Geotechnical Engineering II / Foundation Engineering
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Lecture - 40
Pile foundation (Contd.)

Hi once again let me continue the Pile Foundation. And we are discussing pile foundation various aspect and then I have just stopped in my last lecture that pile capacity and that too pile capacity of single pile and again that too restricted to pile capacity of single pile and that is that too in driven in sand.

So, that is the very specific; that means, single pile driven in sand, what would be the capacity, how to determine that is somehow I have done something. And, let me continue from there and to and discuss about that point and then next to that, I will take capacity of the pile driven in clay also.

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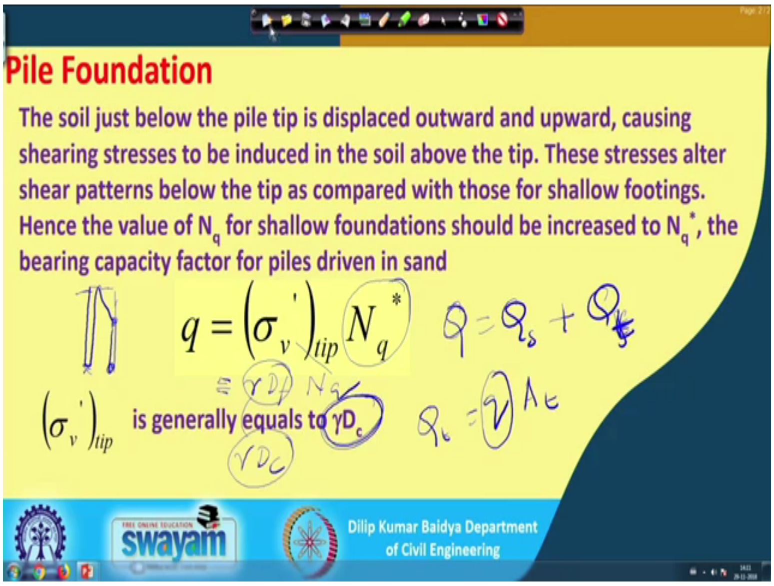

So, for these let me see the first slide and perhaps we have discussed that we have discussed that Q will be equal to Q s and Q f sorry Q s means Q s or f that is friction or skin and Q t; that means, tip. And, Q tip will be nothing, but and Q s will be I have shown the detail procedure and Q t will be nothing, but q multiplied by base area; so, area A t.

And to find out Q that bearing capacity at the base of the footing, we have shown that that same bearing capacity formula; that means, cN c plus gamma d f N q plus half gamma v n gamma or 0.3 v gamma or 0.4 v n gamma v gamma n gamma that depending upon stiff circular and square.

And, then and we have seen that that compared to that your surcharge as that bearing then since we have considered only a pile driven in sand that cN c part is absent. And, then between surcharge part and unit weight part, again we have seen that the unit weight part, again that will be very very may become negligible, because of the small size compared to the surcharge component.

So, because of that we decided to ignore that gamma half gamma or 0.4 gamma or 0.3 gamma b n gamma that component we have ignored then ultimately Q will be having equal to is nothing initially will be Q will be equal to gamma D f, N q and then this gamma D f actually; D f is the depth of embedment. And, if there is a pile something like this and as I have we have discussed that that your pressure the lateral pressure instead of increasing linearly, it will increase up some depth and then it will become constant. So, that is why we have considered that instead of gamma D f, we have decided to take that gamma D c ok.

So, that is actually it is in general term sigma v dash tip, that is nothing, but gamma c gamma D c. And, then N q whatever N c N q N gamma we have got in shallow foundation and since that deep foundation because of so, much of confinement, that failure pattern here will be something different than the shallow foundation. And, as a result this bearing capacity will be more. How to reflect that? That N q must be greater than that? So, that is why the N q whatever we have got from the shallow foundation here N q will be big larger and that N q instead of N q now we are using N q star to differentiate from bearing capacity of shallow foundation N q.

So; that means, sigma v dash tip so; that means, whatever pressure here this here also same pressure, that is why we are writing in general sigma v dash tip N q star and sigma v dash tip is nothing, but gamma time D c that is what already we have discussed before and N q will be replaced by N q star. How to find out N q star, we are not going in detail only thing whatever recommended by the past researcher and for calculation that I will show and which you can be used. So, for that let me go to the next slide.

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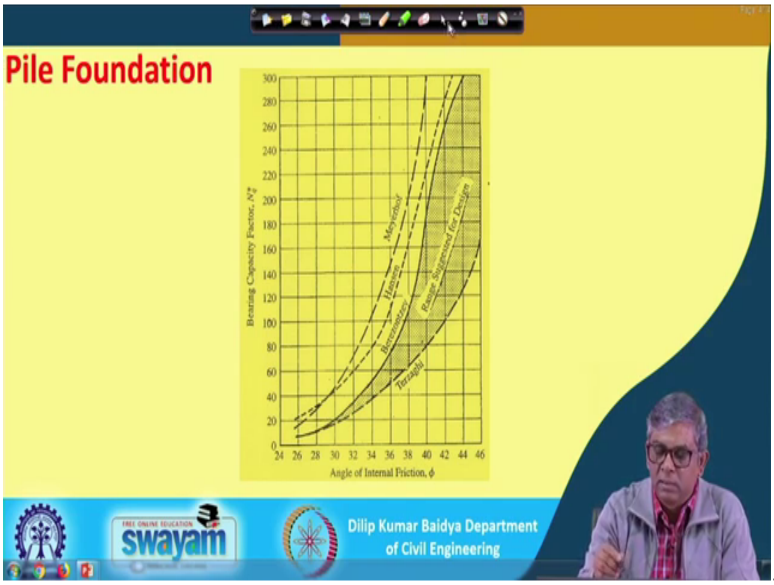

And you can see that different people actually gave that bearing capacity factor N q star versus angle of internal friction phi, and you can see that terzaghi gave this value, very less; that means, which is very conservative and (Refer Time: 05:34) is given this value Meyerhof given this value, Hansen is given this value, these are the different curves of N q the phi value.

So, ultimately it is suggested that anywhere actually if you draw an average line that can be taken as N q star, sometime some people also given in the tabular form. So, from in here in between these 2 curve anywhere we can suppose from this y equal to 42 degree according to this we are getting some value and according to this something value so, in between average value can be taken. So; that means, N q star can be obtain from this chart or somewhere there will be available in the form of table also that can be also utilized.

So, in the exam generally if this type of problem is there generally N q value will be given; you do not have to worry about it. So, the ultimately; that means, your bearing capacity or capacity of a single pile will be skin friction part, and then your tip resistance part, and fiction part we have shown how to find out and tip part how to find out the both we have shown.

Now, if you if you add together and then you will get the actual capacity ultimate capacity of the single pile driven in sand. So, that one let us go to the next slide you can see this is the thing we have shown.

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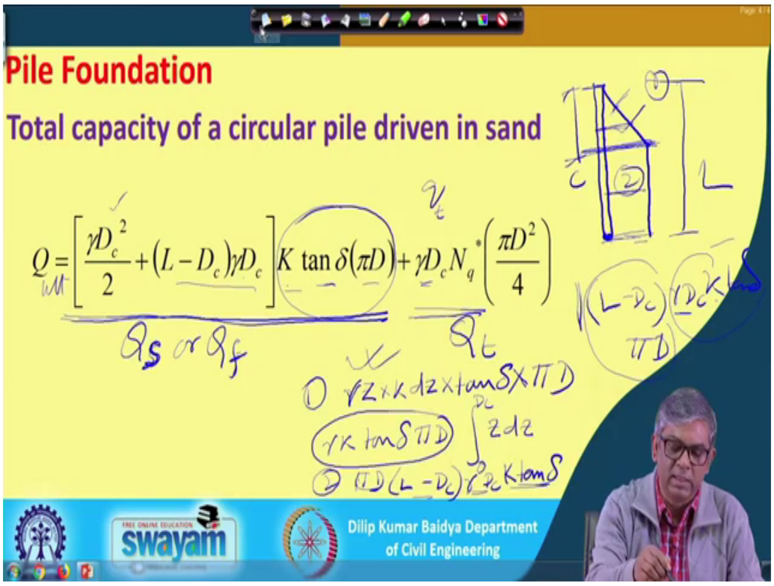

So, from here to here from here to here this part actually because of this is you can say Q s or Q f both sometime we are using, Q s means skin friction and f is only friction. So, both are same either Q s or Q f and this is actually Q t.

And, how to get this one actually we have shown already once again I will repeat so, that it will be easy to understand for you. So, I have shown the pile here and then I have to draw the lateral pressure diagram and then vertical pressure to lateral pressure. So, pressure diagram will be something like this. And, if it is shown then what how we can do it, I can take a small element here. And, on that element actually you see some at depth z at a depth z.

So, it will be sigma will be gamma times gamma sigma will be gamma times z ok. And if you multiply it by k then it will become lateral pressure and then if you multiply by dz so that become force. And then you have to multiply the friction. So, you have to multiply by tan delta to get the actual frictional resistance force multiplied by tan delta.

And, we are I have consider one point here, but if you consider around surround the pile, but around the pile entire area perimeter, then what we have to do number of points actually there instead of considering one each. So, we can multiply to consider the entire perimeter I can multiply by pi D.

And, so, these are actually so, these are these are the thing. So, what are this is the variable only z is variable. So, it will be gamma then k, then tan delta, then pi and D all will be constant. So, I will take out an integral sign z d z and that is suppose 0 to D c. So, that means, this is D c and if you see if you multiply if we integrate then it become z square by 2; so ultimately D c square by 2.

So, you can see gamma d c square by 2 multiplied by k tan delta pi D whatever is there. So, this part so, up to this up to this by this integration is coming that is gamma D c square by 2 k tan delta pi D. And from here to here how to get that will be equal to if total length is L, if the total length will L. So, L minus D c that will be there and here actually pressure is constant gamma times D c and then k, then tan delta, we are doing and then that is 1.2 we have considered and since it is a constant.

So, what you can do we so, so gamma D c so, at any point actually gamma D c into k tan delta is a friction, and then if I consider entire perimeter then you have to multiply again pi D, and then and 2 consider from here to here. So, you have to multiply by length. Since, it is a constant no nothing everywhere it will be same. So, simply you multiply by L so, L L here actually L minus D c. So, it will be L minus D c so, this part. So, from here to here it is actually L minus D c multiplied by gamma D c and K tan delta and then pi D of course, will be there.

And, you can see L minus D c is there here gamma D c gamma D c is here, L minus gamma D c and K tan delta pi D it is common for both so, because of that it is kept outside. Otherwise so, I can I can instead of remember if this in the form of formula, simply I can consider this is 1 part 1 I can consider this as part put 2. And, this is part 1 and this is part 2 and if you sum it then you get from here to here that is Q s.

And, then this part is you can see here actually sigma at the pile tip is gamma times D c as I have mentioned that, it has to be restricted up to critical at beyond critical depth. And so, gamma D c time N q star is the your Q, that is that is actually Q base Q t. And, then if you multiply the area then you are getting the Q t. So, these two together ultimately you are ultimate this is actually Q ultimate this is actually Q ultimate. So, Q ultimate become summation of Q s and Q t; so, how to find out that I have shown here.

Now, if there is in between if there is a water table up to surface, then instead of gamma it has to be used gamma submerged. And, suppose if the water table is our surface, if it is somewhere here then up to this full gamma to be taken and beyond this you have to take gamma submerged. So, because of that corresponding pressure diagram you have to do and then you have to integrate may be in 2 and 3 parts. So, that part I will show you with the numerical example.

Otherwise, the up to critical depth your lateral pressure will vary linearly and beyond that it will be constant. So, this part actually your fiction will be different at different depth. So, because of that to get the effect cumulative effect you have to integrate it, because at different depth different value. So, you can imagine that infinitely small depth we consider at that depth you calculate what is the friction. Like, that you can add and so, if you want to add those things small small things what is the best way to do by integration.

So, that is the thing we have done here by this and this part actually since is constant. So, surface area and what and friction actually constant throughout the depth here.

What is that gamma D c time K times tan delta is the constant? So, constant pressure multiplied by cylindrical surface. So, cylindrical surface is how much? L minus D c multiplied by pi D. So, that is the surface and this is the friction. So, that if you multiply then it if you add 2 then you will get the Q t. So, this is the way to be estimated. So, you have to if you see some numerical problem perhaps it will be further it will be clear.

So, let me see next slide.

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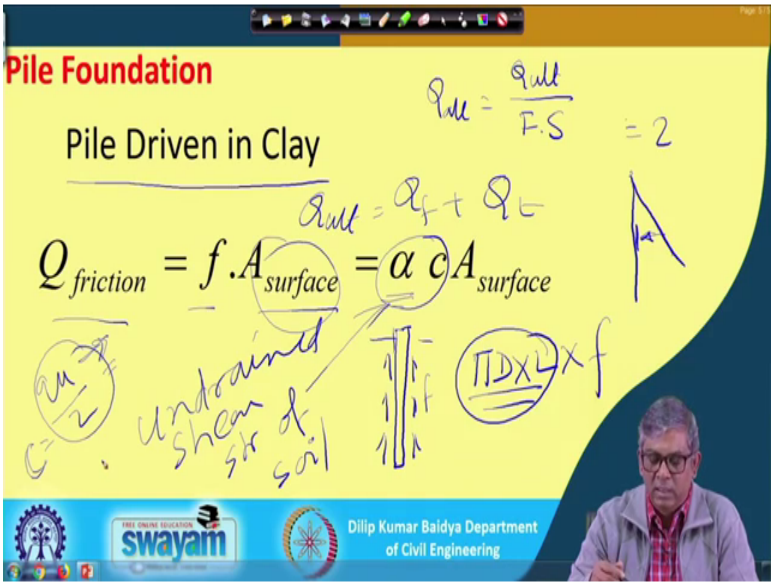

So, now actually we have done already pile driven in sand. So, Q ultimate we have got and if you want to get Q allowable that is Q allowable generally, Q ultimate divide by factor of safety. And for single pile for single pile when you calculate the ultimate and to get the allowable generally we use factor of safety equal to 2. So, you can just half whatever estimated value will come half of that will be taken as the allowable value and that to be used in the design.

Whereas in shallow foundation bearing capacity bearing capacity factor actually factor of safety we use in bearing capacity of shallow foundation between 2.5 to 3 not less than that, until unless it is specified less important problem. So, that will be less value will be used otherwise shallow foundation factor of safety 2.5 to 3 whereas, this type of problems single pile when I want to find out allowable pressure, or allowable load, then Q ultimate divided by factor of safety and that factor of safety is 2 for single pile.

Now, let us take pile driven in clay soil again it will have two component that is Q ultimate will be equal to Q f plus Q t both will be there. And so, Q f nothing, but Q f friction here actually friction multiplied by a surface. Suppose, if there is a friction pile it is a like that and you have friction like this and friction like that; so, f is constant throughout the depth.

Then what I will do? I will find out area of the surface area of the pile what is the surface of the pile? So, surface area pi multiplied by D is the perimeter multiplied by L this is the surface area and multiply by f that become your Q f and see pi D L here actually it is written as a surface. So, a surface multiplied by f and A f actually most of the time for cohesive soil will be taken constant unlike in granular soil or sand, that the friction is since friction depends on the lateral pressure normal pressure.

So, frictional force will be will depend on what is the normal force here? And so, normal force actually this in the normal direction force will be nothing, but lateral pressure. And, that lateral pressure depends on what is the vertical pressure? And, we know vertical pressure with depth is changing. So, because of that lateral pressure also changing and then friction also change. So, granular soil actually we have taken linear variation of friction. After of course, D c critical depth you have taken constant, but up to at this D c we have seen linear variation we have taken.

But, when cohesive soil we take that friction is constant throughout the depth and which is nothing, but alpha times c. You can take c value actually alpha time c is actually c is the c is the undrained shear strength of the soil shear strength of the soil c is nothing, but undrained shear strength of the soil, and if you do suppose unconfined compression test if you get q u that by 2 is the c c will be q u by 2. So, if it is a unconfined compression test you get q ultimate from there you divide by 2 then you will get the c.

How to get this 1 I have discussed you have learned from soil mechanics. So, I will not go in that point. So, the c is nothing, but undrained shear strength of the soil and that actually that is c is nothing, but adhesion between the soil and pile and that entire value can give you the frictional resistance, but we generally modify this adhesion by a factor called alpha.

And, this alpha always less than 1 and this value alpha how to find out that I will show you in the next slide. And, this purpose of using the alpha s during actually driving the pile actually your the soil will be disturbed, and then adhesion; adhesion to the between the soil and pile may not be as good as it was without before driving. So, because of that it generally reduce it and how to reduce it that I will show you in the next slide.

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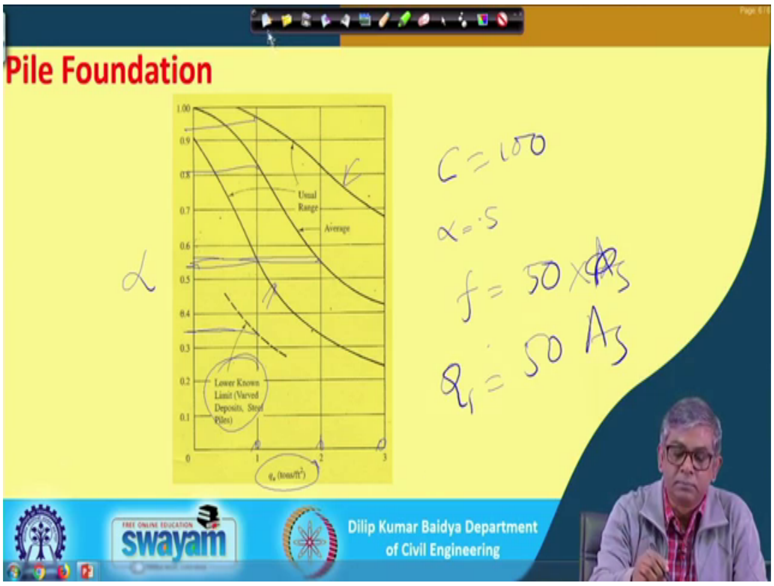

You can see here that to calculate adhesion factor alpha this is alpha and this is the Q ultimate ok, unconfined compression strength this is unconfined compression strength and this is alpha and that actually depending upon that. And, so, what we can takes if it is a value of in this unit of course, tons per this chart is given in a particular unit; that means, Q should be in tons per feet square and accordingly if it is 1 tons per feet square, or 2 tons per feet square, or 3 tons per feet square.

Then accordingly you can see you can produce on to the different curve to get the adhesion factor. So, here adhesion factor you are getting here if you use these value this is the value you are getting, if you use this one, you get this one, if you use this one, you get different adhesion factor you get, but this is the lowest limit some varved deposits steel pile and steel pile combination if you this is the alpha value to be taken.

Otherwise this is the highest range this is the lowest range and most of the time you can draw an average line and based on that we can calculate, the we can assume you can estimate the alpha value to be taken. So, if you see 2 tons per and if you produce here it comes around 0.5 5 ok. So, the C value will be 5.55. So, accordingly you have to if just if your C value is if your C value is 100 and alpha value is actually 0.5, then your f become 0.5 into 100 means 50. And, 50 multiplied by a surface will give you sorry 50 Q s will become 50 multiplied by A s ok.

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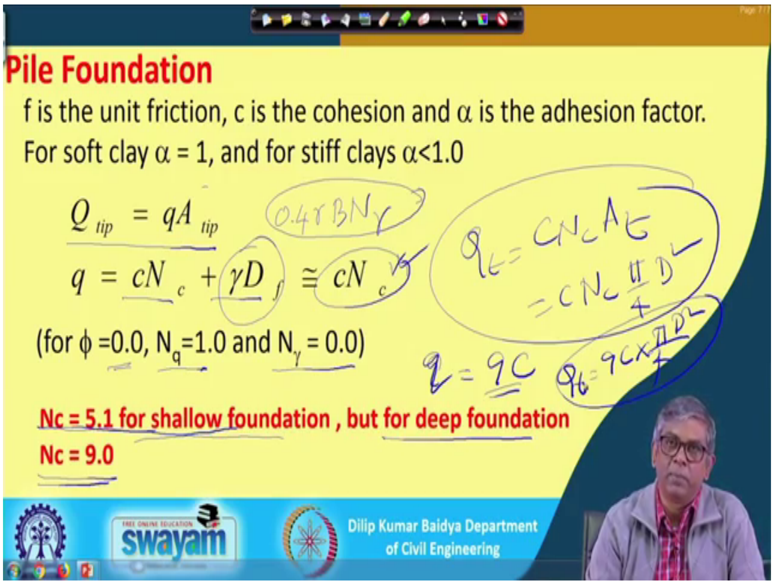

Next one you can see now you have to find out the second component that is Q tip equal to Q tip will be equal to Q multiplied by a tip. And, you can see now that if you look back bearing capacity formula, then general bearing capacity formula cN c plus gamma D f plus 0.4 gamma B and gamma that part was there. And, since it is a clay and for clay actually you can see for 5; that means, 5 equal to 0 then N q will be 1 and N gamma equal to 0.

So, because that this part will be 0. So, it is not shown here and N q is 1. So, it is gamma D f N q supposed to be there. So, I have not written, that only gamma D f I have written.

So; that means, your when the pile driven in clay. So, Q at the base will be cN c plus gamma D f. And, again this gamma D f part and if you compare with the c N c part it will be small. So, sometimes it will be ignored. So, ultimately Q tip for pile driven on clay we generally base resistance we consider as cN c c times N c; that means, if you know the c cohesion of the soil and then multiply by N c then we will get the Q value at the base.

And, then you multiply then if you want to find out Q t then it will be c N c multiplied by A t; that means, c N c times pi by 4 D square. So, this is the way Q t can be obtained. Now, you can see now c N c and we have seen bearing capacity equation bearing capacity theory in shallow foundation, there we have got bearing capacity value N c N q N gamma for pi equal to 0 some what are the values are there, and when it is c equal to when phi equal to 0 then your N c value when phi equal to 0; that means, for clay N c value is 5.1 for shallow foundation; so 5.1 actually given by Myerhoff and others and basic and whereas, 5.71 given by Terzaghi.

So, we are taking generally we take 5.1 most of the time. So, lower value we take 5.1. So, in conventionally when phi phi equal to 0 we take N c value 5.1 for shallow foundation. Whereas, when it is a deep foundation; that means, pile foundation particularly single pile, then it will be deep foundation and for that actually N c unlike like a N q value whatever there in the shallow foundation. And, in the deep foundation N q value also replaced by N q star, which is higher than the N q value in the shallow foundation.

Similar to this N c value also for deep foundation will be different not the same value. And so, that what is the different value? That different value is actually N c equal to 9 to be taken. So; that means, N c value can be so, I can write actually Q equal to nothing, but I can directly I can write Q at the base nothing, but 9 times c better to write. So, I do not have to remember separately. So, 9 times c and then if I want to find out Q t then 9 times c multiplied by pi D square by 4.

So, this is Q t. So, this is Q t I have shown Q f. So, this if you put together that become ultimate capacity of the pile when driven in clay.

So, here actually already f is the unit friction, c is the adhesion and alpha is the adhesion factors in this adhesion here actually for cohesive soil nothing, but your cohesion only. And, and for soft clay alpha equal to 1 and for stiff clay alpha equal to alpha less than 1. For soft clay why it is 1? Because if you disturb immediately will regain when it is stiff clay when it is, when will during driving; it will be disturbed and regaining that c value again it will take longer time. So, because of that alpha value always for stiff clay will be less than 1 whereas, if it is soft clay it can be taken as 1 or close to 1.

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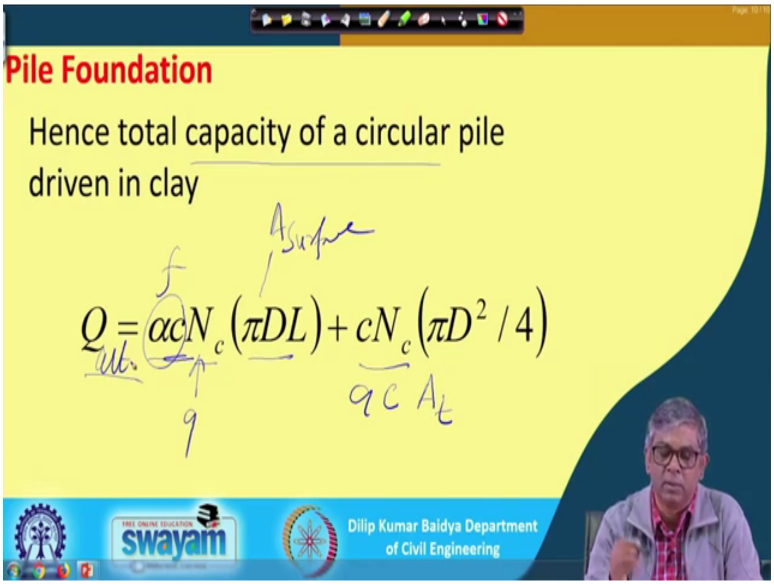

So, you can see now we put together and then your equation become something like that Q become alpha c N c pi D L. So, this is actually nothing, but f and this is N c which is can be written as 9 and pi dl this is nothing, but a surface and c N c this also can be written as 9 C and this pi D square by 4 means it is A tip ok; so this is the ultimate. So, this is actually Q ultimate. And, again if you want to find out allowable pressure allowable load you have to use a factor of safety of 2.

Now, this is the capacity estimation.

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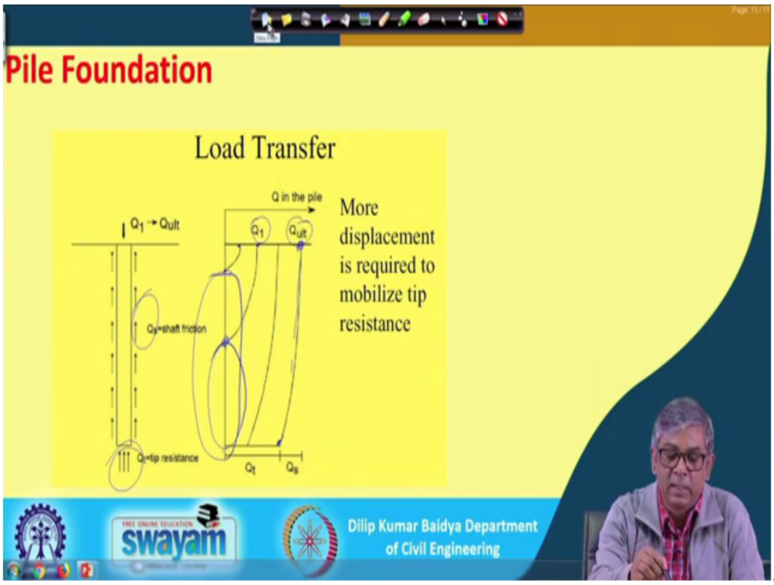

Now, if you have a capacity of a pile, but if you do not apply the full loading, then how it will what will happen or what is the load transfer mechanism? So, like that if you give ultimate if you put Q ultimate then your actual resistance will be coming from friction and at the tip, but if you apply.

So, Q ultimate is a value of Q and if you apply a load Q 1 which is much smaller than the Q ultimate, in that case your load distribution along the length will be at the surface will be this much Q 1 and at this actually it will be 0. And at the base actually no load will be there and this up to this depth this much depth pile will be ineffective.

Similarly, if you increase from Q 1 to Q 2 then it may have Q 2 value here and 0 here then this much depth will be ineffective. And, when you will be reaching to Q ultimate actual ultimate, then you will have the ultimate here and at this point there will be some value which will be equal to Q s ok. So, this is the typical load transfer mechanism in the pile.

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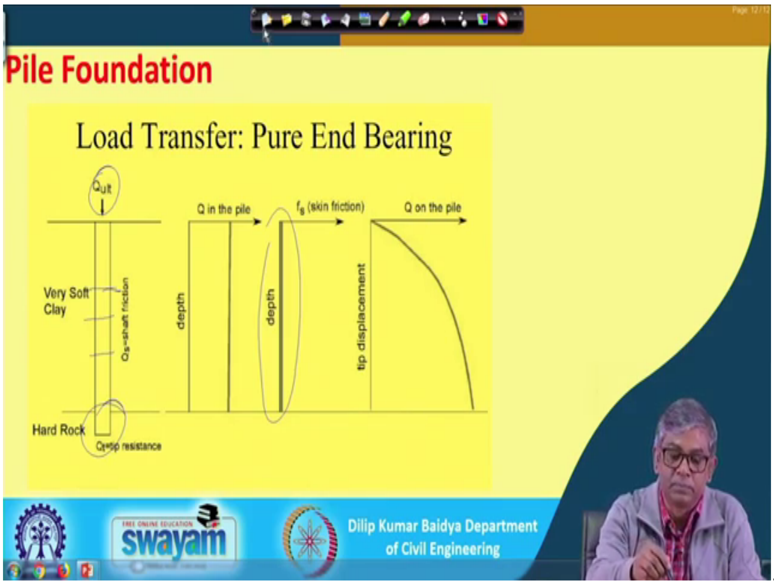

And, you can see here that when is a end bearing that if you apply load here and it is supported from here it is like a it is like a axial member.

So, if I apply if I pull then entire pull will be taken by this pile at any cross section it will P by area will be the stress, or if I push them there also cross sectional area anywhere if you take a stress in the pile or cross in the pile will be P by area. So, that is in same thing; that means, throughout the depth will be Q ultimate will be there. Q anywhere if you cut it will be Q ultimate and; that means, pressure will be Q ultimate by area. And because of that you can see Q in the pile throughout the depth is the same and friction over the depth is 0 almost. So, nothing is the visible and load displacement curve will be something like that.

And, instead of that if you take a friction pile.

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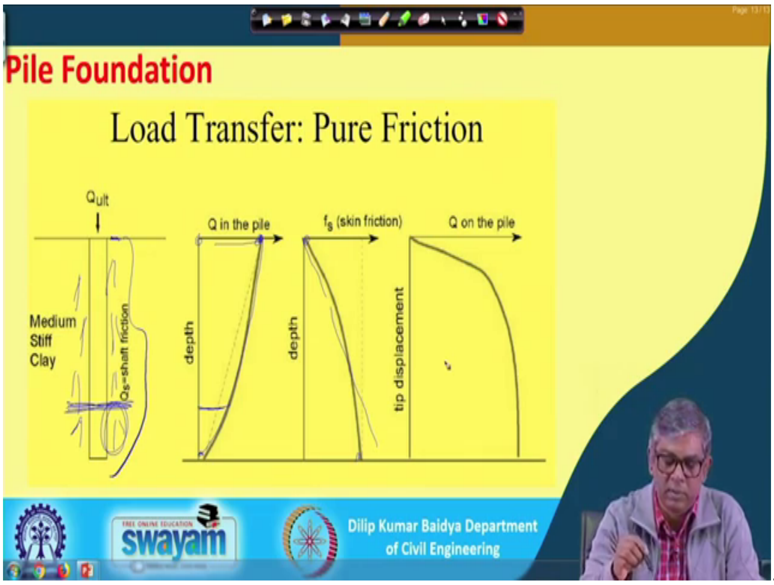

Then, you can see that friction pile you will have maximum Q would be here and; that means, if you consider a pile here and it is friction develop throughout the depth suppose like this. And, I want to find out at this depth what is the load because of the Q friction. So; that means, I have to integrate only this much depth so; that means, your load will be this much.

But, when I will go what is the load up to this depth because of your friction, then you have to integrate over the entire depth. So, because of that you will have larger value. So; that means, Q friction will be maximum at the surface it will decreasing it will be 0 at the tip. And, similarly skin friction also generally we have taken that it is linearly varying like that, but may not be like that. So, it will be some curved 1, it will be 0 at the surface and maximum at the base and load settlement typically will be like this.

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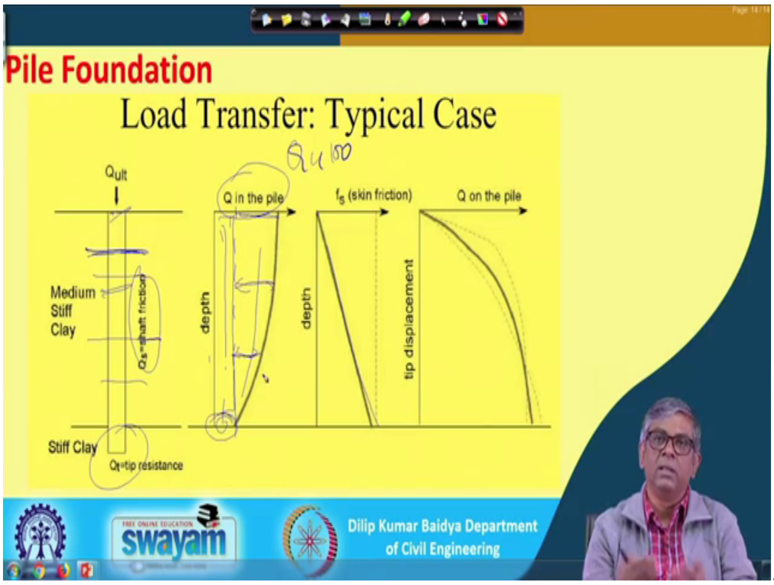

Similarly, if I take a general type of one first one whatever I have shown, that is partially friction. And, partially end bearing then your Q will be here shown will be quite high and it will be at the base which will be seen this is equal to Q tip actually. And, your this will be Q tip and this variation this is actually frictional component at up to this depth, if I go here this is the frictional component up to this depth and this is the frictional component up to this step.

So, frictional component if this is the part and your tip resistance this is the part and typically skin friction will be varying like this and load settlement curve will be something like this. So, this is the typical load transfer mechanism; that means, this is the load this is a your this is a pile which is having both end bearing and friction. And, it has a Q ultimate suppose some 100 and if I simply apply only 10 kilometre load, then the pile will be loaded up to this depth. That is the point I wanted to make here.

And, if you slowly increase 20 it will go little deeper it may 50 it may little deeper when you will reach 100, then only you will get a load distribution curve like that; that will be pile load will be shared by the entire length of the pile. Whereas, if you put much smaller than the capacity then the partially low pile will be loaded partial length rest of the length evening length will be idle with this I will stop here.

Thank you.