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

Lecture No -25
Shallow Foundation: Settlement- III

So, last class I was discussing about the plate load test. So, I have discussed that ultimately we apply pressure and you will measure the settlement and we will get the pressure versus settlement curve and that curve will be used to calculate the bearing capacity or the settlement of the foundation.

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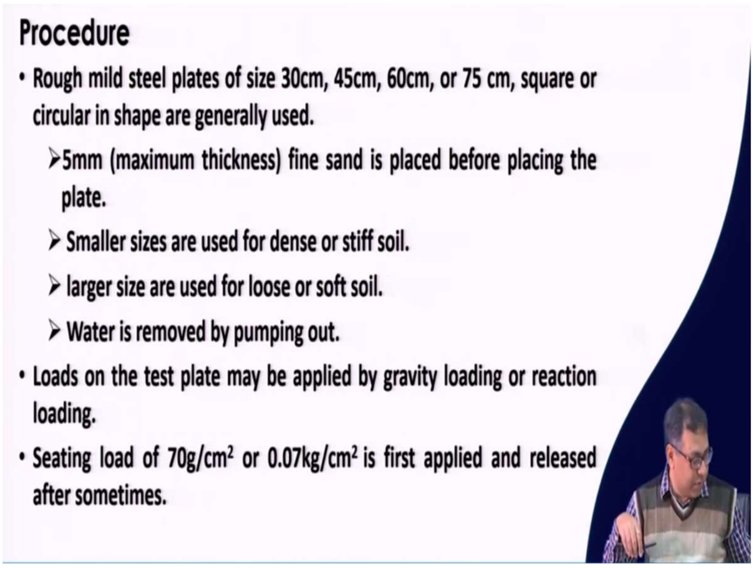

So, I was discussing about the procedure that we have to apply 5 mm fine sand before we place the plate and then we have to apply the rough plate of 30 cm to 75 cm either square or circular and less than 30 cm plate is not recommended. And if I use the plate size more than 75 cm then the size effect will not give any significant change in result.

So, now the smaller sizes are used for dense or stiff soil and larger sizes are used for loose or soft soil and you have to remove water and you have to apply a seating load before you apply the original road.

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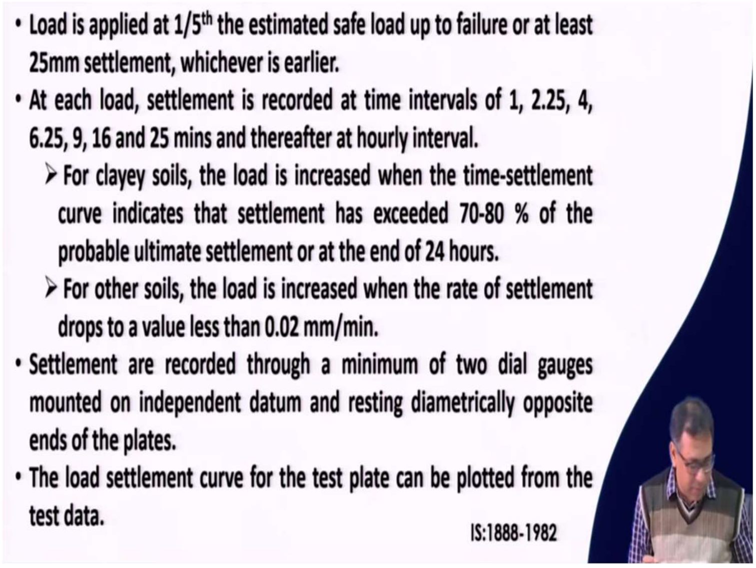

Now the load is applied at $\frac{1}{5}$ of estimated safe load up to failure or at least 25 mm settlement whichever is earlier. So, first, based on the soil parameters, we have to roughly determine or calculate the safe load by using those bearing capacity equations that how much load this plate can take. And then initially we have to apply $\frac{1}{5}$ of that safe load and then $\frac{2}{5}$ of that load, then $\frac{3}{5}$ of that and so on. So, that means $\frac{1}{5}$ of estimated safe load is the increment.

So, and you have to go up to failure or if the settlement reaches 25 mm. So, whichever will reach first, you have to stop your test there. So, now after first $\frac{1}{5}$ increment we record the time interval for 1, 2.25, 4, 6.25, 9, 16, 25 minutes, and thereafter at one hour interval and once, for the two criteria's for clay soil, if load is increased when the time-settlement curve indicates that the settlement exceeded 70% to 80% of the probable ultimate settlement or at the end of 24 hours.

That means for clay soil if the loading is applied up to 24 hours then we can apply the next loading or next increment. So, that means maximum, we can go for 24 hours, or if we see that the other settlement is 70% to 80% of the probable ultimate settlement. Again as I mentioned that we have to get those ideas that what will be the probable ultimate settlement then if it reaches 70% to 80% for that particular load then you stop there.

Or either you have to keep it for 24 hours. As you know, for the clay soil it is a long term settlement. So, this test is short term. So, that is we have to go for 24 hours. So, there may be a possibility that after 24 hours, 70% to 80% settlement may not be achieved. So, that we have to go for 24 hours at least then we will apply the next increment. But for the other types of soil the load is increased if the rate of settlement drops to less than 0.02 mm/min.

That means if the settlement is less than 0.02 mm for a particular minute and you are getting less than 0.02 mm settlement then you stop there. Then you apply the next incremental upload and so on. So, that means for the sandy soil, duration of test will be less compared to the clay soil as expected. So, the settlement, we have to apply minimum two dial gauges and that we have to place on the two opposite corners of the plate.

And the average of these two dial gauge readings will give you the settlement of the plate. So, that means the ultimately load settlement curve will be plotted from this test.

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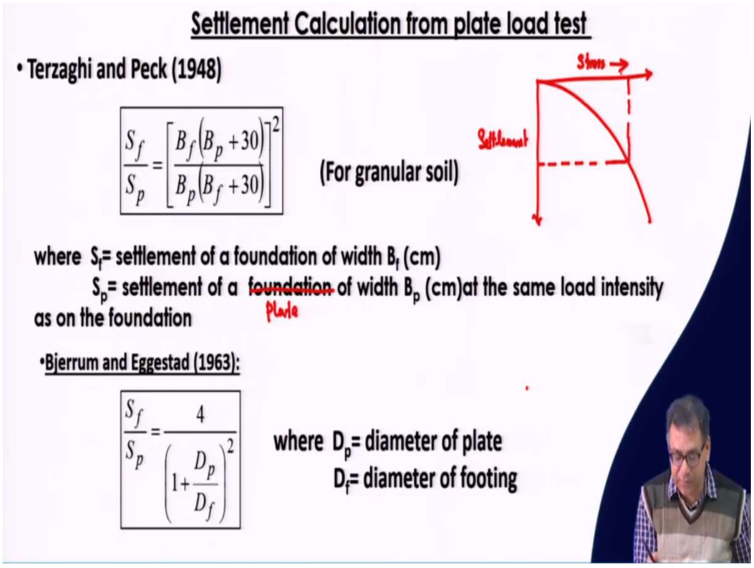

So, now we get the load settlement plot. So, this is stress or the load and this is settlement and then we have to use these correlations to get the actual settlement of the foundation. So, suppose first we are given Terzaghi's and Peck's correlations. So, this is the correlation and remember that your S_f is the settlement of the foundation and S_p is the settlement of the plate.

Actually the S_f is settlement of the foundation and S_p is the settlement of a plate of width B_p at the same loading intensity as on the foundation. So, that means S_f is the settlement of foundation of width B_f and remember that B_f, B_p all are in cm, then only you can write 30. So, this 30 you can write if these dimensions of the plates are in cm.

So, now it is 30 you can write the dimensions of the plate and the foundation are in cm. So, S_p is the settlement of the plate of width B_p at the same load intensity as on the foundation. Similarly we can use the second equation also where B_p is the diameter of the plate and B_f is the diameter of the footing and this equation also we can use but here this is the ratio, so unit is not an important thing.

So, that means how we can get that, suppose permissible settlement of the foundation is S_f and we know the width of the footing and we know the width of the plate. So, we will calculate by using the permissible settlement we know. So, that means here we put the permissible settlement of the foundation then we will get the settlement of the plate.

Now corresponding to that settlement of the plate the load that we are getting from the stress that will be the maximum stress that foundation can take, for example this is the settlement we are getting. So, we know permissible settlement of the foundation, we know the width of the foundation, the plate then we put those values and only unknown is the settlement of the plate. So, I will get the settlement of the plate.

Now, corresponding to that settlement of the plate, the stress that I will get that will give me the allowable stress. So, that much of stress can be applied on the foundation because this settlement is for the same loading intensity. So, in this way I can determine the load carrying capacity of the foundation also or vice versa if for a particular load if you have the settlement, for example, if you have the loading intensity of the foundation on the other side.

So, corresponding to that loading intensity, what is the settlement of the plate you can calculate? Now once you get the settlement of the plate then by using this equation, you will get the settlement of the foundation. So, either if you have the permissible settlement of the foundation, then you will get the allowable load carrying capacity of the foundation. You have the load intensity that is acting on the foundation.

Then you will get what would be the settlement of that foundation then you check whether that settlement is within permissible limit or not. So, these two equations are applicable for granular type of soil.

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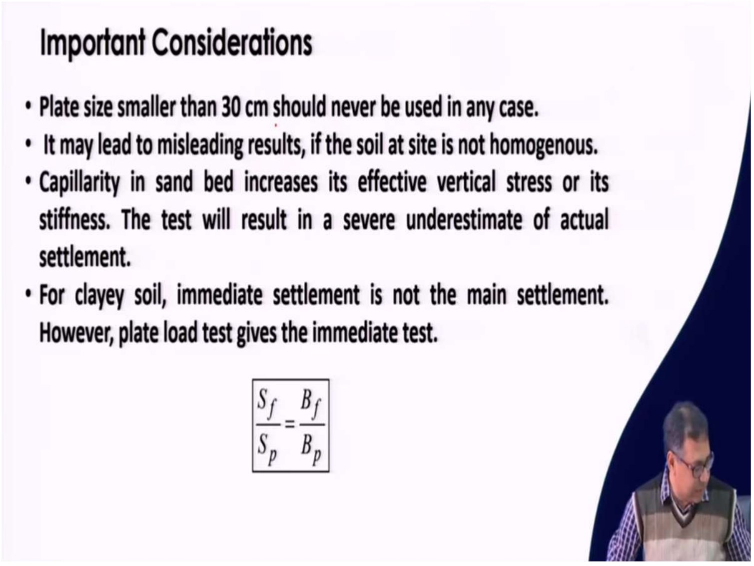

Now for clayey type of soil, this is the equation $\frac{S_f}{S_p} = \frac{B_f}{B_p}$. So, these things are already mentioned that do not use the plate size less than 30 cm and these are some notes that you should remember that it may lead to misleading results if the soil at the site is not homogenous because this is important, because this is one of the limitations of this test. Suppose if the soil is homogeneous soil then it is okay, no problem.

Because your influence zone will be one particular soil only and you will get the bearing capacity and settlement for that particular soil itself, but if it is layered soil and your foundation sizes is obviously larger than the plate size. Now the foundation size is larger than the plate size then the influence zone of the foundation is also larger than the influence zone of the plate.

So, if there is a layered soil then it may be a possibility that the influence of the plate may not go to a deeper layer. But for foundation the influence zone may reach that deeper layer. So, in the plate load test, you will not get the effect of the deeper layer in the test result, whereas your foundation bearing capacity or settlement will be affected due to that layer. So, that means that layer effect will not be reflected in the test results that you are getting by the plate load test.

So, that means this is very suitable for the homogeneous soil and if it is a layered soil, then you have to use this data very cautiously when you are designing the actual foundation. And obviously in the clayey soil the immediate settlement is not the main settlement; however plate load test is an immediate test. So, that means we have to use short term test data for clay soil and again you have to be very cautious.

And then for sand bed if it is totally saturated then there is a possibility of the capillary rise of the water and so negative pore pressure will develop and so effective pore pressure will increase. So, it may mislead the actual settlement. So, you keep these things in mind that means you should not use a plate size less than 30 cm. If there is a capillary rise or the soil layer is not saturated then there is a possibility of capillary rise which may increase your effective stress. So, the data that you will get will mislead you.

So, that means you have to be careful and if you want to use the plate load test data for clay soil, you have to be very cautious because in clay soil the settlement is long term, but plate load test is a short term test. Then if the soil is a layered one, then also you have to very careful when you use the plate load test data for your real foundation design. So, these things you should keep in mind.

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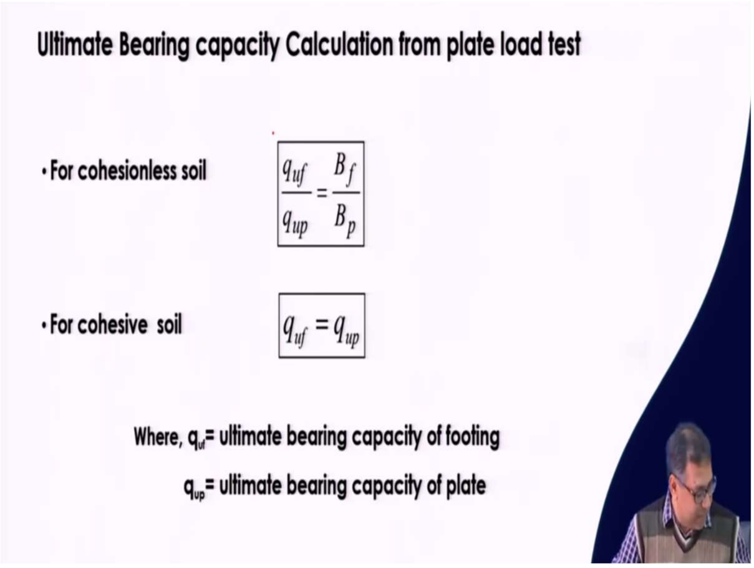

Now, as I mentioned not only the settlement but also the bearing capacity of the foundation we can get for the cohesionless from this equation and for cohesive soil, the ultimate bearing capacity of the plate is equal to ultimate bearing capacity of the foundation. As you know the width is not an important thing for the cohesive soil. And this is the cohesionless soil, this is the equation and one more thing that depth of the plate ideally should be the depth of the foundation.

If it is not, then you have to apply the corrections during the settlement because you have to apply the depth correction in such case and the depth of the foundation will be the difference between the depth of the plate and depth of the foundation. So, you have to consider that depth for determination of the correction factor. So, as I mentioned when you are doing the plate load test you are removing the soil.

So, and then you have placed it so actually the bearing capacity that you are getting on the plate load test where the second term contribution is not there it will be the first term or the second term or if it is the cohesive soil only the third term will play into picture because you are getting the bearing capacity third term contribution in your plate load test because it is a surface footing because you have removed the soil from your pit.

So, surface and as well as c is 0 if c is only present and then surface footing ϕ third term will be 0 only for this first term.

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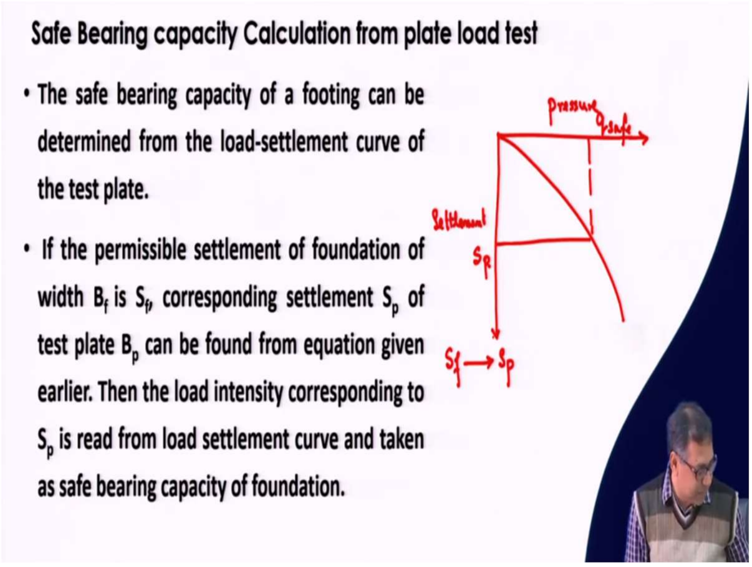

So, now how to calculate the safe bearing capacity from the plate load test? The safe bearing capacity of a footing can be determined from the load-settlement curve. Suppose if the permissible settlement is known and these things are already discussed I think the same thing is written here. I am discussing again that if this is your pressure and this is settlement. And you have this kind of curve.

So, if your permissible settlement of foundation with width B_f is S_f then the corresponding settlement of the plate can be found from this equation. Then the load intensity corresponding to S_p is read from the load settlement curve and taken as the safe load capacity of the foundation. As I mentioned that if permissible settlement of the foundation is available then you calculate the settlement of the plate by using the given equation corresponding to that permissible settlement.

Now corresponding to that settlement you calculate the pressure. So, this is S_p and calculate the pressure. So, first from S_f you get S_p, now that S_p you use and this gives you the q_{safe}. And one thing that when you convert to something you convert once only for example in this case suppose you have the settlement of the foundation then you are converting this settlement of the foundation to settlement of the plate.

Then you are calculating the safe load then do not need to convert that settlement for plate to the foundation because you have already converted once and these settlements are for equal stress intensities, that means this settlement in the previous slide I mentioned that settlements of our equal loading intensity. So, no need to convert them again. So, that means the q_{safe} that you are getting from this pressure settlement curve is the final that is the q_{safe} for the foundation also.

That is the common mistake that we found that students are doing that first from the foundation they are converting to plate then you are getting the q_{safe} and then you are converting that q_{safe} for the foundation that means you will get a very high value, you know, that is not true because this is the settlement for same loading intensity. So, once you convert it for settlement of the foundation to plate then the corresponding q_{safe} will be the q_{safe} for the foundation itself. So, you convert it for once not twice.

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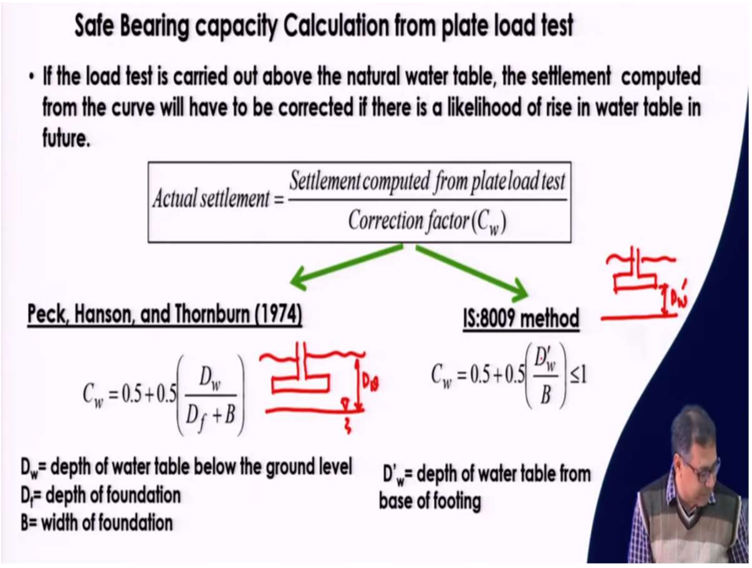

So, now once you get the same bearing capacity from the plate then we have to apply the settlement. For example, during your test water is not present but there is a possibility that during rainy season, water will present in your site and then it will make an effect on your bearing capacity. So, that means if the water is not present under that condition, we have done the plate load test, then that data you have to correct.

So, that data we have to correct by using this correction factor to incorporate the water table effect. If your test is done under saturated condition or the actual water table condition, then it is fine then the correction is not required, but if the test is not done in presence of water, then we have to apply the correction due to water table to incorporate the water table effect. So, that means here the difference between the corrections for bearing capacity and the correction for settlement due to water is slightly different.

What is that, in bearing capacity correction due to water the bearing capacity will get reduced. So, that means we are getting a correction factor which is less than 1 and then we are multiplying that correction factor with the bearing capacity, due to the water the bearing capacity will be reduced. But in settlement what will happen it will be opposite it will not reduce the settlement because water has always the negative effect.

So, if it is in terms of foundation bearing capacity, it will reduce the bearing capacity but in terms of settlement it will increase the settlement. Because in bearing capacity we are always going to the lower side and in settlement you are going to the upper side because that is a permissible value that is the limit value and we cannot go beyond that limit. So, that means in case of bearing capacity you will reduce the settlement by applying the correction factor and in case of settlement you will increase the settlement by using the correction factor.

So, here in actual this settlement is computed from the plate load test divided by the correction factor. So, in bearing capacity or multiplying the correction factor, but here we have to divide the correction factor because as the correction factor is less than one. So, if I divide it by this correction factor, your settlement after correction will increase. So, this correction factor we can calculate by two ways one is Peck, Hansen and Thornburn method and another is the IS code method.

So, but that is a difference that this is the expression here in this case D_w is the depth of water table below the ground level, so suppose this is your equation in this case if this is the foundation. So, this is your water table position, so this will be your D_w so, D_w is the depth of water table below the ground level. But in IS code method, the depth of water table from the base of the foundation is D_w'. So, this is the difference between two cases.

So, it means that if $D_w' = 0$ that means the water table is at the base of the foundation then this is 0.5. So, that means if the water table is between the surface and base of the foundation it is always 0.5. But in this case it will change. So, that means you can either use this method or the first one whichever is suitable for you to apply the correction factor.

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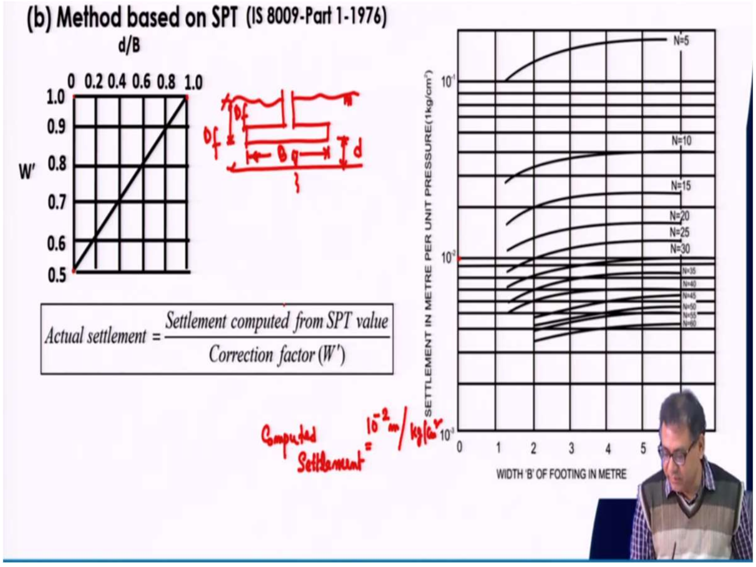

Now the second method is based on SPT. So, this method is proposed in IS : 8009-Part 1-1976. So, you will get the actual settlement from the computed settlement by applying the correction factor, and I mentioned when you have to apply the correction factor due to water and when not.

So, once you get the corrected value and then this W' the correction factor is same as this one, this equation is discussed but here it is given in the graphical form where *d* is depth of the water table from the base of the foundation. So, here this is the *d*, this is the water table and this is ground surface, this is D_f and this is the width of the foundation. So, for example, *d* = 0 means your correction factor is one.

If your *d* = *B* that means $\frac{d}{B} = 1$, means here your correction factor will be 1 and if your $\frac{d}{B} = 0$ means correction factor will be 0.5. So, if $\frac{d}{B} = 0$ that means the water table is at the base then correction factor will be 0.5 and if *d* = *B* then the correction factor will be 1.

And if your water table is at ground surface or in between ground surface and the base of the foundation then also correction factor is 0.5. So, that means if it is within D_f then also correction factor is 0.5 and D_f is not up to this D_f is up to the base of the foundation. So, that means if it is at the base of the foundation and above water table then the correction factor will be 0.5 and below that within the width of the foundation you have to calculate by using this chart.

And then once you get the *N* value this corrected *N* value you have, and now you will calculate the settlement. So, here it is mentioned that first you have to calculate the settlement by SPT once you get the settlement then you have to apply the corrections. So, first let me explain that how I will calculate that settlement because you have the SPT value and you know the width of the foundation.

So, corresponding to that *N* and the width of foundation you will get the settlement in meter per unit pressure that means I will get a settlement say 10^{-2}, that means my *N* value is say this is 15, 20, 25. So, my settlement value is this one so that means the settlement value is 10^{-2} m per 1 kg/cm^2. So, that means for 1 kg/cm^2 your settlement is 10^{-2} m.

That means the settlement is in meter per unit pressure that means this settlement is for unit pressure if your pressure increases the settlement will accordingly increase. So, I will solve one particular problem then I will show you how you can use this data. So, right now if you know the width of the foundation if you know the *N* value you will get the settlement which is in meter per unit pressure that is in kg/cm^2.

And then once you get the computed settlement then apply this water table correction and then you will get the actual settlement. So, that means the computed settlement divided by the water table correction factor, you will get the actual settlement. So, that actual settlement you have to check which is within the permissible limit or not. So, based on that you can decide your width of the foundation.

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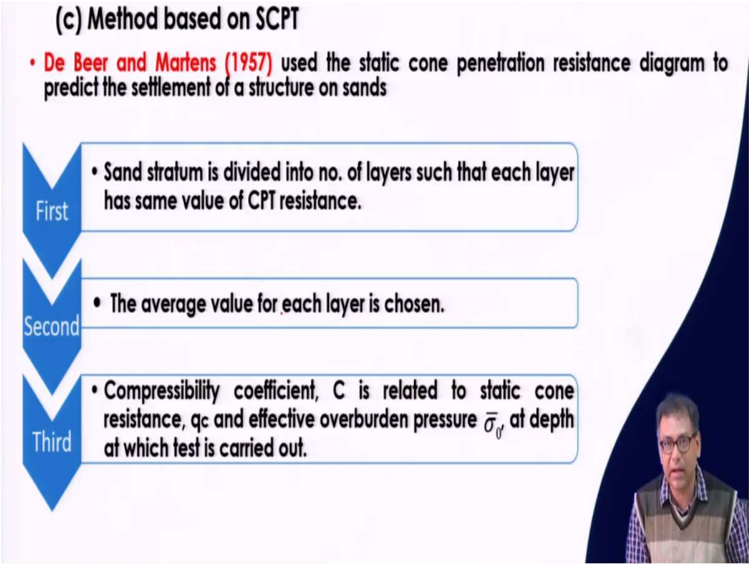

So, next one is based on the SCPT that means the static cone penetration test which is similar to the consolidation settlement. So, that means for each layer we take the CPT value. Actually it is SCPT and then we average that value and then we will apply the equation.

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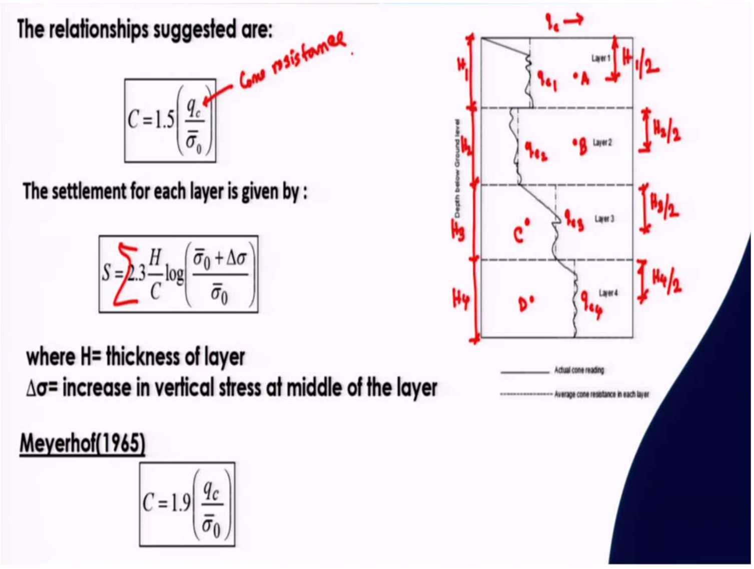

For example suppose we have these three layers, so this firm line is the actual cone reading, means the q_c value. So, actually this is the q_c value and then we have to average it. This dotted line is giving the average value. So, that q_c value for each layer this is q_{c1}, this is q_{c2}, this is q_{c3} and this is q_{c4}. Because these are the actual firm lines and then we take the average for all the layers.

So, σ that means the q_c value for a particular layer is same throughout that layer thickness, so we average that q_c value then you take this to calculate that. Again in the same way you have to determine $\overline{\sigma}_0$ and $\Delta\sigma$ as I discussed for the consolidation theory that means for this layer also each layer thickness, you have to consider points and again, I will take only one point for each layer. So, this is a center line.

So, suppose this is your layer thickness H_1, this is H_2, H_3, H_4. So, this will be the $\frac{H_1}{2}$. Similarly this one will be $\frac{H_2}{2}$ and this one will be $\frac{H_3}{2}$ and this one also, $\frac{H_4}{2}$ and same way we can calculate the $\overline{\sigma}_0$ effective overburden pressure then $\Delta\sigma$ the additional stress due to the applied load and we can use this equation then once you calculate it for each layer then you have to apply the summation.

And here *H* is the thickness of each layer and then this increase of vertical stress at middle layer that means I have discussed and then once you get for each layer we do not to have to add them and then how I will calculate the *C* value that *C* value I will calculate either by using this equation or this equation. So, the upper one is given by De Beer and Martens in 1957 and this one is given by Meyerhof.

So, you can use any of them. So, this q_c is the cone resistance and again $\overline{\sigma}_0$ is the effective overburden pressures at that point either A, B, C, D. So, you have to calculate $\Delta\sigma$ and $\overline{\sigma}_0$ at the respective points that means at the middle of each layer using this equation. So, this is the cone resistance that will get from SCPT test.

So, once you get that then you will sum them and you will get the settlement. So, which is similar to the consolidation settlement and I will solve one problem for consolidation settlement also and then it will be very easier for you to understand in better way that how we can calculate these values and we can determine the settlement. So, I have discussed the consolidation settlement. I have discussed the three methods that means the three field methods.

One is your plate load test, then the SPT and then the SCPT and how we can calculate the settlement of the granular soil. So, next class, I will discuss another two methods that is the semi-empirical methods and influence line method and then I will solve one problem, the example problems to show you how we can calculate the settlement. And then we will go for the next part that is our fourth topic that will be the beams on elastic foundation, thank you.