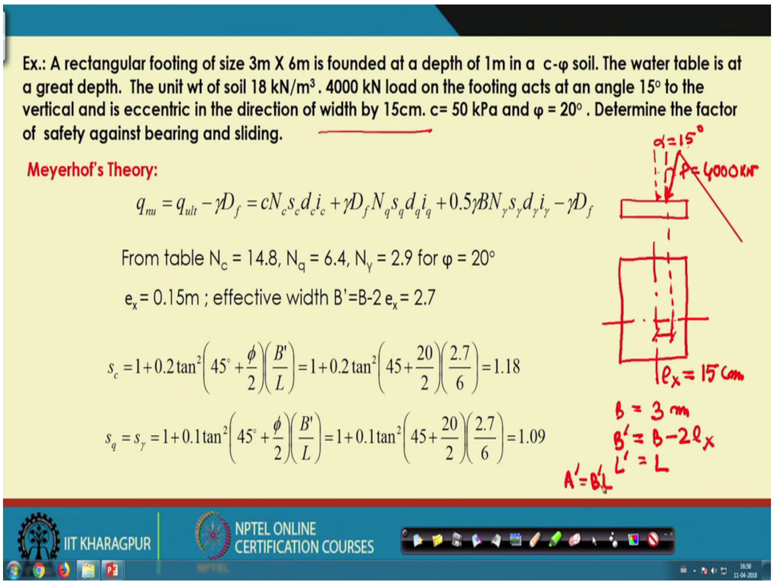
Foundation Engineering
Prof. Kousik Deb
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture – 26
Shallow Foundation – Design VI

So, this class I will discuss about the design of footing under inclined and eccentric loading condition. So, I have considered both inclined loading as well as eccentric loading. So, last class discussing that we have to keep the loading in within the one-third middle one-third portion of the footing so, that there should not be any tension developed in the base of the foundation.

(Refer Slide Time: 00:53)



So, I have selected this problem that a rectangular footing of size 3 meter cross 6 meter is resting on a c phi soil, with a depth of foundation is 1 meter. The water table is at great depth; that means, we have not considering the water table affect. The unit weight of the soil is 18 kilo Newton per meter cube and 4000 kilo Newton load is acting on the footing with an angle 15 degree with vertical and eccentric in the direction of the width by 15 centimeter. So, that means, if we draw the section so; that means, if this is the footing so, it is vertical. So, it is acting this load P is equal to 4000 kilo Newton and which is acting at angle alpha is equal to 15 degree.

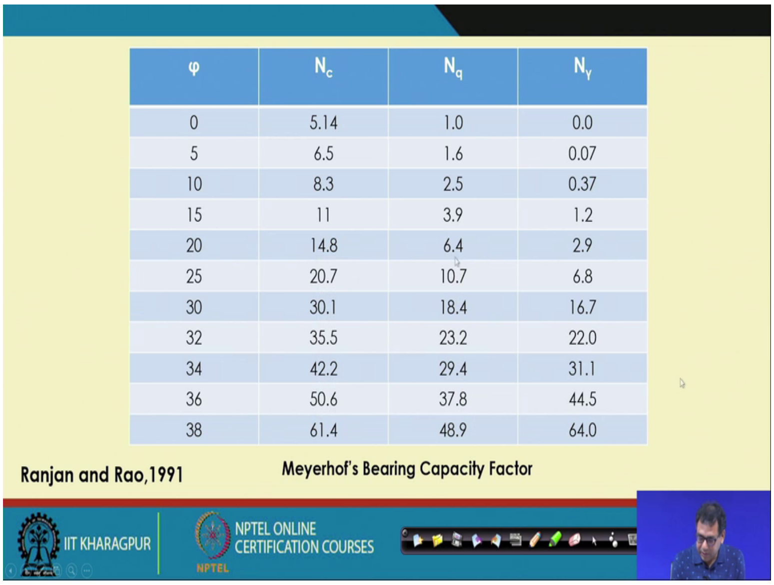
And so, and if we draw the plan of the footing so, this is the central line of the footing and it is eccentric with ah. So, it is in centre so; that means, the load will be eccentric. So, that is why I have to just correct this one so; that means, it is alpha value is this one. So, and so, that is mean it is this is the amount of eccentricity. So, and this it eccentricity e x is equal to 15 centimeter ok.

So, and the vertical lengthwise direction there is no eccentricity. So, eccentricity is only in the widthwise so, it is widthwise direction is 15 centimeter. And so, that mean the total width is B is equal to 3 meter. So, if I do that B by 6 so, that is greater than 15 centimeter so, it is within that curve portion. So, there will be no tension developed in the foundation. So, another one is that we can write that B dash is equal to B by 2 e x and L dash will be equal to L, as there is no eccentricity in the lengthwise direction. So, if there is the eccentricity in the lengthwise direction then we have to take the effective length also so; that means, the effective area will be B dash into L; in this case if there is a two way eccentricity then it will B dash into L dash.

So, so, now, I am using the available theories. So, I have discussed about total 6 theories first that Terzaghi theory, then the Skempton, then Meyerhof, then Hansen basic and IS code. So, among these 6 theories so, I am because the Skempton theory is only applicable for phi equal to 0 condition, but here it is phi is there so, we cannot use that theory here. And as well as Skempton theory the eccentric that inclined loading condition is not incorporated so, we are not using that theory. In the Terzaghi also that inclined loading theory is not incorporated so, inclined loading effect is not incorporated in last theory. So, that is why we are not using Terzaghi also here.

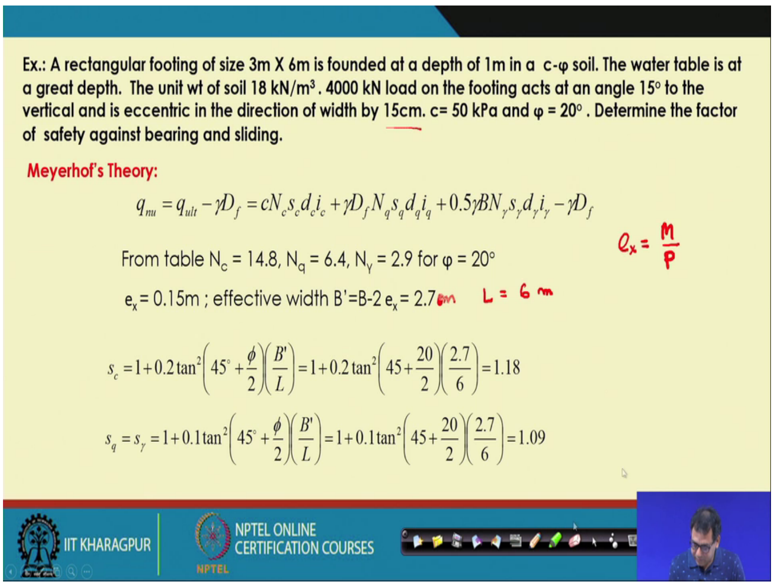
So, remaining 4 theories we are using here and let us see how we can use the different theories under these eccentric and the inclined loading condition. So, first theory is that we have considered the Meyerhof theory, where we are using the net ultimate. So, this is the expression of the Meyerhof theory. So, s c d c i c I mean s d i are the shear factor, de factor and inclination factor. So, here if the i is I mean inclined alpha is not I mean loading is not inclined alpha is equal to 0; that means, perfectly vertical then this i c i q i gamma you have to know we will not consider; because these are one because that effect is not there. But so, here first we have to determine the N c N q n gamma.

(Refer Slide Time: 06:11)



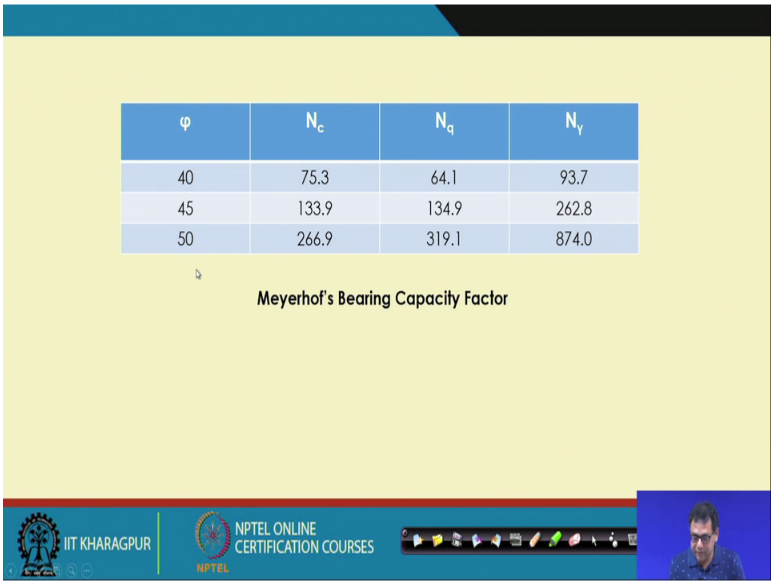
So, that is why from the table so, it is 20 degree [FL]. So, N c is 14.8 N q is 6.4 and N gamma is 2.9 so, that is why 14.8, 6.4 and 2.9. As I mentioned earlier also that if the phi value that is given in the table is within that range; suppose the phi value is given 20 and for 25 or for 30 and your phi value is 22 degree then you have to linearly interpolate that value between the given values. And so, now the e x value is given 15 centimeter that is 0.15 so, effective width will be 2.7 meter. So, affect will be 2.7 meter and L will be as well as this is the because, there is no eccentricity so, L will be meter 6 ok.

(Refer Slide Time: 06:59)



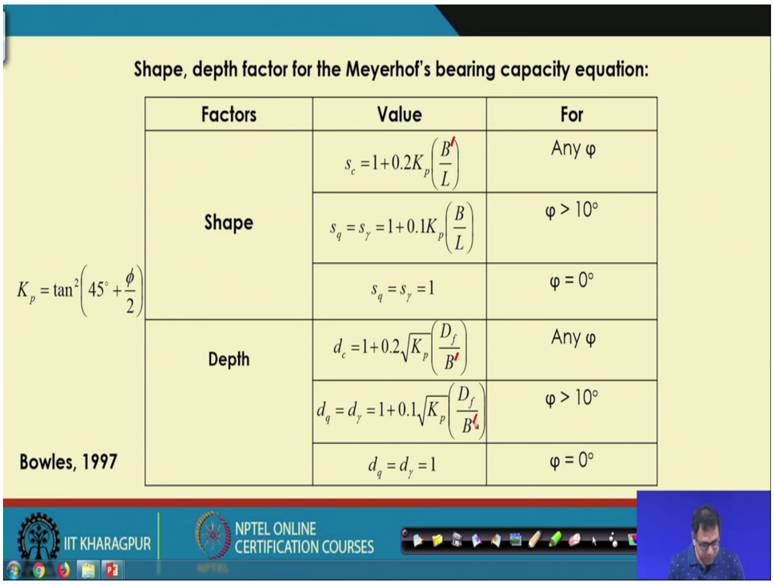
And another thing that here the eccentricity directly is mentioned, but sometimes the moment and the vertical load is mentioned. So, in that case if the moment is in the lengthwise direction or the widthwise direction depending upon which direction the moment is so, suppose if the moment is now widthwise direction then we have to calculate the eccentricity e x by M into divided by P ok. So, this P is that vertical load that is acting. So, this way also eccentricity can be given, but here eccentricity is directly given.

(Refer Slide Time: 08:07)



So, that is why we will have B dash and L and when if I look at this so, these are the table for Meyerhof bearing capacity factor. This is the table and this is for the 40 40 45 and 50 degree this is a table, the same table.

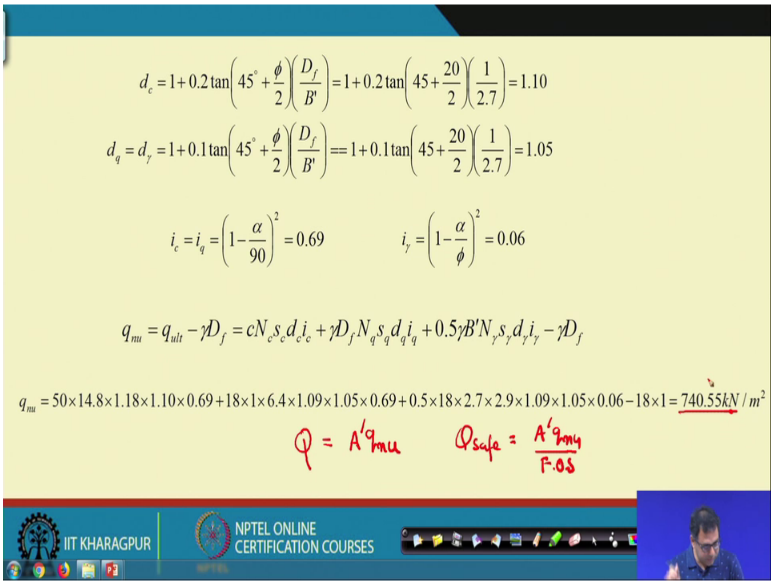
(Refer Slide Time: 08:15)



And then these are the shape and the depth factor for Meyerhof's bearing capacity equation. So, here the shape factor s c we are using so, 1 plus 0.2 K p B by L and this is what any phi. So, as you are using it is for eccentric loading and so; that means, instead of B we will use here B dash and as L dash is equal to L so, we will keep L. If there is the L dash also so, then you have to use B dash and L dash both. So, similarly K p value will get from these expression, this is tan square 45 plus phi by 2.

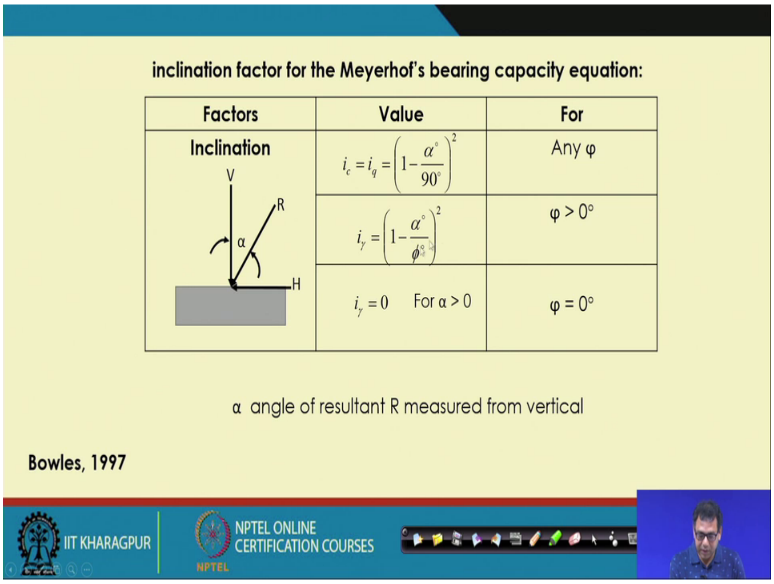
And similarly for phi greater than 10, this is the s q and s gamma factor and similarly depth factor also we are using d c and d q and d gamma ok. So, this is 10 greater than 10 degree. So, we are using these expression these expression these two and here also this will be B dash, this will be B dash ok. So, similarly when now if I go back to the s c so, s c these expression so, this will be B dash L. So, if I put this value I will get 1.18 similarly, s q s gamma will give you 1.09.

(Refer Slide Time: 09:40)



Now, d c it will give you this is D f by B dash. So, it is 1. by 2 2.7 because B dash is 2.7. So, it is 1.1 and these value is 1.05.

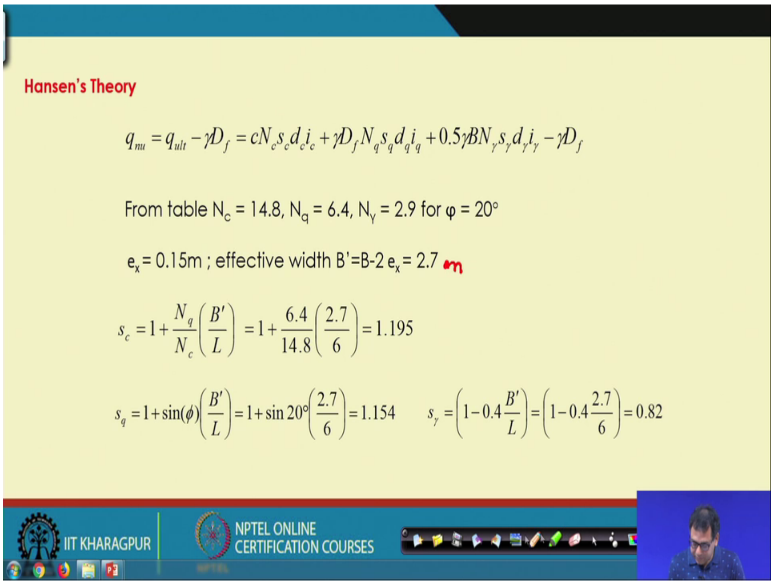
(Refer Slide Time: 09:55)



And we have from this table, where this is the i c i q i gamma expression for any phi i c i q and this is was phi equal to 0 degree and this is phi equal phi greater than 0 degree, this is phi equal to 0 degree. But I will use this one as the phi value is greater than 0 degree. So, this is the alpha which is 15 so, alpha value is 15 degree. So, if I use this co factors then I can get, this is the i c i q 0.69 and i gamma is 0.6.

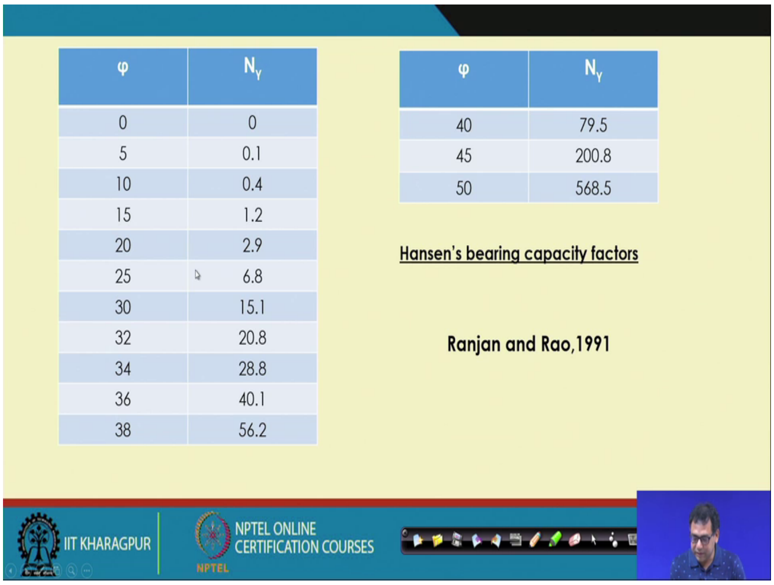
So, ultimately if I put this value in this expression so, I will get the value of ultimate load carrying capacity is 740.55 kilo Newton per meter square. Now, if I want to calculate the total load then Q will be A dash into q net ultimate ok. Now, if I want to apply the calculate the safe load, then this will be A dash q net ultimate divided by factor of safety which is 2.523. So, this is the Meyerhof approach by which we are getting these value. Now, what I will do? I will do go for the next approach which is the Hansen's theory.

(Refer Slide Time: 11:18)



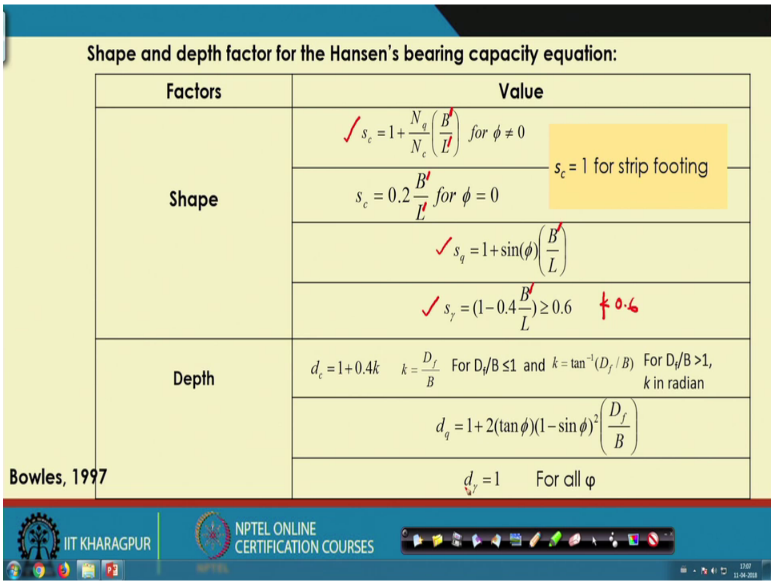
The basic theory is same only the corrections only the bearing these factors and the bearing capacity factors and these shape factor, depth factor, inclination factor they are different.

(Refer Slide Time: 11:38)



So, here the again that we have a table for Hansen bearing capacity factor because, N q because other values N c and N gamma and we have to use the Meyerhof N c and N gamma in case of Hansen. So, that is how only N q table is given, N c N gamma we have to take it from the Meyerhof's table. And so, that is why N c N q are same only N gamma is 2.9, as for 20 degree it is 2.9. So, that value is taken here and again e max is 0.15 so, effective width is 2.7 meter.

(Refer Slide Time: 12:22)

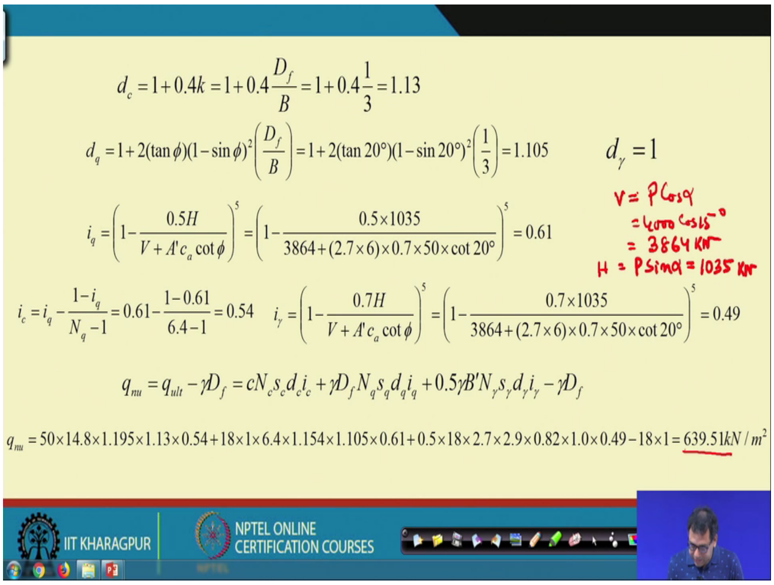


And then if we go for this factor so, this is a factor. So, if you see this factor s c is equal to phi not equal to 0, this is the s c factor which is function of N q by N c B by L. So, here also instead of B we have to use B dash and L dash because, L dash is e r equal to L so, you will use the B dash by L. If that is a both way, then you have to go for B dash and L dash. So, now similarly here also B dash L dash, but these expression we will not use because this is for phi equal to 0.

So, I will use these expression and for the s q and s gamma I will use these expression, where this will be the phi dash B dash, this will be the B dash. And remember that these factor cannot this is greater than 0.6. So, its cannot be less than 0.6 remember that, if it is coming less than 0.6 then you have to take 0.6 ok. And but, when we are determining the d c and d q and d gamma so, as per the Hansen's suggestion we will use B, remember that we will not use B dash ok. So, because idea is that because these effective area so, that will mainly effect the shape factor. So, that is why for the depth factor it is not used. So, this is the difference between Meyerhof because, Meyerhof we are using all B dash L dash whether it is shape factor or depth factor.

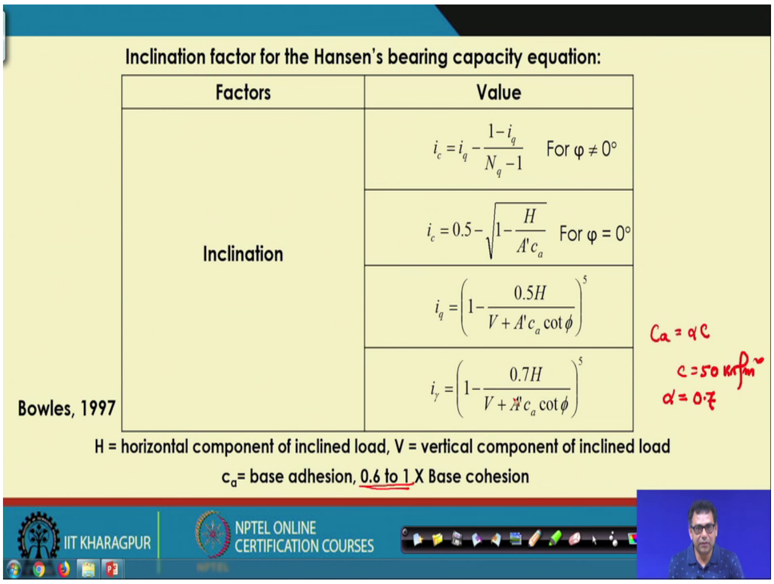
But here in the shape factor we are using B dash L dash, but depth factor we are using B. So, this is the d c so, as D f by B less than 1 in this case. So, we will use these expression and then we will use this expression and d gamma is always 1 for phi for all phi. So, now, if I go for this one and then I will get this is the B dash. So, s c value, this is also the B dash s c and s q and s gamma value if I put in this expression so, it is greater than 0.6. So, we have to use 0.82 ok.

(Refer Slide Time: 14:42)



So, similarly d c we have use the B, we have not use the B dash. So, and then d q also we have used B and then d gamma is always 1.

(Refer Slide Time: 15:01)



Now, in case of Hansen's approach the inclination factors when I am calculating which is there we have to use the horizontal and vertical component of the load, because load is inclined. So, here H is the horizontal component and V is the vertical component and there is a term c a which is adhesion. So, as I mention that c a adhesion is always alpha into c ok. So, thi[s]- here c value is given 50 kilo Newton per meter square and alpha value we have to chose from these range 0.6 to 1. So, I have taken alpha value is 0.7 from this range ok, but in the in the assignment problems so, this alpha value may be given. So, we have to use that alpha value so; that means, this is the vertical component.

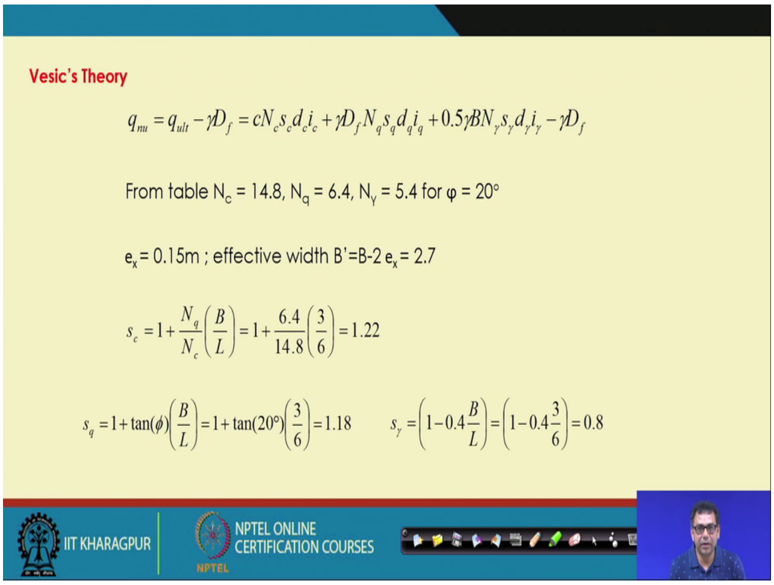
And remember that and this is the horizontal component, another one that here we have to use the effective area. Again, here also that effective area we have to use that is A dash ok. So that means, here inclination factor we are using the effective dimension, depth factor we are using the effective, we are shape factor we are using the effective dimension. But depth factor we are not using the effective dimension; we are using the original dimension in case of Hansen approach.

But in Meyer approach all the 3 factors: shape factor, depth factor and inclination factor, though in the inclination factor there were no dimension B or L; that means, in shape and depth both factor we are using the effective dimension. So, this is the difference that is why I am solving with different approach. So, now, here if I use so, this is not equal to phi so, I will use these s c and so, I will use this one and this is one.

This three because it is for this is these two are for any phi and this is for phi equal to 0 and this is for phi equal to 0 and this is for phi equal to 0 and this one phi not equal to 0. So, now if I use these expression so, here the as I mention that the vertical component will be P cos alpha so; that means, 4000 into cos 15 degree. So, this value is 3864 kilo Newton vertical load and horizontal load is P sin alpha. So, that is equal to that value is equal to 1035 kilo Newton.

So, now if I put here it will be the effective area, effective area means 2.7 into 6. So, if I put this value this will be 0.61 then i c is 0.54 and i gamma is 0.49 and then if I put this value here in this general expression so, ultimately this is coming out to be 639.51 ok.

(Refer Slide Time: 18:34)

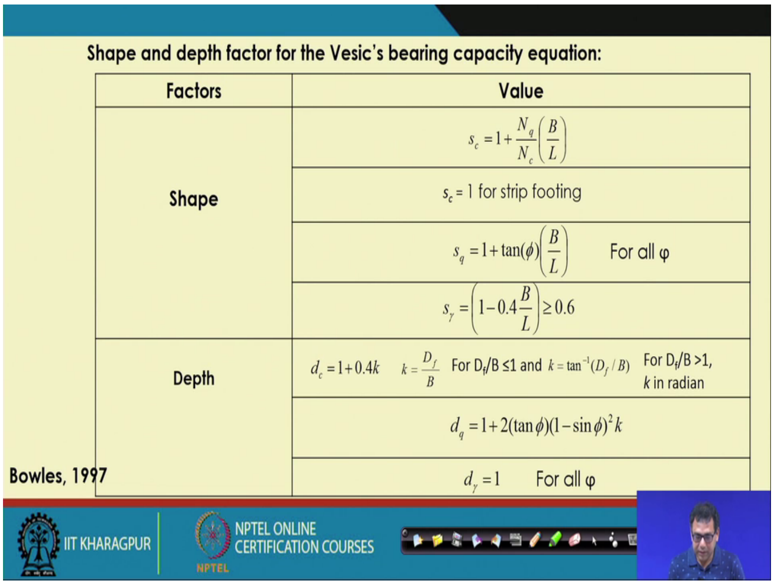


So, now I will go for the next approach or next theory that is our Vesic's theory. Again, the basic equation is a same so, and we have to use different bearing capacity factor.

(Refer Slide Time: 18:45)

So, again here N gamma value is given because the other N c and N q will be same as the Meyerhof bearing capacity factor. So, we are using the same Meyerhof bearing capacity factor for N c and N q. But N gamma Vesic has suggested a new factor and that is the table that is for the bearing capacity factor N q only, because i N c i N gamma you have to take for the Meyerhof table.

(Refer Slide Time: 19:19)

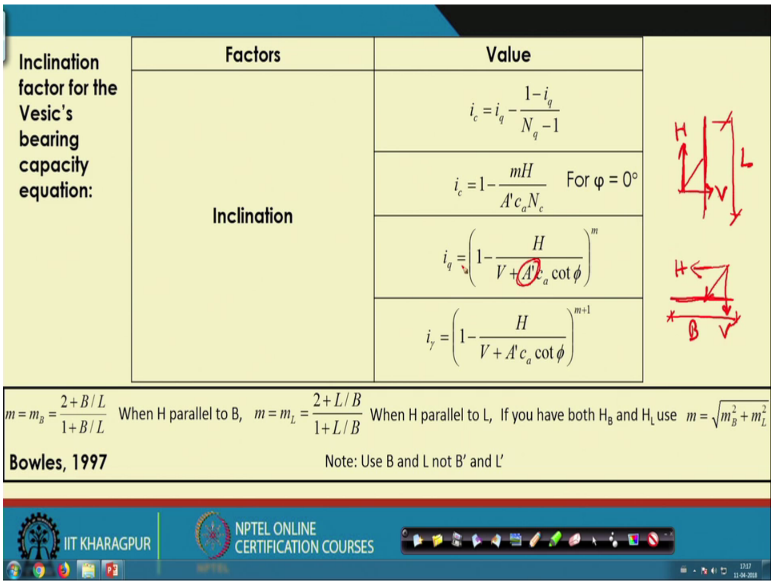


And then for the shape factor and depth factor which is similar to the Hansen, but there is a some difference. What is that difference? Because, again this is a similar to the Meyerhof to the Hansen, but this one is I think this is different, because in case of Hansen it was sin phi what I. So, in case of Hansen it was yeah, it was sin phi, but here it is tan phi. So, that the only difference in this chart otherwise all are same. So, yeah otherwise all are same ok.

So, only it is given a k, but that is also D f by B. So, this is the shape factor for Vesic's bearing capacity equation. But the difference is that, in case of Hansen's we use effective dimension for shape factor, but we did not use the effective dimension for the depth factor. But here shape factor and both depth factor we will not use the effective dimension. The recommendation is there we have to use both cases the actual dimension; that means, B and L ok.

So, that is the major difference between this when it is inclined loading, because inclined loading case only these effective area concept will come; otherwise that means, we have to use the B i L. But in the Hansen, we have in shape factor we have to use the effective dimension and um, but in case of basic in shape factor also we will use that the actual dimension which is B and L.

(Refer Slide Time: 21:28)



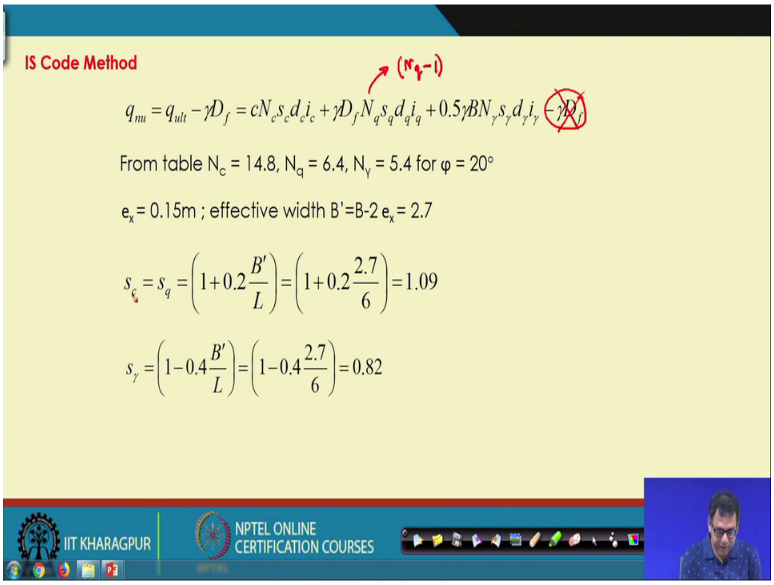
So, now and for the inclination factor which is also similar, but here in case of Hansen it was phi to the power phi, but here it is to the power m. So, how I will calculate this m? So, m we can calculate by using these expression when H is parallel to B. So, in our case this case H is parallel to B. So, we will these expression, but if your eccentricity is in lengthwise direction in that case H will be parallel to your L.

So, if because here if this is the width so, if this your width is if this is the width so, your load acting in this way so, it is parallel. This H horizontal component, this is the vertical component so, horizontal component parallel to the width axis. Now, if your horizontal component is parallel to the length axis, this is V H in that case because this is L in that H axis then you have to use this expression. But remember that when I will calculate m or we will we have to use the actual dimension of the footing; that means, B and L. But we have to use effective area when we will calculate the inclination.

So, that is why I am explaining this portion in detail because there are where you have to use which dimension so, that is important. So, in basic all the factors you use that actually dimension B and L, even for m calculation. But when you use this area for the inclination so, then that case you have to use the effective area that is the recommendation. So, and that is why if I use this value so, similar way I am using that is why B by L for s c s q and s gamma. And because it is also greater than 0.6 so, we will take 0.8 and d c also I am using the B and d q also and when I am calculating m it is in width direction. So, and using this actual dimension B by L, but here I am using the effective area 2.7 cross 6. So ultimately, I will get these coefficient and m value is coming out to be 1.67.

So, if I put this expression so, I will get 0.57 and if I put remember that if in the original expression that will be B dash ok, that is true for all the cases. When I use the B dash so, that is true for all the cases. But when I calculate the bearing, calculate the factor correction factors, in those cases we have to use different dimension in different cases. And ultimately this value is coming out to be 800 kilo Newton per meter square. So, next approach I am considering that this is basic bearing capacity factors and the correction factors.

(Refer Slide Time: 25:01)

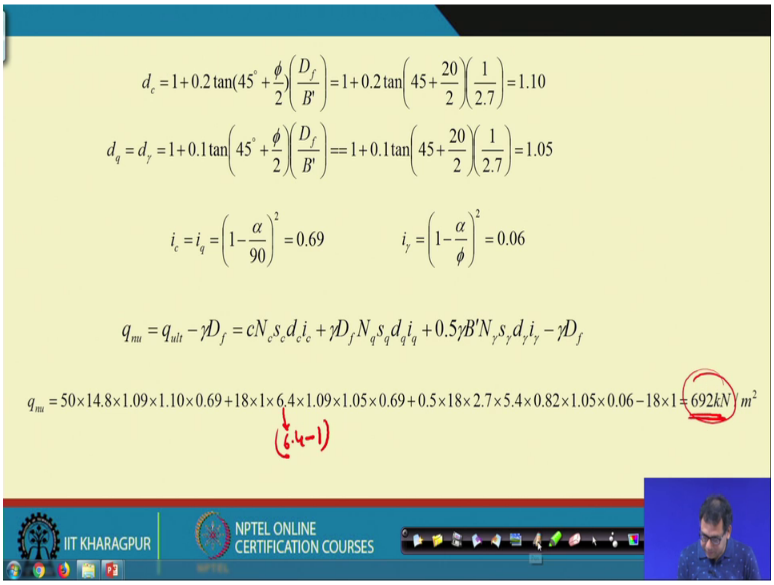


And next approach that is IS code method; the IS code method, here in IS code method we have to use as per IS code method. So, here also I have use the actual dimension by actual application, but IS code method suggest that in here also because, this is N q N dash this one; this is actually this term is N q minus 1. So, this is not there as per the IS code, but this is general expression.

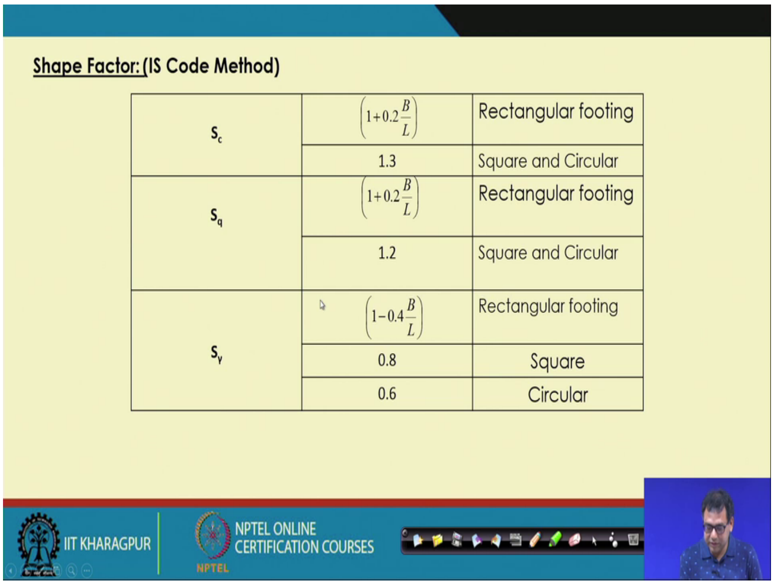
So, in the IS code you use this one, but then your value will be slightly changed because, if I use because this is the actual recommendation for N q minus 1 as per IS code. But other case you have to as I mention you have to follow these general expression, but as for IS code is recommended in N q minus 1 so, you will you that N q minus 1.

So, above this IS code the N c N q N gamma is the basics N q N c N gamma. So that means, I will take the N c N q for the Meyerhof table and the N gamma from the Vesic's table and then we will use the effective. So, this is the all the cases are to use the effective dimension is used for shape factor and for depth factor and inclination factor.

(Refer Slide Time: 26:32)

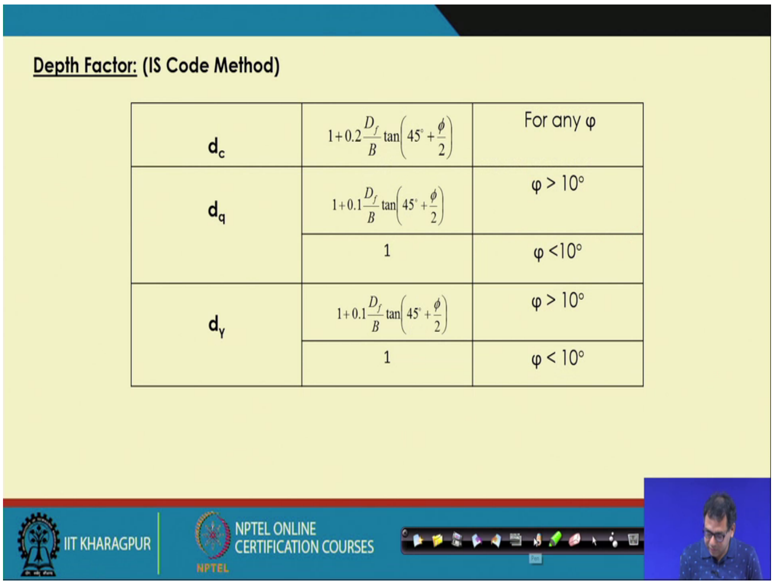


(Refer Slide Time: 26:36)



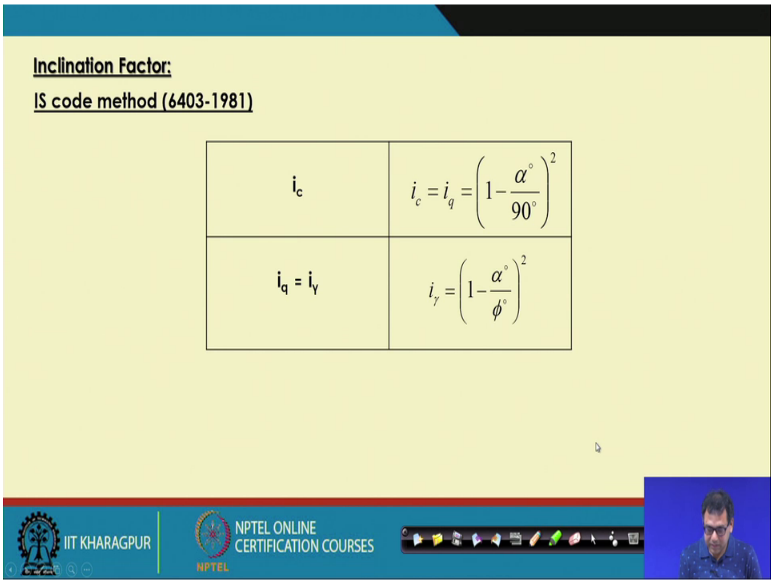
So, this is the table so, all the cases we have to use the effective dimension. This will be the B dash, this will be L dash, B dash, L dash, B dash, L dash ok.

(Refer Slide Time: 26:50)



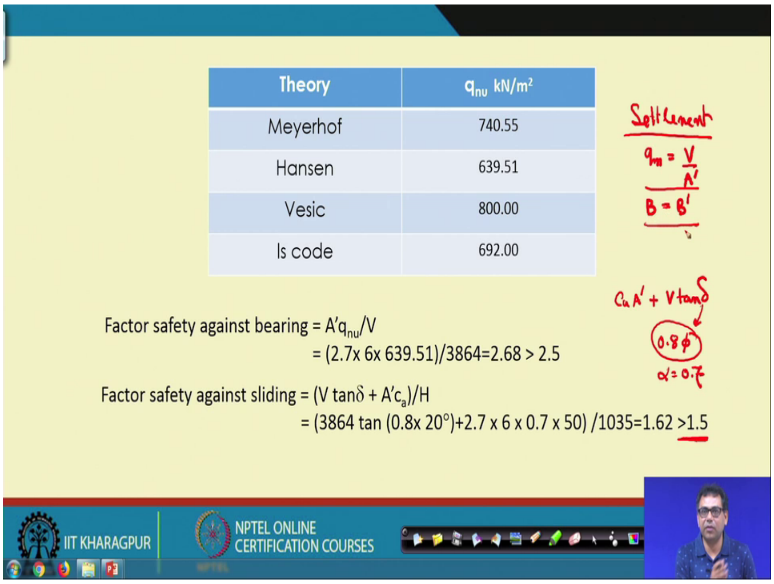
And here also it will be B dash, B dash, B dash depending upon which one you will be consider, it is mentioned here.

(Refer Slide Time: 27:01)



And this is the alpha is 15 degree. So, depending upon the your condition you will chose the appropriate factor. And so, now, if I put these values so, remember that this will slightly change in this case so, here this will not be here. So, in that case in place of that will be the this is 6.4 so, it will be this one will be 6.4 minus 1. So, this value will slightly change ok. So, just correct this thing its value will be slightly change. So, so, because that is the way it is been represented. So, and then after I putting all these values so, I will get close to these value. So, now, if I take all the values in one table so, this is IS code factors ok.

(Refer Slide Time: 28:02)



So, now if I take all the table so, Meyerhof is given 740.55 and Hansen is given 639.51, Vesic is given 800 kilo Newton per meter square, IS code is given 692 kilo Newton per meter square. So, now, if I use the actual IS code recommendation these value will slightly reduce these value will slightly reduce so, or it may increase. So, what is the so, that is the slight variation, but it will be around this one. So, from here I can see that Hansen expression is given the lowest values ok. But that also depend on the c phi value that you are choosing, it is not that always the Hansen expression will give you the lowest value. So, that also depend the c phi that you are choosing.

So, and then ah, but this is the summary of this problem. So, I have used all these expression and then after all the we have to calculate the factor of safety against bearing. So, the factor of safety only vertical component against vertical component we will check. So, the actual load will be the A dash q net ultimate divided by the V that is the vertical load is coming.

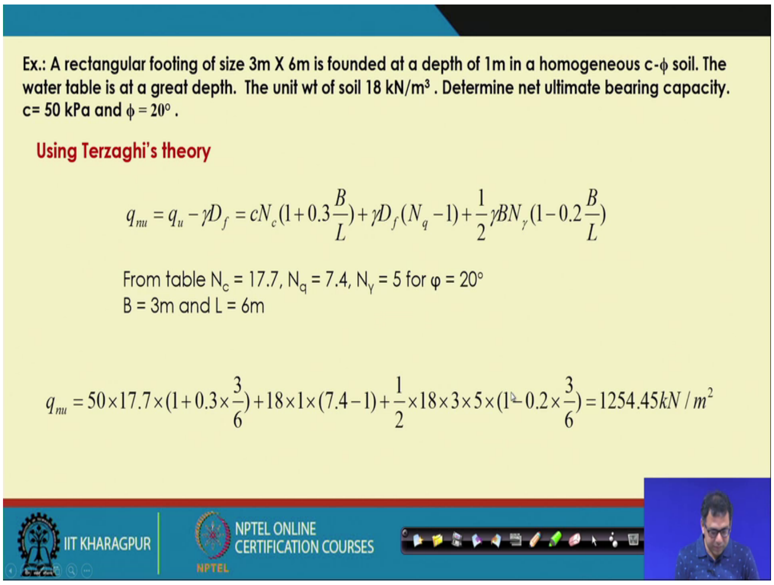
So, if I use that this effective area so, and this factor of safety is coming 2.68 which is greater than 2.5. So, ok, but there is a another term the sliding, sliding means there is a horizontal component. So, this horizontal component which slide the foundation in lateral direction ok. So, that also we have to prevent. So, how we will check that? So, simple that we have to use that our c a into the effective area over which it is acting plus the normal force into the tan delta.

Tan delta is the friction between any other material to the soil, here material is the foundation may be the concrete ok. So, that is why V value is taken here, delta value is taken 0.8 times of phi in this case, but so, in the in the problem it will be mentioned. So, here it is taken 0.8 phi and alpha is taken as usual 0.7. So, now, if I put this value 0.7 into 50 divided by the horizontal components because these horizontal components only giving the sliding. So, it is 1.6 62 and the sliding factor of safety is 1.5 so, it is safe.

So, this way we have to do the design and remember that I have explained what are the difference when we calculate the factor different factors, for different approach and different approaches. And then whether I mean in which factor you will use effective and which one you will use the actual dimension that I have discussed, because it is different for different approaches ok. So, and the final one that when I will now, it is the bearing check is done I have to do the settlement check. So, in the settlement check you have to calculate that your q a not net pressure that is that the pressure that will be the vertical component and the effective area, that will be your net pressure which is acting the vertical component of the q n.

And when you calculate the settlement so, then in that case so, in your settlement calculation you consider B equal to B dash. And your net stress that is acting on the base, will be the vertical component of your load divided by net area. So, that will be the net stress acting at the base and you consider that and instead of B you consider B dash, then rest of the calculations are same as I discussed for other problems. For settlement calculation whether it is in sand or it is in clay ok.

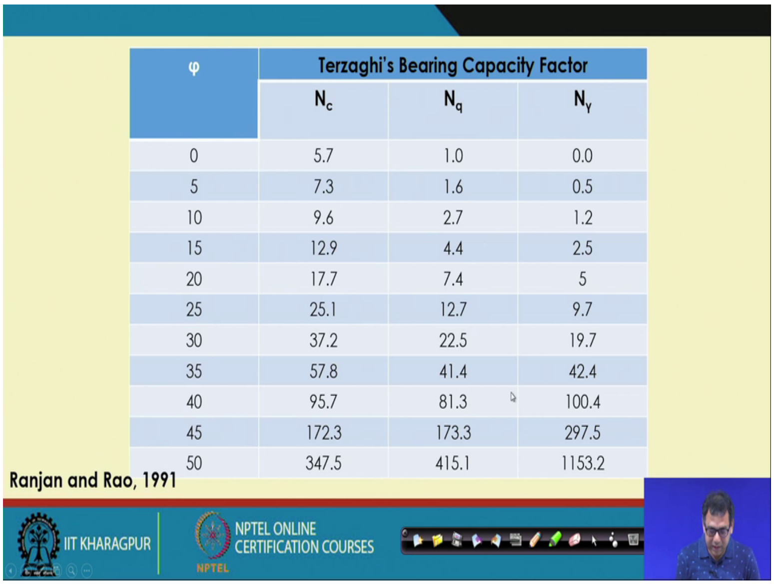
(Refer Slide Time: 32:50)



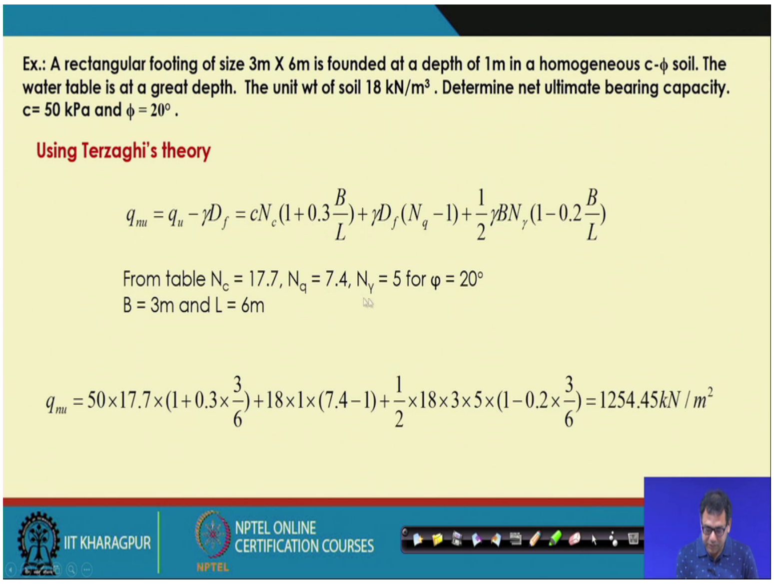
So, now, just one thing; so, in the lecture 13 I have solve the same problem with a value of i equal to 40 degree and c was 0. Now, I have taken a sets of different values of c and phi and let us see what is the difference of different theories. I am now, here I have taken your c is equal to 50 kPa phi equal to 20 degree. And previous lecture 13 I solve the similar problem with phi equal to 40 degree and c equal to 0 ok. And in the next problem I will solve with phi equal to 0 and c with some value. And then we will compare a tab[le]- make a table and we compare what is the difference between the all the theories ok.

So, the bearing capacity expressions is same for this is, but this case I can use the Terzaghi and if it is pure clay then I can use the Skempton also. So, you can use the Terzaghi, the expression is same and discuss the how I got this correction factors and this is the N c N q N gamma and this is the correction factors for the rectangular footing.

(Refer Slide Time: 33:57)

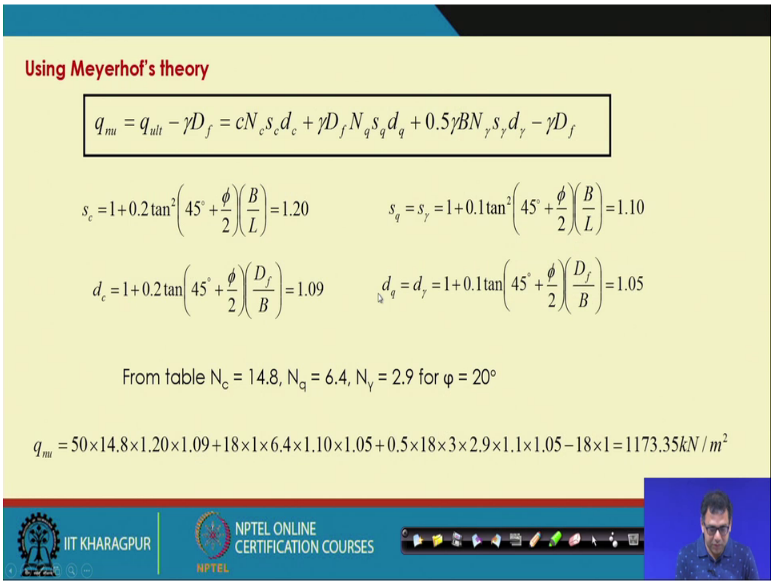


(Refer Slide Time: 34:09)



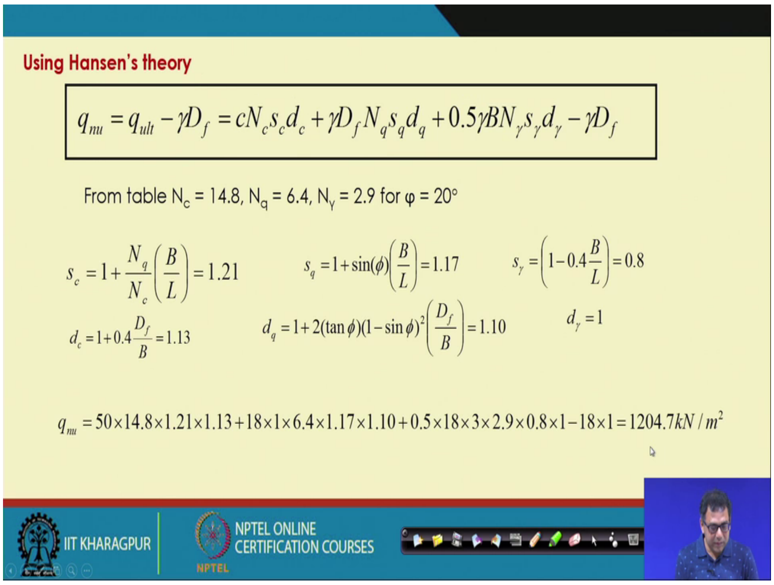
Similarly, this is the Terzaghi bearing capacity factor table where, I am getting that value that degree 20 degree is 17.7 and 7.4 and 5. So, that is the value I am taking.

(Refer Slide Time: 34:11)



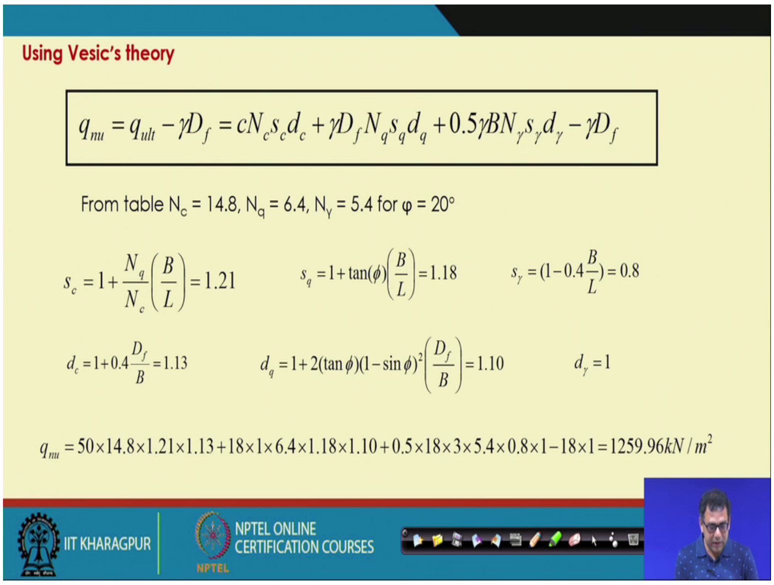
And so, then for the Meyerhof theory the same theory I am using here and for this I am I have explained how I have using this factors from the table and then I am getting this value.

(Refer Slide Time: 34:23)



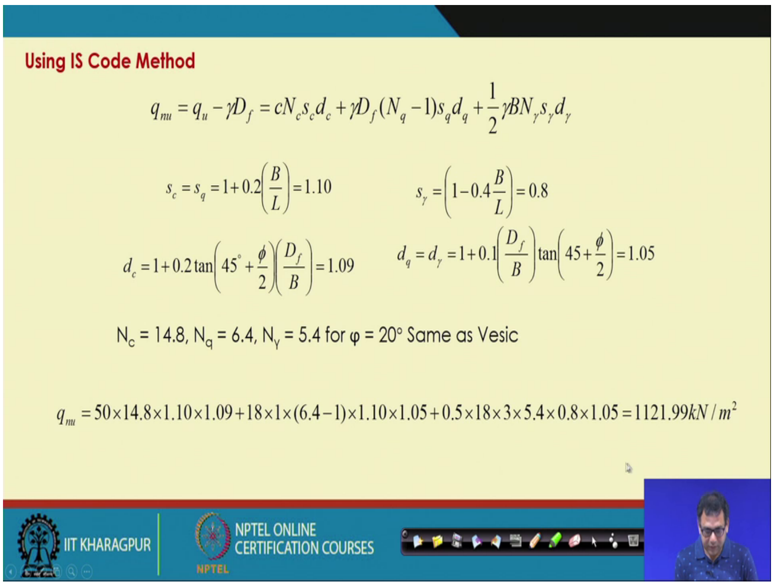
Similarly, for Hansen theory I am getting 1204.7.

(Refer Slide Time: 34:30)



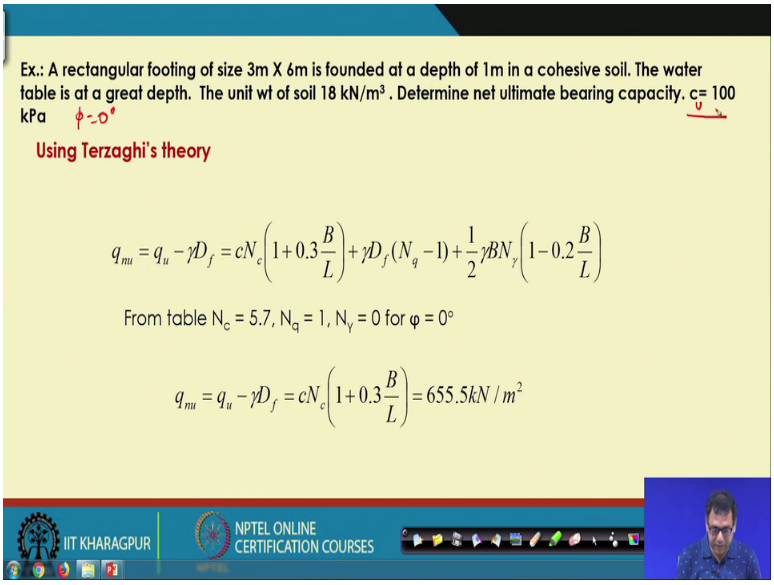
And then I am using the Vesic's theory, where this is not the inclined or eccentric load this is the same problem with vertical loading. So, that is why all dimension are the actual dimension B and L and then and there is no eccentricity, no inclination. So, that inclination factors are also not calculated because, intonation is not there.

(Refer Slide Time: 34:54)



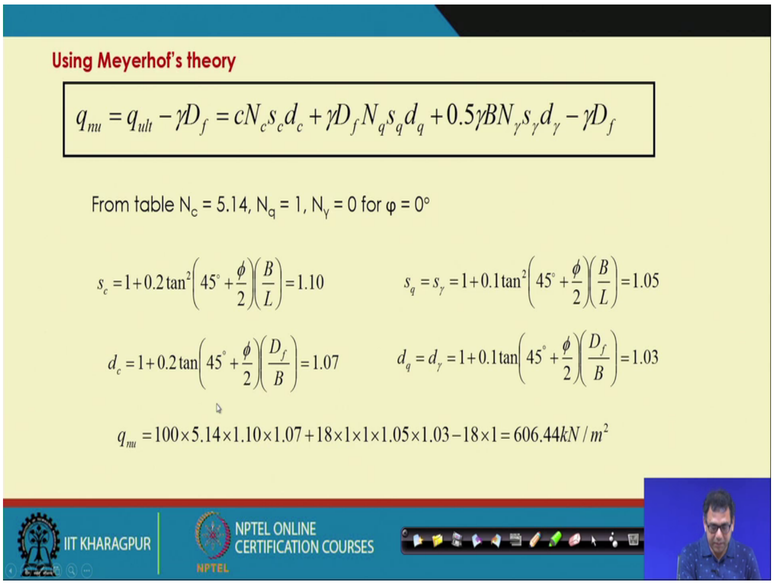
And then this is the other values and this is the IS code, where this is here the actual condition is taken.

(Refer Slide Time: 35:05)



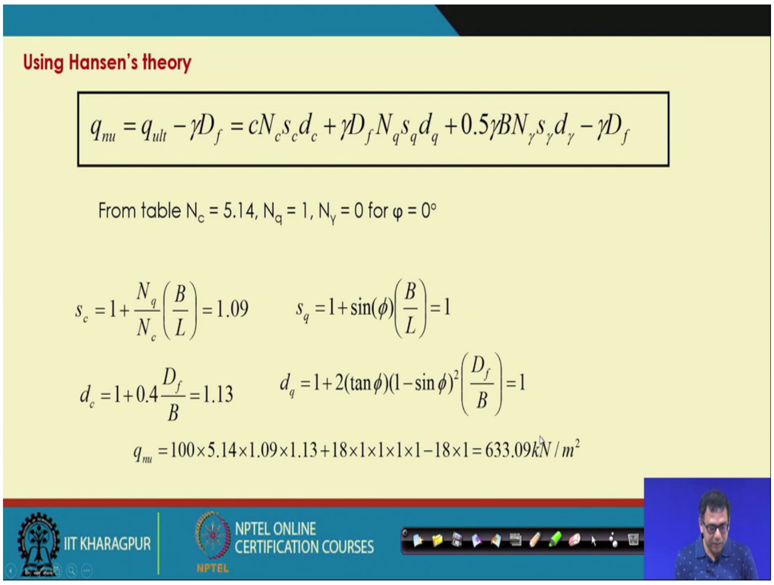
And then this is the IS code and that same problem I am solving with c is equal to 100 kPa and phi is equal to 0 ok. So, phi is equal to 0 degree and c u is equal to; that means, this will be the c u is 100 kPa. So, now, I can use the all 6 theories because it is only for the clay. So, I can use it for the Skempton also ok.

(Refer Slide Time: 35:36)



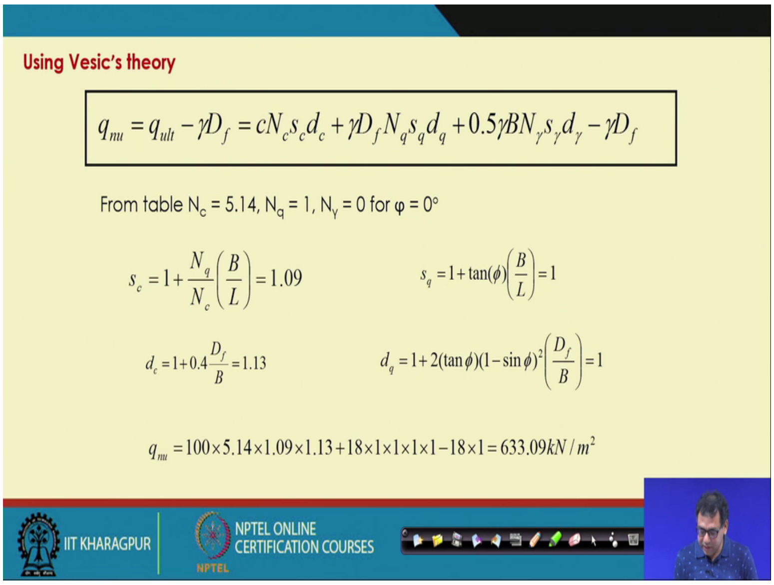
So, now, if this is the Terzaghi's theory then this is the Meyerhof theory I am using and with this all factors; again, the load is perfectly vertical and acting and the centre that no inclination, no eccentricity. So, and this is the value.

(Refer Slide Time: 35:49)



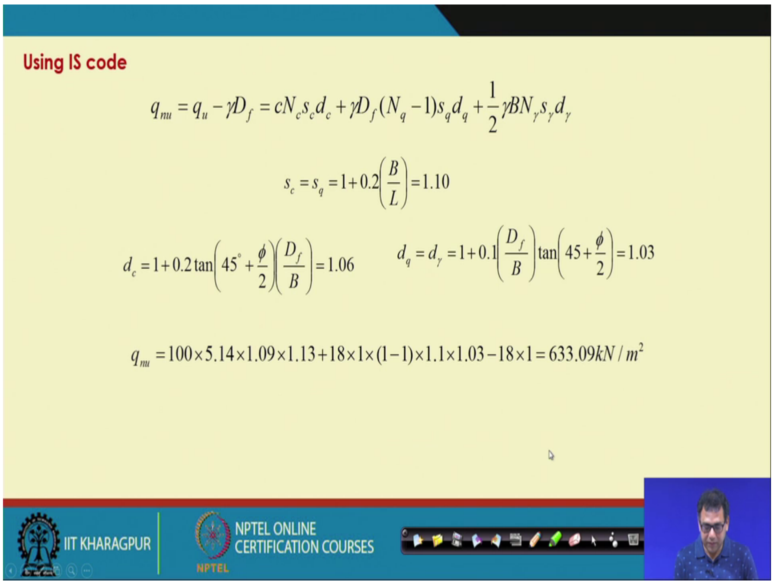
And similarly, for Hansen's theory I am getting this value ok.

(Refer Slide Time: 36:54)



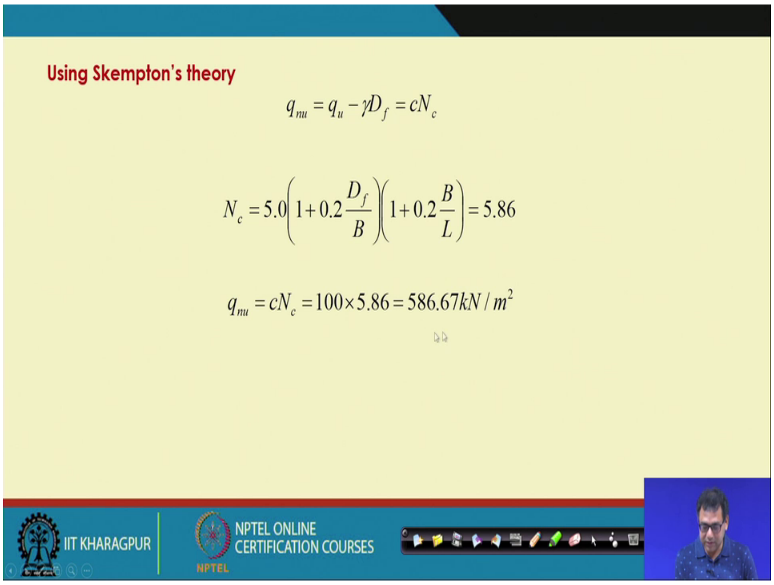
And for using the Vesic's theory, I am using 633.09 kilo Newton per meter square.

(Refer Slide Time: 36:00)



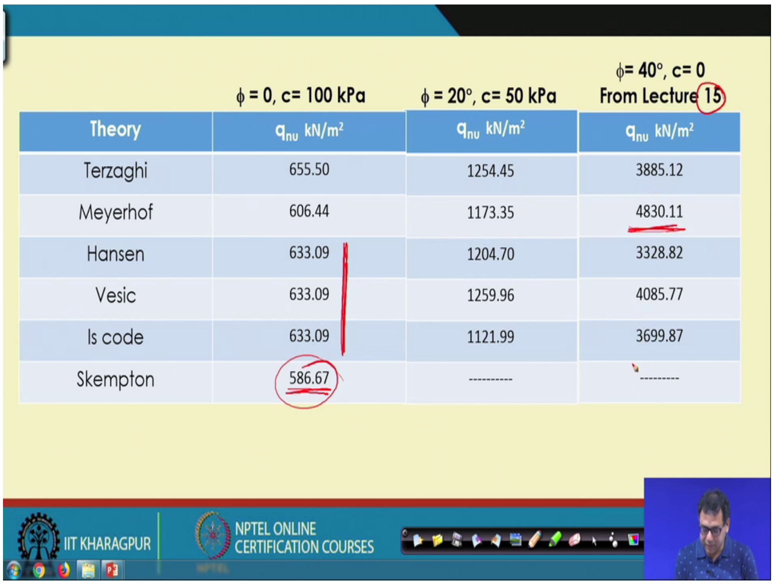
If I use the IS code method, then I am getting 633.09 kilo Newton per meter square.

(Refer Slide Time: 36:07)



Now, as I mentioned I can use the Skempton theory also, this is for the rectangular footing. So, this is the Skempton theory if I put this value D f by B and this is the net ultimate c N c or c u N c and this is the value that is coming out.

(Refer Slide Time: 36:26)



	ϕ = 0, c= 100 kPa	ϕ = 20°, c= 50 kPa	ϕ= 40°, c= 0 From Lecture 15
Theory	q_{nu} kN/m²	q_{nu} kN/m²	q_{nu} kN/m²
Terzaghi	655.50	1254.45	3885.12
Meyerhof	606.44	1173.35	4830.11
Hansen	633.09	1204.70	3328.82
Vesic	633.09	1259.96	4085.77
Is code	633.09	1121.99	3699.87
Skempton	586.67	---------	---------

And so, now I have taken all the combinations. This is for phi equal to 0 c u equal to 100 kPa, this is phi equal to 20 degree c equal to 50. This is from the lecture 15, this is lecture 15 ok. So, this is lecture 15 I am taking the phi equal to 40 degree and c equal to 0 degree. So, these are the all values. So, from here you can see for only cohesive soil this Skempton is giving the lowest one. These all the three values are same ok, for all these 3 methods.

And Meyerhof is given slightly lower values from these 5 and this is the lowest. And from this one is all the theories are given more or less the same values and here Meyerhof is given slightly higher values. And Terzaghi's bearing capacity theory is giving values within the I mean in it is in the almost the average value is given.

So, but it is not the all the cases so, that that is why the my intention to do all this problem in different c r parameters is that depending upon your c phi, strain parameter your I mean different theory it does not mean that one theory always will give you the higher value, one theory always give you lower value. It is not like that, it may change depending upon the strain parameter values that we are considering. So now as I mentioned for cohesive soil that Hansen theories give better prediction compared to the Terzaghi's theory.

But here I have use Skempton for our my all the problems on clay because it is giving the giving the lowest value. So, to be in the safer side I am using that, but here now the question is which equation we will use. So, as you can see that Terzaghi’s expression is simple one and you can use it because, it is given the average value and it is also given almost the similar type of value for other theories. It is giving within the within the middle of the all the ranges range that I have received. So, that is why I can use the Terzaghi’s theory because that is the simple. But if the load is inclined then that we can use for the Meyerhof theory because, that is also predicting values which is slightly lower side.

So, so that is why the depending upon that which theory is you are using so, that you have to decide. But this is the as a engineer you have to decide which theory you will use because, ultimately that is the table I have shown you that it does not mean that one table will always give you the higher value. But I would recommend that is for the soft soil only clay Skempton is good one. And for other theory you can use the Terzaghi because, it is giving because it is very simple and it is given more or less reasonable value.

And, but if it is inclined loading then you can use the other theory this is like Meyerhof theories. And so, that is why this is the comparison of the all the theories. And so, this is the end of the shallow foundation part. So, next class I will start the next chapter which is the deep foundation and mainly the pile foundation. And I will discuss the pile foundation under compressive load only.

Thank you.