Advanced Foundation Engineering
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Lecture - 12
Shallow Foundation: Settlement Calculation – II

I have discussed about the settlement calculation of shallow foundation and how to calculate the immediate settlement and the consolidation settlement of soil. Now, today I will start the calculation of settlement based on the field test data, and it is basically for the granular soil. So, what are the different field tests that I have already discussed in the first section? Now, by using those field data how to calculate the settlement of the soil for the shallow foundation, those things I will discuss in this lecture.

Now, this here I will mainly concentrate on the calculation of settlement for granular soil and mostly the test that data that I will use that SPT and the CPT data and or the static standard penetration test or the cone penetration test data. In addition to that, I will explain another field test, that is, the plate load test and how to use the plate load test data to calculate the settlement. And later on, I will explain how to use the settlement or the plate load test data to calculate the bearing capacity of the soil, when I will discuss about the allowable bearing capacity calculation.

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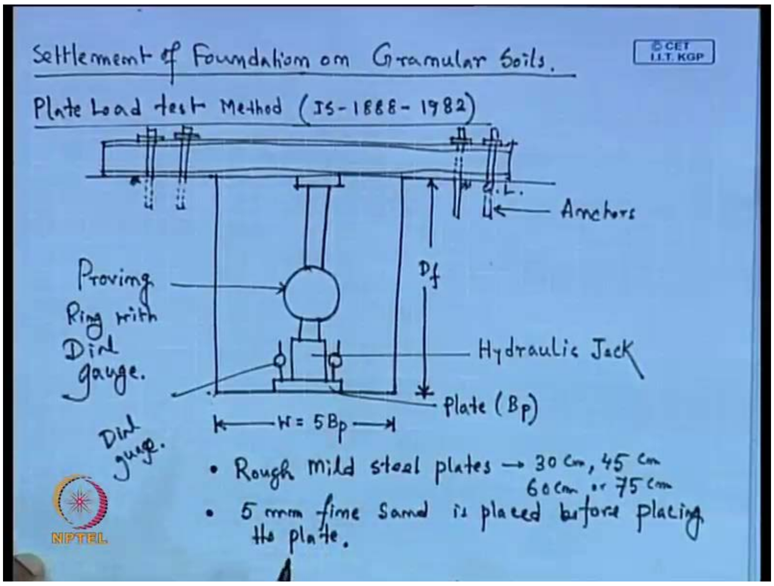

So, first today's class that I will discuss mainly on the settlement calculation by using different field test data. Now, first we will discuss about the settlement of foundation on granular soil; now, the first thing that for the disadvantage of the for the calculation of settlement based on the on the field test for the clay soil is that, for the clay soil this all the settlement of the field test that generally we conduct that is for short term test; and for as the in the consolidation calculation for the clay soil, this is for the long term test, long term calculation. So that means, due to the consolidation, for that is why for the cohesive soil the using the field data to calculate the settlement is not a good idea. So, it will be better if we use this field test data to calculate the settlement for the granular soil because this granular soil it is the most of the settlement for the immediate settlement and that is for the short term and test that we are conducting the field that is also short term.

So, for the cohesive soil as it is the long term settlement due to the consolidation, so if that if we use this short term test data for the calculation of consolidation settlement or the consolidation for the cohesive soil settlement, then that be where will we will not get the appropriate or accurate results. So, that is for this field test data we mainly we will use for the settlement calculation of granular soil. Now, first test that we have already discussed about the SPT and the CPT test or the cone penetration and standard penetration test.

Now, today we will discuss another test that is called the first it is called the plate load test; Plate load test method that we will discuss and here we will discuss about the I S method, Indian standard method 1888 to 1982.

Now, plate load test is conducted on the soil and it is ideally we should conduct on the as the foundation level; that means, the here we will instead of footing we will use a small plate to stimulate the footing behavior and then that plate should be placed at the foundation level; that means, we have to construct one D or then we have to remove the soil sample up to the foundation depth and then we will where there you can place the plate and then we can conduct the test on that plate.

So; that means, here directly we can calculate what the bearing capacity of the soil by using this plate load test data. So; that means, the here for the plate load test. Suppose, this is the depth of foundation here this is the feet or the test feet and this is the depth of foundation and here this is the ground surface is here. So, this is G L or the ground surface and this is the arrangement that here this is the D f or the depth of footing or the foundation and the width of this portion or the feet that should be; that means, width is should be 5 times B p or the width of the plate.

So, here we will place the plate. So, this is the plate or width B p, B p is the width of the plate. So, here first in the test feet, this is the depth of the foundation or the real footing, at the base of these feet will place the plate here. Then by hydraulic jack because this is the hydraulic jack and this is the proving ring, so this is hydraulic jack and this is the proving ring with dial gauge.

So, here we will by this proving ring we will apply the load and here we will place one beam or the section on the ground surface which is attached with the ground by this anchors, so these are the anchors. So, these are the anchors that will place in the soil to fix this beam or the loading frame and by the use of this loading frame or the beam we will apply the pressure on this plate by this hydraulic jack and the load that we are applying and corresponding settlement we have to measure by using this dial gauge. So, these are the dial gauges.

So, these are the test arrangement; that means, this is the pit at the base of the foundation we will place the footing or the plate here, this is the D f depth of the foundation then by using this hydraulic jack and this we will apply the load, and this is the fixed loading frame, by using the hydraulic jack we apply the load and corresponding load that we will apply we can measure this load by this proving ring and corresponding settlement of this plate we will get by using this dial gauges. So, this is the total arrangement of the plate load test and the settlement and after the test is done then we will plot the load versus settlement plot.

Now, first these are the, what are the different sizes of the plate that basically this is the mild rough, mild steel plate. This dimension of the size is 30 centimeter, 45 centimeter or 60 centimeter or 75 centimeter. So, these are the different sizes of the plate.

Now, this generally the square type of plate is used. Now, before the plate is placed on 5 millimeter fine sand is placed before placing, so before placing the plate on 5 millimeter fine sand is placed at the base level this level.

So, now the condition is if the soil is very stiff or dense then we will use the smaller plates and if the soil is very lose and soft then we will use the larger plate. Now, for the during the testing we have to remove the water from this test feet; that means, dewatering we have to conduct or we have to done the dewatering to remove the water within this feet and then we will apply the load.

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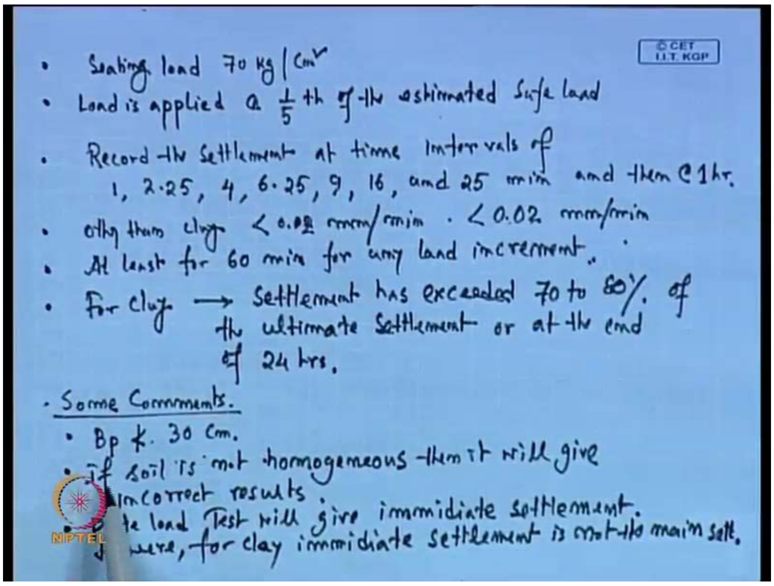

Now, the loading application first state that we will place one seating load, the first step of this loading application that we will place first seating load, load 70 kg per centimeter square is first applied and it is applied for a time. So, some for the sometimes it is applied this seating load, and then the next the load is applied at a width of one-fifth of the estimated safe load.

So, loading applied, so first we have to estimate the safe load that this foundation or the soil can carry. Now, the first increment of the load will be one-fifth of this safe load so; that means, was one-fifth, one-fifth increment we have to apply the load and we have to apply the load until the failure of the soil or at least the 25 millimeter of the settlement. So, at least for the 25 millimeter settlement or up to the failure load whichever is earlier. So, whichever is earlier either 25 millimeter settlement or up to the failure of the soil. So, whichever is earlier up to that you have to conduct the test.

Now, next one is that now one increment, suppose when we apply the increment then we have to record the settlement. Now, settlement you have to record or record the settlement at an interval, at time interval of 1 minute, 2.25 minute, 4 minute, 6.25 minute, 9 minutes, 16 minutes and 25 minutes and then at 1 hour interval.

So; that means, when we apply the first increment of loads say one-fifth of the load, then we will record the settlement at 1 minute, 2.25 minute, 4 minutes, 6.25 minutes, 9 minutes, 16 minutes and 25 minutes interval then at every one hour interval we have to apply the load or we have to record the settlement.

Now, for the any other soil other than clay, now the rate of loading is 0.02 millimeter per minute. So, other than the clay when this rate of settlement that we will get, because we will calculate the settlement at different interval. Now, if the rate of settlement is less than 0.02 millimeter per minute then we will apply the second increment, or for at least for 60 minutes we have to apply for any load increment. That means, any load increment that we have to apply at least for 60 minute, that is compulsory and then when we will observe other than the clay soil if this is the rate of settlement that we are measuring that 0.02 millimeter per minute; that means, this is less than 0.02 millimeter per minute then we will apply the next increment.

And for the clay soil if the settlement exceed 70 to 80 percent of the ultimate settlement or at the end of 24 hours; that means, for the clay, for the sand or for the soil other than clay the condition is that for any increment we have to apply for at least 60 minutes and if the settlement increment is 0.02 millimeter per minute then we have to apply the next increment of loading.

Now, for the clay soil if the settlement has exceeded 70 to 80 percent of the ultimate settlement or at the end of the 24 hours, but in the clay soil the condition is if the settlement has exceeded 70 to 80 percent of the ultimate settlement or at the end of 24 hours, we have to take the reading.

Now, these are the different condition of the test that we will conduct. So, now when we will conduct, so there a few points. So, what are the few advantages of these plate load test is that that this from this plate load test, directly we will get the ultimate load carrying capacity of the soil because suppose other type of field test over the SPT or CPT then, where we will get some vale and based on the correlation that we are getting the parameters of the soil or ultimate load carrying capacity of the soil; that means, we have to use this parameter then we will get the ultimate load carrying capacity of the soil.

But the advantage of this plate load test that in the field itself we will get the ultimate load carrying capacity of the soil. So, that is one advantage now thing is that there is some limitations also the some comments that we should note, that some comments that for any condition this B p should not be less than 30 centimeter; that means, for any condition this B p should not be less than 30 centimeters.

Now, another condition is that, that if the soil is not homogeneous then it will give incorrect results. Now, one thing that I have already explained that for the clay immediate settlement is not the main settlement, but plate load test will give the immediate settlement. So, this plate load test will give settlement; however, for clay is not the main settlement. So that means, these are the condition that B p should not be less than 30 centimeter and if the soil is not homogeneous then it will give incorrect results. Its mean that, suppose because the plate dimension is 30 centimeter that is the minimum dimension and maximum is that we are using the 75 centimeter.

So that means, the influence zone for this plate, if we use the 75 millimeter centimeter plate also; that means, the influence zone will be up to the 2 B because as I have already mentioned that for the bearing capacity calculation I will consider the up to B depth and for the for the settlement calculation mainly, we will consider up to the 2 B zone below the depth of the foundation or the base of the foundation.

And now if we are using the plate which is the smaller size plate and; that means, the influence zone will be very less. Now, actually in the prototype or in the real field that dimension of the footing is much more than the plate that you are using. Suppose, the plate we are using 30 to 75 centimeter, but in the field that dimension may be say 3 meter or 4 meter dimension. So, that the if we take the four meter real footing dimension then the influence zone up to say 3 meter into 2 then the 6 meter. Now, whereas if we use the 75 millimeter centimeter plate that means influence zone will be 150 centimeter.

So, you can see that the there is the zone of influence for the plate and the real foundation is very, there is a different, and now if the soil is not homogeneous suppose if the soil is homogeneous; that means, the influence zone about the that soil whether it is the 150 centimeter or 600 centimeter that will be same, but if there is a layers if it is a layer soil and if suppose the one layer is thickness is say 2 meter or 200 centimeter. So, then we what will happen if we use the 75 millimeter 75 centimeter plate; that means, influence zone will be 150 centimeter and if we use the same plate load test data for the real foundation that width say three meter and that means, influence zone will be say 600 centimeter. So that means, in actual clay is the influence zone in the second layer which is present below the 200 centimeter from the base of the footing, that will influence actually in the real footing, but where is in the plate load that influence; that means, the second layer influence will not come into the picture.

So, basically we are not actually taking the care of the second layer if it is the layer soil in case of plate load test, where in the footing that second layer soil is influenced by the footing load. So, in that case we will get some erroneous results. So, if the soil is homogeneous, then this plate load will give the correct results, or otherwise if the layer soil is there then it will give erroneous or incorrect results as compared to the real footing.

Another condition is that the clay if this plate load test mainly it will give the immediate settlement, but the for the clay soil the immediate settlement is not the main contribution from the settlement, the main contribution of the settlement is at the consolidation settlement. So, that is why for the clay soil this plate load test data if we use the settlement calculation that is not, is not give will not give the correct result it may give the incorrect or erroneous results.

And another condition this is the capillary action, due to the capillary action of the sand soil, so that the strength of the sand that may also increase. So, those things we have to consider when we will do the plate load test and then when we will use this data for the our real footing calculation then we have to consider all these situation; whether soil is homogeneous or not, what are the size of the plate that we have used, what are the type of the soil that we are testing. So, those things we have to consider before we use this data for our real design.

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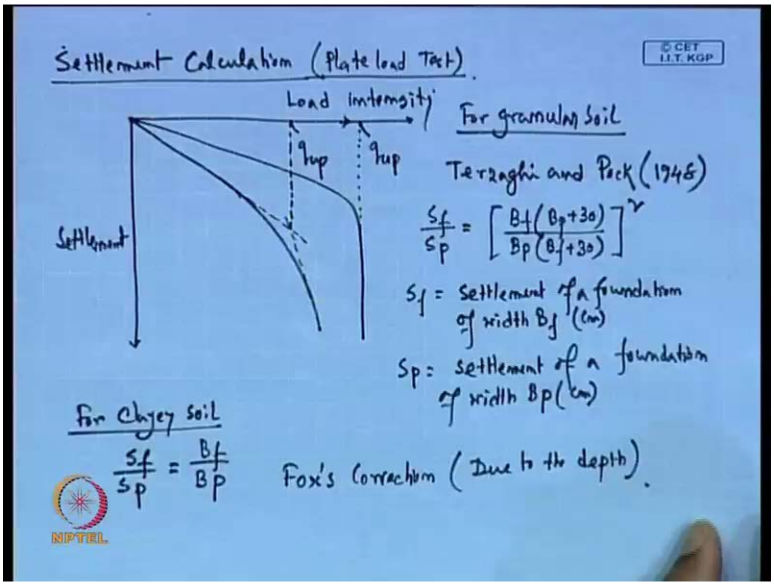

Now, the next one that we have done the plate load test, then how to use those data. Now, the for the settlement calculation, this is from the plate load test. That plate load test once we get the plate load test first we will get this type of graph. So, here we will may get say this type of graph or we may get this type of graph also. So, there are the different types of graph that will get. So, suppose this is our load intensity and this is settlement.

So, if I get this type of graph some then from if we extend this state portion, we will get the ultimate load carrying capacity of this plate. If we get this type of graph by double tangent method, so this initial state portion and the final state portion. So, this one will give us the q u p, ultimate load of the plate.

So, if we will get this, so these two methods we will get the ultimate load carrying capacity of the plate. So, this is the load settlement graph of the plate and if we will get this type of graph that is, the extension of this state portion will give you give us the ultimate load of the plate, and from here for by double tangent method we will get the ultimate load of the plate. And from here then for corresponding to any loading condition we will get the settlement of the plate or vice versa, corresponding to any settlement we will get the load from the plate.

So, now for the granular soil if I want to calculate the settlement then we can use the expression which is proposed by the Terzaghi and Peck, 1948. So, that is the S f divided by S p that is equal to B f into B p plus 30 B p by B f plus 30 to the power square. Now, where S f is the settlement of a foundation or footing, foundation of width B f, so this width is in centimeter. So, here this width is in centimeter then S p is the settlement of a foundation of width B p which is also in centimeter.

So, here S f is the settlement of the footing real footing S p is the settlement of the plate, now B f is the width of the footing which is in centimeter and B p is the width of the plate which is in centimeter. So, here suppose if we know the settlement of the plate and we know the settlement of width of the plate and width of the footing, then we can by using this expression we will get the settlement of the real foundation.

Now, the for the clay soil this is for the granular soil, now for clay soil because same expression we can use the S f by S p that is equal to B f by B p and after that we will we have to use the Fox's corrections for due to the depth correction due to the depth; that means, if the depth of the plate and depth of the foundation real foundation are same then no correction is required for the depth, but if there is a difference between the depth of the foundation and depth of the plate then we have to apply the depth corrections for both the when we calculate the settlement of the real footing by using the Fox's method that I have explained in the last class.

So, this is the settlement calculation based on the plate load test for granular soil and clay soil. Now, if I want to calculate the bearing capacity of the soil, then how we will calculate the bearing capacity of the soil by using the plate load test.

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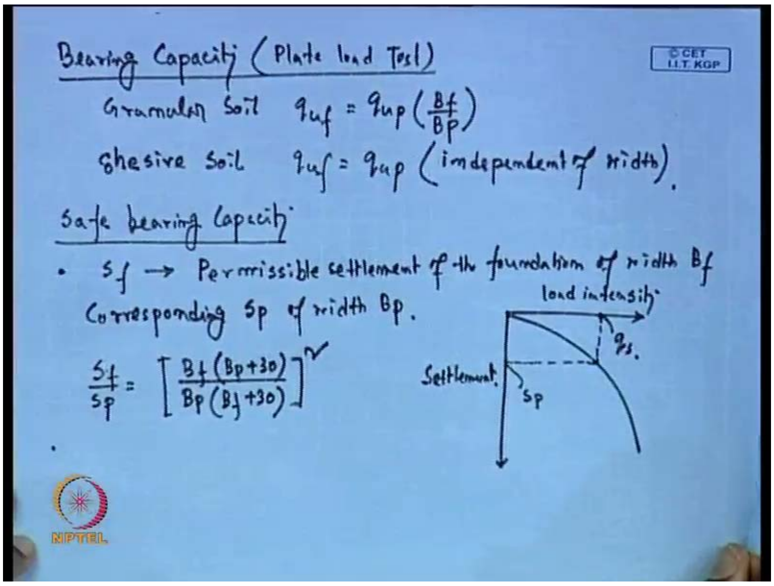

So, this is the bearing capacity this is also by plate load test. Now, for the granular soil that q u f ultimate load of the foundation is q u p into B f divided by B p. Same that q u p how we will get the q u p that I have explained from this plate load settlement graph or the plate load test, we will get the ultimate load carrying capacity of the plate and if we know the width of the plate and the footing, then we will get the ultimate load carrying capacity of the real footing, this is for the granular soil.

Now, for the cohesive soil or clayey soil that q u f is equal to q u p, as in case of cohesive soil this is independent of B of width. The cohesive soil the ultimate load carrying capacity of the plate is equal to the ultimate load carrying capacity of the footing. So that means, by using the plate load test we will get the settlement of the foundation as well as the load carrying capacity of the footing or now we will get the safe load carrying capacity. Now, here how to calculate the safe bearing capacity of the foundation, by using plate load test data. So, now the permissible settlement, suppose the S f is the permissible settlement of the foundation of width B f.

Now, we have to determine the corresponding S p settlement of the plate of width B p. So that means, from here suppose this is the load versus settlement plot this is the load intensity and this is the settlement and this is the plate load test graph.

So, first we will suppose S f is the permissible settlement of the foundation of width B f and the width of the plate that we are using is B p, now by the giving expression S f by S p. So, that expression that I have given that by using this expression, so this is B f B p plus 30 B p B f plus 30 to the power square.

So, here S f is known that is the permissible settlement, B p is known width of the plate, B f is also known width of the foundation, so only unknown is S p. So, corresponding to the permissible settlement of the foundation we will get the S p value. Now, once we get the S p value corresponding to the permissible settlement S f then from this chart, suppose this is the S p value that we will get this is the S p value. Now, from this chart the intensity that we will get that will give us the q safe.

So, this q safe will give us the safe bearing capacity of the footing. Similarly, this is the safe bearing capacity that we will get, now similarly how to calculate the actual settlement from this plate load test.

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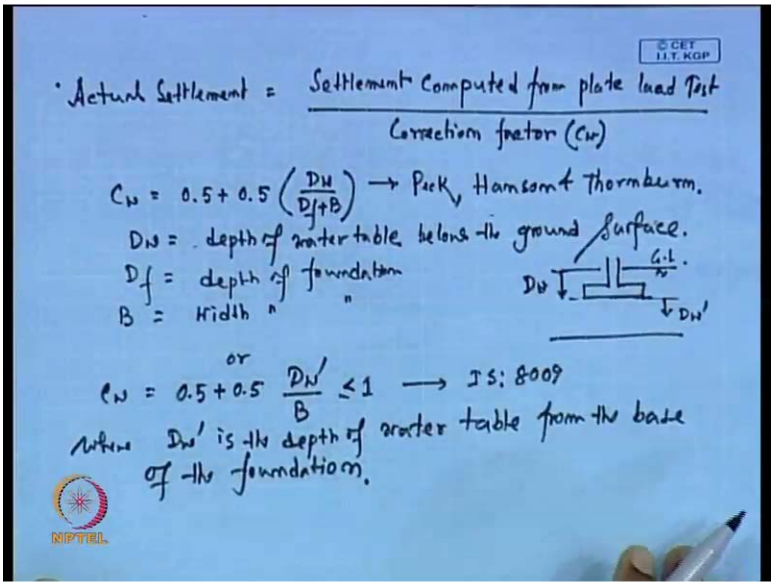

Suppose, the actual settlement that I will get the actual settlement that the foundation, that is, give the settlement computed from plate load test divided by correction factor or c w. This correction factor is basically for the water table position correction factor because in the actual settlement that you are getting from the plate load test where we are not considering the water table effect.

So, actual settlement will be the settlement computed from the plate load test by the correction factor, by this correction factor c w we can calculate by using this expression 0.5 plus 0.5 D w divided by D f plus B. This is given by Peck Hanson and Thorn Burm, where D w is the depth of water table below the ground surface and depth D f is the depth of foundation and B is the width of foundation.

Now, this calculation we can use or we can use the I S recommendation, that is, c w is 0.5 plus 0.5 D w dash by B and that should be less than equal to 1, this is given by I S 8009, where D w dash is the depth of water table from the base of the footing.

So, now if we want to incorporate the, what will effect within the actual, so we will get the actual settlement, then we have to use the correction factor then the settlement computed from the plate load test by the correction factor. Now, this correction factor either which we can use the Peck Hanson and Thorn Burm, expression where this D w is the depth of water table below the ground surface and suppose this is the footing width and this is the ground surface and this is the base. So, the water table position from this expression this depth is D w is from here; that means, from the ground surface and D w dash is basically from the base of the footing.

So, D w dash is measured from the base of the footing, where D w is measured from the ground surface, this is the ground surface, from the ground surface these are the two different. So, D w is from the ground surface and D w dash is from the base of the foundation this is the only difference of this expression. So, these expression either we can use this one or this one to calculate the water table correction.

Now, the next step that how to use this data to calculate the plate load test thing so; that means, the next one is here we are using the single plate to plate load test data to calculate the settlement and bearing capacity of the foundation.

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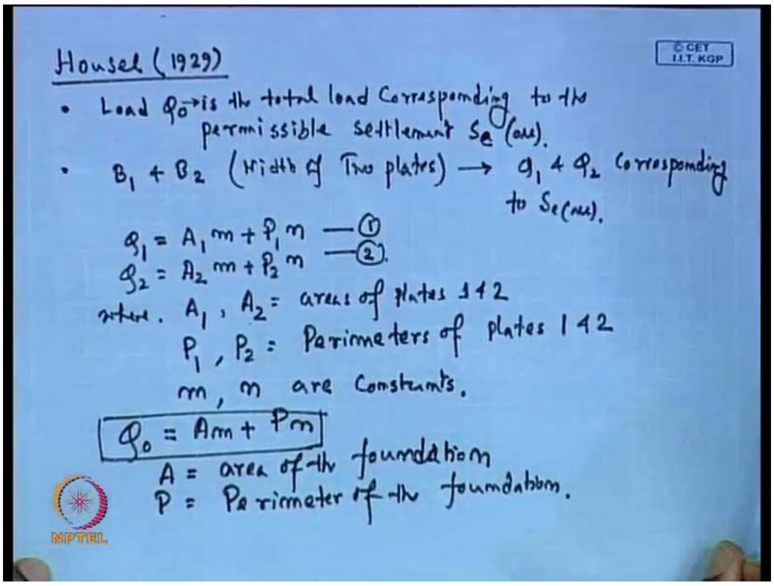

Now, another process is proposed by the Housel in 1929 that here we will use the two plates. Suppose, here say load Q o is the total load corresponding to the permissible settlement S e or is allowable. So, permissible settlement S e allowable, so corresponding total load that is Q o. So, we will conduct the two plate load test; so one plate dimension is B 1 and B 2. So, this is the width of 2 plate one is B 1 and B 2.

Now, from the load settlement plot, so this is the width of the two plates say B 1 and B 2 or the 3\two plates B 1 and B 2 dimension and from the load settlement curve determines the load Q 1 and Q 2 corresponding to the settlement, S e. So that means, we will get load settlement curve for two different plates. So, from these two different plates corresponding to the permissible settlement S e allowable will get the total load that this plate can carry corresponding to this permissible settlement. So, that will be say Q 1 and Q 2 are the two load that this two plates is carrying corresponding to the permissible settlement S e allowable.

So, suppose these two loads are Q 1 and Q 2; Q 1 and Q 2 corresponding to S e allowable. Now, what we will use suppose this is Q 1, so total load is A 1 m plus P 1 m and Q 2 is A 2 n plus P 2 n; where A 1 and A 2 are the areas of plates 1 and 2.

So, A 1 is the area of first plate and A 2 is the area of the second plate. Similarly, P 1, P 2 of the perimeter plates one and two, P 1 is the perimeter of the first plate and P 2 is the perimeter of the second plate and m and n are 2 constant these are the two constants. So, the value of these two constant we can determine by using this equation number 1 and equation number 2.

So, here we will get the Q 1 and Q 2 from the graph A 1, A 2, P 1, P 2 is the known things. So, from these if you solve these two equations we will get the m and n value. Once we get the m and n then finally, these we will get the Q o value that is A into m plus P into m. So, where A is equal to the area of the foundation and this is foundation area and P is perimeter of the foundation.

So, here if we real foundation if we know the area of the foundation and the perimeter of the foundation then this known value is m and P, m and n corresponding to. So, we will get the Q 0 is the total load corresponding to the permissible settlement S e. So, corresponding to the permissible settlement S e what will be the load this foundation can carry is Q 0. So, in this fashion on this way we will determine the load that foundation can carry corresponding to this permissible settlement. This is one process where we are using the two plates.

So, next one that we will discuss about the calculation of different other techniques then how we will calculate the load settlement for the different other technique that we will discuss here.

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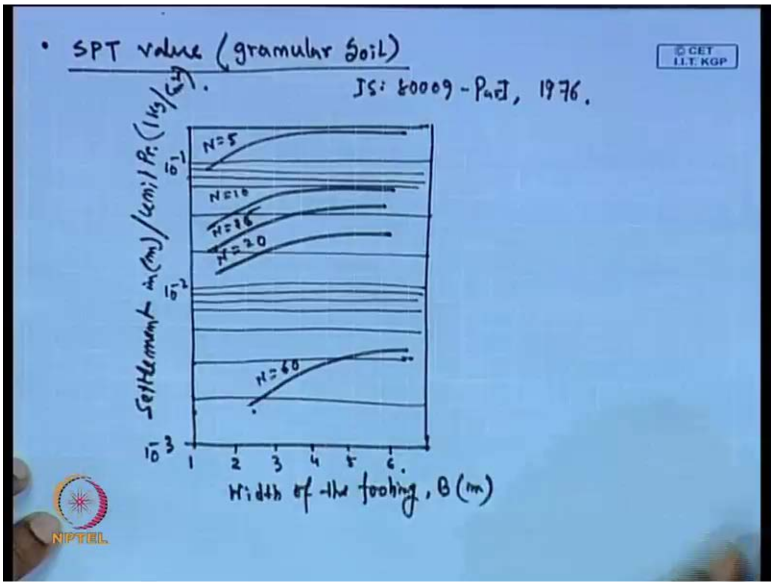

So, next one is the. So, next field to test that we are using that is our SPT value, this is also for the granular soil. So, first test that I have explained that is for the plate load test, the SPT test I have already explained. Now, here we will get one data. So, here from the IS code is recommend that, this is for the IS code recommendation this is part 1976.

So, IS code produce one chart in this fashion. So, this is this side this is width of the foundation, B in meter this is the settlement in meter; this is settlement in meter divided by unit pressure. This is 1 kg per centimeter square, so that means, the ratio that we will get that is the settlement in meter per unit pressure.

So, suppose this is the 1 meter width, second 2 meter width, this 3 meter width, this is 4 meter width, this is 5 meter width, this is 6 meter width, so we will get this type of chart. So, this is for the 10 to the power minus 3 and the middle one is 10 to the power minus 2 or the top one say 10 to the power minus 1 and corresponding this value we will get from here. So, this is in the log scale.

So, from corresponding to the N value, so this is the one chart N equal to 5, corresponding this is N equal to 10, this is 15, this is 20, so this is N equal to 10, N equal to 20, 15 this is, N equal to 20. So, in this way up to the N equal to say 60 we will get different chart in between this two, these value. So, if I know the width of the foundation of footing and then corresponding N value we will get this the settlement in unit pressure. So that means, we have to calculate the pressure or the pressure at that level then we have to multiply that ratio with that pressure, here that pressure we have to calculate in terms of k g per centimeter square.

So, this is the one process by using the IS code or IS chart we will get the settlement for the granular soil.

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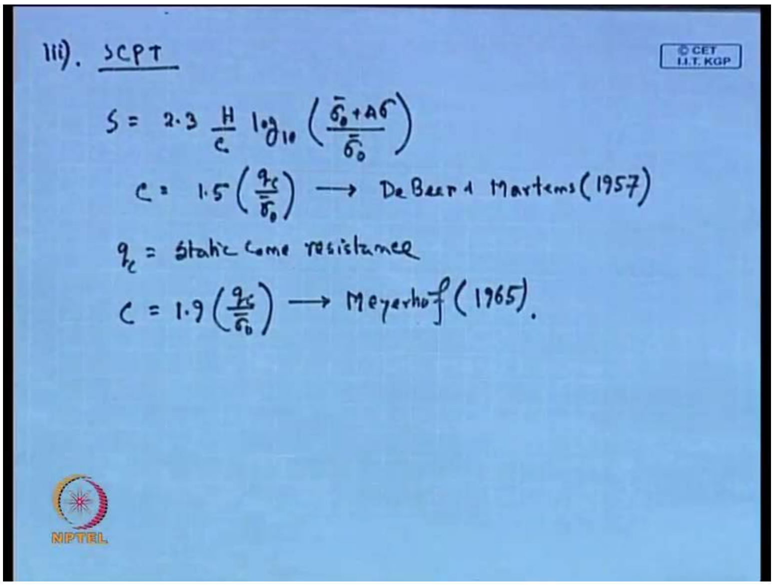

So, next one we will get the third one, that we will use the SCPT or Static Cone Penetration Test value. This is for also granular soil; here the settlement that we will get the expression is 2.3 H by C log 10 sigma 0 bar del sigma by sigma 0 bar. Now, here this coefficient C we will get in terms of 1.5 into q c by sigma 0 bar. This is proposed by De Beer Martens, 1957; where sigma 0 bar is the effective overburden pressure at the depth at which the test is carried out and q c is the static cone resistance, q c is the static cone resistance, H is the thickness of this layer, and del p is the increment of the stress due to the application of the load.

Now, furthers Meyerhof suggested this C the compressibility coefficient is 1.9 q c by sigma 0 bar, this is suggested by Meyerhof in 1965. So, first expression is suggested by De beer and Martens, 1957; where they proposed this thing, where H is the thickness of the soil layer, C is the compressibility coefficient, which is given by this expression by De Beer and Marten and this expression by Meyerhof. And there is that this sigma 0 by effective overburden pressure at the depth, at which the test is carried out, and del sigma is the increment of stress due to the applied of footing load.

So, how to calculate the stress increment that we have already explained. So, again we will solve one example in the next class, then we will get how to calculate this sigma del sigma. So, these are the different methods, by which we can determine the settlement of the soil for the granular soil, that is, one first one is by the plate load test then by the SPT value where the charts available by which we will determine the settlement for the granular soil, then by using the static cone penetration test we can also determine the plate load settlement of the granular soil.

In the next class we will solve few examples on this how to calculate settlement by using this methods and we will discuss few more other techniques by which we will determine the settlement of the granular soil.

Thank you.