Foundation Engineering
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Lecture – 14
Shallow Foundation – Bearing Capacity IV

In this lecture 4 for Shallow Foundation Bearing Capacity and overall lecture 14, we will discuss about the available various bearing capacity theories for by which we can determine the bearing capacity of foundation. And we have I have already discussed about the Terzaghi's bearing capacity theory. Now this class we will discuss the others bearing capacity theories and then we will compare their results.

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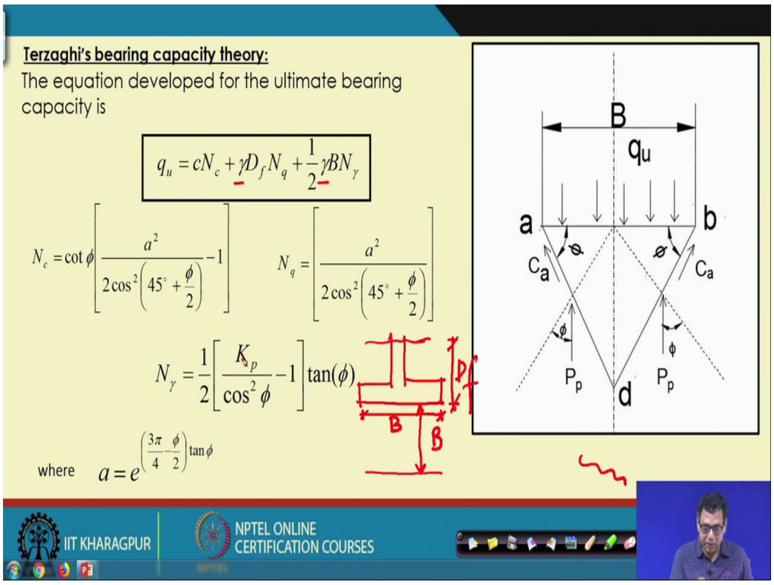

Now, I have already discuss about the Terzaghi's bearing capacity theory. This is the final form of the bearing capacity which is c N c gamma D f N q plus half gamma B N gamma and here we can see that we have two gamma values. So, these gamma values is representing the soil, which is above the base of the foundation and this gamma value representing the soil which is below the base of the foundation.

And another thing that when we are talking about the influence zone of the bearing capacity then we are taking the influence zone from the base of the footing up to the B or width of the footing; that means, if we have a footing here. So, this is the ground surface. So, if this is the D f D f is the depth of the foundation up to the base of the footing. Then the influence zone, influence zones means the zone up to which we have we the stress as the influence into the soil.

So, and then that zone soil we have to consider during our bearing capacity calculation; that means, the properties that we are get using then you have to use the properties up to that zone and so that means here the influence zone generally for the bearing capacity calculation we consider up to the b, where B is the width of the footing, so, from the base of the footing up to the B value. So, that is why in the water table effect also that I discussed in the last class that we considered the water table effect up to the depth B from the base of the footing. If the water table location is greater than that zone then we do not consider the water table effect into the bearing capacity equation.

So, here that is why so; that means, this is the first gamma term is the gamma above the base of the soil and the second gamma term is the below the base of the soil and this N c N q N gamma are the bearing capacity factor and we can determine this bearing capacity factor with the help of this equation or we can determine from this chart also.

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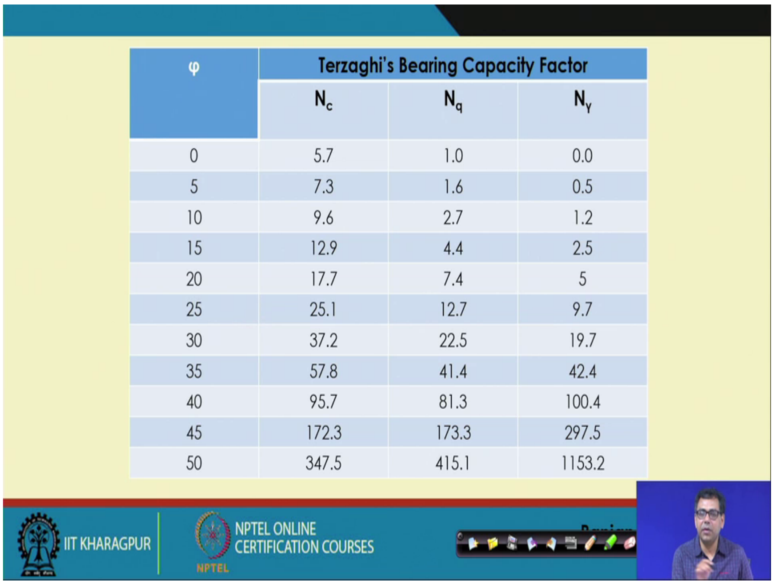

φ	Terzaghi's Bearing Capacity Factor		
	N_c	N_q	N_γ
0	5.7	1.0	0.0
5	7.3	1.6	0.5
10	9.6	2.7	1.2
15	12.9	4.4	2.5
20	17.7	7.4	5
25	25.1	12.7	9.7
30	37.2	22.5	19.7
35	57.8	41.4	42.4
40	95.7	81.3	100.4
45	172.3	173.3	297.5
50	347.5	415.1	1153.2

This chart this chart is developed from these the those equations only.

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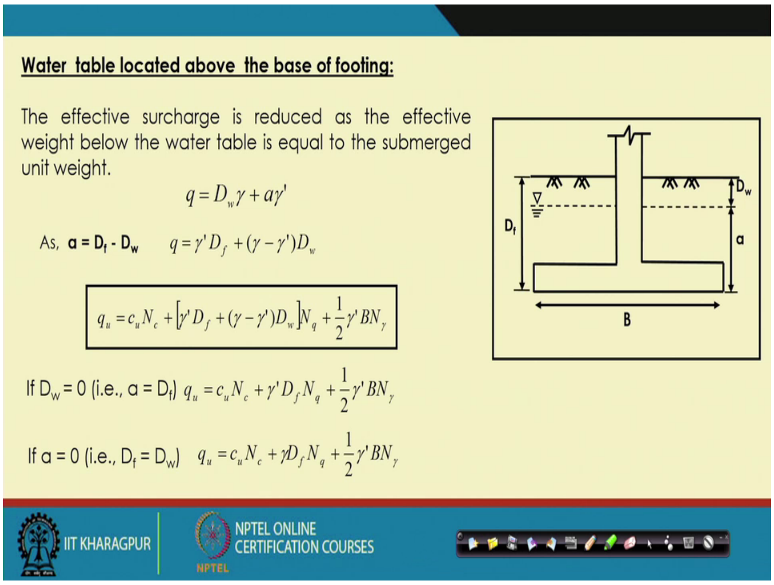

So, and then we discuss about the shape effect on the Terzaghi's bearing capacity expression. Then we discuss about the water table effect, now if the water table is above the base of the foundation then this is the expression, that we are using and if the water table below the base of the foundation then we are using these expressions. So, these things I have discussed.

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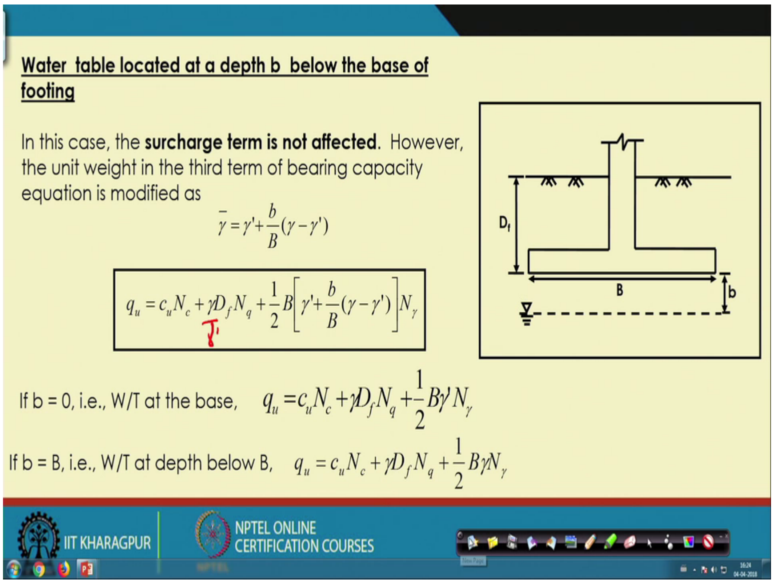

Now, keep in mind that if the water table is above the base of the foundation and at the ground surface then both the gamma will be gamma bar, if it is above the ground surface and above the base of the footing at the ground surface. Now if the foundation or if the water table is at the base of the foundation then the gamma of this second term gamma will be the gamma or gamma bulk and the this third term gamma that will be the gamma sub because that is below the water table.

So, I will solve one problem on this water table effect then you will find that how we can incorporate the water table effect in the bearing capacity expression. In another way that when we are talking about the Terzaghi's bearing capacity expression so, we have the final expression it has three terms; though the term 1, this is the contribution due to the cohesion, the term 2 this is the contribution due to the surcharge and the term 3 this is the contribution due to the weight of the soil.

So, these are the three contributions that we are getting and we these things are discussed when we discuss about the passive pressure resistance for because we are getting the resistance because of three contributions; one is because of the surcharge, one is because of the cohesion, another is because of the weight of the soil. So, when the Terzaghi's bearing capacity equation it has the limitation that it can only be used if your depth of the foundation is less than or equal to the width of the foundation.

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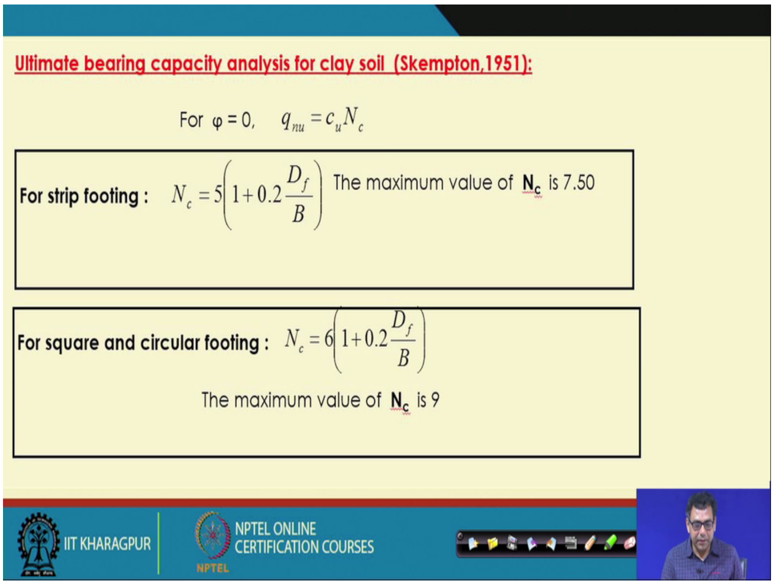

So, keeping in mind the Skempton 1951, proposed ultimate bearing capacity equation or theory for only clay, clay soils so; that means, here phi value is 0 and we are getting the net ultimate. So, that is the net ultimate. So, if the phi value is equal to 0 so, N q will be 1 and N gamma value will be 0. So, our q net ultimate will be c u N c as it is the phi 0. So, you are using c u undrained cohesion and this N c is the bearing capacity factor and this, but the advantage of this theory that it can be used for any depth.

So, because in previous one Terzaghi's theory its applicable for the shallow depth if the depth of the foundation is less than equal to b, but it can be used for the immediate, but the this N c value will change depending upon the depth that we are using and the type of footing.

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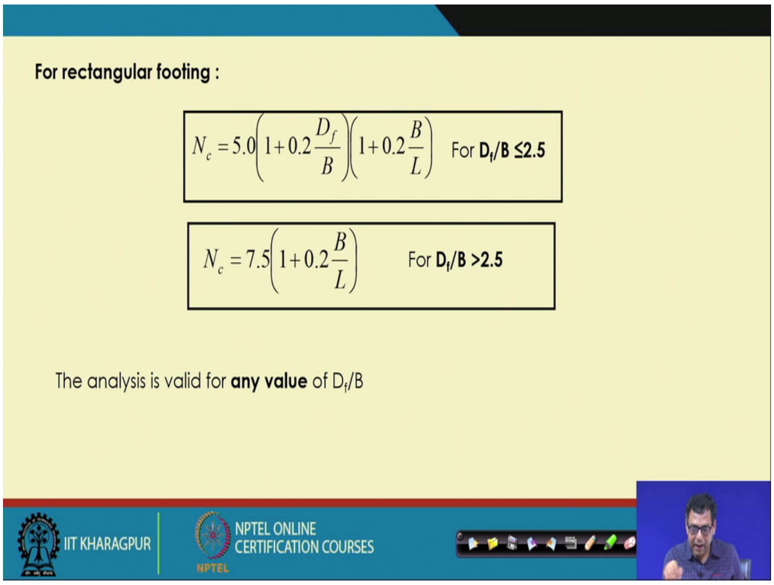

For the rectangular footing, we have this two equation; so, 1 D f by B less than equal to 2.5, then we have these equation and if the less D f by B is greater than 2.5 then we have these equations so, these equations where we can get the bearing capacity factor N c and that we can use for the equation which is given by the Skempton so, but this analysis valid for any value of D f by B.

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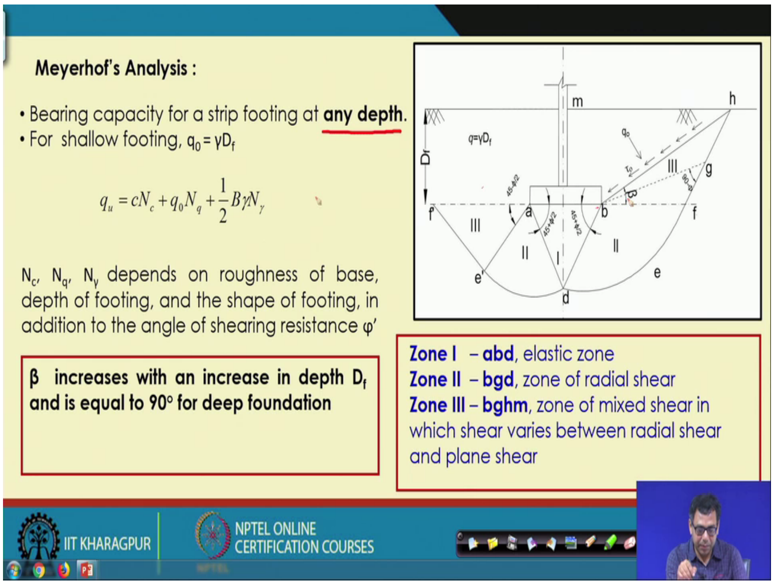

So, next analysis is proposed by the Meyerhof's where the this is also another advantage that each analysis we can use for any depth and this is further so, we can use for the this analysis and another advantage is that because in case of Meyerhof's analysis the N c N q n gamma that depends on the roughness of the footing, depth of the footing and the shape of the footing and the inclination of the loading in addition to the angle of shearing resistance phi.

So that means, in the bearing capacity factor in case of Terzaghi, it was function of phi, but here this is a function of I mean other factors are also included along with this bearing capacity factor. So, which includes the inclination of the load which include the roughness of the base of the foundation we include the shape of the footing which include the depth of the footing.

So, now you can see that here also similar failures similar type of failures surface assumption is considered. So, here if you look at this figure here the right side is given the Meyerhof of failure surface and the left side is given the Terzaghi's failure surface. So, this side is the Terzaghi's this side is the Meyerhof's and the you can see that that in case of Meyerhof's in case of Terzaghi this angle the internal angle of phi, but the Meyerhof is given this is 45 plus phi by 2.

And here another important thing is that the Terzaghi's bearing capacity theory the failure surface is extended up to base of the footing. So, that is why the contribution of this zone above the base of the footing is not considered , but whereas, in the Meyerhof bearing capacity theory the failure surface extended up to the surface of the up to the ground surface.

So, here that is why the contribution due to the soil above the base of the footing is also incorporated into the analysis. So, that is why we here also it has 3 zones. So, zone 1 abd is the elastic zone then zone 2 bdg is the zone of radial shear like the previous one this Terzaghi's bearing capacity theory and the zone 3 this zone this is b g h m is the zone of mixed shear in which shear varies between radial shear to the planar shear.

So, that is why here this is the contribution that we are getting from the soil above the base is also incorporated and there is a value beta that value increases we can increase of D f and it equal to 90 degree for the deep foundation. So, in case of deep foundation this weight value will be will increase and it will it will it will close to 90 degree. .

So, the after analyzing these failure surface then Meyerhof proposed these equation where similar type of bearing capacity factor N c N q N gamma but it has a different value.

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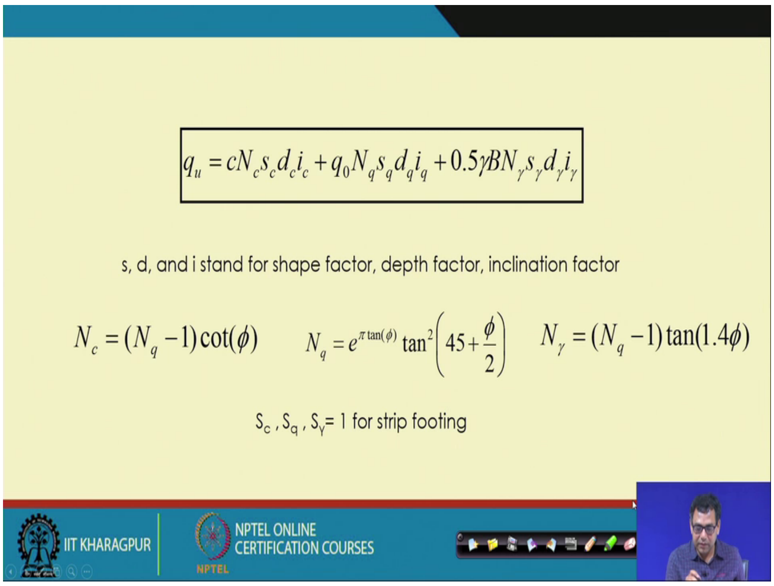

So that means, here ultimately final form of Meyerhof equation is this one. So, here some S c d c i c S q d q i q and S gamma d gamma I gamma these are incorporated along with the N c N q N gamma. So, these are the factors. So, these are the so, S denotes the shape factor, S c means this is the shape factor for N c and then d denotes the depth factor, i is the inclination factor.

So, the here the in Terzaghi's theory the load is vertical and, but here load can be inclined also. So, that inclination effect is also included in this equation. So, along with the depth effect and shape effect and then; obviously, N c is the function of phi. So, here N c N q and N gamma can be determined by using these equations. So, now for the strip footing this S c S q S gamma is equal to 1 for strip footing.

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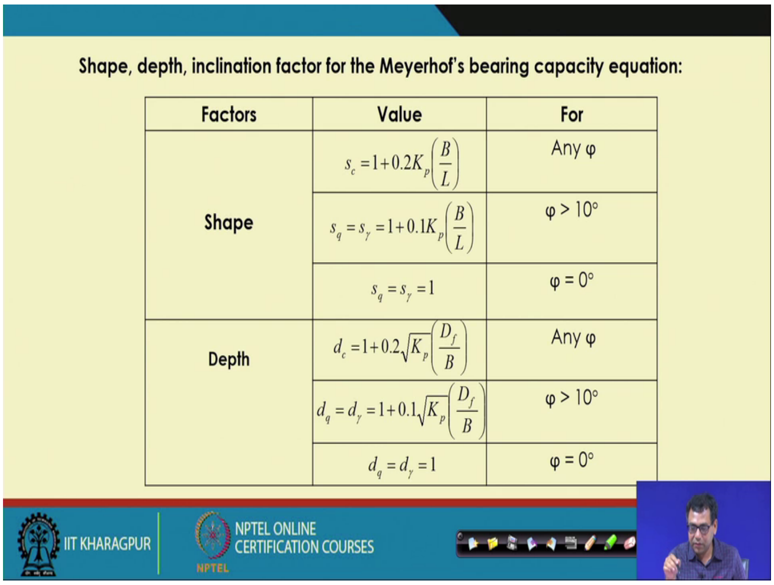

Factors	Value	For
Shape	$s_c = 1 + 0.2K_p\left(\frac{B}{L}\right)$	Any φ
	$s_q = s_\gamma = 1 + 0.1K_p\left(\frac{B}{L}\right)$	φ > 10°
	$s_q = s_\gamma = 1$	φ = 0°
Depth	$d_c = 1 + 0.2\sqrt{K_p}\left(\frac{D_f}{B}\right)$	Any φ
	$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}\left(\frac{D_f}{B}\right)$	φ > 10°
	$d_q = d_\gamma = 1$	φ = 0°

Now for so, Terzaghi's Meyerhof's suggested the, this S c S d and i corrections. So, these are the factors. So, this is a shape factor S c S q and S gamma. So, this S c we can determine by using this equation. So, for any phi and for these two if it is phi greater than 10 degree if it is phi equal to equal to 0 degree, but in between that then we have to linearly interpolate the value if the phi value is in between 0 to 10 degree similarly, for the depth factor and then for the inclination factors.

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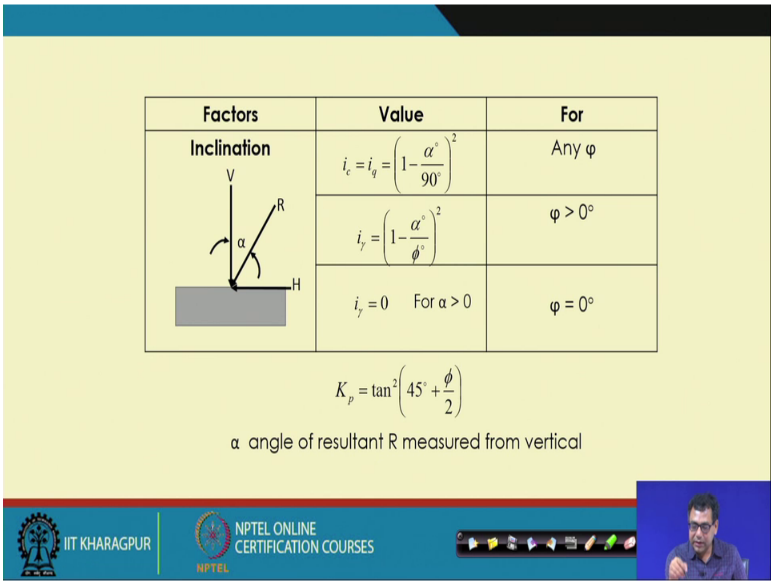

Here this alpha value is the angle the load is making this is the direction of the loading this R is the direction of the loading and it which alpha value and this loading making with the vertical angle. So, this is the alpha. So, this is and similarly K p value is given tan square 45 degree plus phi by 2.

So, this is the things that I have mentioned it is the form with these alpha values making the angle with the vertical. Now the next so, based on the these equations Meyerhof's is also presented one one table, so where you can see if phi value is equal to 0 as per the Meyerhof's N c is 5.14, N q equal to 1 and n gamma equal to 0, but in case of Terzaghi N c was 5.7.

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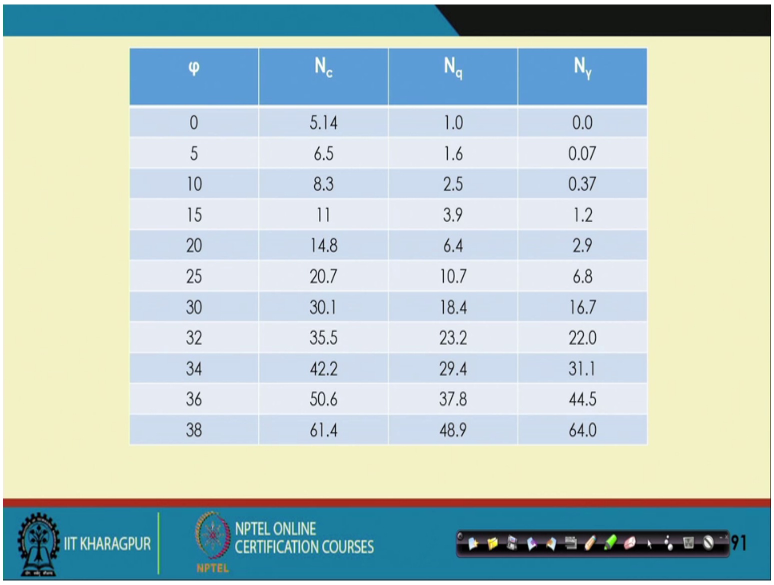

φ	N_c	N_q	N_γ
0	5.14	1.0	0.0
5	6.5	1.6	0.07
10	8.3	2.5	0.37
15	11	3.9	1.2
20	14.8	6.4	2.9
25	20.7	10.7	6.8
30	30.1	18.4	16.7
32	35.5	23.2	22.0
34	42.2	29.4	31.1
36	50.6	37.8	44.5
38	61.4	48.9	64.0

So, that is why as the we are talking about the way the roughness effect is in incorporated. So, this N c value is 1.4 5.14 is for the smooth footing and if it is 5.7 if it is a rough footing; that means, base is rough then 5.7 if base is smooth then 5.14 and then these are the other factors for different phi. So, phi value is in degree.

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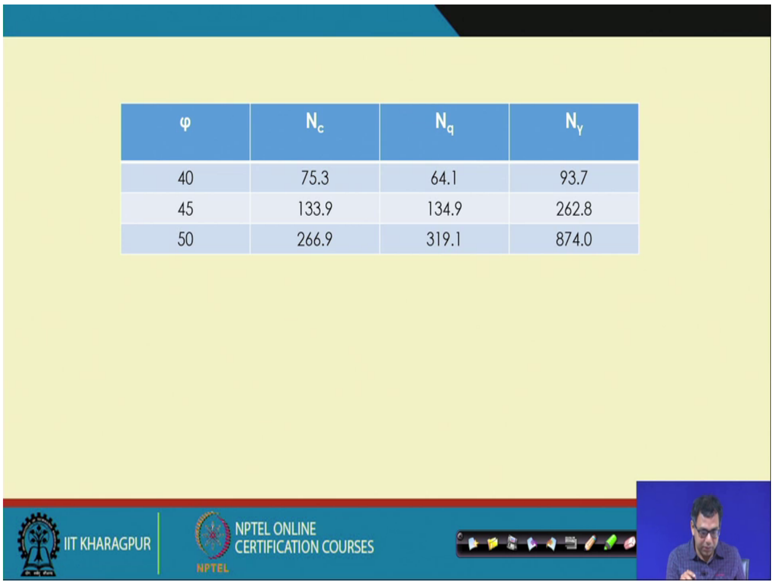

φ	N_c	N_q	N_γ
40	75.3	64.1	93.7
45	133.9	134.9	262.8
50	266.9	319.1	874.0

So, similarly value for the other phi values; so, this is the bearing capacity factors.

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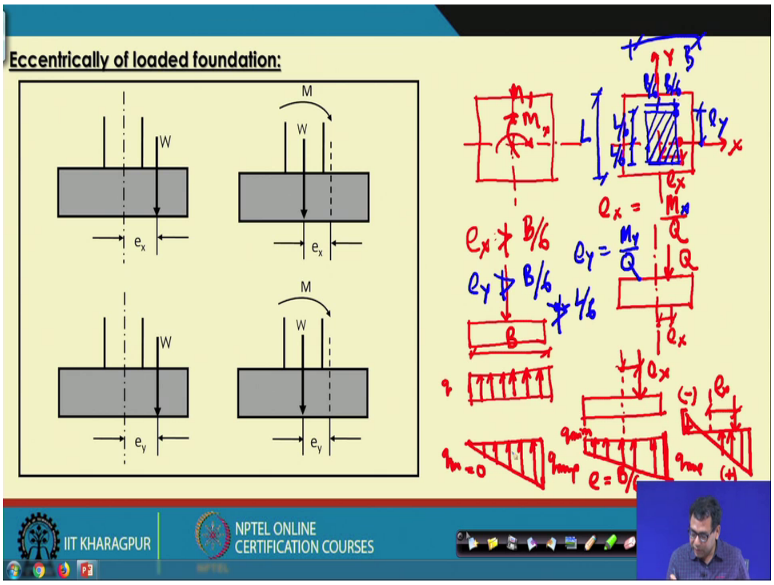

Next one that we are talking about that eccentrically loaded foundation. So; that means, we have discussed about the inclined loading. So, now, but if the in loading is inclined still the point of application of the load is at the center, but if the loading is not at the center it is some away from the center then how we will incorporated that thing into the bearing capacity expression.

So, suppose here instead of only loading you are applying a moment into the foundation. So, suppose this is your foundation this is the center. So, we are applying a say moment in this direction if it is a one way moment. So, this moment is acting suppose M, now the loading the equivalent loading is not the acting in the center so, it is acting somewhere away from the center.

So, that is why this loading is; that means, these things is converted like that that your loading is acting suppose this is the center line of the foundation. So, your loading is acting if it is one way then it is acting here. So, we tan value of say e x, if this is x and this is y ok. So, this and the loading is acting here so; that means, e x I can determine with a value of M by Q.

So, in the section if I take the foundation section then so, this is the center line of the foundation then your loading Q is acting here we can distance of e x. So, because of that what will happen that your now the, your foundation will be loaded not uniformly it will be loaded like this because here your load is acting away from the center. So, it is not the stress distribution below the saw a foundation is not uniform.

Suppose if it is your foundation is loaded suppose if this is the foundation it is loaded at the center then your stress distribution will be more or less uniform because you have the stress distribution like this. So, this is the, your assumes stress distribution.

But if the, it is loaded like this if this is the center line and if it is loaded then more stress will act in this side compared to this. So, in that case the stress distribution will be like this ok, so; that means, here the side where the loading is acting there will be more stress and the opposite side there will be less stress. So, that and if it is the value of e x.

Now there is a possibility that here this, your stress distribution if the e x value if you further increase the e x value from the if you increase the distance of the e x value from the centre then what will happen your stress in the other side will reduce. Now there is a possibility that if you further increase the say suppose e x value then your stress may be like this also.

So; that means, here it is positive and here it is negative so; that means, this zone there will be attention which is not recommended for any design. The reason is that is tension means that your foundation is not if the contact with the soil so; that means, it is lifted; is not it? So, that is why that is not recommended. So, that is why we have to design our foundation such that there should not be any tension in the foundation. So, that if there is a tension there will be a separation between the soil and the foundation. So, foundation will be a lift up. So, that is not recommended.

So, that is why the e x value that will be there should be a limit of the ex value such that your stress on the other side is not negative. So; that means, that you your the maximum recommended stress diagram can be this one, where your stress is this is 0 and this is the if this is the q max and this one the q min and q min can be 0, but q min cannot be negative.

So, here your q is uniform; q this is uniform if it is centrally loaded. So, that is why this is your q max and this is your q min. So, q min cannot be negative. So, this is the limiting condition. So, this limiting condition is achieved if your e value is equal to B by

6 ok. So, that is why we can say that any condition your e x cannot be your e x cannot be greater than B by 6.

So; that means, from here if this is the B value with of the foundation if this is the B value so, your e x should be within this sighted from here it should be the B by 6 and from here also it should be the B by 6, it cannot go B by 6 beyond the B by 6 in any side. So; that means, it should be within the one needle one-third of the foundation. So, this is the one way moment and now if we apply a moment in both the directions.

So; that means the, if we apply the moment this direction in if applied the moment in this direction also. So, this is the moment M x this is the M y, so that means, here instead of this point you are now footing the load will act here. So, this will be the e x and this will be the e y, but the condition is remain same. So, here e y also we can get this is the my divided by Q and this then this will be the M x by Q.

So; that means, here Q is now acting here if it is two way moment. So, now, and again that your e y cannot be greater than your B by 6 or L by 6 if the square footing then B is equal to L and if it is rectangular footing so, it is L by 6. So that means, it cannot be greater than L by 6 also.

So, these conditions we have to satisfy if it is the eccentrically loaded foundation. So, keep in mind that your e value e x or e e y such that it should be within this zone. So, that is the recommended zone.

So, this value is the this is the this is B by 6, this side also B by 6, this one is L by 6, this one is L by 6 if it is L and this one is equal to B. So, this means the middle one-third of the footing you are loading should be applied in this zone. If we apply beyond this zone or eccentricity value greater than this B by 6 or L by 6 then there will be tension will developed in the foundation there will be separation which is not recommended.

So, these are the all information that I am giving for the eccentrically loaded foundation. So, another thing is that because of these loading so, your effective width of the foundation or effective length of the foundation that will reduce. S o so, now, if your effective length or effective width of the foundation is reduce then how we calculate that effective length and width of the foundation.

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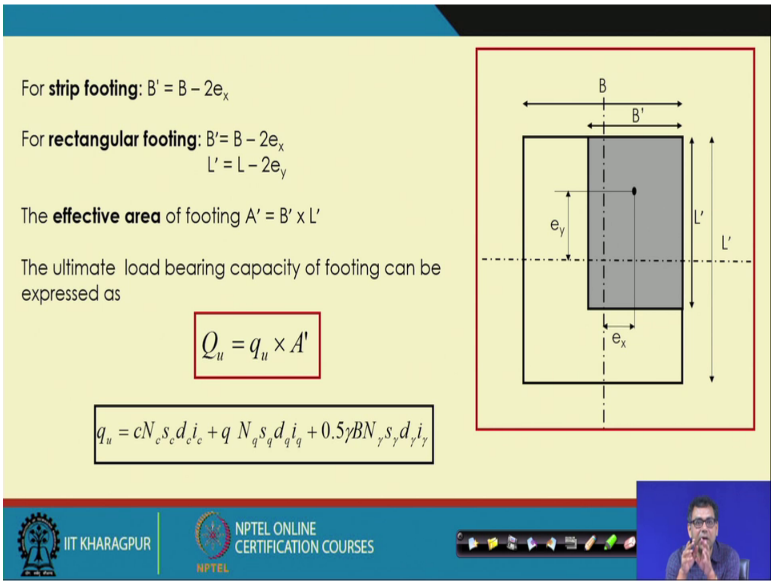

So, now this is the for the strip footing B dash is your, this is the area which is basically effective now because your footing is not in the center. If it is centered then your B is equal to B and L is equal to L because the total area is effective you are using the total area, but if your it is loaded in one side then your effective area that will reduce. So, this is the effective area because you are load is in the acting here.

So, that is why the B dash we can determine by B minus 2 e x and L dash we can determine my L minus 2 e y and final effective area of footing A dash, it will be B dash into L dash and then Q u will be capital Q u will be q into A dash and then the based on that the next theory that is developed is that Hansen's bearing capacity theory which is which is giving better results if it is cohesive soil compared to the Terzaghi's equation.

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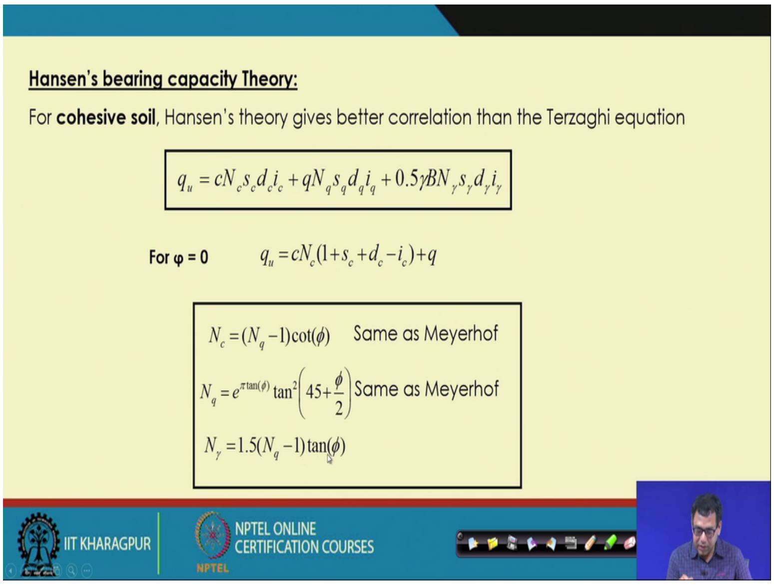

So, now if it is phi is equal to 0 then this is the expression again this S c d c i c all are the shape factor depth factor and inclination factor for the N c and similar to N q and the N gamma. So, these are the N c N q the N c and N q they are as the Meyerhof's recommended N c N q are using, but N gamma expression is different compared to the Meyerhof.

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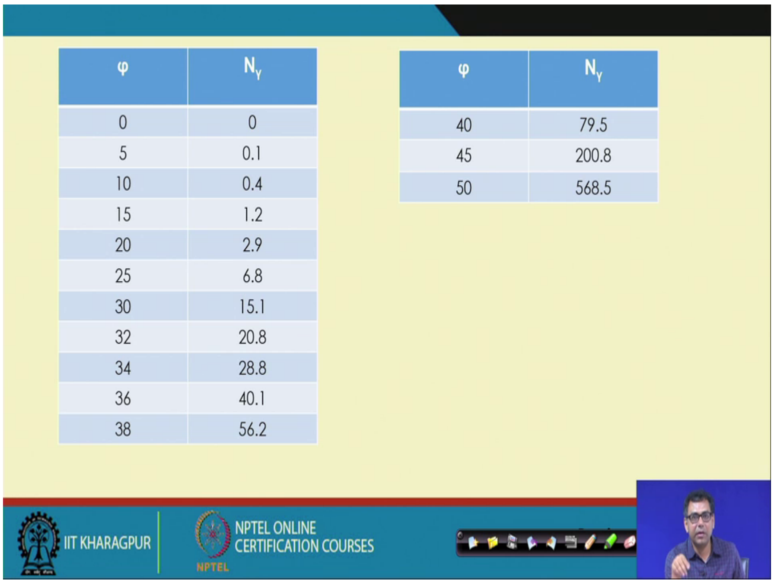

Now this is the table of N N gamma is given because N q and N c is the same as the Meyerhof table, but the N gamma value is different.

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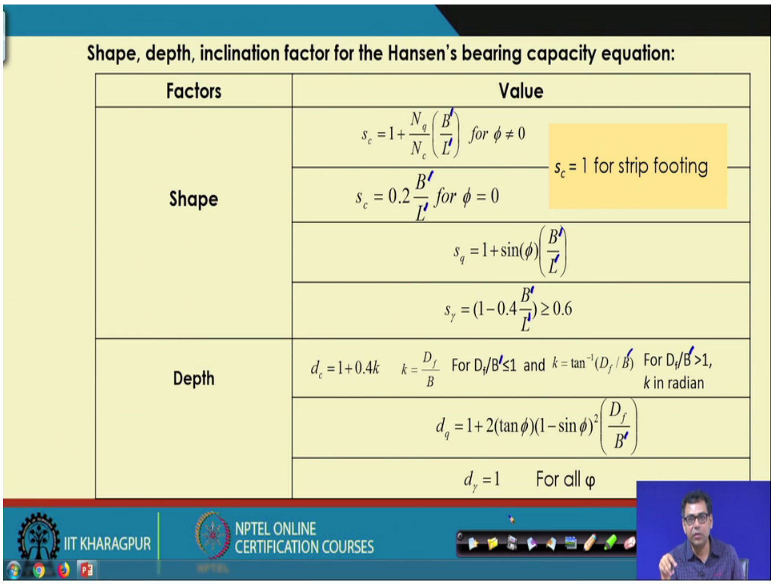

Now, here the correction factors or the factors for in bearing capacity equations also different; so, here if it is in eccentrically loaded footing then instead of B it will be B dash it will be L dash. So, if it is eccentrically loaded. So, this will be also L dash, this will be B dash, L dash then this will be the B dash. So, all the B and L will be converted to your B dash and L dash. So, this is the B dash and so, these are the value this is for phi equal to not equal to 0, this is for phi equal to 0, but for strip footing these value is 1.

So, these are the all depth factor because these factors these tables you have to use during the bearing capacity calculation and then similarly this is the value for the i c inclination factor and then this is A dash is the effective area and c a is the base adhesion because here this adhesion effect is incorporated.

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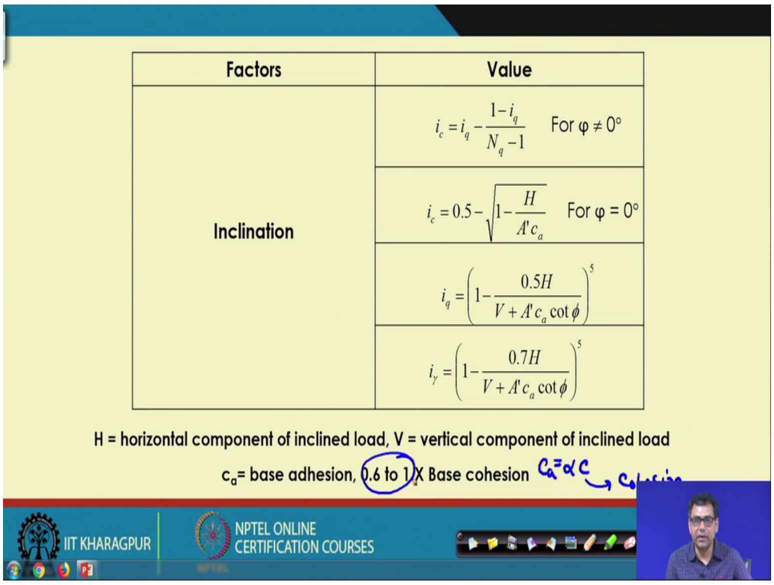

So, as I mentioned in the last class that adhesion basically alpha into c that is equal to adhesion. So, adhesion alpha e it is between soil to soil the alpha value will be 1 and but if it is in other material because your foundation is the different material. So, this value this alpha value varies from 0.6 to 1 and then the base cohesion c value. So, this is the cohesion.

So, this alpha value 0.6 to 1 which is recommended and then we can use these inclination factors and the other factors. So, the so, these are the others bearing capacity theories those we use for the bearing capacity calculation. So, in the next class I will discuss Terzaghi's bearing capacity theory and our Indian standard IS code recommendation then how we can calculate the bearing capacity by using the IS code and then we will try to compare these results and will show how they are varying each other in the next class.

Thank you.