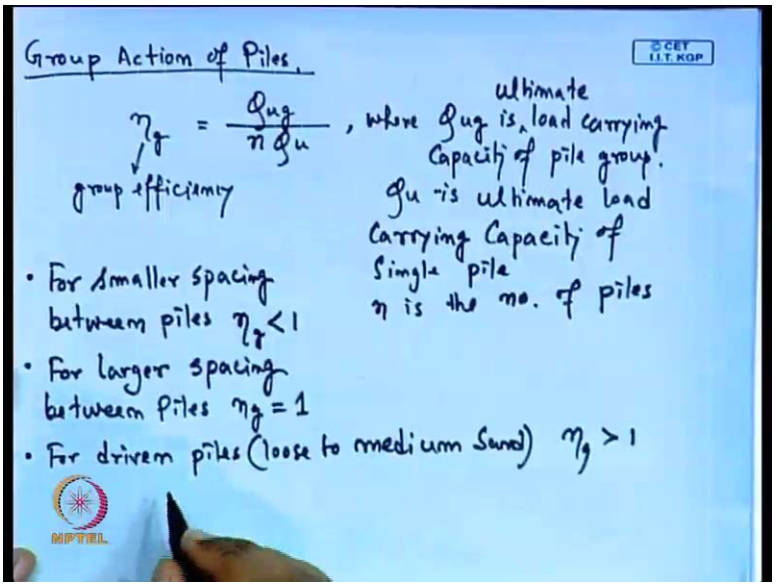
Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 17
Pile Foundation- Load Carrying Capacity-I

In the last class I have discussed about the load carrying capacity of single pile, but generally pile these are used in a group. So, now today I will discuss about the load carrying capacity of the pile or in group or the group action of the pile. Then I will discuss the other method by which we can determine the load carrying capacity of the pile. Now, first I will discuss about the group action of the pile.

(Refer Slide Time: 00:46)



In the group action of the pile, now when pile is used in a group then we can calculate the efficiency of the pile group, now that efficiency if we write that this is the efficiency of group or the group efficiency, that we can write in this form this Q u g divided by n into Q u, where Q u g is load carrying capacity of pile group and Q u is the, you can say this is the ultimate load carrying capacity of the pile group and Q u is the ultimate of single pile. And n is the number of piles; that means, is here n is the number of piles in the group Q u is the ultimate load carrying capacity of the single pile, and Q u g is the ultimate load carrying capacity of the pile group. So, here to grade these group efficiency we have to calculate the ultimate load carrying capacity of the pile in group, consider this

pile as a whole and then this Q use the single pile. Now, this now for this smaller spacing between piles generally efficiency or the group efficiency less than u 1 or less than 100 percent. So, that means...

So, that it indicates that that; that means, here these in a group the pile that can fail in as failure can be occurred as individual pile failure or failure can be occurred as a group or as a block type of failure of the considering the total all the piles that as a group and that can fail as we whole or it is a block type of failure. So, that is one type of failure another is individual pile failure. Now if the spacing is very small then this will occur this group type of failure generally occur and in that case the efficiency is less than 1. Now for the larger spacing it is group efficiency is equal to 1. So, now, for the largest type of spacing where individual pile failure will occur.

So, we will get the group failure is equal to the individual pile load carrying capacity into the number of piles that means, Q u g will be equal to is n into u g that means, the contribution from each pile will, summation of contribution of each pile will give the group load carrying capacity of the pile in that case this efficiency of book will be 1 and if it is less spacing is very small then we will get the, because the over load due to the over liking over lapping of the stress zone or the influence zone for the single pile individual piles. Though; that means, the group failure will occur in that will less than the load carrying capacity of the individual pile, if you sum the all the load carrying capacity of the individual pile that will be generally more than the pile load carrying capacity as a. So, in that case if the spacing is very small then the group load carrying capacity is smaller or the lower than the summation of call individual piles load carrying capacity.

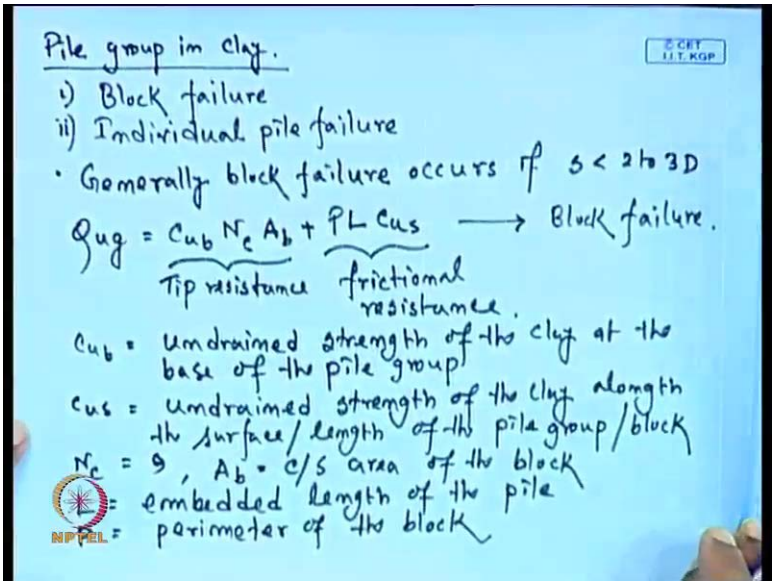
So, in that case this efficiency will be less than 1. Now another thing that for the driven pile is loose to medium sand loose to medium sand this efficiency can be greater than 1 this is because there is one pile is driven into a loose to medium say and then sand become dense. So, in that case because of the installation of the pile the group can capacity of the pile surrounding the soil pile soil surrounding this pile at get dense. So, that is why the efficiency that will increase.

So, there is a three possible cases that for the smaller spacing between the pile. So, as the summation of all individual pile load carrying capacity that is more than the group

carrying capacity group load carrying capacity of the pile. So, within that case efficiency will be less than 1 now if the larger spacing in that case basically the individual pile failure will occur and if the spacing is very less in the group type of the block type of failure will occur. So, if the spacing is very large. So, individual pile will failure will occur in that case the group load carrying capacity is equal to the summation of the all individual pile load carrying capacity.

Now, in third case in the driven pile if it is driven in the in the loose to medium sand in that case the density the sand the sand become dens. So, because of this nature the group carrying capacity or the efficiency of the pile that will increase and that efficiency is sometimes even greater than 100 percent or greater than 1. Now for in we will discuss about how to calculate the group carrying capacity of the pile.

(Refer Slide Time: 08:23)



So, in that case we can write that pile group in clay; first we will calculate the group carrying capacity of the pile if it is in the clay. So, as I have mention there is a two types of failure one is that block failure and second one individual pile failure. These two types of failure will occur if the spacing is generally more spacing between the two piles. So, more than this individual pile failure occur, and if it is less than the block failure is occur generally, but in then now for the another thing that is condition for the clay that generally block failure will occur if spacing is less than 2 to 3 D, now if the spacing less than 2 to 3 D this the diameter of the pile and if thus largest spacing individual pile

failure will occur. In that case if we calculate Q u g that is the group load carrying capacity of the pile that is C u b at the base then N C then A b at the base plus P into L into C u s.

So, in that case here the similar to the individual this expression. So, this is the from the tip resistance and this is the friction resistance. So, this is the tip resistance and this is frictional resistance. So, now we can write that C u b is the undrained strength of the soil at the base of the pile of the clay of the clay at the base of the pile. So, this is tip resistance is coming from the base. So, this is at the base of the pile

So, similarly Q u s this is the undrained strength of the clay along the surface or length of the pile group or block and the here also we can write this is pile group. Similarly in C values we can write is equal to 9 like the single pile then we can write A b is equal to cross section area of the block this is the cross section a of the block L is the embedded length of the pile pile and P b or P; that is the perimeter of the block.

So, here this u g we are calculating by considering the block failure to the, if we consider this is the block failure, and then we calculate this this is the tip resistance and this is the friction resistance. So, C u b at the undrained resistance at the base of the pile n C is 9 A b is the cross section area of the block P is the perimeter L is the embedded length, and Q is the undrained resistance along the surface for the pile group or block, so same as the single block.

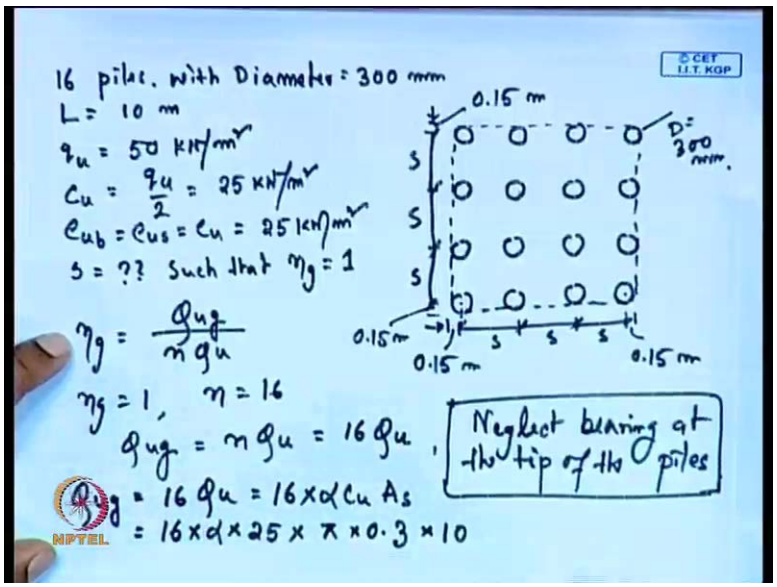
Now, if we can similarly we can write we can determine the or we can write the expression for the pile in the sand the same while using the same type of expression for the sand because this is similar to the single pile and already thing is the here the cross section area the expression of same in the cross section area in case of single pile we are consider there is a cross section area of the single pile, here the cross section area we have to consider the block when you calculate the tip resistance. Similarly in the calculation of the single pile friction resistance we use the area is the surface area of the single pile here we have to consider the surface area of the block; that means, the perimeter and the length of the block.

So, that is the only difference when you consider the group and the individual failure individual pile load carrying capacity. So, this is the load carrying capacity for the clay similarly while using the same expression like the single pile in the in the sand we can

determine the load carrying capacity of the pile in the sand. Generally and sometime as I have mentioned that in driven pile is efficiencies greater than 1. But one we design this things we can consider that efficiency equal to 1 and you can design. So, now so that means, we are now giving the expression for the clay and similarly the same expression as a given for the single file that we can used by slide modification for the cross section area for the base and the cross section area of the surface area of, to consider the cross section area of the block and the when we calculate the steep resistance. And when the cross section area of the surface area of the block when we calculate the friction resistance that is the difference between the single and group others the expression are almost same.

So, now we will solve one example which we can determine that how we can calculate the load carrying capacity of the pile, and the single pile and the group pile and then we will determine then the other factors also and the spacing also.

(Refer Slide Time: 16:28)



Suppose problem is that that we have 1 block this is the element of the pile in that thing this is the total 16 piles of their so 4 columns and 4 rows, total 16 piles. Now, it is a in the clay soil. The diameter of the pile or D of the pile is 300 millimeter this is the diameter of the pile, now the thing is that this is the total number of 16 piles with diameter is 300 millimeter, length of the pile or embedded pile is 10 meter now undrained Q u undrained strength of the soil is 50 kilo newton is unconfined compressive

strength of the soil this Q so; that means, C we can calculate C u and then C is 10 of the soil that will be Q u divided by 2. So, that is 25 kilonewton per meter square; so C u, so we are considering the same C u for the surface as well as at the base. So, that. So, that mean C u b and C u S similarly C u b is equal to C u S equal to C u equal to 25 kilonewton per meter square. So, Q u equal to 50 kilonewton per meter square C u will be Q u by 225 kilonewton per meter square.

Now, we have to determine the spacing, what will the spacing such that, that grouped efficiency will be exactly 1, why we can check any other value also so they can take the 0.9 0.8. So, here we will design these things such that the group efficiency will be exactly 1 what will be the spacing. So, as I have mentioned that here we have to consider the single and as well as the block failure.

This is the block basically for the group. So, suppose we consider this is the spacing between the space this S and similarly this is one is also S, this is S, this is S, this is S. Now distance from this because this is the center of the each pile. So, distance from this center to this h is 0.15 meter similarly this one is also 0.15 meter as similarly this one is also 0.15 meter and this one is also 0.15 meter, because the total diameter is 0.3 meter. So, half of this is 0.15 meters.

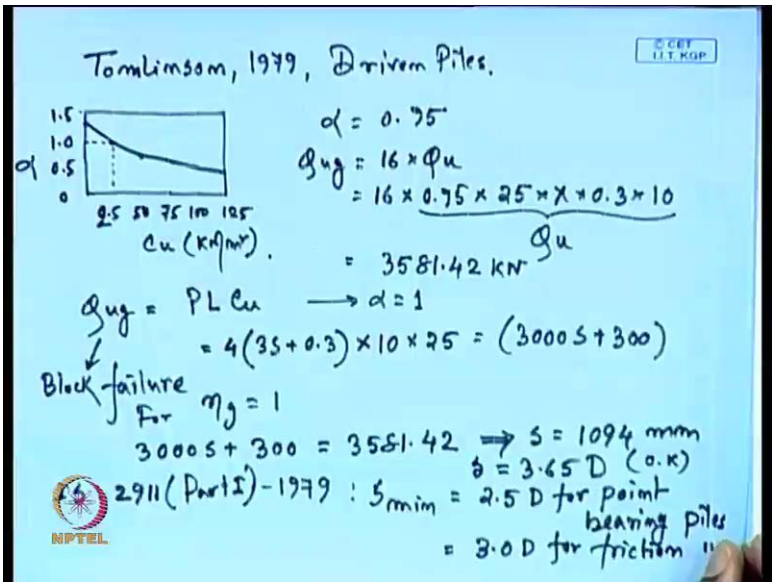
So, as calculate the group efficiency Q u g is n into Q u. Now here Q u g is 1 n is equal to 16 in is the number of pile. So, now, if Q u g is equal to 1 so that means, Q u g if efficiency is equal to 1 so that means, Q u g will be n into Q u or Q u g equal to 16 into Q u. So, now, first we will calculate the Q u g and here another thing the condition is that we can neglect the tip resistance of this pile that mean the resistance we are getting. So, we can neglect it, neglect neglect the bearing at the tip of the piles, because these are the in the clay. So, that in the these are the friction pile. So, the resistance coming from the friction will be more as compared to the resistance coming from the tip.

So, the one condition that we can we are neglecting that friction components so that means, Q u g will be equal to that I have mention that is the 16 Q u. So, the single pile capacities 16 into alpha into C u into A S area at the surface. So, now, here this is 16 into alpha into C u is 25, area is pi into 0.3 into 10 is the length.

So, area is pile D L. So, pi into 0.3 into point into L is the 10 meter and this alpha we have to calculate. So, in the last class I have given one chart. So, calculate the how to

calculate the at a will how to calculate this alpha value and here based on this C u value I am giving another figure by which we can determine the value of alpha.

(Refer Slide Time: 23:03)



And that figure is proposed or this is proposed by the Tomlinson 1979 and this is for the driven pile. So, in this figure. So, this is. So, this point we can say this is alpha this is 1.5 this one is 1 this is 0.5 and this is 0; and this side this is 0.5 sorry this is 25 50 75 100 125 this is the value of C u it is in kilonewton per meter square.

So, the point that we are get in. So, these are the points. So, we can if you join this points this is the chart. So, this is from here we can determine what will be the value of alpha corresponding to 25 because our C u value is 25 kilonewton kilonewton per meter square. So, now, what will the value of alpha as corresponding to 25 kilonewton per meter square. So, with this value you can calculate this alpha is coming 0.95.

So, we can calculate the value of Q u g in terms of 16 into Q u and this is 16 into alpha is 0.95 into 25 is C u into pile into 0.3 into 10. So, this is this part is 16 and that this basically this part is 0.95 alpha into 25 into pi into 0.3 into 10 this is this total thing is equal to the individual pile load carrying capacity ultimate pile load carrying capacity of the individual pile. So, the total load carrying capacity is 3581.42 kilonewton; that is the load carrying capacity of the pile in group.

So, here all the calculation we are doing for the compressive load carrying capacity of the pile. So, next term we will we can calculate this Q u g in terms of blocks failure this is this is in terms of individual failure now we other time in terms of block failure we can write this is P perimeter into L into C u. When we are calculating this block failure here we consider that our alpha is basically 1 the reason is that here is the alpha is the addition. So, that mean this here the addition your this is the addition factor and this addition your considering when it is a single pile; that means, there the addition is between the pile surface and the soil.

So, that is why have to consider alpha value because your two different materials we are considering, it is the pile different materials and the soil is the another different materials, but when you are considering the block this a block failure. So, there is blocks this said this is the interaction between the soil and soil. So, both are same material that is why we are considering here we consider this block failure we consider alpha equal to 1, but when we consider the individual pile failure that is the interaction between the pile surface of pile material and the soil to the two different material that is why we consider different alpha value, but here interaction between the two same soil the here we will consider the alpha equal to 1, because the interaction between the soil and soil when this is a block.

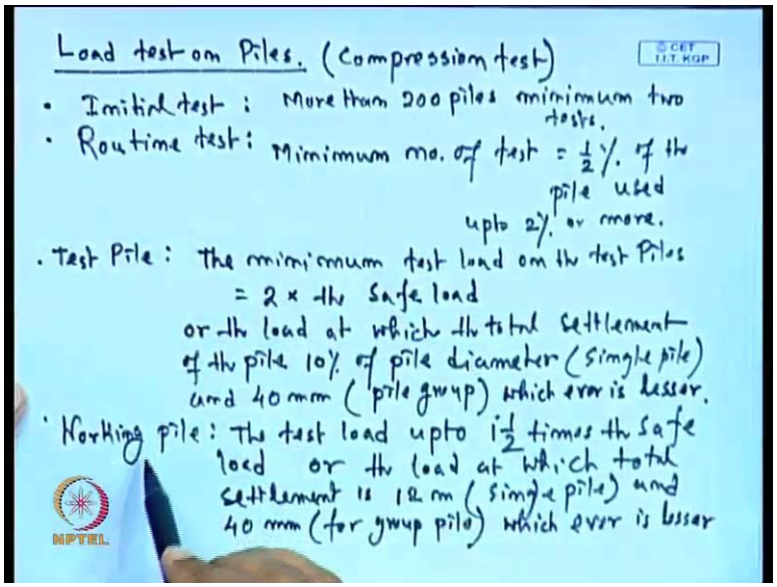
So, now here we can write this P is the perimeter is 4 into 3 S because if I look this block total. So, when we are considering the block failure this most of the surface here interaction is soil to soil, individual piles interaction in the soil and pile. So, that is we are considering alpha in the block, but the side one is 3 S plus 0.15. plus 0.15 So, 3 S plus 0.3 is one side another is also 3 S plus 0.3, because here this is the square type of arrangement so; that means, we can write the perimeter is 3 S plus 0.3 into 4 because this is one side another 4 side into L into 25. So, this is 3000 S plus 300 now for efficiency is equal to 1 we can write that 3000 S plus 300 that is equal to 3581.42.

So, now from here we can calculate that S is coming 1094 millimeter or S is equal to 3.65 D where D is the diameter of the pile, this is the diameter of the pile. Now then another thing that we have to check with that IS code recommends that 2 IS 2911 this is part I 1979 that for the minimum spacing or S minimum that is equal to 2.5 D for point bearing pile piles and equal to 3 D for friction pile friction pile.

So, here it is minimum spacing here you designing this for the friction pile the minimum requirement is 3 D, but here our calculation is coming 3.65 D; that means, is o k. So, to get efficiency equal to exactly 1 we have to provide a spacing 3.65 D. So, that spacing we can provide to get spacing exactly one exactly efficiency exactly 1. So, if we want to design it for the different efficiency then we have to put that value and then corresponding spacing we have to calculate.

So, first we assume the diameter, the diameter we are choose and based on that we can determine what do the spacing required to get a particular amount of efficiency group efficiency. So, in the next section I will discuss about, these are the… So, in the first class I have mention about this these are the four different wave by which we can determine the load carrying capacity of the pile the first one the by the static expressions or the formally that part I have I finished. Next one that I will discuss about the pile load test so by pile load test also we can determine the load carrying capacity of the pile. So, next one is the pile load test that we will discuss in that section.

(Refer Slide Time: 32:20)



So, now, in the pile load test, so this part we will discuss about this load test or the on piles. So, by pile of test also we can determine the load carrying capacity.

Now, this is basically this again this pile load test one any fail it is suitable for cohesion less soil. Now here we will do the different types of pile load test we can perform one is compression test, one is pool out or tension test and one is lateral load test. So, here we

will discuss about the compression test how we can do the compression test to determine the load carrying capacity of the pile. So, here basically you are discussing the compression test in addition to this we can do the pool out test or the tension test or lateral test to know the lateral load carrying capacity of the pile. Now before we go to the pile load test we have two things that we should know that is one is initial test and next one is the routine test.

So, initial test one term it this is carry out on the test pile this is the carry out on the test pile to estimate the allowable load carrying capacity of the pile, all to know the settlement of the pile corresponding to the working load. So, that is the test pile. So, this is the test pile that we carry out on the pile to estimate the allowable load and to predict the settlement and the working load. Now routine test, can this carried out to check the working pile load to and to know the corresponding settlement of the pile corresponding that working load.

So, that in the routine test will perform on the working pile and initial test that we will perform on the test pile. So, now, this thing is the more than, the condition is that more than 200 piles the minimum 2 test is equal. So, more than 200 piles minimum 2 initial test is required and for the routine test this minimum number of test is generally half percent of the pile used or that can vary up to 2 percent or more that means, the initial test that is conducted on the test piles and the rooting test that is conducting on the working piles.

Now, in test piles means this piles are constructed to for the testing purpose this is not constructed for the load carrying capacity or load carrying purpose of the supper structure; it is not constructed for the working condition it is just constructed for the testing purpose and then once the test then this piles are not used. So, these are not used to carry the load which is coming from the super structure and routine piles are routine test are conducted on the working piles. So, working piles are the piles where the actual load of the super structure that will come it will work that means, the routine test will conduct for the working piles on the working pile and initial test will conduct on the test pile. Now more than 200 piles minimum 2 test piles or initial test these are required, and for the minimum number of the routine test is given half percent of the pile used for it up to 2 percent or nearly more.

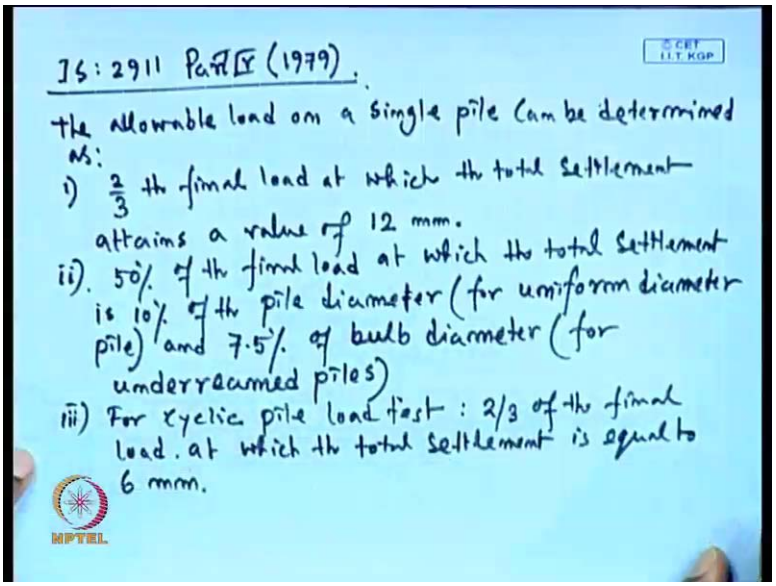
Now, when this this is test pile, so now, thing is that test pile and working piles, used only to load test does not carry load of the supper structure that I have already mentioned this things. Now the minimum test or the load that these piles are taken, the minimum test load on the test pile that is equal to 2 times the safe load. The minimum test load on the minimum test load on the test pile is two times the safe load. This safe load we can determine by using the static expression that I have already explained.

So, now this load test are attained a value for this load test is generally two to the safe load or the load at which the total settlement of the pile is 10 percent of pile diameter in case of single pile and 40 millimeter in case of group pile. So, that mean this minimum test load on the test pile in 2 times the safe load or the load at which the total settlement of the pile 10 per attains the 10 percent of the pile diameter for the single pile or 40 millimeter for the group pile. Similarly for the working pile; that means, the routine test the test load is generally up to 1.5 times the safe load or the load at which total settlement is 12 millimeter again for the single pile and 40 millimeter for group pile whichever is lesser. Here also this is also whichever is lesser so that means the these are the all the information regarding the initial test routine test then; that means, the initial test is conductive on the test pile the test pile.

So, the pile which is constructive for the testing purpose not for the it will not take the load which is coming from the super structure, and the routine test is conductive on the working pile now this working piles of the piles which will take the load; that is coming from the supper structure. Now more than 200 piles minimum 2 test piles are required initial test that is required and minimum number of test is half person for the pile used the routine test of 2 percent, and more and the test pile the minimum test load is 2 times the test load or the load at which is the settlement attention that value of 10 percent of the diameter for single pile or and 40 millimeter for the group pile whichever is lesser.

And working pile the test load up to which 1.5 times the safe load or the load at which is total settlement is 12 millimeter for the single pile or 40 millimeter for the group pile whichever is lesser. So, these are the condition for the different test and the different type of piles which are used for the pile loop test.

(Refer Slide Time: 42:17)



Now next we will discuss about the how to will calculate the load carrying capacity of the pile using the pile load test is 2911 this is part IV 1979. So, this IS code according to this IS code now load is applied on the R C C cap for the pile and the applied increment of 20 percent of the safe load and corresponding settlement of the pile is recorded by using the at least three dial gauge attach in the pile cap. So, pile cap is used and where the load is applied with an increment of 20 percent of the safe load and as I mentioned the safe load is calculated based on the static expressions and the settlement corresponding to the each incremental load is recorded which is measured by using at least 3 dial gauges. Now, the allowable load how will get the allowable load of the pile.

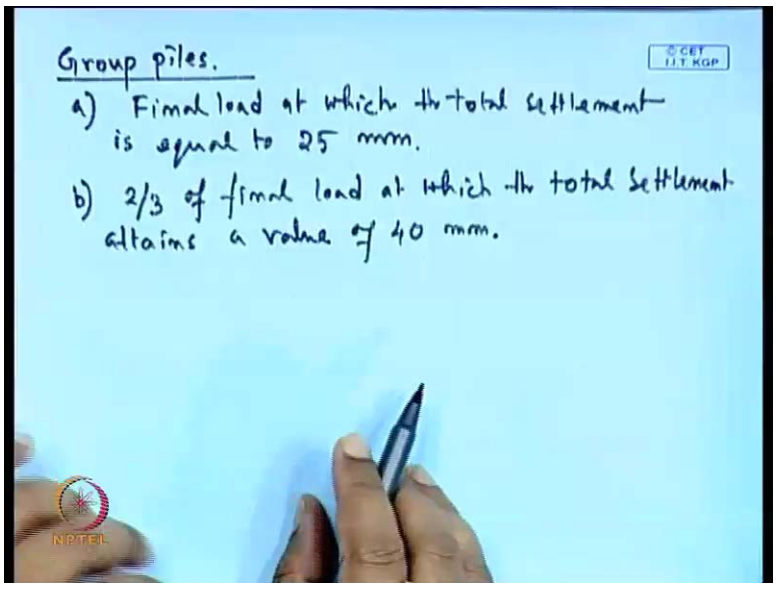
So, how we will can determine the allowable load on a single pile. So, one first condition is the two third the final load at which total settlement attains a value of 12 millimeter. So, if that means, the two third of the final load at which the total settlement attains a value of 12 millimeter. That means, if nothing is specified mean we can consider the permissible settlement of the single pile is 12 millimeter and the load at which this 12 millimeters attain we have to consider two third of that final load.

Now, if any permissible settlement is mentioned other than this 12 millimeter then we have to calculate the load two third of that final load at which the total settlement attain that permissible limit which is specified. Now in or second case the 50 percent of the final load at which the total settlement is 10 percent of the pile diameter, this is for

uniform diameter pile and 7.5 percent of bulb diameter this for under reamed piles. So that means, this is the conditions is the one is first one is (( )) second one is the 50 percent of the final load at which the total settlement is 10 percent of the pile diameter for the uniform diameter pile and 7.5 percent of the pile diameter for under reamed pile. Now another condition is that now this we can used third one of the third condition this is the single pile.

Now, for the cyclic test this is the for the static test complicit now if we can do the cyclic test if we want to know the tip resistance as well as the friction resistance of the pile separately. If I go the static test for the single pile that will give us the total resistance of the pile and if you know want to know the tip resistance, and the friction resistance separately then we have to go for the cyclic test. Now for the cyclic test pile load test that means, the two third of the load final load at which the total settlement is equal to 6 millimeter. So, there we can replace this one, this is the similar to the number one condition, but here this is two third the final load at which total settlement is equal to 6 mm. So, the minimum of all this condition that we will consider as our allowable load on a single pile that is determined from the based on pile load test.

(Refer Slide Time: 48:56)



Now, for the group pile or the group pile same thing we can use from condition. So, that first one is similar that the final load at which settlement is equal to 25 millimeter. So, now, this load test we can perform on the single pile as well as on the group pile.

Generally in the group piles is the permis is nothing is specified then the permissible limit is, settlement is 25 millimeter. Now the final load at which this settlement is attained that will one condition.

So, now if any other permissible settlement is mentioned then we have to calculate that final load corresponding to that specified permissible settlement, if nothing is specified then will consider for the group permissible settlement of the pile is 25 millimeter. Now b is that is two third of final load at which the total settlement attains a value of 40 millimeter. So, if this is the second condition this two third of the final at which total settlement attains a value 40 millimeter. So, the minimum of these two we will consider the allowable load carrying capacity of that group.

So, these are the condition that we have to satisfy when you calculate, determine the load carrying capacity of the pile, single pile as well as the pile group. So, these are the condition. So, we have discussed about the initial test the routine test and test pile and working pile and what are the condition by which we candidate by using those condition we have to determine the load carrying capacity of the single pile as well as the group pile. Now this up to this we have discussed about the load carrying capacity of the pile. So, this will give us the total load carrying capacity of the pile, allowable load carrying capacity of the pile.

Now, if we want to determine or going to know the resistance that we are getting in individually from the keep as well as from the friction, then we have to go for the cyclic pile load test. In the next next class I will discuss about the cyclic pile pile load test by which we can determine what is the contribution from the friction part, and what is the contribution from the tip resistance of the pile individually.

Thank you.