Foundation Engineering
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Module – 01
Lecture - 03
Shallow Foundation

So, in the last lecture, we discussed the Terzaghi bearing capacity equation. And also some of the applications have been demonstrated by solving few problems. So, today I will continue with the same and discuss few more problems and then extend it as the theory as given by Meyerhof and for the eccentric load footings.

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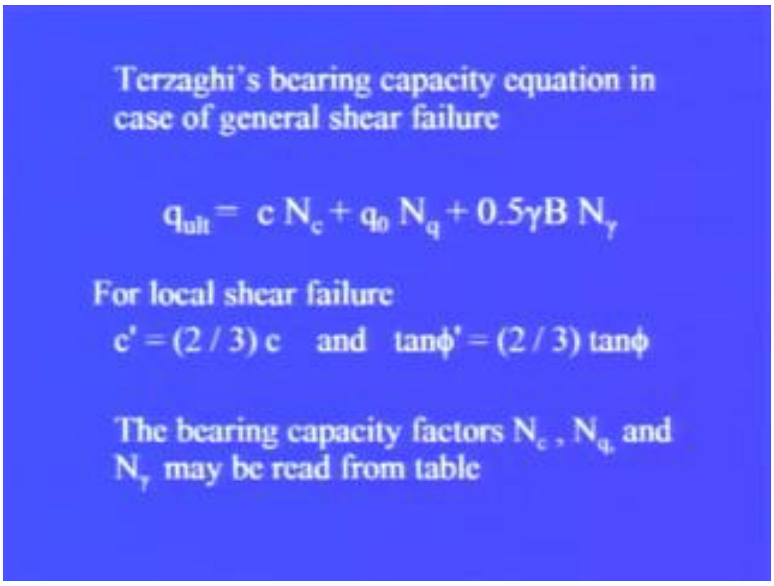

So, Terzaghi bearing, Capacity equation as we have seen, for the general shear failure case is given by q ultimate equal to c Nc plus 0.5 gamma B N gamma plus q 0 Nq. Where Nc Nq N gamma factors are determined on the basis of the angle of shearing resistance tables have been provided and also the figures for the Terzaghi bearing capacity factors. In case of local shear failure c is taken as two-third of c and phi is determined by this equation tan phi dash equal to two-third of tan phi. So, these bearing capacity factors can be read from the table.

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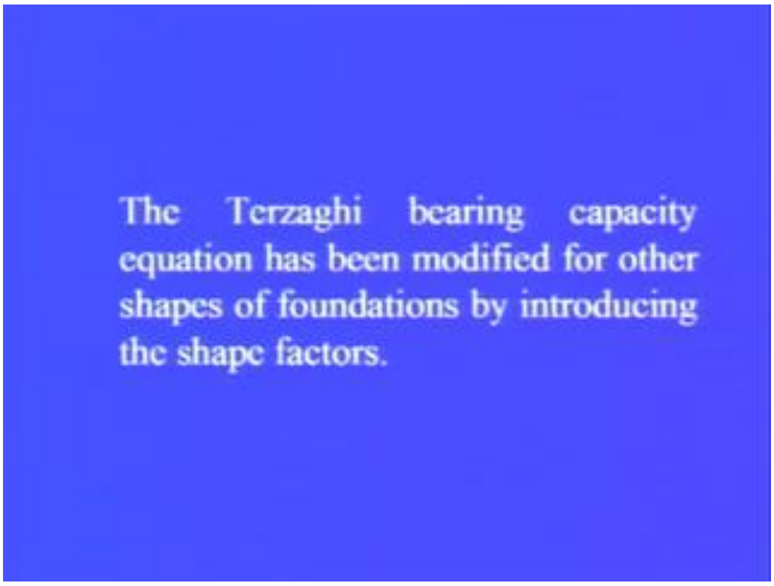

The Terzaghi bearing capacity equation, we have seen has been modified for the other shapes of foundations like, for the case of.

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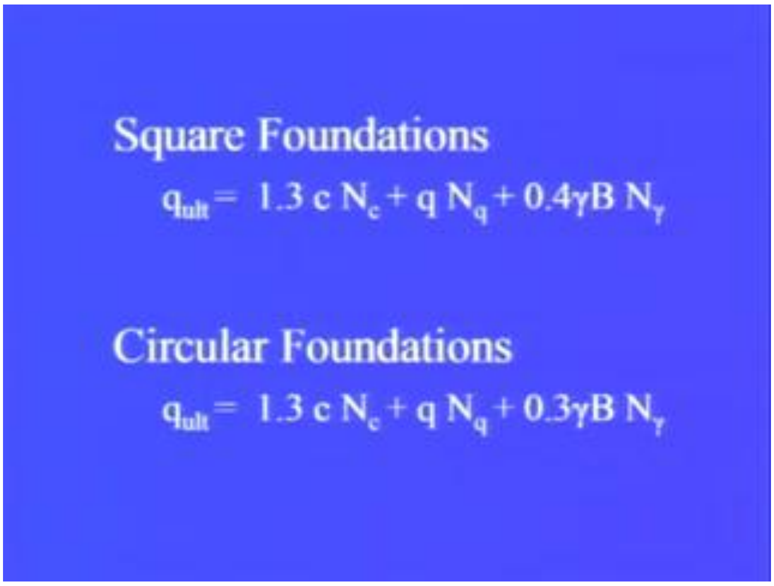

Square foundations for the case of circular foundations, in the case of square foundations, the equation comes out to be 1.3 c Nc plus q Nq plus 0.4 gamma B N gamma whereas, for the case of circular foundations, it is 1.3 c Nc plus q Nq plus 0.3 gamma B N gamma.

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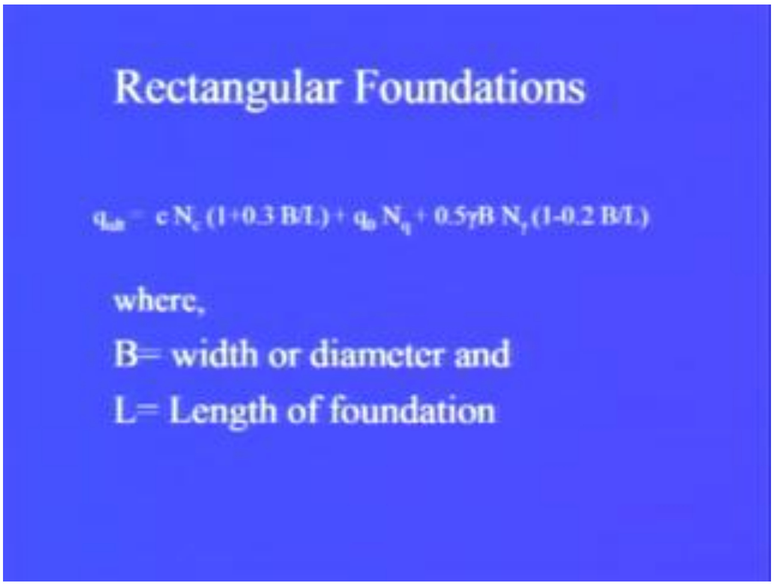

In the case of rectangular foundations, we use this bearing capacity equation in, which a it is given by c Nc 1 plus 0.3 B upon L plus q 0 Nq plus 0.5 gamma B N gamma 1 minus 0.2 B B upon L. Where B is the width of the footing or foundation or the diameter of the footing and L is the length of the foundation.

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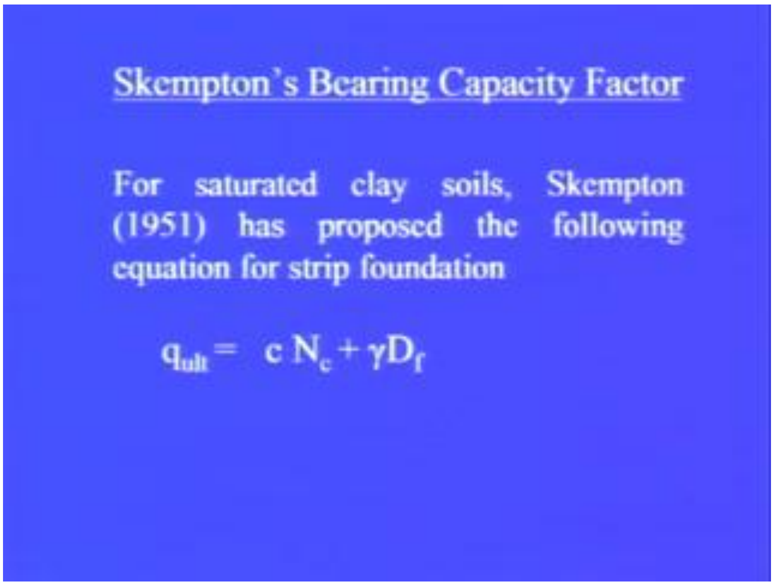

We have also seen that, in the case of a cohesive soil Skempton has proposed the following equation for the case of strip footing, q ultimate equal to c Nc plus gamma Df.

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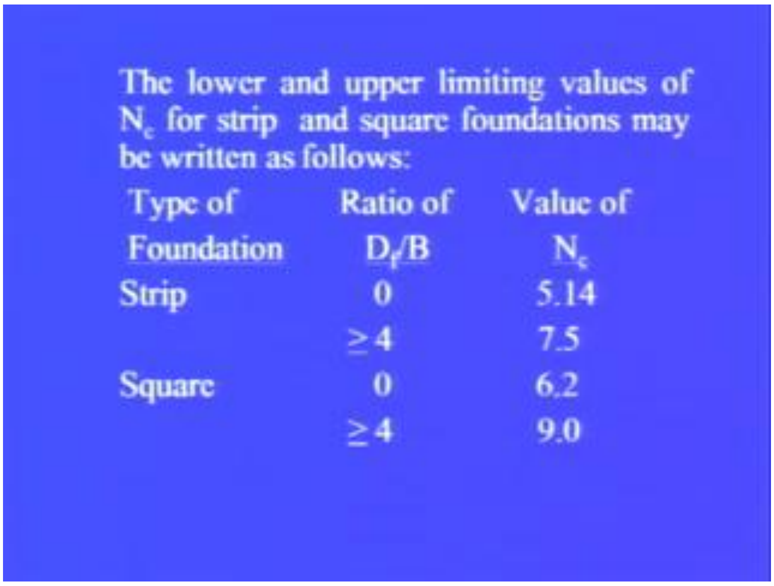

The lower and upper limiting values of Nc for strip and square footings, may be written in the follows, like for the case of different type of foundations depending upon Df by B ratio. We can obtain or we can read the values of Nc from this particular table or.

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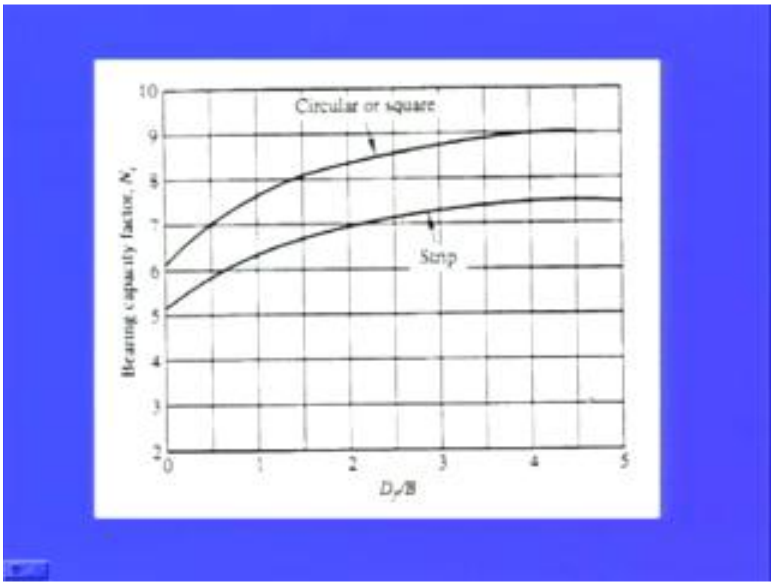

We can use this particular plot between bearing capacity factor Nc and Df by B and D from using this, particular graph, we can obtain for different values of D by f B D by Df by B ratio.

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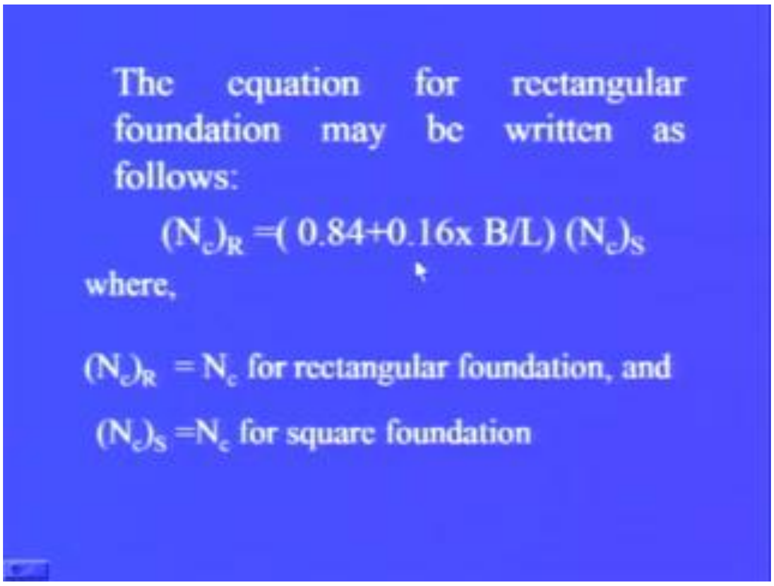

The equation for rectangular foundation may be written, for the case of Nc it is given by 0.8 4 plus 0.1 6 B upon L into Nc S, where Nc S is the Nc for square foundation, Nc R is the Nc for rectangular foundation. We have also discussed the effect of water table on bearing capacity of shallow foundation. We know that due to fluctuations in the water table during different seasons, the bearing capacity is affected. And this bearing capacity can we corrected for water table using following equation.

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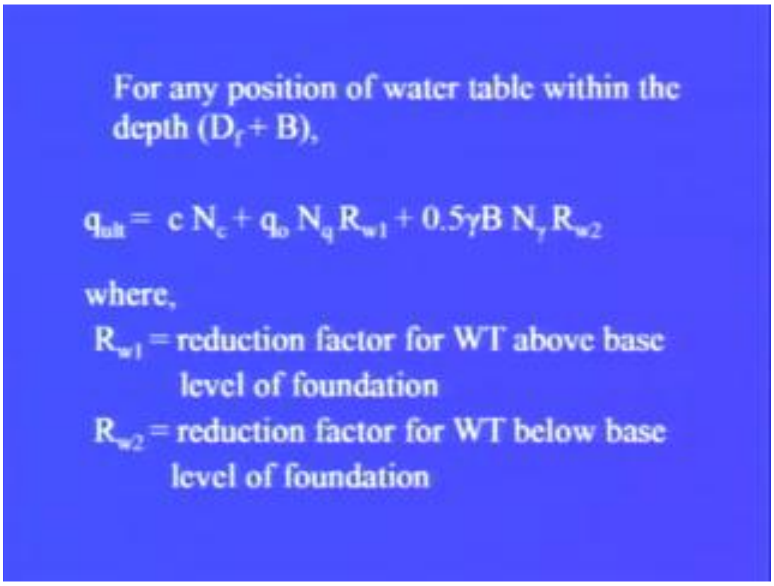

So, here if the water table is within the depth Df plus B, we can use this particular occasion as q ultimate c Nc plus q 0 Nq Rw 1 plus 0.5 gamma B N gamma Rw 2. Where Rw 1 and Rw 2 are the reduction factor for water table, when water table is above the level of foundation this is Rw 1 and when water table is below, the base level of foundation Rw 2.

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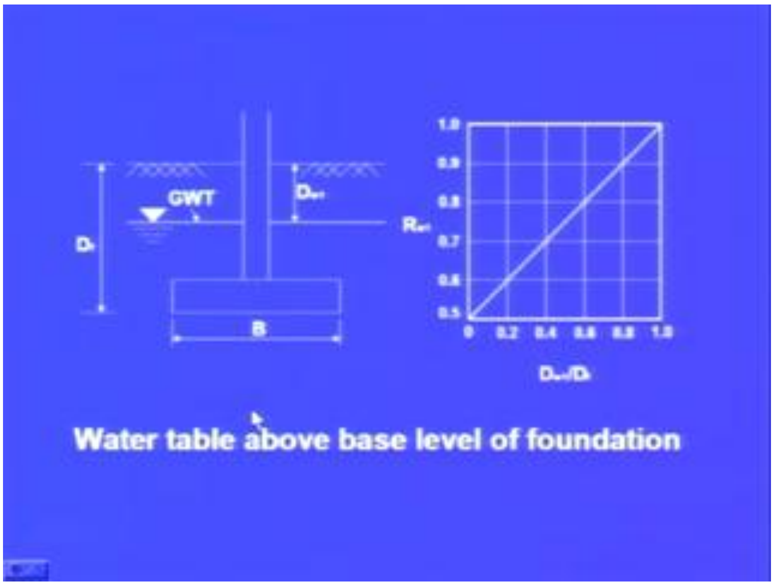

Now, this Rw 1 and Rw 2 can be obtained using this chart; you can see from here this is the depth of foundation. This is width of foundation, this is the position of the ground water table, which is at a depth Dw 1 below the ground surface and using this chart we can find this, Rw 1 depending upon Dw 1 by Df ratio.

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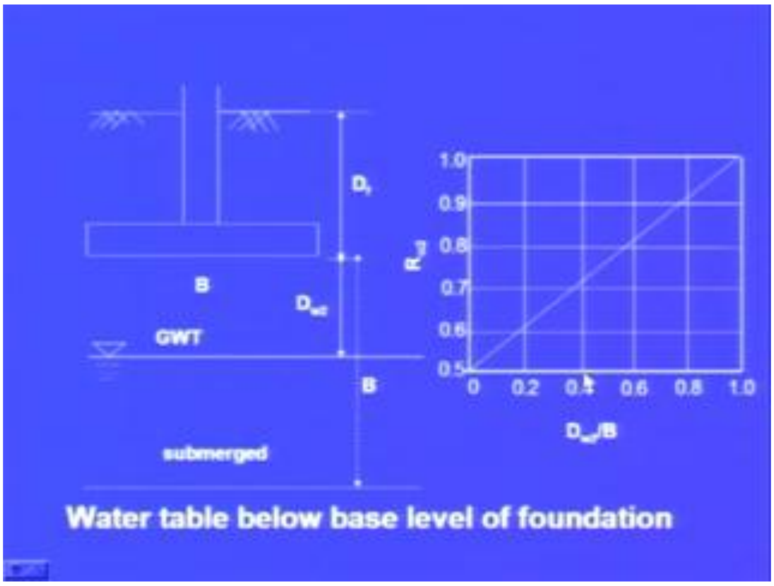

Similar to this, if suppose water table is below the base level of the foundation. And it is at Dw 2 below the base level. Then and it is within the width, within the depth equivalent to width of the foundation, then we can use this particular chart to find out Rw 2. So, here, Rw 2 can be read or it can be calculated by the equation which we discussed in the last lecture.

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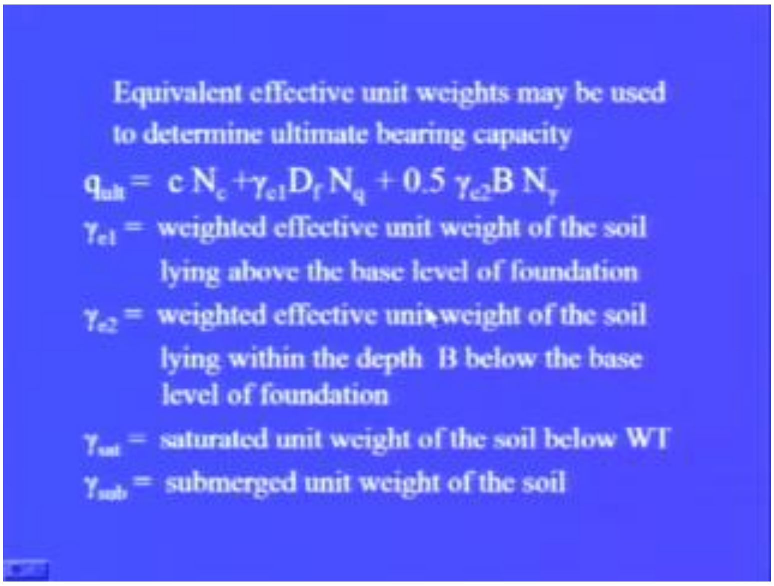

Another method, for considering water table is by making use of equivalent unit weight effective, unit weight gamma e 1 and gamma e 2. And these equivalent effective unit weights can be determined for the 2 cases. When the water table is above the foundation level and when the water table is below the foundation level. Now, various terms used are gamma e 1 gamma e 2 gamma saturated and gamma submerged.

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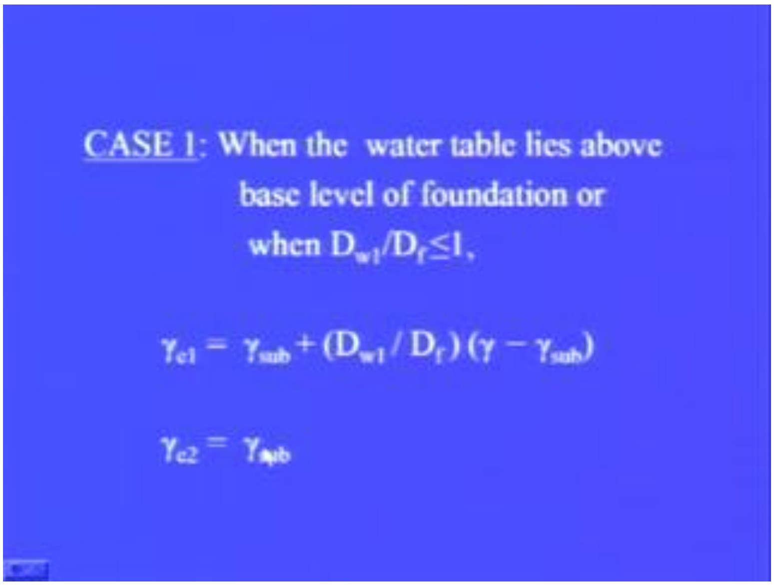

For the case, when the water table lies above the base level of foundation or when Dw 1 by Df is less than 1 gamma e 1 is taken as gamma submerged plus Dw 1 upon Df gamma minus gamma submerged. Whereas, gamma e 2 will simply be equal to gamma submerged.

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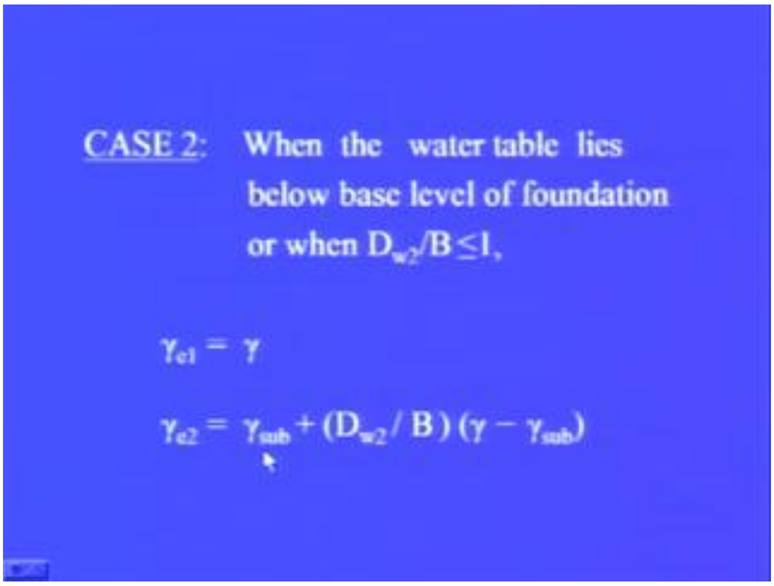

When the water table lies below base level of foundation or when Dw 2 by B is less than or equal to 1 then gamma e 1 is nothing but the unit weight of soil, above the foundation level. And gamma e 2 is gamma submerged plus Dw 2 by B gamma minus gamma submerged.

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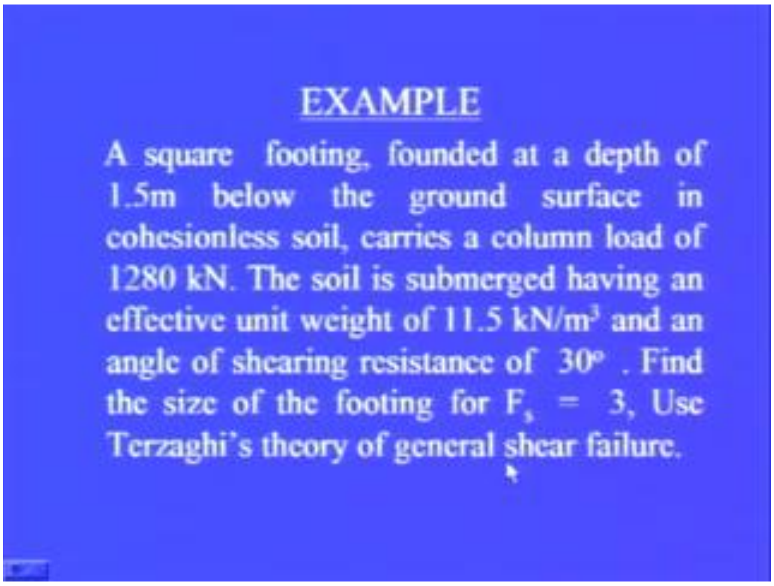

So, this is what we have discussed in the last class, last lecture. Now using the same concept we will solve some more few more problems and so, that the application of these particular occasions are very clear. One such problem is that of square footing founded at a depth of 1.5 meter below, the ground surface in cohesion less soil means, c equal to 0 it carries a column load of 1280 kilo Newton. So, the column load is given the soil is submerged having an effective unit weight of 11.5 kilonewton per meter cube and an angle of shearing resistance phi equal to 30 degrees. We will have to find the size of the footing for a factor of safety equal to 3 and using the Terzaghi's theory of general shear failure.

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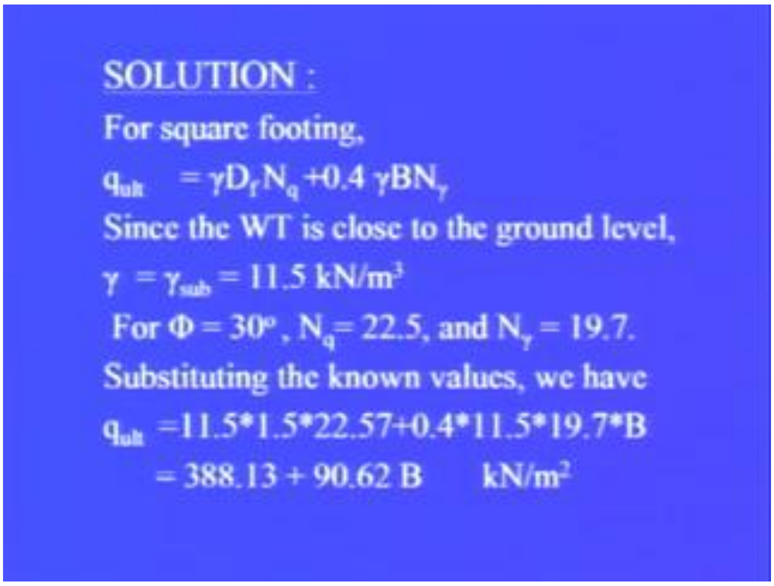

Now, in order to get solution, we know that the for the case of square footing in the cohesion less soil q ultimate will be given by, gamma Df Nq plus 0.4 gamma B N gamma. You can see from here, that this factor is 0.4 is not 0.5, which is in the case of strip footing. Since the water table is close to the ground level the unit weight will be the submerged unit weight and which is already given 11.5 kilonewton per meter cube. Now, for phi equal to 30 degrees from the tables we discussed, we can find out Nq and N gamma these are 32.5 and 19.3 respectively. Now, when we substitute respective values in the ultimate bearing capacity equation we will find that the ultimate bearing capacity equation comes out to be 388 0.13 plus 90.62 B, where B is the width of the column footing.

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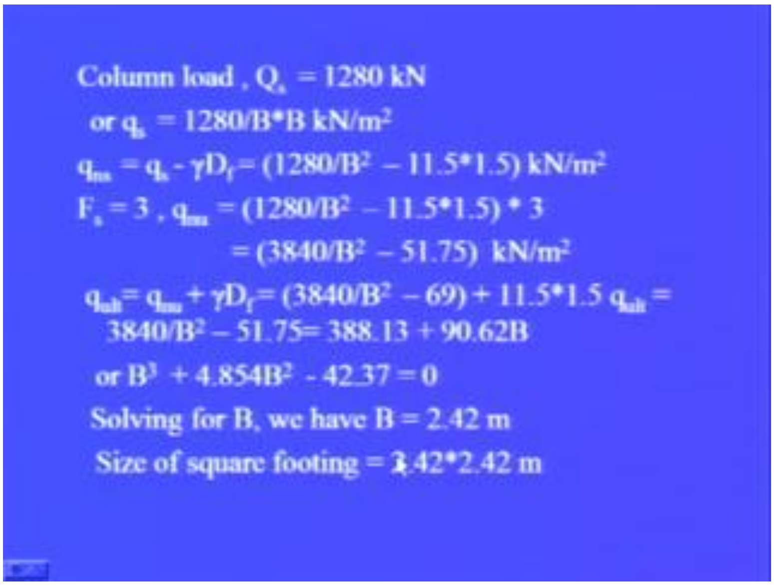

Now, from the data given as that of column load is 1280 kilo Newton. We can find out what should be the ultimate corresponding to this what should be the ultimate bearing capacity sufficient. So, that this can be taken up by the soil, so, in order to do that, first of fall we will find out. What is the safe bearing load or safe bearing capacity? That is nothing, but this load divided by area of the footing, here we have assume width of the footing as B. So, the area of footing will be B into B, so, 1280 divided by B square. Now, once q shape is known we can find out q net shape that comes out to be qs minus gamma Df. So, when we substitute values of gamma Df, we will get this as 1280 by B square minus 11.5 into 1.5 total in bracket kilonewton per meter square. Now, it is also given that, the factor of safety is equal to 3.

So, we can find out net ultimate using this factor of safety, we multiplied by factor of safety, and finally, we find out q ultimate that is q q net ultimate plus gamma Df. So, when we substitute, we will end up with an equation, which will be 3840 by B square minus 51.75. Now, we have already, determined this ultimate bearing capacity from the Terzaghi equation. And when we substitute, we compare this Terzaghi equation with this value, we will get a cubic equation in this form B cube plus 4.854 B square minus 52.37 equal to 0. This we solve by trial and error, by solving we will get width of the footing and that comes out to be 2.42. So, the size of the square footing, which will be sufficient for 1280 kilonewton load will be 42.42 meter by 2.42 meter. Another solved example which will make in which we make use of the Terzaghi bearing capacity equation is a footing of 1.5 meter diameter it carries a safe load of 800 kilo Newton, that including its self weight.

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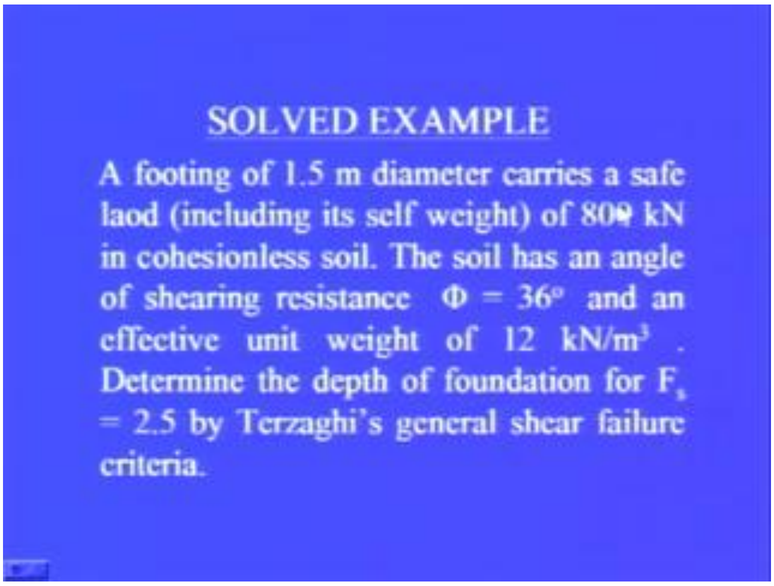

So, it is the total in cohesion less, soil the soil has an angle of shearing resistance phi equal to 36 degrees. Now, as phi equal to 36 degrees, we will consider this case of the general shear failure and an effective unit weight of the 12 kilonewton per meter cube. Determine the depth of foundation for which Fs factor of safety is equal to 2.5 again using Terzaghi's criteria.

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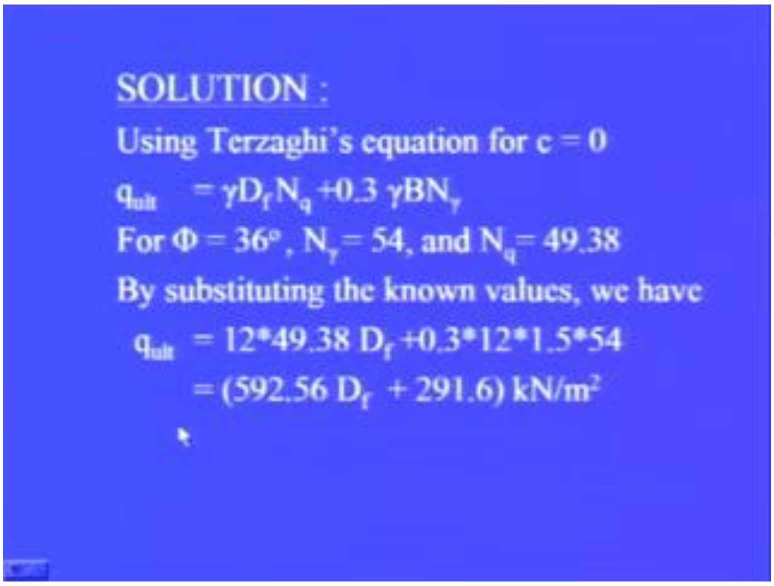

Now, using Terzaghi's equation for c equal to 0, we end up with equation as q ultimate equal to gamma Df Nq plus 0.3 gamma B N gamma. Now, here you can see this is 0.3 which is for the case of a circular foundation. Now, similar to the other cases for different values of phi, we can obtain N Nq and N gamma factor. So, here phi for phi equal to 36 degrees N gamma and Nq can be directly read from the table. And when we substitute these values? We will get this ultimate bearing capacity, equation in which depth of foundation is unknown and that will be given by 5 92.56 Df plus 2 91.6 kilonewton per meter square.

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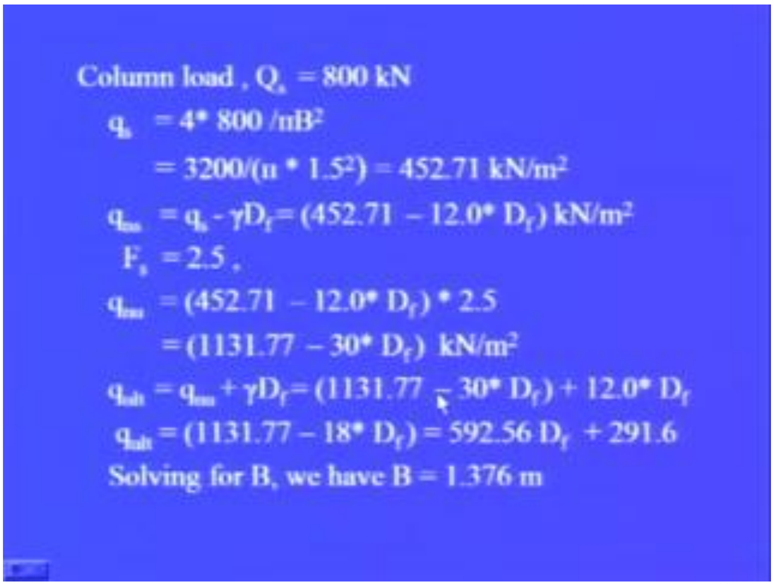

Now, from the given data the column load is 800 kilo Newton. So, 800 kilonewton 4 into 800 kilonewton divided by pi by B square, that will be the q safe that comes out to be 3200 divided by pi into 1.5 square 452.71 kilonewton per meter square. Now, q safe is known, we can find out q net safe that comes out to be q safe minus gamma Df. If you know factor of safety we can find out q net ultimate, if you multiply this q net safe by factor of safety. So, we will get this as 1131.77 minus 30 into Df in which Df is the depth of foundation which is unknown.

Now, after getting this q net ultimate, we can find out q ultimate by adding gamma Df to the net ultimate. So, it comes out to be 1131.77 minus 30 Df plus 12 in into Df. Now, we have already; obtain 1 expression for ultimate bearing capacity using Terzaghi criteria. When we compare this, with the that equation and we solve it by trial and error we will get the width of the foundation, that is the diameter of the foundation as 1.376 meter it means, this much even if you provide 1.4 that will be for this particular case.

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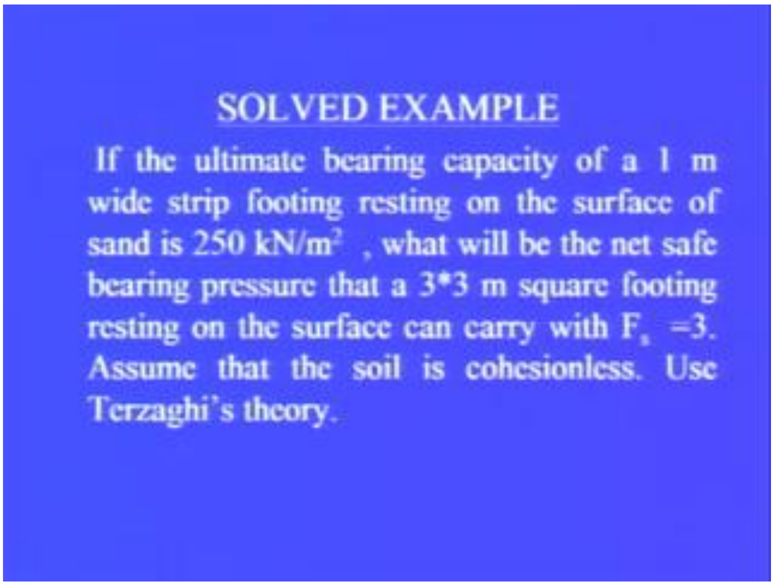

Now, if you see another example, again we use Terzaghi bearing capacity if the ultimate bearing capacity of 1 meter wide strip footing resting on the surface of sand is 250 kilonewton per meter square. What will be the net safe bearing pre pressure? That a 3 by 3 meter square, footing resting on the surface can carry. So, using the data of strip footing, we can use it for the square footing and obtain the solution.

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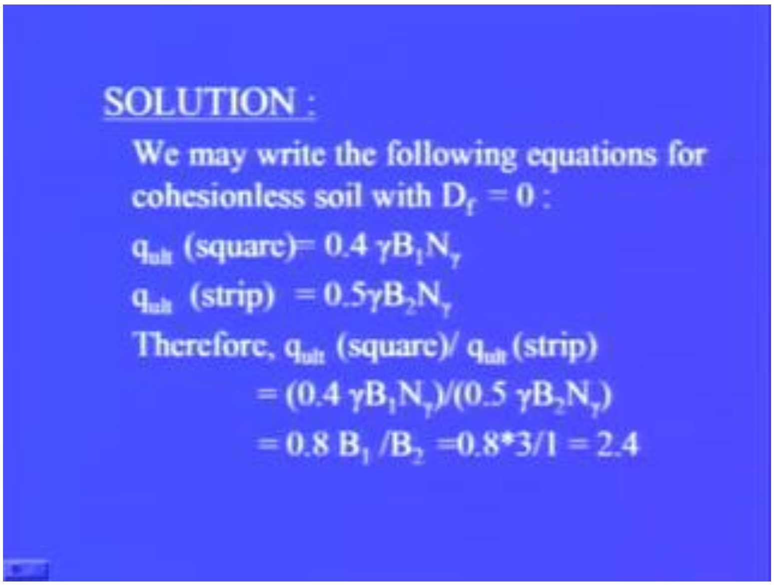

We may write the following equations, for cohesion less soil with depth Df equal to 0 q ultimate for square footing equal to 0.4 gamma B 1 N gamma. Where B 1 is the width of a square footing and q ultimate for strip footing is 0.5 gamma B 2 N gamma, where B 2 is the width of strip footing. So, the ratio of q ultimate of the square and q ultimate of the strip, that will come out to be 0.8 B 1 upon B 2 that is 0.8 into 3 upon, 1 that is equal to 2.4.

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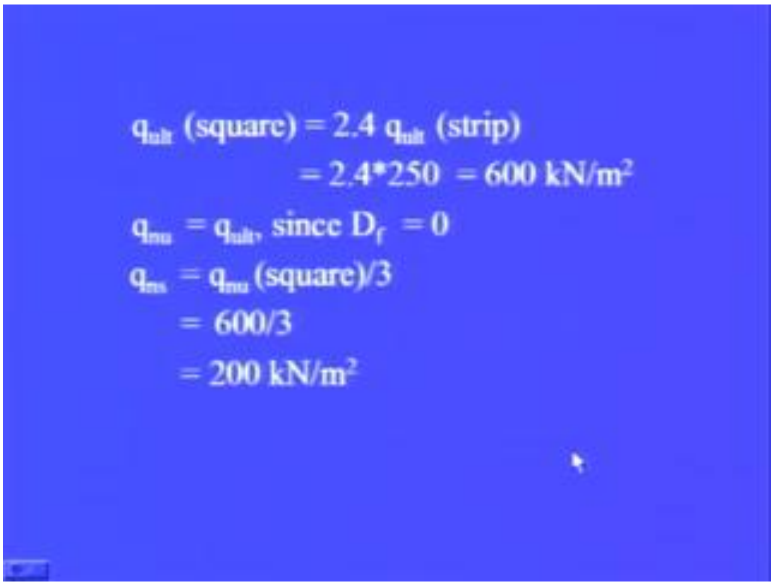

Now, q ultimate of square will be equal to 2.4 times q ultimate of the strip and that q ultimate of the strip is given as 250. So, q ultimate of the square will be equal to 2.4 into 250 that is equal to 600 kilonewton per meter square. Now, q net ultimate will be equal to q ultimate since the footing is resting on the ground itself. And hence q net safe can be equal to q net ultimate of the square, divided by factor of safety that is 3. That is equal to 600 by 3 comes out to be 200 kilonewton per meter square.

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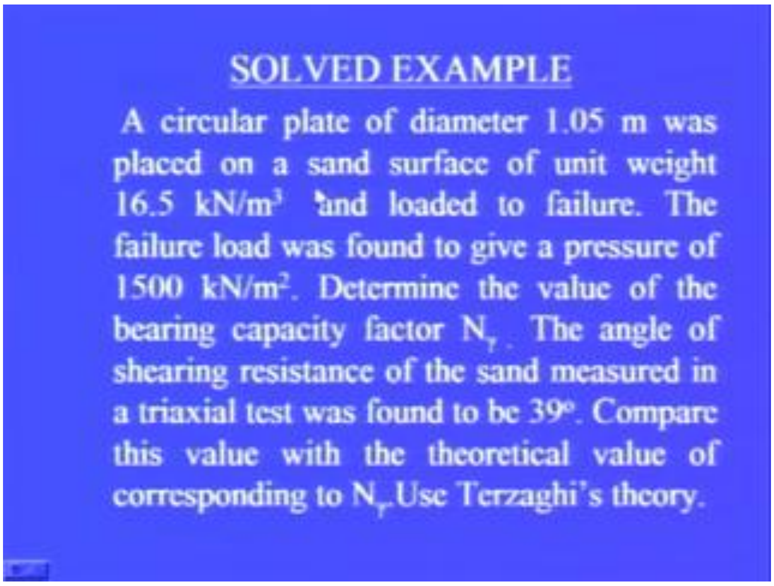

Now, in another solve problem, that is the case of a circular plate of diameter 1.05 meter was placed on a sand surface of unit weight 16.5 kilonewton per meter cube. And loaded to failure the failure load was found to give a pressure of 1500 kilonewton per meter square. We will have to determine the value of bearing capacity factor N gamma, the angle of shearing resistance of the sand measured in a triaxial test was found to be 39 degrees. We will have to compare this value with the theoretical value of corresponding to N gamma using Terzaghi theory.

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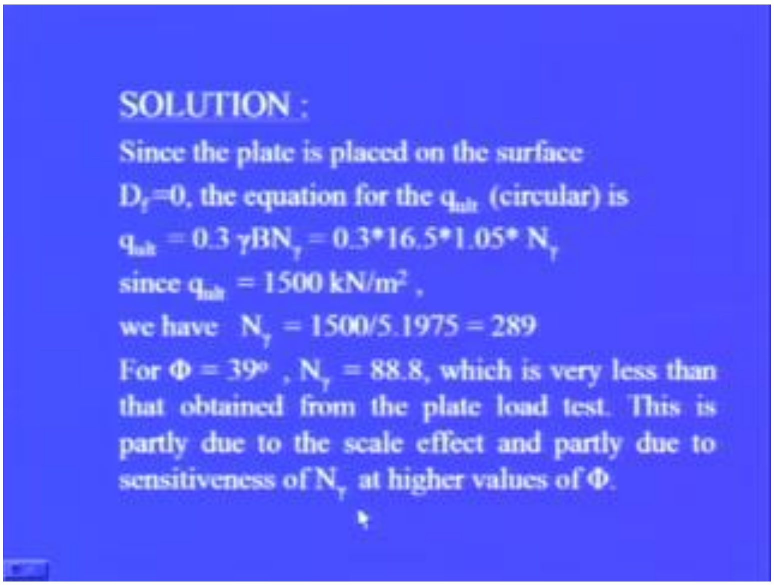

Now, in order to get solution, we know that the plate is placed on the surface. So, Df equal to 0 plate is circular. So, q ultimate is 0.3 gamma B N gamma and when we substitute the values. We will get 0.316.5 into 16.5 into 1.05 N gamma, since q ultimate equal to 1500 kilonewton per meter square. So, N gamma will come out to be equal to 1500 divided by 5.1975 that is equal to 289. Now, for phi equal to 39 degrees, N gamma equal to 88.8, which is very less than we obtained from the plate load test. This is partly due to the scale effect and partly due to the sensitiveness of N gamma at higher values of phi.

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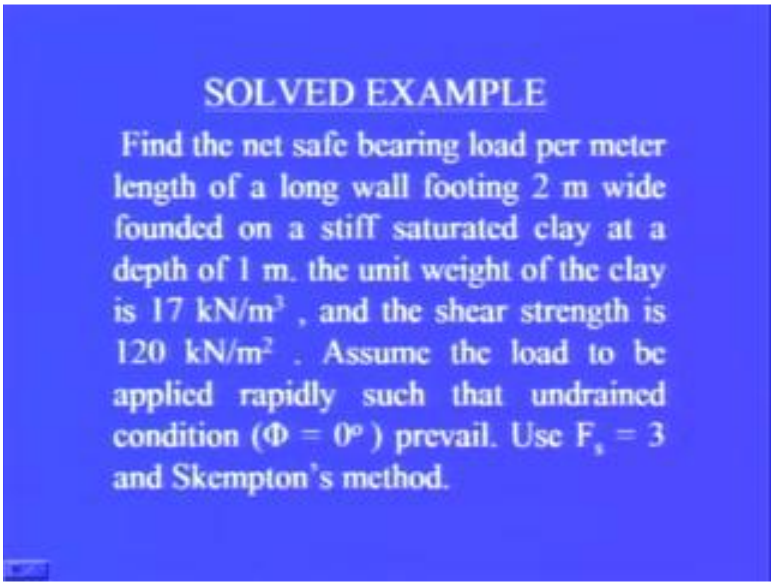

The next solve problem is, about to find the net safe bearing load per meter length of a long wall footing 2 meter wide founded on a stiff saturated clay at a depth of 1 meter the unit weight of the clay is 17 kilonewton per meter cube. And the shear strength is 1020 kilonewton per meter square, assume the load to be applied rapidly such that undrained condition phi equal to 0 prevail use factor of safety equal to 3 and use the Skempton's parameter.

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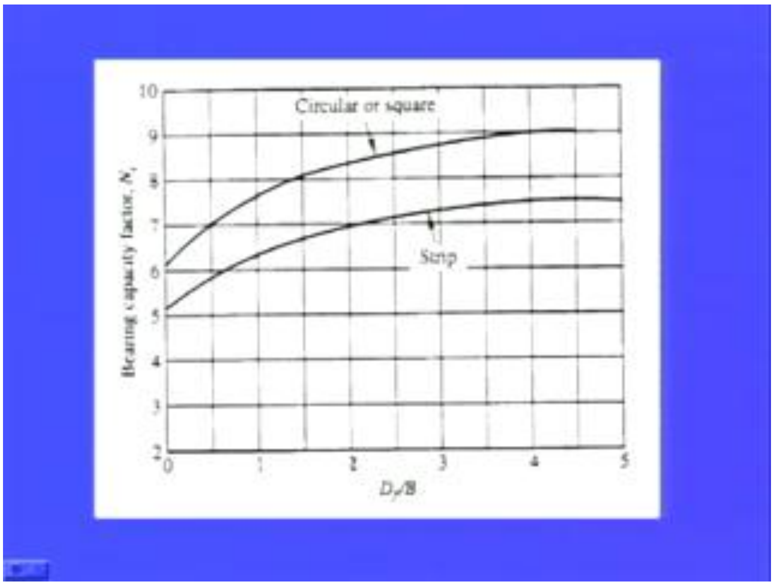

Now, Skempton parameter Nc can be obtained by this chart, which we have discussed in the last lecture.

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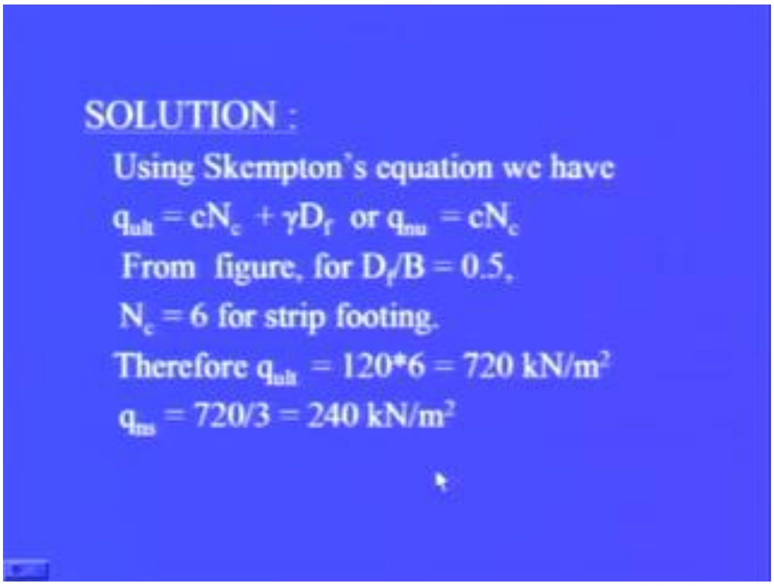

Now, using this chart and the equation given by Skempton we have find out this q ultimate equal to cNc plus gamma Df where this Nc is obtained by the previous chart and as it is on the surface. So, this Df equal to 0 we will end up with q net ultimate, that is equal to cNc. Now, from this figure for Df by B equal to 0.5 Nc comes out to be 6 for square footing strip footing therefore, q ultimate equal to 120 into 6 that is 712 kilonewton per meter square q net safe comes out to be 720 divided by three that is 240 kilonewton per meter square.

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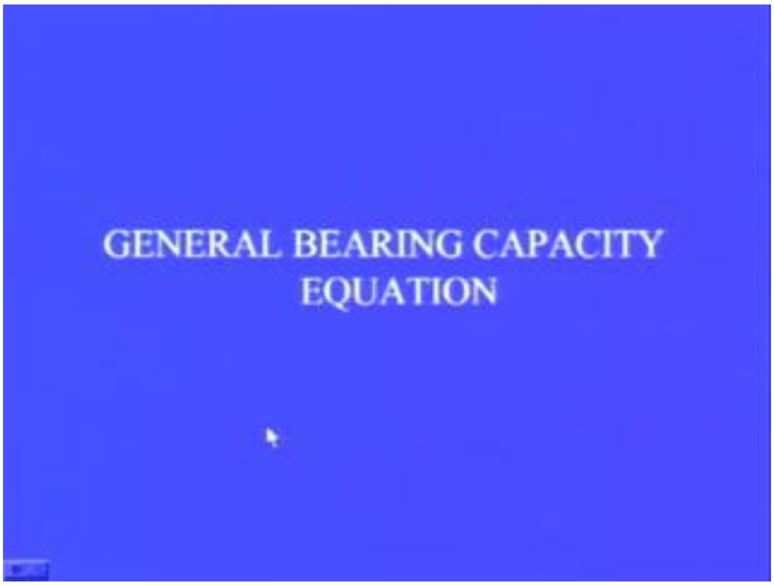

So, for we have discussed about the Terzaghi, bearing capacity equation. And we have taken different problems, variety of problems by which we can either find out ultimate bearing capacity. We can find out net safe bearing capacity, we can find out safe bearing capacity and also in few of the problems, we have discussed such that depending upon the unknown. Let us say, whether it is width of the footing or the depth of the footing or the bearing capacity factor N gamma, we can obtain using Terzaghi bearing capacity equation. Similar to this we have also discussed about how to apply the water table correction? Whether, the water table is above the base of the foundation or below the base of the foundation.

Now, this general bearing this bearing capacity safe bearing capacity, equation has been extended by many researchers. And the, they have obtained general bearing capacity equation, the form of the equation has been found to be similar to that of Terzaghi bearing capacity equation. Only, difference is in the parameters like Nc Nq N gamma basically you will find that Nc and Nq are almost similar as that of Terzaghi. But there will be difference only in the value of N gamma, they have also extended it for the different safe factors. So, now, onwards I am going to discuss the modifications, which are being done by various researchers in the Terzaghi bearing capacity equation. So, that is general bearing capacity equation.

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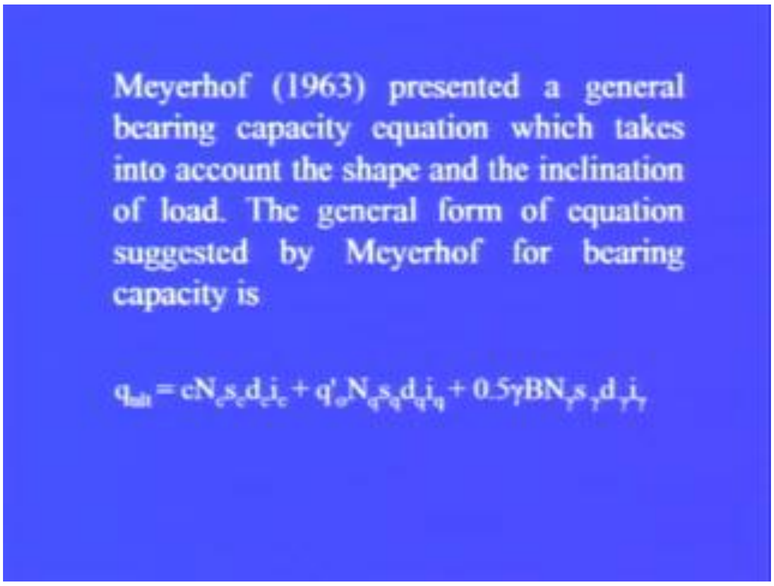

It was Meyerhof in 1963, who presented a general bearing capacity which takes into account the shape of shape and the inclination of the load the general form of equation. Suggested by Meyerhof for bearing capacity is given as cNc sc dc ic plus q 0 dash Nq sq dq iq and plus 0.5 gamma B N gamma s gamma d gamma I gamma now here.

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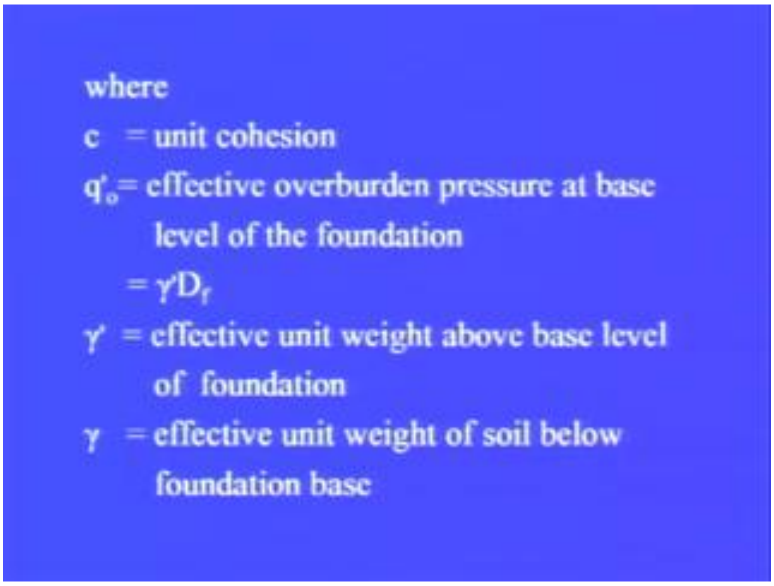

C is the unit cohesion q 0 dash is the effective overburden pressure, at the base level of foundation. Which can be determined, if we know effective unit weight gamma dash and the depth of foundation Df. Where gamma dash is the effective unit weight above the base level of foundation and gamma is the effective unit weight of soil below the base level of foundation.

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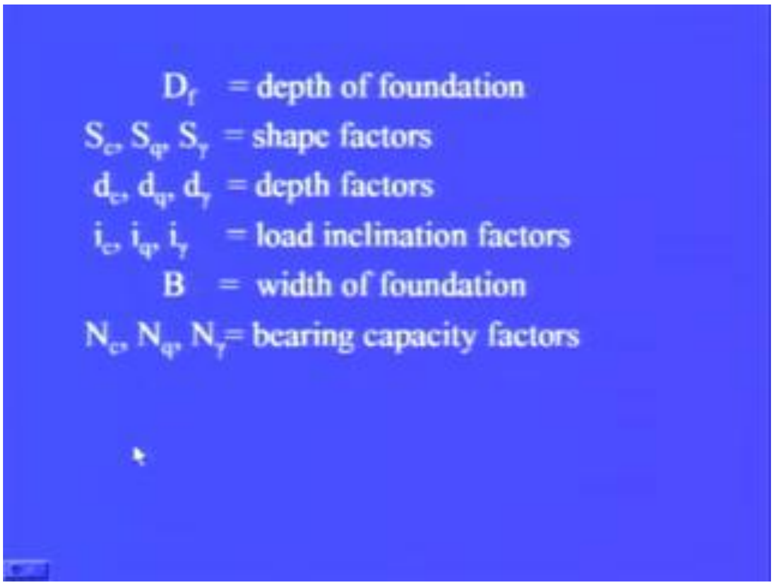

Df is the depth of foundation Sc Sq S gamma are the shape factors, dc dq d gamma are the depth factors, ic iq I gamma are the load inclination factors, B is the width of foundation and Nc Nq and N gamma are the bearing capacity factors.

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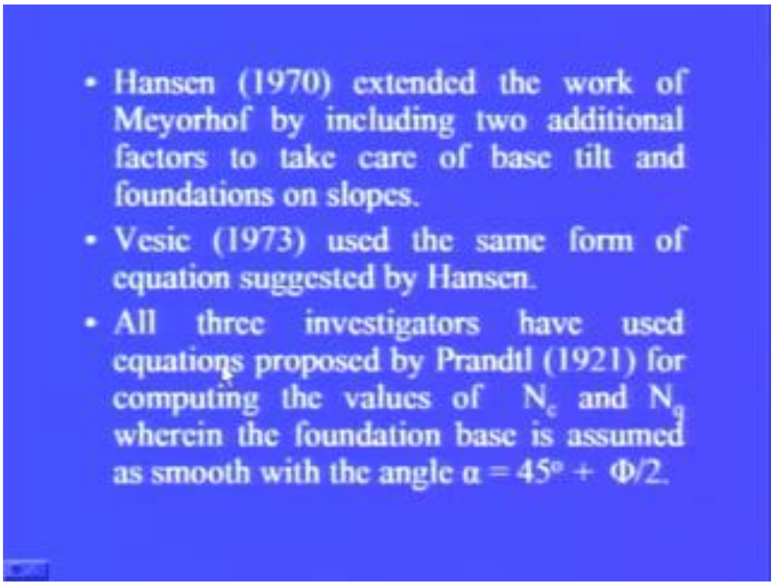

Hansen in 1970 extended the work of Meyerhof by including 2 additional factors to take care of the base tilt and the foundations on slopes. Another researchers Vesic in 1973 used the same form of equation, suggested by Hansen all 3 investigators have used equations proposed by Prandtl 1921 for computing the values of Nc and Nq. Where in the foundation base is assumed as smooth and it is incline at an the the sides of the wedge are incline at an angle of 45 plus phi by 2.

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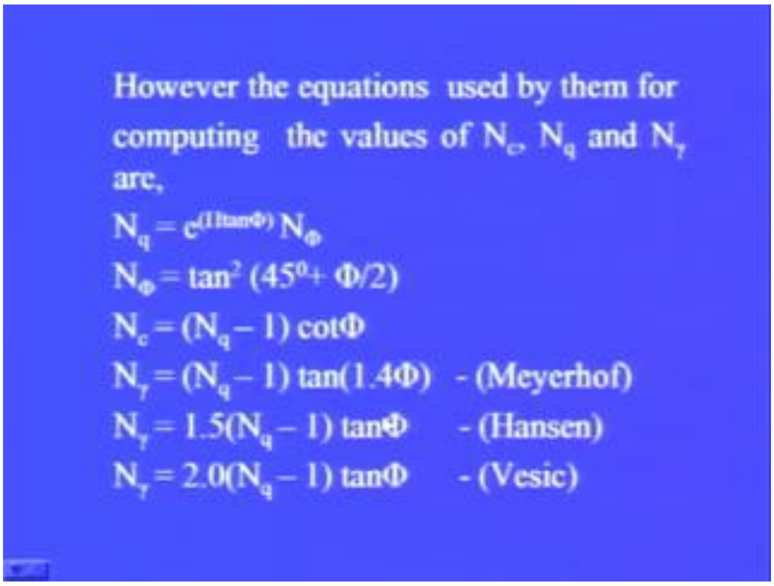

However, the equations used by them for computing the values of Nc Nq and N gamma are slightly different from that of Terzaghi. And are given by like Nq equal to e to the power pi tan phi multiplied by N phi where N phi is tan square 45 plus phi by 2 Nc equal to Nq minus 1 into cot of phi. So, Nq and Nc are similar only difference by different researchers, like Meyerhof Hansen and Vesic are in the value of N gamma as per Meyerhof N gamma equal to Nq minus 1 tan of 1.4 phi. Whereas, as per Hansen N N gamma equal to 1.5 Nq minus 1 tan of phi and as for Vesic N gamma, equal to 2 Nq minus 1 into tan phi.

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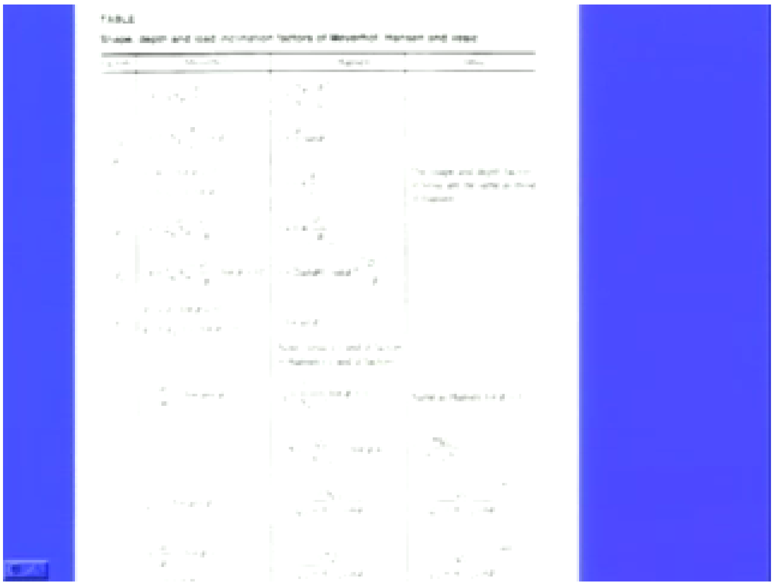

C at Sq and N gamma are given by these equations, like as per Meyerhof Sc is given by 1 plus point 2 N phi B upon L. Whereas, by Hansen it is 1 plus N phi upon Nc B upon L whereas, the shape and depth factors of Vesic are similar to those of Hansen. Similar equations have been given by for Sq, similar equations have been given by S gamma. They have also proposed equations for dc dq and d gamma like 1 plus 0.2 and a root of N phi Df by B is given by Meyerhof 1.4 Df by B is Given by Hansen. Similarly, they have also proposed like this the these 2 equations for dq, and this equations for d gamma. They have included the inclination factors are ic, iq and I gamma like Meyerhof has given this value of ic as 1 minus alpha by 90 square.

Where alpha is the inclination and iq equal to 1 minus iq upon Nq minus 1 for 5 greater than 0, given by Hansen. And for 5 equal to 0 it is 0.5 1 minus Qh upon Af into ca to the power half for 5 equal to 0. Whereas, Hansen has given 1 minus Nqh upon Af ca into Nc. So, similar expressions have been suggested by Meyerhof Hansen and Vesic for Iq expression is like this, for I gamma expression is like this. So, using this table, we can find out the inclination factors the safe factors. And depth factors, which are to be used in the general bearing capacity equation the different terms which have been used in calculating the parameters are given as follows?

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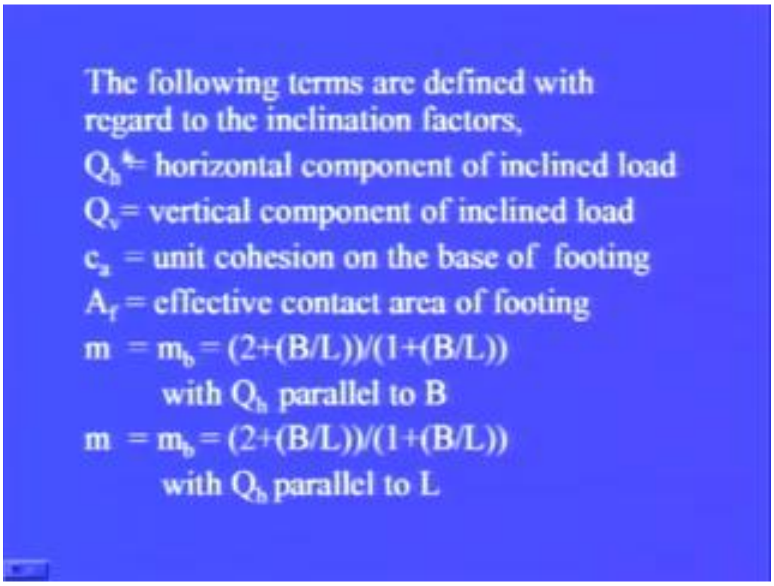

Like Qh is the horizontal component of the inclined load, Qv is the vertical component of inclined load, ca is the unit cohesion on the base of the footing. Af is the effective contact area of the footing, m equal to mb is given by this particular equation which says 2 plus B upon L divided by 1 plus B by L with Qh parallel to B and if Qh is parallel to L. Then it will be m equal to mb 2 plus B upon L plus 1 divided by 1 plus B upon L.

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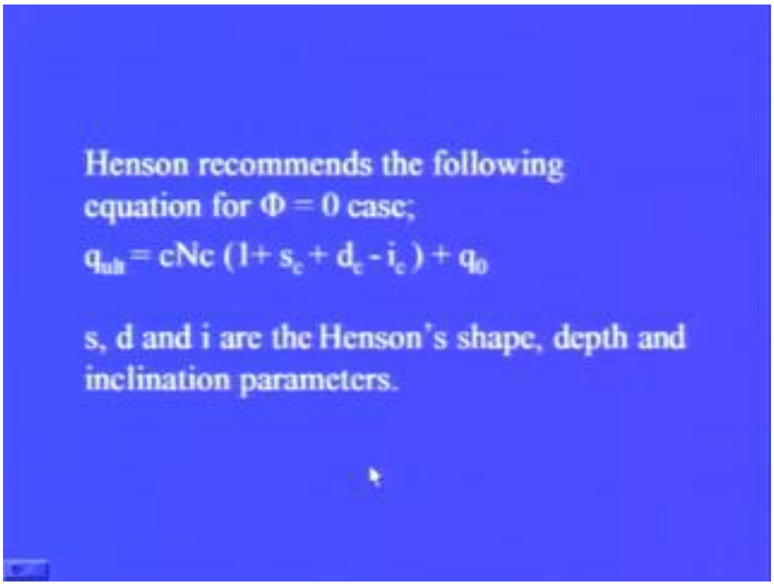

Henson recommends, the following equation for phi equal to 0 case, that is equal to q ultimate cNc in bracket 1 plus sc plus dc minus ic plus q 0. Whereas, d and I are the Henson's shape depth and inclination parameters and these can be read from the table given in the book by V N S Moorthy.

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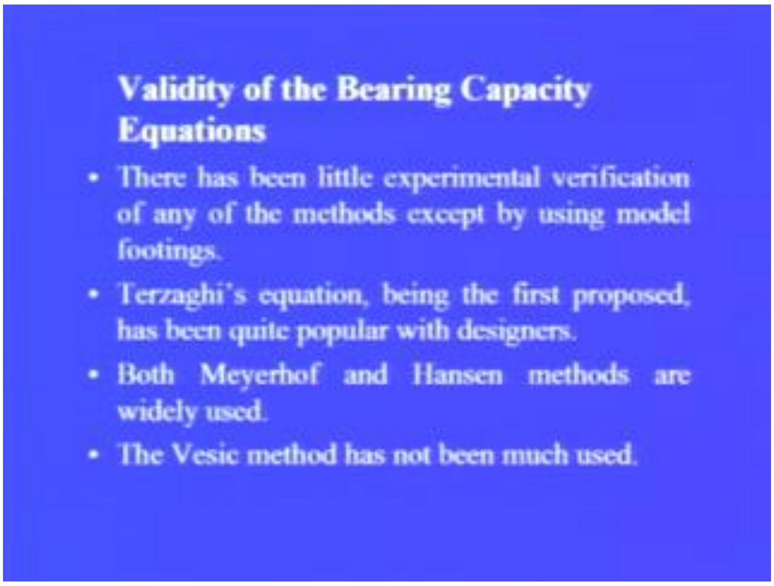

Validity of bearing capacity equations, there has been little experimental verification of any of the methods. Except by using model footings Terzaghi's equation being the first proposed has been quite popular with the designers. Now, both Meyerhof and Hansen methods are widely used the Vesic method has not been much used.

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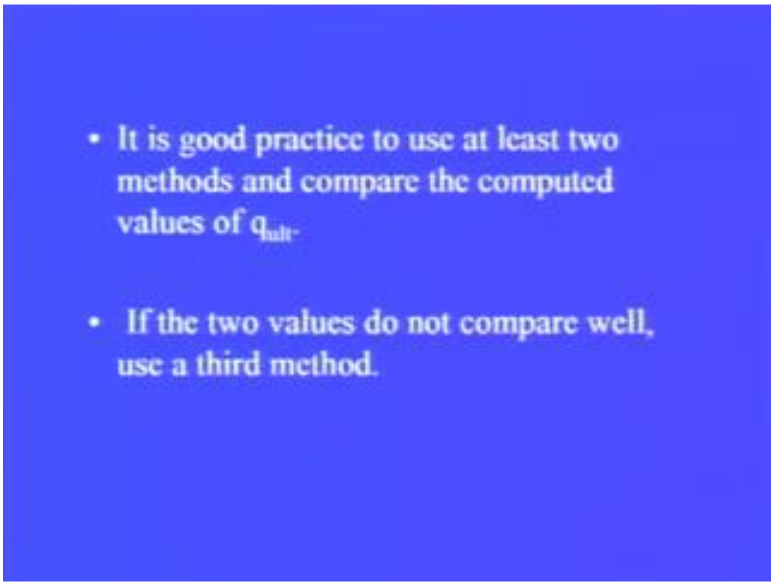

It is a good practice to use at least 2 methods and then compare the computed values of q ultimate. Now, if the 2 method values do not compare well then we use a third method out of these, as I said the Terzaghi bearing capacity equation is widely used.

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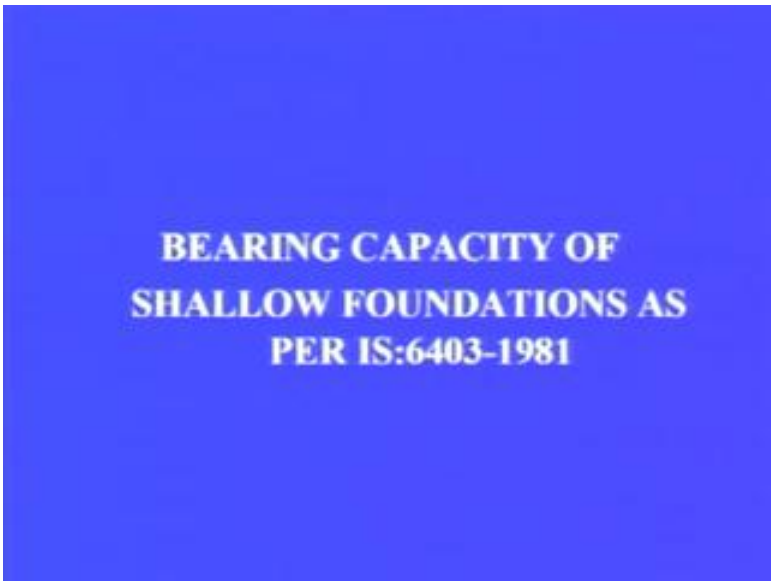

Now, as per our Indian Standard 6 4 0 1 9 8 1, they have consider the equation which was given by Brinch and Hansen.

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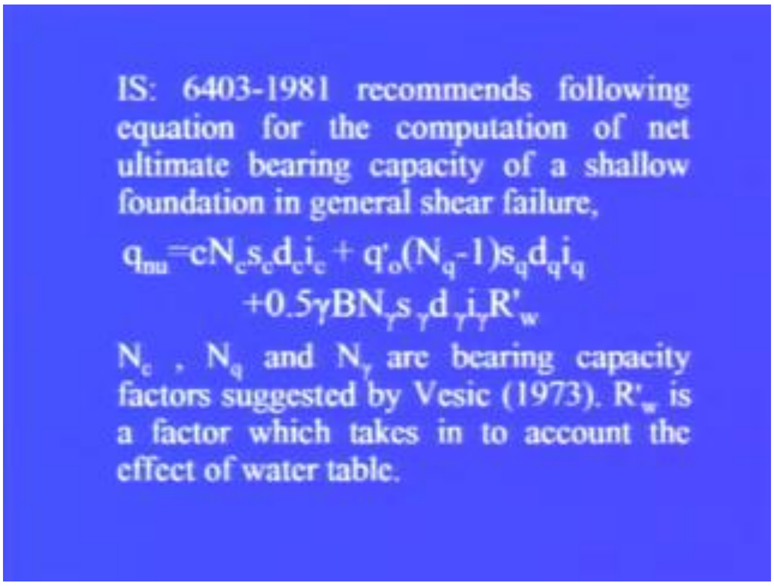

And that equation is recommended for, used to determine net ultimate bearing capacity of a shallow foundation, in the case of a general shear failure case. And this equation is q net ultimate equal to cNc plus sc dc ic plus q 0 dash. Where this is the effective overburden pressure at the level of foundation Nq minus 1 sq dq iq plus 0.5 gamma, B N gamma, s gamma, d gamma, I gamma and Rw Rw dash. That is the reduction factor for water table or correction factor for the water table. Now, all these safe factors are given in the tabular form in IS 6 4 0 1 9 8 1. So, here again Nc Nq and N gamma are the bearing capacity factors, that are suggested by Vesic and Rw dash is a factor which takes into account the effect of water table.

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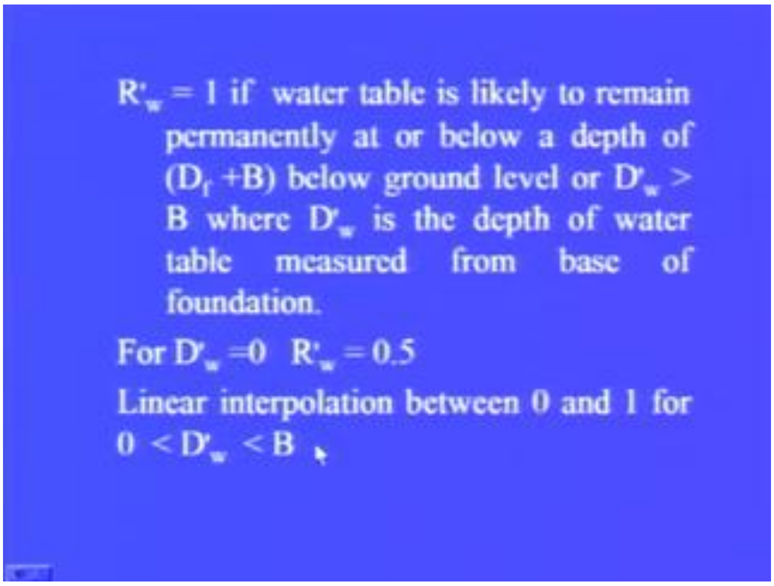

Rw will Dash will be equal to 1, if water table is likely to retain permanently at or below a depth of Df plus B means, at a large depth below the ground level or Dw dash is greater than B. Where Dw dash is the depth of water table measured from the base level of foundation. For Dw dash equal to 0 means the water table is just at the level of foundation then this Rw dash is taken at equal to 0.5. Now, for the intermediate values we can use linear interpolation between 0 and 1, when the Dw dash is ranging between 0 and width of the foundations. So, this is the width and we will have to go up to the width of the depth equivalent to width of the foundation.

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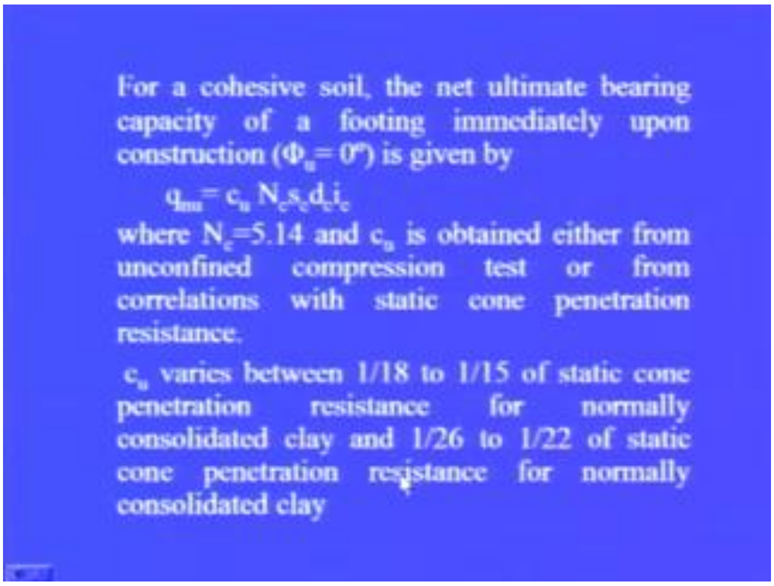

For a cohesive soil, the net ultimate bearing capacity of a footing immediately, upon construction immediately, upon construction, we know that the undrained conditions prevail. So, we take phi u equal to 0 and for that case this net ultimate bearing capacity will be given by cu Nc sc dc ic. Where Nc is taken as 5.14 and cu is obtained either from the unconfined compression test or from correlations with static cone penetration resistance, that is of field method to determine the resistance of the strata. Cu varies between 118 to 115 of static cone penetration resistance for normally consolidated clay whereas; it is 126 to 120 second of static cone penetration resistance value for over consolidated clays.

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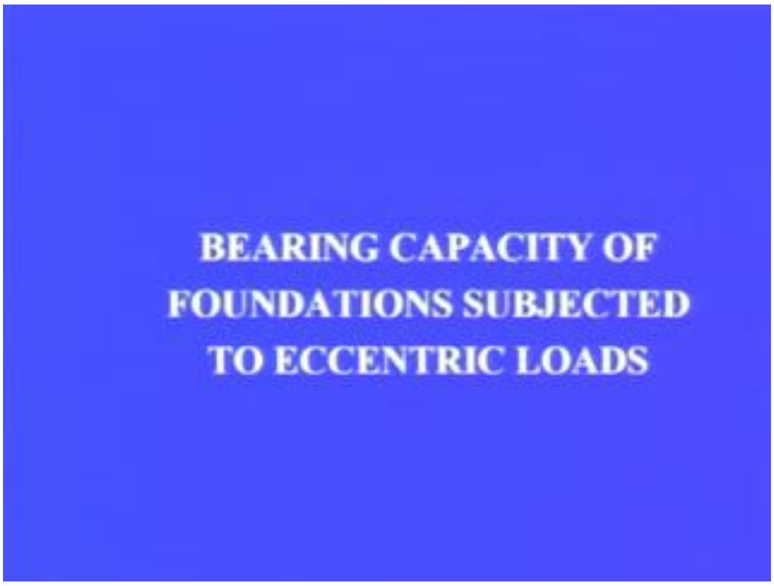

Now, so for we have considered the case of the foundations, in which the load is vertical, application of the load is vertical. However, inclination factor, inclination parameters given by Meyerhof Hansen and Vesic can be used for inclined loads. But when there are many situations, in which we get the load, which is applied on the foundation eccentrically.

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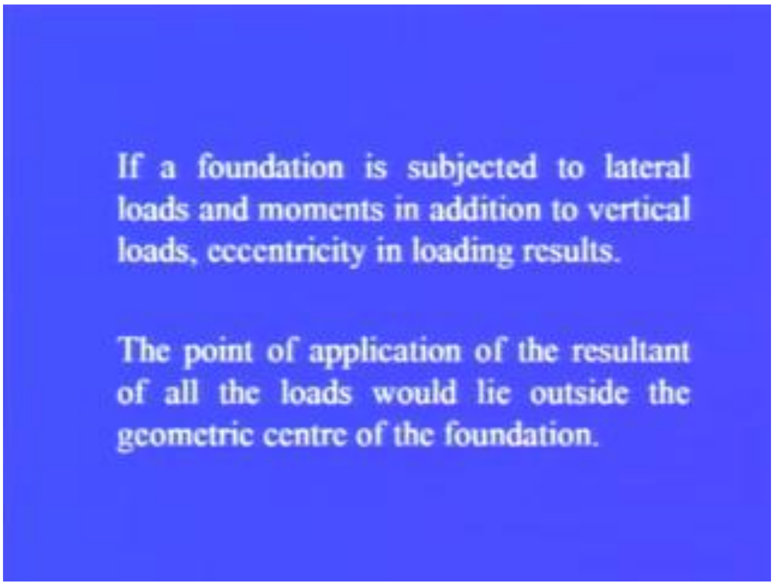

So, in order to determine bearing capacity of foundations subjected to eccentric loads like due to such as if a foundation is subjected to lateral loads and moments in addition to vertical loads, eccentricity in loading results. It may be inclined load or it may be a moment, which is acting on the column. And then finally, foundation is subjected to that moment, the point of application of the resultant of all the loads, would lie outside the geometric centre of the foundation.

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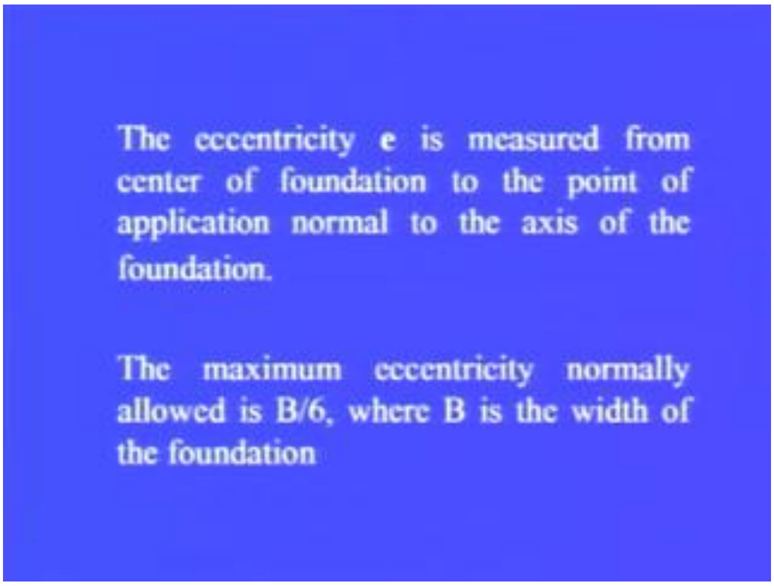

The eccentricity e is measured from the center of foundation to the point of application. Normal to the axis of the foundation the maximum eccentricity normally, allowed is B upon 6, where B is the width of the foundation.

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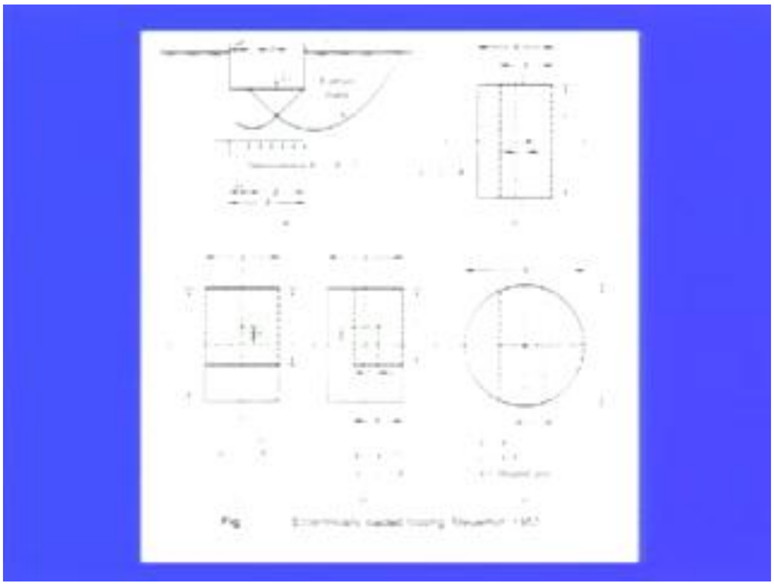

Now, we can see from this particular figure, let us take the case of a foundation, which is resting at this particular depth. Now, this load Qd, which is applied not applied at the center, but it is centrically placed at this particular location. So, the eccentricity measured is e. Now, when this, when this eccentric load is applied then the pressure, which is exhausted on the side of the eccentricity is more than the pressure exhausted on the other side. And this becomes effective the width of the footing becomes, effective that comes out to be B dash minus 2 e. Now, the same case you can see for in the plan let us say we have a rectangular footing and eccentricity is in the direction of the width.

So, length will remain as it is, but width will be reduced by B minus 2 e, if this is e then it will come out to be 2 e. Now, in another case, let us say that the eccentricity is applied in the direction of the length. Then the effective length will be equal to L minus 2 ey, where ey is the eccentricity, which is measured from the center of this foundation. Now, it is quite possible, that the load, which is applied may be eccentric in both the directions. Like, if you have this point and this is the center of the footing, then this ex in the x direction. That is the in the width direction and ey is in the y direction, that is in the case of length direction similar is the case, when the circular foundation is considered.

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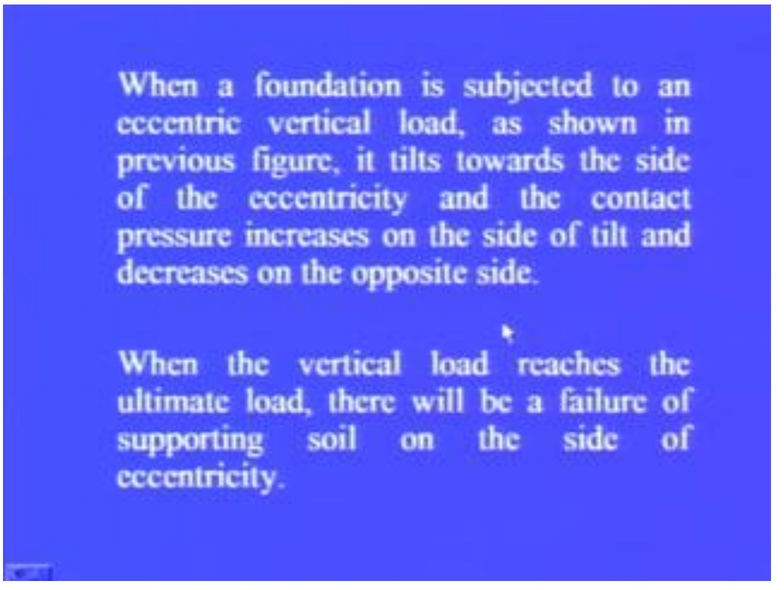

So, when a foundation is subjected to an eccentric vertical load as shown in previous figure, it tilts towards the side of the eccentricity. And the contact pressure increases on the side of tilt and decrease on the opposite side. Now, when the vertical load reaches the ultimate load, there will be a failure of supporting soil on the side of the eccentricity.

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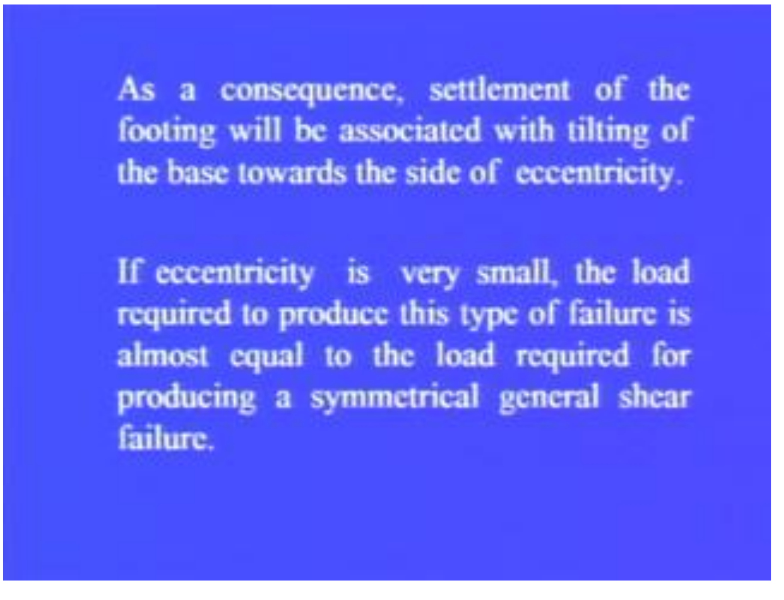

As a consequence, settlement of the footing will be associated with tilting of the base towards, the side of eccentricity. If eccentricity is very small the load required produce, this type of failure is almost equal to the load required, for producing a symmetrical general shear failure.

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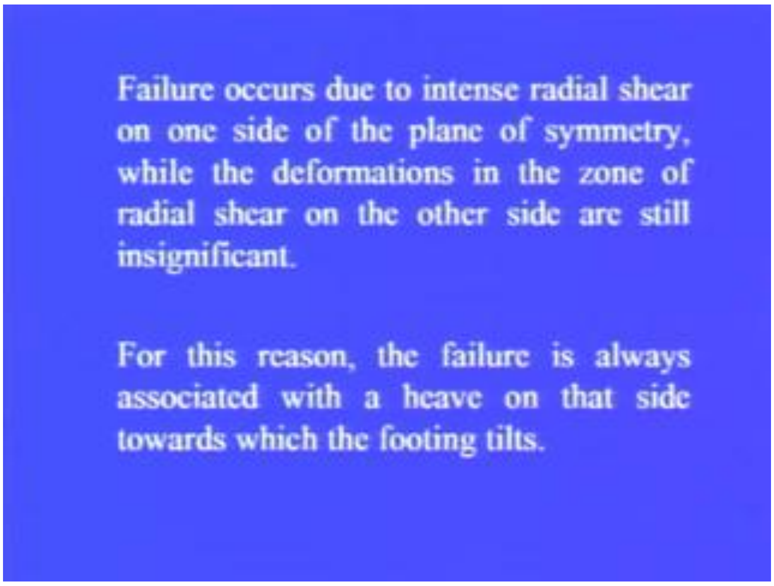

Failure occurs, due to the intense radial shear on 1 side of the plane of symmetry. While the deformations in the zone of radial shear on the other side are still insignificant for this reason, the failure is always associated with a heave on the on that side towards, which the footing is tilting.

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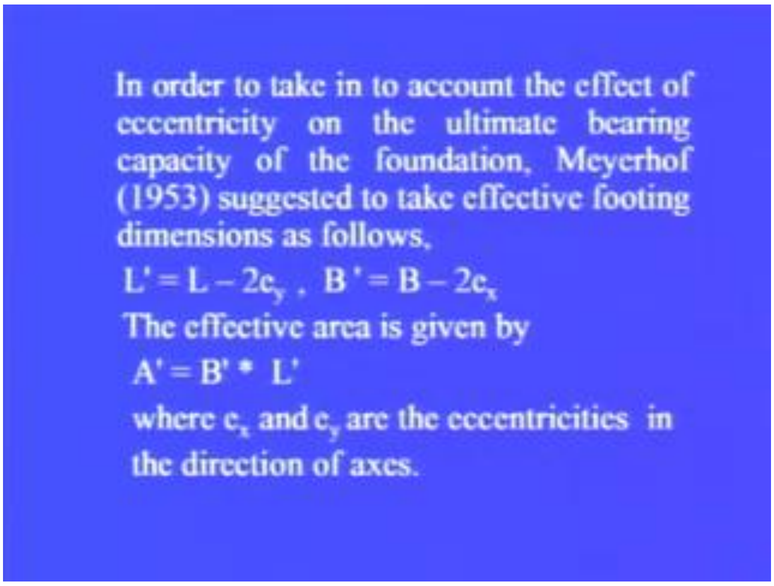

In order to take into account, the effect of eccentricity, on the ultimate, bearing capacity of foundation, Meyerhof suggested to, take effective footing dimensions as follows. If the eccentricity is on the length direction, then and if, suppose the load is acting at a distance of e by from the center of the footing L dash will be written as L minus 2 ey, whereas, if it is in the width direction. And if the load is acting on at a distance of ex from the center, then the effective width will be given by B minus 2 ex. Now, if it is, eccentric in both the directions, so, we will be considering this effective length and then effective width. So, the effective area will simply be given by B dash into L dash, where ex and ey are the eccentricities in the direction of the axes.

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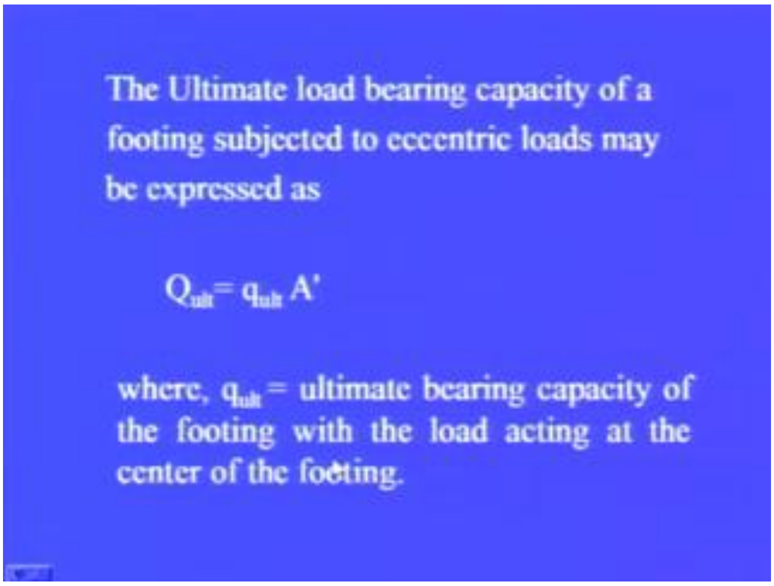

The ultimate load bearing capacity of a footing subjected to eccentric loads may be expressed as Q ultimate. That will be equal to q ultimate bearing capacity and this is the Q ultimate load multiplied by the effective area.

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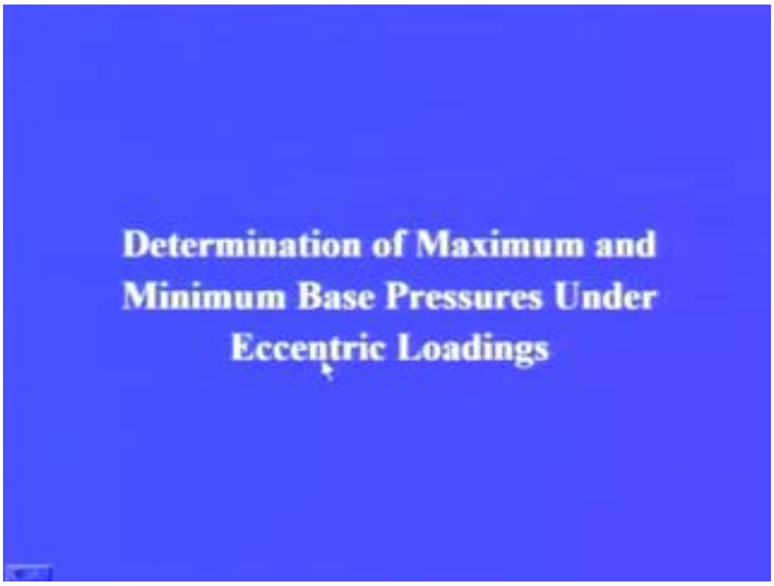

Now, in order to determined, a maximum and minimum base pressures, base pressures under eccentric loading.

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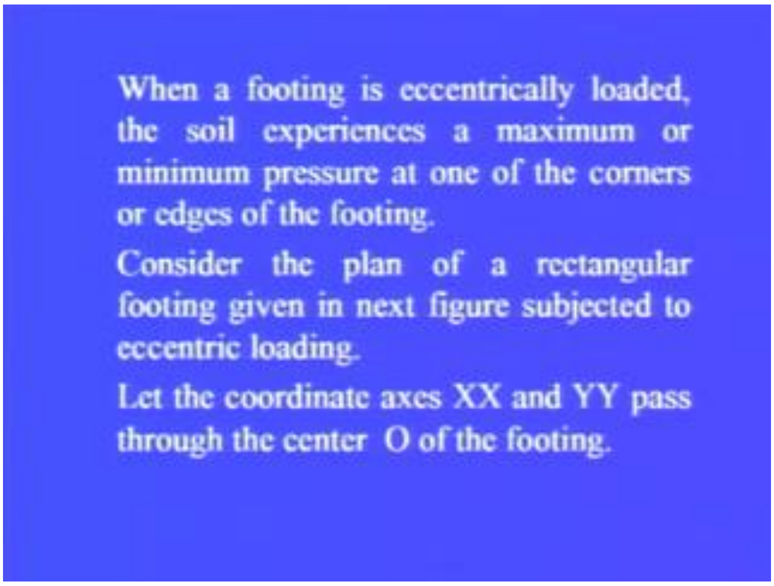

Now, when a footing is subjected to eccentrically loaded the soil experiences as we have seen a maximum or minimum pressure, at one of the corners or edges of the footing. Now, let us, consider the plan of a rectangular footing, given in the next figure subjected to eccentric loading. Let the coordinate axis are XX and YY pass through the center O of the footing.

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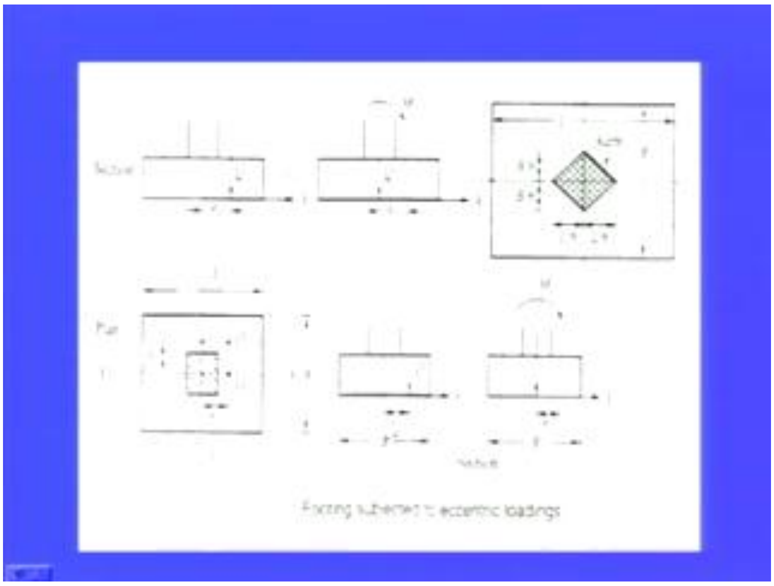

So, this is the case of a rectangular footing the dimensions are L and D and the, a coordinate axis are XX and YY passing through center of the footing. Now, corresponding elevation is shown here now it is the case when this load is acting a the eccentricity may be resulting due to the load which is acting at a distance ex in the direction of x. Or it may be resulting due to load is applied from a at the center, but there is a moment mx which is acting in this direction. So, there will be eccentricity e y. similar to this is the case when the load there is 2 way eccentricity in the x direction.

As well as in the y direction when this particular foot, footing foundation is subjected to the moments in both the directions or the load is not applied at the center. And it is at a distance of ex from the in the x direction and it at a distance of ey from the y direction. Now, here you can see that there is a dashed area shown in which this allowed it eccentricity is B by x B by 6 shear and B by 6 on the other the side. Similarly L by 6 shear and L by 6 on the other side this area is known as cone as for as the bearing cap the load is applied within this area. Then you will find that no tension is developed anywhere in the foundation which will be more made more clear by the following discussion.

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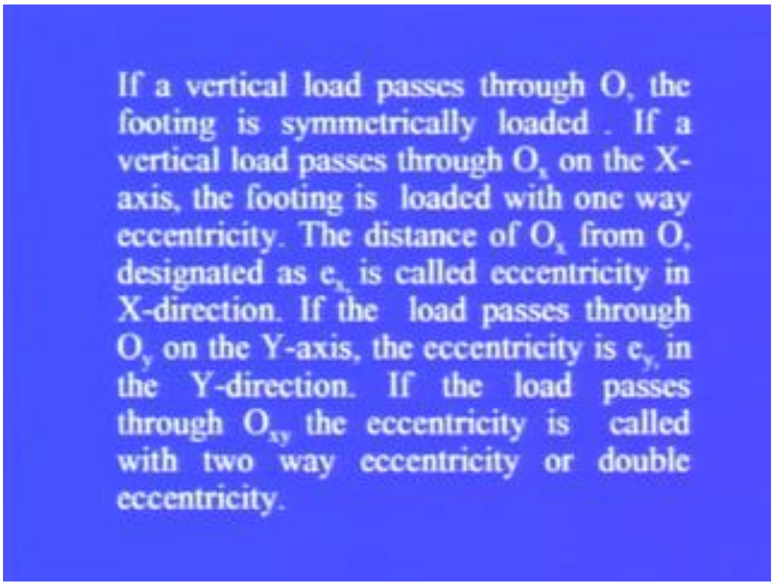

If a vertical load passes through O the footing is symmetrically loaded if a vertical loaded passes through Ox on the X axis the footing is loaded with 1 way eccentricity. The distance of Ox from O is designated as ex is called the eccentricity in the X direction. Similarly, if the load passes through Oy on the Y axis the eccentricity is ey in the Y direction if the load passes through Oxy the eccentricity is called with 2 way eccentricity or double eccentricity as we have seen in the previous figure.

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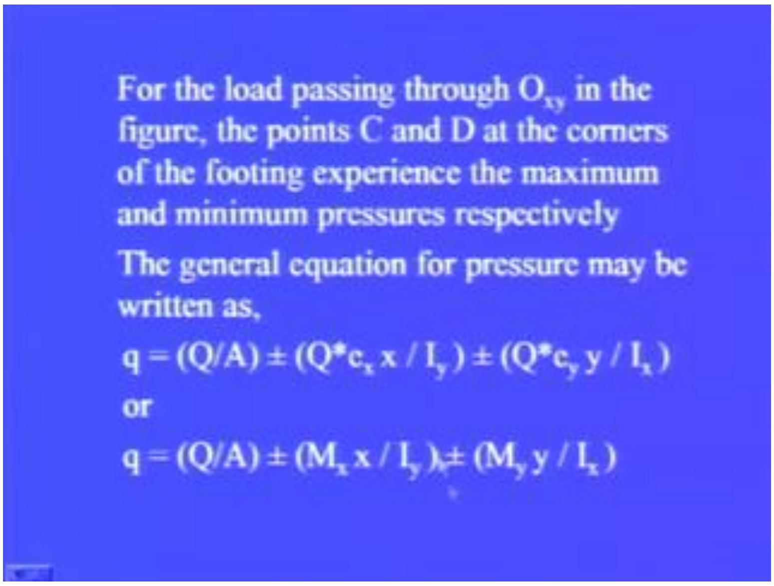

Now, for the load passing through Oxy in the figure the point C and D at the corners of the footing experience the maximum and minimum pressure respectively. And these maximum and minimum pressures can be determined by following equation where q is the pressure Q is the load A is the area and ex and ey are the eccentricities and Ix and Iy are the moment of inertia. So, this q will be given by Q upon A plus minus Q into ex into x upon Iy plus minus Q into ey into y upon Ix or Q upon A equal to q equal to Q upon A plus minus Mx into x where Mx is the moment. So, here this Q into ex is nothing but the moment which is applied in the x direction similarly Q into ey is nothing but my which is applied in the y direction.

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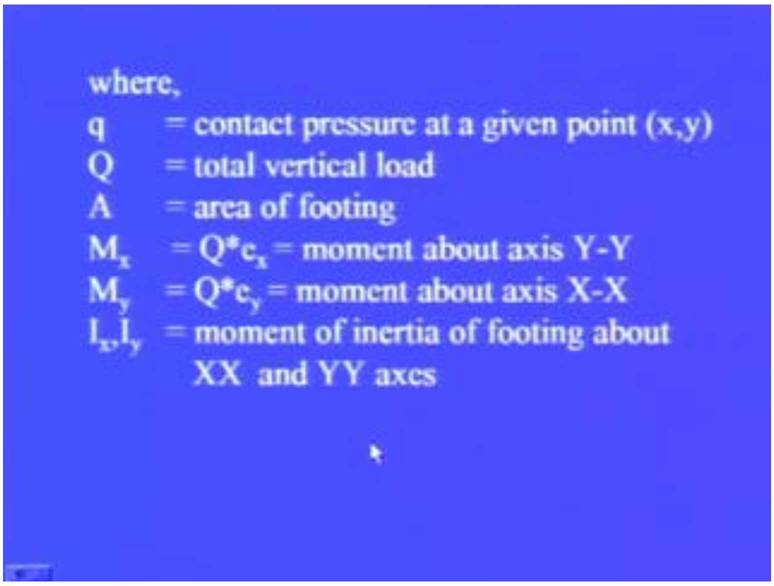

So, these are self exploratory q equal to contact pressure at a given point whose coordinates are given by x. And y Q is the total vertical load A is the area of footing Mx is the Q into ex moment about axis YY My is Q into ey. That is the moment about axis XX and Ix and xy are the moment of inertia footing about XX and YY axis.

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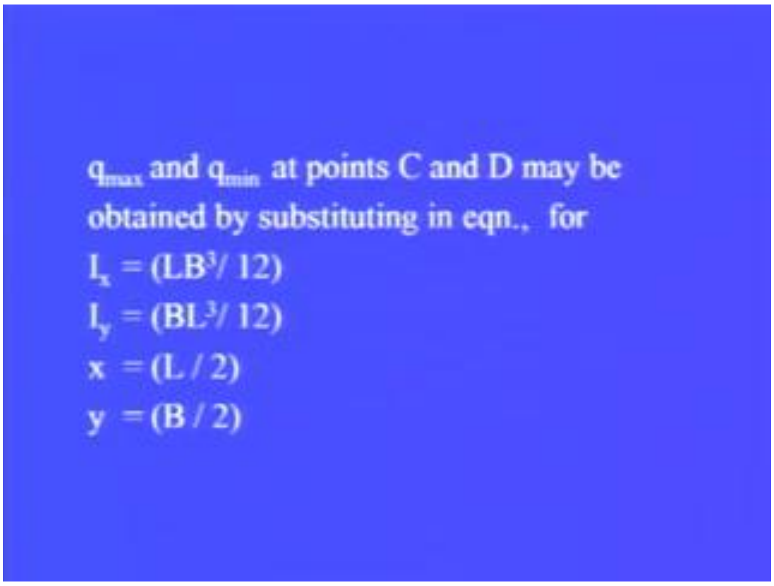

Q max and q minimum at point C and D may be obtained by substituting in equation for Ix that is equal to LB cube upon 12 and Iy that is equal to BL cube upon 12 x equal to L by 2 and y equal to B by 2.

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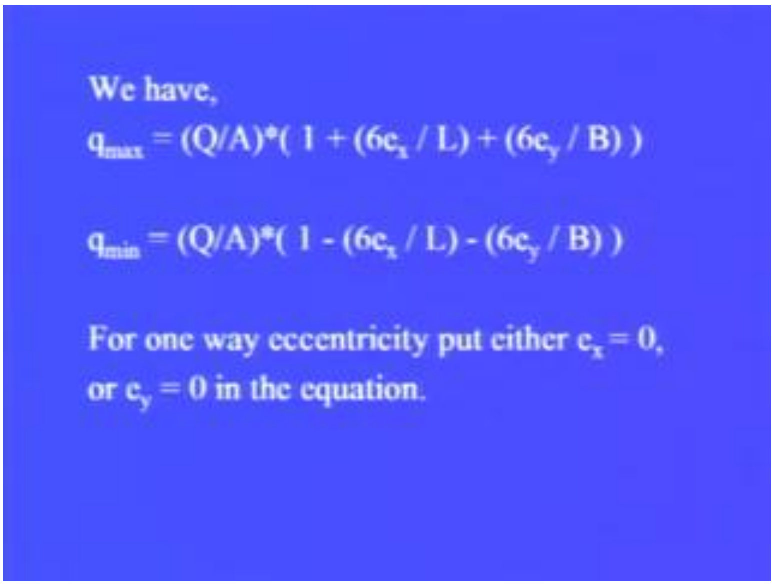

When we substitute these values, we will get q max as Q upon A 1 plus 6 ex upon L plus 6 ey upon B q minimum will be equal to Q upon A 1 minus 6 ex upon L minus 6 ey upon B. For one way eccentricity put either ex equal to 0 or B ey equal to 0 in the equation we will get q max and q minimum.

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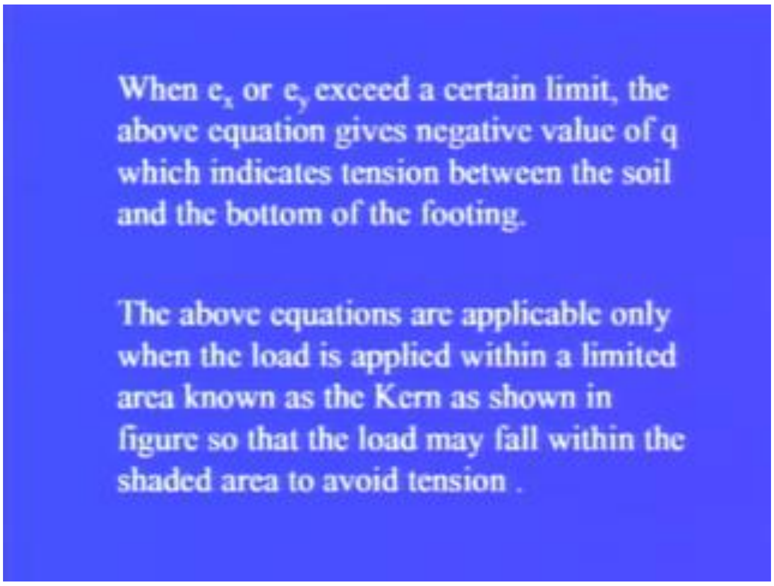

When ex or ey exceed a certain limit the above equation gives negative value of q which indicates tension between the soil. And the bottom of footing the above equations are applicable only when the load is applied within a limited area known as the Kern as shown in the figure. So that the load may fall within the shaded area to avoid any tension in the subsoil.

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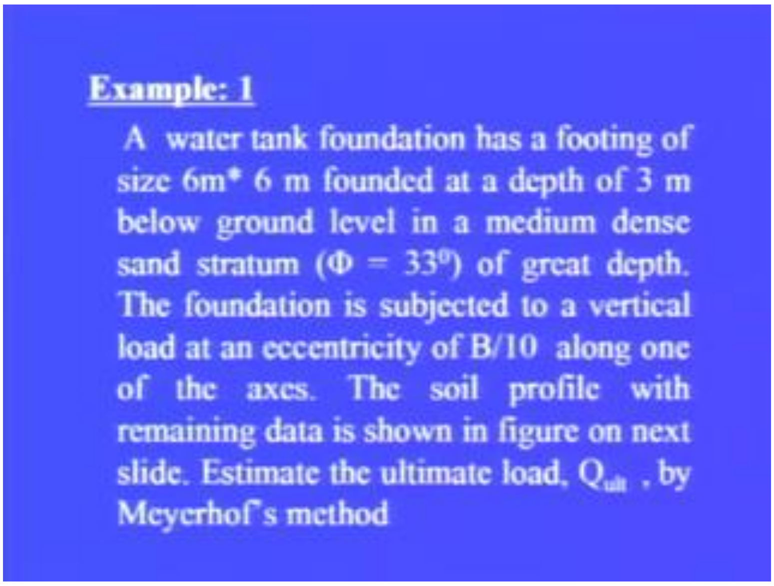

Now, we can discuss the, this with an example. Let us consider and this example in which a water tank foundation has a footing of size 6 meter by 6 meter founded at a depth of 3 meter below ground level in medium dense sand for which phi equal to 33 degrees. That is extending up to a great depth the foundation is subjected to a vertical load at an eccentricity of b upon 10 along one of the axis the soil profile with remaining data is shown in figure on the next slide. Estimate ultimate load Q ultimate by Meyerhof method.

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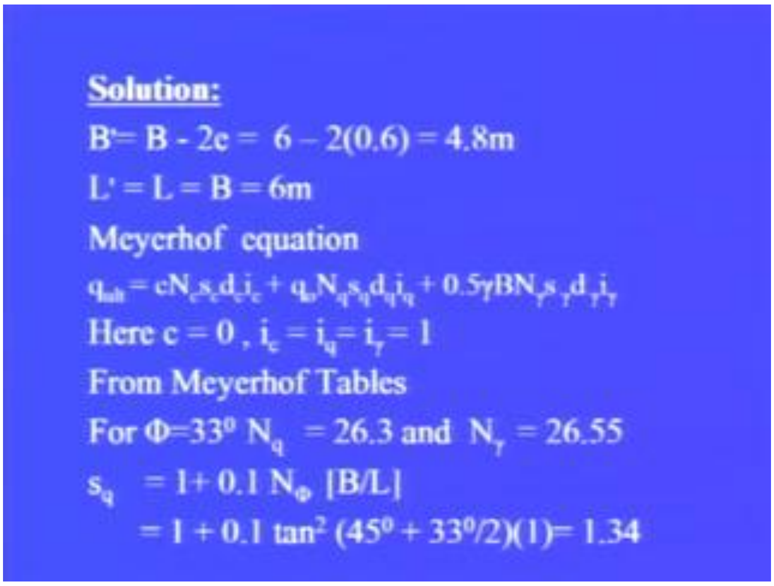

So, in order to get the solution B dash can be determined as B minus 2 e 6 minus 2 into point 6 that is equal to 4.8 meter L dash will remain as it is, because it is eccentric only in the width direction. So, L dash equal to L that is equal to B because it is a square foundation equal to 6 meter. And the Meyerhof equation is given by cNc sc dc ic plus q 0 Nq sq dq iq plus 0.5 gamma B N gamma s gamma I gamma d gamma here c equal to 0. So, ic equal to iq equal to I gamma equal to 1 from Meyerhof tables for phi equal to 33 degrees Nq comes out to be 26.3 and N gamma equal to 26.55 sq will be equal to 1 plus 0.1 N phi B upon L where phi equal to 33 degrees. And phi equal to tan square 45 plus phi by 2. So, substituting value of phi we will get this sq as 1.34.

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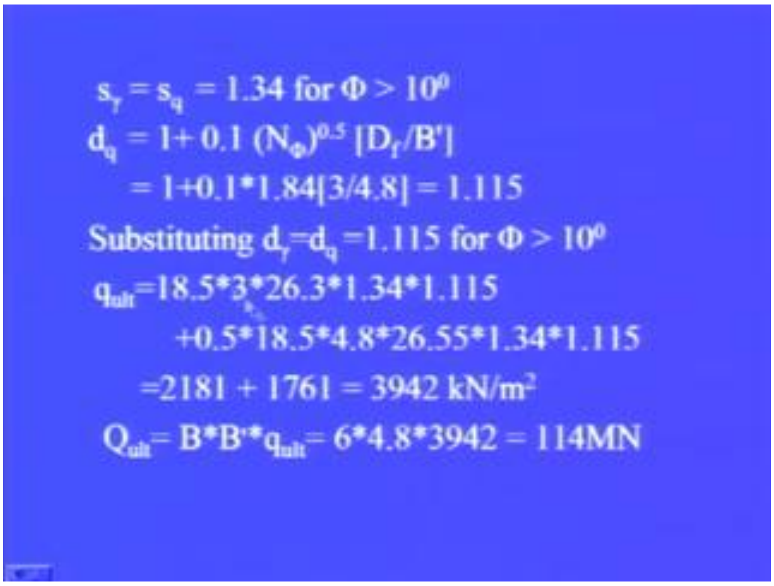

S gamma and sq will be equal to 1.34 for phi equal phi greater than 10 degrees and dq will be equal to 1 plus point 1 N phi to the power 0.5 Df upon B dash. So, here this is 1045 plus phi by 2 1 plus 0.1 when we substitute these values we will get dq as 1.115. Now, substituting d gamma equal to dq equal to 1.115 for phi greater than 10 degrees in the ultimate bearing capacity equation, we will get ultimate bearing capacity as 3942 kilonewton per meter square. And hence the ultimate load that will be equal to B into B dash here this is the effective area. And this effective area is reduced due to the eccentricity multiplied by ultimate bearing capacity. And that comes out to be 114 Mega Newton.

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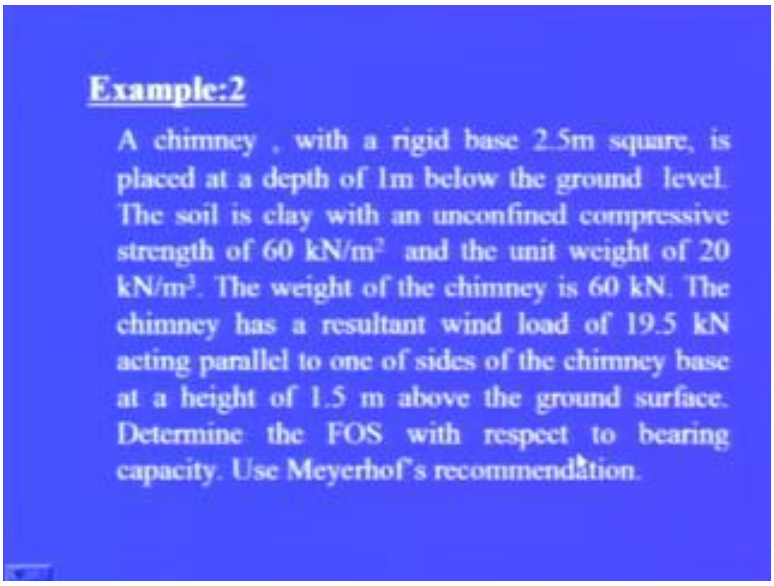

There is another example of eccentricity a chimney with a rigid base 2.5 meter square is placed at a depth of 1 meter below the ground level. The soil is clay with an unconfined compressive strength of 60 kilonewton per meter square. And the unit weight of is 20 kilonewton per meter cube the weight of the chimney is 60 kilonewton. The chimney has a resultant wind load of 19.5 kilonewton acting parallel to 1 of the sides of the chimney base at a height of 1.5 meter above the ground surface. So, that we can find out what will be the moment? Determine the factor of safety with respect to bearing capacity again using Meyerhof recommendations.

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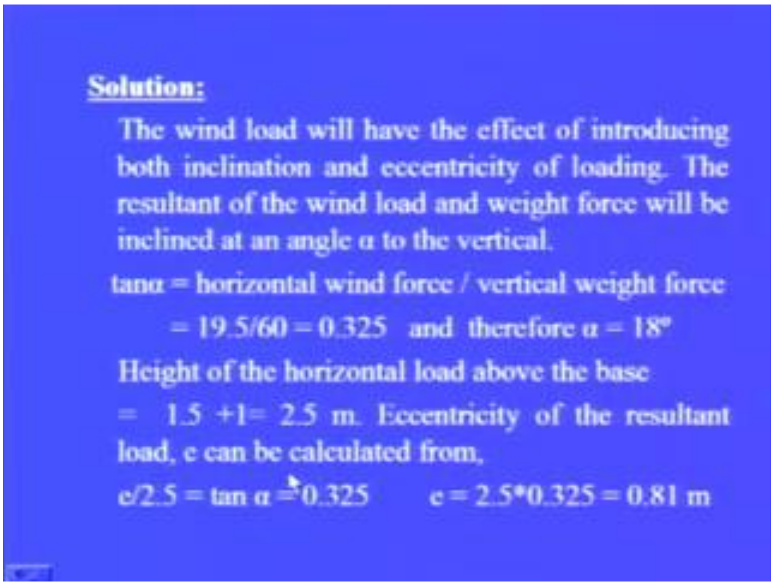

Now, the wind load will have the effect of introducing both inclination and eccentricity of loading the resultant of the wind load. And the wind force will be inclined at an angle of alpha to the vertical where this alpha will be given by this particular equation tan alpha equal to horizontal wind force divided by vertical weight force that will be 19.5 divided by 60 equal to 0.325. And therefore, alpha equal to tan inverse of 0.325 comes out to be 18 degrees. Height of the horizontal load above the base of the footing is 1.5 plus 1. That is the depth equal to 2.5 meter eccentricity of the resultant load e can be calculated from e upon 2.5 equal to tan of alpha equal to 0.325 which we have obtained from here. So, e can be taken calculated as 0.81 meter.

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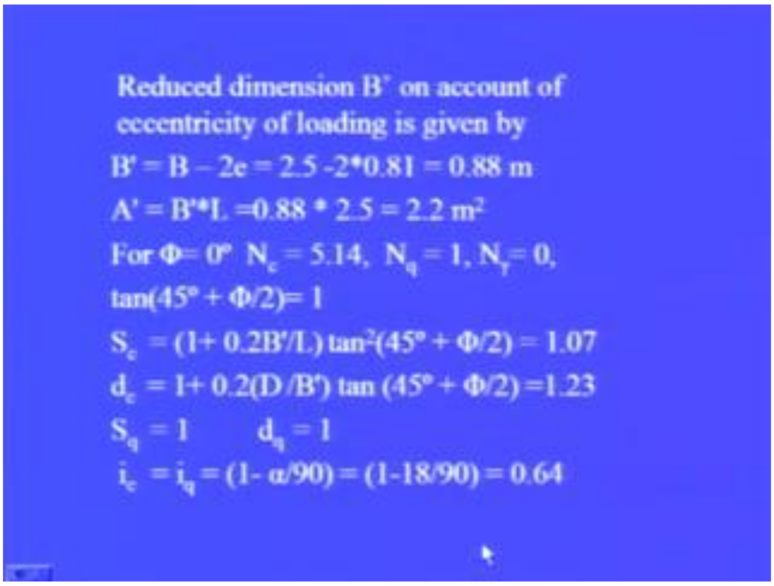

Once e is known we can find out reduced dimension B dash and that B dash will be equal to B minus 2 e. So, substitute value of eccentricity here that is 0.2 8 0.81, you will get B dash equal to 0.88 meter and effective area will be equal to B dash into L 0.88 into 2.5 that is equal to 2.2 meter square. Now, for phi equal to 0 Nc will be equal to 5.14 Nq equal to 1 and N gamma equal to 0 tan of 45 plus phi by 2 equal to 1 sc by using different equations suggested by Meyerhof. We can find out sc that comes to be 1.07 dc that comes out to be 1.23 and sq equal to 1 dq equal to 1. Similarly, we can also obtain inclination parameters ic and iq both are equal equal to 1 minus alpha by 90 and when we substitute value of alpha we will get this as 0.64.

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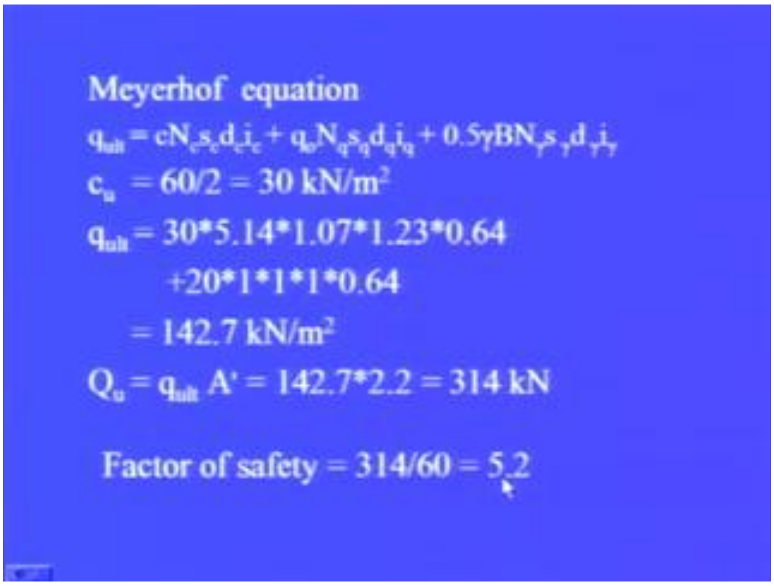

When we substitute all these parameters in the Meyerhof equation which is given by cNc sc dc ic plus q 0 Nq sq dq iq plus 0.5 gamma B N gamma s gamma d gamma. And I gamma cu is equal to 60 by 230 kilonewton per meter square based on the unconfined compressive strength q ultimate. When you substitute all these values here we will find that it comes out to be 142.7 kilonewton per meter square. And hence the ultimate load is equal to ultimate bearing capacity multiplied by effective area and that comes out to be 314 kilonewton. Now, for a factor of safety we will get the factor of safety we will get as 314 divided by 60 that is equal to 5.2. So, the factor of safety for this particular case will be 5.2.

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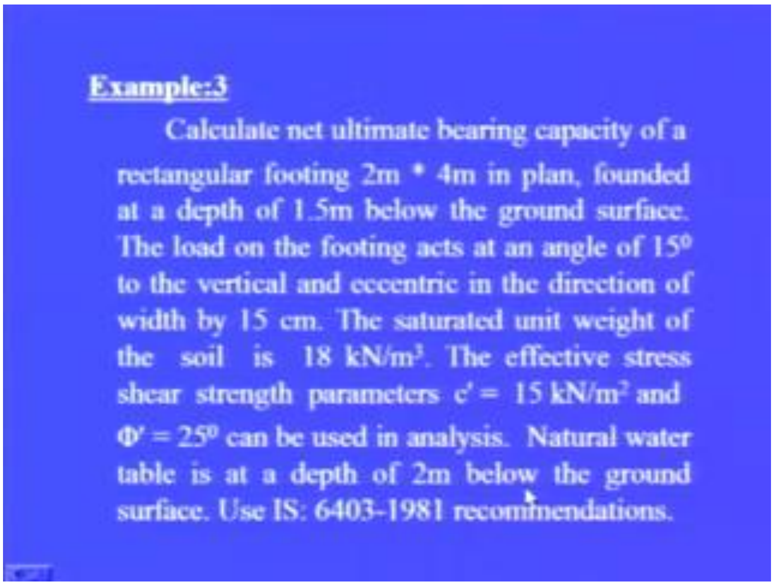

Now, another example calculate net ultimate bearing capacity of a rectangular footing 2 meter by 4 meter in plan, founded at a depth of 1.5 meter below the ground surface. The load on the footing acts at an angle of 15 degrees to the vertical and eccentric in the direction of width by 15 centimeter. The saturated unit weight of the soil is 18 kilonewton per meter cube the effective stress shear strength parameters c dash equal to 15 kilonewton per meter square. And phi dash equal to 25 degrees can be used in the analysis natural water table is at a depth of 2 meter below the ground surface. Now, we will have to determine the bearing capacity using the IS 6403 1981 recommendations which we have discussed previously.

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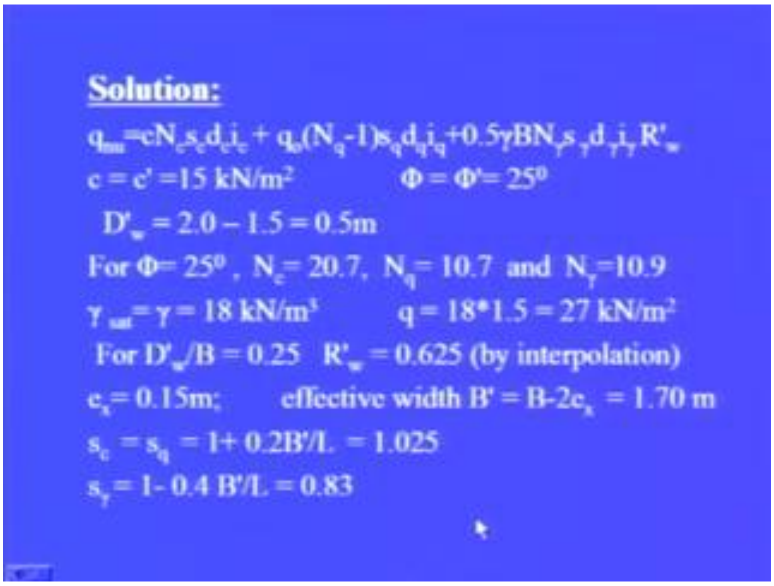

Now, in order to get solution, what we will have to do? We will have to find? All the parameters which are there in the bearing capacity equation like sc dc ic safe factors sq dq iq and s gamma d gamma I gamma and the water table correction factor. Now, c is equal to 15 kilo Newton per meter square phi equal to phi dash. That is given 25 degrees Dw dash is the depth of the water table below the base level of the foundation at that comes out to be 2 minus 1.5 that is equal to 0.5 meter. Now, for phi equal to 25 degrees, we can obtain from the table Nc equal to 20.7 Nq equal to 10.7 and N gamma equal to 10.9 gamma saturated is given as 18 kilo Newton per meter cube.

So, we can find out the, q or q 0 that is equal to 18 into 1.5 that is 27 kilo Newton per meter square. Now, from the graph by interpolation, we can find out the value Rw dash for Dw dash by B ratio equal to 0.2 5 that comes out to be 0. 6 2 5 eccentricity is given in the x direction as 0.1 5 meter 15 centimeter. So, effective width will be equal to B dash minus 2 ex that is equal to 1.7 meter. And safe factor will be given by 1 plus 0.2 B dash upon L here, effective width will be used in the expression and it comes out to be 1.0 2 5 similarly s gamma comes out to be 0.8 3 using this particular expression.

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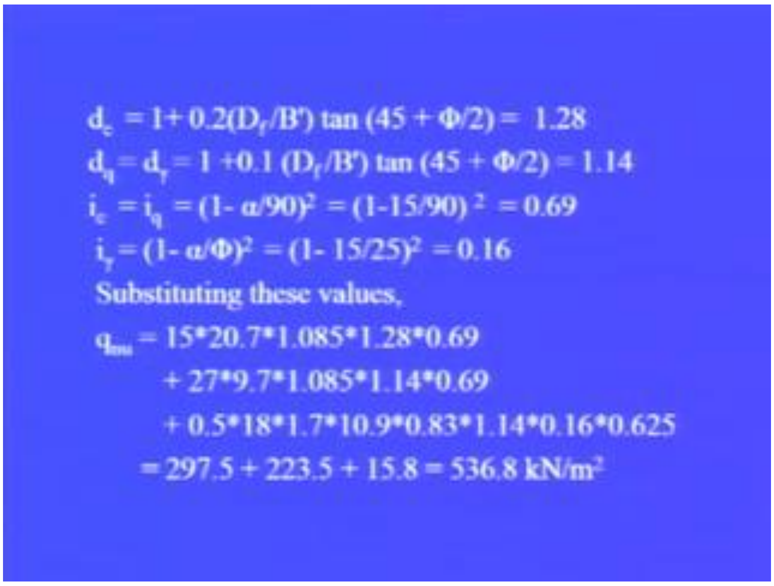

Similarly, if we know phi and different parameters like, depth and width, we can obtain parameters dc dq ic and I gamma. Now, these values can be obtained by respective equations. So, here these comes out come out to be 1.2 8 1, 1.1 4, 0.6 9 and 0.1 6 is respectively, when we substitute these values in the net ultimate bearing capacity equation, when then after calculation. We will get this net ultimate bearing capacity as 536.8 kilo Newton per meter square.

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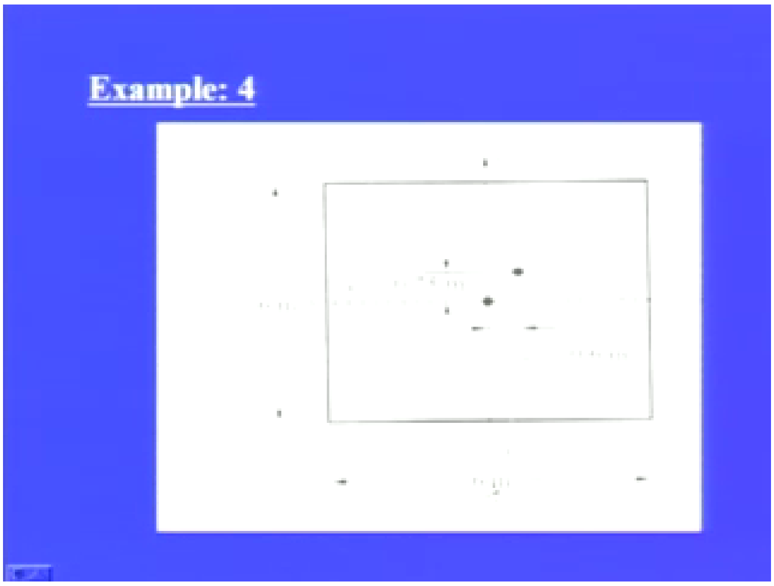

Now, this is another example of 2 way eccentricity now, this is of footing of size 6 meter by 6 meter load is acting here, which is eccentric by 0.75 meter in this direction and by 0.6 meter in the other direction.

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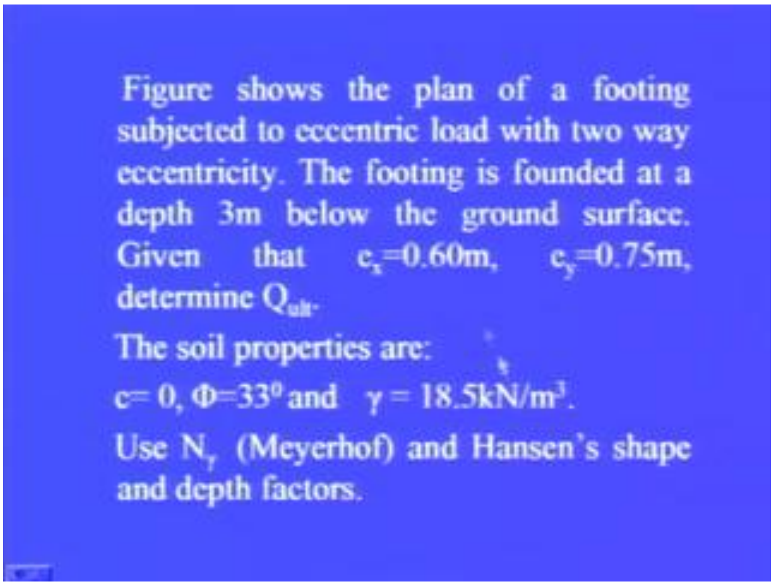

Now, figure shows, the plan of a footing subjected to eccentric load with 2 way eccentricity the footing is founded at a depth of 3 meter, below the ground surface. Given that ex equal to point 6 meter ey equal to 0.75 meter, we will have to determine Q ultimate load. The soil properties are given like this c equal to 0 phi equal to 33 degrees and gamma equal to 18.5. We will have to use N gamma parameter given by Meyerhof and shape and depth factors given by Hansen.

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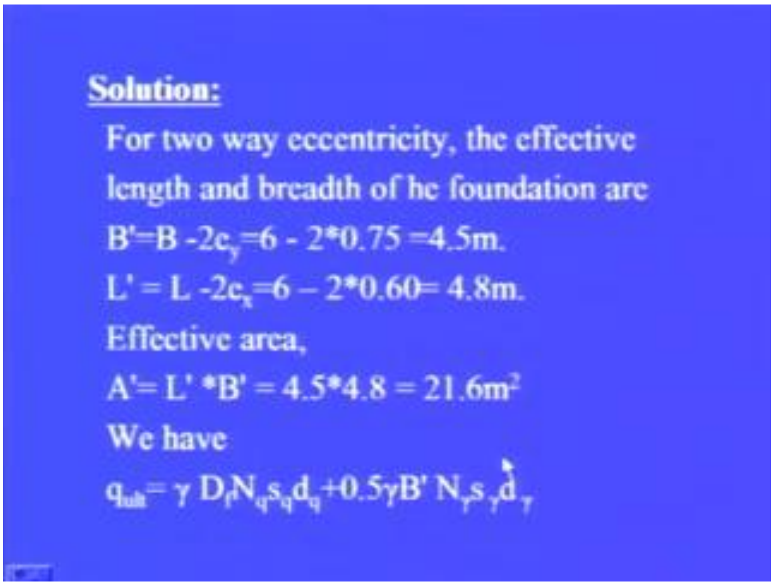

Now, again in the case of 2 way eccentricity, we will have to find out effective width. And effective length which is given by B minus 2 ey L minus 2 ex when we substitute this we will get effective width as 4.5 meter effective length as 4.8 meter. So, effective area is the multiplication of these 221.6 meter and we have the ultimate bearing capacity equation as this.

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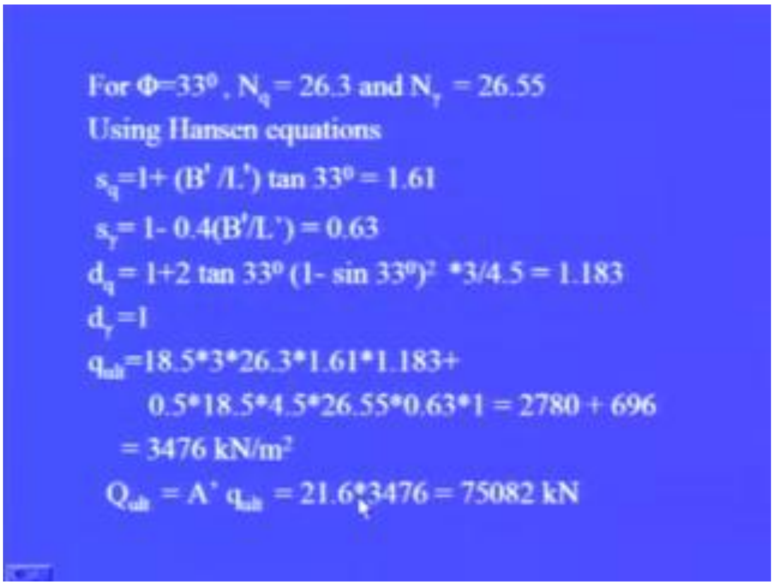

For phi equal to 32 degree 33 degrees we get Nq and N gamma. And using Brinch Hansen equation we can find out sq s gamma dq d gamma. And when we substitute these values in we will get ultimate bearing capacity as 3476 kilonewton per meter square. And hence the ultimate load multiplied by the effective area will be 75082 kilonewton. So, through this lecture we have discuss the modifications made by Meyerhof Vesic and Hansen. They have given safe factors inclination factors and depth factors. And we have also discussed the cases of eccentric loads in which eccentricity is either in one direction. Or maybe two way eccentricity when the footing is subjected to the moments like a ven force. We have also tried to discuss solved problems which will take into account all these factors and also the eccentric loads.

Thank you.