Foundation Engineering
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Module - 02
Lecture - 12
Pile Foundations - 7

Hello viewers, in the last class, we were discussing about the spacing of piles in pile group, we saw that if they are closely spaced, then the efficiency of the pile group reduces to larger extent as compared to unity. However, if they are placed at the large distance that is if the spacing of the piles in pile group is large, then you require larger size pile cap, which leads to the uneconomical design of that pile draft.

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Now, let us try to see that, what exactly is the recommendations by IS code as far as this spacing of piles in pile groups are concerned. So, IS 2911 part I-1979 recommends a minimum spacing of 2.5 times the shaft diameter for point bearing piles and three times the shaft diameter for friction piles. By the time that mainly two types of pile as far as the load transfer mechanism is concerned they are there one is point bearing pile and another is friction pile.

So in case, if the pile is going to behave as point bearing pile in that case, the minimum spacing between two piles that is centre to centre spacing should be minimum 2.5 times the shaft diameter. So, if the pile of diameter equal to 1 meter is to be installed, then the minimum spacing between two piles should be 2.5 meter in case of point bearing piles and it should be 3 meters in case of friction piles.

In loose sands or fill deposits a minimum spacing of 2 times the shaft diameter is suggested. So, depending on the type of the soil in which the piles are to be installed the spacing also varies, so we have to take into account and then these are so site specific. Let us say at one particular site if the spacing work out to be say 2.5 times the diameter of the shaft, then and the at the another site it can be more than or less than that 2.5 times.

So, there you have to use your engineering judgment and find it out that, what is the suitable spacing of the pile in pile group. Now, let us try to have a look that depending on type of the soil in which is to be installed, how the behavior of the pile group is going to vary.

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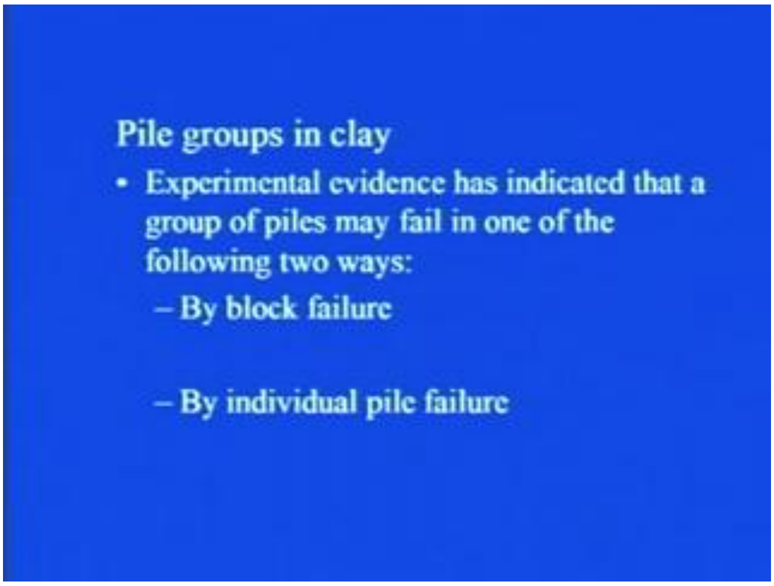

So, first let us try to take the pile groups in case of clay that is the piles are to be installed in clay deposit.

So, experimental evidence has indicated that group of piles may fail in one of the following two ways one is by block failure and another is by individual pile failure; that means by block failure means we say that, when the piles are there in a group. They behave as if they are one pile; that means, one pile of the whole area which is covered by different piles or the failure can occur due to the failure of any individual pile. So, let us try to see 1 by 1 that how exactly what exactly is the mechanism behind this.

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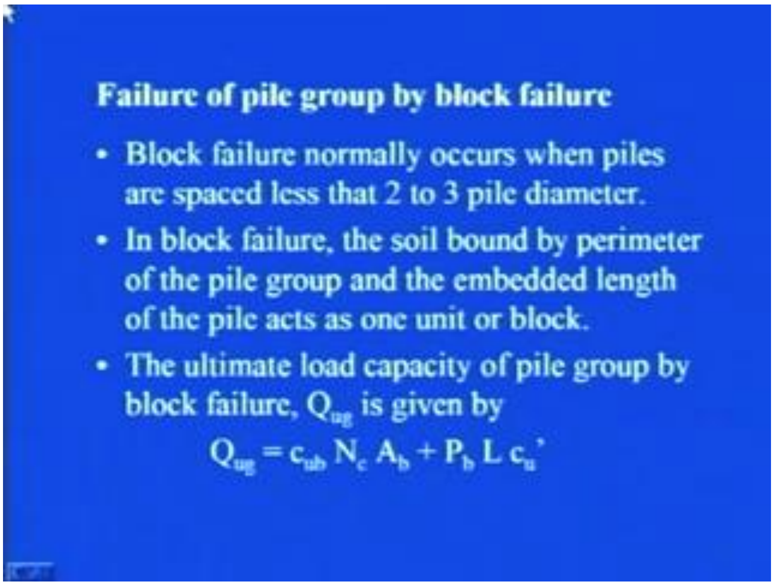

So, first let us see that failure of pile group by block failure, so this block failure normally occurs when piles are spaced less than 2 to 3 times pile diameter. See when the spacing is less; obviously, the overlapping of the distribution of the load, how the load is getting distributed, over the length of the pile shaft, that will be more and so it is likely to fail as block in case that when the spacing is less than 2 to 3 times the pile diameter.

In block failure, the soil bound by perimeter of the pile group and the embedded length of the pile acts as one unit or block. So let us say, you are having 100 piles together in that particular group, so what will happen, the area which is being covered by those 100 piles it will behave as if there is only one pile of that larger size. And, the length will be the total overall length of the pile, so that total thing will behave as one particular unit or a block.

Then in that case, the ultimate load capacity of the pile group by block failure that is Q ug, g stands for group is given by this particular expression, where this Q ug is equal to cub into N c A b plus P b L C u prime.

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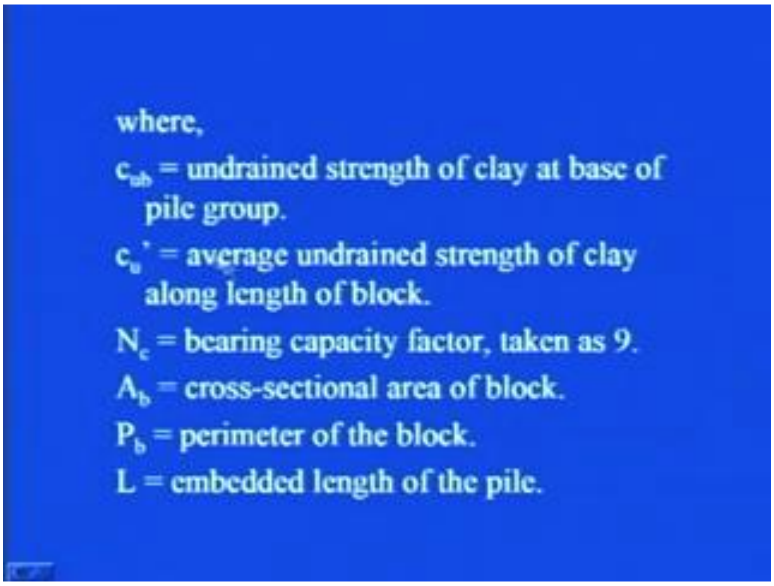

Now, let us try to see that what exactly are these terms that is C ub is undrained strength of clay at base of pile group. So in this case, what will be the base of the pile group, it will be the total area of the base in which all the piles let us say 100 piles are there if a 100 piles are there in that group then total 100 piles are lying in that particular area.

Then, cu prime is average undrained strength of clay along the length of block, N c is as usual bearing capacity factor which is usually taken as 9, A b is cross sectional area of block. So, you should always remember this thing that when we find out Q ug that is ultimate load carrying capacity of the group by block failure. In that case, you are A b represents the cross sectional area of the block not the cross sectional area of one particular pile. P b is the perimeter of the block again it is not the perimeter of one pile but of block, L is embedded length of pile.

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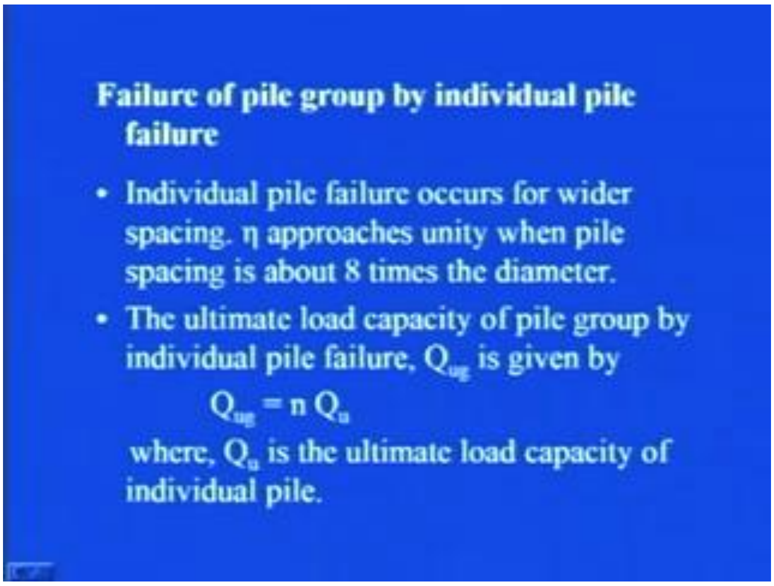

Now, that was all about the failure of pile group by block failure, let us try to have a look that, how we can find out the ultimate load carrying capacity, when we are considering individual pile failure.

Individual pile failure occurs for wider spacing that is eta approaches unity, when pile spacing is about 8 times the diameter. So, we have seen that when the spacing is closer, eta is less than unity and when the spacing is larger, the eta is closer to unity, why is it, so because the definition of eta is like that, eta has been defined as the ultimate load carrying capacity of the group divided by the load carrying capacity of one particular pile into the number of piles.

So, in case the piles are spaced largely that is with large spacing, then in that case eta approaches unity and what large spacing it can be? It can be of the order of 8 times the diameter of the pile. So, as it was there that in case of block failure it was occurring when the spacing was less than 2 to 3 times pile diameter, however in case of individual pile failure, when the spacing is more than 8 times the pile diameter it is likely to occur.

So, the ultimate load capacity of pile group by individual pile failure which is Q ug is given by this particular expression that is Q ug is equal to n times Q u, where Q u is the ultimate load carrying capacity of an individual pile. See the thing is since this eta is tending to unity for larger pile spacing, so when this eta is the ratio of this quantity to this quantity, so when that tends to unity; obviously, this Q ug will be equal to n times Q u.

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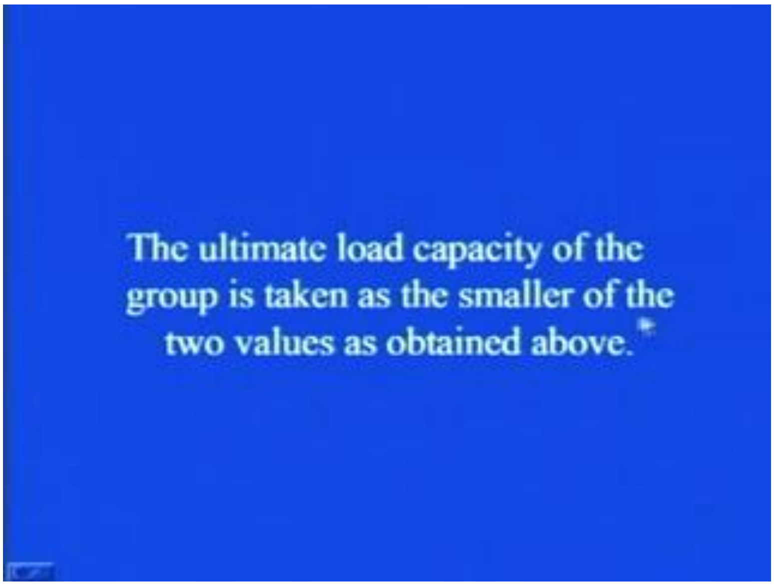

So, now you must be thinking that, what exactly will be the type of failure how you will get to know that it will be failing by block failure or by individual pile failure, how will you decide upon that? So, what we do is, we try to get the ultimate load carrying capacity by both the methods that is by block failure or by individual pile failure and then we compare these two values and we get the lesser one.

So, the ultimate load capacity of the group is taken as the smaller of the two values as obtained above. So, we obtain the ultimate load capacity you considering block failure and considering individual pile failure and whichever value is the minimum that we consider the ultimate load capacity of the group. And then, we can find it out that, how it is going to fail, because when load comes from the super structure whichever load is reached earlier the pile will be failing by that mode.

Let us, say that the ultimate load capacity of the pile group by block failure is reaching earlier when the load is coming from the super structure; obviously, the failure will take place at that particular movement it will not be waiting that individual pile should fail and then it will fail. So, minimum of the two values you have to take as ultimate load capacity of the pile group, now this was all about the pile groups in clay.

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Now let us discuss, some of the aspects related to pile groups in sand. The value of eta for free standing pile groups in sand when piles are driven into the soil is invariably greater than 1 for closer spacing and its tends to approach unity when pile spacing is increased to 5 to 6 times of pile diameter.

So, I hope that you remember that we discussed two type of pile group that free standing and another one was fixed standing, where the pile caps where fix related to each other pile top were related to each other with the help of a pile cap.

Now, here in this case in free standing pile you have seen that the pile cap was not in contact with the soil. So in that case, for closer spacing eta value will be greater than 1; however, it will approach to unity when you increase the spacing of the pile to 5 to 6 times the pile diameter.

In dense sand eta can be less than 1, so you have to keep in mind that in clay it was the vice versa case. So, that that distinction you must keep in your mind.

An efficiency of factor of one is commonly assumed in design, because it is really a complicated thing that how the load will be transferred or what will be exactly the mechanism that any particular pile will be following when the load will come from the super a structure to it. So, that is why usually this eta is considered to be unity that is efficiency of the pile group is considered to be unity, in case you are analyzing the pile groups in sands.

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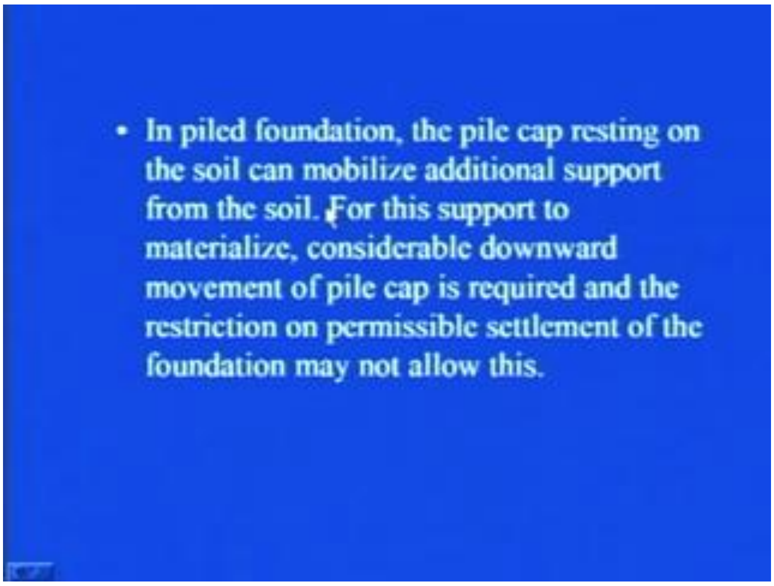

Then, in pile foundation the pile cap resting on the soil can mobilize additional support from the soil, when see in case of free standing pile group the pile cap is not there in contact with the soil. However, in case of piled foundation the pile cap is in contact with the soil that is it is it rest on the ground.

So, the contact between the pile cap and the soil it mobilizes additional support from the soil. So, for this support to materialize considerable downward movement of pile cap is required and the restriction on permissible settlement of the foundation may not allow this.

See there are two things; one thing is that the vertical movement of the pile, that is one thing and out of that also you have seen that the soil at the base can move there can be compression in the pile itself and all other things. So, in this case to mobilize this additional soil support which is their due to the contact of pile cap to the soil, what happens say, is for this to mobilize you need to have the downward deflection or movement of the pile cap that movement should be sufficient enough such that it can mobilize that additional support.

So, when this will get mobilized for that thing you need to have this considerable downward movement and you that for each and every structure there is a limitation on the settlement. So, whenever you say that this much of the settlement of the pile group should be required to mobilize this much of the additional support, so for that you need to allow that much of the permissible settlement.

But; however, in case of different type of soil or the different type of structure or foundation this may not be possible in many cases.

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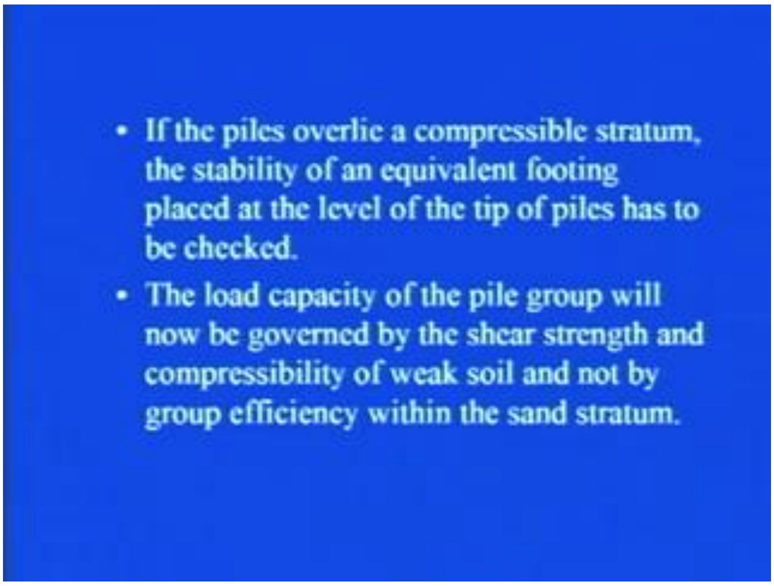

So, if the piles overlie a compressible stratum, the stability of an equivalent footing placed at the level of the tip of pile has to be checked. Overlying of compressible stratum means that when the soil stratum is poor in nature, it can be clay of high compressibility or it can be loose sand.

But here, we are talking of pile groups in sands, so it is loose sand in nature, in that case what you do is, that you assume an equivalent footing at the tip of the pile and then you check it is stability, that what exactly is it is stability, if it is a stable from safety point of view as well as from serviceable point of view.

The load capacity of the pile group will now be governed by the shear strength and compressibility of weak soil and not by the group efficiency within the sand stratum. So, in case any compressible stratum or loose sand stratum is present in that case.

The load capacity of the pile group will be governed by the properties of that weak soil not that what is the group efficiency, that eta can be good, it can be close to unity or even more than that; however, in spite of that fact the pile group can fail it may not be stable due to the presence of this over line compressible stratum.

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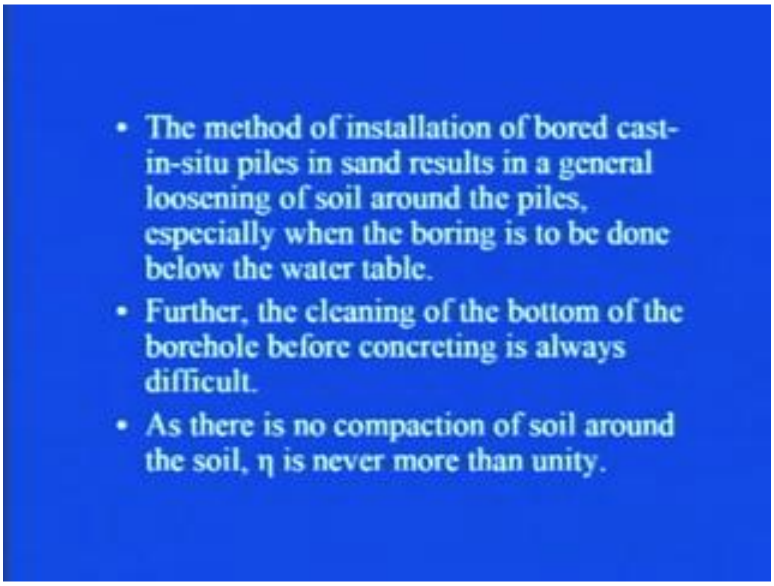

The method of installation of bored cast-in-situ piles in sand results in a general loosening of soil around the piles especially when the boring is to be done below the water table. This aspect we have already seen although it is bored cast-in situ pile, so in which you create a borehole or you create a void and then you install the pile in that; however, in case of sand when you try to create the borehole or while you create that void in that case in that particular process the soil around the walls of borehole it gets loosened.

So, because of that the problem occurs, then further the cleaning of the bottom of the borehole before concreting is always difficult. We really do not know if the pile is let us say of the pile length this the order of 25 to 30 meter we are not sure of that below the ground level, what exactly is the condition at 25 or 30 meter depth, because before concreting is done the borehole has to be cleaned properly.

So, that the concrete can attain its full strength and whatever you are finding out as ultimate load carrying capacity the pile should serve that purpose that much ultimate carry load carrying capacity should be there for that particular pile.However in case of in the absence of proper cleaning of the borehole that strength may get reduced. So, that is an undesirable situation.

As, there is no compaction of soil around the soil eta is never more than unity, so it is better for us when the eta is more than unity. But, since there is no compaction of soil around the pile then eta is never more than unity.

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So, usually in design practice the value of eta is taken as 1, so in case whenever you go for the analysis of pile group in case of sand, you should assume eta to be equal to 1. And that in that particular case, you can find out the group ultimate load capacity of the group as equal to the number of piles in the group multiplied by the ultimate load capacity of individual pile.

Now, this was all about the ultimate load carrying capacity of pile group, now see the thing is that even though the pile is able to take that much of the load which is coming from the super structure, but if the settlements are more than permissible settlement we really cannot go ahead with that particular soil pile system.

So, we need to have a check on the settlement that the settlement is within permissible limit. So, for that we the IS code has given recommended standard values for this permissible settlement in different type of soil, in different type of foundation lets us say for isolated footing for raft or for combined footing it has prescribed. The values of permissible settlement depending on that which type of soil the pile has been installed into.

But, how we will be able to know, whether the settlement of the pile group is within the permissible limit or not for that first we need to find out the settlement of the pile group.

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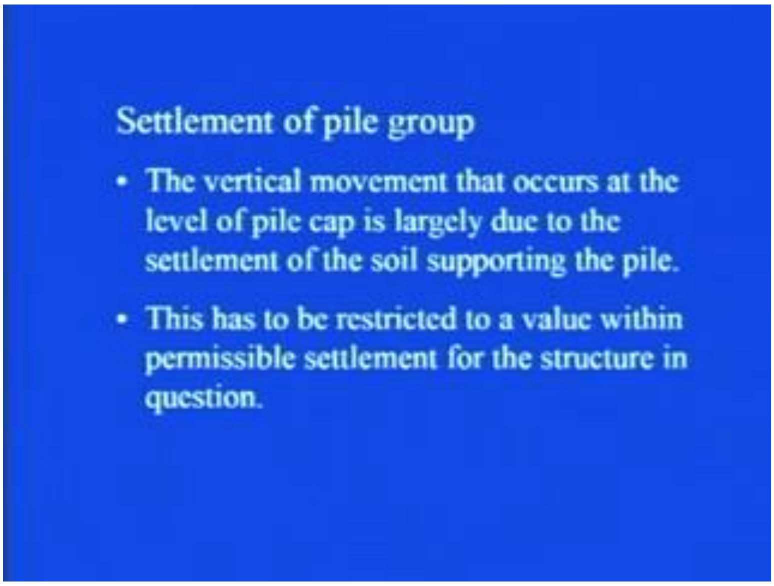

So, how it is done let us try to see, the vertical movement that occurs at the level of pile cap is largely due to the settlement of the soil supporting the pile. So, the vertical movement which is occurring see vertical movement is occurring throughout the length of the pile, starting from the pile cap till the base of the pile that is pile tip. So, at the top it is mainly due to the settlement of the soil which is above their surrounding the pile.

This has to be restricted to a value within permissible settlement for a structure in question. So, because as I explained you IS code has given the provision that permissible settlement for this particular type of soil or this particular type of foundation that should be limited one. So, we need to really find it out that, what exactly is the permissible settlement for that particular structure.

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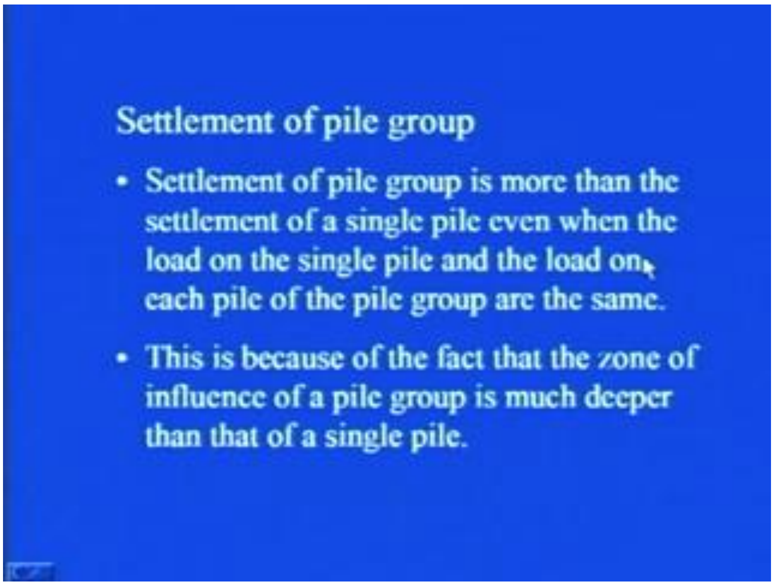

Then, the settlement of pile group is more than the settlement of a single pile, even when the load on a single pile and the load on each pile of the pile group are the same. So, let us that the some load is coming from the super structure.

So, there can be two cases that, whatever load is coming to the pile group that is more or less or equal to the load which is coming to the individual pile. Let us say there are 100 piles and say 1000 kilo Newton load is coming from the super structure to the pile cap and in case the 100 piles are there.

So, I am assuming a situation when this 1000 kilo Newton load is will be transferred or will be shared by all the piles equally, then in that case all the piles will be subjected to 10 kilo Newton of the load. I am just giving you a picture just to make you understand this particular point; however, the load is quite higher as far as coming from the super structure is concerned.

So, in that case if whatever load is coming to the pile group, it is getting equally transferred to each and every pile even though in that case the settlement of pile group is more than the settlement of a single pile. So, although the load transfer is same, but the settlement of the pile group is more as compared to the settlement of single pile.

This is, why it happens is, because of the fact that the zone of influence of a pile group is much deeper than that of a single pile. See when it is in a group; obviously, when the load is coming it is forming larger bulb of the influence zone as compared to in case of single pile.

So, that is why you get settlement of the pile group more because when what where is the load coming from the super structure, when more soil strata is incorporating into that that is that particular soil strata is causing settlement to that. So, more the soil strata more will be the settlement, so this soil strata which is considered in case of the settlement of pile group is always will always be higher as compared to the individual pile and so its settlement.

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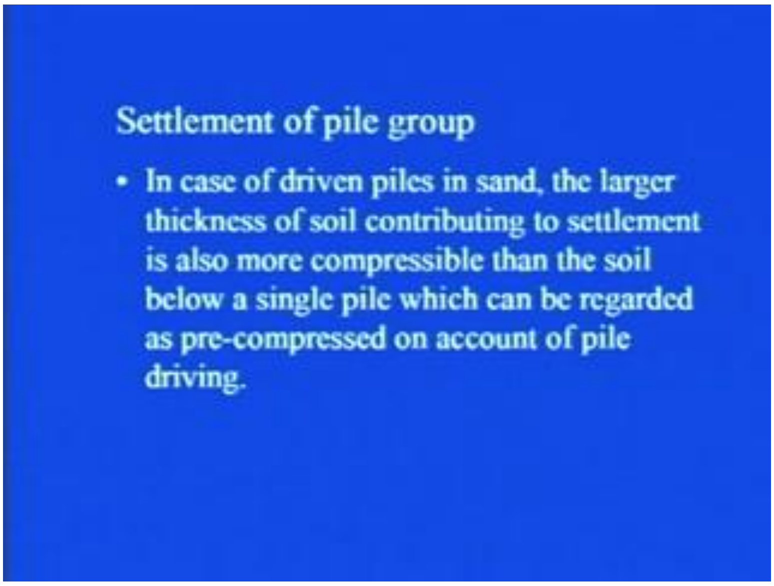

In case of driven piles in sand the larger thickness of soil contributing to settlement is also more compressible than the soil below a single pile which can be regarded as pre-compressed on account of pile driving.

See, what is happening is that, when you drive one particular pile, what happens is in the process of driving that particular pile; the soil surrounding the pile gets compressed. So, the when the soil is getting compressed it is in better state; however, what happens in case of group of piles. Although, it will be compressed within the group but if you see that group over all.

So in that case, the compressibility of the soil is quite high; that means, it is highly compressible as compared to a single pile which gets compacted while driving the pile; however, which is not the case in case of pile group. So, when the piles are driven in sand, there is larger thickness of the soil which will be contributing to the settlement and at the same time this larger thickness will be compressible in nature.

However in case of single pile, what happens is, the soil strata which is contributing to the settlement is first thing, it is lesser as compared to the group of piles at the same time, it is less compressible as compared to the group of piles. So, two advantages are there and that is why you get the more settlement in case of group of piles.

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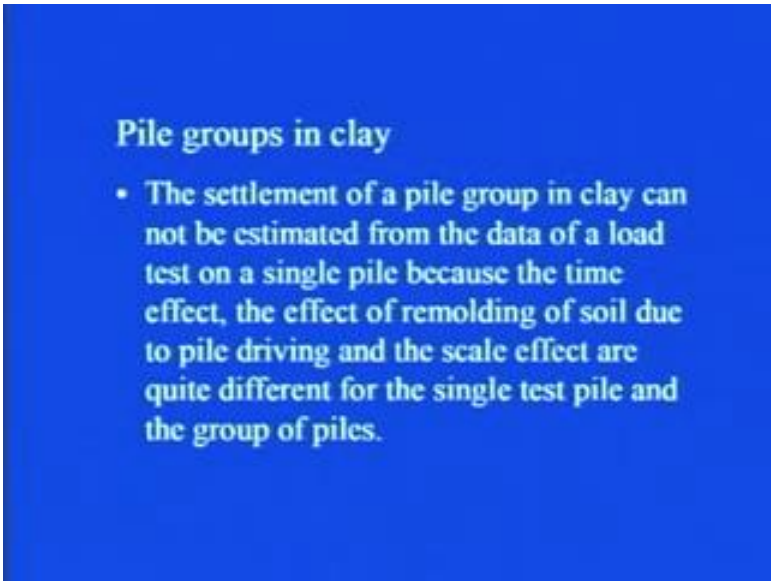

Now, this pile groups in clay that is, what that we were discussing about the sand, so how we can find out the settlement of pile group in clay. The settlement of pile group in clay cannot be estimated from the data of a load test on a single pile, because the time effect of remolding soil due to pile driving and the scale effect are quiet different for a single test pile and a group of piles.

See, what happens in case of clay, when you install the piles the clay gets remolded and it is with time that it gains its strength. So, in case of individual pile the disturbed area of the soil is less as compared to that in case of pile group. So, that is why you cannot estimate the settlement of a pile group from the data which you will be getting from the single pile load test.

As you have seen, that we have already discussed that how this pile test are conducted in the field. You saw that there were two types of test and then we plotted that load settlement curve and from there we found out the ultimate load carrying capacity and corresponding to that you can find out the settlement also.

So, the test has been conducted only on one single pile not on the group of pile, so that data cannot be used confidently in finding out the settlement of pile group in clay. So, that we must take into account that it is happening that because while you that you drive the pile the clay gets remolded and with time only it regains it is strength. So, you cannot really on the test data which you have conducted on a single pile.

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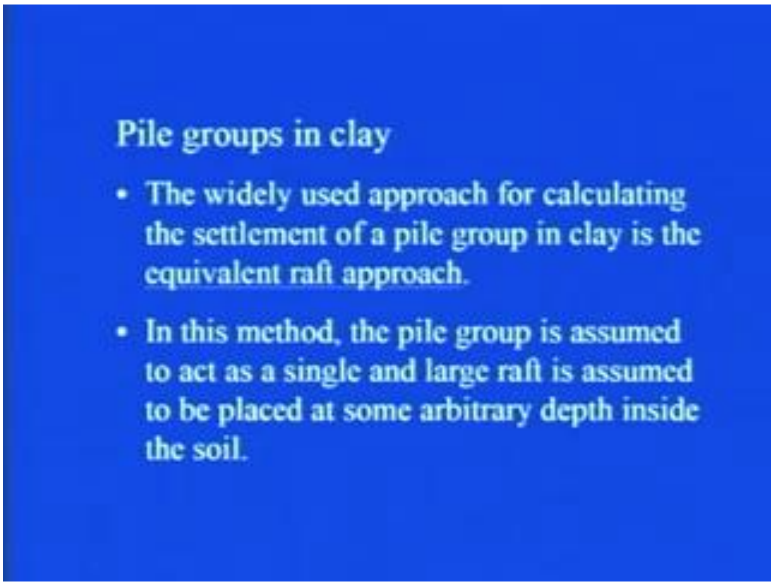

The widely used approach for calculating the settlement of a pile group in clay is equivalent raft approach. This is an very important aspect or approach that you must understand properly, so equivalent raft approach, as the name is suggesting that it is not exactly the raft,, but it is what we are considering is as equivalent raft.

So, let us try to see that what exactly is there in this particular approach, so in this method the pile group is assumed to act as a single and large raft is assumed to be placed at some arbitrary depth inside the soil, what is assumed is that, the pile group is behaving as one single pile.

It is not the group of pile, but we say that it is a large diameter single pile and whatever is the raft that is assumed to be placed at some arbitrary depth below the ground surface and inside the soil. So, how you can decide upon, let us say that one is the length of the pile, so it is here I am quoting that it is some arbitrary depth.

So, what should be the value of this depth from the ground surface be it at half of the length of the pile or two-third of the length of the pile or one-third of the length of the pile or wherever, it is that some of the guide lines have been given based on the experience of different you know practitioners and engineers and let us try to see that what exactly are they.

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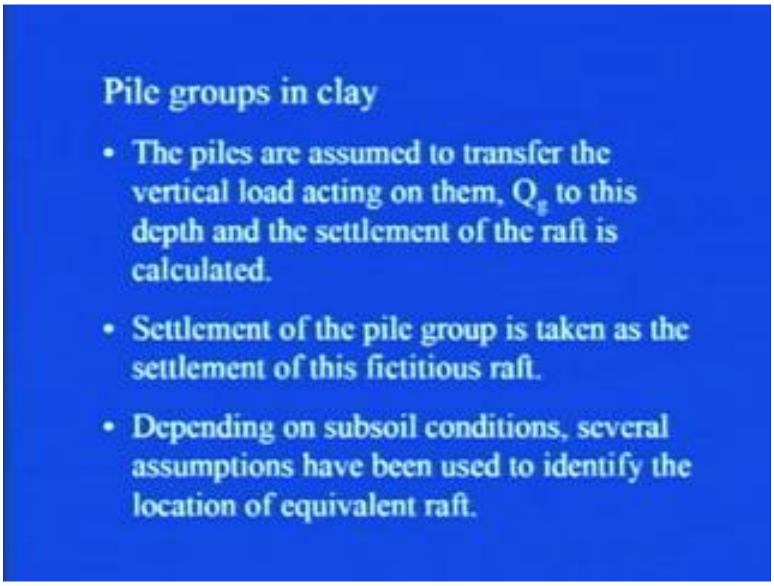

Then, we will be seeing that in subsequent slides, but for the time being that, how you can calculate the settlements in case of pile groups in clay, we see we are seeing the steps.

The piles are assumed to transfer the vertical load acting on them that is Q g to this particular depth and the settlement of the raft is calculated. So, in shallow foundation you have already seen that, how you can find out the settlement of the raft.

So, let us say that we forget that here there is any pile, we replace the pile and draft system by an equivalent draft which is placed somewhere at some arbitrary depth inside the soil. And, there we simply assume it to be simple raft and then whatever is the area which is below that raft which is contributing to the settlement we get the settlement as per the things that we have already followed in shallow foundation chapter.

The settlement of the pile group is taken as settlement of this fictitious raft, so I am first thing is that I am assuming that the pile and the soil pile and the pile cap system that is pile raft system whole thing as I am assuming to be only raft, which I am calling as equivalent of which I am placing at some arbitrary depth in the soil.

Then, the whole of the load which is coming from the super structure will have to be transferred to this particular depth and to this raft. And then, this fictitious raft is being analyzed as if there is no pile at all and whatever is the settlement of this fictitious raft that is considered to be the settlement of pile group.

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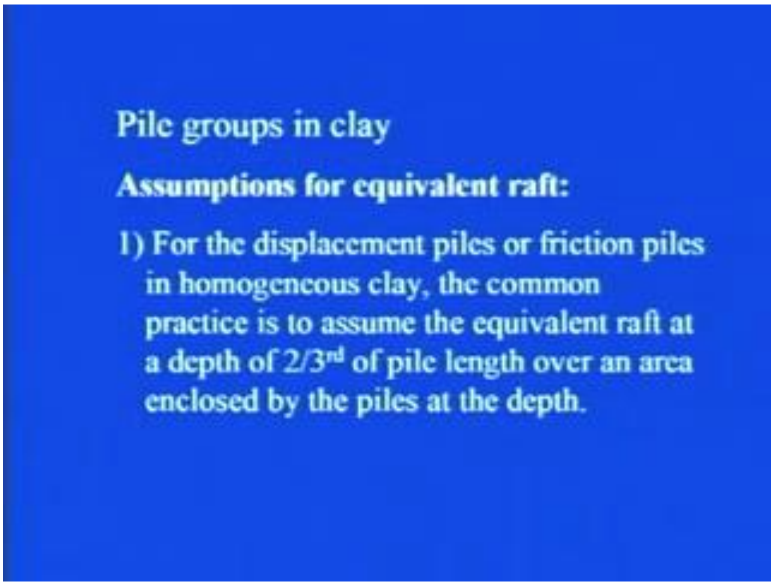

Depending on sub soil condition several assumptions have been used to identify the location of equivalent raft. So, what are they, let us try to see that incase of these are the some of the salient points related to assumptions for equivalent raft.

So, for the displacement piles or friction piles in homogeneous clay, the common practice is to assume the equivalent raft at a depth of two-third of pile length over an area enclosed by the piles at the depth. So, when pile group is there, what happens is that on top of that you connect all the piles, and that forms of pile cap.

So, the size of the pile cap depends on that in what extent of the area, the piles have been spread. So in that case, whatever is the area which is covered by the pile group, we place the raft of the same size at the depth of two-third of the pile length over that much particular area. So, whatever is the area which is enclosed by all the piles, we place the raft of the equivalent area at two-third of the length of pile.

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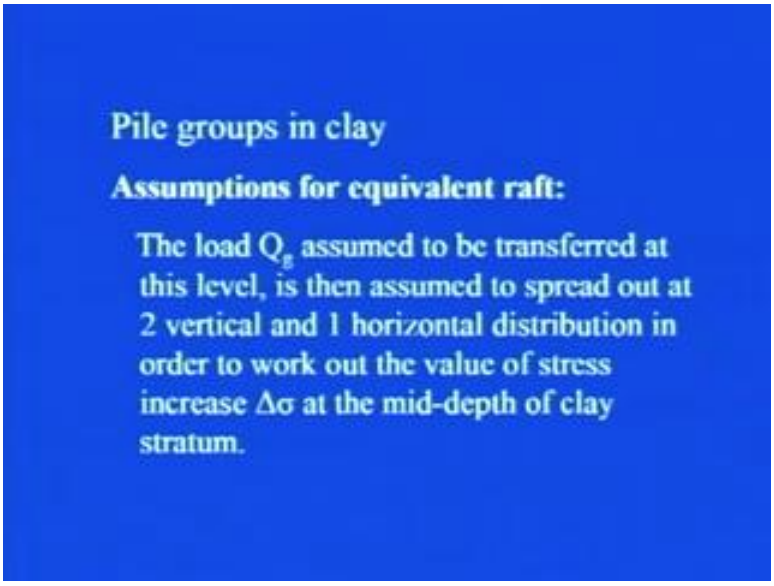

The load Q g assumed to be transferred at this level is then assumed to spread out at 2 vertical and 1 horizontal distribution in order to work out the value of stress increase delta sigma at the mid-depth of clay stratum.

As, you have seen in case of shallow foundation chapter that, how you are you were calculating the settlement, below the below any footing or foundation system. Usually, what we see is that, when the raft has been placed at that particular depth then the load; obviously, will get transferred to the soil which is lying beneath that. So, it gets transferred in 2 vertical and 1 horizontal systems.

So, accordingly you know you there will be getting spread out and then you have to find out that, whatever is the thickness of the soil stratum, which we will be corporating incorporating to the settlement. Then in that case, at each layer at the middle of each layer you have to find out this increase in the vertical stress, so that can be done with this kind of load spread that is 2 vertical and 1 horizontal. See, we will be solving 1 or 2 example related to this, then this will become more clear to you.

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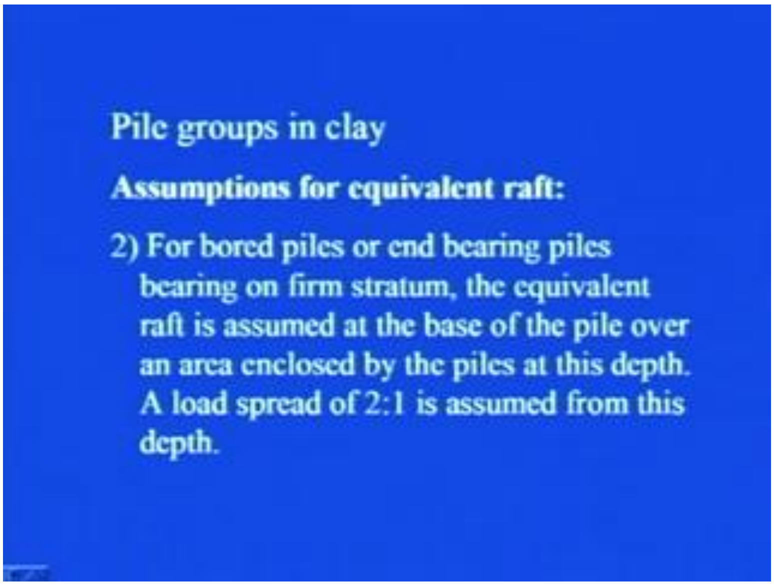

Then, the second point is that for bored piles or end bearing piles on firm stratum, the equivalent raft is assumed at the base of the pile over an area enclosed by the piles at this depth and then a load is spread of two is to one is assumed from this particular depth. So, as I mentioned you earlier that, this equivalent raft is assumed to be placed at some arbitrary depth.

So in case, in the first point you saw that it can be placed at two-third of the length of the pile. However, in case of bored piles and end bearing piles which are lying on the firm strata this raft is assumed to be placed at the base of the pile tip. So, and then beyond that you can assume that 2 is to 1, as you were doing in case of the 0.1.

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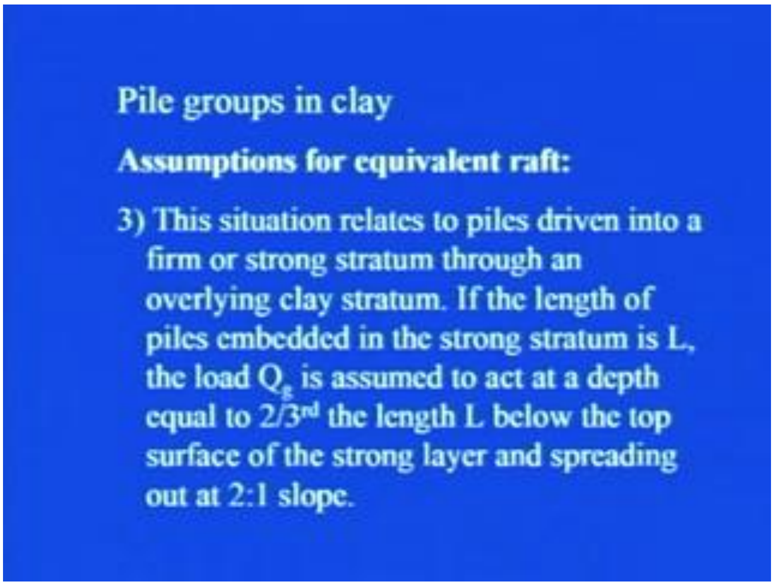

Now, third point is that, this situation relates to piles driven into firm or strong stratum through an overlying clays stratum. So overlying, the clay is lying above the firm strata and in that case, how you can assume that, if the length of piles embedded in the strong stratum is L the load Q g is assumed to act at a depth of equal to two-third of the length L below the top of the surface of strong layer and spreading out at 2 is to 1 slope.

So, if this strong stratum length of the pile in a strong stratum is L, then you simply take that two-third of the length and from top of the strong stratum, you measured two-third of the L and then you place the raft. And then, below that exactly in the similar manner you have to assume the load spread in 2 is to 1 manner.

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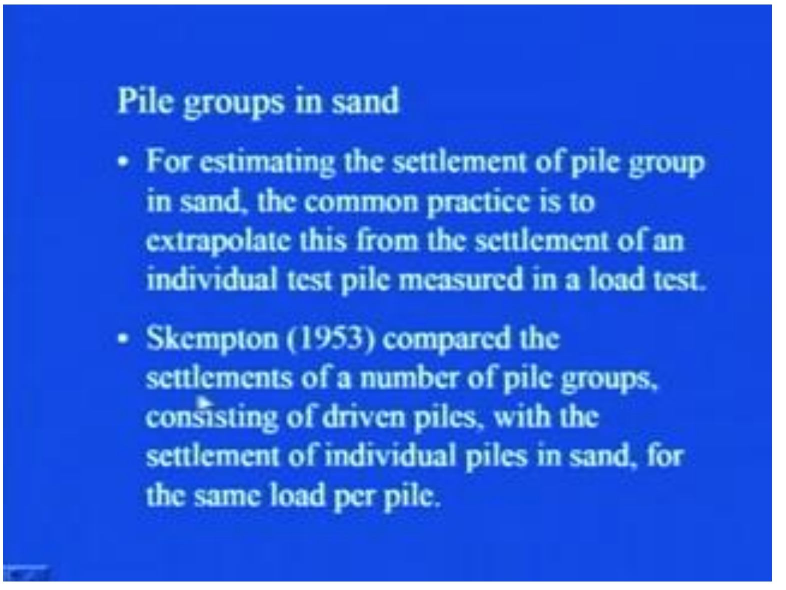

Pile groups in sand, so this was all about the clay that, you have to assume that equivalent raft and you have to place it in the soil and then find out the settlement as if there is no pile only raft is there. In case of sand, how do you do, that for estimating the settlement of pile group in sand, the common practice is to extrapolate this from the settlement of individual test pile measured in a load test.

You have already seen that, how this load test is being carried out being performed in the field on a single pile. So, how you can get that load settlement curve in case of single pile, so for this case, when you find out the settlement of the pile group, you can extrapolate the result of that individual pile.

In case, you are finding out the settlement of pile group in sand; however, you have already seen that in case of clay, the load settlement characteristic which you obtained from the lab that is field test was not being able to use in case of group; however, in case of sand you can do that.

Then, Skempton in 1953 compared this settlement of a number of pile groups consisting of driven piles with the settlement of individual piles in sand, for the same load per piles.

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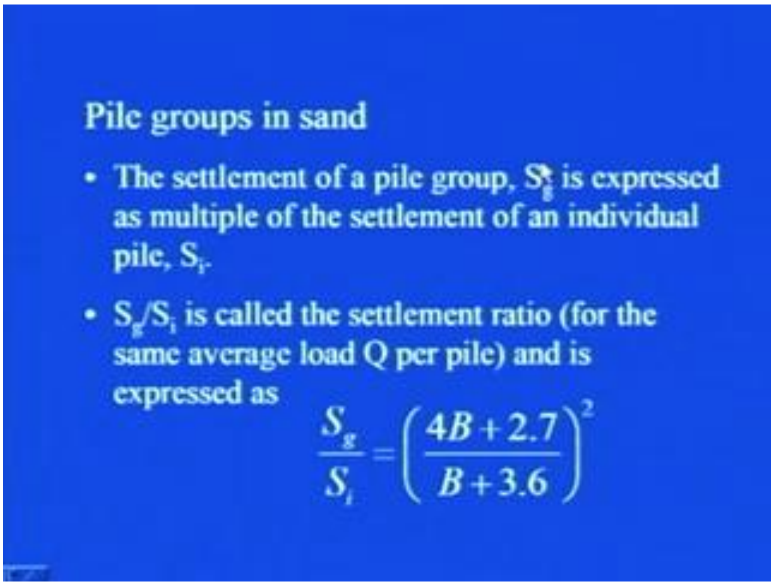

How he has done that you see the settlement of a pile group that is S g is expressed as multiple of a settlement of an individual pile that is S i. Obliviously, this S g will not be equal to N times Si where N is the number of piles; however, it is some multiple of the settlement of an individual pile. So, that is why usually we talk in terms of settlement ratio which is defined as the settlement of group of piles and the settlement of individual pile.

So, that S g by S i is called a settlement ratio for the same average load Q per pile you have to be very sure about it that whatever is load on the pile group it should have the same proportion, when it is coming to the individual pile. This is expressed as 4 B plus 2.7 by B plus 3.6 whole square.

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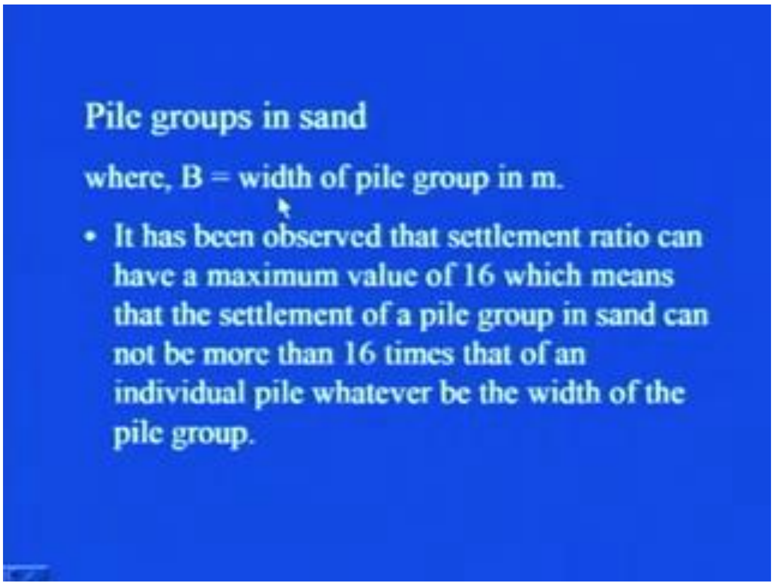

Where B is width of pile group in meter, as I told you that Skempton has given from his experience which he got by conducting various test on driven piles. So, this particular expression is an empirical 1. (Refer Slide Time: 37:17) So, you have to be careful about the unit, so B is in meters; however, these are all empirical parameter that have been obtained by Skemptom.

(Refer Slide Time: 38:15) It has been observed that settlement ratio can have a maximum value of 16 which means that the settlement of a pile group in sand cannot be more than sixteen times that of individual pile whatever be the width of pile group.

So you see here, (Refer Slide Time: 37:17) it has been seen from different you know experimental experience that this S g by S i should be that is its maximum value can go up to the extent of 16. So, if I say let us say if I say that it is maximum 16, so in that case S g by S i will become 16 and that will give rise to S g is equal to 16 times S i.

So, in any case although here, it is apparent that this ratio S g by S i is dependent on the width of this one, that is width B, width of the pile group (Refer Slide Time: 37:17) but in case, the limiting value is 16. So, in case if this ratio is becoming more than 16, then you have to restrict this ratio to 16 only.

Then beyond that that is more than 16 times it is not dependent on the width of the pile group. So, whatever is the width of the pile group the maximum settlement of the pile group can be 16 times the settlement of individual pile.

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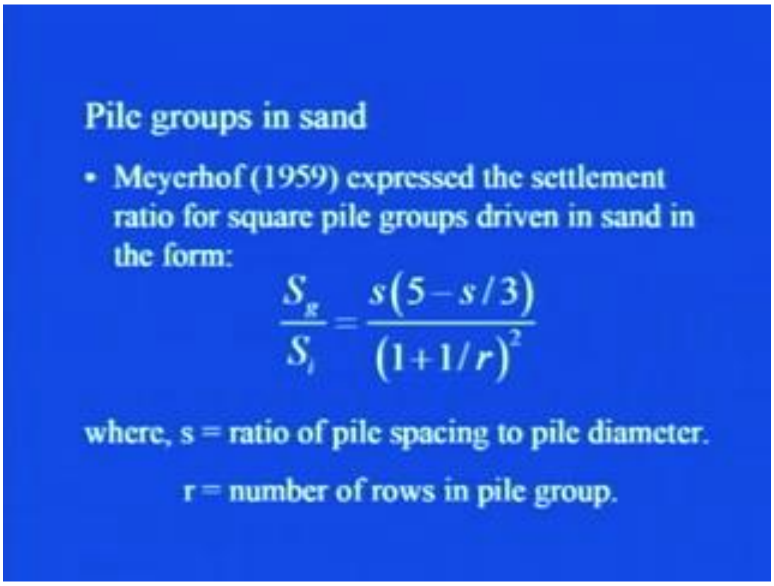

Then, like Skempton gave one particular empirical relation in 1953 likewise Meyerhof in 1959 expressed the settlement ratio for square pile groups driven in sand in the form that S g by S i is equal S into 5 minus S by 3 divided by 1 plus 1 by r whole square where S is the ratio of pile spacing to pile diameter that is, whatever is the pile spacing, divided by the diameter of the pile and then r is the number of rows in pile group. So, since it is square pile.

So, in both the directions the number of piles are going to be same that is why this is valid for square pile groups.

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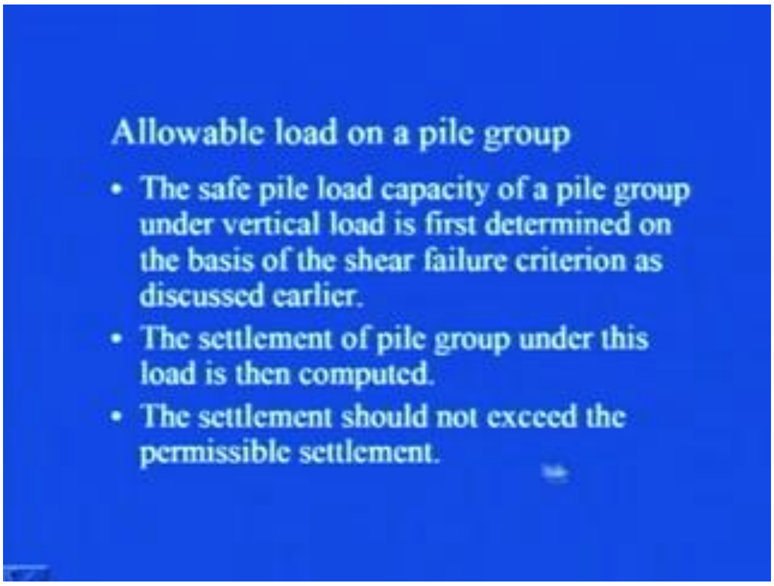

Now, how we can get this allowable load on a pile group, we have seen that, how we can find out ultimate load capacity of the pile group, then how we can estimate the settlement of the pile group, be it in sand, be it in clay. And then, now we can we have we see that how we can find out this allowable load on the pile group.

The safe pile load capacity of a pile group under vertical load is first determined on the basis of shear failure criteria as discussed earlier. We have seen that, how you can find out the ultimate load capacity of the pile group, and this simply you divide it by factor of safety that will give you safe pile load capacity as you already did in case of individual pile.

Then, the settlement of pile group under this load is then computed. So, how you can calculate the settlement, so depending on this particular safe pile load capacity, whatever is that load corresponding to this you can find out the settlement of pile group.

The settlement should not exceed the permissible settlement; obviously, because from serviceability point of view, the settlement has always has to be less than the permissible settlement.

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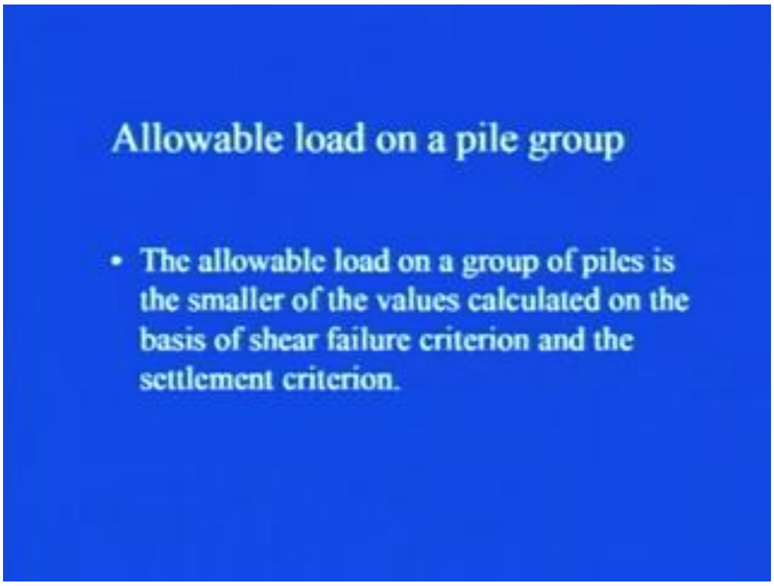

Then, the allowable load on the group of pile is smaller of the values calculated on the basis of shear failure criteria and the settlement criteria.

See the thing is that you have to have that it has to be stable or safe against shear failure as well as the settlement should be less than the permissible settlement. So, these are the two criteria, one is stability point of view, another is serviceability point of view. So, we get we find out the allowable load carrying capacity from both of these aspect and whatever is the minimum value that will be treated as allowable load on a pile group.

Now, see we will be discussing one example and then all the aspects that we discussed as far as pile groups are concerned they will become more clear to you.

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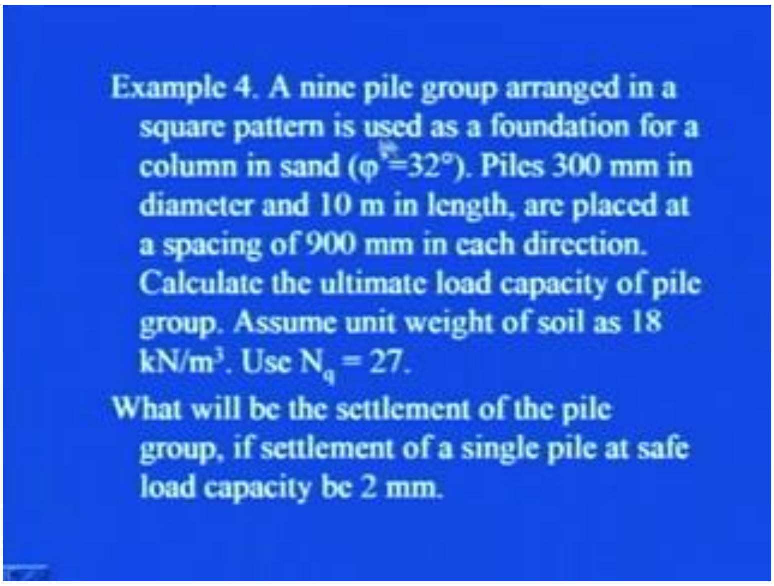

So, the statement of the problem is a nine pile group arranged in a square pattern is used as foundation for a column in sand, phi prime is 32 degree, so you have to remember that pile groups in sand. Since, it is sand cohesion is 0 phi prime is 32 which is given.

Piles 300 mm in diameter and 10 meter in length are placed at a spacing of 900 mm in each direction. Since, it has been arranged in a square pattern, so 900 mm is the spacing in both the directions. Calculate the ultimate load capacity of pile group then assume unit weight of soil as 18 kilo Newton per meter cube and use N q as 27.

Then, the second part of the problem is that will be the settlement of the pile group, if settlement of single pile at safe load capacity be 2 mm.

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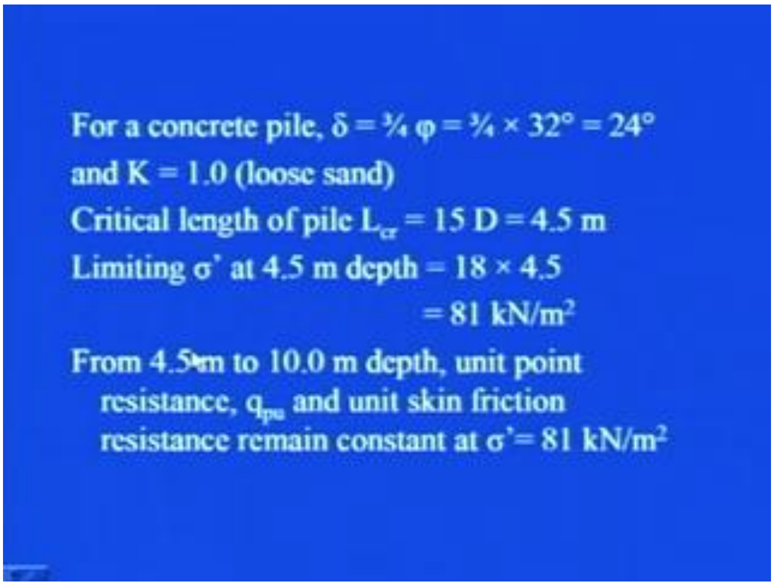

So, let us see that how exactly we can find it out the pile group is in sand, so we have to forget about the pile group, whatever we followed in case of pile group in clay just concentrate on pile group in sand. So, for a concrete pile you already know that delta that is angle of friction between the pile and the soil is three-fourth of phi, phi is 32 degree which results into this delta to be equal to 24 degree.

Then, it is loose sand, so K corresponding I gave you standard tables in last few classes that K is equal to 1.0 and as we discussed that the critical depth concept comes into picture when the piles are to be driven in sand. So, here it is that particular case, so critical depth concept will come into picture for that first we need to find out that, what is the critical length of pile that is, L critical it is 15 times the diameter in this case is 300 mm. So, that results in to 4.5 meter.

So, we know that from the ground surface till particular depth of 4.5 meter, the over burden will be increasing linearly and beyond this depth till 10 meter it will be constant. So, limiting sigma prime at 4.5 meter depth will be your unit weight into this particular depth which is equal to 81 kilo Newton per meter square.

Now, from 4.5 meter to ten meter depth unit point resistance that is q pu and unit skin friction resistance remain constant at sigma prime is equal to 81 kilo Newton per meter square. Because, you know that in critical depth concept this sigma prime or this one limiting sigma prime it increases till the critical depth, beyond that it remains constant.

So, whatever is the unit point resistance or unit skin friction that you will be finding out beyond this particular depth it is going to remain constant.

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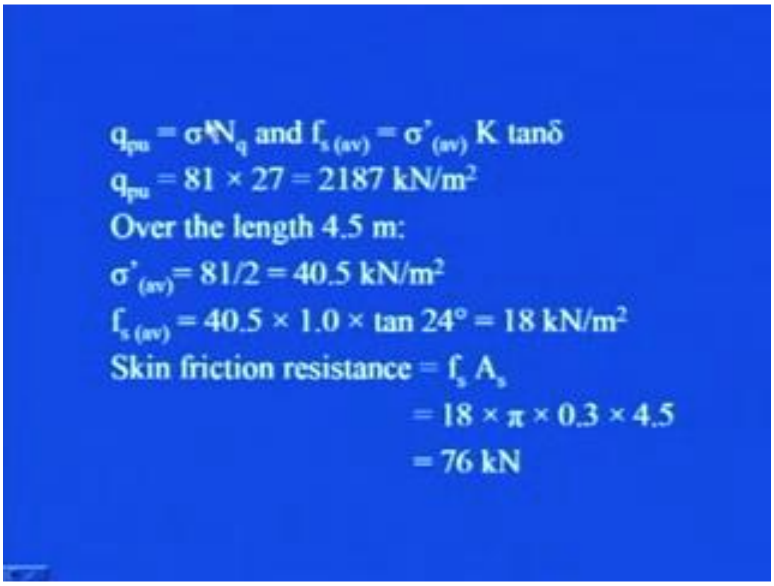

So, we have standard expression, we can find out this q pu as sigma prime as N q and f s average that is unit average skin friction to be equal to sigma prime average into K into 10 tan delta.

So, q pu sigma prime we have already found out that is 81 kilo Newton per meter square multiplied by N q which is given in this case that is 27. In case if it is not given then corresponding to a value of phi you can pick the value, so that results into 2187 kilo Newton per meter square that is unit point resistance.

Then, over the length 4.5 meter, your sigma prime average will be because it is at the ground surface and it is 0 and at 4.5 meter it is 81. So, average will be half of the 81 that is forty point 5 kilo Newton per meter square.

Then, f s average will become from this particular expression that is 40.5 into 1 K, because of loose sand and tan 24, it results into 18 Kilo Newton per meter square. So once, we know this unit skin friction resistance we can find out total skin resistance which will be acting on the surface area of the pile shaft.

So, you have to simply multiple this unit resistance by that particular area which is phi diameter and over the length on which it is acting. So, above between 0 to 4.51 value and then 4.5 to 10 meter another value, so here it is from the over the length 4.5 meter, we are talking of over the length 4.5 meter you are getting this 66 kilo Newton as skin friction resistance.

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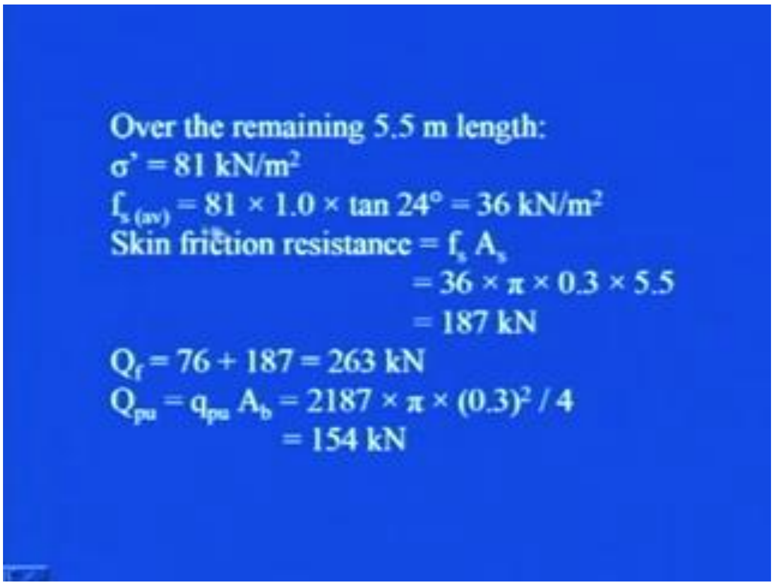

Now, over remaining 5.5 meter length, you can find out using the same expression because sigma prime is going to be uniform now over this particular depth. So, that will be 36 kilo Newton per meter square.

And, skin friction resistance in the similar manner you can get by multiplying this unit friction, skin friction resistance by this area of the pile shaft on which it is acting which is phi D into L, L is in this case 5 point 5 meter, so that becomes 187 kilo Newton. So, your total skin friction resistance will be 76 plus 187 which is 263 kilo Newton and then what about this total point bearing resistance, that is q pu, we have already found out into area of the pile base. So, that is 2187 into phi, this is diameter of the pile that is D square by four and this result into 154 kilo Newton.

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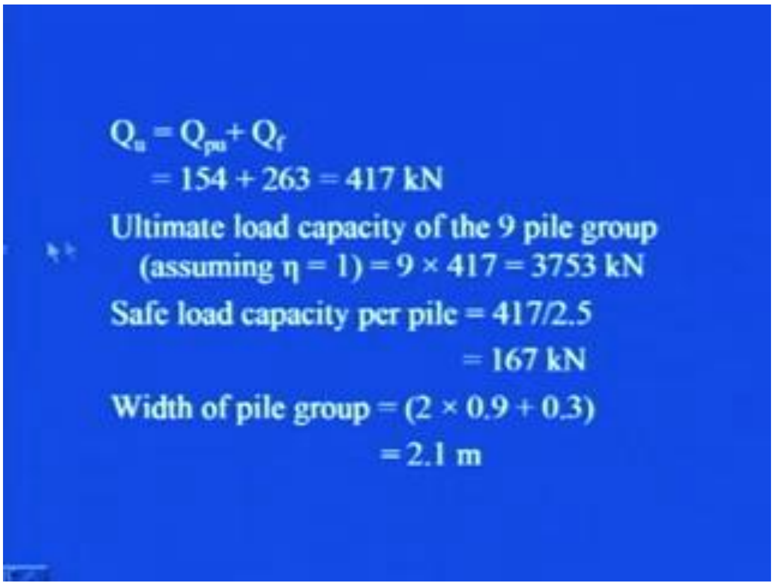

So, the total load capacity of one particular pile will be its point bearing resistance and skin friction resistance, if you add them up you will get that as 417 kilo Newton.

Now, since it is sand we have seen that the efficiency which is eta to be assumed to be 1, so in this case, if I assume that that it to be equal to 1. So, ultimate load capacity of 9 piles groups that it a group which is comprises of 9 piles, so that will become 9 times the load carrying capacity of 1 pile, because we are assuming the efficiency to be equal to 1.

So in that case, it wills simply you have to multiple this quantity by number of piles in group that is 9 into 417 that will result into 3753 kilo Newton. Then, how you can find out the safe load capacity per pile, simply you have to divide by factor of safety of 2.5. So, this is per pile I am finding out, so that is 417 by 2.5 which will result in to 167 kilo Newton.

Now to get, the settlement because we have to find the settlement also as per the statement of the problem, we need to find out the width of the pile group. Because, without knowing that we will really not be knowing that to what extent the soil will be contributing to the settlement.

So, first we will find out, what is the width of the pile group, that is 2 into 0.9, which is the spacing, because you have seen that it is 9 piles put it in square forms. So, there are 3 piles in each row and there are 3 rows of that kind, so the width of the pile group will be since there are 3 piles, so 2 times the spacing plus the half of the diameter from one side half of the diameter from another side. So, that will become the 1 diameter, so that I am adding it here, this will result into 2.1 meter.

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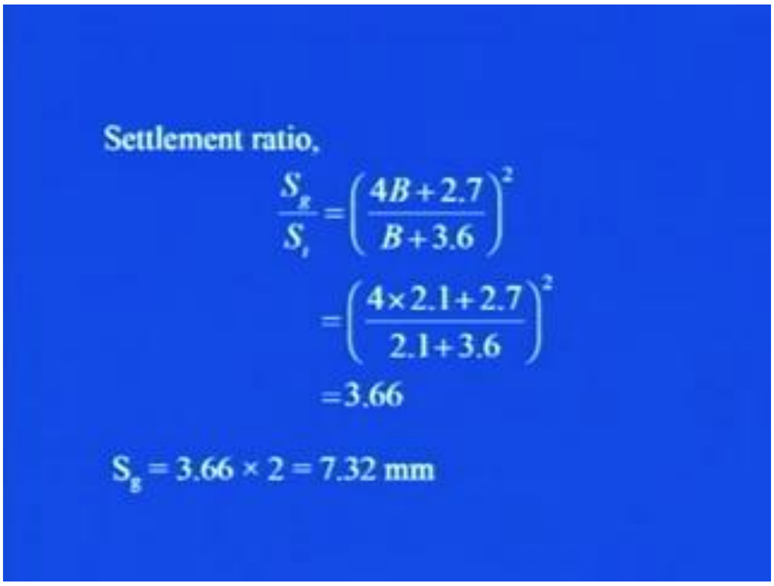

So, we are using that expression for settlement ratio, when the pile groups are in sand, then we have this width of the pile group just now we worked it out to be 2.1 meter.

So, if you put it here that is 3.66 which is less than 16, so S g will be equal to this 3.66 into S i and in the statement of the problem it is given that for individual pile it is 2mm. So, if you multiply that so group of the pile will have the settlement of 7.32 millimeter.

So, I hope that, whatever we discussed in the theory part that becomes more clear to you, after having a look on this particular example. So, this was the case when the pile groups were there in sand.

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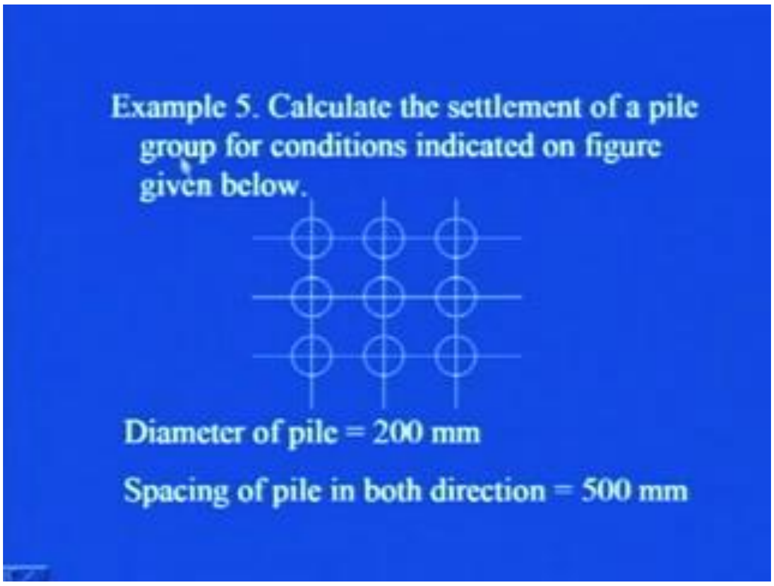

Let us try to have another example, in which the settlement of the pile group we need to find out, when the piles are to be driven in clays. So, what exactly is the statement is that, calculate the settlement of a pile group for conditions indicated on figure given below, where the diameter of the pile you see 9 piles are there, placed in square pattern.

Diameter of pile is 200 millimeter spacing of pile in both the direction is 500 millimeter, please mind that that this is not to the scale. So, it just representative sketch that I am giving you, so the spacing that is from here to here it is 500 mm and in this direction also it is 5 100 mm; however, the diameter of this pile is 200 mm.

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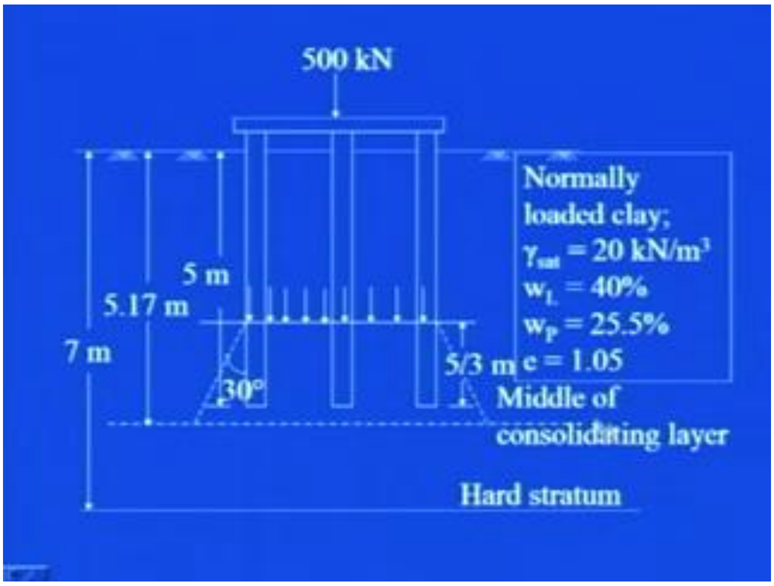

So, this is the figure which has been given you in the problem that 3 piles have been shown another 3 rest 6 are there in that particular direction perpendicular to this. This is normally loaded clay with comma saturated to be 20 kilo Newton per meter cube, liquid limit 40 percent, plastic limit 25.5 with wide ratio to be equal to 1.05.

Then, the length of the pile is 5 meter in this case has been shown, and the dispersion, so as we were discussing that it has to be this equivalent raft. This is pile cap, so I am placing the equivalent raft at a depth two-third of this particular thing.

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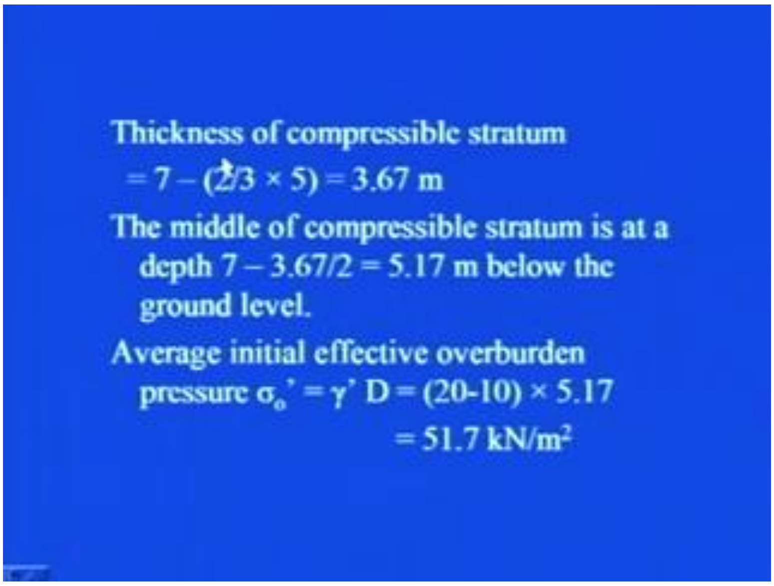

Let us say that, how the thickness of compressible is stratum will be 7 minus two third of 5, because at two third of the 5 we are placing that equivalent raft. So, that is becoming 3.67.

(Refer Slide Time: 53:16) So, middle of compressible stratum is at a depth 7 minus 3.67 by 2, that this is where the middle of the consolidating layer is this much, if you place your draft here, so equivalent width will whatever will be the contributing will be this because here it is hard stratum which is lying at 7 meter.

So, that will be your 7 minus this 5 by 3 that 7 minus 2 times that 5 by 3 that is 3.67 and then it will be 5.17 below the ground level, that from ground level this is 5.717 which is middle of the consolidating layer. Then, average initial effective overburden pressure will be gamma priming to D, so gamma prime is given here, it is twenty and it is saturated.

So, effective will be saturated minus gamma of W that is of water which I am considering 10 here in this case. Then, multiply by 5 point one seven. So, you will be getting the pressure at this particular level.

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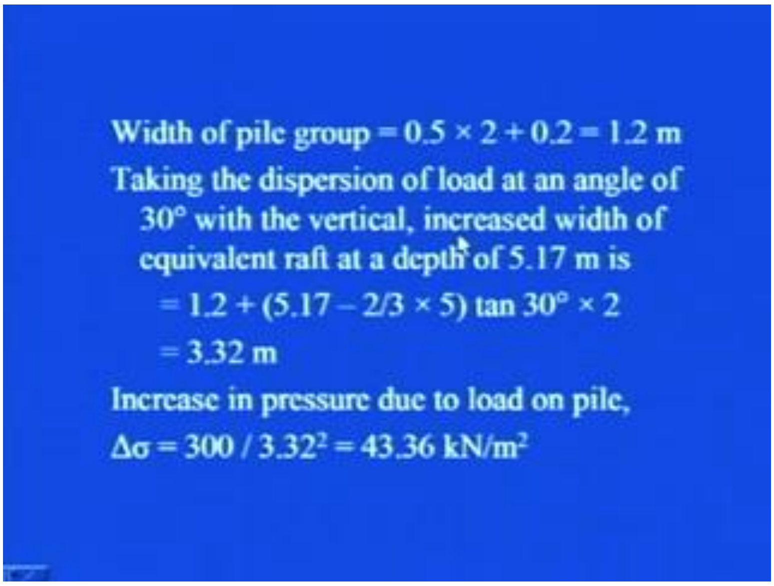

Width of the pile group exactly in the similar manner as you found out in the last example that is 1.2 meter. So, if you take the dispersion of load at an angle of 30 degree with the vertical increased width of equivalent raft at a depth of 5.17 meter will be that you can find it out.

You see here in this figure (Refer Slide Time: 53:16) you take this dispersion to be 30degree. So at this particular depth, you can find out this depth by simply by trigonometric expression which will work out to be 3.32 meter.

So, increase in pressure due to load on the pile will be, whatever was the load which was coming, divided by that much particular area. So, the load intensity will work out to be 43.36 kilo Newton per meter square.

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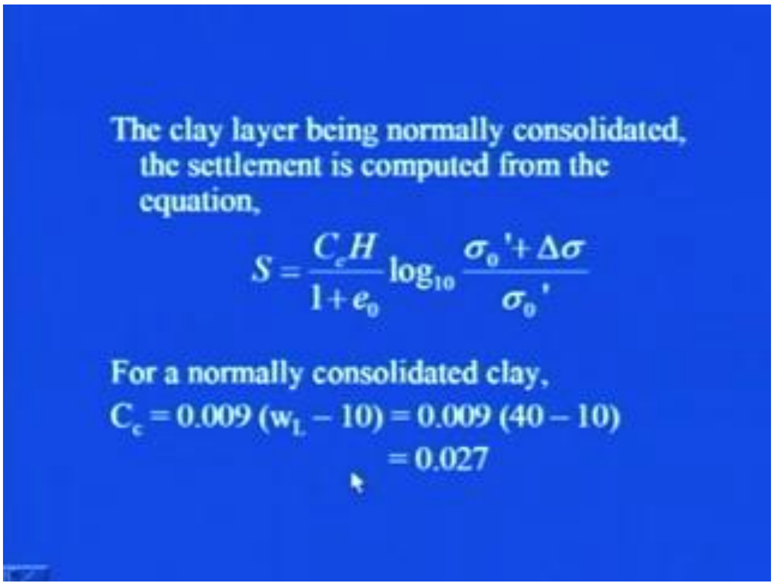

Now, the clay layer will be giving or contributing to the settlement and it is normally consolidated soil. So, the settlement expression that it is Cc H by 1 plus e naught log of 10 sigma o prime plus delta sigma divided by sigma o prime.

And then, you it has been given to you in the problem that, what exactly is the liquid limit, so you can find out this Cc value using this 0.009 W L minus 10 you can get this 0.027 value.

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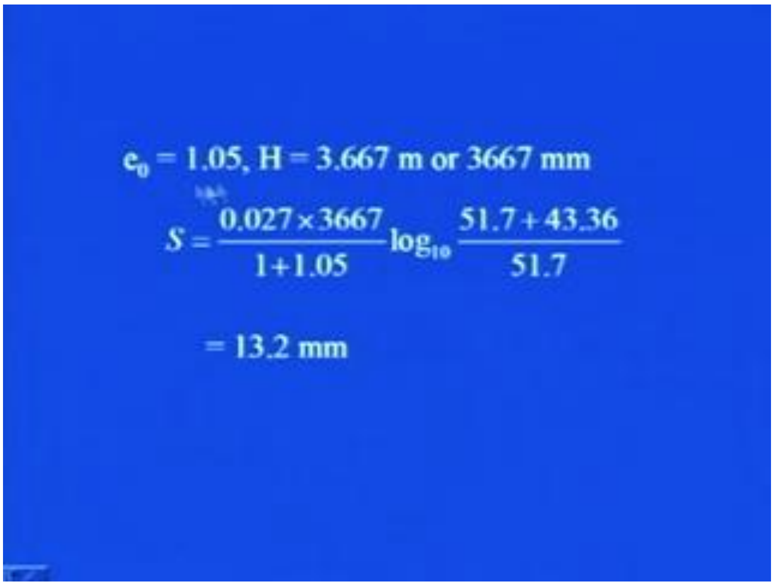

And then, you known this e naught value H value and you put in this expression, then simply you will be getting this 13.2 millimeter of the settlement.

So today, we saw with the help of two examples that, how you can find out the load carrying capacity of a pile group and its settlement, first we saw with the help of an example that, how you can analyze the case in pile groups in sand and the second one that, how you can use that equivalent raft approach to find out the settlement of the pile group.

So, overall we have seen that, how individual pile behaves, how pile group behaves, what exactly is the effect of spacing on the efficiency of the group of piles, how you can get the ultimate load carrying capacity settlement and allowable load carrying capacity of a pile group.

Thank you.