Advanced Foundation Engineering
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Lecture No -26
Shallow Foundation : Settlement- IV

So, last class I have discussed few methods by which we can determine the settlement of granular soil and I discussed four methods that are based on SPT, then plate load test, then SCPT. Actually I have discussed three methods to determine the settlement of granular soil. Now today I will discuss the remaining two methods.

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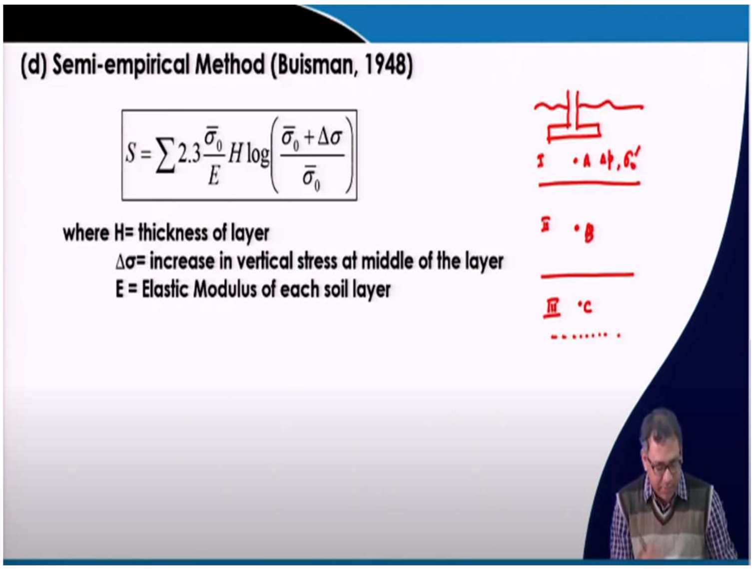

The fourth one is the semi-empirical method which is similar to the consolidation problem. So, where every layer that means if we have a number of layers or granular layers, so this is the foundation. So, this is layer 1, layer 2 and layer 3, which is same as we did for consolidation settlement case or we did for the granular settlement determined by the SPT test or SCPT test data.

So, that means we have to take a point at the middle of each layer from the base of the foundation up to the influence zone. As I mentioned the influence zone for settlement calculation is 2 times the width of the footing. So, suppose if the influence zone is up to this, so this is the influence zone and then there will be three different points as there are three layers. And I have already discussed that you can divide one particular layer into a number of layers and take the points at the middle and then do the calculation.

But in this example problem or this course, I will take only one point at the middle of each layer. And these are the three points A, B, C and this is up to the influence zone. And at every point we have to calculate the increment of stress due to the application of load, $\Delta\sigma$ and effective overburden pressure, $\overline{\sigma}_0$. And as I mentioned $\Delta\sigma$ we will calculate by 2 : 1 distribution and effective overburden pressure we will get at different points.

And then first we will calculate the settlement for each layer and then we will add the settlement of all the layers and you will get the total settlement of the foundation. So, this is the total settlement we can get by summation of settlement of each layer and E is the elastic modulus of the soil layer and I have also given you the tables by which you will get the elastic modulus of the particular soil.

But it is better to have the actual E value for that particular soil, but if you do not have the actual E value depending upon the type of soil, you can also select the appropriate E value by using the tables that are given.

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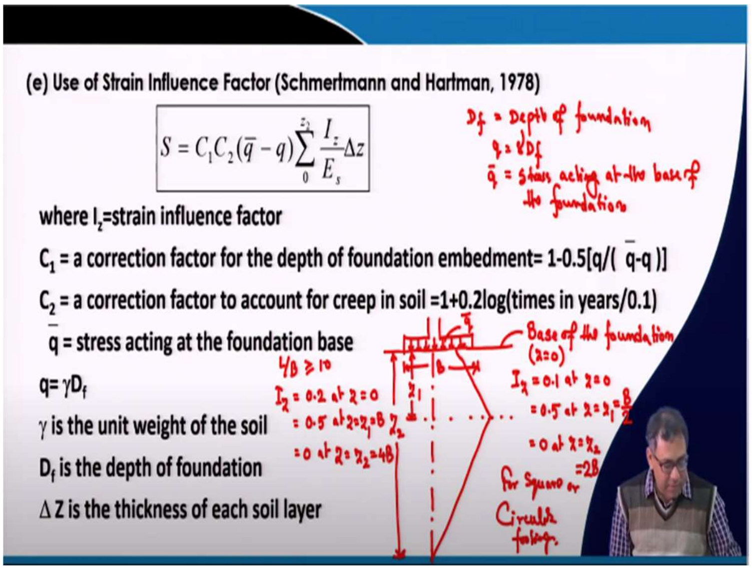

So, the next method is the strain influence factor method. So, this method was proposed in 1978.

So, this is the expression, so the settlement is $C_1C_2(\bar{q}-q)\sum_0^{z_2}\frac{I_z}{E_s}\Delta z$ where, $\bar{q}$ is the stress acting on the foundation base and q is γD_f and here γ is the unit weight of the soil and D_f is the depth of the foundation and Δz is the thickness of each layer. So, in previous equation it is given H which is also thickness of each particular layer. Here it is written in different form.

Now, Δz is also the thickness of different layers and then we have to integrate. We have to take the summation from 0 to z_2. Now I will give you that, what is z_2 and two correction factors are given, a correction factor for the depth of foundation embedment, which is the depth correction factor and the correction factor due to creep in the soil. So, that means two correction factors are proposed, one is due to the depth of the foundation and another is considering the creep effect of the soil.

So, these two correction factors C_1 and C_2 can be calculated by using these expressions where, this time is in years divided by 0.1. So, now what is z_2 and how I will get the strain influence factor, I_z for a particular foundation? So, suppose if we have a loading this is the ground surface and we have a foundation. Now foundation can be at any depth also. Here I am just drawing the foundation and you consider this is not actually the surface.

It is actually the base of the foundation, This line represents the base of the foundation. And that is z = 0. Now if this is central line of the foundation or the loading area and we have two different z values. One is z_1 to draw the influence line and another is z_2. So, here also the summation is given from 0 to z_2. So, now how I will decide the z_2? Because this is my z_1 value and this is z_2. Now corresponding to z_1 I am drawing this line, so this influence line or influence factor we will get by using this line.

So, that means your z_2 will also extend up to this point. So, now how I will get z_1 and z_2 and how we will get the I_z value? So, now suppose if D_f is the depth of foundation then there is a term q. Now $q = \gamma D_f$, where, γ is the unit weight of the soil and $\bar{q}$ is the stress acting at the foundation base. This is basically $\bar{q}$. That means that is the stress at the base of the foundation.

So, that means here you consider at the base of the foundation. That means at the base of the foundation the net pressure that is acting is $\bar{q}$ and q is the γD_f. Now this is the influence line I_z line and how I will get the I_z value? Now this is the width of the foundation and $z = 0$ at the base of the foundation. Now here this is the line.

And I am giving the value of z_1 and z_2 that for $I_z = 0.1$ at $z = 0$ and $I_z = 0.5$ at $z = z_1 = \frac{B}{2}$ and $I_z = 0$ at $z = z_2 = 2B$. And this is for square or circular footing. So, that means for square or circular footing actually z_2 is basically the influence zone that is considered during the calculation. That means as in my previous settlement calculation problem, I said that the influence zones from the base of the footing is $2B$.

So, here also for it is taken up to $2B$ but that is for square or circular footing. So, that means this I_z value will increase with depth up to a certain depth and then it will decrease. So, how these I_z values are calculated? So, I_z values will be calculated, sorry this is not because this should be 0. Because it will increase then it will decrease. So, this is 0. So, this is not 1 this is 0. So, that means it will start from 0.1 at the base of the foundation then it will increase up to z_2 which is $\frac{B}{2}$, where, $I_z = 0.5$ then again it will decrease.

So, that is the influence line which is proposed and then it will be equal to 0 at the influence zone. So, that means $z = z_2 = 2B$ where the $I_z = 0$ and it will start from 0.1 and then this value is 0.5 which is z_1 and that is $\frac{B}{2}$. Now if your foundation $\frac{L}{B} \geq 10$, that means strip footing, then I_z will start with 0.2 at $z = 0$ then it will be maximum at $z = z_1$ and that is equal to B. And this is 0 at $= z_2 = 4B$.

So, that means again the maximum value is 0.5 but only the starting value here is 0.2 and now the influence zone is more in case of strip footing compared to circular or square footing is also 2. Because it has been observed that the influence zone of strip footing is more than the influence zone of square footing. So, that $2B$ I am talking about that is the actual influence zone for a square footing.

One for strip footing the influence zone is taken as $4B$. But for these conditions you have to use for this particular problem, but in general where any type of footings you can consider influence zone up to $2B$. For other problems like consolidation problems or the methods that are discussed where the influence zone is required. So, this particular case you consider for strip footing it is $4B$.

But for a square and circular footing it is $2B$ but for other footings you consider the influence zone as $4B$ for the settlement calculation and B for the bearing capacity calculation. So, this is the general rule that I will follow but actually you remember that for the strip footing your influence zone is more compared to the square footing. So, that means for $\frac{L}{B} = 1$, it is $2B$. Now it will increase from 1 to 10.

That means when $\frac{L}{B} = 10$, the influence zone is considered as $4B$. So, if you increase it from 1, 2 towards the 10 then the value will increase. It is not twice it is more than $2B$. Generally, we consider the influence zone for settlement as $2B$ but in this particular problem you have to take $2B$ for circular and square and $4B$ for your strip footing.

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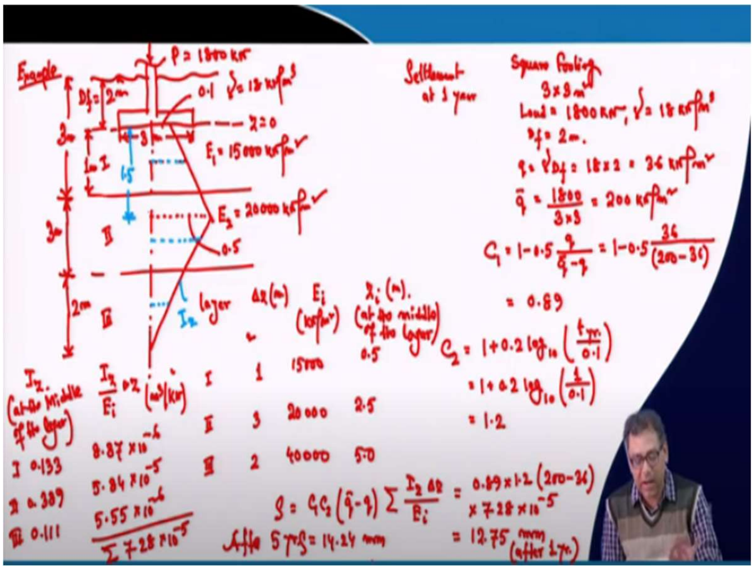

Now I will solve one example problem. For this particular case, your footing is square footing which has dimension of 3 m × 3 m square. Now load is acting on the footing which is 1800 kN and unit weight of the soil is 18 kN/m^3. Again remember that when you calculate the γD_f then you consider the effect of water table if it is present. But now here it is not present. So, that is why you will not consider the water table effect.

So, that is why the unit weight is same throughout the soil and that is 18 kN/m^3 and depth of the foundation D_f is 2 m. So, as I mentioned we need $\bar{q}$ and q. So, q will be γD_f. Here, γ is 18, D_f is 2. So, that q is 36 kN/m^2 and the $\bar{q}$ which is the net pressure acting at the base of the foundation. So, the net pressure is the total force divided by the area.

So, the total force is 1800 kN divided by the area which is 3 m × 3 m square. So, this will be 200 kN/m^2. So, now the C_1 expression is given. The C_1 expression is given that is for the correction due to the depth of foundation which is $1 - 0.5\frac{q}{\bar{q}-q}$. So, that means $C_1 = 1 - 0.5\frac{q}{\bar{q}-q}$. And that is 1 - 0.5, q is 36 then $\bar{q}$ is 200. So, C_1 is 0.89.

Similarly the expression for C_2 is given which is due to the creep of the soil, that is $C_2 = 1 + 0.2\log_{10}\left(\frac{t}{0.1}\right)$. That is t in year. So, now for this case we are calculating the settlement for 1 year. So, calculating the settlement for 1 year and that is 1 + 0.2 log 10 divided by it is in year, 1 divided by 0.1, so settlement at 1 year.

You can calculate for lesser time also. But I have taken 1 year. So, you can calculate for higher time period also. But as it is, I mean immediate settlement is settlement for the granular soil. So, if you increase the time then not much variation will happen. So, that means this is 1 + 0.2, sorry we have written that. So, the value which is coming is 1.2. So, now the C_1, C_2 correction factors are determined.

Now the next step is to determine the I_z value. So, now we have the foundation. So, this is the base of the foundation and here it is considered as $z = 0$ and then this foundation, it has three layers. So, this is layer number 1, this is layer number 2 and this is layer number 3. So, this is layer number 3, this is layer number 2 and this is layer number 1. So, this D_f is 2 m and this load P is 1800 kN.

Now, depth of foundation is $D_f = 2$ m. Now the thickness of this layer is say 3 m. So, layer 2 it is also 3 m and there is a layer 3. So, layer one is 3 m, 2 m is the depth of foundation. So, the thickness of layer 1 below the base of foundation is 1 m, for layer 2 it is 3 m and it is a square footing whose dimension is 3 m. So, the influence zone for the square footing is up to $2B$.

So, it will be 6 m from the base of the foundation. So, it is 1 + 3 then another 2 m will be in the third layer. So, total $2B$. B is 3 m, so 6 m from the base of the foundation. So, 1 m will be in the first layer, 3 m will be in the second layer. So, this is 3 m and remaining 2 m will be in the third layer. So, now I have to draw the influence line and that is for $\frac{B}{2}$ and B is 3 m.

So, at 1.5 m so this is 1 m, so that 1.5 m this value will be more. So, it will start like this and then it will end like this and this is your 2 m basically. Up to this point it is 2 m. So, now this is 0.5 and this is 0.1 because it is a square footing. So, now let us calculate the I_z of each different layers and then Δz is the thickness of each layer then E_i. And then this z_i is in m.

And now E_i value for every layer is also given. So, E_1 is 15000 kN/m^2 and E_2 is 20,000 kN/m^2 and E_3 is given as 40,000 kN/m^2. So, I am writing E_3 on this side. So, now what are the things that are given? That means the dimension of the footing is given 3 m × 3 m. The total of load is 1800 kN.

Then the unit weight of the soil of the first layer is given. So, that is 18 kN/m^3. For the other layers it is not required. That is why it is not given. You can also see that all the soil properties can be given. So, depth of foundation is 2 m which is given then the time at which I want to calculate the settlement that is 1 year that is also given.

Then the thickness of every layer is given and the properties of each layer and the properties which is required is elastic modulus. So, elastic modulus of all the layers are given that is 1000 kN/m^2 for the first layer then 20 MPa for the second layer and 40 MPa for the third layer. So, now I will calculate settlement for the layer 1, layer 2 and layer 3. So, layer 1 what is the thickness of the layer from the base of the foundation? First layer thickness is 1 m because that is from the base of the foundation.

Second layer thickness is 3 m and third layer thickness up to the influence zone that is $z_2 = 4B$ is 2 m. Now E_i value for the first layer is 15,000 kN/m^2. So, this is 20,000 and this is 40,000. Now we have to calculate the influence factor for every layer. Now where we will calculate? Suppose this equation there is a summation and then where we will calculate all these influence factors I_z?

So, we have to calculate at the middle of each layer, we did the same thing for other cases also. We calculate the effective overburden pressure or the stress increment at the middle of each layer. Here also we will calculate I_z at the middle of each layer; z_i is the depth at the middle of each layer below the foundation base. So, from the base because everything we are calculating from the base where this $z = 0$. So, from the base to the middle of the first layer will be 0.5 m, the thickness or the distance from the base to the middle of the first layer is 0.5 m because the thickness of the first layer is 1 m.

Now for the second layer, it will be 1 m + 1.5 m. So, it will be 2.5 m. So, for the third layer, it will be 1 m + 3 m + 1 m. So, it will be 1 m for the first layer then 3 m second layer, 4 m plus the middle of the third layer. So, that is 1 m. So, that will be 3 and 5 m. So, now I will calculate the I_z value.

That is at the middle of the layer. And here I will calculate $\frac{I_z}{E_i}\Delta z$ which is in m^3/kN. What we are doing? We are basically calculating this part that is $\frac{I_z}{E_i}\Delta z$. And then we will add them and then we will multiply with these common factors and this $\bar{q} - q$. So, remember that here the addition is only this portion and in the previous addition is total addition and definitely that 2.3 will go outside.

So, other parts we have to add but here the addition is only for this portion. So, then I_z at the middle that means here, this is my middle portion here this the middle portion, this the middle portion, here this is the middle portion and here this is the middle portion. So, what we have to do? We have to linearly interpolate these values and will get the I_z values because this is the I_z line. So, I know that at $z = 0$, $I_z = 0.1$ and at $z = \frac{B}{2} = 1.5$, $I_z = 0.5$.

This is $\frac{B}{2}$. So, at 1.5, $I_z = 0.5$. So, then I can get what is the value of I_z at 0.5. I know that at 0 and at 1.5 then I can linearly interpolate this value and I will get what is the value of I_z at 0.5. So, that value at 0.5 thar I am calculating. So, by linear interpolation so that means here for first layer I_z value is 0.133. So, because this is 0.1, this is 0.5. So, these values at 0.5 so this distance are 0.5. It is 0.133.

For layer 2, from the base of the foundation at a distance of 2.5 m. So, here at 1.5 m say 0.5. At 6 m it is 0, so again by linear interpolation I will get what is the value at 2.5 m from the base of the foundation and that value is 0.389. For the third layer it is 0.111. So, basically just from similar triangle you can determine, you know how to do the linear interpolation.

Because this is for this triangle, you know at this portion you take this triangle this lower triangle and then you will get the I_z value corresponding to this dotted blue line by linear interpolation. And that is the I_z value for the second layer and this is the I_z value for the third layer. Then we will add them and in addition we will get 8.87×10^{-6} the addition of these factors.

I mean, once we get the I_z then I know the Δz then I know the E_i. So, basically this column is $\frac{I_z}{E_i}\Delta z$ for each layer and that is 5.84×10^{-5} and 5.55×10^{-6}. So, if I add them, then this will be 7.28×10^{-5}. Why we are adding them? Because we have to add them for each layer. Now the final settlement will be equal to your $C_1 C_2(\bar{q} - q)\sum_0^{z_2}\frac{I_z}{E_s}\Delta z$.

So, that means C_1 is 0.89, C_2 for one year is 1.2. Now the $\bar{q}$ is 200, q is 36. So, $(200 - 36) \times 10^{-5}$. So, this means the settlement is coming as 12.75 mm after 1 year. Now in similar way after 5 years, you can calculate, only difference is that you have to change the C_2 value. Because it is considered that is the creep. So, remember that why we are considering that 1 year and 5 years and 10 years?

You can say that this is the immediate settlement. Why you are considering that much of time? 5 years or 1 year because it is due to the creep. This C_2 effect is due to the creep of the soil. So, that is why creep is a time dependent phenomena. So, that is why you are checking what the additional settlement due to the creep is. So, after 5 years this value is 14.24 mm. So, that means not much variation is there and most of the settlement will have occurred in very short duration.

Because it is immediate settlement and then due to creep there will be some increment of the settlement and you can see that after 1 year that is 12.75 mm. And after 5 years settlement is 14.24 mm. So, that means this is the procedure then you take the different layers and then draw the influence line depending upon your foundation then at the middle of each layer you calculate the I_z value by linear interpolation.

Because you know the values of two end points and you know the distance. So, you will get the I_z values at those points then add them all the I_z values and this term, add them then multiply the other factors you will get the settlement at respective year. So, I have discussed the different settlement methods by which you can determine the settlement for clayey soil as well as the settlement for granular soil.

So, this is the method that I have discussed so as per my suggestions you should use these methods for this particular soil that I have discussed. That means the two methods, one is for immediate settlement of clay and another is for consolidation settlement of clay. Then the rest of the five methods are for granular soil. So, next class I will discuss the next topic which is the beams on elastic foundation.

Because here we have discussed bearing capacity and the settlement and these are two design criteria. But here we have not considered the interaction between the foundation and the soil and we have concentrated mostly on bearing capacity and the settlement. But in addition to that we also need the bending moment and shear forces to design the foundation. So, how to calculate the settlement then the bending moment, slope or shear force of the foundation considering soil foundation interaction, so that I will discuss in the next class. Thank you.