Geotechnical Engineering II / Foundation Engineering
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Lecture - 39
Pile foundation (Contd.)

Well let me continue with Pile capacity. In my previous lecture I just stopped how to find out frictional sorry how to calculate the capacity of single pile. And there as I have shown that the pile at general pile general type of pile I have shown; that means, there will be frictional resistance and base resistance. And I have shown some terminologies; that means, F is unit is skin friction, S is the surface area of the pile and all those things.

And now we will go detail finally, to arrive at the capacity actually in terms of pile capacity in terms of pile dimension; that means, diameter and length and then soil properties. And then soil to pile that surface condition based on some frictional coefficient to be used; so, in terms of that finally, you to arrive at the capacity of the pile.

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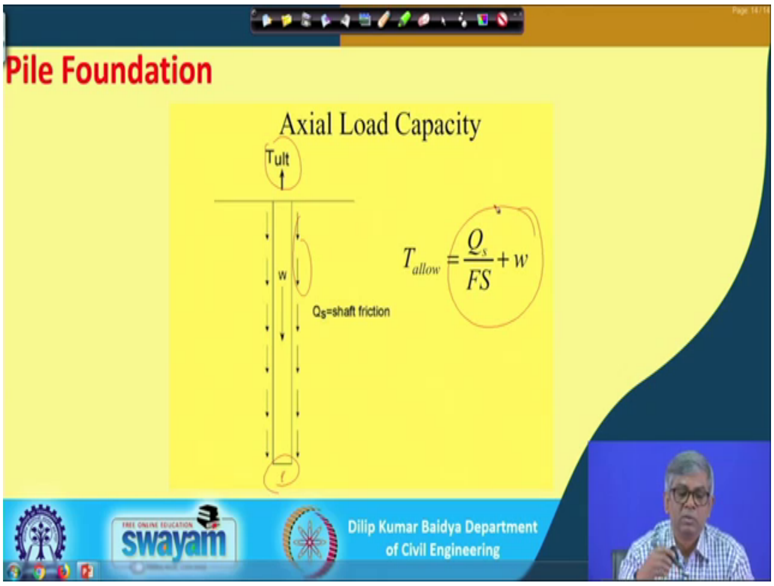

So, we will just continue with that let me. So, I have shown actually earlier that pile actually axial pile, but it is for compression. And we have seen that there was a tip resistance and there was a frictional resistance frictional resistance and tip resistance. But pile can be also used as a uplift actually tension in that case you can see here if that T ultimate applied here.

There is no chance of having tip resistance only frictional pile will be hold by friction only. If I pull like this the pile entire pile will be hold by the frictional resistance develop between the soil and the pile. So, because of that you can see on the around the surface of the pile we have the friction. And then finally, what should be the allowable tension can be applied.

So, Q s frictional resistance you have to calculate divide or factor of safety plus W, W is the load in the pile of the weight of the pile so these are the things. So, we will not discuss much because pile most of the time 99 percent actually used for compressive load axial compressive load. So, I will try to concentrate on how to estimate the pile capacity for compressive load. So, let me go to the next slide.

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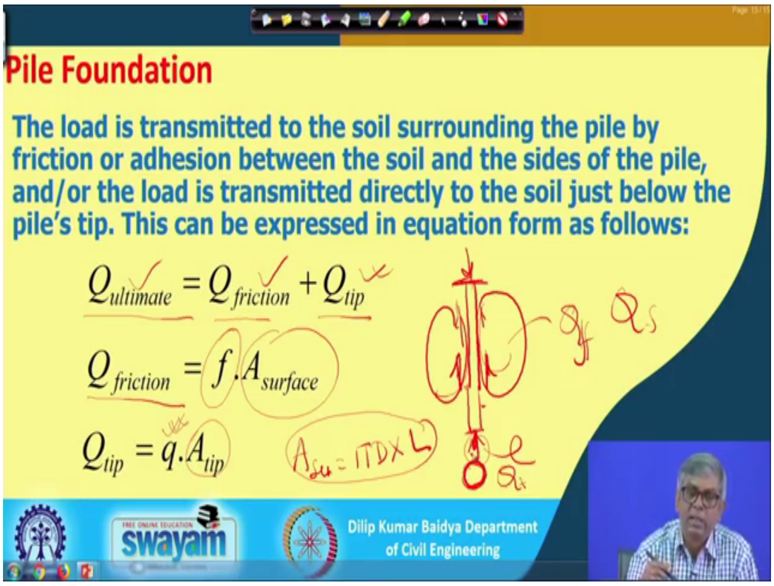

You can see as I have told before that Q ultimate will be equal to Q friction per Q tip. And the load is transmitted to the soil surrounding the pile by the friction or adhesion. That means, if there is a pile so surrounding the pile I am just showing the elevation actually so it will be like this. So, by friction or adhesion between the soil and pile there will be frictional resistance load so that will some load will be transferred here actually.

And the side of the pile and or the load is transmitted directly to the soil just below the pile tip. So, that means, they are actually directly below this load also will be transmitted. So, if I apply load here so some load will be transmitted here by frictional adhesion and some will be directly transmitted here. And these two together this is called Q tip and this is called Q friction Q f Q f or Q s Q sometime Q f means Q friction and sometime Q s also used; that means, Q skin friction.

So, skin actually the initial of skin is used sometime Q f or Q s both are same and here actually Q tip or sometime Q end also they people are using Q b also sometime Q s all those things are a similar thing. So, so; that means, in general Q ultimate will be Q friction plus Q t and Q friction will be f multiplied by A surface. So, f is the unit skin friction somewhere here actually unit skin friction; that means, what is the value.

And then you have to multiply by the surface area. If it is cylindrical pile then what will be the A surface? A surface will be equal to per cylindrical surface pi multiplied by D multiplied by L. What is that? That means, the here actually if I see this is the pile top view; that means, perimeter is pi D. And the surface vertically up to ground surface if you go that if you multiply then you will get entire vertical surface that surround the [pi/pile]- around the pile as entire area is resisted.

So, that is why the surface means entire cylindrical surface of the pile to be consider. So, A surface actually pi D into L and Q tip here Q tip actually Q multiplied by A tip. A tip is actually area of the base of the pile and Q is actually is nothing, but bearing capacity of the soil at this depth so that to be estimated. So, this is in general terminology while calculating bearing capacity or capacity of the pile you have to do this. So, let me go to the next slide.

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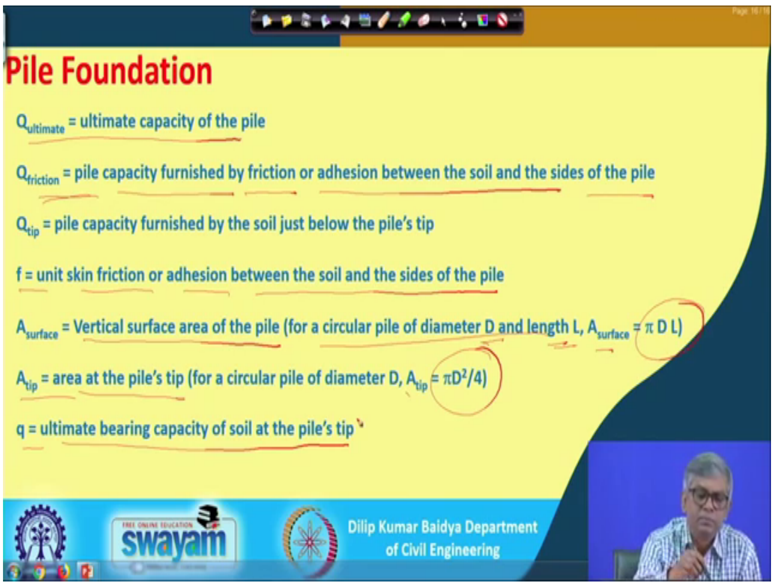

And you can see I have again elaborately defined all those term Q ultimate means; ultimate capacity of the pile Q friction means pile capacity furnished by friction or adhesion between the soil and pile and the sides of the pile. So, Q friction so Q f or sometime Q s is nothing, but pile capacity furnished by friction or adhesion between the soil and the sides of the pile.

And F is the unit skin friction or adhesion between the soil and the sides of the pile. And so what should be the unit? so ultimately that units skin friction multiplied by area you are getting the load. So that means, it will be area should be kilometre per meter square actually in the pressure unit A surface actually vertical surface area of the pile. So, that will be actually for a cylindrical with D diameter length L A surface equal to pi D into L.

And A tip is the area of the piles tip; that means, bottom of the pile what is the area. And if it is a uniform cross section throughout the length of the pile then pile tip will be equal to the diameter of the pile itself. So, a tip will be nothing, but pi D square by 4 cross sectional area of the pile. And Q is the ultimate bearing capacity of the soil at the piles. So, we have learned actually bearing capacity of the soil for shallow foundation and you know the pile is a deep foundation and it where shallow foundation actually used to be at within 1 or 2 meter.

Whereas, deep foundation or pile foundation will be beyond 10 meter depth actually most of the time; so, it will be 10, 15, 20, 30, 40, anything it can be. So, at a great depth bearing capacity calculation will not be same as we have done in the shallow foundation bearing capacity. So, what are the bearing capacity at the ultimate bearing capacity of the pile tip that has to be also learned. So, we will discuss that also.

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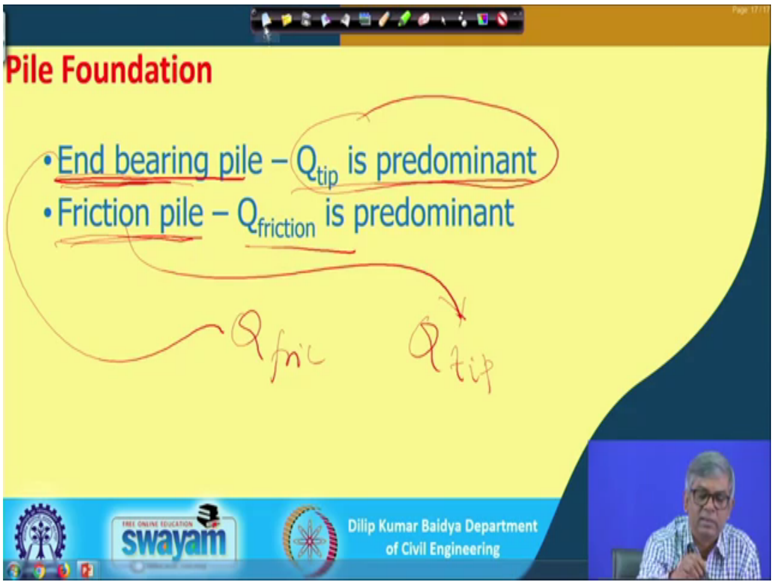

And you can see here we have discussed in general that pile will have a resistance from the surface surround the surface and the base. But and also we have classified different term end bearing pile, friction pile, and a general type of pile. And you can see here it is my end bearing pile end bearing pile Q tip will be predominant. So, though sometime we send many pile; that means, a pile will be resting on a very stiff strata or on rock.

So, in that case it will have actual capacity will be coming from the pile tip only. But sometime some amount of resistance will be there from the side also. So, in general we can say when it is end bearing pile we can say Q tip will be the predominant. That means, larger quantity of resistance will come from the base of the pile. Whereas, is the friction pile when it is a friction pile the friction is predominant the friction pile though it is a friction pile.

And throughout the depth actually friction resistance the, but ultimately pile resting on the some soil. So, that whatever may be the soil because of the bearing capacity of the soil some resistance also will be at the tip, but that contribution from the tip for friction pile will be some time negligible or small compared to the frictional resistance. So, because of that we can say for frictional pile that Q friction is the predominant. So, you have Q friction.

And Q tip the two component for each pile where the end bearing pile this is predominant. And the friction pile this will be predominant that is the one thing I wanted to mention here. So, sometime we ignore so when it is a end bearing pile Q friction we ignore and when it is a friction pile sometime Q tip we ignore so that is the point I wanted to highlight here.

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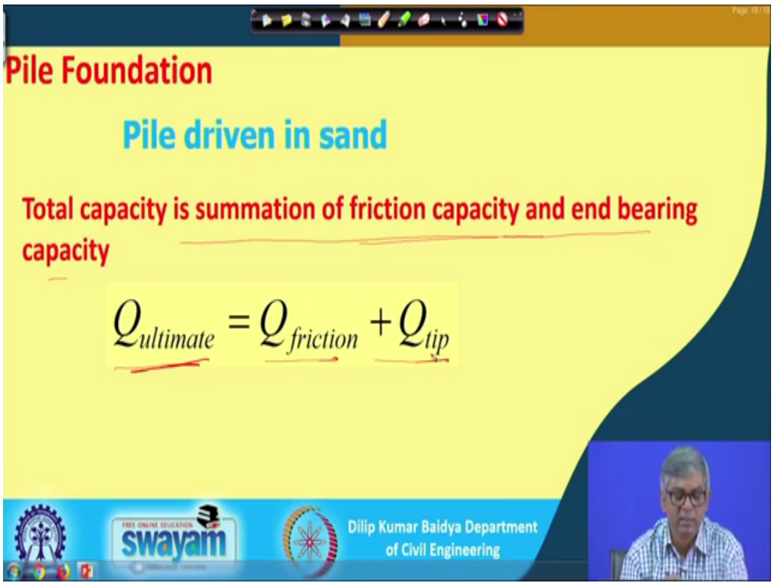

Now, pile driven in sand; so, again as I have mentioned that I had to find out the capacity of the pile. Then pile when it is driven in sand and pile driven in clay capacity will be different and calculation everything will be different. So, because of that one by one I will take.

First of all I take pile driven in sand how to find out the capacity and what should be the capacity finally, outcome will be there. So, let me see here actually total capacity again is the frictional capacity and friction capacity and end bearing capacity. So, Q ultimate will be Q friction plus Q tip these two things we have to estimate.

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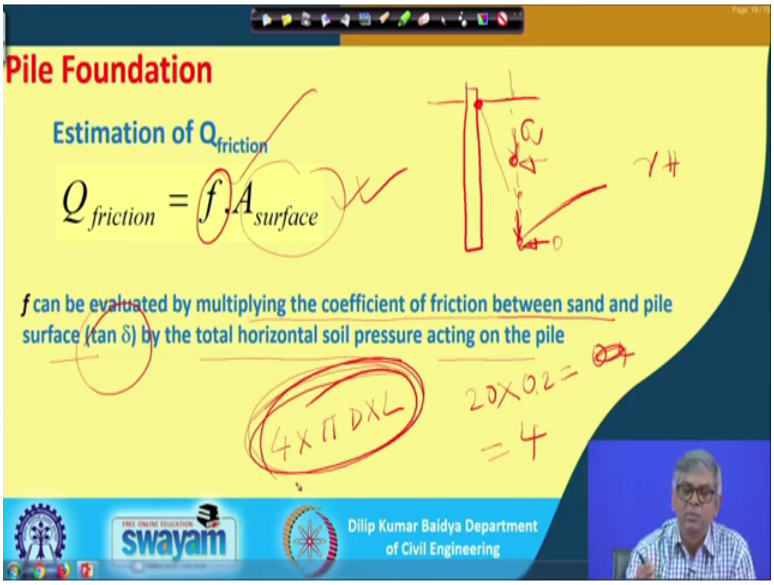

And next one you can see that Q friction will be f multiplied by A surface already I have mentioned f multiplied by A surface. A surface already if it is cylindrical per pile then you know the what is the A surface. But f to be estimated f can be evaluated by multiplying the coefficient of friction between the sand. And pile surface that is called tan delta by the total horizontal soil pressure acting on the pile.

So; that means, if there is a pile is driven something like this and as usual because of the soil pile there will be vertical pressure. So, different depth there will be different vertical pressure. What is the vertical pressure here? That will be gamma times h actually suppose if the height is h. So, vertical pressure is gamma time h. And then coefficient of lateral earth pressure if you multiply then there will be then vertical pressure form.

Initially we get vertical pressure from their multiplying by multiplying by the lateral at pressure coefficient then you will get the horizontal pressure. And after getting horizontal pressure you multiply by tan delta ok. If that your lateral pressure is P suppose 20 then multiplied by tan delta suppose 0.2 then your fraction will be 0.4 not 0.2 it will be 4. So, unit skin friction will be 4 and then capacity will be equal to 4 multiplied by pi this pi D multiplied by l.

So, this will be the capacity frictional capacity. So; that means, here to calculate the frictional resistance A surface is known already you have to find out f. How to find out the f? First find out the vertical pressure so along the length at different depth you find out the vertical pressure. Then by multiplied by the lateral earth pressure coefficient you find out lateral pressure. Then multiplied by the frictional coefficient that is tan delta that will be your units skin friction.

Now, if the unit skin friction is constant throughout the depth then we can find out the capacity like this. But your unit skin friction will not constant mainly because if I change from here to here now then sigma b will be less here then lateral earth pressure will be constant. So, the horizontal pressure will be less here and if you multiply by another constant then ultimately your unit skin friction will be lesser than at this step. So, that means and at the step at the surface your vertical pressure is 0 lateral pressure also will be 0 multiply by coefficient of friction then it will become 0.

So, that mean unit skin friction will be 0 here and it will be maximum here. So, it may varies by some means generally it can vary like linearly that we can show you later on. So that means, unit skin friction will be varying by some way and then if it vary then we will not be able to estimate the capacity like this. If it is a constant then pi DL the surface area multiplied the constant frictional resistance. Multiple variable then you have to do something else that I will show you later on.

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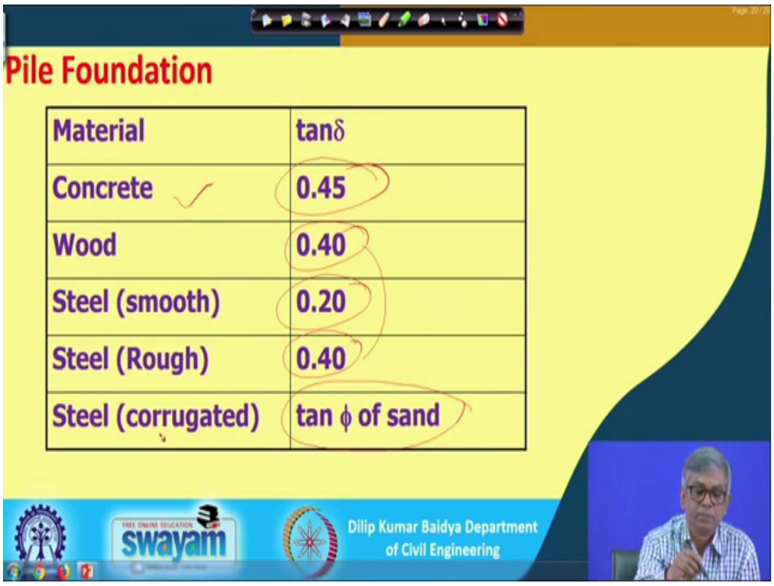

Material	$\tan\delta$
Concrete	0.45
Wood	0.40
Steel (smooth)	0.20
Steel (Rough)	0.40
Steel (corrugated)	$\tan\phi$ of sand

And you can see as I have mentioned that between the material and the soil type your tan delta will vary. That means, what I have said smooth pile and then cohesive soil smooth pile and cohesion less soil. Similarly, rough pile with cohesive soil rough pile with cohesion less soil. So, then there are so many combination like that so you can see in general if there is a material generally most of the time based on material actually fix the tan delta and it can be vary little bit in between.

And so if the you can see here material based on concrete generally we take a value of tan delta equal to 0.45 if it is wood slightly less 0.4. If it is steel then it will be steel less 0.2. And if it steel with rough steel then it is again same as concrete 0.4 and steel corrugated then it will be equal to tan phi of sand. Whatever 5 value there on the sand then we will find out tan phi will be equal to tan delta when corrugated steel pile is used.

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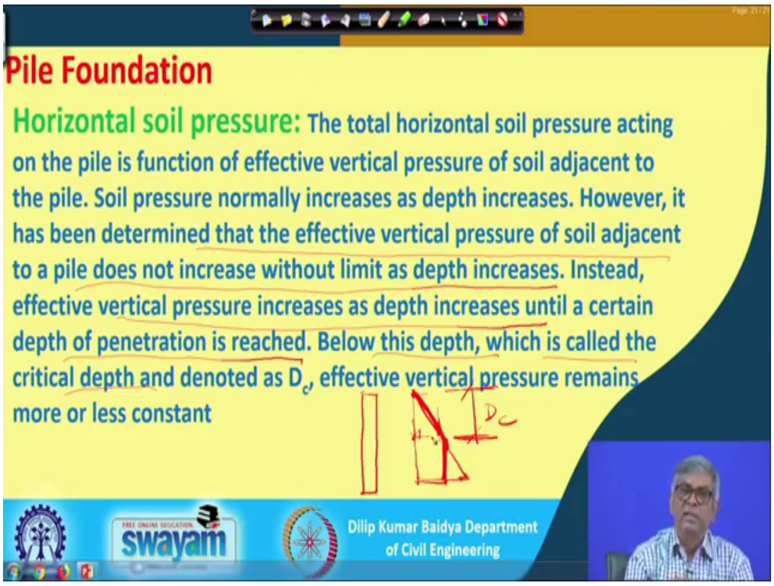

And horizontal soil pressure this is the one very important as already I have explained that way. And you can see that horizontal soil pressure this is the pile, 1 second I will do here. And at this point suppose I want to do horizontal pressure at this point vertical pressure 0 then horizontal pressure also 0. At this step horizontal vertical pressure will be some value horizontal pressure also bigger than 0.

So, maybe suppose the value is somewhere here. So, I can this will be definitely linearly varying gamma times h it is a linear. So, it will go this to this. And if I now reach here then definitely value will be something like this so it will be like this. So, lateral pressure actually is continuously increasing ok, but for calculation of unit skin friction we will not consider this concept. You can see the total horizontal soil pressure acting on the pile is function of effective vertical pressure of soil adjacent to the soil.

So, that means what is the vertical pressure horizontal pressure lateral pressure it depends on the effective vertical pressure that already I have told you. First of all you find out vertical pressure, then multiply by the lateral earth pressure then you will get the horizontal pressure. Now; however, it has been determined that the effective vertical pressure of soil adjacent to the pile does not increase without limit as depth increases.

So, this lateral pressure for the pile in fact, may be it may increase. But for calculation of capacity will not allow or will not take that in increasing up to the pile length. So, that is what it is without limit actually it do not increase. So, that is what it is mentioned instead effective vertical pressure increase at a depth increases until a certain depth of penetration is reached. And below this depth which is called the critical depth.

That means,; that means, that variation of horizontal pressure adjacent to the pile increasing linearly up to up to depth and then we keep it constant. So; that means, instead of this way if I imagine that up to these the horizontal pressure is increasing linearly and from here to here I will keep constant. So, then horizontal pressure diagram become like this your horizontal pressure diagram become like this.

And depth up to which we are considering the variation of lateral pressure that is called critical depth. So; that means, instead of considering the horizontal pressure increasing up to the length of the pile bottom of the pile will restrict the variation of lateral pressure linearly up to a particular depth. And that depth is called critical depth and beyond critical depth we consider that lateral pressure is constant. And this critical depth how it will be determine there is a guideline I will tell you in the next slide.

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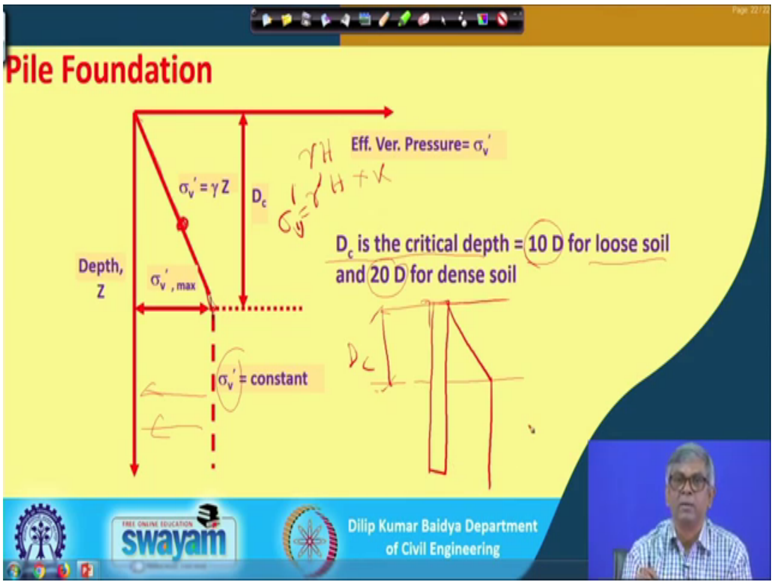

You can see now the diagram again drawn here where neatly. You can see here if I calculate sigma V dash at any point suppose here. Sigma V dash if I calculate here how what will be here it will be if it is no water table if it is no water table it will be gamma times H. And if it there is water table some it is under water table it is gamma some are time being because it is effective vertical stress you have to calculate actually effective vertical stress ok.

And then lateral pressure actually will be multiplied by whatever K value. If you multiply then it will be a lateral. So, if you multiply then you will get the horizontal pressure and this vertical pressure actually instead lateral pressure actually we do not know we know only vertical pressure. So, if I restrict the vertical pressure then automatically I can restrict the horizontal pressure because lateral earth pressure coefficient is constant. So, that is what it is shown that whatever I have discussed in the previous slide that variation of vertical pressure will be increases linearly up to some depth that depth is called critical depth.

And beyond depth it is called it is taken as constant that is sigma V dash at this depth whatever value get we keep it same everywhere. And this D c is the critical depth as I have mentioned and approximately it can be estimated 10 times the diameter of the pile for loose soil and 10 20 times diameter for dense soil. So that means, this D c how much depth up to how much depth this linear variation will consider when loose soil we will consider only 10 times diameter of the pile whereas, if it is dense soil then we will use 20 times the diameter of the pile ok.

So; that means, if there is a pile if there is a pile like this and you will see the soil condition. And based on that I will fix the at critical depth and then I will draw the vertical pressure diagram. And then using this diagram I can find out the capacity of the pile.

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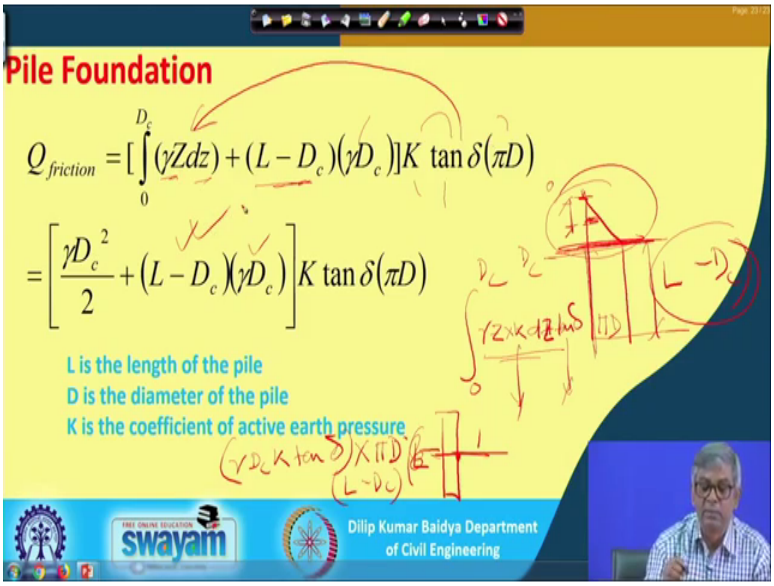

You can see now if the variation is like that if the variation is like that you can see if you are variation something like this; that means, at any depth at any depth if I take a small small length, then it will be at this depth actually vertical pressure actually gamma times Z. And then if I multiplied K then it will be lateral pressure then if I multiply by D z then it become force.

And then if I multiply by tan delta then it become unit skin friction. And now I have taken this z as a variable. Now, if I integrate this one from 0 to suppose D c 0 to D c ok. Then I will get the because of the friction the load taken by the pile is I can find out. So, that is what it is shown here actually you can see. First one integrated 0 to D c and see out of this. So, many variables K is constant tan delta also constant.

So, K and tan delta I have taken out. And after getting the unit skin friction what we have to do we have to multiplied by pi times perimeter. Because length already variable we are taking length is variable length is coming by integration only what. And I am suppose if the if this is the pile I am considering at a one point. Then the around the pile there will be n number of points.

So, how to consider that, but just by multiplied by pi D. So; that means, this multiplied by this pi D will be actually your skin friction for this small element. But if I want to find out from 0 to D c then we have to integrate. So, if that is what it is shown integration symbol is 0 to D c gamma z D z actually multiplied by K tan delta pi D.

So, this is one part this is one part whatever I up to this. And beyond these beyond this actually what happen if the length of the pile is L and critical depth is D c. So, remaining depth from here to here actually this is L minus D c. So, length you have got L minus D c and the lateral pressure is gamma times this is this is actually vertical pressure gamma time D c.

And then multiplied by K then it becomes horizontal pressure. Then multiplied by tan delta and pi D then I will get your. So, L minus D c already I have taken here. So; that means, from here to here if I want to find out what I could have done I could have done; gamma time D c multiplied by k multiplied by tan delta that is constant this part is constant throughout the depth.

So, because of that you can multiply by actually length pi D into L pi D pi D multiplied by L is how much here? L actually L minus D c sorry L minus D c. So, that is the thing is done here L minus D c gamma times D c sorry L minus D c gamma times D c and tan delta pi D is they are outside k pi tan delta is outside.

So, there are two components; that means, we are integrating from here to here one part and then here actually unit skin D friction throughout the depth is constant. So, that is what; L minus D c gamma D c k tan delta pi D this is. So, so that way if I simplify now or I can write differently may be two part that will be convenient for you.

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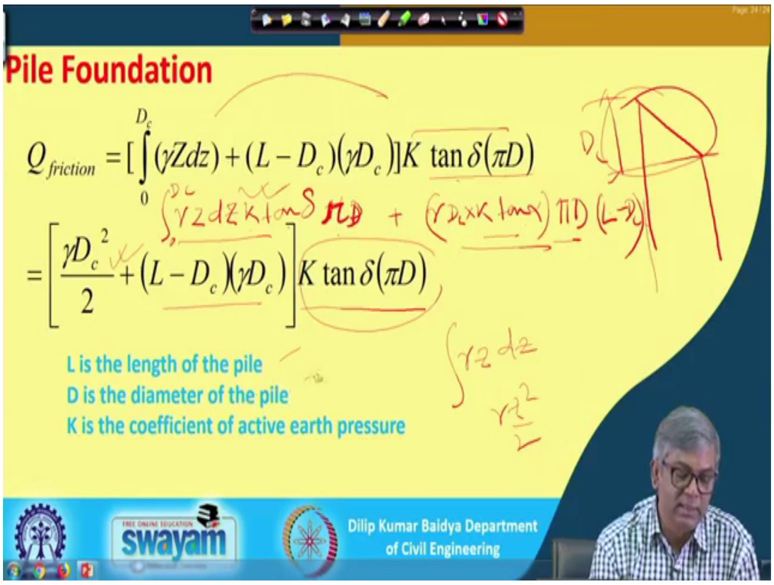

Let me write once again let it be clean. So, it will be gamma times z D z multiplied by K tan delta pi D and this will be 0 to D c so; that means, when I am considering this is D c. So, this one this one give you this is pi actually this is pi this is pi times D. So, this is giving you load from here to here.

And remaining depth here actually unit skin friction will be constant. So, unit skin friction will be how much this will be plus gamma time D c multiplied by k that become unit skin friction. And multiplied by your tan delta that become unit skin friction. And then if this is constant then surface area you have to multiply surface area will be pi L minus D c pi multiplied by D multiplied by L minus D c.

So, you can see these two this part was written. So, these plus this is nothing, but this actually I have little differently I have written here because these are the common thing K tan delta pi D you can see K tan delta pi D common. Here also k tan delta pi D is common so because that is taken out and this is kept inside this is kept and this is integral. And if you do integrate filter you integrate this ultimately you get gamma D c square by 2 plus L minus D c gamma D c and K tan delta pi D so this will be outside.

So; that means, you are getting this one this expression is giving you the skin load taken by pile because of the skin friction only and that too when the pile is driven in the sand ok. So, what you have to remember gamma D c square by no need to this remember if you calculate this way based on the fundamentals actually you do this way and this way.

And then if we integrate this one ultimate and you keep this thing outside then you will get is gamma z actually gamma z D z.

So, gamma z D z actually if you integrate so it will be gamma z square by 2. And then if you put limit so ultimately gamma D c square by 2 that is what it has come and here actually there is no variable. So, L minus D c gamma D c is there k tan delta pi D. So, this is actually that skin friction of the pile. Now, you have to find out so L is the length D is the diameter k is the coefficient of active earth pressure or lateral pressure. Next we have to find out the base resistance.

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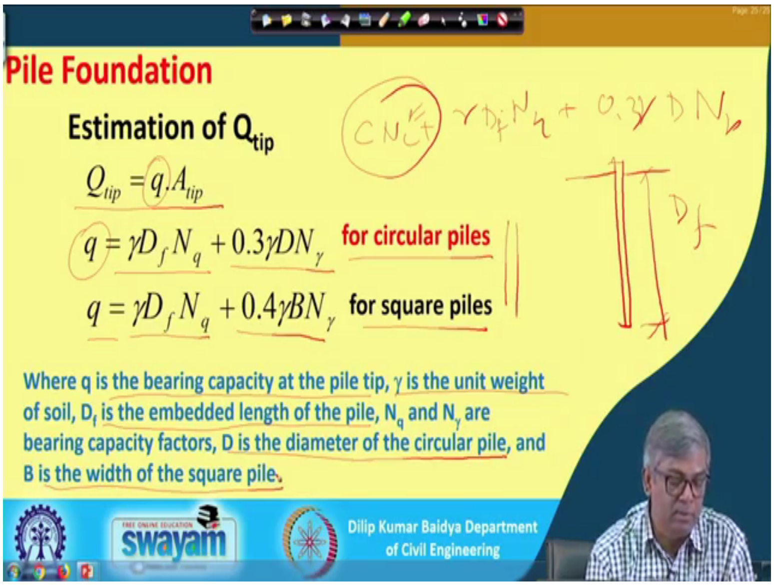

And you can see for the base resistance Q tip will be Q times A tip. A tip actually you know the if the diameter of the pile same as the bottom A tip is nothing, but pi D square by 4. So, Q is important to find out Q will be actually if it is I have consider pile driven in same then cohesion part is not there otherwise you could have written CN c plus gamma D f N q plus 0.3 gamma DN gamma I could have written.

So, since it is a cohesion less soil then because of this part is 0. So, both the cases actually CN c is not there. So, that means q ultimate for cohesion less soil is gamma D f N q plus 0.3 gamma DN gamma for circular pile you have learned in the bearing capacity of the soil shallow foundation. Similarly q equal to gamma D f N q plus 0.4 gamma BN gamma for square pile this is also we have learned in shallow foundation or bearing capacity.

So, these are principally they are same and there are lot of theories available for bearing capacity estimation of pile, but we will not go in detail. But what final recommendation is given which will be useful for you that I will discuss and here actually I will give you whatever notation used that I have explained; q is the bearing capacity at the pile tip, gamma is the unit weight of the soil D f is embedded length of the pile.

That means, if this is the pile this is the pile and this is here this is actually D f. So, embedded length of the pile N q and N gamma are the bearing capacity factor, D is the diameter of the circular pile and B is the width of the square pile ok. Width of the square pile or even if it is circular; that means, it will be a similarly diameter.

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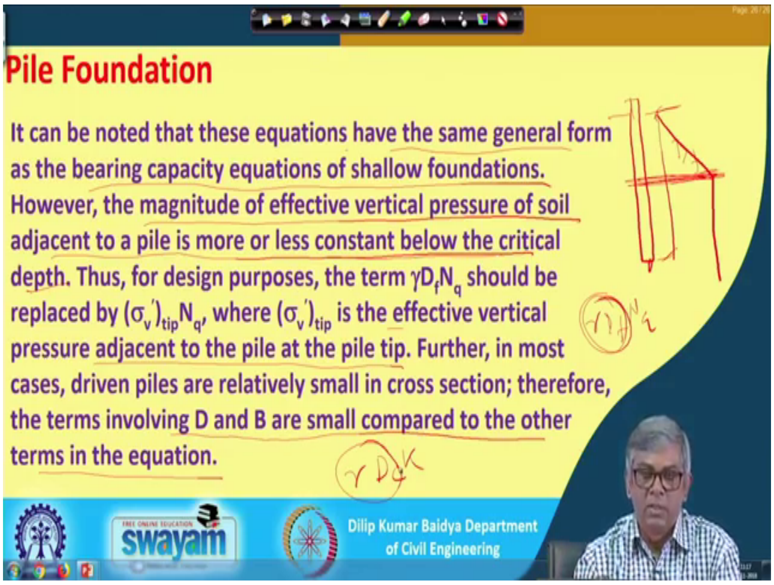

Now, you can see here some discussion I have made here. It can be noted that the equation have the same general form as the bearing capacity equation of shallow foundation as I have already mentioned. The magnitude of effective vertical pressure of soil adjacent the pile is more or less constant below the critical depth is not.

So that means, if the pile is here and this is here I am considering D f then here actually gamma times D f N q that we are considering as I have mentioned that already previously that adjust the pile more or less critical depth is constant. So, we to a take pressure diagram something like this is not. So, instead of gamma D f N q what we can take gamma D c actually that is what that is for design purpose the term gamma D f N q should be replaced by sigma B dash tip N q where sigma B dash tip is the effective vertical pressure adjacent the pile at the pile tip.

And how to do that? As we have restricted horizontal pressure here same pressure will be here so; that means, it will be nothing, but gamma times degree centigrade gamma time D c multiplied by k. So, that is the effective pressure at the pile tip. Further in most cases driven piles are relatively small in cross section. Therefore, the terms involving D and B are small compared to other terms in the equation.

So, you can so; that means, whatever equation two terms we have got we have got one gamma D f N q. And another is 0.4 B gamma N gamma. So, instead of gamma D f you have to take gamma D c that is one thing. And second thing is the second part point three b gamma n gamma that part and the first part gamma D f N q that part if you consider and you will see that the second part value is quite negligible. So, because of that what sometimes we what we do we consider the bearing capacity of the pile.

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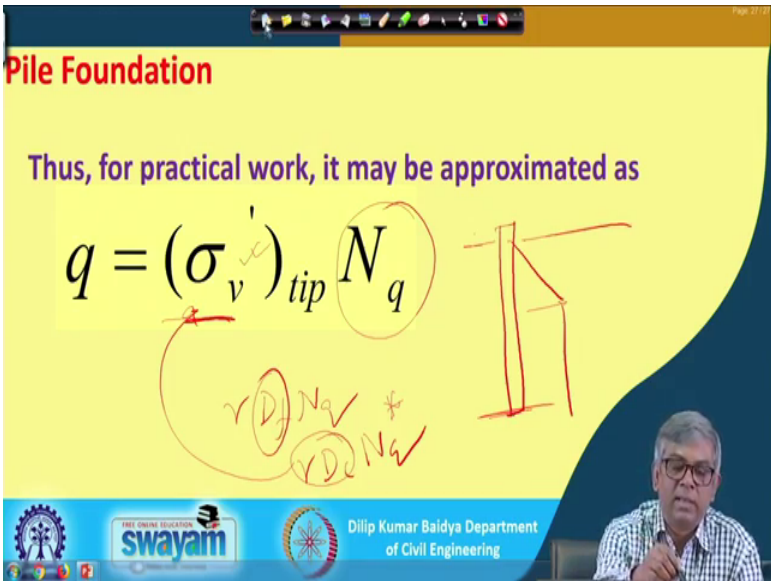

We express by this equation we consider q equal to sigma v dash tip N q. And this N q is not the same N q of shallow foundation N q. We will discuss that actually the a subsequent lecture. For the time being I will tell you that sigma v tip means if there is a pile something like that then gamma D f actually has a your equation says gamma D f N q. .

But instead of we take since it is restricted so it will be gamma D c N q to be taken and then instead of N q then we can say N q star and this gamma D c actually nothing, but this one. And, N q to be estimated separately for deep foundation whatever we have learned N q N c for shallow foundation that cannot be used here because, of this depth effect the value will be different it will be more.

In fact, and that thing I will discuss in the next part. So, for the time being as I have mentioned that pile capacity will have two components. One is the frictional component another is base resistance component. When frictional resistance what is the value? Frictional and base resistance what is the value separately you have calculated and these two, if you add then that become the pile capacity. I will take that part in the subsequent lecture; with this I will stop here.

Thank you.