Advanced Foundation Engineering
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Lecture-09
Shallow Foundation: Bearing Capacity III

So, during my last lecture I have discussed about Meyerhof's equation, then Hansen's and Vesic's bearing capacity equations. And then for eccentric loading what are the conditions as per different theories, those are also discussed. Now today's class I will first discuss about the IS code recommendation then I will solve few example problems.

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So, like previous different bearing capacity theories IS code also as recommended.

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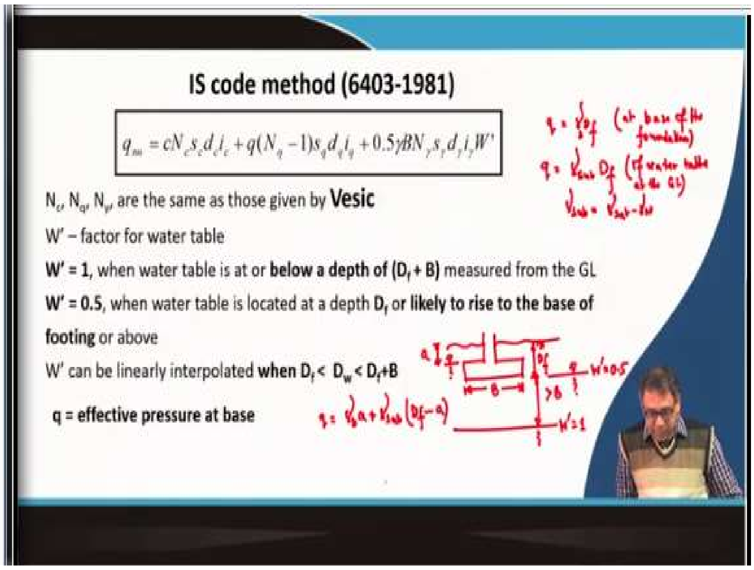

Bearing capacity equation by which we can determine the net ultimate bearing capacity. So, this is the equation which is similar to the general equation that we have discussed. Here also s_c, d_c, i_c that means the shape factor, depth factor, inclination factor those are proposed. And the N_c, N_q, N_γ values are similar to the values proposed by Vesic, we have to use.

So, Vesic's table we have to use for N_γ calculation and N_c and N_q are similar to Meyerhof's bearing capacity factor. So, and then there is a term W here, water table effect is also incorporated into the equation but in previous equations the water table effect we have to incorporate by using the equation those I have given or I have explained during Terzaghi's bearing capacity equation.

So, I have already discussed Terzaghi's bearing capacity equation and then I have also discussed that how we can incorporate the water table effect in that equation. The same way the water table effect can be incorporated to other bearing capacity theories also. So, that means in Meyerhof, Hansen, Vesic, we can incorporate the similar way the water table effect into those theories.

But the IS code has given directly a water table effect in its equation, so as per IS code we have to use that. Remember that in other bearing capacity equations the net ultimate bearing capacity is given, ultimate - γD_f. But here that γD_f part actually, so we know that here q or q_0 is γD_f. So, here that part is incorporated here, so that means you can see that this q is γD_f.

So, that means we have to subtract that γD_f to calculate the net ultimate bearing capacity. But again you can see that all these s_q, d_q, i_q terms are also included into that subtraction. So, that is the difference. Because for other cases we first calculate the ultimate bearing capacity and then we subtract γD_f to get the net ultimate bearing capacity.

But in IS code directly we will get the net ultimate bearing capacity by using this equation and where water table effect is also incorporated. But in other equations water table effect also we can incorporate by using the equation or the procedure that I have discussed in my previous lectures. So, where the water table effect is there, so water table effect W' value is 1, when water table is located at a depth greater than equal to width below the base of the footing.

So, that means it is same as the previous water table effect that if the water table is below the depth which is equal to the width of the foundation from the base of the footing, then no water table effect will be there. So, for example that if this is my foundation. Now this is the B and if water table is here and this depth is greater than B, then water table effect will not be considered.

But even if it is equal to 1, then the W' value will be 1, so that means basically there is no water table effect, 1 means no reduction, nothing. So, that means water table will play a role in the bearing capacity equation, if this position of the water table is within a depth equal to the width of the footing below the base of the footing. So, that means if it is within this zone and above base of the foundation and above the foundation then the water table will play a role.

Now W' is 0.5 when water table is located at a depth D_f or likely to rise to the base of the footing or above. So, that means here it is mentioned as per IS code that if water table is at the base of the footing, then W' will be 0.5 and here $W' = 1$. So, that means if water table position is within ground surface and base of the footing, then the W' value will be 0.5 as for this recommendation.

So, that means if this water table is at the base of the foundation or above then the W' value is 0.5. That means if the water table is at the surface that is also 0.5, and if the water table at the base of the footing then also 0.5. And we can linearly interpolate the value of W' in between these two bases and at a distance of B below the base of the foundation, we can linearly interpolate, q is the effective pressure at the base.

Remember that when we use the q definitely it is effective, because in other case we incorporate the water table effect, here it is given. So, that means here W' is applied at the third term but the second term also we have to apply the water table effect. So, that means suppose if your water table is at the base of the foundation then your q will be simply $\gamma_{bulk} \times D_f$, γ_{bulk} means unit weight above the water table.

But if your water table is at the surface then q will be $\gamma_{sub} \times D_f$. So, if water table is at the ground level then this is $\gamma_{sub} = \gamma_{sat} - \gamma_w$, γ_w is the unit weight of the water. If it is at the base of the foundation then this will be γ_{bulk}, so γ_{sat} is the saturated unit weight, γ_{sub} is the submerged unit weight.

So, that we have to use for soil below the water table and γ_{bulk} is the bulk unit weight that we have to use for soil above water table. So, now if the water table is in between that, so suppose your water table is here. So, as per our IS recommendation if water table is within the base and the ground surface then W' will be always 0.5. But q value will be here, so suppose this distance is say a, and this is γD_f and then in such case your q will be $\gamma_{bulk} \times a + \gamma_{sub} \times (D_f - a)$, clear.

Because we have to consider the effective pressure at the base. So, that means what is the effective pressure? We have to consider effective overburden pressure at the base of the footing and that will be always effective. And this is the way we can incorporate the water table effect in both the terms, the first term as well as the second terms as well as the third term also.

But in other theories you can use the procedure that I have discussed which is also similar to this type, which is a slight variation. But in similar way also you can include the water table effect in the bearing capacity equation as I have discussed during Terzaghi's bearing capacity equation.

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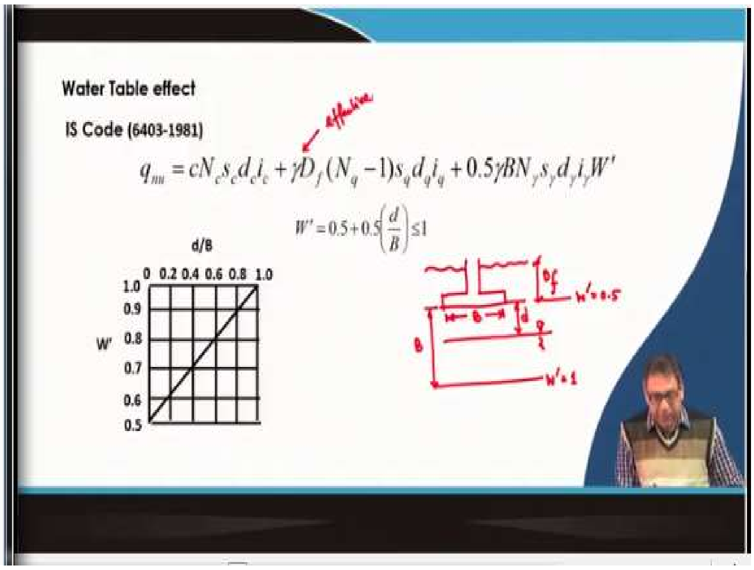

So, now as I mentioned we have to linearly interpolate the value if the water table is from the base to a depth of *B*, then we have to linearly interpolate from 1 to 0.5. So, or we can use this chart also, so suppose if what is the *d*, so this is your foundation, this is the base, this is the depth of foundation and say suppose this is the distance *B*, width of the foundation is *B*.

And water table position is say, that depth is *d* from the base of the foundation. So, now if $\frac{d}{B} = 1$, that means $d = B$ that means your water table is at a depth of *B* from the base of the foundation, then definitely W' will be 1. Because we know $W' = 1$ here and at this position $W' = 0.5$. Now if $d = 0$, that means water table is at the base of the foundation, then the W' value will be 0.5.

In between that we can use this chart, so that means $\frac{d}{B}$ will vary from 0 to 1, so this will vary from 0 to 1. Then for 0 it is 0.5, for 1 it is 1, so in between that we can use this chart or you can linearly interpolate the value also. So, you can use this chart also to calculate the W'. And then other factors you will get for bearing capacity factor same as Vesic and γD_f as I mentioned is always effective.

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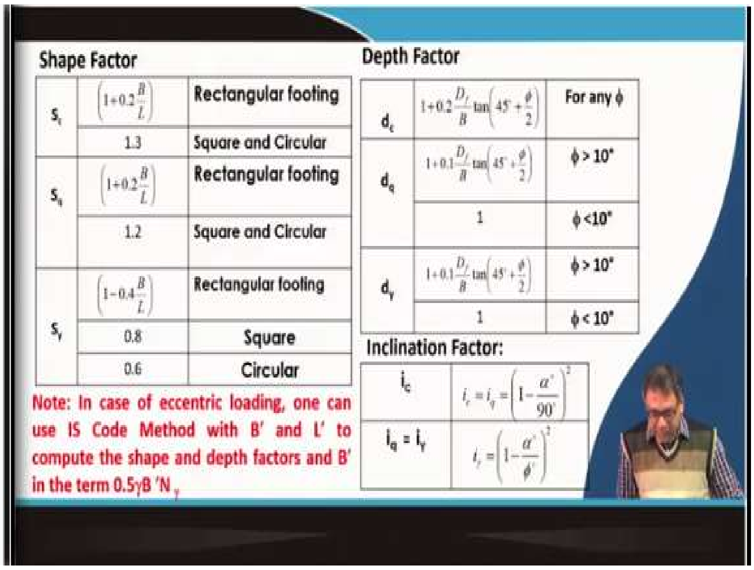

For the shape factor, depth factor, inclination factor you will use these charts. The shape factor you will use for rectangular footing, square and circular footing, rectangular for square footing s_q and s_γ also you will get from this table. Depth factor also I will get from this table for any ϕ, if $\phi \geq 10°$ for this equation.

And the d_c is varied for any ϕ and d_q if $\phi < 10°$, then it is taken as a 1. And for d_γ also if less than 10° taken as a 1, if $\phi > 10°$ then this equation we can use. For inclination factor also I can use these equations. So, you will get the shape factor, depth factor and the inclination factor.

Again you remember that for eccentric loading one can use the IS code method with B' and L' to compute the shape and depth factors and B' in the term $0.5\gamma B' N\gamma$. So, that means here like Meyerhof we have to use B' and L' to compute the depth factor and the shape factor. In the third term we have to use B' in case of eccentric loading.

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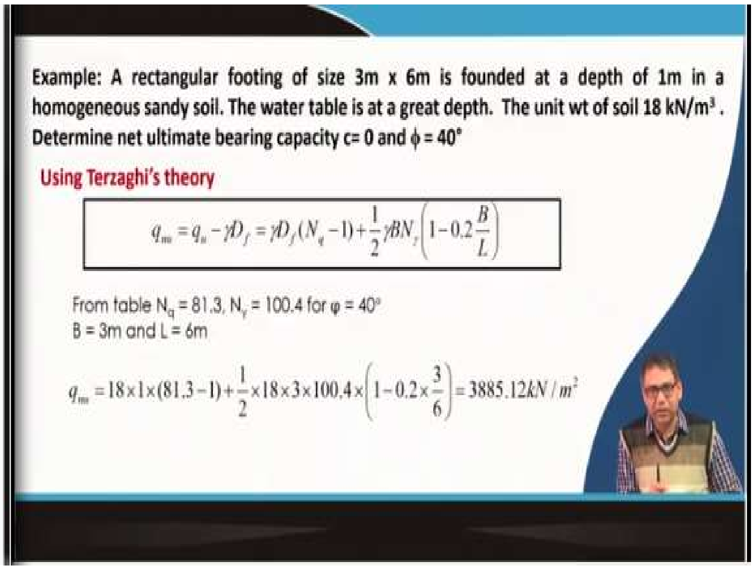

So, now this is the first example problem where a rectangle footing of size 3 m × 6 m is placed at a depth of 1 m in a homogeneous sandy soil, the water table effect is not considered. Because water table is at a great depth, I mean below depth of *B*, the unit weight of soil is 18 kN/m^3. Determine the net ultimate bearing capacity when $c = 0$, $\phi = 40°$.

So, $\phi = 40°$, that means it is a general shear failure. So, because I mean sandy soil based on ϕ you have to judge whether there will be a general shear failure or local shear failure or it is a intermediate state. But in case of c-ϕ soil based on the stress strain plot we have to judge whether there will be a local shear failure or the general shear failure.

So, in the question that will be given for c-ϕ soil that whether it is a local shear failure or the general shear failure based on that you have to use your equations. So, here it is a general shear failure and you are using Terzaghi's theory, so that is the expression and it is for rectangular footing. So, these terms are also used, the first term is not considered because $c = 0$.

So, from the table I we will get N_q value, N_γ corresponding to $\phi = 40°$ and then finally if I put this value in the equation I will get a value of 3885.12 kN/m^2. So, this is the net ultimate bearing capacity because here this γD_f part is already taken. Because here there is no shape factor, depth factor, inclination factor, so I can write this equation in this way. So, this is the value that I am getting as per Terzaghi's theory because here shape factor is incorporated because this is for rectangular footing. But the depth factor or the inclination factor because the inclination factor will not be applied here. Because it is not inclined load, load is perfectly vertical and it is acting at the center.

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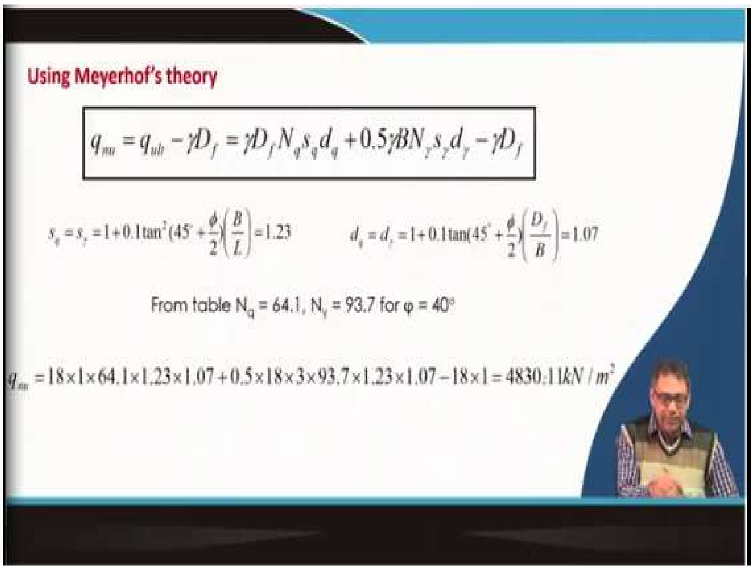

So, using Meyerhof's equation this is the equation I will get the net ultimate bearing capacity. So, I will use these shape factors and depth factors because I will get these things from the table that I have given for Meyerhof's bearing capacity equation. I will get the N_q and N_γ value corresponding to $\phi = 0°$. For general shear failure and I will get this value, for net ultimate bearing capacity as per the Meyerhof's bearing capacity theory.

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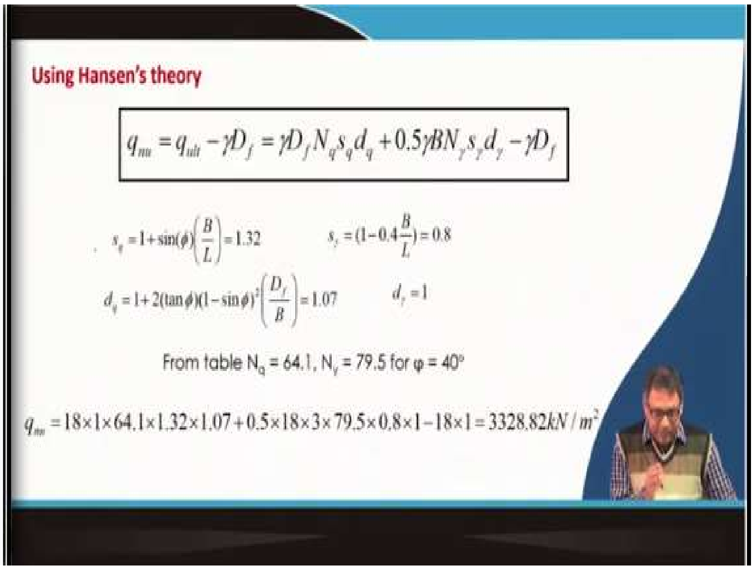

Similar way I will get the bearing capacity as per Hansen's theory because it is a very straight forward case. Because loading is not inclined, it is not eccentric, so I can use any theory because all the theories can be applicable in this case. So, this is the value that 3328.82 kN/m^2 as per Hansen's theory. Only you have to take these factors from the table and then we will put the values and you will get the bearing capacity. And you have to select the proper bearing capacity factor corresponding to different theories.

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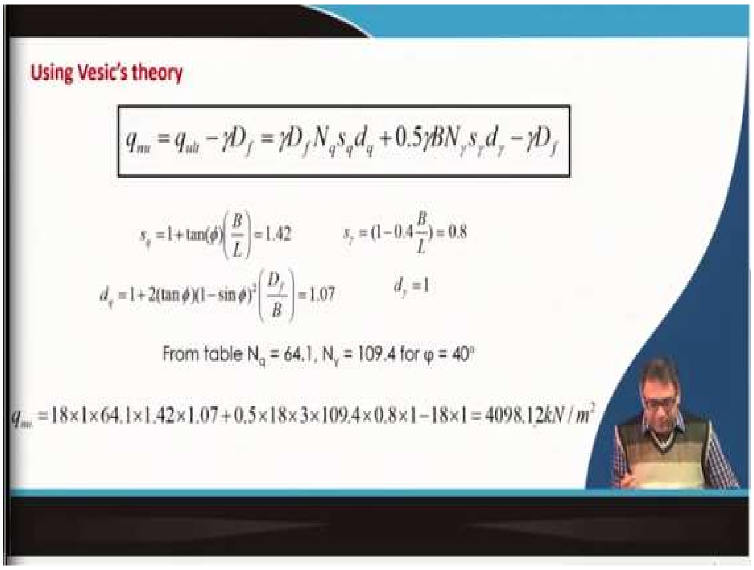

And then as per Vesic also I will get this value which is 4089 kN/m^2. I will get the s_q, s_γ, d_q and d_γ is 1 as per Vesic, as per Hansen also d_γ is 1. So, this is the bearing capacity factor and I will get this value.

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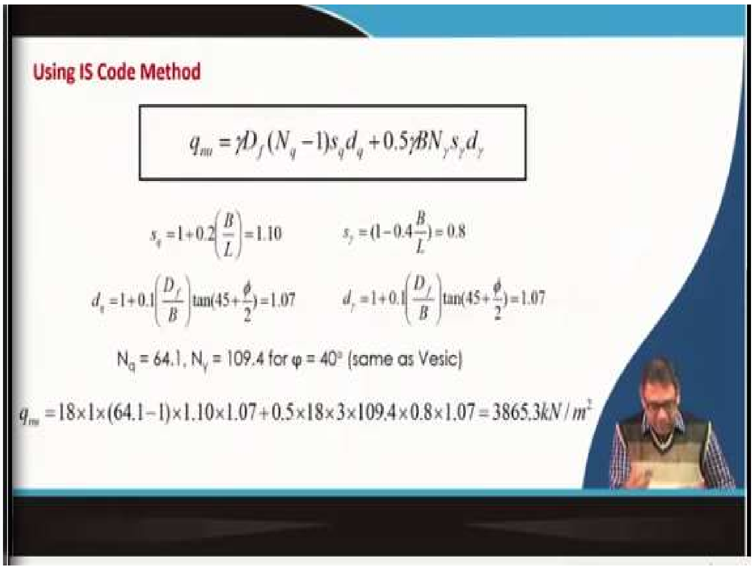

Then as per IS code here water table effect is not considered, so W' is taken as 1. So, this is the bearing capacity factor which is same as Vesic and then the shape factor and depth factor is taken from the table and then I will get this value.

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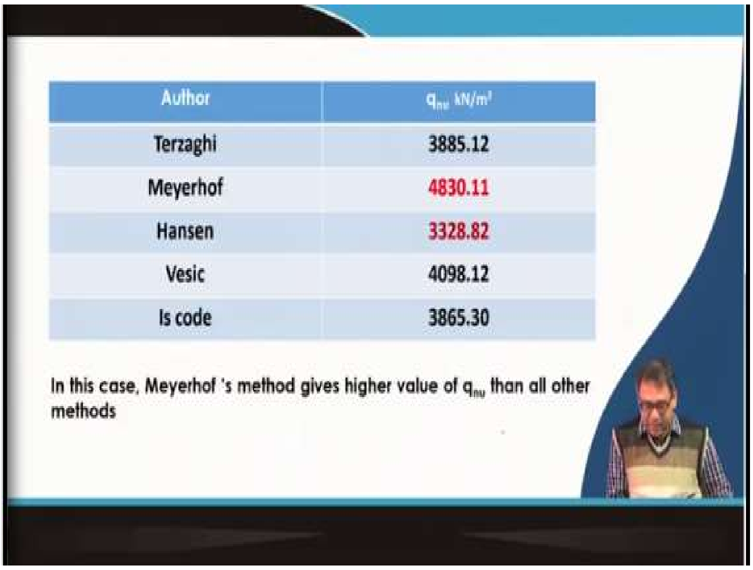

So, ultimately if I summarize these values then I will get that for this particular problem Meyerhof's method have given higher value. And then Hansen's method has given the lowest value but compared to other methods. But this is I have not incorporated Skempton's theory because Skempton's theory is not applicable for sandy soil, it is applicable for the clay soil.

So, but it is not true for all the cases, that Meyerhof's theory will give always higher value and Hansen's theory will give lowest value, it is not true for all the cases.

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	$\phi = 0$, c= 100 kPa	$\phi = 20°$, c= 50 kPa	$\phi = 40°$, c= 0
Theory	q_{nu} kN/m^2	q_{nu} kN/m^2	q_{nu} kN/m^2
Terzaghi	655.50	1254.45	3885.12
Meyerhof	605.00	1177.85	4830.11
Hansen	632.22	1204.70	3328.82
Vesic	638.90	1259.96	4098.12
Is code	605.00	1121.99	3865.30
Skempton	586.67	---------	---------

Because if you look at this table, here I have taken different values and then I compare the bearing capacity values for different theories. And you can see for $\phi = 0°$, that means cohesive soil where I can use Skempton, where the Skempton's equation is giving the lowest one and other theories are more or less giving the similar value as IS code and Meyerhof's theory have given, it is the same value.

Because their factors are similar, then Vesic and Hansen have given the similar type of values. Because this Vesic and Hansen are similar type of equation, Terzaghi's theory has given slightly higher value. But for c-ϕ soil for $\phi = 0°$ and c soil c = 100 kPa for $\phi = 20°$ and c = 50 kPa, where this case it is considered as a general shear failure. And in first case also it is considered as a general shear failure, for all the 3 cases it is considered as a general shear failure.

So, and this is c = 50 kPa, so here also I will get this value and the $\phi = 40°$ and c = 0, here also I will get the value. So, you can see the different cases different theories are giving the higher value and different highest value or lowest value. It is not the one particular theory will always give the lower value and always give the higher value, it is not the true.

Even if you change the footing dimension also, then also these things will change. So, that means we cannot say that which theory will always give the higher value and which theory will give the lower value. But it is always recommended to use at least 2 theories when you calculate the bearing capacity. And later on I will summarize this thing that when we will use which theory based on the loading condition.

Then the other loading directions all these things based on which theory or the ground condition which theory we will use. So, later on I will discuss all these things. But right now I can say that you always use two theories to calculate the bearing capacity.

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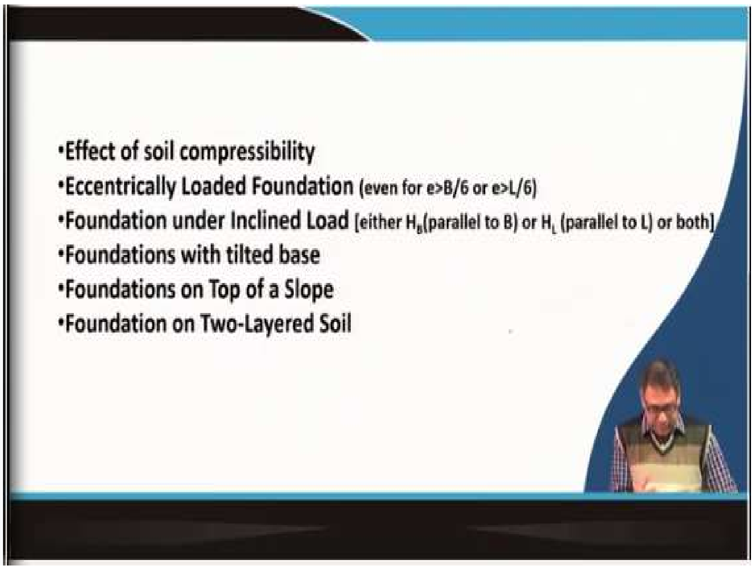

So, now next part that I will discuss because in this advanced foundation engineering course, these are the things which are not normally discussed in our UG level foundation engineering course or UG level core foundation engineering course. Because this course is also a UG level course, UG students can take this course. So, these are the effect of soil compressibility and eccentrically loaded foundation.

Because even for $e \geq \frac{B}{6}$ or $e \geq \frac{L}{6}$. Then foundation under inclined load, so in our bearing capacity equation we generally discuss that load is inclined with vertical with such angle. But we never discuss that if load is parallel to width or length. We discuss only the loading is acting with an angle of α or i with vertical but we are not bothered about whether the load is parallel to B or width or load is parallel to L or length of the foundation.

But if the load is parallel to B or parallel to L or both the horizontal loads are present both are parallel to B and parallel to L, then what will happen? How I will calculate the bearing capacity by using different theories? That is also important, so that thing will be discussed. Then most of the cases we consider foundation base is perfectly horizontal. But if foundation base is tilted one, then how we can calculate the bearing capacity?

Then if foundation is on top of a slope then how we can calculate the bearing capacity? And then very important that in our normal foundation design we take weighted average value for layered soil. Now for foundation resting on a layered soil, but in this case I will discuss the two-layered soil system only. So, if foundation is resting on a two-layered soil system that means the sand above soft clay or clay above a clay, both the layers are clay.

Then one layer is sand, top layer is sand, bottom layer is clay then what will happen, how we can calculate the bearing capacity? So, those things will be discussed. So, first that I will discuss the effect of soil compressibility and then I will discuss one by one about the other effects also.

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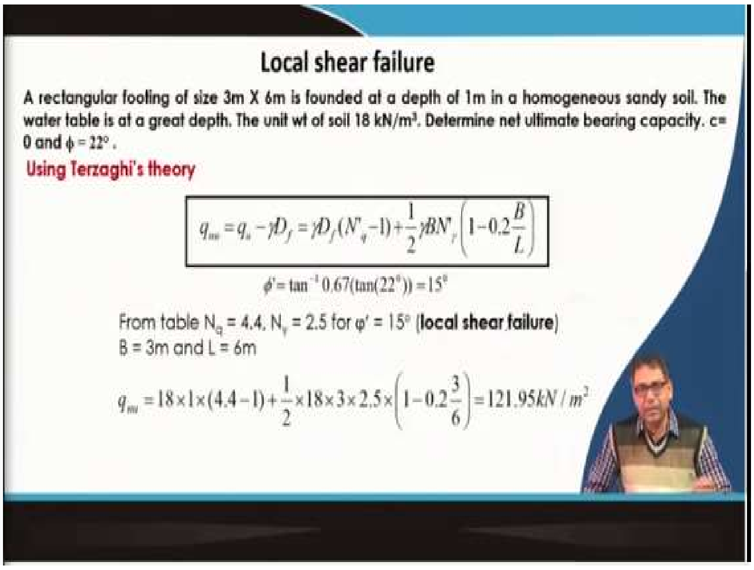

So, in the previous example problems the general shear failures are considered ok. So, now if the soil is in a local shear failure then what will happen? That means here ϕ is 22° which is less than 29°, so it will be a local shear failure. Then what will happen, how we can calculate the bearing capacity? So, I have discussed as per Terzaghi's bearing capacity theory we have to take the $\frac{2}{3}c$ but here c value is 0.

So, here we have to modify the ϕ value, so that ϕ value will be used in this equation. That $\phi' = \tan^{-1}\left(\frac{2}{3}\tan\phi\right)$. So, that ϕ originally 22°, so ultimately I will get a ϕ' value sometimes it is called ϕ_m value, which is modified, is 15°. So, that 15° initially in general shear failure we use the ϕ which is given to calculate the bearing capacity factor.

But here we will not use 22° to determine the bearing capacity factor. We will consider ϕ' = 15° to determine the bearing capacity factor. So, from the table given by Terzaghi, we will get the N_q, N_γ value corresponding to ϕ' and then you will get this value 121.59 kN/m^2.

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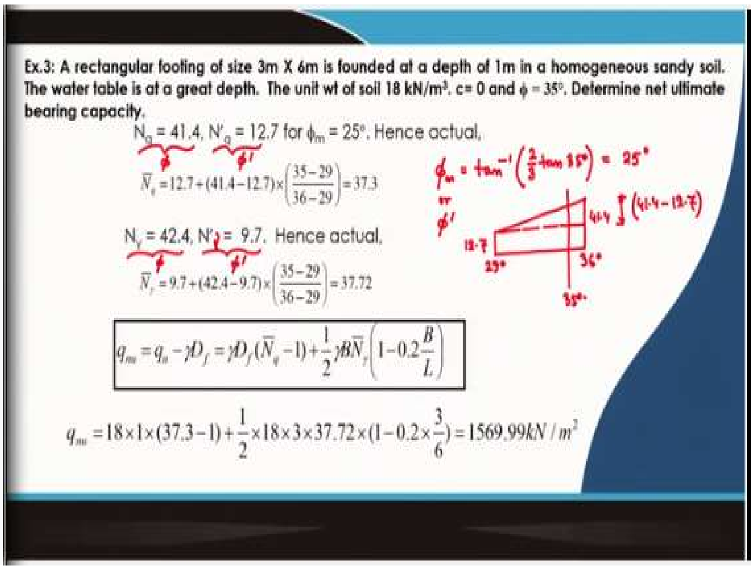

Now if the ϕ of the soil is greater than 36°, then it will be a general shear failure and if ϕ of the soil is less than 29° then there will be the local shear failure. Now if the ϕ of soil is within 29° and 36°, then how we can calculate that. So, in such case this is the example in such case we can determine the bearing capacity by using both the theories.

That means general shear failure case as well as the local shear failure case. So, first what we will do because here our ϕ value is given as 35°. So, we will calculate the ϕ' or ϕ_m. So, same way we can calculate that ϕ' or ϕ_m which is equal to $\tan^{-1}\left(\frac{2}{3}\times\tan 35°\right)$ and that is coming out to be 25° here. So, what we will do? We will calculate the bearing capacity factor corresponding to ϕ_m = 25°.

So, that is the local shear failure consideration, so N_q is 41.4 and N_q' is 12.7, that means the local shear failure. So, that means this is corresponding to your ϕ' or ϕ_m and this is corresponding to ϕ. So, we have to calculate the bearing capacity factor corresponding to ϕ and ϕ' both. So, this is corresponding to ϕ and this is corresponding to ϕ'.

Similarly this is N_γ corresponding to ϕ, this is corresponding to ϕ', that is why it is N_γ',. But we have the value corresponding to ϕ, if I take corresponding to ϕ value which is given as 35°. Then we are basically considering the general shear failure case. And now if you calculate the reduced ϕ and then calculate the bearing capacity factor, so that is our local shear failure consideration.

So, that means if I calculate the bearing capacity factor by considering ϕ that will give us the general shear failure consideration. And if you calculate the bearing capacity factor considering the reduced ϕ or ϕ' or ϕ_m, that is the local shear failure consideration. But our case it is intermediate, so we have to interpolate between these two values, how will I interpolate?

So, suppose we know for general shear failure it is 36°, and local shear failure it is 29°, and for local shear consideration the value is for example this one is 12.7. And for general shear consideration corresponding to real ϕ, because you may ask that I have calculated the bearing capacity factor corresponding to $\phi = 35°$, but I am writing 36°, why?

Because ϕ that I am calculating that the bearing capacity factors that I have calculated considering ϕ = 35°, actually that is the general shear failure consideration. So, that is why I am writing 36°, because that is the limit, and the bearing capacity factor that I have calculated considering the ϕ' or reduced ϕ that is the local shear failure consideration.

So, that limit is 29°, so that is why I am writing 29°, so now this is 41.4. Now we have to linearly interpolate these values and our case is here which is 35°. So, now we can interpolate this thing because this value is nothing but 41.4 - 12.7, so that is the thing. That means $12.7 + (41.4 - 12.7) \times \left(\frac{35-29}{36-29}\right)$ because this is 35, this is 35 - 29 and this is 36 - 29, the bigger side of that angle, so 36 – 29, 35 - 29.

So, in this way we can calculate the bearing capacity factor. So, this is for $\overline{N}_q$ that means you have linearly interpolated the value and in a similar way we can calculate the $\overline{N}_\gamma$. And then finally we will use these bearing capacity factors in the equation and I will get these values. So, this is the bearing capacity for the case, when the ϕ value is in between the local shear failure and general shear failure, that means the intermediate case.

So, that means here I have discussed how will I calculate if the failure is local shear failure or intermediate?. So, in the next class I will discuss that how these things can be incorporated in another way by considering the soil compressibility? Because this local shear failure is basically the compressibility of the soil. So, that effect we can consider in our general bearing capacity equation.

And then we can incorporate the soil compressibility effect if the soil is more compressible. Then similar to the local shear failure, how we can calculate that bearing capacity? So, next class I will discuss that compressibility effect and other effects, thank you.