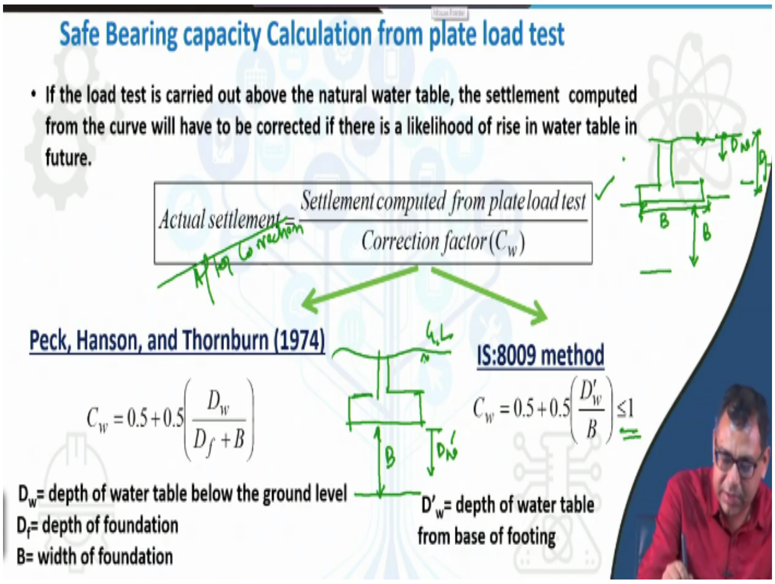
Soil Structure Interaction
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology – Kharagpur

Lecture - 6
Design of Shallow Foundation

In the last class, I have discussed about the settlement calculation procedures and I have discussed the plate load test and then immediate settlement for clay and consolidation settlement for the clay, and then today, I will discuss about the design of shallow foundation on sand and as well as on clay.

(Refer Slide Time: 01:04)



So, in last class, I have discussed about the plate load test and I have discussed about how to calculate the safe load carrying capacity of the foundation based on plate load test data, then how to calculate the ultimate bearing capacity of the plate and from that plate to the foundation. I have given some correlations for clay soil to determine the settlement of foundation based on the settlement of the plate and for the clay soil also, and similarly, if I know the ultimate bearing capacity of plate, then by using correlations, we can get the ultimate bearing capacity of the foundation.

Then we will get the load carrying capacity of the foundation based on bearing criteria. We will get the ultimate load carrying capacity, then we divide it with factor of safety, we will get the safe load carrying capacity from the bearing capacity criteria, then we will get the safe load carrying capacity of the foundation from settlement criteria based on the permissible settlement okay. Then the lower of these two will give you the allowable load carrying capacity of the foundation, but one thing is that in the plate load test, I have not discussed the water table effect okay.

So, now if your water table is within the influence zone or even if it is at the base of the foundation, so then also you have to take the water table effect. So, these are the water table effect. So, in the bearing capacity calculation also, we introduce the water table effect and remember that in bearing capacity calculation, our bearing capacity decreases due to the presence of water, and as I mentioned if the water table is at the foundation or as the ground level, then the building capacity will roughly reduce by 50% as compared to the bearing capacity without considering any water table effect.

So, remember that means the water table correction is generally less than 1. So, it varies generally in between 0 to 1 okay. So, it is less than 1, water table correction should not be greater than 1. So, that means in case of bearing capacity, you have to multiply water table correction, but in case of settlement here, that means if bearing capacity decreases due to the presence of water, so that means that water has a negative effect on the bearing capacity and definitely it will have a negative effect on the settlement.

So, here this bearing capacity factor correction factor, we have to divide to get the actual settlement after correction. So, that means here if I multiply, the settlement will reduce, but that is not the case, bearing capacity will reduce but the settlement has to be increased because of the water tablet effect because water table will give you a negative effect. So, that is why in case of settlement when you apply the water table correction, remember that you have to divide it by the measured or the computed water settlement okay.

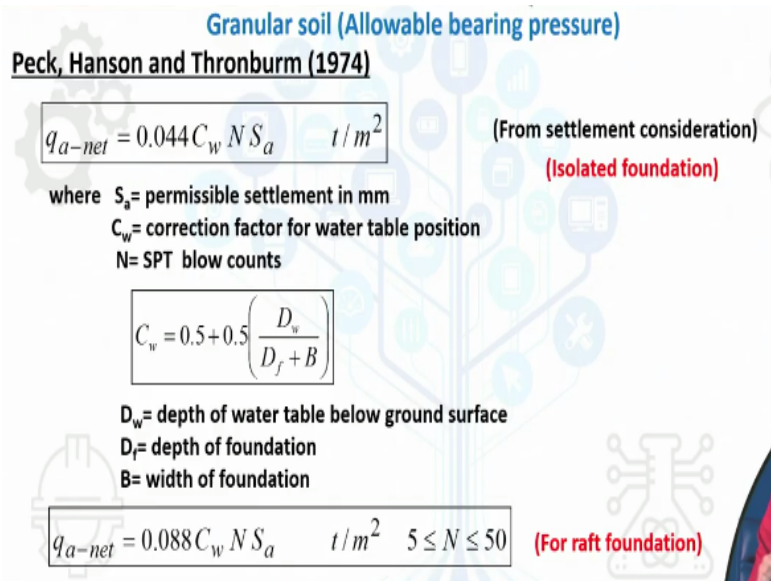
So then only, your actual settlement after correction will increase. Suppose for example, if your bearing capacity say 200 kN/m^2, and if you apply water table correction 0.5, then bearing capacity will come down to 100 kN/m^2 and if your measured settlement is 20 millimetre and if you apply the water table correction, then it has to be 40 millimetre, not 10 millimetre because remember that if you apply the water table correction, your bearing capacity will decrease, but settlement will increase.

So, that is why this is the actual settlement after correction. This is the after correction. So, the settlement computed from the plate load test divided by the settlement factor. Now settlement factor you can calculate either using Peck, Hanson and Thornburn equation or either using IS code method IS 8009 method. So, but as I mentioned, it should not be greater than 1. So, this Dw and Dw', if this is your foundation or the base of the plate and this is your ground level, then your Dw is measured from here, this is Dw.

So, Dw is the depth of water table below the ground level. So, Dw is calculated from the ground level and it is restricted upto this is B, this is D_f by B and B is the width of the foundation okay. On the other hand, your Dw' dash is measured from the base of the foundation. This is ground level, so this is measured from the base of the foundation. Again, the range of this Dw dash is also up to the B.

So as per IS method if your water table as the base or above, then the correction factor is 0.5, and if it is below the base of the foundation, then it is greater than 0.5, but less than 1 or within 1 or if it is at the base, then it will be 1, but as per this method if your water table is at the depth of the foundation, then it is not equal to 0.5. This is 0.5 if the water table is at the ground level, then only this value is 0.5. So, you can use either this one or this one depending upon which type of code you are following okay. So, this is the water table correction okay.

(Refer Slide Time: 07:36)



Then one thing I want to give you that now I have discussed that how to calculate the bearing capacity of the foundation or soil shallow foundation and then how to calculate the settlement of a foundation okay. So, because as I mentioned these are the two criteria for the design, now when I discuss the bearing capacity of soil, then I have discussed how to calculate the net ultimate bearing capacity of soil or foundation based on a SPT value. Now, here also I am giving another correlation by which you can directly calculate the allowable bearing capacity of the shallow foundation based on SPT.

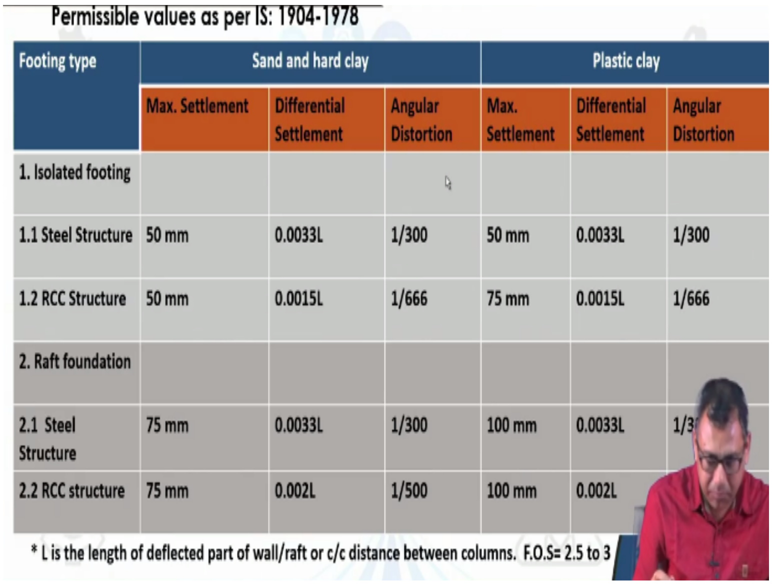
So, the previous expression will allow you to determine the net ultimate bearing capacity in terms of bearing failure okay, but here it is allowable, that means the minimum of bearing and settlement. So, that means when these expressions have taken care both bearing criteria as well as the settlement criteria. So, if you have the N value and if you have the permissible settlement by using these two equations or the expressions, one is for the shallow isolated foundation and this is for the raft foundation you can determine.

So, this is the expression in terms of ton per meter square, you can convert it to kN/m^2. So, this Sa is the permissible settlement, you put the permissible settlement value, N value which is N value or corrected N value and this is the water table position and Dw, I have already discussed just now, what is Dw and that is the depth of what table below ground surface okay, Dw is the ground surface, Df is a depth of foundation and B is width of foundation. So, we calculate the water table correction.

This is the water table correction depending upon the position of water table and then you put them here, you will get the net allowable bearing capacity of foundation in terms of t/m^2 for isolated foundation. Similarly, for raft foundation you can use this expression, but remember that this is the limit, this should be greater than 5 N value and less than 50 okay, you can use this expression.

So, these are empirical expressions, so unit is very important. So, if you are using this expression, the unit has to be t/m^2, so then you can convert it to kN/m^2.

(Refer Slide Time: 10:35)



Permissible values as per IS: 1904-1978

Footing type	Sand and hard clay			Plastic clay		
	Max. Settlement	Differential Settlement	Angular Distortion	Max. Settlement	Differential Settlement	Angular Distortion
1. Isolated footing						
1.1 Steel Structure	50 mm	0.0033L	1/300	50 mm	0.0033L	1/300
1.2 RCC Structure	50 mm	0.0015L	1/666	75 mm	0.0015L	1/666
2. Raft foundation						
2.1 Steel Structure	75 mm	0.0033L	1/300	100 mm	0.0033L	1/3
2.2 RCC structure	75 mm	0.002L	1/500	100 mm	0.002L	[illegible]

* L is the length of deflected part of wall/raft or c/c distance between columns. F.O.S= 2.5 to 3

So, as I have discussed that when you are designing a new foundation, so, now we should know what are the permissible criteria to design a foundation. So, I am discussing only the IS code recommendations because now I will design a foundation on clay as well as the sand. So, now here these are the IS 1904-1978 is given the permissible value of settlement for the design of shallow foundation. So, these are the 3 things; the maximum settlement, differential settlement, and angular distortions.

So, one is for sand and hard clay, another is for plastic clay. For isolated footing if it is a steel structure, then this is the maximum permissible settlement value. If it is the RCC structure, then this is the maximum permissible value. For raft foundation, this is the permissible and this is the raft foundation for RCC structure. So, the isolated footing on sand or hard clay it is

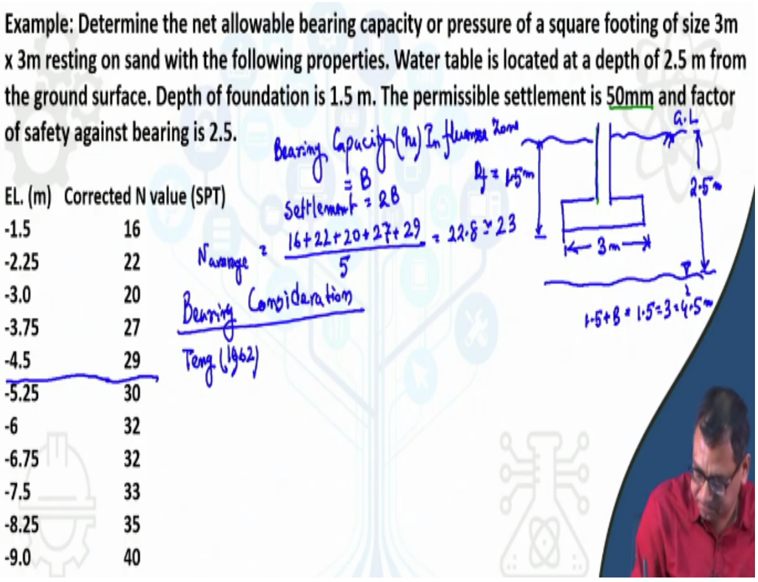
50 millimetres and isolated footing on sorry raft foundation on sand and hard clay 75 millimetres. By isolated footing on plastic clay, then this value is RCC 75 millimetres and for the raft it is 100 millimetres.

So, that means, this is the maximum one. That means the raft foundation on plastic clay is 100 millimetre maximum permissible I can go and this is the lowest for isolated footing on sand or isolated footing on clay, but RCC structure is 50 millimetres, but these are the other criteria also that you have to follow, but generally, the design problem that I will solve, I will check only the maximum settlement. We assume that the soil foundation or the building will be deformed uniformly, but there may be some possibility that one column is taking more load compared to the other column.

Then you check the settlement for individual column and then determine the differential settlement. If differential settlement is not within this limit, then you redesign your foundation, because here I am not designing a total building, I am designing a particular one column or one foundation, and if I am designing the raft, then also I will concentrate only the maximum settlement. We are assuming that other two settlements are within permissible limit, but if they are not within permissible limit, then also you have to redesign the foundation.

So, that means, you have to check individually all the column settlement, then check the differential settlement or the angular distortion is within permissible limit or not. Here, I will discuss only the maximum settlement and assuming that all the other two criteria are satisfied okay.

(Refer Slide Time: 13:55)



So, first example problem for the design part. So, determine the net allowable bearing pressure or pressure of a square footing of size 3 meter cross 3 meter resting on sand with following properties. The water table is located at a depth of 2.5 meter from the ground surface. Depth of foundation is 1.5 meter. The permissible settlement is 50 mm okay. The permissible settlement is 50 mm because as I have discussed that for the isolated footing, this is isolated footing on sand and we are assuming it is the RCC structure.

Then your permissible settlement will be 50 mm and the factor of safety against bearing is 2.5. So we will check both in terms of bearing, in terms of settlement also okay, and then we will provide what will be the safe bearing capacity or the allowable bearing capacity of the foundation okay. So here the size of the foundation is given and we are calculating the SBC safe bearing capacity, but it can be reverse also okay. That means you have the SBC, then what would be the dimension of the foundation, but remember that that your SBC is also function of the dimension of the foundation.

Because if it is a granular soil, definitely your bearing capacity is the function of your dimension of the foundation. So, that means generally either we have the soil property, and based on that we determine the dimension or we have the dimensions, based on that we determine the safe bearing capacity. So, here the dimension is given or and then what would be the safe bearing capacity that we will calculate. So, first suppose if we calculate the foundation.

So this is I am using say different colour, so this is the foundation okay and this is ground level and your depth of foundation is given 1.5 meter. So, this is 1.5 meter, depth of foundation Df or D is equal to 1.5 meter. Now, width of foundation, it is a square footing is 3 meter okay and water table location is 2.5 meter. So, suppose this is the water table location which is 2.5 meter below the ground. So, this is the problem and these are the corrected N value. So, as I mentioned for granular soil, we will use the field test data, and for the cohesive soil we will use the lab test data.

So, here we are designing the foundation on sand, that is why we are using the N value or the field test data also, but if you have the phi value also, friction value or the other parameters, then also you can use the available bearing capacity expressions to determine the bearing capacity of the shallow foundation on sand, but here we have these data available that is why we use this data for the design. So the N value is given at different depth, so minus 1 means it is at the downward direction, minus 1.5 meter is 16, 3 meter is 20, 6 meter is 32, up to 9 meter it is 40.

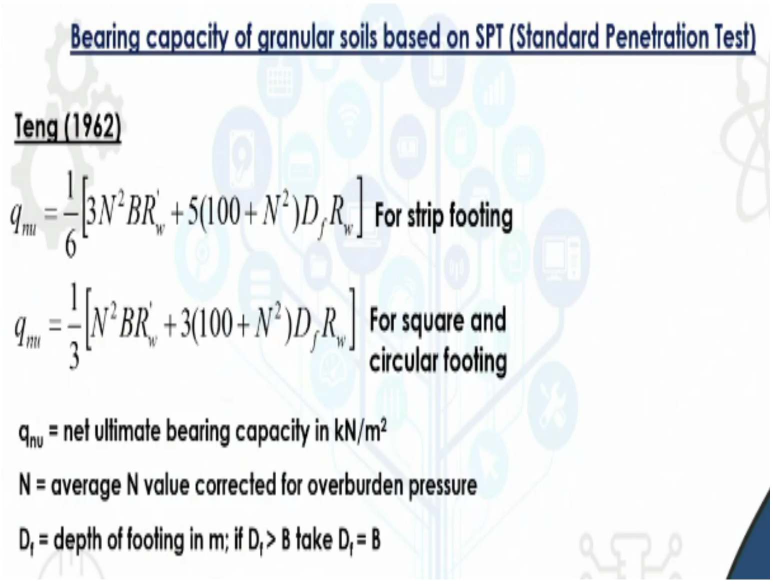
Remember that that the influence zone, what would be the influence zone, up to which depth we will consider the N value for a design. So, remember that generally for the bearing capacity calculation or ultimate bearing capacity calculation, the influence zone for the bearing is equal to B okay and for the settlement the influence zone is equal to 2B okay. So when you calculate the ultimate bearing capacity are safe bearing capacity, the influence zone is B, B means the width of the foundation and for the settlement calculation, influence zone is twice B, generally varies from 1.5 to 2.

So, I recommend you to consider the 2B. So, remember that these are the very important information that for the bearing capacity calculation, your influence zone, that means the zone up to which your foundation load will influence the soil is B and for the settlement calculation it is twice B. So, first we will calculate in terms of bearing. So, for the bearing it is B, so that the first your influence zone is 3 meter from the base of the foundation. So, our base of the foundation is here okay, 1.5 meter and the influence zone is 1.5 meter.

So influence zone will be 1.5 meter plus B. So, that is equal to 1.5 meter plus 3, so that is equal to 4.5 meter okay. So it will go up to here, so 4.5 meter means up to here okay. So this is point 0.5 to 4.5. Remember that the B is not from the ground level, it is from the base of the foundation. So, I will take the average N value, so average N value N average, what will be the average N value? So, average N value will be $\frac{=(16+22+20+27+29)}{5}$, so there is 5 N values which I am taking, so average this is of 5.

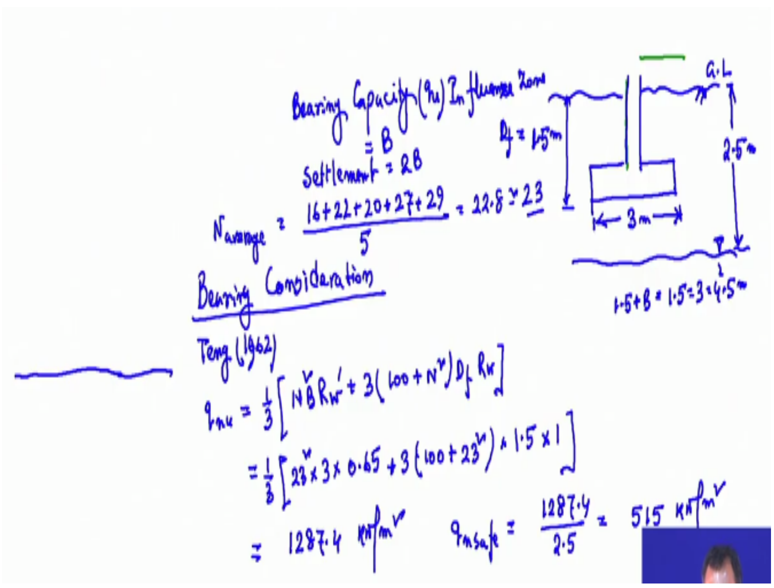
So this value is 22.8 or roughly 23. So N corrected value for the bearing capacity calculation that is 23 because it is up to the B. Now the bearing consideration, so I have given you the Teng expression okay 1962. So that Teng expression I have given I can show you that expression again okay.

(Refer Slide Time: 21:55)



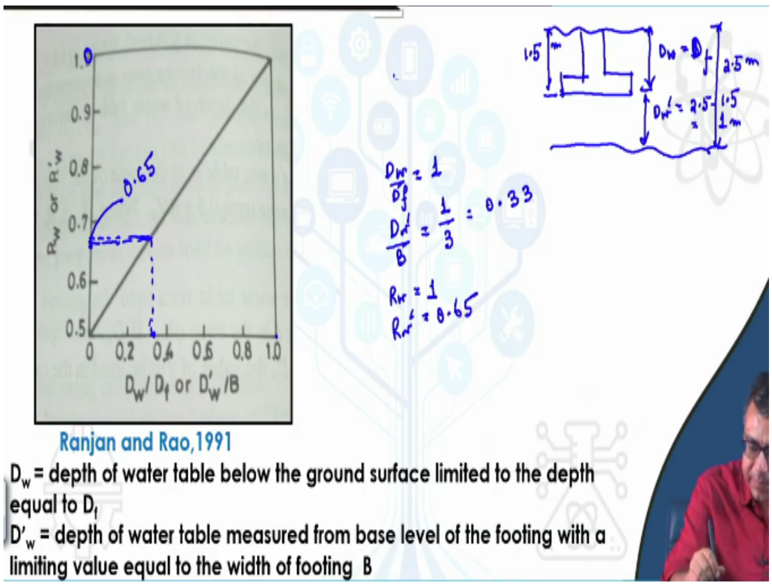
So, I can show you this is the Teng expression that I have given. So, remember that this is the expression that was given and then this is for the square and circular footing, this is for strip footing. So, but our case it is a square footing, so we will use this expression, the second one okay. So, here I will get the net ultimate bearing capacity. So, that means, first we write these two expressions, then we will go for the next part.

(Refer Slide Time: 22:27)



So, this is the bearing capacity expression that I am giving that for $qnu = \frac{1}{3}(N^2BR_w^/ + 3(100 + N^2)D_fR_w)$. Now here N average is 23. Now, we have to calculate the R/w and Rw. Now how we will calculate these two things?

(Refer Slide Time: 23:19)



So we will get these two things from this curve. So, what is your Rw part. This is the foundation. So your Dw is the depth of water table below the ground surface limited to depth equal to Df okay. So here it is written that your Dw is here equal to B because water table is here okay, so that is 2.5 meter, so your Dw is limited to Df okay. So, this is Df and D/w, D/w dash is this one and here it is 1.5 meter and this is 2 meter. So, your D/w dash is equal to 2.5 minus 1.5.

So, that is equal to 1 meter. So, $D'w$ is 1 meter and Dw is equal to Df let us consider because it is below the base of the foundation. So, form these expression that Dw by Df is equal to 1 here and $D'w$ by B is equal to here it is 1 meter plus B is 3 meter. So, this value is one-third means say 0.33, okay. Now if corresponding your; this value is 1. So that means if Dw by Df is 1, so that means the correction factor is Rw, will be 1 because this is 1, this will be also be 1, but if your Dw dash B is 0.33 which will be, this is 0.3, it will be around here okay.

This is 0.33. So, if I so get this value is from the curve, from the point so this is more or less here. So, this is 0.33. So this value is coming out 0.65 from the chart. So your Rw dash will be 0.65. So I am getting Rw is 1 and Rw dash is 0.65 for this case okay. Now, I am going back to the bearing capacity equation, the Teng equation okay. So this Teng question is given., I am putting those values quickly. $qnu = \frac{1}{3}(23^2 \times 3 \times 0.65 + 3(100 + 23^2)1.5 \times 1)$

So, I will get our net ultimate is 1287.4 kilo newton per meter square. So, this is the net ultimate. So q net safe is equal to, you have to divide it by factor of safety that is given here 2.5. So, 2.5 is the factor of safety, this is 515 kilo newton per meter square okay. So in terms of bearing capacity criteria or bearing consideration, your net safe bearing capacity is 515 kilo newton per meter square okay.

So, in the next class, I will discuss that how I will consider the settlement criteria also and then I will consider the allowable bearing capacity criteria and we will determine the safe load carrying capacity or allowable load carrying capacity of the soil or SBC. Thank you.