, actually load will be actually a frictional force now here, whatever because of this frictional unit friction multiplied by the frictional surface, the total load will be acting in this section. So, accordingly there will be stress, and because of that stress what is the compression, so that is the way one can calculate, but detail I will not go. Actually, I will just try to use the show the formula, how to calculate because of this because of these and all. So, these three parts as I have mentioned will be showing one by one.

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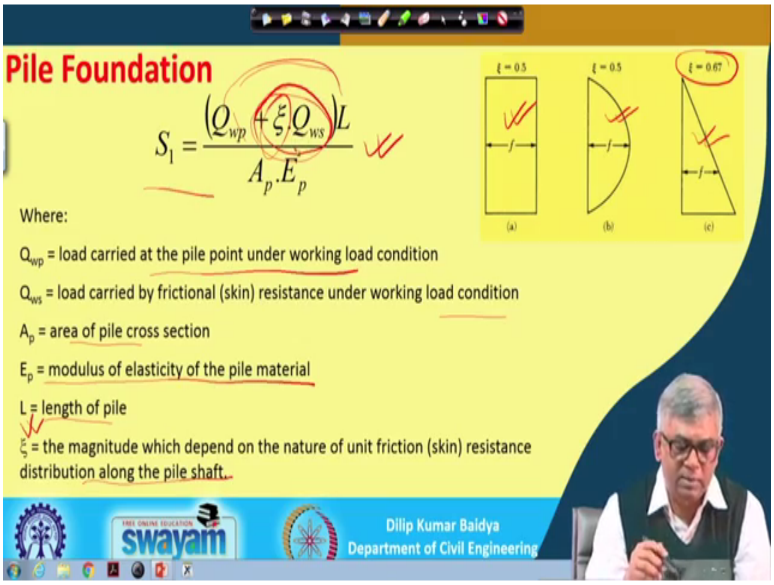

And next I will go to that different component you can see here, it is shown the elastic settlement S 1, and this is because of the Q wp is the total load carried at the pile point under working load condition ok. And then there is a Q wp L by A E, this is just elastic formula from the strength of materials.

If I leave this one, then Q wp into L divided by A p E p could be the settlement of the elasticity of the file. But, there is a prohibition here kept epsilon time w Q ws that cube that means, if the frictional force distribution, how if it is a uniform distribution or if it is a parabolic distribution or a linear distortion like this, accordingly this value introduced, and accordingly it can be taken.

So, you can see here that Q ws load carried by friction under working load condition, and A p is the area of the pile, E p is the modulation of elasticity of pile, and length, and epsilon value that means, these two out of these two component. Actually, can see that how this friction because of the frictional resistance, how to incorporate you can see this depend on the friction resistance distribution on loading another pile shaft.

If this is the type of distribution, then you can take 0.5. If this is the type of distribution, then also you can take 0.5. And this is the type of distribution, then you can take this has a value of epsilon. So, then so this is actually, because if I leave this one, this is that just like this because of this, if I leave this one, this is just a shaft. If there is a if I pull or push, then because of the elastic property, it will settle that much is this one. And this is actually because of the additional frictional load, how it is coming, and that frictional load will be vary from top to bottom to top, and so because of that this will vary also, but that average value has been taken by this equation. Now, go to the next slide.

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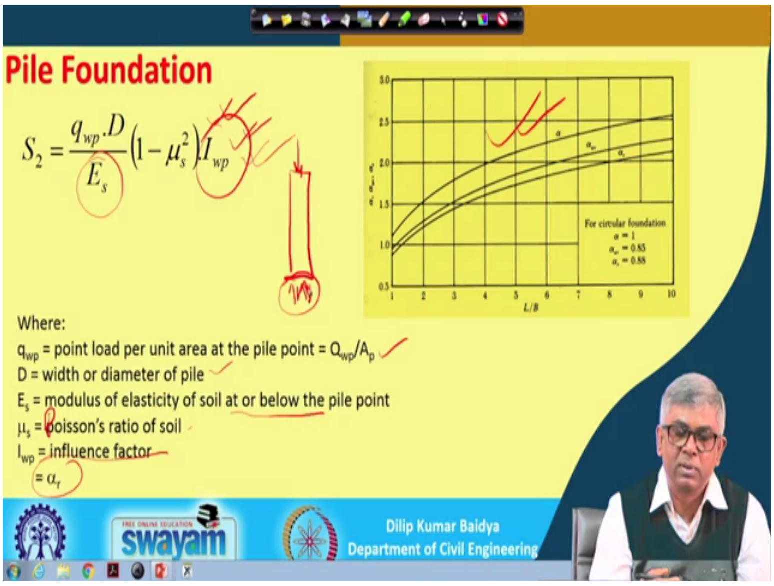

This is S 2, you can see the S 2 actually given the formula q wp D diameter E s 1 1 a mu square by that is actually your elastic settlement formula actually because of that your if there is a loading putting loaded, then you know that what will be the settlement elastic settlement. So, based on that this is the soil at the bottom, and suppose this is the one, this is the someone.

And if I apply load, and then bottom that will be pressure, so because of this pressure, and what to do the settlement of the elastic settlement of the soil below that is actually from the floating we have done that elastic center of the so similar formula actually q wp D by E s 1 minus mu square I wp, this is the influence factor.

And you can see here point load per unit area and that is the one, and then D is the width of the width or diameter of the pile, and E s modulus elasticity of soil. And previous formula actually you have taken modulus elasticity of the pile material, here actually soil that mu s is the Poisson's ratio, this should be capital. And this is the influence factor, and alpha r and which can be taken from this diagram.

And alpha equal to 1 for circular foundation alpha average 0.85, alpha maximum is 0.88. So, this is the for circular foundation, but otherwise we can find out from alpha average from here L by B versus this value ok. So, this is that means, because the pile compression. And this is at a compression of the pile t soil compression, elastic compression of the soil below the pile, so that is the second part.

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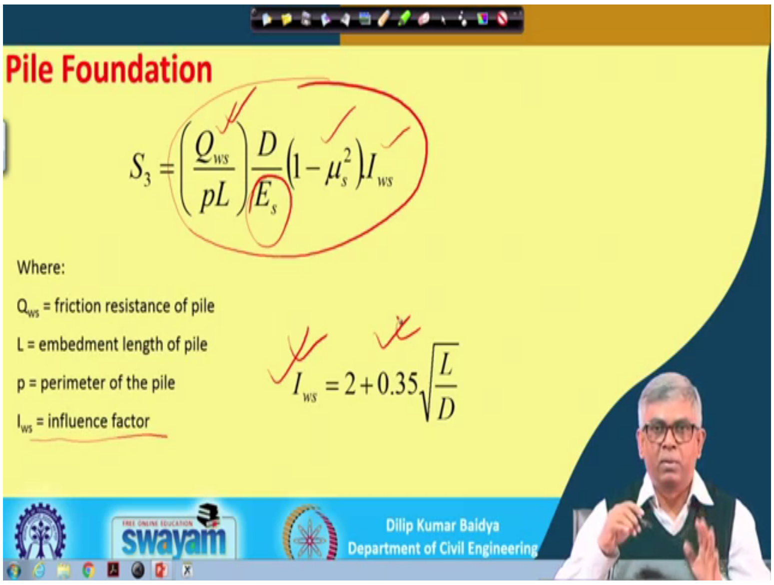

And third part you can see S 3, actually again that is because of the soil compression only. And you can see the how you will differentiate whether it is soil compression or file compression based on this actually, what modulus value was taken. So, Q is the frictional force p L Q s w p L E s 1 minus mu square s, this is actually another component because of the friction, the side soil also compress, and because of that also entire thing will also will foundation also will compress.

So, because of that the third part is taken, and L is the embedment length, and p is the perimeter of the pile, and then I ws is the influence factor, which can be calculated by this equations. So, S 1, S 2, S 3 or together actually will be elastic settlement of the pile that means, the elastic settlement will also can have three different ways, actually if the pile itself compress, then because of the load transferred at the pile tip. If the soil below, elasticity will be settled.

And also when pile load transferred through the friction from the side of the pile, then that during transferring that the elastically also will settle some amount. So, all three together will be total elastic settlement of the foundation and pile foundation ok. So, next I will go to next slide.

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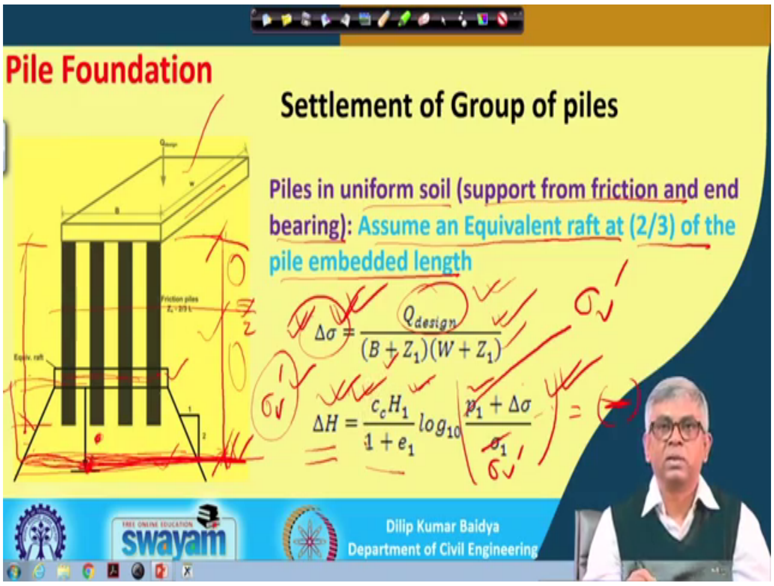

You can see that as I have mentioned that settlement of the group piles is the most important, because this has to be settlement general would be very large. And here actually you have to model, if it is the pile on sand, and even it a group that I will discuss later on. Most of the time pile can be different ways pile can be up to this portion is suppose sand, and there may be some where there may be some where your better I will come that one later on.

So, let me consider that this is a friction ply pile particularly cohesive under cohesive soil, and uniform throughout that means, these zone and this zone the for soil is same that means, up to a great depth soil is uniform cohesive soil. And in that case, pile group will be considered as a equivalent draft at a depth equal to two-third of L. So, if it is this is L, if this is L, then a two-third L depth will assume a equivalent draft.

And then based on that equivalent draft, I can find out at any point you can find out any point, what is the delta sigma pressure increase. And that pressure increase will be equal to load the divided by with that the suppose I want to find out at this one, what is the area of the cross section area of the distributed load. So, this distribution we have shown in that shallow foundation. If this is a B here, then B plus Z 1 will be here.

Similarly, if it is B here, other direction it will be W plus Z 1, so W is this direction. So, B plus Z 1 and into W plus Z 1 is the area at this level. So, (Refer Time: 12:08) load divided by area will be your pressure increase. And this is the first thing you have to do that means, because of the loading in the pile how much increase in pressure in the layer itself and the compressible layer.

And then before loading what was the effective stress in the soil, so that actually what you have to do, you have to consider suppose I want to calculate at this point. So, I have to calculate, what is the weight of the soil, effective weight of the soil up to this depth. So, if there is a layer actually, if some water table is here, then you have to take dry unit here, submerged unit here, unit weight here, and then I had to find out sigma dash sigma V dash at this level. So, it was sigma V dash was there originally, before applying load.

And then applying load, del sigma is there. And if you know that that present loading and past loading, and if you know the soil properties like C c void ratio, then we can find out by log formula the settlement consolidation settlement of the group, and that is actually C c multiplied by H 1. H 1 is nothing but a thickness of the layer. If it is from here to here, suppose I want to find out this thickness is H 1 or if some other depth actually there is a layer, so that whatever thickness of the compressible layer that I will take at the H 1 log 10 base p 1 or you can say, this is p 1 plus del sigma, p 1 was you can say this is I have not changed.

So, this is nothing but p 1 means sigma v dash I can say, and yes this is also sigma V dash, and this is delta sigma that is because of the loading what is the pressure sigma V dash plus del sigma plus sigma V dash, so that is log. And then if you calculate this one, whatever will be there that will be consolidation settlement of the layer. And so what is the case actually here, we have seen that if the pile is driven in cohesive soil, suppose that is frictional pile, and is uniform up to certain a great depth.

And in that case what we assume, we assume the at one equivalent draft. This is the pile cap, and this one I can assume at a depth equal to two-third of length of the pile. And then from there, I will see this is the all are compressible layer. So, if there is more than layers, actually we can divide into more parts. But, otherwise if it is a single layer, I can find out middle of the layer, what is the width of the footing, and what is the length of the footing.

And based on that I can find out delta sigma and at this point before applying load, what was the effective vertical stress before applying load, which is nothing but the weight of the soil. And weight of the soil, when there is a water table, we have take some module into it. When there is a dry or above water table, you will take just total unit weight; so based on that I can find out sigma V dash here.

And then I can calculate delta H is equal to C c H 1 1 plus e 1 log 10 sigma V dash plus del sigma by sigma V dash. So, this is already elaborately, we have done in shallow foundation, same formula only we will be using for calculating the consolidation settlement of this layer under this pile group. So, this is one type of thing that means, when you will see the pile group, and the soil profile based on that you have to first model, the system for calculating the founder. This is one model that means when the piles in uniform soil, that we support from friction and end bearing both are there.

Assume if we can equivalent draft at two-third of the pile embedded length that means, if the embedded length is L, then two-third L depth actually you have to consider the equivalent draft. And based on that you have to calculate these, I have to calculate these, and then I have to use this formula, you can find out the consolidation settlement.

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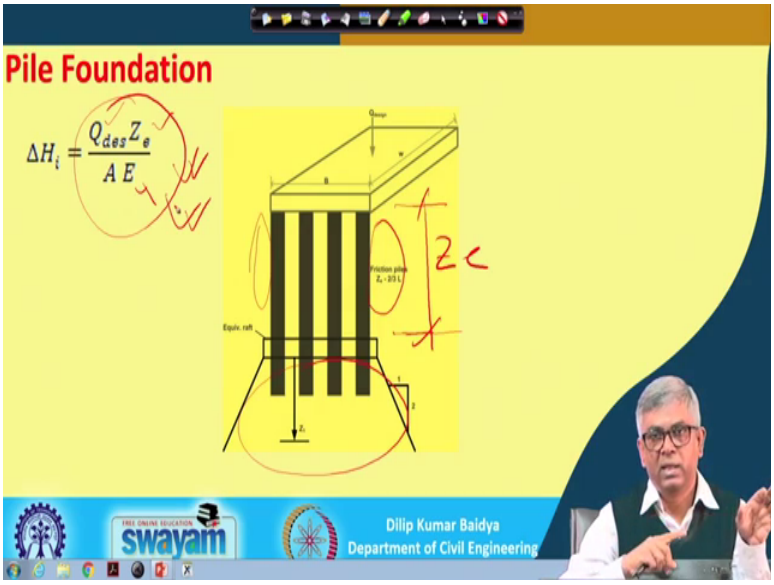

Next I will go to the another case, actually you can see of course as I have mentioned that even for group also there will be consolidation settlement, if it is a compressible soil, any addition to that there will be elastic settlement also for the group. And elastic settlement will happen, because you can see that throughout the length actually since friction is there, then there will be elastic settlement of the soil.

But, here we will consider since we have considered the raft here ok, so beyond that from here to here we have considered the consolidation of the soil consolidation of the soil in this zone. So, these zone actually, soil also will compress because of this friction, how to calculate that one you can see here this is there Q design Z e Z e is nothing but that your the where actually you are considering your this is Z e, where you are considering this that means, this depth of soil will be compressed under friction.

So, because of that depth will be taken and A E. And A is the cross sectional area of the of the raft and also E is the actually soil modulus to be taken, because so this is the one actually the elastic settlement. So, if you add this with the consolidation settlement, whatever you had done that will together will be your total settlement.

And so this is most of the time some this very frequently we use, but this is one thing that is a one component will be there that will be comparatively smaller, but one may do or may not do. So, just for that it is I am showing this equation, otherwise that when there is a while driven in compressible soil that consolidation settlement calculation become more important, so that is there is whatever I have shown in the previous equation.

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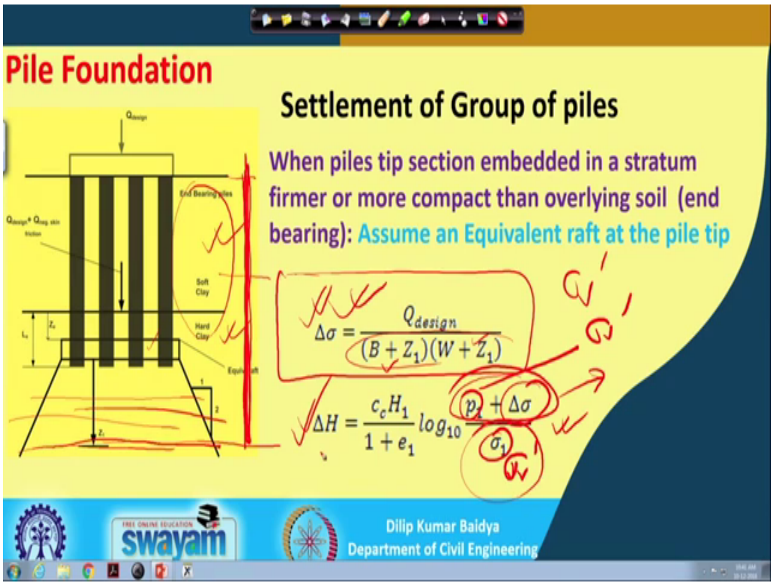

Next one actually you can see, this is another type of a system that I have told you that for calculation of a settlement you have to model the pile soil system. And one model we have done, I have shown that. When the pile is you embedded in uniform friction pile, and that to cohesive, then you have to assume a an equivalent raft at a two-third length of the pile.

But, if the soil is either suppose this is actually this zone is suppose sand, this zone is sand, and then the so pile will become this zone is sand, and somewhere there may be some will compressible layer is there or if this is a soft clay and this is a stiff clay, then there will be chance of having n bearing. So, under this situation that means this is soft clay, and this is the hard clay that is one situation or if it is sand, and there is a clay somewhere here.

Under these two cases, you have to assume an equivalent raft at the pile tip. And you can see here at the pile tip equivalent raft is considered. And after considering the equivalent raft here by a by using similar procedure that means, taking a dispersion of the load to vertical versus one horizontal, then we can find out width of the footing at any depth, so that is B plus Z 1 and W plus Z 1. Like the way I have shown in the previous one. And based on that I can find out Q divided by area, so that will be delta sigma ok, so that means, previously what we have done, we have considered equivalent raft at two-third length of the pile at a depth two-third length of the pile.

And here actually when the pile embedded in the stiff soil, then you can consider that is a the entire thing is transferred at the pile tip that means, end bearing type. And then you have to consider the equivalent raft at the pile tip. And then from the pile tip up to the compressible layer, we can find out what is the width, and then what is the length, and based on that what is the delta sigma because of the additional load of the pile. This you can calculate.

And also we can calculate what was the before applying load, what was the your what was your effective vertical stress. And suppose if that is the point if you want to find out the effective stress, then vertical effective stress, then you have to consider soil weight up to this entire depth soil weight up in up entire depth. And if in between water table there, then you have to above water table you have to take total unit weight, and below water table you have to take the submerged unit weight and based on that you have to find out delta sigma V dash.

And once you get the delta sigma V dash, we can find out the delta H that means, settlement will be equal C c H 1 1 plus l log 10. And this is actually instead of p, we can say sigma V dash, this is also sigma V dash, before applying load, and this is the delta sigma after applying. So, this is actually this sigma V dash plus delta sigma that is the effective stress after application of the load through the foundation, and this is actually effective stress before application, so that p 2 by p 1 actually that is log formula, so that same thing can be used and one can find out the compressible consolidation settlement of the layer, so that means this is a load this is a model that is actually you have to consider the equivalent raft at the pile tip. So, two option whether at either at two-third height or at the pile tip.

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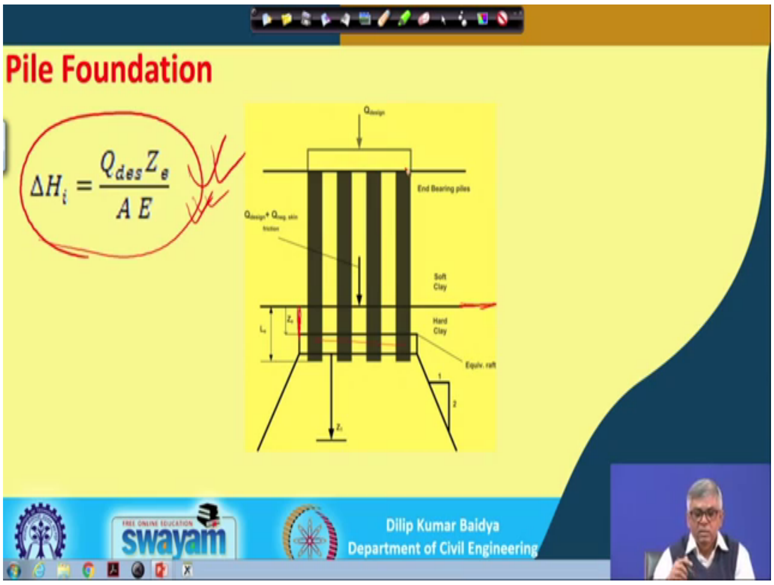

Next one again similar to this actually you can see here that elastic settlement also will be there. So, so this is the suppose stiff layer suppose this is the stiff layer, and this the pile is embedded in the stiff layer to have the bearing resistance. So, in under this condition, we have assumed that the equivalent raft will be at this depth, but because of this depth between AE is the embedded length sorry m yeah embedded in the stiff layer.

And the equivalent raft at the pile tip, suppose this distance actually sometime to be taken will be elastically settled. And for that actually you can find out another equation by similar to the previous one. Instead of taking the entire length, you are taking only this length this length ok. And for how to find out this length, there are different accommodation is there you can see from the book, generally 50 percent or 75 percent of the entire length can be taken and dc yeah this formula can be used for finding out the settlement. So, this plus that previous one will be the total settlement of the group ok.

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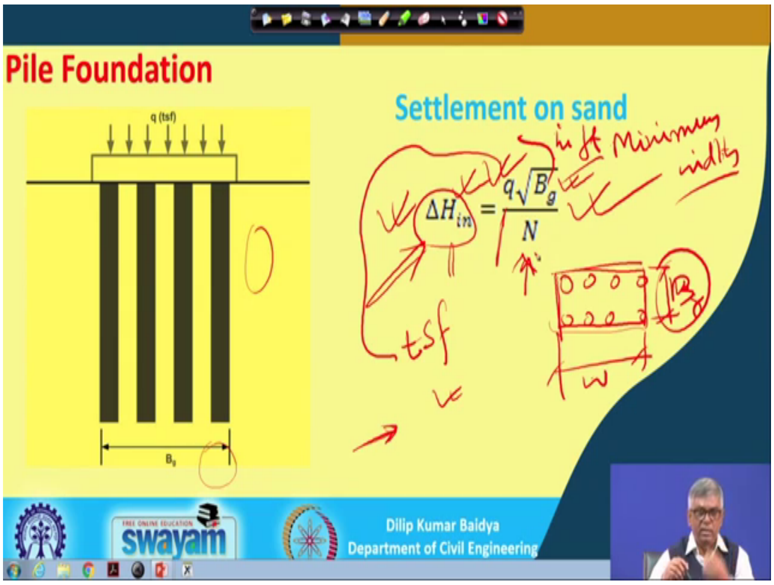

So, now let me go to the next. And when the pile is embedded in sand suppose like this you can see here that the this is also sand, this is also sand, and then maybe no compressible layer close to it. In that case, entire settlement will be because of the elastic settlement of the group.

And in that case, of course in the literature there are number of formula available, but out of that based on SPT correlation, this is the formula available in the literature a little small variation also available. So, this can be used how you can see what are those actually, you can see the expression is given that delta H will be coming in inch actually finally. And this q will be used in tonne per square feet, q will be used q (Refer Time: 24:28) unit of tonnes per square feet. And B g actually B g is what actually if there is a group, if there is a group something like this.

If this is a group suppose, so minimum width so this is actually one dimension that is our W, this is suppose B. So, two different width we are getting. So, there is a minimum one actually to be taken for calculating this settlement. So, minimum will be this one; so, B g actually minimum width of the block, and how to get the block actually, as I have shown that you have to draw tangent to the outer row of the pile from this direction, and from this direction.

And then whatever area will get that is actually your from there, actually we will get the width and length. And then q multiplied by under root B g by N. And B g actually is actually is should be minimum width first of all minimum width, so that means, whatever I have solved these and these, you have to take always this one.

And that two unit is in feet B g in feet and q in tonnes per square feet, and N actually your the SPT number. And this if you put these all those things, and based on that we will get some value that will be expressed in inch, and that will be the elastic settlement of the this is of course empirical totally. And such empirical many such empirical equations are available in the literature also.

If you have interest, you can go through this. And now so that means, we have now three different model. One is actually pile embedded in uniform compressible soil that is actually in that case, what you have to do, we have to consider the pile equivalent raft at two-third length of the pile. And then rest of the calculation like, what is the delta sigma, and what is the effective vertical stress, before applying load and then based on that one can find out the consolidation settlement.

Similarly, another model was that if the pile is driven in compressible soil, and finally rest on a stiff soil, then in that case the it will be modelled as equivalent raft at a depth at a pile tip. And then based on that model one can calculate what is the delta sigma, what is the equivalent vertical stress, and then finally using that log formula one can find out the compressible settlement.

A third model is if the soil is embedded in uniform sand, in that case it will be there because of the elastic settlement, and that elastic settlement one can calculate by using this formula. And the delta H, this is this is actually empirical formula, and it is unit dependent whatever unit mentioned here, same unit only you have to use. Other than that if you use, then you will not get the correct result.

The outcome will be in inch, and q should be used in tonnes per square feet, and B g should be used in feet. And that to this B g is the minimum width of the group, and N is the SPT block round for the soil layer. So, with this I will stop here, and I will try to show you some numerical example to explain.