Advanced Foundation Engineering
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Lecture - 37
Design of Shallow Foundation - II

So, last class I was discussing that how we can use the plate load test data to determine the settlement or allowable bearing capacity of real foundation. Now, as discussing about how we can use the plate load test data for two different plate sizes and then we can determine the dimension of the foundation.

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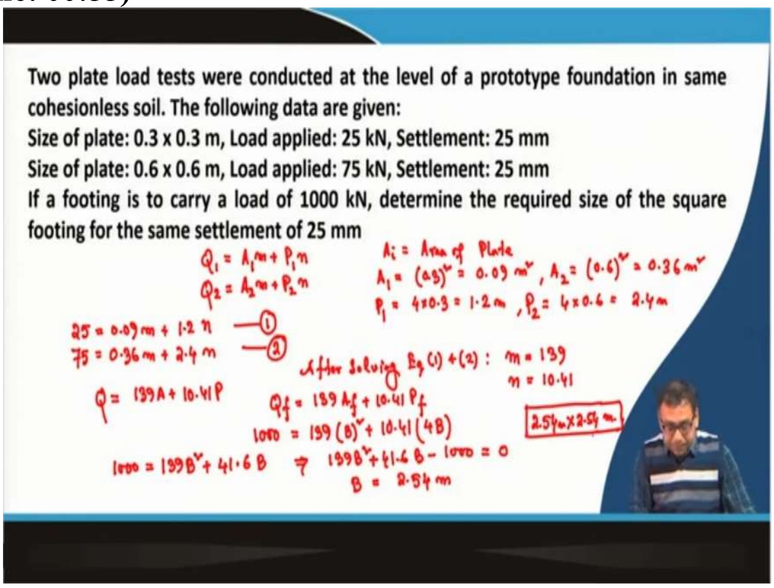

So, this is the problem. So, where the smaller plate of size 30 cm × 30 cm giving 25 mm settlement under 25 kN load and the largest size plate of 60 cm × 60 cm giving 25 mm settlement under 75 kN load. So, what would be the dimension of a square plate, a square foundation to get 25 mm settlement under 1000 kN load.

So, now for this particular case, we have to express this total load in this way. That is the $A_i m + P_i n$. Where m and n are the two constants and the A_i is the area of plate and P_i is the perim of the plate. So, now for this particular case there will be a Q_2, second plate also that will be $A_2 m + P_2 n$. So, now A_1 is the area of the first plate, so that will be 0.3^2. So, this will be 0.09 m^2 and the perim P_1 for the first plate will be 4 × 0.3.

So, this will 1.2 m that is the perim of this square plate, A_2 is the area of the second plate 0.6^2 that is 0.36 m^2. So, the perim of the plate 2 will be 4 × 0.6 that is 2.4 m. So, I can write two equations. So, in the first case our applied load is 25 kN that is Q_1. So, Q_1 is $0.09m + 1.2n$. So, this is equation 1 and the second equation is $75 = 0.36m + 2.4n$.

Now if I solve these 2 equations, I will get, $m = 139$ and $n = 10.41$. Suppose you have a data of say three plate load tests then also use you will get the three equations, equation 1, 2 and the third one, 3, but your unknown is 2, it is m and n. So, in such case you have to take the 2 equations separately, for example you solve equation 1 and 2 then you will get one set of m and n values. Then you solve equation number 1 and 3.

Then you will get another set of m and n values. Then you solve equation 2 and 3 then you will get another m and n values. So that means you will get 3 sets of m and n values in that case. So, you take the average of that m and n values and that average will be your actual m and n values. But here are the two plate load test data are given. So that is why we are using only two equations and two unknowns. So, one set of values we are getting and that is 139 and 10.41.

So, the general equation is $Q = 139A + 10.41P$. So, it is a square plate now, this general equation we have to use for the square footing whose dimension we want to determine. So that dimension is a square we say it will be the $B \times B$. So, we can write that this equation as $Q_f = 139A_f + 10.41P_f$. So, the Q_f is 1000 kN because we have to use the same settlement.

So, corresponding to same settlement you have to compare all the cases. So that settlement is same Q is 1000 kN, so, this will be 139 and your area of the foundation is $B^2 + 10.41 \times 4B$ remember that. We are comparing this 1000 directly because we are taking the same settlement. So, we have to compare it for the same settlement value, footing and the plate.

So, now, finally we can write that $1000 = 139B^2 + 10.41 \times 4B$ or you can write $139B^2 + 41.6B - 1000 = 0$ and after solving this equation, we will get $B = 2.54$ m. So, the dimension of the foundation will be 2.54 m × 2.54 m. So, the dimension of the foundation will be 2.54 m × 2.54 m. So, this is the minimum dimension that is required for this particular foundation to get 25 mm settlement under 1000 kN load. So, now in this way also you can determine the dimension of the foundation by using plate load test data.

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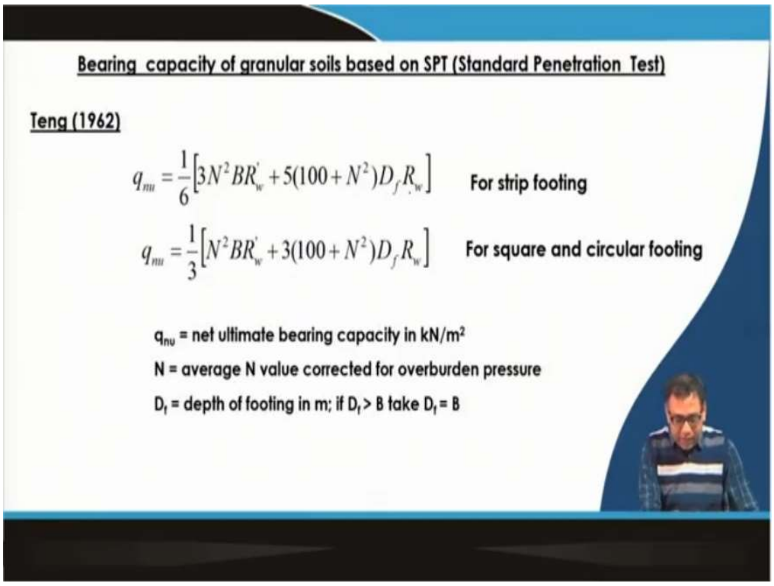

So, next one that I will discuss that how you will use the SPT value or Standard Penetration Test value to determine the bearing capacity and then finally determine the dimension of the foundation. So, Teng (1962), proposed empirical equation by which we can determine the net ultimate bearing capacity for strip footing, square and circular footing by using these two equations. So, the first equation is for strip footing and the second equation is for square and the circular footing.

So, these are empirical equations where D_f is the depth of foundation and R_w and R_w' are the correction factors due to water table. So that I will discuss how you will determine the R_w' and R_w. N is the average N value corrected for overburden pressure. So, what is the average N value? That I will also discuss. And if the depth of foundation is greater than B, you consider depth of foundation is equal to B. So, these are the two equations.

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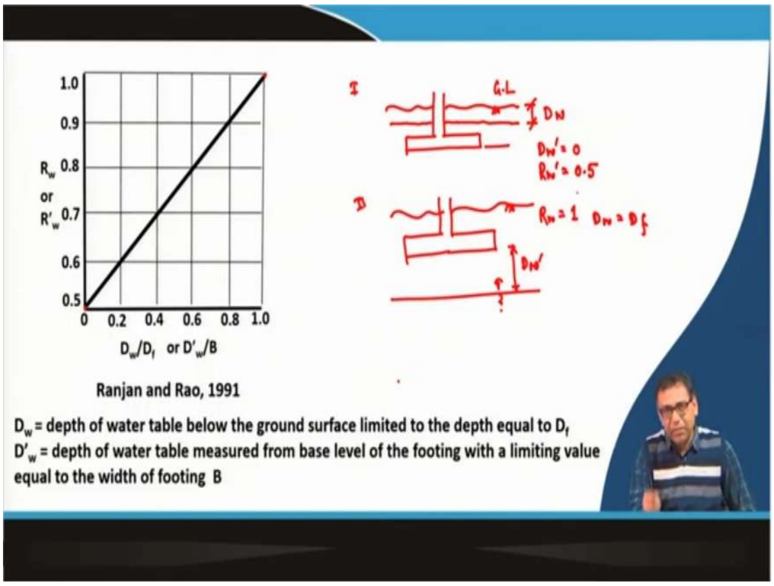

Now how I will calculate the R_w and R'_w? So, what are R'_w and R_w? So, by using this chart we can determine the R'_w and R_w. So, here suppose we have the foundation this is the base of foundation, this is the ground level. So, now these are the two cases, the first case where water table position is here. So that means this distance, the position of the water table from the surface is called D_w and in the second case this is ground surface and this is the position of the water table which is below the base of the foundation.

So, in case 1, water table is above the base of foundation, in case 2 it is below the depth of foundation. So, this is the water table position, now here this is D'_w. So, in your first case D_w has a certain value and $D'_w = 0$. For your second case, D'_w has a starting value but the $D_w = D_f$ if water table is not present. So, this value or this correction factor will be, this correct correction factor $R_w = 1$ because in this case you can consider that $D_w = D_f$.

Because $D_w = D_f$, that means water table is at the depth of the foundation. So, in first case we can consider D_w has a certain value and in that case $D'_w = 0$ that means, here you can consider D'_w at the base of the foundation. So that means because water table is above the base of the foundation. So, in the first case D_w has a certain value, $D'_w = 0$. In second case $D_w = D_f$, depth of foundation and D'_w has certain value or you can consider in second case, $R_w = 1$.

So, now here $\frac{D_w}{D_f}$ and $\frac{D'_w}{B}$ are given. So, the R_w is corresponding to $\frac{D_w}{D_f}$ and R'_w is corresponding to $\frac{D'_w}{B}$. So, this way we can calculate the correction factors R_w and R'_w. So, these two values will be determined based on the position of your water table. So, you can see in the second case always the $R_w = 1$ because see I consider $D_w = D_f$, so, this value will be 1, so, 1 corresponding to correction factor is 1 and because 1 because here water table is below the base of the foundation.

And so, in your first case that R_w' is always 0.5 because it is above the base of the foundation, so, R_w' you can see if I consider $D_w = 0$, so, this is 0, this is 0.5, so, 0 corresponding to correction factor is 0.5, this is 1 and corresponding correction factor is 1. So that means for the first case R_w' is 0.5 and R_w we have to determine and second case R_w is 1 and R_w' we have to determine.

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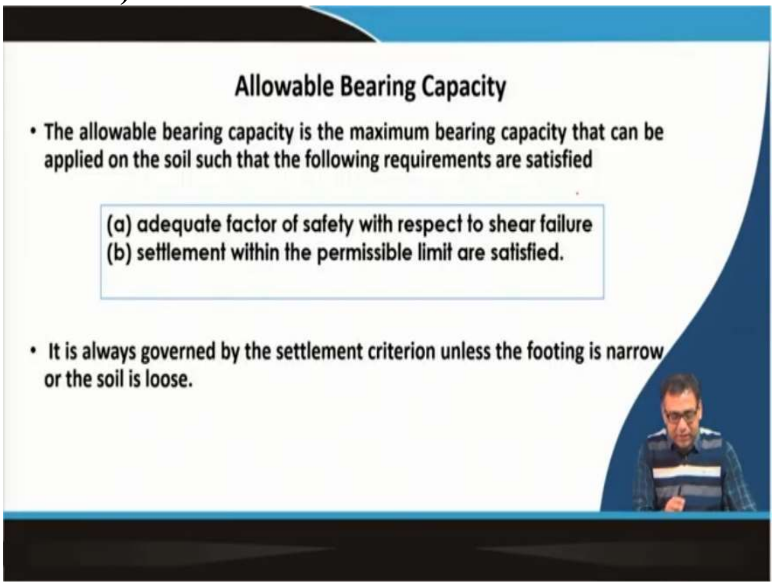

Now the next one that this bearing capacity equation or this SPT value, here we are getting the net ultimate bearing capacity that means it is in terms of bearing capacity only. Now empirical correlations are also given considering the settlement as well as the bearing capacity consideration. That means your settlement is within the permissible limit and there is an adequate factor of safety with respect to your shear failure.

So, considering that settlement effect also because the initial correlation is given considering the bearing capacity, but if we consider both then that will be the allowable bearing capacity.

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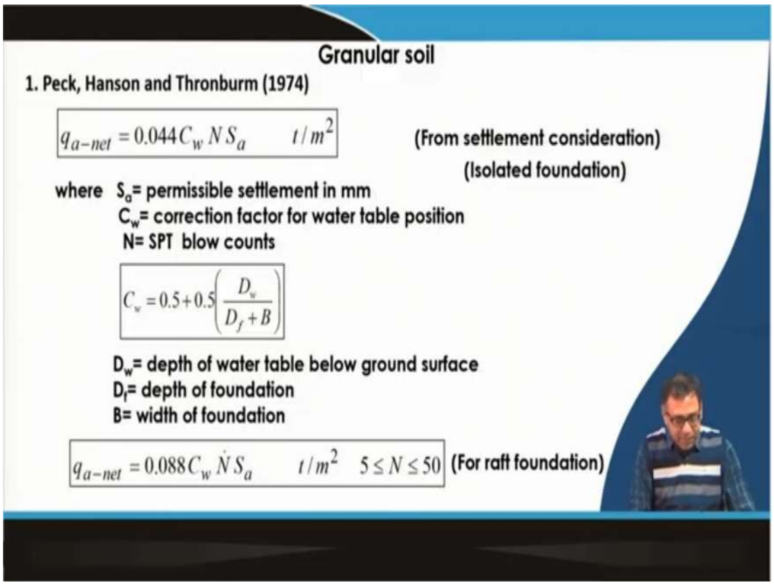

So that allowable bearing capacity also can be determined based on the SPT value, so, if you know the SPT value, so, if I use these two correlations, so, this is proposed by Peck, Hanson and Thornburn (1974). So, this is the first correlation which is suitable for isolated foundation and second correlation is suitable for raft foundation and remember that these correlations are valid if your *N* is within 5 and 50.

And this is the empirical correction so unit is very important you can see the unit is t/m^2, but your settlement is in mm, remember that. And you have to apply again water table corrections and remember that D_w is depth of water table below ground surface. Here it is not at the base of the foundation, it is below ground surface. And then this *N* is your corrected SPT value and this is the net allowable bearing capacity of the foundation we can determine.

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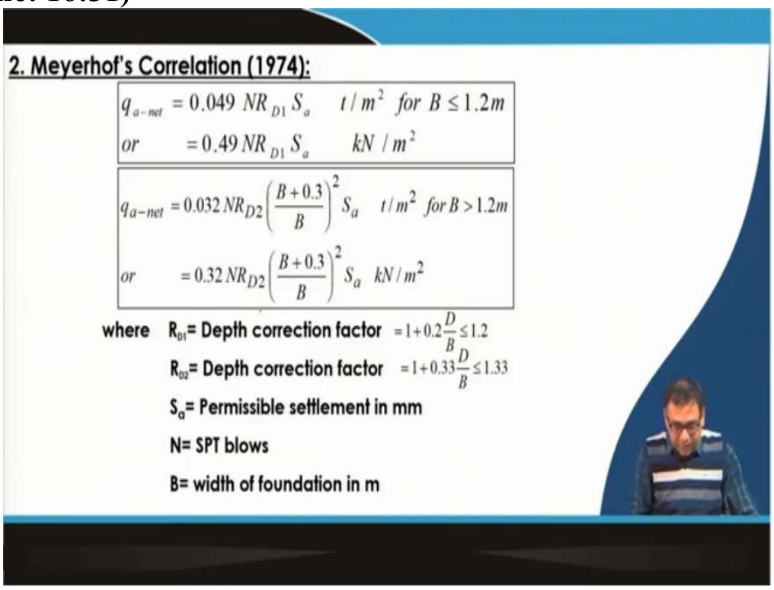

Similarly, Meyerhof also, given us some correlations by which we can determine the net allowable bearing capacity. So, this is the correlation which is given in terms of t/m^2 in terms of kN/m^2 also. So, again the settlement is in mm, so, this $R_{D1}$and R_{D2} are the depth correction factors, which are given.

So, R_{D1} is applicable if your width of foundation is ≤ 1.2 m and if the width of foundation is > 1.2 m then that will be R_{D2}. So, these two corrections we will get so, the corrections are given and then permissible settlement and width of the foundation.

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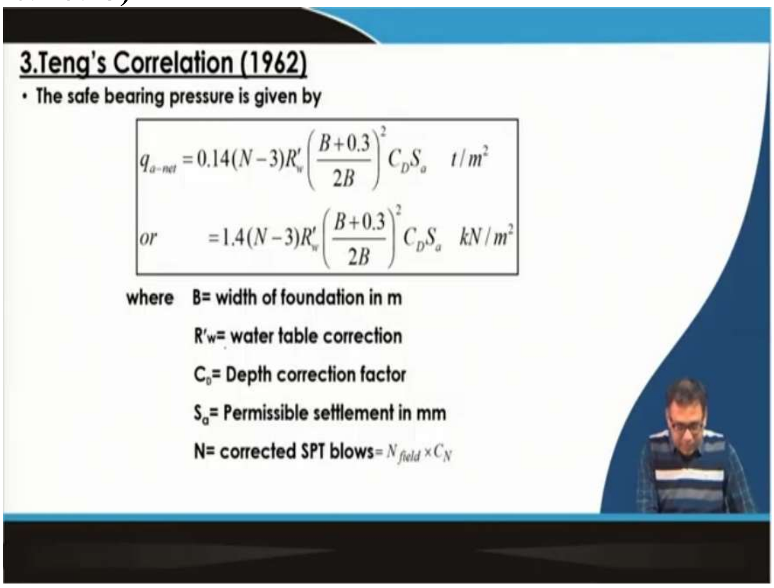

So, this correlation we can use then. Teng's correlations also you can use, so these correlations also here R'_w is given, R'_w is the water table correction and N is the corrected SPT value that field N × the correction factor which we have to apply. But here most of the cases the corrected N value is given in the problems. So, this S_a is the permissible settlement which is in mm, C_D is the depth correction factor and this R_w is the water table correction factor.

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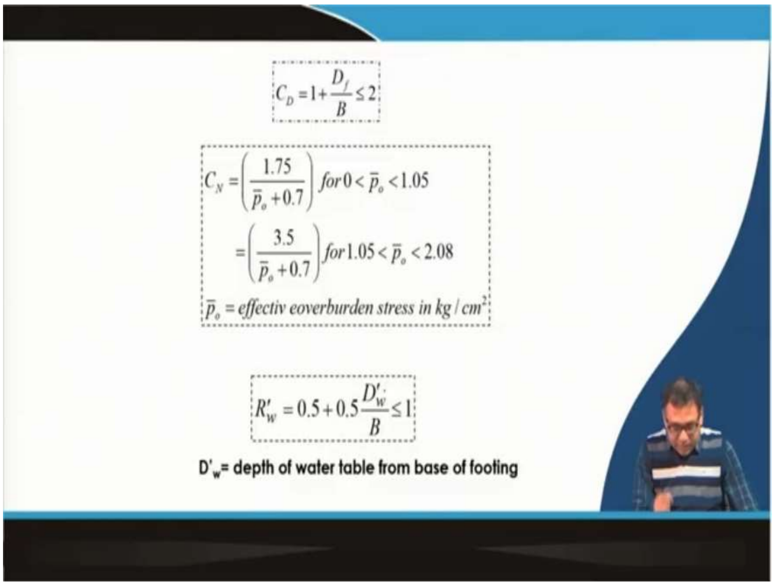

So now, how we will calculate the C_D? C_D will be calculate by using this equation and C_N correction is given. Suppose if your uncorrected or field *N* value is given then how we can correct the *N* value, so that C_N correction factor you have to apply, so this is N_{field} means the measure *N* value and the C_N is the correction factor. So that correction factor you can determine by using these correlations.

So, this $\bar{p}_0$is the effective overburden pressure and again these are empirical relationships. Remember that, this unit is very important so this stress is in kg/cm^2. So, if $\bar{p}_0$ is within these limits then you use these expressions and if it within these limits then you use this expression, to determine the C_N. And another case, if the corrected SPT value is given then you can use them directly.

If the field *N* value is given then you have to apply the correction factor C_N by using these equations. So, this is correction factor basically for overburden pressure. As I mentioned during my SPT discussion that in some cases the corrections are done by using only the overburden, in some cases the corrections are done by using all other correction factors.

Because correlations are given only for corrections by overburdened pressure or by using all the corrections factor. But this case this correction is based on overburden pressure. So, an R_w' is the depth of water table form the base of the foundation. So, here this is R_w', so, remember that different way these water table corrections are incorporated.

Most of the cases the two types, one way is water table is considered from the base of the foundation, another way water table is considered from the surface of the footing or ground surface, surface of the soil or the ground surface. So, you remember that which or you have to use the proper correction factors recommended by the different theories. So, here the D_w' is depth the water table from the base of the footing.

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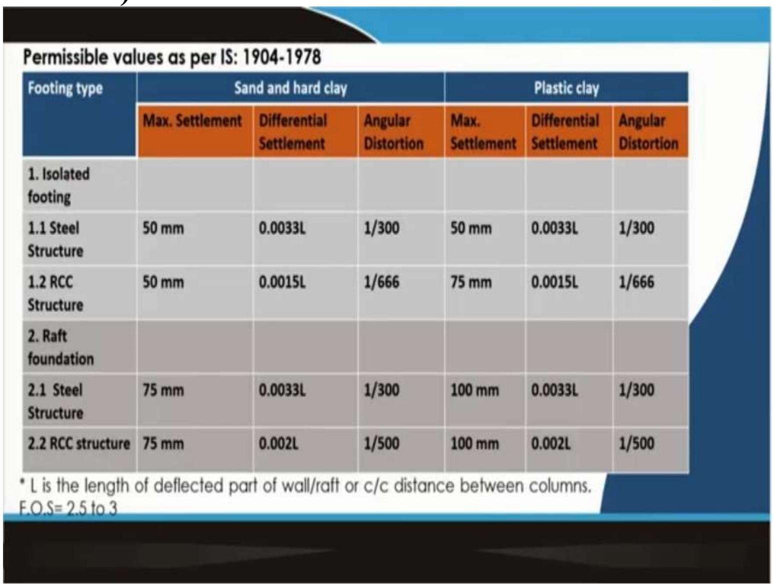

Permissible values as per IS: 1904-1978

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	1/300
2.2 RCC structure	75 mm	0.002L	1/500	100 mm	0.002L	1/500

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

So, now when you are talking about the permissible values of settlement then here, as per the IS code that for different foundation on different types of soil, this permissible settlement values are given. So, this is the chart for the permissible settlement value that is for isolated footing whether it is steel structure or RCC structure the permissible settlement on sand or hard clay is 50 mm and for raft foundation is 75 mm.

Whereas, for plastic clay this is for isolated footing it is steel structure is 50 mm and RCC structure is 75 mm and for steel structure and RCC structure, for raft foundation on plastic clay is 100 mm. Similarly, you have to check the differential settlement and angular distortion also, those limits are also given. So, as I mentioned in most of the cases in our design problems that we will solve, I will discuss the maximum settlement only.

And we will assume the differential settlement is within the permissible limit or angular distortion is also within the permissible limits as I mentioned. So, there are three types of displacement checks we have to do as in my previous lecture also have discussed that is the maximum settlement, differential settlement and the distortion.

And the difference between the differential settlement and angular distortion, in differential settlement suppose two particular footings will deform in by different amount and in the angular distortion the total structure will deform in such a way that it will tilt. So that these things we have to also check. But here if your soil type is different for your different foundation or the loading amount on different foundation is significantly different then we have to also check the differential settlement and angular distortion.

But in this case, we will assume that all the problems or soil params are more or less same or there is not significant difference of the loading amount and the soil params, so, we will check only the maximum settlement. But remember that not only the maximum settlement check is sufficient, but most of the case this is the major check, but if the soil param is different or the loading amount is different on different columns or foundation then you have to check the other two settlements which are the differential settlement and the angular distortion.

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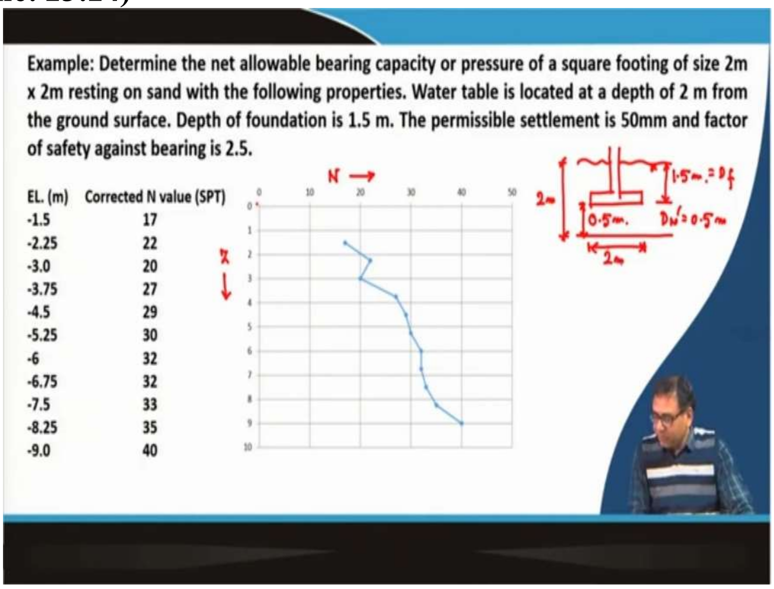

So, now, we have the second another example problem. So that example problem is based on the SPT value that I have already discussed. So, determining the net allowable bearing capacity or pressure of a square footing of size 2 m × 2 m resting on sand with the following properties. So that means, how much allowable bearing capacity pressure we can apply on a foundation of 2 m × 2 m square, resting on the stand whose SPT values are given.

So, water table is located at the depth of 2 m from the ground surface, the depth of foundation is 1.5 m, the permissible settlement is 50 mm and factor of safety against bearing capacity is 2.5. So that means, in this problem we have to determine the allowable bearing capacity, so, you have to consider the bearing capacity as well as the settlement, both the cases you have to consider.

So, we will get the allowable bearing capacity. And so that means, we have to use the correlations that I have discussed in few correlations, it is only bearing capacity will give and few correlations will give directly the allowable bearing capacity where the settlement and the bearing, both the things are considered. So, now, we will discuss or we will consider one by one all the bearing capacity equations or the correlations.

So that means this is the chart or the SPT vs. depth. So, this is my corrected SPT value. So, this is the N value and this is the depth or Z. Z is the elevation of the depth from 0 to 10 m. Here the SPT values are given, 0.75 m interval, this is 1.5 SPT value is 17 and to 9 SPT value is 40. So, in this chart this inverse is depth plot here. So, this is the variation of the SPT value with depth.

Now, we have to determine the allowable bearing capacity for this particular footing dimension. In one way also we can, if we have the allowable bearing capacity then we can determine the dimension of the foundation. But this allowable bearing capacity is determined under different dimension of the footings. So that dimension is given 2 m × 2 m. So, now we have to determine the allowable bearing capacity of the foundation.

Now, here suppose we have that foundation, whose depth is 1.5 m, water table position is 2 m from the ground surface that means, from the base of the foundation is 0.5 m. So, our D'_w is 0.5 m, D'_w is the depth of the water table from the base of the foundation and D_f is 1.5 m and width of the foundation B is 2 m.

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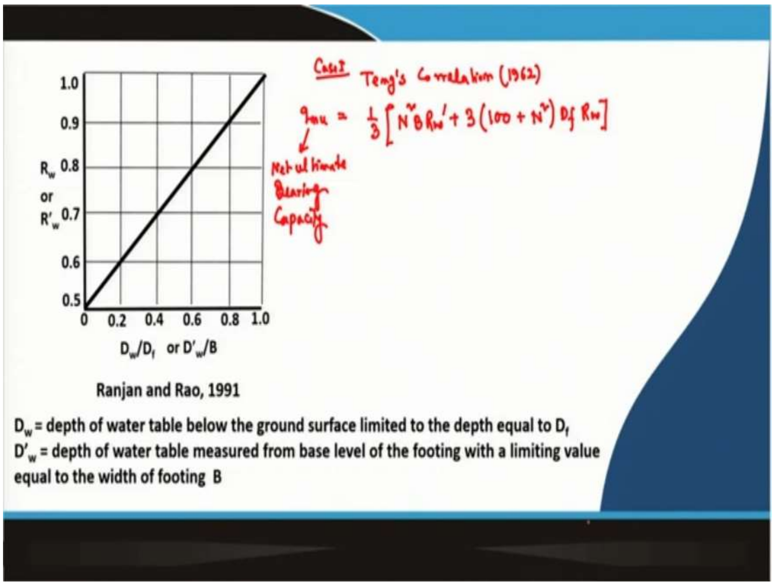

So, first correlations that will use is Teng's correlations. So, first correlation that is my case 1 that we will consider Teng's correlations, 1962 and this is for square footing. So, as for the Teng's correlation net ultimate bearing capacity is $\frac{1}{3}\left[N^2BR_w' + 3(100+N^2)D_fR_w\right]$. So, this is the correlation that we have to use. So, this *N* value you have to determine. So, as I mentioned during that Teng's correlation this *N* is the average *N* value.

So, how will determine the average *N* value? And how we will determine the R_w' and R_w that I will discuss in the next class and then I will also discuss the other correlations where we can directly calculate the allowable bearing capacity. Here we are getting the net ultimate bearing capacity. The bearing capacity means you have to apply the factor of safety and allowable bearing capacity is in terms of permissible settlement. So, factor of safety is not required. So, those things will be discussed in the next class.