Advanced Foundation Engineering
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Lecture - 9
Shallow Foundation: Bearing Capacity - IV

Hello, now last class I have discussed about the footing, which is loaded eccentrically. I have discussed about the one way eccentricity and two way eccentricity. Now, on this class I will discuss the how to calculate the bearing capacity of the soil in layer condition now, as we know that soil is not a homogeneous soil. Because but but till now the most of the things that I have discussed is to calculate the bearing capacity of homogeneous soil. Now, soil is our layer type of material. So, now the property of the soil according to depth is not same, it is changing. Now, if the soil is the is the condition is the layered condition then how to calculate the bearing capacity of these layered soil, that I will discuss in this class.

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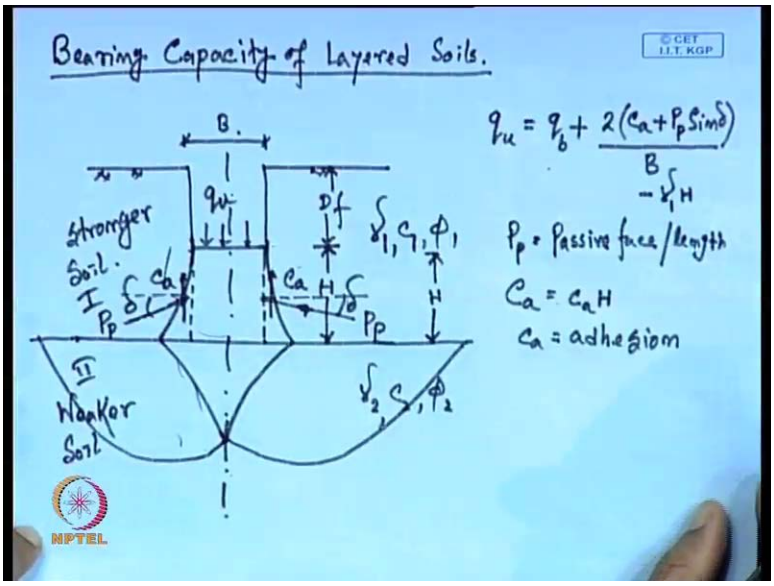

Now, suppose if we go for the bearing capacity of a layered soil system. Now, I will discuss the bearing capacity of layered soil. Now, the the derivation or the expression which is available for this to calculate the bearing capacity of the soil, which is basically for the homogeneous soil. Now, if the soil is in this form that this is the ground surface.

Here we are applying this footing, this is a ground surface and this is width of the footing, and this is the depth of the footing D f. Now, we are considering the two soil layer, this is one layer which is the strong soil, which is stronger soil or layer 1 and layer 2, which is weaker soil. So, this is the stronger soil and this is the weaker soil.

Then how to calculate the bearing capacity of this soil condition and suppose the this is the properties gamma 1 C 1 and phi 1 for the layer is layer 1 and gamma 2 C 2 and phi 2 for layer 2. Now if this stronger soil, if this is the inter phase if the stronger soil and one thing that the depth of this stronger soil from this base of the foundation is H that is the, up to this the up to H depth from the base of the foundation is the stronger soil then weaker soil.

Now, if the depth H is relatively small, then what will happen? Then then there will be a punching type of shear failure for this stronger soil layer and then general shear failure for the weaker soil. So, suppose this is the punching type of failure surface, punching shear failure type of failure surface for this strong soil and then this is the general failure surface which is expected for the weaker surface. So, these type of failure surface that will tabular, so now if I draw one line vertical line. So, what are the forces which is acting suppose in this because here it is the general shear type of failure so that means, we can calculate this is the q bottom or the bottom layer and for this punching shear failure what are the forces that is acting.

So, first is the adjacency a, this is which is acting two side of this layer because suppose this is the one block which is falling or that means, this is the size. Now, another thing the passive resistance the surrounding soil; that will provide for this zone or this zone that is the passive resistance P p, which is acting at angle of delta. Similarly, this side also this is the P p which is acting another angle delta. So, this two types of force which which is these are are acting here both this is the central line. So, one is the adhesion in the both side of this layer and passive resistance coming from the soil of this side and soil from this side which is acting at the angle of delta to the perpendicular of this line. This is P p, P p is the passive resistance. Another thing that if this H value, here if this H which is the distance which is depth of this layer or from the base of the footing is relatively small then we will get this type of failure surface.

Now, if the distance is relatively large then we will get the most of the failure surface will be in the stronger layer. So, the failure surface of the effect of the loading intensity of the footing load will not act suppose this is the footing load that is q ultimate. That effect will not go to the second layer or the weaker soil layer. So, most of the failure surface or will be located at the stronger layer. In that case the general expression for the shear failure expression, general shear failure expression for the or for homogeneous soil or single layer soil that we can use to determine the loading of the or bearing capacity of the soil. Now, if it is relatively small then we will go for this approach. Now, one thing is that that this value. So, if I go for the different loading condition.

So, what will be the different loading condition for this case. So, first we will calculate the q u for the loading condition, the vertical load q u which is acting in the downward directions, that is equal to the perpendicular load that is acting so the resistance that q u is the total load bearing capacity. This is the some portion of the resistance that we will get from the bottom layer and some portion we will get from the top layer. So, this is the summation of the resistance or the load which is carrying by some portion by the strong layer and some portion by the weak layer or the bottom layer and the top layer. Suppose in the bottom layer it is as usual the general shear failure. So, we can write this is the resistance that is q bottom. So, q bottom is the load carrying capacity of this bottom layer or the resistance that is coming from this bottom layer, plus the resistance that is given by this top layer that will be 2 into C a, it is the adhesion 2 means one from this side, another from this side plus because here P p which acting as the delta.

So, the sine component that will act in the upward direction, so that will give the upward resistance, so that is P p into sine delta. So, that means these are the upward forces divided by B, because these things acting as a width of P minus gamma 1 into H, because this is the, this load or the q that is acting here gamma 1 into H that is the surcharge below the base of the foundation up to the second layer or up to the starting of the second layer or up to the end of the first layer. So, that is the total force. That means, the contribution of the q is the contribution from the bottom soil, plus the contribution from the top layer and minus this value surcharge that we are detecting. Because these surcharge we will not consider as a contribution because it is it was existing previously.

So, now these are the total load. Now, here P p we can write that is passive force per unit area. So, that is the passive force per unit length. Here we can write that C a is equal to small c a into H. Because C a is the total load that is total resistance due adhesion and small c a is the adhesion, which is per meter. So, that is the total and then as it is acting as a these planed H these will be C a into H.

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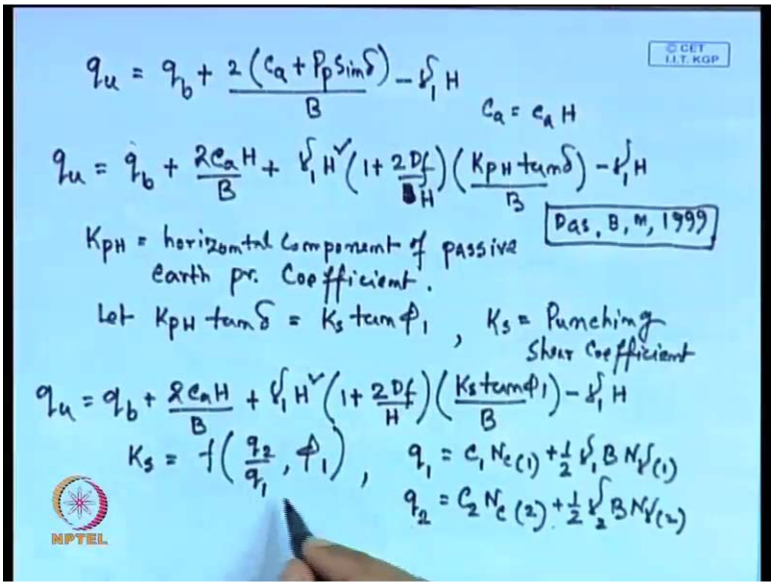

See, if I put if I put this value in this final expression then the form of this expression will be because our original expression is q u is equal to q b that is the bottom resistance into 2 into C a plus P p into sine sine delta divided by B minus gamma 1 into H. Now, here C a is basically small c a into H. If we write put small c a in this expression, then q u that will be q b plus 2 small c a into H divided by B plus now we can write P p and the other terms in in the final form is gamma 1 H square 1 plus 2 D f B K p H into tan delta divided by B into gamma 1 into H. Now, these expressions again we are taking from this book by B M Das, this is Das B M 1999. So, this is the final form of this expression that we are using where K p H horizontal components of passive earth pressure coefficient.

So, so this is the final expression that we are getting to get the calculate the ultimate load carrying capacity of these layer soil and K p H is the horizontal component of the passive earth pressure coefficient.

Now, let that K p H tan delta that is equal to K s into tan phi 1 where K s is equal to punching shear failure or coefficient. So, as I have mentioned that for the first layer will be punching shear type of failure. So, this is the punching shear coefficient. Now, if we put this K K p H tan delta is equal to K s tan phi then the q u expression will be q b plus

2 c a H B plus gamma 1 H square 1 plus 2 D f into H into K s tan phi 1 by B minus gamma 1 into H. Now, in this form we will get this. So, here this expression, this is also D f by H. So, this is 2 D f by H and this also 2 D f by H and then we just replace this K p H tan delta by K s tan phi 1.

Now, here now K s this punching shear coefficient is a function of two things. One is q 2 by q 1 value another is phi 1 and here it is mentioned that phi 1 is the friction coefficient or friction angle of the first layer and q 2 and the q 1 where q 2 or q 1 is the C 1 N c 1 for the first layer plus half gamma 1 B N gamma 1. And q 2 will be C 2 N c 2 plus half gamma 2 B N gamma 2. So, here we can see that the that the one second component that is due to the surcharge which is not present here. So, that means, the q 1 and the q 2 are the bearing capacity if the low footing is placed at the surface. So, that means, this is for the surface loading conditions where q is 0. So, second term that is also 0. So, that is if we for the same material properties this q 1 is the bearing capacity for the first layer for the surface loading and this is q 2 is the bearing capacity of the second layer for the, again for the surface loading.

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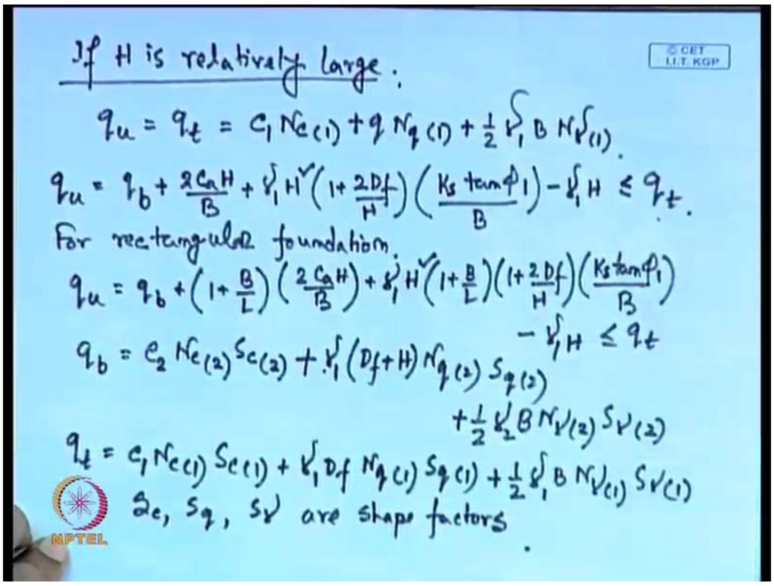

Here we are not applying any correction factor, this is in the general form. So, that means, q 1 and q 2 that we will get by these things. So, this K s is the function of q 2 by q 1 and phi 1. So, if we know this q 2 by q 1 and phi 1 then we can calculate K s. Now, another thing that this is this is applicable if H is relatively small.

Now, these expressions we can use in different form then if H is, H is relatively large as I have mentioned that if H is relatively large then all the field surface will be on the first layer itself. So, that means, our q u will wait that is equal to q t, where q t is the bearing capacity of the top layer. So, that means, we will get C 1 N c 1 plus q N q 1 plus half gamma 1 B N gamma 1. So, by using these expressions we can calculate the bearing capacity, ultimate bearing capacity of the top layer because if H is relatively large. So, now we can conclude that that if because the bearing capacity as the first layer or the top layer is stronger layer and the second layer is weaker layer.

So, bearing capacity of the combine contribution coming from the combine of first layer and the second layer, that cannot be greater than the contribution or the bearing capacity of the top layer itself, because the second layer is the weaker layer. So, bearing capacity of these first layer is q t and if the all the failure surfaces are located in the top layer then that is the maximum load carrying capacity. That is q t because the first layer the top layer is the stronger layer and second layer, bottom layer is the weaker layer.

Now, if the H is relatively large then this q t will give you the load carrying capacity of the soil, and that is maximum. Now, if H is, H is relatively small then the contribution of the first layer that will reduce and the contribution of the second layer that will that will introduce in this ultimate load carrying capacity and that part will increase and that the contribution of the second layer that cannot be greater than the contribution of the first layer as the second layer is weaker layer. So, if I get the combined bearing capacity that is contribution from the first layer and the second layer that should not be greater than the contribution of the first layer itself. The contribution I am telling that that if H is relatively high than the all the contribution all the bearing capacity is due to the resistance of the top layer. Now, if H is relatively small then the sum the bearing capacity, ultimate bearing capacity that we will get that is the some part its coming from the resistance of the top layer and some part is resistance from the bottom layer.

Now, summation of these two the some part of the top layer and some part of the bottom layer that cannot be greater than the total contribution or the contribution coming from the top layer itself. So, in that conclusion we can write that q u is equal to that q b bottom layer plus that is the contribution from the bottom layer plus 2 C a H B plus gamma 1 H square 1 plus 2 D f by H into K s tan phi 1 divided by B minus gamma 1 H that cannot be greater than q t. So, this is always less than that can be equal. So, this is less than equal to q t. So, in this, now further it is given that for the rectangular footing, for the rectangular foundation we can write that q u is the contribution from the q b plus 1 plus B by L, it is introduced for the rectangular footing into 2 C a H divided by B plus gamma 1 H square 1 plus B by L into 1 plus 2 D f into H into K s tan phi 1 by B minus gamma 1 H that cannot be greater than q.

So, this is for the rectangular footing. Now, again we we can calculate the, what is the value of q b and the q t where q b is the ultimate load carrying capacity of this bottom layer. So, this will be C 2 N c 2 into S c 2, S c 2 is the shape factor plus gamma 1 D f plus H that is the surcharge which is coming from the top layer into N q 2 and S q 2 then plus half gamma 2 B N gamma 2 into S gamma 2. This N c 2 N q 2 and N gamma 2, these are the bearing capacity factor and S c 2 S q 2 and S gamma 2 these are the correction factor for shape or shape factor.

Now, similarly q t for the top footing that will be C 1 N c 1 S c 1 plus gamma 1 here D f, this is the surcharge into N q 1 S q 1 plus half gamma 1 B N gamma 1 into S gamma 1. So, here S c 1 or 2 S q 1 or 2 S gamma 1 or 2 are shape factor. So, this is the way we can determine the q b for the bottom layer loading ultimate load carrying capacity q 2 is the ultimate load carrying capacity of the top layer which is we are including the shape factors also.

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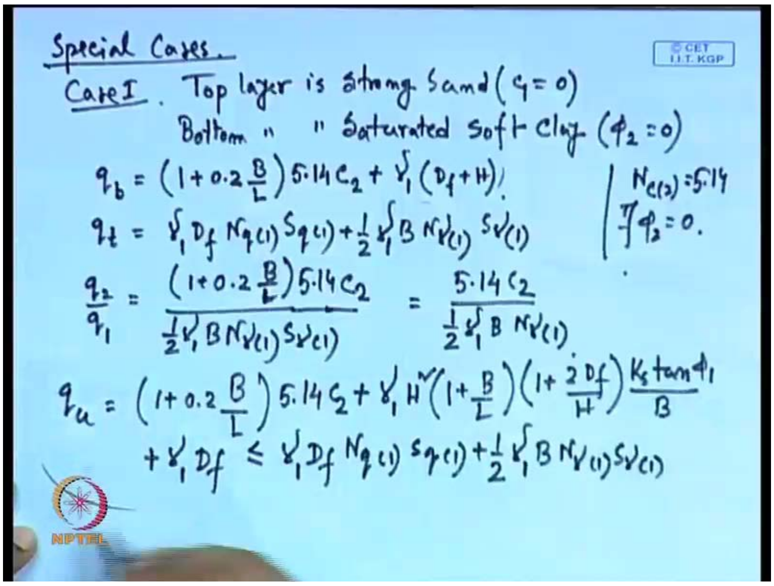

Here, this D f plus H is the surcharge for the bottom layer and D f into gamma 1 is the surcharge for the top layer and D f plus H into gamma 1 is the surcharge for the bottom layer. Now, the next thing I will discuss few special cases that or the different conditions then how to get the different conditions, the special cases that is first case, the condition is the top layer is strong sand that means, this is purely sandy soil whose, that means, C 1 is equal to 0 and as the top layer is the strong layer. So, this will be strong sand.

And the bottom layer is saturated soft clay that means phi 2 is 0. So, this is the weaker soil. So, that means, the for the top layer C 1 is 0 if the bottom layer phi 2 is equal to 0. So, now if I calculate the q b with the shape factors then we can write 1 plus 0.2 B by L that is for the shape factor and as for the bottom layer phi 2 is equal to 0. So, this is the then the C, that means the C 2 and the N c will be 5.14 and this is C 2. So, this is basically C, C 2 N c 2 and S c 2 S c 2 is 1 plus 0.2 B by L C 2 is C 2 is the coefficient of the second layer or the bottom layer and N c will be 5.14 if because we know the N c 2 is equal to 5.14, if phi 2 is equal to 0, that we know. And again that N q that part is also 1 and N gamma part will vanish if phi is equal to 0 that we know because this is the common things for the all the cases. Now, we will get only the surcharge that gamma 1 into D f plus H that is the bottom layer and similar the top layer that will give you give you that this is the C 1 is 0 top layer. So, first part is C 1 is 0. So, first part C C 1 N c 1 and S c 1 that is 0.

So, in second part we can write this is gamma 1 D f into N q 1 and S q 1 plus half 2 gamma 1 B N gamma 1 into S gamma 1. So, the in this fashion we can determine the q t and the q b. Now, as for the q 2 and the q 1, q 2 is basically here corresponding to the second layer or the bottom layer and it is in the surface. So, if it is in the surface then this surcharge part that is also 0. So, q 2 we can write that q 2 1 is 1 plus 0.2 into B by L that is divided by half into gamma 1 B N gamma 1 into S gamma 1 and we can because this part this and again this 5.14 into C 2 because the surface part as it is the surface putting. So, this part will be 0 and this part will be also be 0.

So, only this here, so surface part if I if we neglect. So, this one will be 5.14 C 2 divided by half into gamma 1 into B into N gamma 1, so here we will get the q 2 and q 1. Now, how to use this q 2 and the q 1 that will explain by using the because charts are available to determine these q 2 with this help of this q 2 and q 1, and now we will discuss these things after we complete the different cases. Now, next one that means, here for the first case q u will be 1 plus 0.2 B by L 5.14 C 2 plus gamma 1 H square 1 plus B by L 1 plus 2 D f by H into K s tan phi 1 divided by B plus because here gamma gamma 1 D f plus gamma 1 H is there, but in the original expressions also this q u, this minus gamma 1 H is there.

So, minus gamma 1 H and plus gamma 1 H these are cancels, so only gamma 1 and D f that is present. So, only gamma 1 and d f that should should be less than equal to the q t where q t value is gamma 1 D f N q 1 S q 1 plus half gamma 1 B N gamma 1 S gamma 1. So, these will give us the ultimate load carrying capacity of the soil for this condition.

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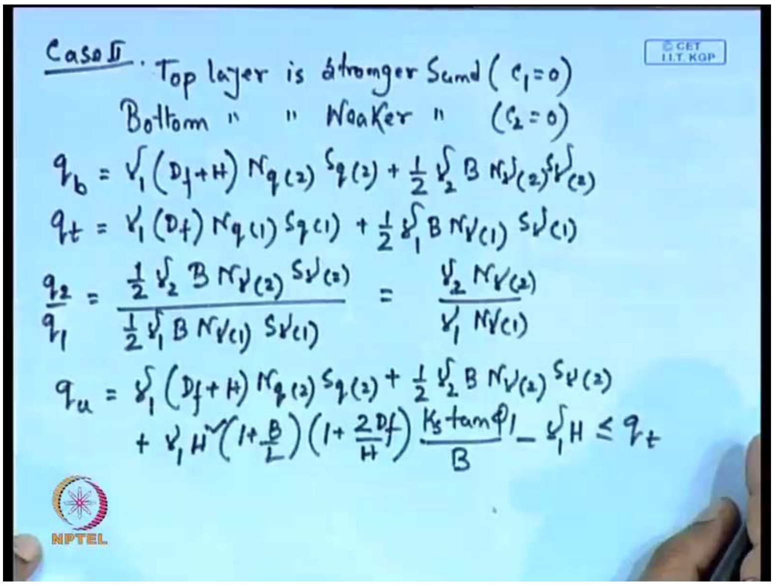

Now, the next case or the case two that if top layer is stronger sand. That means, C 1 is equal to 0 and bottom layer is weaker sand and here C 2 again is 0. In first case the C 1 was 0 and phi 2 was 0 and the second case C 1 is equal to 0 and C 2 is also equal to 0, so here the q b that will be equal to gamma 1, because C 1 and C 2 both are 0. So, first term will be 0 for the both the cases gamma by q b and q t. So, gamma 1 D f plus H into N q 2 S q 2 plus half gamma 2 B N gamma 2 and S gamma 2. Similarly, q t will be gamma 1 into D f into N q 1 S q 1 plus half gamma 1 B N gamma 1 S gamma 1. So, similarly q 2 by q 1 here we can write, but which is in a surface footing. So, this part is 0 because surface footing both the cases it is surface footing.

So, second part is go, it is not that because this is here D f is 0, but this is top case it is 0, but here also D f and H both are 0. That means, for the bottom layer also it is placed at the surface considering that there is no surcharge basically. So, this is 0 this is this part is 0. So, q t by q q 2 by q 1 will be half gamma 2 B N gamma 2 S gamma 2 divided by half gamma 1 B N gamma 1 and S gamma 1. So, these B N gamma S gammas this shape factor we are considering this is same. So, ultimately this will be gamma 2 into N gamma 2 and gamma 1 into N gamma 1. So now how to calculate the ultimate load carrying capacity that is q u, that means, q b is gamma 1 D f plus H N gamma 2 N q 2 S q 2 plus half gamma 2 B N gamma 2 S gamma 2 again where S q S gamma these are the shape factors plus because this here the C is 0.

So, this ultimate the general expressions the C term is also 0. So, that part is gone. So, gamma 1 H square into 1 plus B by L 1 plus 2 D f divided by H into K s tan phi 1 divided by B minus gamma 1 H that is less than q t where q t expression is given by this formula. So, that means, we will get. So, that is could not be get. So, we have to check first we calculate the q u and then we will check by using this q t whether q q u is less than equal to q t or not. So, this should be less than equal to q t, if it is not then we have to use this q t as here our ultimate bearing capacity on the footing under this layer soil condition.

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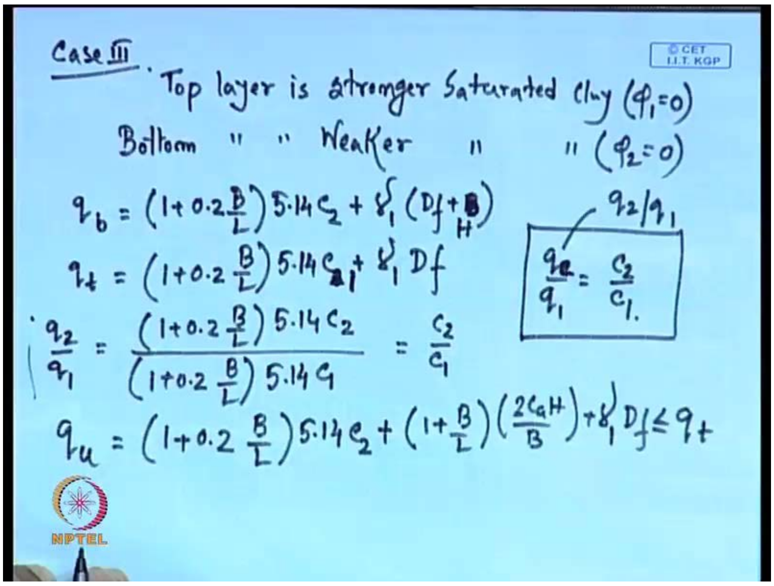

Now, the second third case that is the case three, in the third case the condition is the top layer is stronger saturated clay. That means, phi 1 is 0 and the bottom layer is weaker saturated clay, that means, phi 2 is also 0. So, in the case three phi 1 is 0 and phi 2 is 0, then that means, q b and q t. So, we will have to calculate q b and q t both. So, q b as this phi 1 phi 2 is 0. So, this part 1 plus 0.2 B by L into 5.14 C 2 plus gamma 1 into D f plus H sorry this is H. So, gamma 1 D f plus H because this term, this N gamma 2 that will be 1 and as phi 2 is 0 then N N q 2 is 1 and N gamma 2 is 0 and here N c 2 is 5.14.

Similarly, q torque which will be 1 plus 0.2 B by L, this is 5.14 similarly this is plus gamma 1 into D f. So, ultimately we can write that q 2 by q 1 that ratio where it is in the surface. So, if it is in the surface then this part is gone. So, this part is 0 again. So, that means, this will be 1 plus 0.2 B by L 5.14 C 2 sorry this one will be C 1, C 2 divided by 1 plus 0.2 B by L 5.14 C 1, so that means the ratio will be C 2 by C 1.

So, now the ultimately the q u that will be the q b expression is 1 plus 0.2 B by L to 5.14 C 2 again this gamma 1 D f plus gamma 1 H is present and 1 is minus gamma 1 H. So, both are cancels only gamma 1 into D f will be present. So, now plus 1 plus B by L 2 C a H by B plus gamma 1 D f that is equal to less than q t because as this phi 1 is also 0. So, that general term that tan phi 1 will be 0. So, that part is gone. So, only this part will be present. So, this we can write in this form for the rectangular footing. Now, the question how we will calculate this suppose for this case four we we we know that q 2 by q 1 is equal to C 2 by C 1, then how we will use this charts and how we will use this is q 2 or this is q 2 by q 1. So, that is C 2 by C 1.

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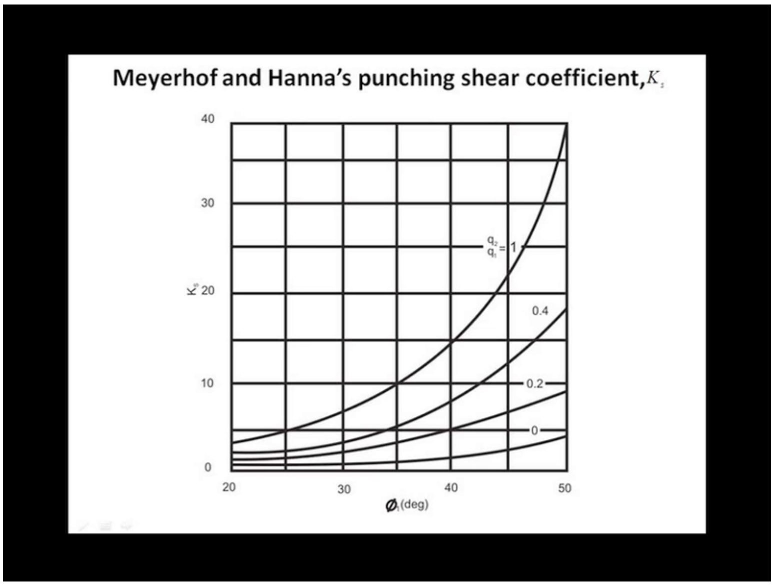

Now, if we go for this chart that this is the chart which is presented by Meyerhof and Hanna's 1978 is also the source is this book. Now, here this is as I have mentioned that this punching shear coefficient K s is function of q 2 by q 1 and phi 1. So, punching shear coefficient in the function of q 2 by q 1 and phi 1.

So, if we know the phi 1 value this is the top layer frictional coefficient and if we know the q 2 by q 1 that is equal to. So, these are the different value 1.4.2 and 0. So, by if we know this phi and corresponding different q 2 by q 1 we can determine the case. Now, this q 2 by q 1 in the different cases - this case one, case two, case three. I have explained how to determine these q 1 and q 2 value this ratio.

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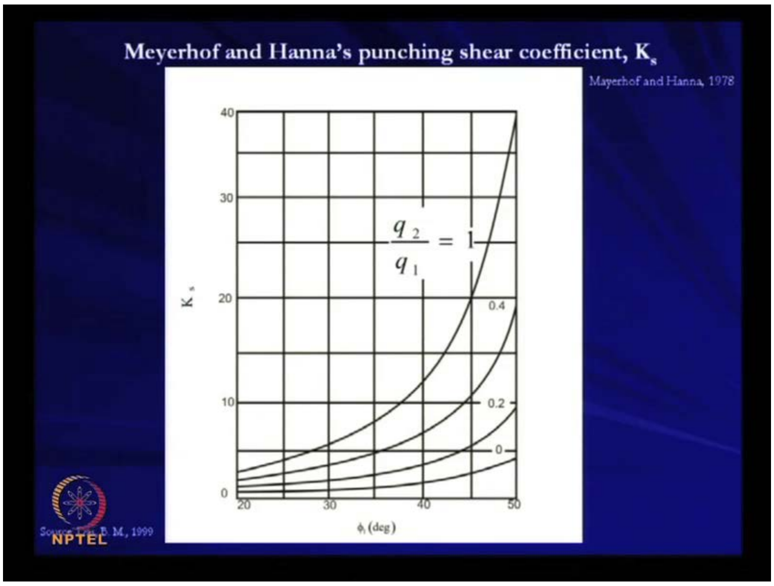

So, first we have to calculate this q 2, because in the final expression this Ks term is present. So, that means, in the case we have to determine. So, to determine the case value we should know how to calculate this case. So, first step is because we know this gamma 1 C 1 phi 1 this is the properties of the top layer and then the gamma 2 C 2 and phi 2 these are the properties of the second layer. So, these parameters are known to us. So, with the help of this two parameters or these thing first we calculate the for the shape factor for different, because the dimension of the footing that is also known to us. So, that means, with the help with the with the if it is not known then by trial and error method, we have to determine these things that how to use the trial and error method for any design of this foundation that part I will explain when we will study the design of this foundation part.

And then once we get this dimension. So, suppose here we assume this dimensions are known. So, once we get the dimension we can calculate this with the help of phi value, we can calculate bearing capacity factors for top layer and the bottom layer, then with the help of dimensions we can determine the shape factor for the top layer and the bottom layer. So, if these things are known to us then we can determine what the ratio of q 1 and q 2. So, once we get determine the value of q 1 by q 2 this ratio and then we know the phi 1 value that is the top layer then we can by using this table or this chart q 1 corresponding the phi 1 we can determine. So, suppose this is q 1 by q 2 is 0.4 and theta is 35 degree, so that means, the Ks value will be phi.

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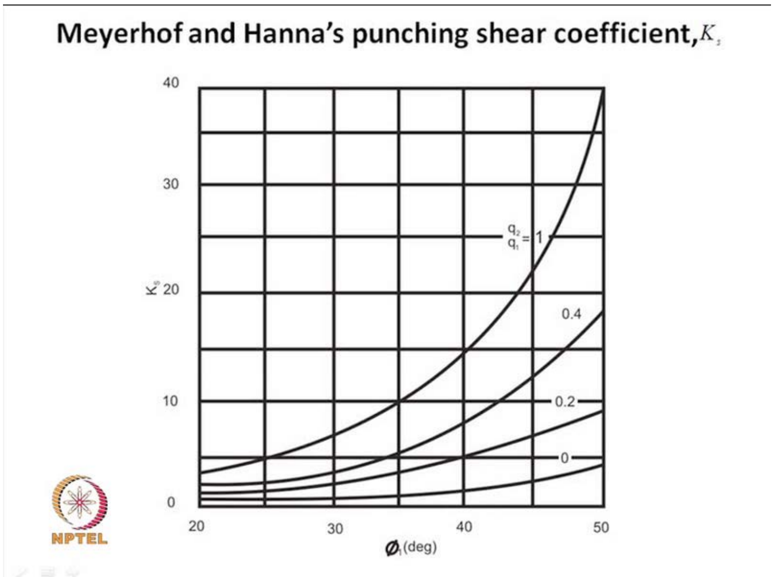

So; that means, here this Ks value will be required calculating the ultimate load carrying capacity of this layer soil. So, that case term is there as in the as you have seen then in this final expression. So, there we will be use the case. So, that is for the, if this phi 1. So, top layer if it is stronger sand because it is we are getting the case for the phi 1.

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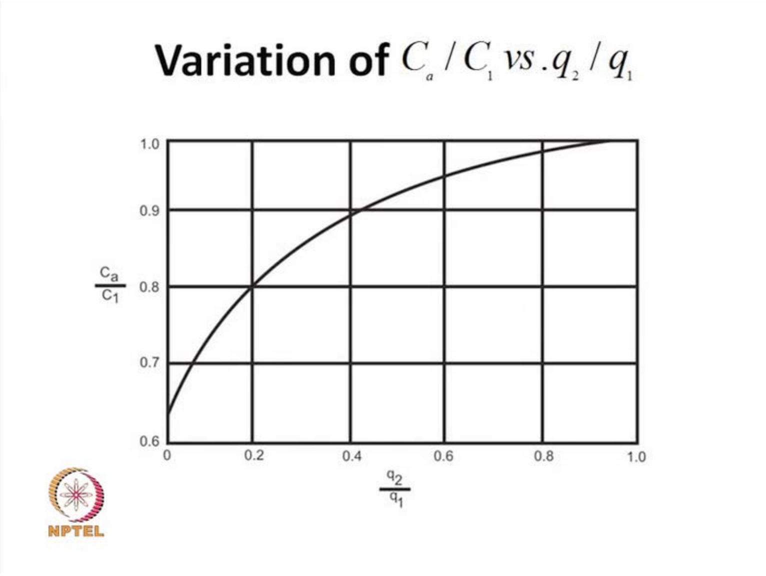

Now, if the top layer is cohesive soil in the last case, because the top layer is stronger saturated plate, where the phi 1 is 0, then how to calculate these properties, because here the phi 1 is 0. Then you have to use this chart, because in that case we should know the C a value, because this C a C a value for that, if the strong the top layer is a stronger sand, then this C a part or the cohesion part that is 0, because we are talking about the purely cohesive soil or cohesionless soil. So, if that is stronger sand, then q the phi 1 is present, but c 1 is 0. Now is the, that means, the is the cohesion or the adhesion is 0, then we have to use for the stronger sand is Ks value.

So, by using the first chart if, both the cases we have to determine this q 2 by q 1. So, once you determine this q 2 by q 1, if the top layer is stronger sand then we should know the value of case. So, in the stronger sand we can calculate q 2 by q 1 and we know phi 1 value. So, by using the first chart or first graph we will get the case value. Now, in the second case if the top layer is stronger saturated clay, then Ks term is not required, but C a term or adhesion term that is required, because here we know that c 1 value, but q phi 1 is 0. So, once you get the C 1 value and here also we can calculate because in the third case we have seen that q 2 by q 1 is equal to C 2 by C 1. So, now we know the C 1 and C 2 value. So, we we can calculate the C 1 and C 2 value ratio, once we get the C 1 by C 2 value that ratio that is equal to the ratio q 2 by q 1.

So, that that q 2 by q 1 is C 2 by C 1.So, this C 2 by C 1 is known, because q 2 by q 1 is C 2 by C 1. So, once you get the C 2 by C 1 we will get the q 2 by q 1. And now using this chart for the this case also, we we can determine q 2 by q 1, then by this using this chart then we know the C 1 value. So, only unknown is C a. So, suppose for the q 1 by q 2 is 0.4. So, C a by C 1 is 0.9. So, that means, C a will be 0.9 into C 1, but here C 1 is also known. So, in this way we can determine the value of different parameter. So, once we get the C a then in the final expression that C a term is required. So, we will get the put the C a value there and we will calculate the ultimate load carrying capacity of the soil, because all the other term the thickness, dimension or the properties those are known, only main unknowns are K s and C a.

So, those two things we can determine by using this chart. So, by in different cases we can we have to judge whether where we will use the first chart and where we will use the second chart. If it is stronger sand in the top layer then we will use the first chart, because we need to find the Ks value, if it is stronger clay then we have to need to determine the C a value, then we will use the second chart, but both the cases we have to determine q 2 by q 1 and I have explained how to determine this q 2 by q 1 in different cases. So, in this fashion we can and in this way we can determine the ultimate bearing capacity of the layer soil.

In the next class, I will discuss how to determine the ultimate load carrying capacity of foundation in slope, and then we will go for the analysis or this is because you know most of the and the up to this, the most of the bearing capacity calculation I have done for the isolative footing or next one we will go for the raft foundation, then how to determine the load carrying capacity of the raft foundation, then we will go for the settlement calculation, because we are always talking about the bearing capacity. Then the next criteria design criteria settlement, so those things we will discuss in the next classes.

Thank you.