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

Lecture - 36
Design of Shallow Foundation - 1

Now, today I will start a new topic that is the design of shallow foundation. So, here design means, I will discuss about how to decide the dimension of a shallow foundation. I mean what would be the length, width and what would be the depth of the foundation. And in my previous modules I have discussed that what are the different types of field test by which we can determine the soil properties?

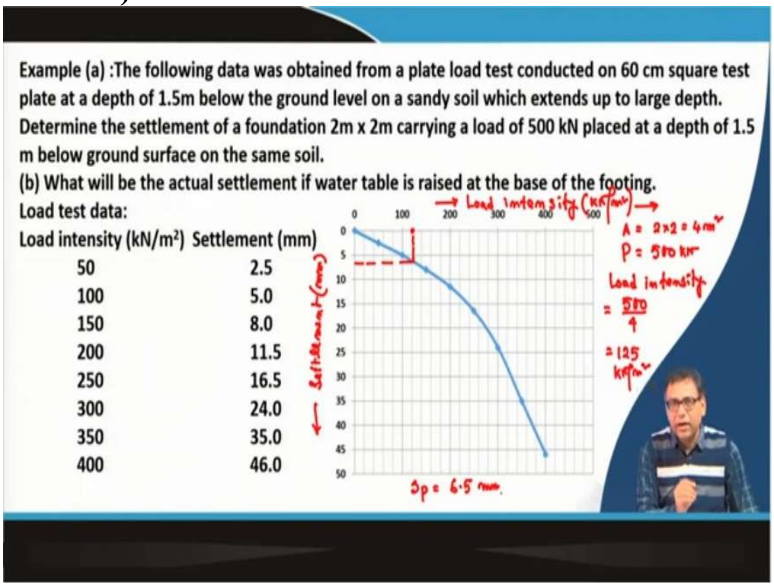
Now, today I will discuss how we can use those properties to design the foundation. Then I have discussed the bearing capacity calculation, settlement calculation. Then in the fourth module I have discussed about the concept of beams on elastic foundation. Then not only settlement and the bearing capacity if we want to determine the bending moment and the shear force how we can determine those properties as well as the deflection by considering soil and the foundation interaction.

Now today first I will discuss the bearing capacity and the settlement checks and then we will decide the dimension of a foundation based on the field test data as well as the laboratory test data. Because as I mentioned that for design of the foundation on sandy soil, we prefer to use the field test data and for clay soil we can collect the undisturbed soil sample. So, we can use the laboratory test data for the design of foundation on clay soil.

So, I will discuss the design of shallow foundation testing on sandy soil by using field test data and then design of foundation on clay soil by using the lab test data. Because as I mentioned that field test data for clay soil we have to use with caution because the field tests or short-term test for the clay soil but the behavior of foundation is long term, for example the plate load test data. So, the plate load test data test is short-term, as you know that the consolidation takes very huge time for clay soil.

So, those field test data like plate load test, in case of clay soil you have to use them with caution. So that is why, we will do the design of foundation on clay soil using the lab test data.

(Refer Slide Time: 03:21)



So, first I will discuss that plate load test design that we have the first example problem that following data was obtained from a plate load test conducted on 60 cm square plate, at a depth of 1.5 m below the ground level on a sandy soil which extends up to a large depth that means it is a homogeneous soil. So, we can use this data, but as you know that for the layered soil also you have to use these data, this plate load test data with caution because the plate load test which is a small-scale test compared to the our actual foundation.

So, if there is a layered soil and there is a possibility that in case of plate load test a particular layer may not get influenced by the plate load test, but actual foundation may be influenced due to the load coming on the foundation. So, in those cases you have to use these data cautiously but here it is homogeneous soil, so, we can use these data for our real foundation also.

So, determine the settlement of a foundation 2 m × 2 m carrying a load of 500 kN placed at a depth of 1.5 m below ground surface on the same soil. So, the depth of foundation and the depth of plate both are same and then, but one case the plate size is 60 cm but actual foundation size is 2 m × 2 m square and then we have to determine the settlement of the real foundation, if the foundation is subjected to a load of 50 or 500 kN.

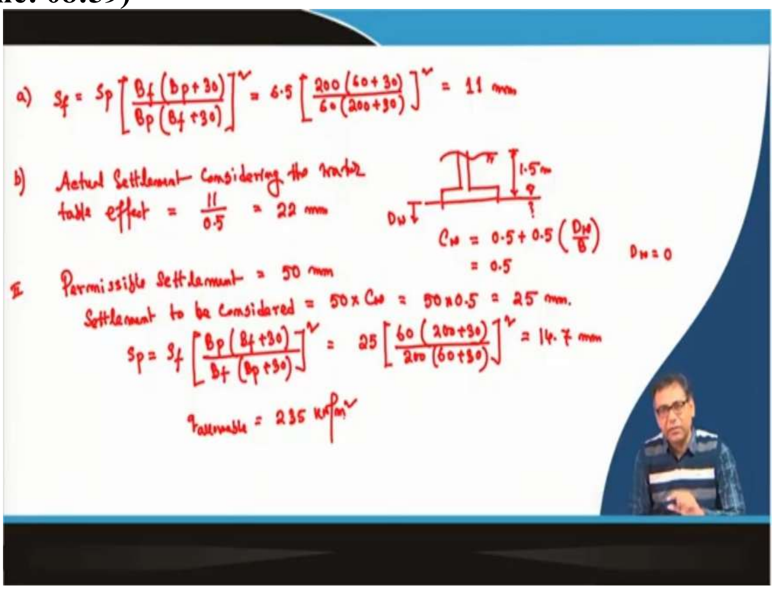
So, now, these are the plate load test data that when we apply the load and measure the settlement. So, I have discussed already the plate load test during my discussion on settlement of shallow foundation. So, now, today I will use that plate load test data to decide what will be the settlement and whether that settlement is sufficient or not for that particular dimension which is chosen based on that plate load test data.

Now this load intensity is given from 50 to 400 kN/m^2 and settlement is given 2.5 mm to 46 mm and based on that we have drawn a load versus settlement graph. So, this x axis it is here, it is load intensity which is in kN/m^2 and in the y axis it is settlement which is in mm, this is drawn. Now we have the area of the real foundation is 2 m × 2 m that is 4 m^2.

And the load which is applied on the real foundation is 500 kN, so, the load intensity that is equal to $\frac{500}{4}$ which is 125 kN/m^2. So, the load intensity of the foundation is 125 kN/m^2, so as I have discussed that this settlement that we will get for the plate as well as the foundation are for the same loading intensity. So that means the load intensity that is coming on the real foundation that we will use to determine the settlement of a particular plate.

So that means here the load intensity is 125 kN/m^2 and so the corresponding settlement of the plate is 125 will be, this is 100, so, this is will be 125, so, corresponding settlement will be around, this is 6.5 mm. So, the settlement of the plate is 6.5 mm corresponding to a load intensity of 125 kN/m^2 but that settlement is a settlement of the plate but we have to convert it to settlement of the real foundation. So, how to convert that? So that conversion techniques, so you know I have given, so it is on the clay soil.

(Refer Slide Time: 08:59)



So, for the clay soil the settlement of the foundation, $S_f = S_p \left[\frac{B_f(B_p+30)}{B_p(B_f+30)}\right]^2$ where, B_f is the width of the foundation, B_p is the width of the plate. So, now the settlement of the plate is 6.5 mm and width of the foundation is 200 cm because in this equation 30 is given.

So, 30 means these B_p and B_f should be in cm, so, actual dimension of the foundation is 2 m × 2 m so, it is 200 cm × 200 cm then plate width is 60 cm. So, then, $S_f = 6.5 \times \left[\frac{200\times(60+30)}{60\times(200+30)}\right]^2$. So, this settlement is 11 mm. So, the settlement of the foundation under a load of 500 kN is 11 mm.

So, what we have done? We have taken the loading intensity corresponding to same loading intensity to determine the settlement of the plate then we converted it to the settlement of the foundation by using the available correlations for sandy soil. But here the effect of water table is not considered because here water table is not considered. So, this is our first part of the problem. So, now the second part what will be the actual settlement if the water table is at the base of the foundation.

So, now initially in the first part the water was not present, in the second part water is present at the base of the foundation then what would be the settlement? So, in the second part, so, water table effect, so, here suppose this is your foundation and foundation depth is 1.5 m from the ground surface and in the same depth the water table is present. So, we have to apply a correction factor, so that correction factor is C_w, so C_w, we know that we can write, $C_w = 0.5 + 0.5\left(\frac{D_w}{B}\right)$, so, here we are using the recommendation given by IS code.

So, C_w is that because I have given the two types of correction factor determination, so, here I am using the correction factor suggested by the IS code, you can use the other one also I have given two of them, but here I am using the IS code 1, so, this IS code because why I am taking the IS code? Because in IS code it is given that if the water table position is within the ground surface and the base, all the cases is 0.5. So that means if the water table is at the base of the foundation, then also it is 0.5.

If it is between the base of the foundation and ground surface then also it is 0.5. So, within the ground surface to the base of the foundation it is 0.5 but other correction factor you will find that at the ground surface it is 0.5 but at the base it will not be 0.5, it will be slightly higher correction factor. So, here I am taking as per IS code but it will give me more safer design because as the correction factor is 0.5 which is the lowest correction factor. So, that means your bearing capacity will be reduced by 50% or the settlement will be increased by 2 times.

So that is why I am taking the IS code recommendations but you can take the other one also but here I have taken the IS code recommendation. So, but here D_f is calculated from the base of the foundation, so, basically D_f is calculated from the base of foundation, so, here water table itself is at the base of foundation, so, the D_f value or D_w value, this D_w value is calculated from the base of the foundation and here D_w is 0.

So that means we can write this as 0.5. So, if the C_w is 0.5, so, actual settlement of the foundation without water 11 mm and as I discussed that if it is a settlement, we have to increase the settlement because settlement will be increased due to the effect of water table and bearing capacity will decrease due to the effect of water table. So, in case of settlement we have to divide it by the correction factor because the correction factor is less than 1.

So that means the actual settlement considering the water table effect is equal to $\frac{11}{0.5}$, so this will be 22 mm, so the actual settlement considering the water table effect is 22 mm. So, it is increased by 2 times. This was the one part of determination of the settlement now you can see that this 22 mm is within the tolerable limit or not. So, if it is within the permissible limit then your dimension is fine.

The dimension that you have chosen for that particular load is fine. But if it is not within the permissible limit then you have to change the dimension. So, this is one way to choose the dimension of the footing, so that means initially you select one particular dimension then determine the settlement based on that dimension of the foundation, then you check whether that settlement that you are getting is within the permissible limit or not.

If it is not within the permissible limit then you have to change the dimension in other ways also. Suppose your permissible limit for example is 50 mm and you are getting 20 or 25 mm then you can change that settlement to modify your dimension of the foundation to make your design more economical. So that your permissible settlement and the settlement that you are getting should be close to each other.

So that is why here I do not know what is the permissible settlement, it is not given in this particular problem, so, we are just only determining the settlement that is 22 mm and we hope that the settlement is within permissible limit. But there is an alternate way also you can use this plate load test data. Suppose in that case your example problem 2, because this is your example problem, say 1, in example problem 2, here permissible settlement is given.

Permissible settlement is given is 50 mm. So, this settlement is considering the water table effect, so that means you can see if we do not consider the water table effect. And for example, why I am talking and we are applying this correction that means when your plate load test was conducted that time this water was not present there. So, that is why you have to consider this water table effect.

That means the plate load test is done when the water table was not present. So, water table is far below the plate depth. So that water table effect is not incorporated or was not within the data that you are getting by this plate load test. But now if in case the water table position is at the base of the foundation in actual case then how the settlement will change, so that is the question? So that means here the permissible settlement is given as 50 mm, so that should be within 50 mm considering the water table effect.

So, we cannot compare this permissible settlement directly with your plate settlement because plate settlement is done without considering the water table effect, but we have to consider the water table effect. So, actually we have to consider the lower settlement value, so that when we apply the water table effect, so that settlement will reach to the permissible settlement.

For example, in initial problem without water table effect the settlement was 11 mm, now once we apply the water table effect then the settlement is 22 mm. So, now your 22 mm should be less than 50 mm, now because permissible settlement is given. So that means, we are going an alternate way initially we know the loading intensity and we determine the settlement.

But now in the second solution case or second problem we know the settlement and we will determine what is the maximum loading intensity or safe load intensity that we can apply on the foundation. So, it is totally the reverse case, initially loading intensity was there and we determine the settlement then we check whether that settlement is within permissible limit or not and second case permissible settlement is given now we are determining what is the safe load that particular foundation can carry.

So, this is the permissible settlement, so settlement to be considered will be 50 × 0.5, so this is 25 mm. So, why we are now multiplying it with 50 mm? Because now 25 mm will compare with our plate settlement, now for example, if I take 50 mm total settlement then definitely the settlement of the plate will also be more and if the settlement of the plate is more then the loading intensity will also be more.

So, but actually we have to take the 50% of the permissible settlement, for why? Because our correction factor is half that is why we have to take the 50% of the settlements, such that, the settlement is 25 mm without considering the water table effect. So that settlement now we can compare with the plate load test data as the plate load test also conducted without considering the water table effect. Now, these 25 mm settlement now if I consider the water table effect, that way reach to 50.

So that is why we have taken 25 mm now we will compare this 25 mm with the plate settlement. Now then the same conversion we have to use, now it is settlement of the plate, $S_p = S_f \left[\frac{B_p(B_f+30)}{B_f(B_p+30)}\right]^2$. So, this is $25 \times \left[\frac{60\times(200+30)}{200\times(60+30)}\right]^2 = 14.7$ mm. So, corresponding 14.7 mm is around here, so, corresponding value is around, this is 220 around 235.

So, this value is around 235 kN/m^2. 230 it will be 238 around, so, this will be 238 or 14.7 around 235. That will be fine because 14.7 will be slightly higher side so, this will be slightly upper, so, it will be 235. So, now if we take 50 itself then this value will be around 30 mm. So, if I take 30 mm, so, loading intensity will be around 320, 25 mm. So that means 325 mm, if I consider total 50 cm, so that will be without considering the water table effect.

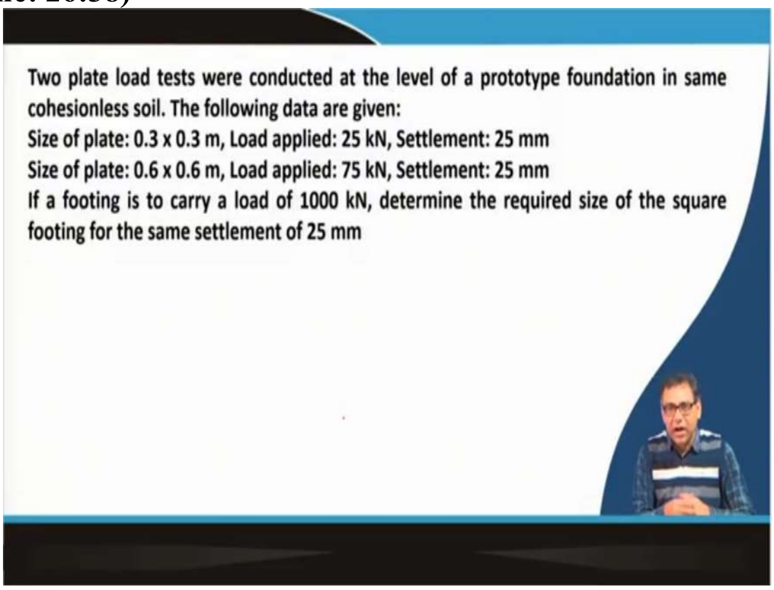
So, you can do in the other way also but it is weighted to apply the correction factor in the settlement and then calculate your loading intensity. So that means if I take 325 kN/m^2, so that will be higher without considering the water table effect. So, if I consider the water table effect, then the bearing capacity will reduce so that is why we are taking the lesser settlement value considering the water table effect.

And then we determine the loading intensity and that is given 235 kN/m^2. So, my q_{safe} or $q_{allowable}$ will be 235 kN/m^2. So, this is also one way by which we can determine the allowable bearing capacity, now you check that under this dimension you can apply this match for loading intensity on the foundation and you will check whether that loading intensity is sufficient or not.

If it is not sufficient then you have to change the dimension. So, these are the two approaches by which we can decide what will be the dimension of the foundation based on the plate load test data and one more thing I want to mention that here, the depth of the plate and the depth of the foundation both are same, so, there may be a case where the depth of plate and depth of foundation, these are not same. So, suppose your depth of plate, obviously, the depth of foundation should be more than the depth of plate.

So, in such case you have to apply the depth corrections. I have already discussed during my settlement calculation part, but I will also show in one of the example problems in this or next classes that how to apply that depth corrections to this settlement value. And the difference of the depth will be your depth of foundation in such case. So that means, what would be that depth of foundation in such case, your difference of the depth between the plate and the real foundation will be the depth of foundation.

(Refer Slide Time: 26:38)



So, next problem that I will discuss that suppose in sometimes we can conduct two plate load tests with different plate sizes. What is the purpose? To minimize the size effect because as I mentioned we are using the small size plate load or plate to conduct the plate load test so, size effect is there, so, to minimize that we can use that two different size plates and then based on that plate load test we can determine what would be the actual dimension of footing.

So, this is an example problem that two plate load tests were conducted at the level of a prototype foundation and here also depth of the foundation and depth of plate, both are same which is actually the ideal case. In same cohesionless soil, this is also sandy soil and the following data are given the size of the plate one is 30 cm × 30 cm where the 25 kN applied load, settlement is 25 mm.

And for 60 cm × 60 cm plate, 75 kN is the applied load, and settlement is 25 mm. Now we have to determine the dimension of a square footing that if we apply 1000 kN load and we will get the same settlement. So that means, we have used the two different plates on the same soil, different plates and one plate is given 25 mm settlement under 25 kN load.

Another plate given 25 mm settlement under 75 kN loads because this plate dimension is 60 cm × 60 cm square. Now we have to determine by using these plate load test data, what is the dimension of a real footing if we want to get the same settlement under 1000 kN load? So, in the next class I will solve this particular problem that how we can use these two plate load test data to determine the dimension of a footing.