Advanced Foundation Engineering
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Lecture – 42
Pile Foundation: Under Compressive Load – II

So, last class I was discussing how to calculate the tip resistance and the frictional resistance for a pile in sand considering critical depth concept and I determined the tip resistance. Now, today I will discuss the frictional resistance first then I will discuss the other topics.

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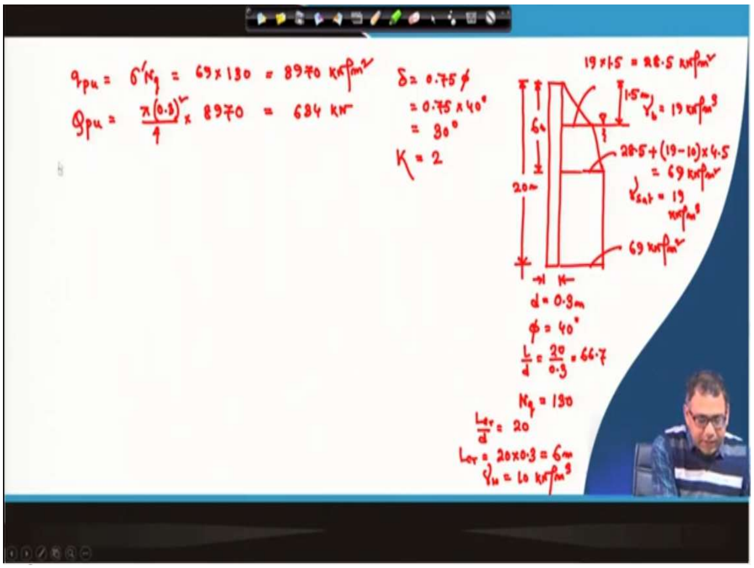

Now, first in the next part, we have to calculate the frictional resistance because we have determined the tip resistance for these particular details, we have a critical length or depth of 6 m and the tip resistance is 634 kN. Now, the frictional resistance I am calculating for three different parts, one is from 0 to 1.5 m and other is 1.5 m to 6 m and other is 6 m to 20 m.

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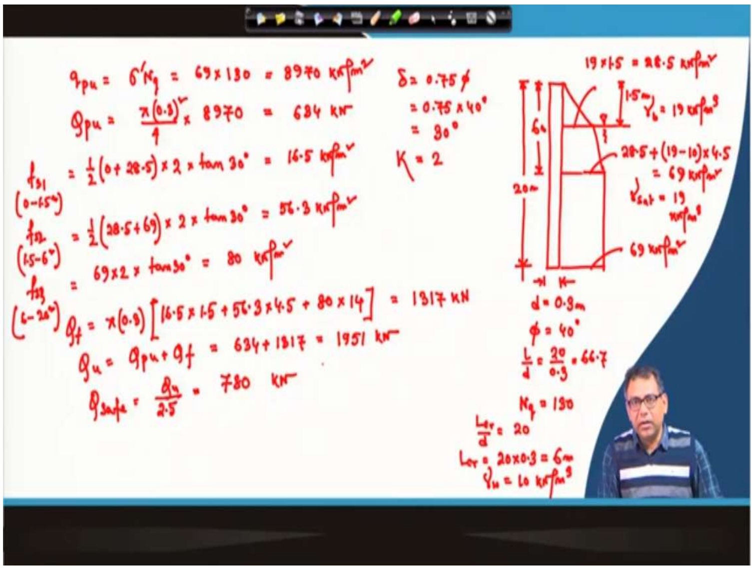

So, for the f_{s1} this is 0 to 1.5 m. So, that is equal to as I have discussed that we have to take the average effective stress. So, this triangle would start from 0 to a certain value. So, the average value will be $\frac{1}{2}(0 + 28.5) \times K \times \tan\delta$ and K value is equal to 2, δ is 30°. So, f_{s1} is 16.5 kN/m^2. Similarly, $f_{s2} = \frac{1}{2}(28.5 + 69) \times 2 \times \tan 30°$, that is equal to 56.3 kN/m^2.

The next one is the f_{s2} which is from 6 m to 20 m. So, now it is uniform so, $69 \times 2 \times \tan 30°$. So, that is equal to 80 kN/m^2. So, total frictional resistance that is equal to πd and for first part it is 16.5 kN/m^2 for a length of 1.5 m, for second part it is 56.3 kN/m^2 for a length is 4.5 m and third part is 80 kN/m^2 for a length of 14 m. So, $Q_f = 1317$ kN. So, $Q_u = Q_{pu} + Q_f = 634 + 1317$. So, this is equal to 1951 kN.

So, $Q_{\text{safe}} = \frac{Q_u}{\text{Factor of safety}}$ and the factor of safety can be taken as 2.5 to 3, so that is equal to 780 kN. So, the allowable or safe load carrying capacity of this particular single pile is 780 kN. Similarly, you can do it for the layered soil also and you can do it for the dry soil also, but here we are taking the homogeneous soil with water table.

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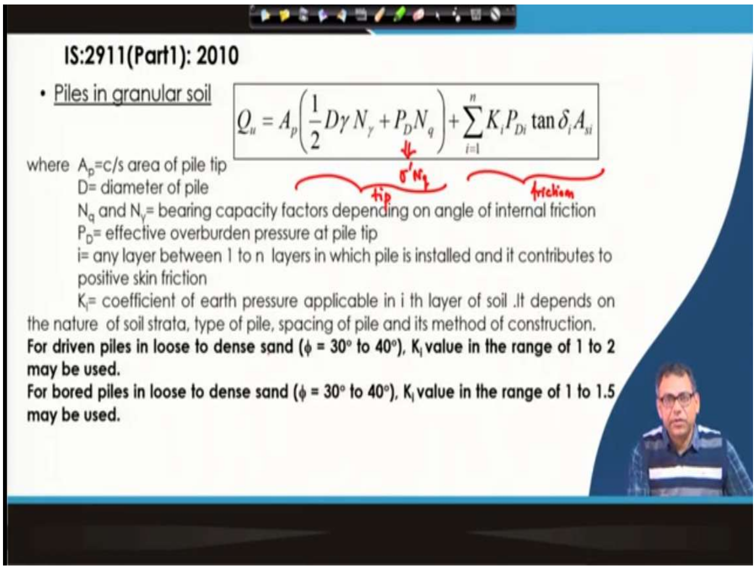

So, next part I will discuss that how IS code recommends to determine the ultimate load carrying capacity of the pile. So, all the equation that we have discussed are for the granular soil here also IS code also recommend these equations which are similar to the previous equation. But the only difference is that in case of previous equation we have neglected the third part for pile load carrying capacity calculation.

Because that third part contribution is less compared to the second part and first part is already 0 because $C = 0$, but IS code also recommends to take that third part. So, this is the equation this is the second part that we are right now, we are using that is $\sigma' \times N_q$ which is similar to that $P_D \times N_q$. And then this is the third part which is $\frac{1}{2}D\gamma N_\gamma$ which we use as per the IS code recommendation and then other is a summation of the frictional resistance.

So, this part is the tip resistance and this part is the summation of frictional resistance offered by different layers. This is frictional resistance which is same as the equation that we have discussed that in the K, P_D, so P_D is the effective overburden pressure at tip and a P_{Di} is the effective overburden pressures at different layers. So, and K_i is the earth pressure coefficient for i^{th} soil layer. So, here also it is recommended that for the driven pile in loose to dense sand this 30° to 40°.

The previous recommendation which is same as the IS recommendation that K value varies from 1 to 2 and for the bored pile for 30° to 40°, K value varies from 1 to 1.5. So, here K value is given for bored pile and the driven pile separately, but previous cases we have to determine the values for the driven pile then by the given recommendation you have to use it for the bored pile.

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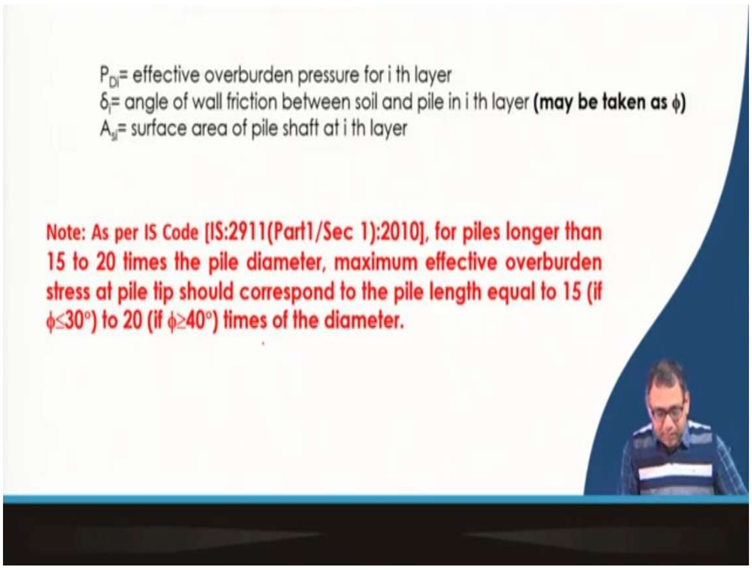

So, this is the equation as per the IS code and then here also IS code also given recommendation for the critical depth. So, that critical depth is again 15 to 20 that means, if $\phi \leq 30°$, then the critical depth is $15D$ and $\phi \geq 40°$,then the critical depth or critical length of the pile is $20D$. If the ϕ value is in between that means loose to dense, then you have to take the critical depth accordingly.

So, and here the δ value is recommended to take as equal to ϕ and again the P_{Di} is the average effective overburden pressure at a particular layer. And the same way it has to be calculated as I have discussed.

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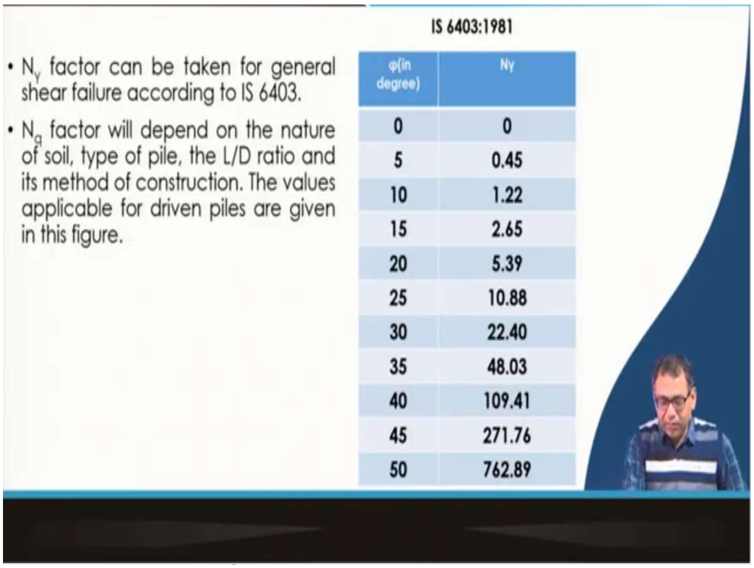

Now, there are two bearing capacity factors, N_γ and N_q. So, N_γ we are using for the shallow foundation and this is the value of N_γ for different ϕ values.

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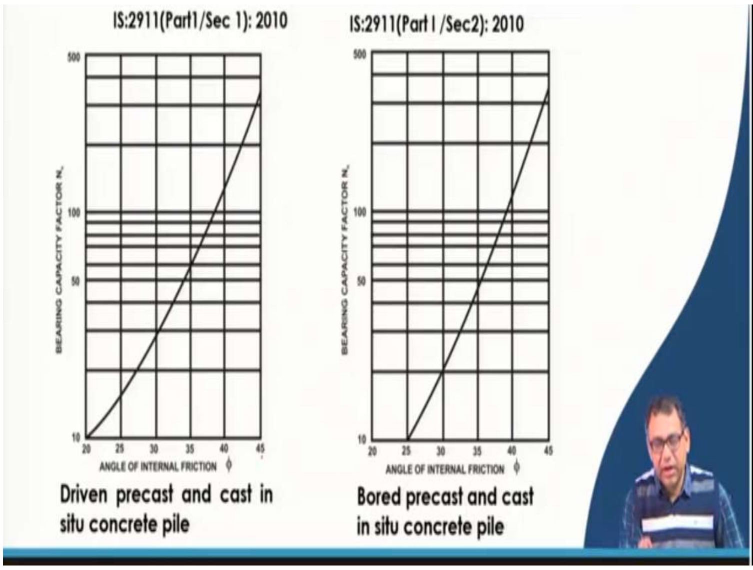

And the N_q we will get from this chart where this is the N_q versus friction angle and the first chart or the left hand side chart is for the driven pile and right hand chart is for the bored pile. So, from here we can get the N_q corresponding to different friction angle values.

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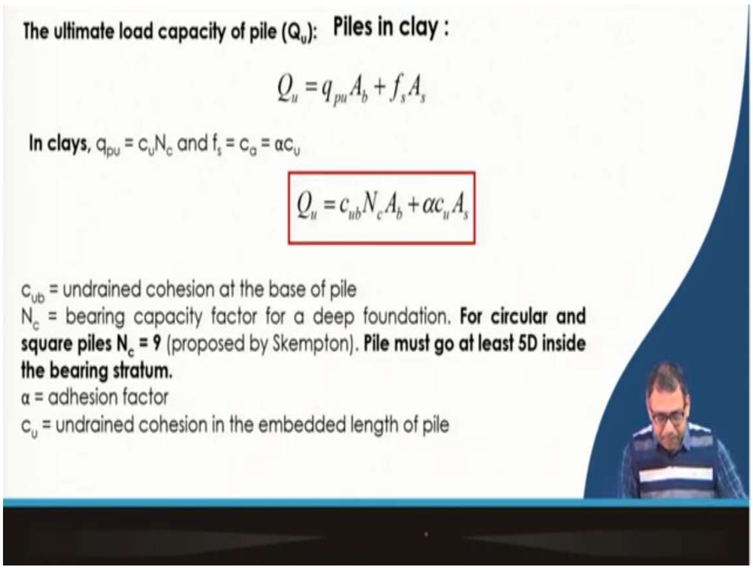

The next part is the ultimate load carrying capacity of pile in the clay. So, here also we have a tip resistance and the frictional resistance. So, tip resistance we will get only $c_{ub}N_cA_b$ where, c_{ub} is the undrained cohesion at the base of the pile, A_b is the area of the pile base area and frictional resistance is the undrained cohesion into the outside area of the pile. So, this expression is given here N_c is generally taken as 9, although different researchers have proposed different N_c values in case of pile also, but generally it is taken as 9.

So, here also we will take these values as 9 and c_{ub} is the undrained cohesion at the base of the pile, A_b is the area of the pile base and α is the adhesion factor and c_u is the average undrained cohesion along the length of the pile, and A_s is the outside area of the pile. So, that means for this particular case pile must go at least $5D$ inside a bearing stratum. But, if I use the tip resistance then the pile has to be inserted inside a bearing stratum upto $5D$.

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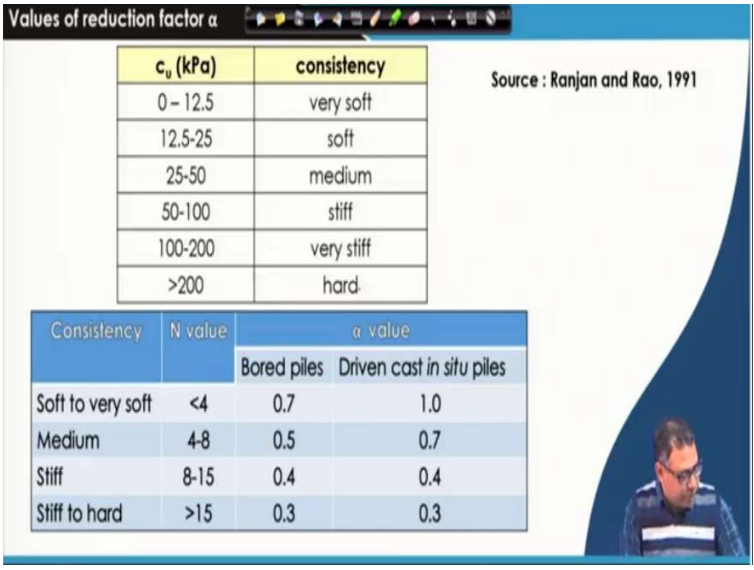

So, you will calculate the adhesion factor from the data given here. So, that means for soft to very soft clay, adhesion factor for bored pile is 0.7 and driven pile is 1, for stiff to hard soil the value of alpha is 0.3 for both bored and driven piles and when you can say this soil is soft, very soft, medium stiff, very stiff or hard. So, as for undrained cohesion value that can be classified, so, that table is also given.

So, if you have the undrained cohesion, then based on that you can understand whether the soil is soft or very soft or stiff then based on that you will decide what α value you will choose.

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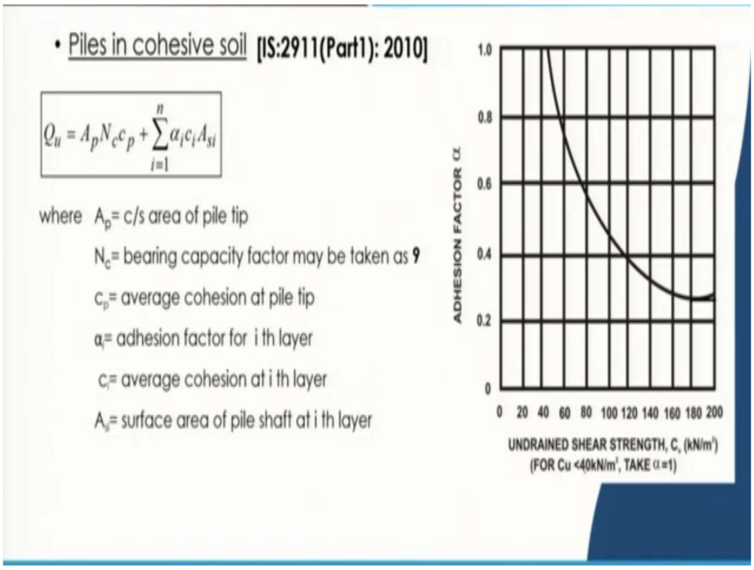

Similarly, IS code also gives the same type of expression where this is cN_c and then the frictional resistance which is summation of the frictional resistance the pile is getting for different layers and here the adhesion factor chart is given for different undrained cohesion values. So, if undrained cohesion value is less than 40 kN/m^2, then you take the $\alpha = 1$, alpha is the adhesion factor. So, you can say if it is less than 40 kN/m^2 then you take 1 otherwise you can take the adhesion factor according to the undrained cohesion value.

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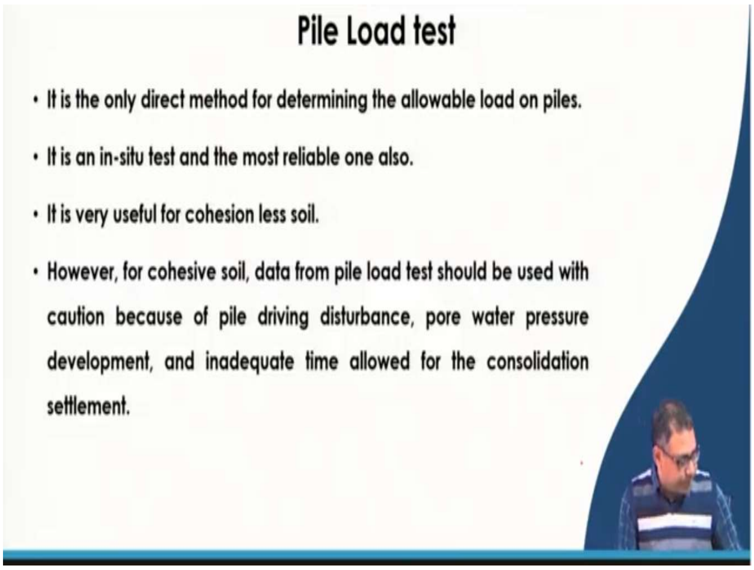

Next one I will discuss about the pile load test because previous case was how to calculate the tip resistance and the frictional resistance theoretically, now, here I will get the load carrying capacity and the settlement of the pile by pile load test. So, it is the only direct method for determining the allowable load on piles it is an in-situ test and most reliable one also because here these things we will get from the field directly.

So, it is very useful for cohesionless soil. However, for cohesive soil you have to use these pile load test data very with caution because the pile driving disturbance, pore water pressure development and inadequate time allowed for the consolidation. So, these are the factors because this pile load test is a short-term test but that means you are not allowing the consolidation or the full consolidation. So, we have to use these pile load tests data with caution for clay.

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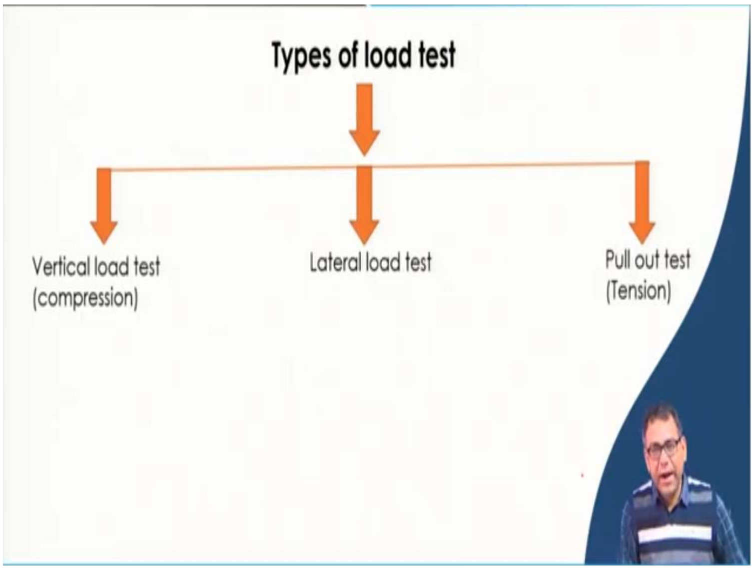

So, pile load test can be done under three different loading conditions vertical load or compression then the lateral load and the tension load. The pile load test can be done in the compression it can be done in the tension and under lateral load also.

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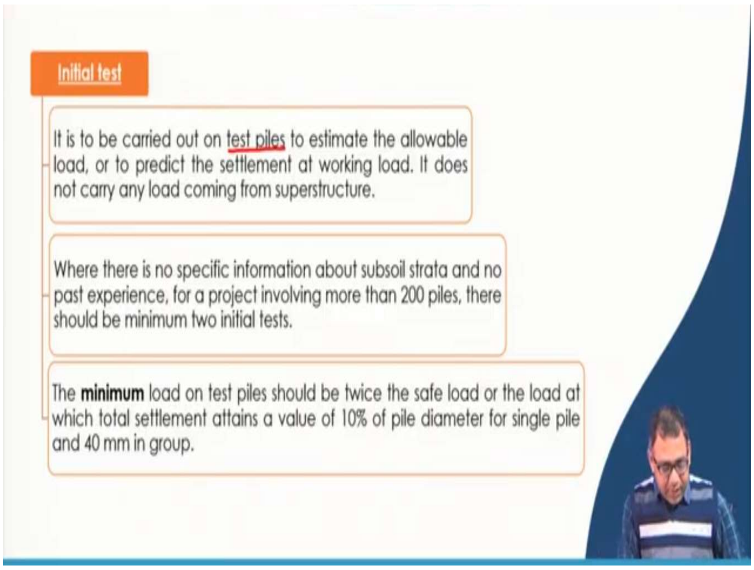

Then pile load test when you are doing we have to do it for the two types of pile, one is called initial test, all those tests are carried out on the test pile. So, that when these piles are test piles, where the initial tests are carried out. So, what are the test piles? Test piles are used to estimate the allowable load and to predict the settlement at working load it does not carry the load coming from the superstructure. So, that mean test piles are used for testing purposes only.

So, these piles will not be used for a real load carrying purpose. So, no superstructure load will come on the test file. So, these test piles are used for testing purpose then there is no use of these piles. So, I mean when specific information is given about the sub-soil data or there is no past experience for a project involving more than 200 piles, there should be minimum two initial test.

So, that means how much load we can apply on a test pile. So, minimum load on a test pile is twice the safe load or the load at which total settlement is 10% of pile diameter for single pile and 40 millimeter in group pile. So that means we have to first calculate theoretically the safe load for a particular pile? Then you have to apply the load during the pile load test twice of the safe load or before the settlement the pile attains as a value of 10% of the diam for single pile or 40 mm for group pile.

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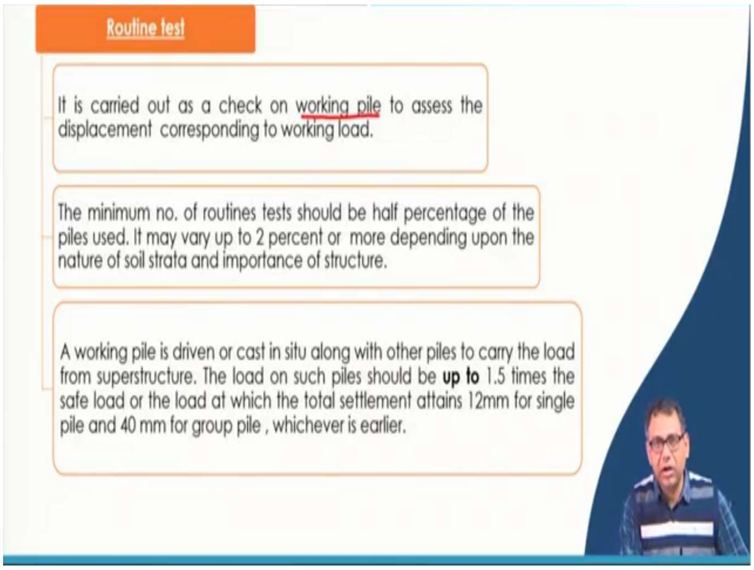

So, now, next one is the routine test which is conducted on working pile. So, working pile means this pile will be used in future also that means the superstructure load will come on this pile. So, after the testing also this pile will be used for the real load carrying purpose. So, these tests are carried out to check on working pile to assess the displacement corresponding to the working load the minimum number of routine test should be half percent of the pile used.

So, it can go to up to 2% depending on the nature of the soil strata and the importance of the structure. So, how much load we can apply on a working file. So, we can apply maximum 1.5 times of the safe load or the load at which the settlement attains 12 mm for single pile and 40 mm for group pile, whichever is earlier. So, in the initial test or the test pile, then we have to apply at least 2 times of the safe load.

But here we have to apply maximum 1.5 times of the safe load we cannot go beyond 1.5 times of the safe load because these piles we have to use after the test or load at which the total settlement attains a value of 12 mm per single pile or 40 mm for group pile, whichever is earlier?

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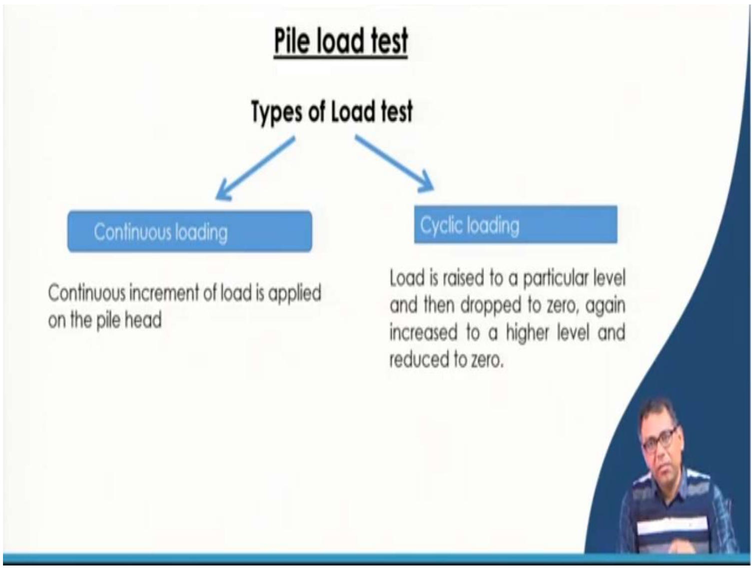

Now, pile load test can be of two types, one is the continuous loading and another is the cyclic loading. So, continuous loading means the continuous increment of load is applied on the pile head. And in cyclic loading; so, loading is raised up to a particular level and then dropped to 0 again increased to a higher level or reduced to 0 and so, on. So, the purpose of the cyclic loading that by cyclic pile load test we can determine the tip resistance and the frictional resistance separately by pile load test.

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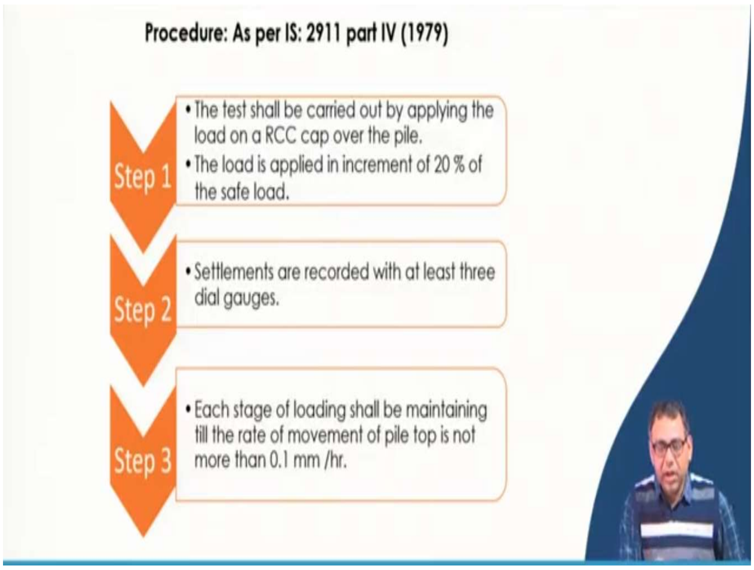

So, the continuous loading or the pile load test procedure is that it is carried out by applying the load on a RCC pile cap, load is applied in increments of 20% of safe load because first you have to calculate the safe load then first increment will be applied as 20% of the safe load then the 40% of the safe load then 60, 80, 100 to 2 times or 1.5 times or up to the specific settlement. Then settlements are recorded at three dial gauges and average values are used as a settlement of a pile corresponding to a particular load. Then at each loading stage, each increment is kept on the pile till the movement of the pile top is not more than 0.1 mm/hour.

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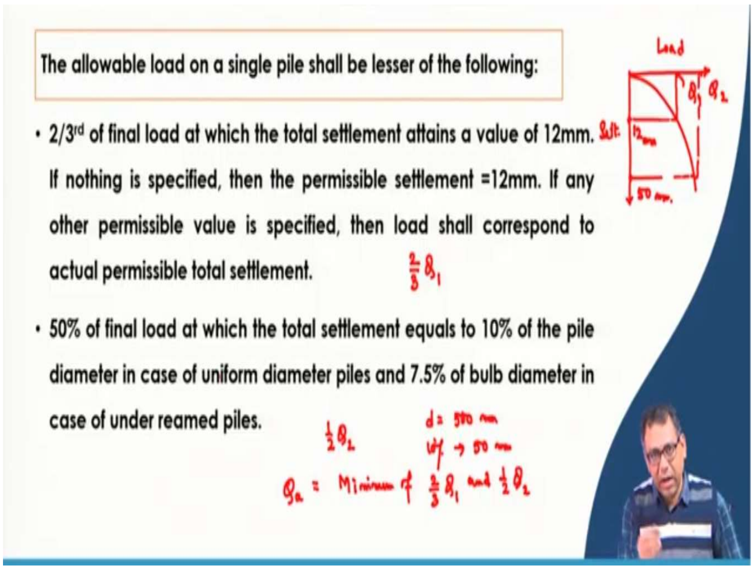

Now, once you complete the pile load test you will get a load versus settlement plot. So, this is the load and this is the settlement. So, we will get particular load versus settlement plot. So, once we get this load versus settlement plot then we can apply this recommendation which is given by the IS code. So, by giving this recommendation, we can determine what would be the allowable load on a single pile

So, that recommendation is the $\frac{2}{3}$ of final load at which total settlement attaining a value of 12 mm. For example, suppose this is a 12 mm value. So, we will calculate corresponding to this load Q_1, so we will get take $\frac{2}{3}Q_1$, corresponding to 12 mm, if other permissible value is specified, then you have to go for that value if nothing is specified, then we will consider 12 mm as the permissible settlement for single pile.

If any other value is specified, then you have to go up to that settlement, but here nothing is specified. So, you are taking 12 mm. So, 12 mm corresponding Q_1 is $\frac{2}{3}Q_1$. Next one is 50% of pile diameter for example, if diameter of the pile is say 500 mm, so, 10% of that will be the 50 mm. So, we will go to 50 mm settlement for this particular case, if the diameter of the pile is 500 mm.

Then this is the corresponding load. So, this is the Q_2. So, you will get 50% of that Q_2 So, you will get half of Q_2. So, the $Q_{\text{allowable}}$ will be minimum of $\frac{2}{3}Q_1$ and $\frac{1}{2}Q_2$. So, in this way we can determine the allowable load carrying capacity of the pile form pile load test data. So, this 10% is for uniform diam pile and 7.5% of the bulb diam in case of under reamed, under reamed pile means where we provide the bulb, so, we will discuss the under reamed pile load carrying capacity when I will discuss the pile in expansive soil. So, that time I will discuss that.

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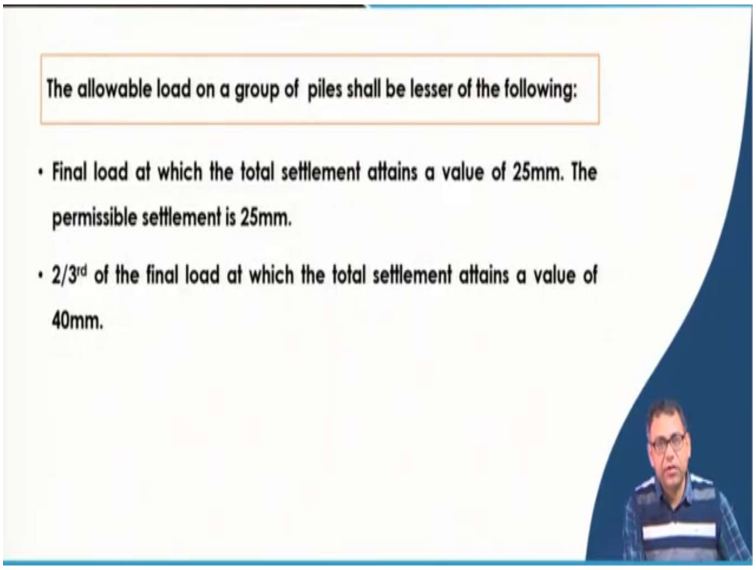

So, now for the group pile, the criteria are that final load at which total settlement attains a value of 25 mm, if nothing is specified then 25 mm is a permissible settlement for the group pile or $\frac{2}{3}$ of the final load at which total settlement attains a value of 40 mm. That means, you will take full value corresponding to 25 mm full load and $\frac{2}{3}$ of the load corresponding to settlement of 40 mm and minimum of these two will give you the allowable load carrying capacity of the group pile. So, initial recommendations were all criteria for the single pile and this is for the group pile.

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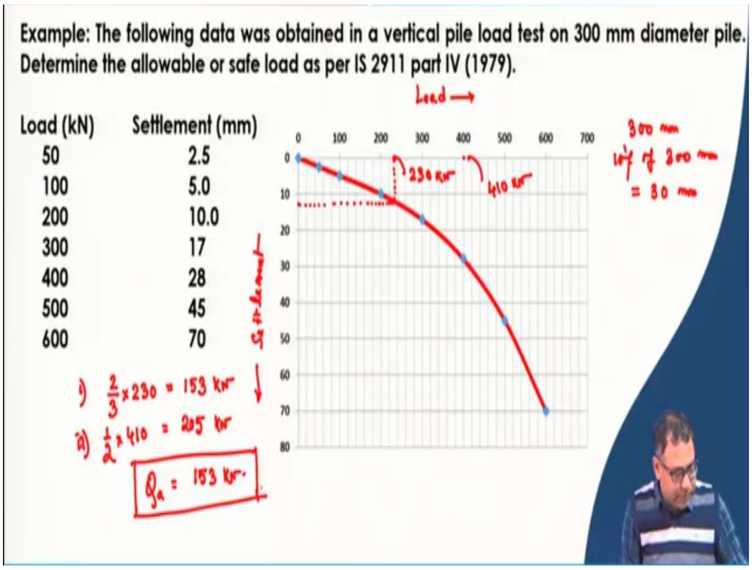

So, now, I will determine the load carrying capacity of the pile based on this plate load test. So, following data was obtained for a vertical pile load test on 30 mm diameter, determine the allowable safe load as far IS 2911 part 4 1979. So, as far this IS code means recommendations that I have discussed previously. So, this is the load versus settlement and I have drawn this curve.

So, this is settlement and this is load. Now, first recommendation was $\frac{2}{3}$ of the load corresponding to settlement of 12 mm. So, 12 mm will be around here and value will be 230 kN. So, first criteria will be $\frac{2}{3}$ of 230, so, that is 153 kN, second criteria is 10% of diameter because it is a uniform pile. So, 10% of diameter means diameter is 30 mm, 10% of 300 mm, so, this is 30 mm. So, 30 mm is here.

So, corresponding value is 400, this is 410 and that load we have to take 50%, so, $\frac{1}{2}$ of 410, so, this is 205. So, minimum of these two is 153. So, $Q_{\text{allowable}}$ is 153 kN. So, in this way we can determine allowable or safe load carrying capacity of the pile based on the pile load test.

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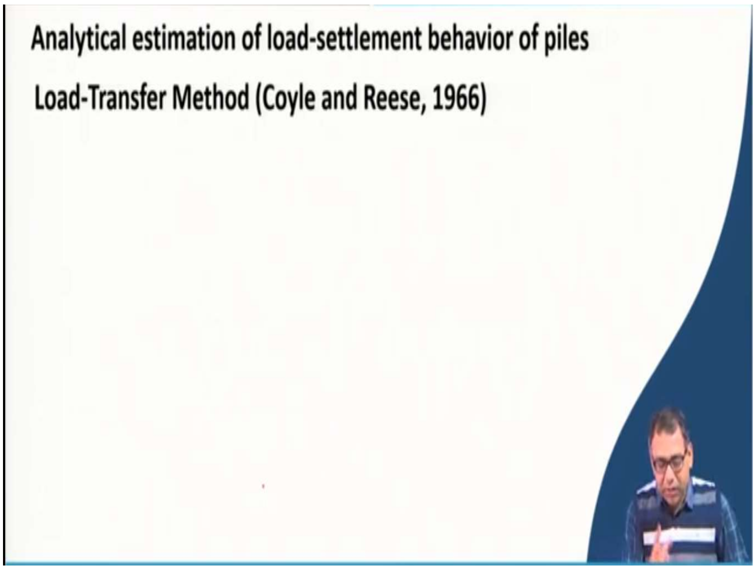

So, the next part that I will discuss in detail that how analytically we can estimate the load settlement behavior of the piles. So, previous problem we can see these load settlement behaviors of the curve that is generated. It is based on the pile load test. So, in the next class, I will discuss that how I can generate this type of load settlement curve a similar to this type of load settlement curve analytically by using the equations not by the plate load test.

Because we have the soil properties and based on those properties, we will try to develop a load settlement curve for a pile in a particular soil. So, that I will discuss in the next class and then I will discuss basically two methods and then I will also solve one numerical problem to show you how we can determine the ultimate load by using that theoretical approach. Where we will get the load settlement curve as well as the settlement.

And the ultimate load or settlement means settlement at ultimate load point or we can get our simple load settlement curve and ultimate load and the settlement by theoretical approach. Thank you.