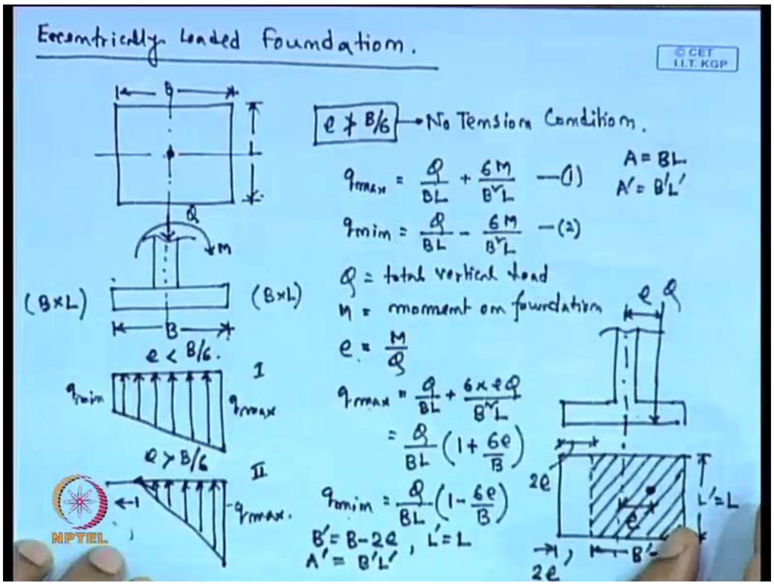
Advanced Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 8
Shallow Foundation: Bearing Capacity – III

Today, I will discuss about the different other conditions of the loading, and how to calculate the bearing capacity of foundation under such loading condition, because in other classes, in the last classes I have discussed that about the Meyerhof bearing capacity calculation, and other bearing capacity calculation. And then then we have the the shape factor, depth factor, inclination factor; all those are introduced in the loading condition to get the bearing capacity of the ultimate bearing capacity of the foundation.

Now, today's class I will discuss about the if the loading is not applied the center of the foundation if eccentrically loaded footing is there, and then how to calculate the bearing capacity. And then when we calculate the shape factor and the depth factor or basically shape factor and the ultimate load carrying capacity of the footing, then how to use those loading condition that eccentric condition in the foundation, those thing I will discuss in this lecture.

(Refer Slide Time: 01:43)



Now, first I will go for the one way eccentric loading, and then I will go for the two way eccentric loading. Now, first case suppose, if I go for this. Now, this is for the eccentrically loaded foundation. In all other cases that suppose this is the footing, and there is the center of the footing. Now, suppose if loading is applied at the center or if I take the cross section of this foundation or footing that this is the cross section, and the loading is applied at the center of the building. In this center of the footing in this case, the previous formula we can apply, but if there is any moment or if the loading is eccentrically, then how to calculate this bearing capacity of the foundation, such thing we can discuss in this section. Suppose, if the loading is, there is a moment which is applied here and this Q is the loading which is applied at the center and m is the additional moment which is applied, and suppose this is the B width of the foundation and dimension of the footing say this is B cross L. So, this is the dimension of the footing or we can say this is B cross L. So, this is this direction is B, and this direction the dimension of the footing is L.

Now, first under this loading condition if the loading, if the loading is applied at the center or there is no moment then the uniform distribution of loading is observed. Now, if the moment is applied. So, the footing is distribution of the load below the footing it will follow this pattern. So, this is the reaction of the soil which is given to the foundation and so now as this moment is applied in this direction. So, this will give you the maximum reaction that is q max and this will give you the minimum reaction that is q min. So, now, this is one condition where this is following this pattern. Now, there is another situation where q max is this value and q min is is a negative value or suppose this is the reaction, this is q max and. So, you can see that if we draw this portion, that means, here this this side the reaction is this is negative, that means, the tension will develop.

So, we will not as we know that that soil cannot take the tension cannot able to take the tension. So, that means, there is a provision to give the separation between the foundation and the soil if the reaction is negative or is the tension force is developed. So, we will we will neglect the second case suppose. This is our case one and this is a case two. So, we will neglect the second case. So, that means, there is a case one which is developed if our e value is less than B by 6 and this is developed if e value is greater than

B by 6. So, that means, our one condition that e should not be greater than B by 6, if it is one way eccentrically loaded foundation.

So, now we can calculate, we have to calculate this e max and e min value, so one condition. So, no tension will be developed and. So, under no tension condition this is one condition. So, this is for the no tension condition condition. So, this is our one condition. The next thing is we have to calculate so that means, this e should not be greater than B by 6. So, that means, always e will be less than equal to B by 6.

So, if e is greater than B by 6 then this tension will develop, that is not acceptable for this foundation design now we will avoid this kind of foundation. So, now we can calculate the e max and e min. So, suppose e max we will get by using this expression that Q divided by B L plus 6 M B square L where Q is the load which is acting in the foundation and N is the moment which we are applying and similarly that q min we will get this value is Q B L minus 6 M B square L. So, Q is equal to total vertical load and M is moment on foundation now the eccentric values is we are talking about that e is the eccentricity. So, that eccentricity we can calculate e is equal to M divided by Q. So, first step we will calculate this if we know the M and Q value we calculate the e value that is M by Q and then we check whether this e is within this limit or not, if it is within this limit, that means, less than equal to B by 6 then we can proceed otherwise you have to redesign our dimension of the foundation, we have to change the dimension or we have to redesign this foundation.

So, that means, that is the first step then the next step if I put this e value in our equation 1 and equation 2, then we will get e max is equal to Q B L plus 6 into e Q divided by B square L or if we take Q by B L common then this will be 1 plus 6 e divided by B. Similarly, Q min we can calculate by this equation Q divided B by L 1 minus 6 e divided by B. So, that means, by putting this e value in equation 1 and 2 we will get the Q max and Q min in terms of Q B L and e. So, this next first we will check this condition then we will calculate e max and min. Another thing is that suppose this the footing is in this fashion, that this is our footing and loading itself is applied is not applied at the center, it is applied at a distance of say e from the center. So, this is the loading q we are applying which is applied at a distance of e from the center and this is also one condition. So, in say you can draw this type of figure. So, this is this type of figure we can draw.

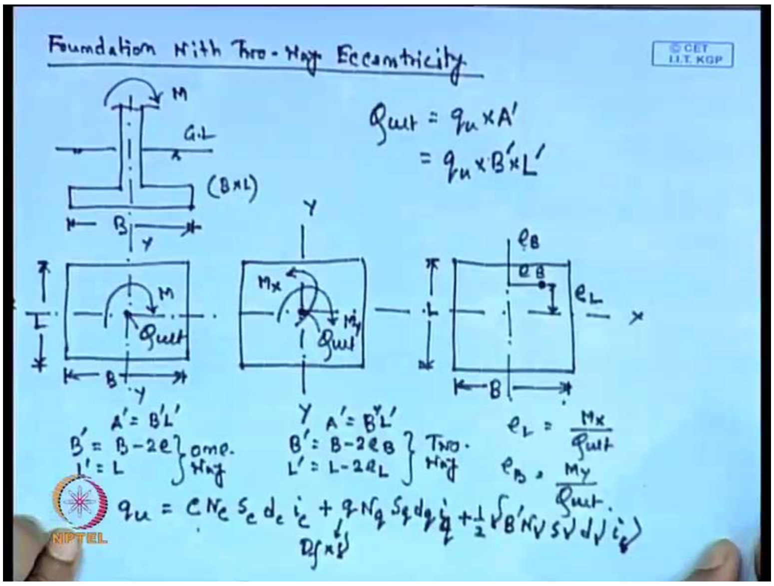
So, that means, this hatch area because as the loading is applied at a distance of e from from the center. So, the effective area if loading is applied at the center then the effective area will be equal to L into B. So, that is the total effective area L into B. Now, because of this eccentricity or if there is moment is applied or both the cases because of this type of loading condition the load is itself is applied at a distance e from the center or it is the moment. So, because of this moment and loading eccentricity the effective area of footing, that means, that now it is considered that this hatched zone is effectually taking the load and this white portion is not taking load, so when we calculate the ultimate load carrying capacity and use this expression. So, instead of using B you have to use this value B dash and here this value L dash, as it is one way eccentricity. So, L dash will be equal to L, but B dash is reduced by some amount.

So, here this white portion it is written as two into e. So, this white portion is written this is 2 into e. So, white portion is two into e and this hatch portion is B dash. Now, here suppose this is the point where loading is applied where e is this value, so now here our effective area is basically reduced because of this loading condition. So, now, when we calculate the this effective area instead of B dash you can calculate that will be B minus 2 e because this 2 e is the white portion. So, B dash will be B minus 2 e and L dash is as usual as it is one way eccentric loading. So, L dash will be equal to L.

So, when we calculate the effective area instead of using A we will use the A dash that is B dash into L dash because if the effective area without any eccentricity is A into B into L, A is equal to B into L then similarly A dash will be B dash into L dash. So, for this first condition is for centrally loaded footing and this second condition is for eccentrically loaded footing, so in this fashion. So, first step if I say again. So, first step we by using if we know the M moment and the load which is acting. So, we will calculate e value or if I know the directly this eccentricity of this loading then we calculate this e value from here we will check whether this e is less than equal to B by 6 or not. If it is less than equal to B by 6 then otherwise the tension will develop when when ideally we will we will not allow the tension to develop. So, we will redesign the foundation.

Then by using these two expressions we will calculate the e max and e min and then next job we will determine the effective width of the foundation that is B dash equal to B minus 2 e, 2 e and L dash is equal to L and then effective area that is A dash will be B dash into L dash. Now, when we calculate this bearing capacity of this loading then instead of using this B, we will use the B dash and as this is one way eccentrically loaded foundation, then we will use L and L dash, these are both are same and when when we calculate the this say factors there also we will use B dash not B.

(Refer Slide Time: 16:11)



Now, the next one is that foundation with. So, first case was the foundation with one way eccentricity now the next case the foundation is two way eccentricity. So, suppose this is the cross section of the footing, this is ground line and this is B and dimension of the footing B cross L. Now, this is the dimension. So, this one is B and this is L, L is the length of the footing and B is the width of the footing. Now, if Q is applied here. So, this is say Q ultimate and one moment is applied here like the one way. So, this is one way eccentricity.

Now, if the suppose this is X X and this is Y Y section. Now, if the same footing this is Y Y and again Q ultimate is this one, this is the load Q ultimate and one moment that is M Y and another moment that is M X both are acting in this foundation. Here only one moment is acting that is one way eccentricity. Now, if the M X and M Y moment with respect to X X axis and moment with respect to Y Y axis both are acting in this footing. So, then this is two way eccentricity.

Now, under this condition, so suppose this is the e where this 1 is equal to e L because this is in terms of length and this is width and this distance is equal to e B. So, this one e

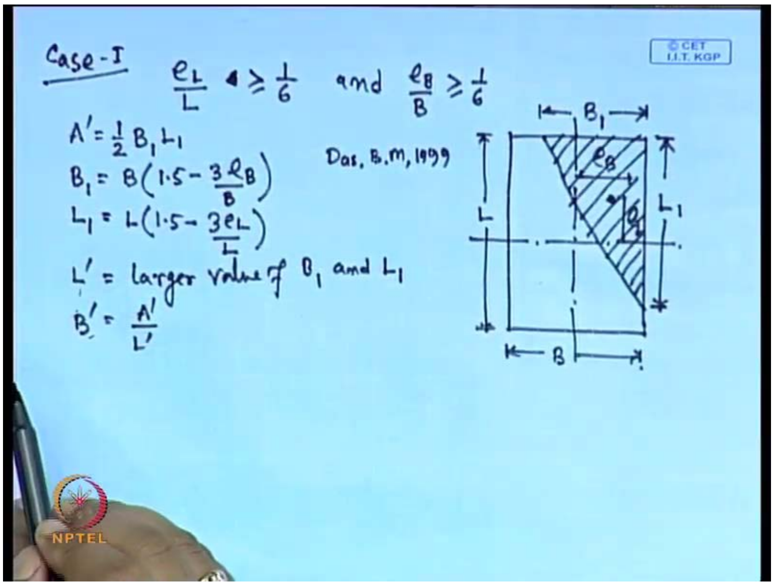
L and this one is e B or we can write this is e L e Y and this is e X. So, here in this lecture we will use e L and e B. Now, where this is the length and this is the B is the width. So, that means, here again how to calculate this, because here also in the previous cases when it was one way eccentricity then our A dash was B dash and L dash where B dash is equal to B minus 2 e and L dash was equal to L that is for one way. Now, again for the two way eccentricity also effective area L dash will be L B dash into L dash, but here again. So, this is B dash.

So, here B dash will be B minus 2 e and L dash will be A minus 2 e. So, here we will use in in case of when we are talking about 2 e. So, we will use this is 2 e B and this is 2 e e L. So, this is for two way eccentricity. Again, how to calculate this e L and e B? So, e L we can calculate by e max e N X divided by Q ultimate and e B will be m y divided by Q ultimate, so in two way eccentricity. So, when we calculate e L we use M with respect to X X axis that is M X divided by Q ultimate and e B that is M Y divided by Q ultimate.

Now, when we calculate the q u value, so then we will use the expression C N c S C d C i c plus q which is equal to D f into gamma N q S q d q I q plus half into gamma B dash N gamma S gamma d gamma i gamma. So, here C is the coefficient of the soil. So, here we know this is the expression suppose this is the general expression. So, here N c N q and N gamma these are the, these are the bearing capacity factors and S c S q S gamma are the shape factor, d c d q d gamma are the depth factor and i C this is i q and i gamma are the inclination factor. So, when we calculate this factor instead of using B or L we will use B dash and L dash and here also we are using B dash not B. So, finally, when we calculate the, suppose we know this Q ultimate Q ultimate load, that means, q u into A dash.

So, that will give us q u into B dash into L dash. So, when we calculate this value we will use B dash into L dash. So, this is the two way eccentricity and then one way eccentricity.

(Refer Slide Time: 24:30)

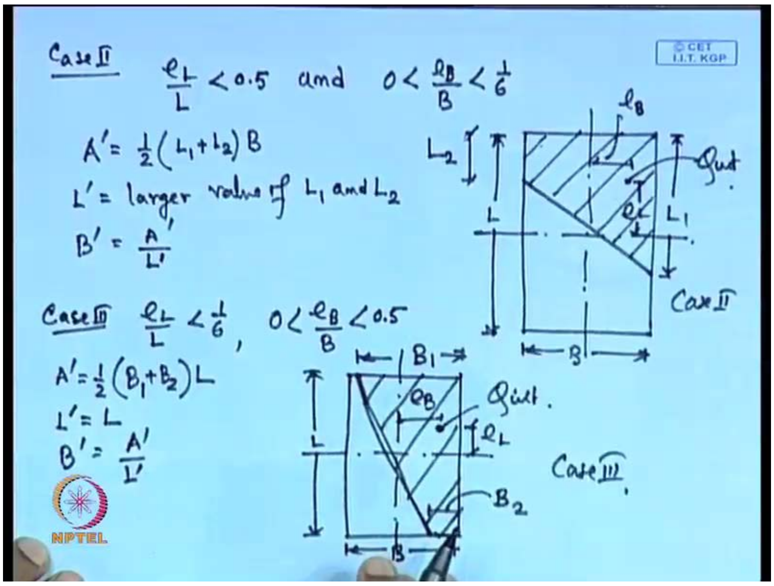


Now, we will I will discuss about the various cases. One of the first case that I will discuss that is case one; in this case the condition is that our e L divided by L; that is greater than equal to 1 by 6 - that is one condition, and e B by B that is also greater than equal to 1 by 6. Now, suppose if this condition arises that e L by B that is greater than equal to 1 by 6, and e B by B that is greater than equal to 1 by 6. In such case what will happen? Suppose if in such case if I do not able to avoid this things, and if this case is still arising then how we will get the, I will design this condition. So, in that case, suppose this is the foundation and this is B, and this is L, and that case we will get this type of effective area. So, this hatch zone will give us the effective area. So, that means, here we will get this is B 1, this is B and this is L 1. Now, here this is the eccentric point e, this is the point where this one is e L and this is e B.

So, now when we calculate the, from this area, because when we calculate the ultimate load then we will determine this effective area. Now, with this effective area a dash will determine by using this expression that half B 1 into L 1, this is half B 1 into L 1 and then I will calculate this this B 1 is given by B into 1.5 minus 3 e B divided by B. Now, this thing is been explained is in B M Das book that is Das B M 1999. So, where this value will get that we can directly use this value and then L 1 we will get similar expression L 1.5 minus 3 e L divided by L. So, by using this expression we will get B 1 and by using this expression we will get L 1.

Now, the effective length L dash will be the larger value of these two, which one is larger that is the effective area. So, effective length L dash is equal to larger value of B 1 and L 1. So, one once we get the L dash then the B dash will be because we we will get A dash directly by this expression. So, there has been B dash will be A dash divided by L dash. So, in this the larger value of B 1 and L 1 will give the L dash value and B dash will be A dash divided by L dash. So, we will get the B dash and L dash. So, once we get the B dash and L dash then we can use this B dash and L dash to get the others factors the n capacity factors or the safe factors and then to calculate the ultimate load carrying capacity of the foundation, and then we we will get the A dash that is half into B 1 into L 1, then we will get the total ultimate load that the foundation can take. So, this is 1 case if this condition is this e L divided by L is greater than equal to 1 by 6 or e B divided by B is greater than equal to 1 by 6.

(Refer Slide Time: 30:22)

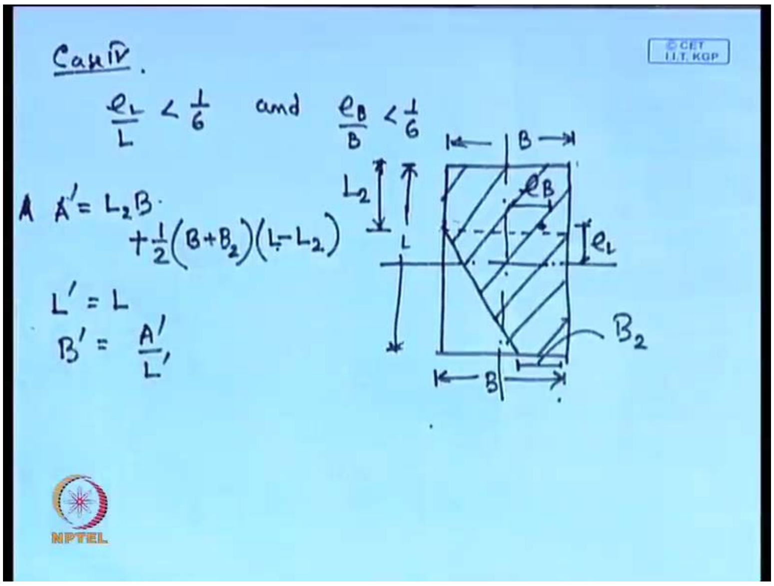


Now, the next case or case two that I will explain this case two thing that this is case two then in the case two that e L by L that is less than 0.5 and another condition that e B by B that is greater than 0 and less than 1 by 6. So, e L is less than 0.5 and e B by B greater than 0, 1 and less than 1 by 6 in such case the effective area will be as follows. Now, this is the footing. Now, this hatch zone will give us the effective area suppose this is the B is the width of the foundation L is the length of the foundation and here this one is the L 1 and this distance is equal to L 2 and this is the A e value say this is e L and this is e B, where condition is e B is greater than equal to 0 and less than equal to less than 1 by 6 B and e L is less than 0.5 value. Now, this is the effective area under this second case. Now, here the effective area we can calculate by this half into L 1 by L plus L 2 into B. So, this is the effective area. Now, the effective length L dash is larger value of L 1 and L 2. So, about this L 1 and L 2 the larger value will give us the L dash.

Now, similarly B dash we will get from a dash divided by L dash. So, once we get this L dash which is the larger value of L 1 and L 2 which whichever is larger and then we will get the B dash by L dash by A dash by L dash. Now, in the case three where the condition is that e L L which is less than equal to 1 by 6 and e B by B which is less than 0.5 and greater than 0, so e L by L less than 1 by 6 and e B by B greater than 0 less than 0.5. So, in such case in the case this is for case two, if I want to draw the condition for the case three. Suppose this is the length, this is B. So, in such case effective area will be this one. So, this hatch portion will give us the effective area.

So, this one is equal to now B 1 and this value will give us B 2, this is L and this one B. So, this this will be the point. So, this is e B and this one e L. So, this point this is q ultimate, similarly this one also this is q ultimate, so now in this condition. So, area effective area of this hatch zone we will get that is half into B 1 plus B 2 into L and L dash that will be equal to L and B dash is equal to A dash divided by L dash. So, here we will get this A dash and L dash is equal to L and B dash is A dash by L dash. So, this is for case three.

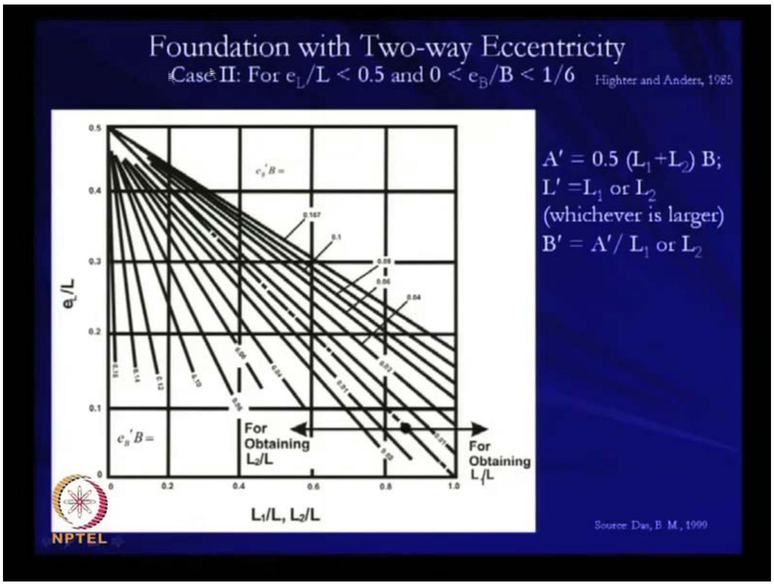
(Refer Slide Time: 36:11)



So, next case that is the case four, so next case case four where condition is that e L by L which is less than 1 by 6 and e B by B which is also less than 1 by 6. So, e L by L less than 1 by 6 and e B by B less than 1 by 6. So, in such case the loading loaded foundation, the effective area will be suppose this is L, this is B. So, effective area will be like this. So, this one, this hatch zone give us the effective area. So, this one is again B, this value is equal to L 2 and this value is equal to B 2 and this is the e, that means, this is e L and this is e B, so in this case. So, this is B 2, this is B this is L 2 and total is L.

So, in this case effective area A dash, the effective area A dash we will get that A dash is equal to L 2 into B, this L 2 if I divide into different portion. So, this one will be L 2 into B this area and the lower part be plus half into B plus B 2, then this additional portion that is L minus L 2. So, this will give us the effective area, again the L dash is equal to L and B dash is equal to A dash by L dash. So, these are the four cases. So, by this using this four cases first we will calculate this L dash B dash and then by using this expression, we can you calculate this effective area. Now, the question is that here in the except the first case, case two, case three and case four, all the cases this L 1 B 1 then B 2 L 2 these terms are involved because here L dash is equal to L because L is known to us. So, we can determine the L dash, but unless we do not know the A dash, it is very difficult to find the B dash. So, once we get the L dash we should know the A dash, so that we can determine the B dash.

(Refer Slide Time: 40:30)

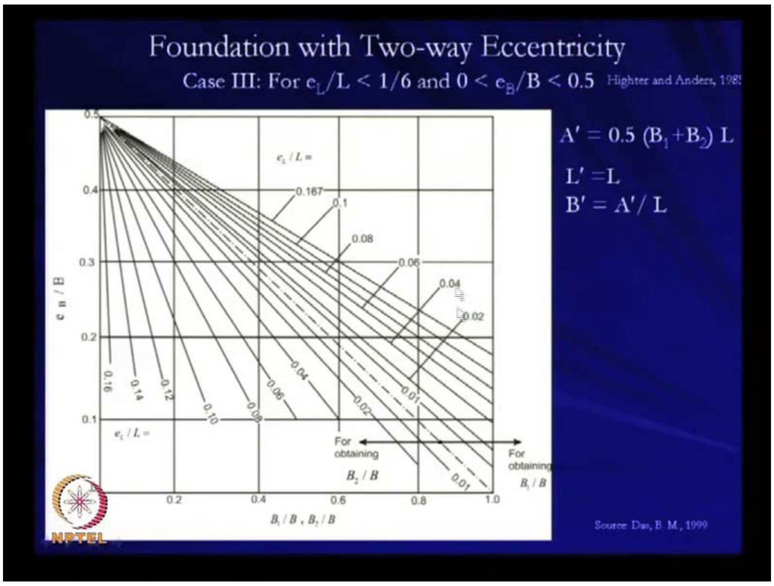


Now, by suppose in this expression we do not know how to what is the value of A dash, because here B we know and L we know, but we do not know L 2 and B 2. Now to use this to determine this L 1 L 2 and B 2 L 2 now the different charts are available. So, now, I will show you the charts for this case, because in the first case this value L 1 and this L 2 this values are directly we can determine by using the given expression, but in the case two because here we should know the value of L 1 and L 2. So, in that case if I use this chart then we can determine this value.

This is taken from this Highter and Anders 1985 they are proposed originally the source it is taken from this again B M Das book this chart, so we can use this chart that. So, here this this axis represent e L by L and this axis represent L 1 L or L 2 L. So, from this point towards this direction value that we will get of this cards that will give for L 1 L and towards this direction the the value that we will get that is for L 2 by L. Now, here this value this is e B dash into B. So, once we get this value. So, this is for 0.167, 0.1.

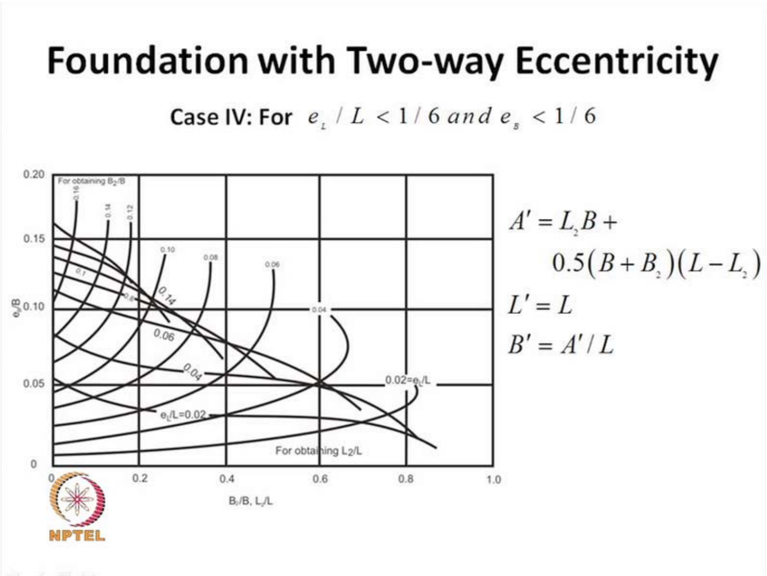
So, we will this side we will get L 1 by L and this side we will get L 2 by L because this e L by L we can calculate suppose e L by L and e B by B e B by B that we also calculate. So, once we get this value we can calculate L 1 by L and L 2 by L and as we know this L. So, we can calculate L 1 and L 2. So, here we will determine those thing these things I have already explained.

(Refer Slide Time: 42:36)



Next is the case three here also similar charts are available this is for e B by B and this is for e L by L, similarly for the first case this is e L by L, this is e B by B, this is e B by B, this is also e B by b. So, here also we will get in this side we will get B 1 and B 2, here from this side onwards this graph this will give us the value of B 1 by B and here this side point point from this point towards this side we will give us B 2 by B. So, here we know the e B by B value corresponding e L by L value. So, suppose this is 0.8 and corresponding this value we will get this B 1 by B and B 2 by B. So, as we know B value. So, we can calculate B 1 and B 2.

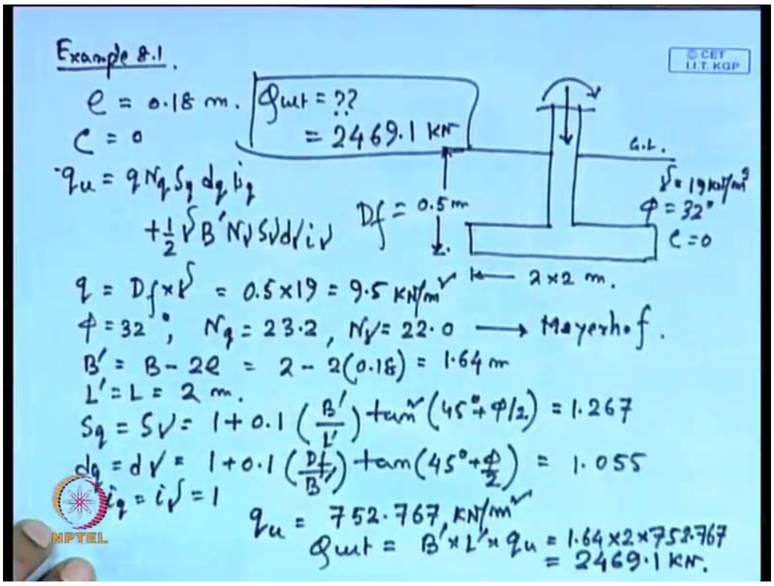
(Refer Slide Time: 43:32)



Similarly, for the case four, so here we should know the B 2 and L 2. So, this is, this axis represent e B by B and this axis represents the B 2 B or L 2 L. So, here this is e L by L. So, corresponding, so obtaining this, so this chart e L by L. So, this chart we will use to get this L 2 by L value and this e L by L because here two charts, here also point these chart represent the 0.02 that is the value of e L by L and this chart represents the again the 0.02 that is also e L by L, but. So, these charts represent thing in the by using this chart we can determine the value L 2 by L and using this chart this one, we can use to determine B 2 by B.

So, once we get B 2 by B and L 2 by L then we know as we know L and B value. So, we can determine this B 2 and L 2. So, once we get this B 2 and L 2 then we can determine the effective area and L is equal to L dash for the case four then once we get the L dash then by using the expression A dash divided by L dash we can determine the B dash. So, in this L dash and B dash, we will use when we calculate the ultimate load carrying capacity of the footing instead of using B dash B or L.

(Refer Slide Time: 45:32)



Now, we will solve one problem. So, that will help us to understand these things very clear. So, suppose this example problem, suppose this is the example 8.1. So, this problem we will solve for one way eccentricity. Similar case by using this chart the the presented charts and the expression that mentioned we can determine the ultimate load carrying capacity of the footing for two way eccentricity also. Now, this condition supposes this is the foundation. So, this is ground line and one we are applying load and one moment. So, now, this dimension of the footing is 2 cross 2 meter and the depth of the footing is 0.5 meter from the ground line.

Now, the density that is 19 kilonewton per meter cube phi value is 32 degree and c value is 0. So, one way eccentricity, this e value directly it is given say 0.18 meter. So, you have to determine what will be the ultimate load Q of this foundation that is the problem. So, this is the footing condition which is placed at a depth of 0.5 meter. So, D f is 0.5 meter and this dimension is 2 cross 2 meter, then unit weight of the soil 19 kilonewton per meter cube phi value is 32 degree, C is 0.

Now, as this is e value. So, now, in this question the C is 0. So, q ultimate that C n C part the first part as C is 0. So, that part is also 0. Now, we can write this q N q this is S q d q and i q plus half into gamma, here we will use the B dash because as it is a one way eccentricity and we will not use B, we will use the effective width B dash, so B dash into N gamma into S gamma into d gamma into i gamma. So, S gamma S q as the shape factor, d q d gamma is the base factor, i q i gamma is the inclination factor.

So, first we will calculate the e q value. So, q value is D f into gamma, here D f is 0.5 meter into gamma is the 19. So, it will coming out to be 0.9, 0.5 kilonewton meter square. Similarly, corresponding to phi is 32 degree. So, if I use the Meyerhof table. So, we can again show you the Meyerhof tables. So, this is the bearing capacity factor tables of which is presented by the Meyerhof.

So, here we will use the Meyerhof expressions or Meyerhof bearing capacity factor. So, corresponding to phi is 32 degree, our N q is 23.2 and N gamma is 22. So, that value we will use. So, our and our N q is 23.2 and N gamma is 22. Here we calculate again the B dash B dash is B minus 2 e. So, that is equal to 2 minus 2 into 0.18. So, this is value is coming 1.64 meter. So, these are Meyerhof bearing capacity factor.

Now, again by using the Meyerhof and here this L dash will be L equal to 2 meter, so again by using the Meyerhof correction factor. So, S q that is equal to S gamma that we can get 1 plus 0.1 into B dash divided by L dash into tan square 45 degree plus phi by 2. So, that value we can we will get the chart from the chart that is present. So, we can show you the chart that is the Meyerhof corrections factor. So, different factors is there and this the expressions. So, here for this the footing we will use the this expression that is what S q S gamma that is 1 plus 0.1 here B by L, but here we will use the B dash and L dash, but L dash is equal to L and this tan square 45 plus phi by 2 for phi greater than 0 degree Meyer because of other factors also use form this table and here phi is greater than 0 degree.

So, once we put this L dash equal to 2 meter B dash equal to 1.64 meter and and phi is 32 degree, we will get this bearing capacity factor value 1.267. Similarly, d q is equal to d gamma that is equal to 1 plus 0.1 D f divided by B into tan 45 degree plus phi by 2. So, here also we in these these value from the table also. Here, if we put d f equal to 0.5 B B here in place of B we will use the B dash. So, this B dash equal to 1.64 meter phi is 32 degree. So, this is coming 1.055 as this inclination part inclination is not present. So, we can write that i q is equal to i gamma that is equal to 1.

So, once you get these things then by using these q u expressions. So, this expression we will just put all the value, because in this expression q is 9.5 kilonewton per meter square, N q is 23.2, S q is 1.267, d q is 1.055, then i q is 2 here then gamma is 19, B dash 1.64, N q N gamma is 22, S gamma is 1.267, d gamma is 1.055, i gamma is 1. So, once we put all the value in these expressions. So, we will get this value that is coming 5 752.767 kilonewton meter square, because this B dash here we will have to put 1.64 meter. So, finally the q ultimate the load that is coming out to be that is B dash into L dash into q u. So, this value is coming 1.64 into 2 into 752 .767.

So, finally, the value that is coming out to be 2469.1 kilonewton, so the answer this Q ultimate that is coming out to be 2469.1 kilonewton. So, this is the answer of this question. So, that is we are getting this Q ultimate. So, now if we want to find the net safe bearing capacity of the footing or ultimate safe bearing capacity of the footing, then we have to apply the factor safety, and I have already discussed how to calculate the net bearing capacity. So, here we have to up to the factor of safety here also. So, in this way we can determine the value for the eccentrically loaded footing.

So, in the next class, I will discuss that if this is for eccentrically loading and now if it is a layer soil, because now for this up to this we have I have discussed all the soil condition is homogeneous. Now, if it is a layer soil then how to calculate the bearing capacity, if this is in the slope then how to calculate the bearing capacity those things I will discuss in the next class.

Thank you.