Geotechnical Engineering II / Foundation Engineering
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Lecture - 42
Pile foundation (Contd.)

Good morning welcome you to again to this Foundation Engineering lecture. And we are discussing on Pile Foundation and this pile foundation various aspects already we have discussed and we have discussed about the capacity of piles particularly single pile. And we know that in the actual practice, single pile hardly used. In fact, pile always has to be used in a group, there are several reason.

So, I will take today the group pile some details how we do and what are the difference when we use single pile and group pile. And then in fact, I have not taken any problem so far on pile foundation particularly for determination of pile capacity etcetera. So, I will take the problem immediately after this actually. Just I will discuss first the group effect; that means, when pile is used in a group whatever analysis we have done for a single pile; how it will be different from that and what modification is required to find out the final capacity or group capacity of the pile.

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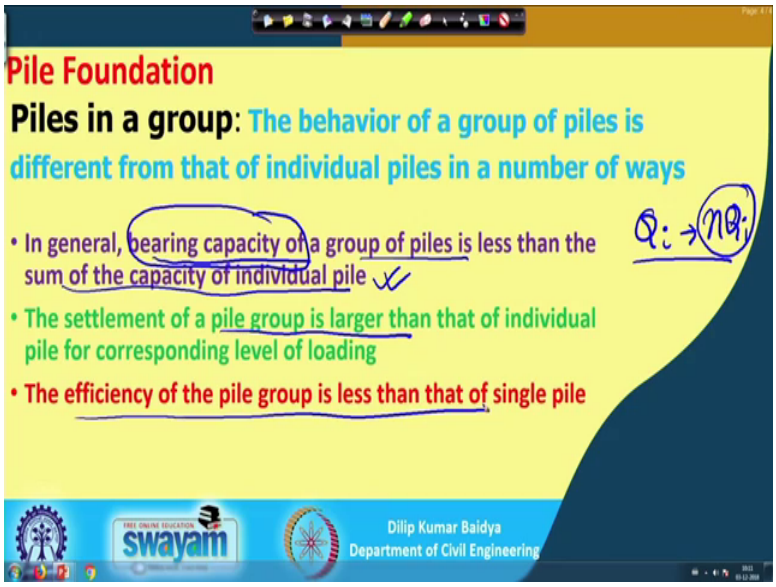

So, let me start with the first slide as I have mentioned already that the piles in a group the behavior of a group of piles is different from that of individual piles in a number of

ways. That means, not only one reason or one point that it is different only this there are several ways in different. And in general you can see bearing capacity or of the group of piles is less than the sum of the capacity of the individual pile.

Suppose if I get a pile or a pile or a particular pile capacity suppose Q i and then I can in n number of piles are used in a group, then n Q i is logically supposed to be. But if I do this and if you find out actual capacity of the group, they are different that is the thing mentioned here. And for pile foundation this bearing capacity term may not be a very good one or it is actually capacity; only capacity may be better capacity of the group. Bearing capacity means only since for pile capacity comes from friction and base and bearing capacity means generally loops proper the brace only. So, though loosely I have used here bearing capacity; it is nothing, but capacity of the group and capacity of the single pile.

How they are different? Logically we may think that group capacity of the pile will be n multiplied by the individual capacity, but it is not so they are different. That is what first point actually you have to make it note. That is the one most important different difference and then settlement of the pile group is larger.

When the piles used in a group whatever amount of settlement will be there and same magnitude of load if we use or not same the corresponding; that means, if n number of piles group piles suppose 10 piles in a group and it is 100 kilo ton, then one pile will carrying approximately 10 kilo meter. Now the 10 kilo meter pile load; if we individually applied to a pile and 100 kilo meter load in the group that settlement again is not same it will be different. And efficiency of the pile group is less than of single pile that is the thing; that means, 100 percent thing will not get.

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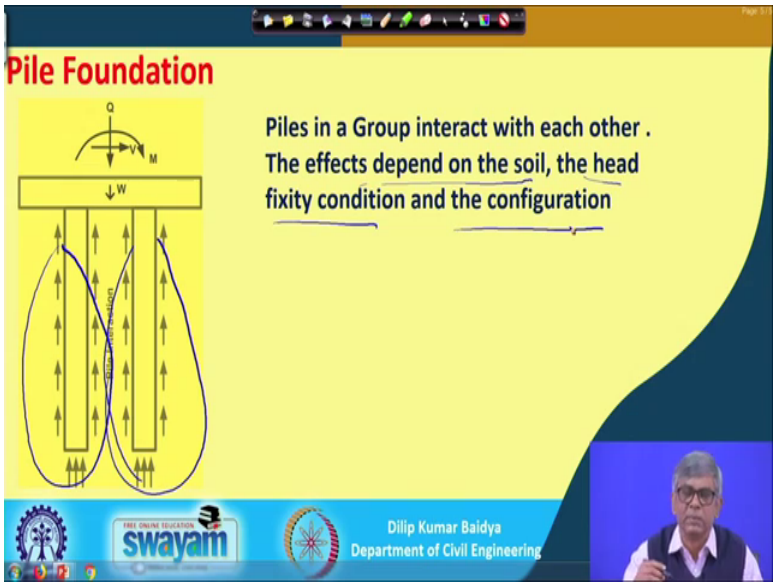

Next thing is that the piles in a group actually when they are in the group particularly in the friction pile or in bearing both are there, then they are actually interact with each other; this pile and this pile. So, it will when it will be transferring the friction like this, then it will have the influence zone something like that and it will also will have influence load like that. So, If they are very close, both the influence diagram will be overlapping and in that case that is called interaction; that means, this pile is affecting this one and this pile affecting this one.

And that happens, then will not get the full capacity that is what the they of the and they affect interact with each other. And this interaction because of this the effects depend on the soil type that what type of sand or clay and the head fixity condition; that means, the site how it is and the other fixity condition and the configuration then how we are arranged. All those things actually the capacity whether in a when you are use in a group, how it will be different from the n multiplied by individual capacity that depends on number of factors such that is pile or soil type is a one of the most important factor actually. In configuration and how closely you are spacing or how widely spacing you are doing that is also another aspect actually it affects.

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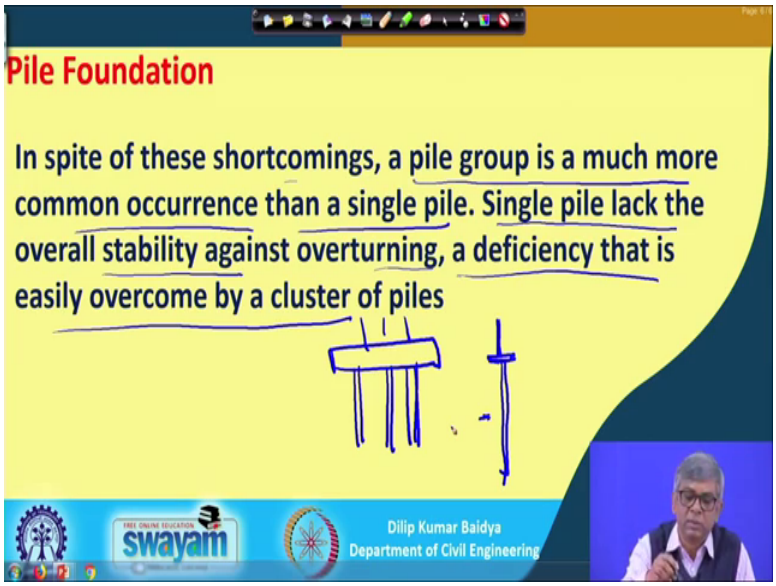

Next thing is as I have told that when you are using in group, you are getting lot of negative; that means, when individual pile capacity if I see that 20, and if I use 5 piles together in a group, then it is not 100. That means, you are getting less; it is a negative again 20 kilo ton load if I apply a pile and then whatever settlement you should getting and five piles will together put a pile cap whatever settlement we are getting that you are getting group settlements more. In that case that is also another negative; that means, or aim in the design actually the keep the settlement within some limit; so if the settlement is more that is also another negative.

So, though we have several negatives still you have to still there is no option other than using pile in a group. So, this is a thing mentioned here that in spite of this shortcomings that whatever I have mentioned, a pile group is a much more common occurrence than in a single pile. That means, single pile hardly used which is always in a group most of the time. Single pile lack the overall stability; that means, if one pile is there and over that if you make a one pile cap and then putting, then looks unstable actually it is always.

So, lack of stability what against overturning deficient that is easily over come at last. Suppose if we this is the one configuration and another configure is suppose you will put pile like this pile like this and then sorry pile like this and then you put a common man and then you construct the column. Then it will be much more stable than this.

So, that is the thing; so because of this first of all since when the load is very large, then you have to use the group. And again if suppose at by the single pile also whatever load you have you can manage, but still we will not do because stability is one of the issue comes there.

So, so, these are the in spite of so many shortcomings that is we are actually using while in a group because of several reason those are the reasons.

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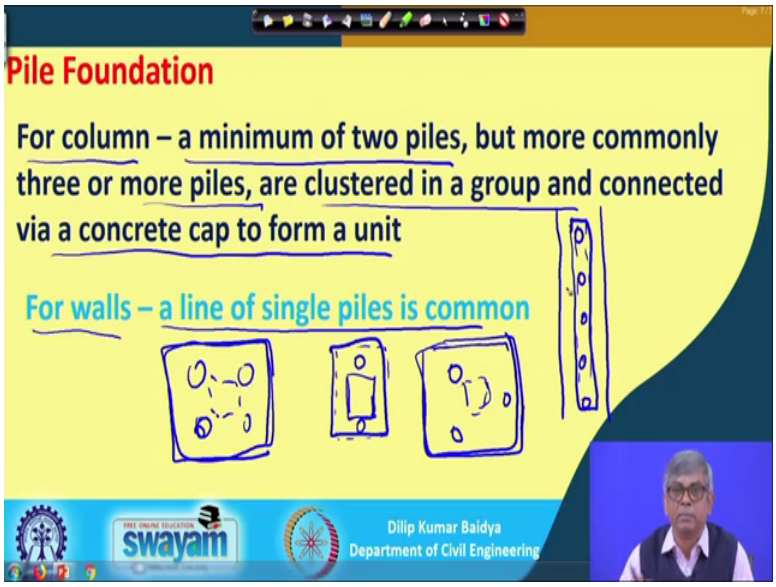

Next let us see that now how we will use and what is the arrangement you can see that for a column a minimum of two piles; that means, if there is a column here this is the column and then actually then you have to make a pile cap something like this. And there may be a putting there may be pile here, there may be pile here.

This is minimum requirement to, but most of the time it will be three or more will be used; that means, sometime it will be like this and it will be like this and then from there will be pile cap and from there actually you will have column. So, or even it is it can be more than the four column four piles, it give a pile cap and then column will be from here. So, that is what for column of a minimum of two piles, but most commonly three or more piles are clustered in a group and connected by a concrete cap to form unit.

So; that means, this is actually this external whatever I am drawing these are actually pile cap. So, all pile cap and pile head all will be connect so, that the all three piles will have

a common support. So, that if I apply load, it will be transferred to the pile equally as far as possible and this is a per for square pile for a column or for oval generally a line of single pile. So, suppose this is the wall to be constructed. So, there maybe you may have pile cap will be something like this.

And your piles will be like this and this pile and then this your pile cap and then from here actually wall will be constructed from here.

So, some time if the wall is carrying less load single line if it carrying a higher load, then you have we have two rows three rows like that it can be. So, these are the; so, this is for a simple one and more commonly there are there are several other ways of clustering the piles in a group which I will show you one by one. You can see here as I have shown the example.

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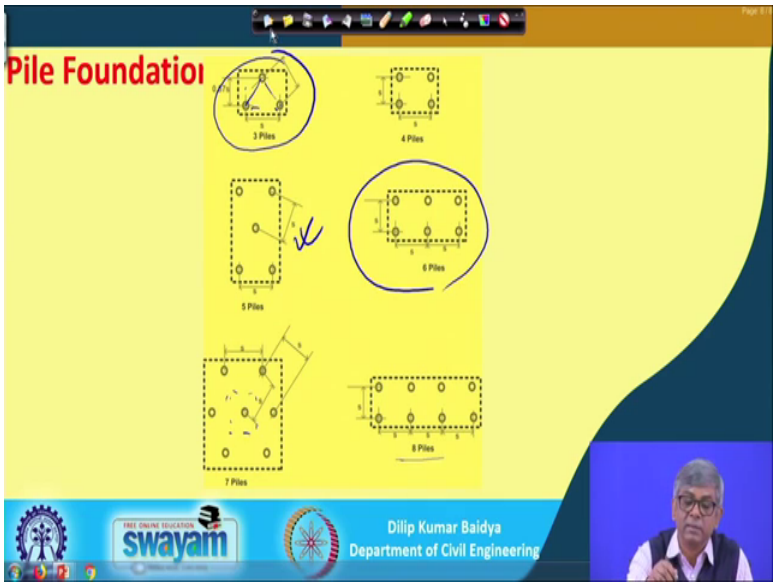

When three piles are used, this is the best way to cluster it. How, because two will be there and third one will be the perpendicular to this and some spacing may be maintained. Spacing here is resolve this to this whatever distance this to this you could lateral diagonal will form all three piles. If it is 4 are used, then your four piles are used then your best way to cluster. It actually 4 corners four will be there and then will be common pile cap. If pile 5 piles are used, this may be the best way of configure it.

If the 6 piles are used this is the best way to do; that means, 2 2 2 like 2 rows. Similarly if 7 piles are used, you can see that is like a hexagonal and 6 corner you put set 6 and middle you put the seventh one that is a best way of configuring 7 piles in the group and there maybe column will be constructed somewhere here which carry heavy load. Or suppose if there are 8 piles are used suppose than that will this may be the best way depending on the requirement actually you can cluster, but this is actually the best way to cluster it.

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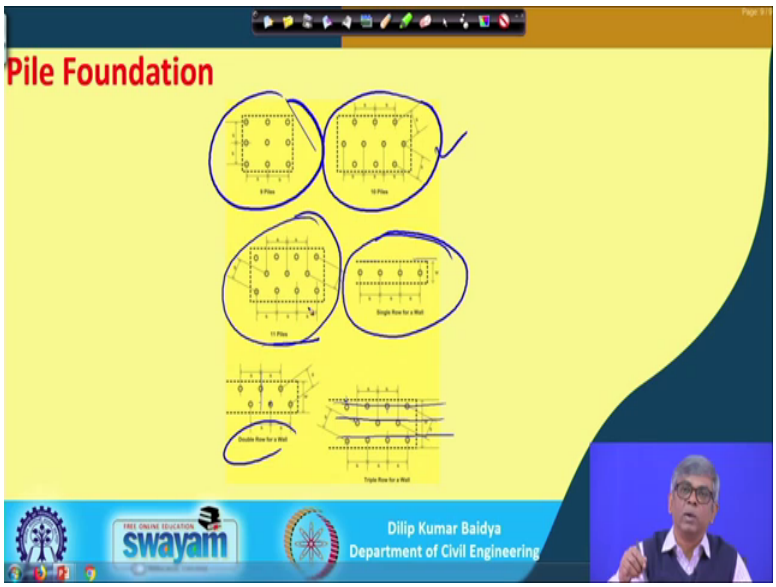

Similarly, if there are 9 piles so, this will be the best way of configuring and if it is suppose 10 pile, suppose this may be the best way of configuring and each here.

Actually you can see the distance between the pile which is called spacing every where it will be same to be maintain and even more than that 10, 11 piles. So, this may be the typical way of clustering and single row when there is a wall this is a single row of piles and then pile cap and then there may be wall will be constructed over that. When it will be double row, then this is the way actually see staggered actually so two pile between two.

If you draw a line perpendicular to that will be third one that will be actually the best way of configuring two ways of piles and if it is three ways then you can see that the, this two will be in line. And then in between there will be middle there will be another pile so, that way three row. So, this is another one row, this is second row and this is third

row and you can see how it is at this and this will be at the same line, but this will be in the middle

So, that is the different ways of clustering the piles. Ultimately over that actually pile cap will be constructed and then over the pile cap the column will be constructed and then the load will be finally, transferred to this pile as far as possible equally. If of course, carry the moment and other things, it will not be how to calculate load in the each pile when the load transferred to the pile cap, but it will you; that means, concentrically and when it is eccentrically how to find out that I will made I may discuss later on. Further time being if the rigid pile cap is there and if we apply the load through the center it is expected that all pile will take equal share. So, that is the assumption we do.

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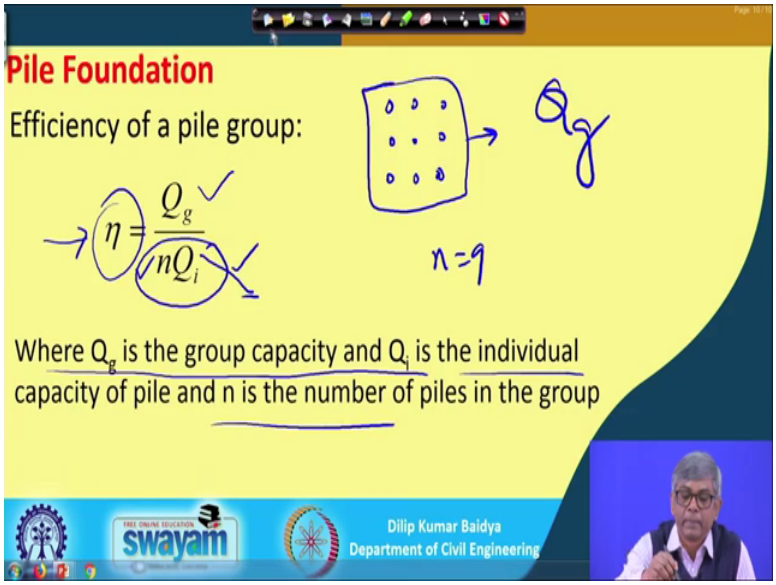

Next one actually this is the efficiency of a pile group. Suppose as I have told that actually if I say when I am using suppose 9 piles in a group and then finally, I have estimated the capacity of the pile as the group. Suppose I say this is capacity of the group is Q g and individual capacity suppose Q i and multiplied by n. So, this is also n times the individual capacity that is actually maximum possible, but best on some analysis I may find out the capacity of this and this will be generally less. So, this divided by this that will be actually efficiency. When actually we get exactly n times the individual pile capacity, then hundred percent efficiency that is also possible in some pile.

Because of some soil type and spacing if we use in such a way that we will get 100 percent efficiency; sometimes we may get more than 100 percent also some situation, but most of the time or in a particular situation that group capacity will be less than the summation of the individual capacity in a group. So, in that case that is denoted as efficiency. And as we know the efficiency cannot be generally 100 not the 100 percent. So, this value should be less than 1 maximum can be 1 only.

So, where Q is the group capacity and Q i is the individual capacity. So, the and n is the number of piles in a group; suppose here actually it is a group; so here n is actually 9.

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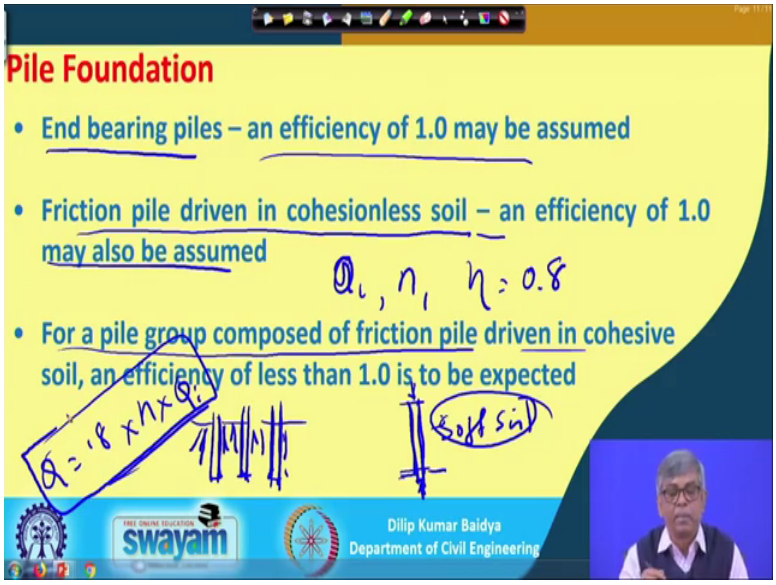

Next I can see that the as I have told that that capacity or efficiency may vary depending of spacing, then type of soil and then function of the pile, how it is transferring the load all mechanisms. So, in when pile is n bearing n bearing pile means what? This pile is here and he here and load is applied here and there may be the only bearing from here. This is so loose soil loose or topsoil suppose here. So, in that case, there is no resistance only there is a steep layer or rock layer.

So, pile is directly resting on the steep layer or a rock in that case, the load will be transferred to the base; that means, n bearing that is called when the pile is n bearing efficiency is 100 percent because there is no interaction actually. It is not your there is no pressure bulb affecting each other. So, directly if I load this is like column actually. So, 100 percent taken by the pile itself. So, it will be efficiency will be one will be taken and

friction pile dividend cohesion less soil; that means, if there is a friction pile and particularly; suppose sand cohesion less means sand sandy soil if you drive the pile, then your efficiency will be some time will be can be taken 1. And in some situation actually it can be efficiency can be more than 1.

What is the reason actually? When you drive the pile in sand some time pile will be demystified because of this densification effect that your actual, the individual theoretically whatever you are calculated based on the soil property then in the actual field condition your pile property is increased or improve and because of that you will have more capacity.

So, that some time though it is more, but we do not take that extra or more value, we take actually 100 percent efficiency. But in individual capacity whatever value you are getting just multiplied by n that whatever it comes that will be itself your group capacity you will not calculate separately. So, though there is a possibility of increase because of the driving in the sand and because of the densification effect, but most of the time we ignore that ok. And when a for a pile group composed of friction pile driven in cohesive soil as I have mentioned that so number of friction pile. Suppose number of friction pile and driven in clay soil actually, then they are all when a clay soil and we will not get much of base resistance mostly it will be from the friction.

That means, piles will be like this only fiction will be there; friction will be there. So, when there is a friction pile and depending upon now the spacing if they are very close, then you will have more interaction between the pile if the spacing is very large wide the interaction will be reduced. So, big depending on that, the pile efficiency will be group efficiency will be will be reduced or it will it will be reduced.

So, that; that means, when pile driven in cohesive soil, then and it is a friction pile in that case your efficiency will be always less than 1 and that has to be estimated. And suppose I get Q i as a individual pile capacity and suppose then n number of piles are there and efficiency suppose I estimated suppose 0.8, then your group capacity will be actually 0.8 is the efficiency multiplied by n multiplied by your Q i something like that you have to answered you have to find out.

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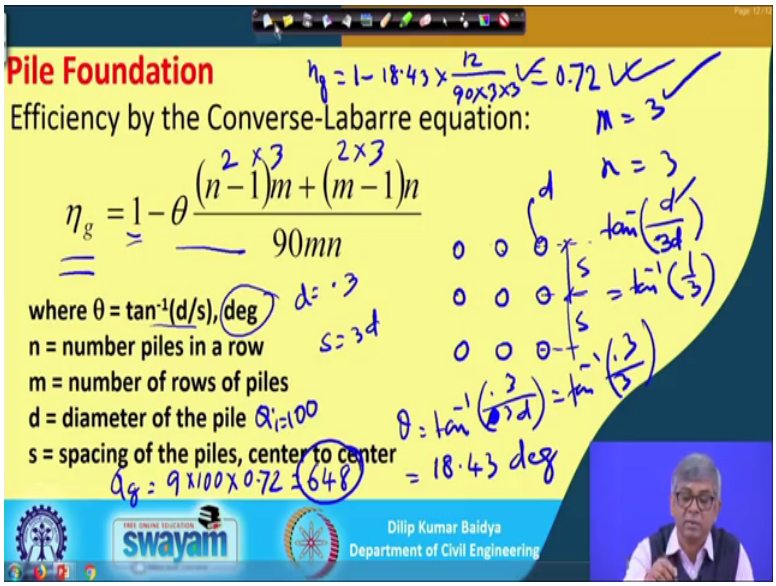

So, that how to find out the efficiency, now we have to see; you can see that there are number of methods are available in the in the book or literature actually to calculate the efficiency of the pile group.

And this is perhaps one of the most used in the practice for calculation of efficiency. And you can see here things are written like this n g that is efficiency of the group is 1 that maximum can be 1 minus this value. So, this value will be sometime 10 percent 20 per 0.2, 0.3 etcetera. So, 1 minus 0.2 means efficiency become 80 percent. This is 0.1 means 1 minus 0.1 0.9 that efficiency is 90 percent so like that. And this formula is given with number of parameters you can see here m n and theta. And this is actually now actually in the group and one can say m is a number of rows and n is the number of piles in a row.

So, suppose if I con if I consider a pile group something like this something like this. So, here both m equal to 3 n equal to 3. So, number of rows 1, 2, 3. So, 3 and each row you can see; so, one row, second row, third row and this row how many piles 1, 2, 3. So, m also 3 n equals to also 3 and so this is this m n is known. Then theta is another unknown theta is actually is given actually tan inverse d by s. So, d what is d? d is the diameter of the pile. And what is s? s is the spacing of the pile. And spacing suppose spacing is what? That means, center to center distance between the pile is the spacing ok. So, this is spacing this is spacing.

So, your theta actually tan inverse b by s d is the diameter, this is d and this is s. So, manlier times actually you when you are using calculator, you have to remember that you have to set the computer a calculator in degree mode. That means, tan inverse d by s it will get in radian and if you use this expression, then you will not get the correct efficiency value. What you have to get? Tan inverse d by s you have to get in degrees. So, you have to set the calculator in degree mode. Suppose and suppose you can see here is a diameter suppose 0.3 and your s spacing a actually 3 times of d equal to 0.3 and s equal to 3 times d.

So, your theta become tan inverse d is actually 0.3 0.3 divided by s equal to 0.3 d. So, this become tan inverse 0.3 by 3 sorry no this is not point 0.3 by 3 ok. So, that has to be obtained in degrees; ao that I if I do that you can see here 0.3 divided by 3 and inverse tan 0.3 by 3 oh no sorry ok.

So, you have to either use tan inverse tan inverse equal to d by point d by 3d is it not; this is diameter and this is spacing. So, it will be untimely tan inverse 1 by 3 ok. So, you can see tan inverse 1 by 3; that means, theta will become 18 0.43 in degrees and if you calculate in degrees as radian, it will come some decimal values. And if you multiply with this, then it will be it will get wrong results. Now after getting this if I put all those things in this equation what are the things actually? You can see n equal to 3.

So, 3 minus 1 it will be 2 and multiplied by 3. Again it is 3 minus 1, it is 2 multiplied by 3. So, 3 into 3 6 plus 6 so, it will be ultimately efficiency of a group will be 1 minus theta is 18.43 multiplied by 12 divided by 90 multiplied by 3 multiplied by 3. If I find out this, then you can see the results how much it is coming multiplied 18.43 multiplied by 12 divided by 90 divided by 3 divided by 3 it comes actually 0.273.

And if you subtract from 1 one minus answer; so that is gives you 0.73 72 so; that means, a pile if you use in 9 piles like this of 300 millimeter diameter suppose used in a group 300 millimeter diameter piles in 9 number of piles used in a group in a spacing equal to 3 times of diameter, then your efficiency coming out to be 0.72. That means, 17; that means, 30 percent nearly 30 percent is reduced ok.

So; that means, if I get now Q i, it is suppose hundred Q i suppose 100 and it is 9 number of piles. So, Q group will be equal to 9 multiplied by 100 multiplied by 0.72. So, that become not 9 multiplied by 100 900, it could have been, but because of this efficiency

reduction when you are used in a group that becomes 900 multiplied by 0.7072. So, 900 multiplied by 0.72 that mean it comes 648 12d it could have instead of 900, it reduced to 648.

So, this because of that one has to be very careful that that depending upon soil type, you have to see that and type of load transfer mechanism, you have to calculate the efficiency and finally, have to find out the capacity of the group. And when are used in a group some very closely sometime this is actually what actually individual pile capacity we have taken; that means, we are assuming when certain amount of load is applied all piles are individually failing.

So, this is actually based on your individual pile failure capacity consideration. So; that means, full capacity is there if I applied to a load when pile will fail that is taken as ultimate and then applying factor of safety you have taken allowable and based on that applying efficiency you have got. Now there will be a situation when pile is space very closely, then the individual pile failure may not occur instead of that there will be a block failure will be there.

When there will be block failure what will be the capacity that I will show you later on. For the time being let it be here efficiency calculation I will discuss that part in the separately later on the in the; a block capacity that is called block capacity.

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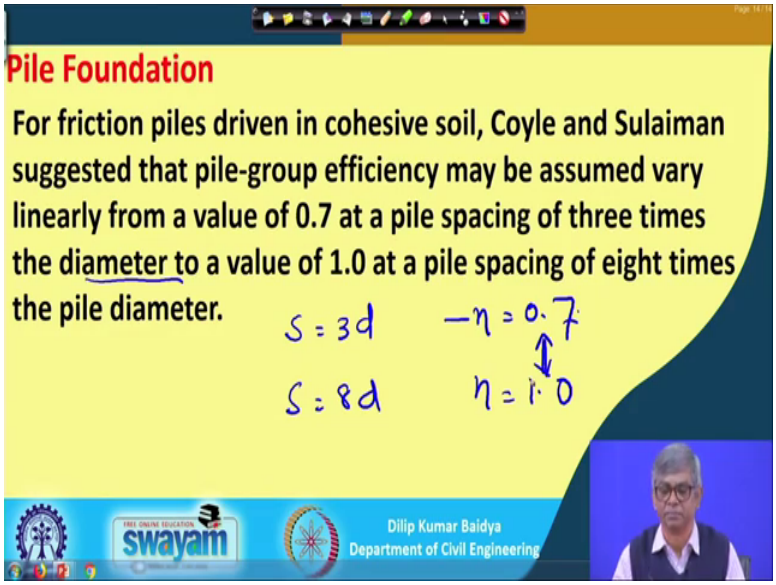

And now as I have mentioned that there are number of methods are there for calculation of efficiency and what method I have discuss that is actually when you are in a square group; that means, square or rectangle square and rectangle group; that means, what it is show? That means, when the piles are like this. Here also it is applicable; here also it will be applicable, but when it is irregular like then this method actually will be the number of rows and columns are I am not able to find out from this; so, this will be not be able to apply that.

So, because of that there are num other ways to find out for friction pile driven in cohesive soil Coyle and Sulaiman suggested that pile group efficiency may be assumed very linearly from a value of 0.7 at a pile spacing of 3 times. That means, when pile spacing your spacing equal to 3 d 3 times the diameter, there actually your efficiency actually is taken as 0.7. And when the pile spacing is and value of one at pile spacing 8 times. That means, S equal to 8d, then you can efficiency can be taken as 1; that means, when the spacing become 8 time there is no interaction. no reduction. So that means, from 3d to 8d, the efficiency wearing from 7 to 1.

So, in between if you use 4d, 5d then we can interpolate the value accordingly between this. That is another method of calculation and that also work like a fine. So, this is other different there are many other methods you can if you use you can read it, but otherwise I will restrict this two methods only for your exam and other things. With this, I will stop here.

Thank you.