Advanced Foundation Engineering
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Lecture - 11
Shallow Foundation: Settlement Calculation-I

In last class, I have discussed about the different types of settlement; that immediate settlement, then primary consolidation settlement and secondary compression settlement. Now in this lecture, I will discuss how to calculate these different types of settlement; that is immediate settlement and consolidation settlement for different types of soil.

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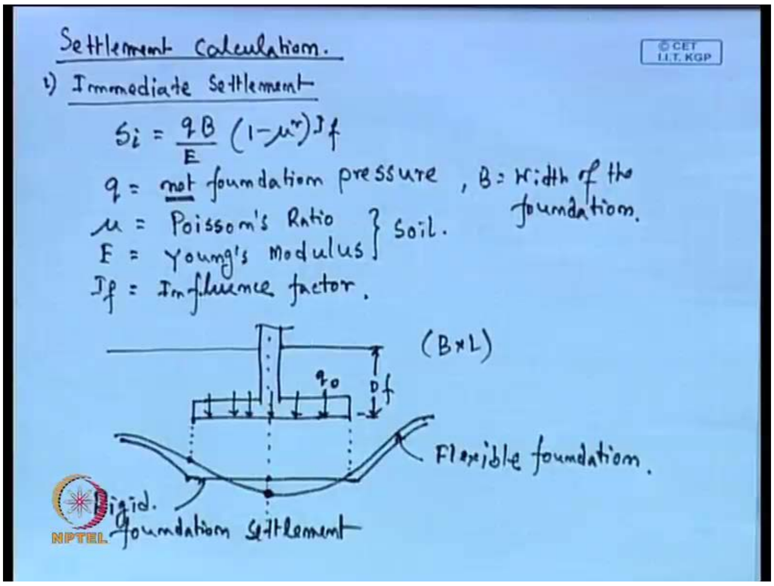

Now, first I will go for this settlement calculation, this is settlement calculation. So, first expression that will give for the immediate settlement calculation; so immediate settlement calculation, so by theory of elasticity approach, this immediate settlement can be determined by q B by E into 1 by mu square into I f. Using this expression, we can calculate the immediate settlement of the soil; where q is equal to net foundation pressure. So, this q is the net foundation pressure. So, this is the net; next mu is equal to Poisson's ratio of the soil, E is equal to the Young's modulus of the soil and I f is equal to influence factor.

So, this q is the net foundation pressure, mu is the Poisson ratio and E is the Young's modulus of the soil. So, these are the soil properties and this is the foundation pressure and B is the width of the foundation and B is equal to width of the foundation. Now, if I f is the influence factor or this factor, we can calculate for different types of footing. That is for the square footing, circular footing and for the rectangular footing and for different types of foundation; because this we can have this we have this flexible type of foundation and or the rigid type of foundation or mat foundation. So, flexible type of foundation is generally the isolated footing and the rigid type of pile foundation is raft foundation or the mat foundation

So, depending upon the type of foundation whether it is the rigid and the flexible or the shape of the foundation, we will get the influence factor. Now this influence factor, when we calculate this influence factor, so first if we want to draw the settlement response of the foundation after the application of loading and the different foundation types, so suppose this is the application of load through the foundation, this is q 0 and this is the depth of the foundation.

Now, for the settlement profile, so this is the B into L say, from the settlement profile, suppose if it is the center, then the settlement profile would be only this type of… if it is a flexible type of foundation. So, we can say that settlement variation at the corner of the footing; this is the corner of the footing. And the settlement variation at this corner of the footing or settlement value at this corner of the footing and settlement value at the center of the footing, both are not same for flexible type of foundation. Flexible type of foundation means, it is the isolated footing. So, that is the example of flexible type of foundation.

So, here you can see that the settlement of the center is more compared to the edges or the corner of the foundation. So, and for the rigid type of foundation, this value is more or less same. And, here we will get this pattern. So, this is for the rigid foundation settlement. Now, rigid type of foundation is mat or raft foundation. Here in the rigid type of foundation you can see that, settlement is throughout the uniform; whether it is the corner or center of the foundation.

So, here the influence factor will be one; because here this settlement variation is nil. That means it is uniform. So, that is corner or center, this value is same; for waves, for the flexible five type of foundation, influence factor value we can calculate the center or you can calculate at the corner. Both are now same. And then you can calculate, consider the average one also. So, that means, this corner and... But at the center, it is observed that we can say that the foundation, rigid foundation settlement is less compared to the flexible and type of foundation.

So, that means the influence factor also is at the, for the, at the center, if I consider this is the less compared to the flexible foundation. So, that means influence factor of the rigid foundation is less as compared to the flexible type of foundation at the center of the loaded region or the foundation.

So, now if I want to calculate the influence factor, so we will get this influence factor same for the rigid foundation or that is corner or center. Then we will get the different influence factor or for the flexible type of foundation at the center and the corner. Then we can consider the average influence factors or factor for the influence flexible type of foundation.

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Source: Ranjan and Rao, 2000

Shape	I_f for flexible foundation			I_f for rigid foundation
	Centre	Corner	Average	
Circle	1.0	0.64	0.85	0.86
Square	1.12	0.56	0.95	0.82
Rectangle				
L/B = 1.5	1.36	0.68	1.20	1.06
L/B = 2	1.52	0.76	1.30	1.20
L/B = 5	2.10	1.05	1.83	1.70
L/B = 10	2.52	1.26	2.25	2.10
L/B = 100	3.38	1.69	2.96	3.40

So, one chart, that table we can consider. This is a table; where by using this table, we can calculate the influence factor for the flexible foundation and for the rigid type of foundation. As I have mentioned the rigid type of foundation, this value is same; whether it is corner or center.

So, this for, this is a shape defined type of foundation. This is the circle, square, then the rectangle. So, rectangle; this is different L by B value if L by B equal to 1.5, 2, 5, 10 to 100. And this is, so as I have mentioned for the flexible type of foundation, this we can calculate the influence factor at the center, corner and this is the average value for the flexible type of foundation.

Then, for the rigid type of or mat raft foundation is value is same for the corner or the center. Now for the circle, it is 1.64 for the corner and average is 0.85 and rigid, in case of rigid, it is 0.86. Now for the square, this center influence factor for the flexible foundation, if it is square footing it is 1.12, but whereas for the rigid foundation it is 0.82.

And for the rectangle, L by B equal to 1 is 1.36, for the rigid 1.06; and for L by 2 is 1.52, for the rigid is 1.2. That is 2.1, this is 1.7, this 2.52 and this is 2.1; and this for the L by B equal to 100, this value at the center is 3.38, whereas this values for the rigid foundation is more or less 3.4. Now for the most of the cases, it is observed that the influence factor at the center for the flexible type of foundation and the influence at a… If you compare this center influence factor for the flexibility foundation and the influence factor for the rigid foundation, it is observed that the influence factor for rigid foundation is 0.8 times with the influence factor of the flexible foundation at the center; because it is almost this 0.8 times.

So, that is where when we calculate the settlement for this rigid type of foundation, then one option that we can directly use the influence factor for the rigid foundation case; that is L by B is different value or square or this is circle. Or if it is a raft foundation, then it is better to calculate the influence factor for the flexible foundation at the center, then multiply it by 0.8 times. Then we will get the settlement of the rigid foundation. That means, the first we calculate the settlement considering the influence factor of the flexible foundation at the center, then if it is a rigid foundation, then we will multiply that settlement calculation by 0.8. Then we will get the settlement of the rigid foundation. That means, first we calculate the flexible found, considering the flexible foundation settlement at the center, then multiply it by 0.8, then we will get the rigid foundation settlement. So, that 0.8 is the rigidity correction that we will apply. So, that one correction is rigidity correction. If it is a rigid type of foundation, that is 0.8.

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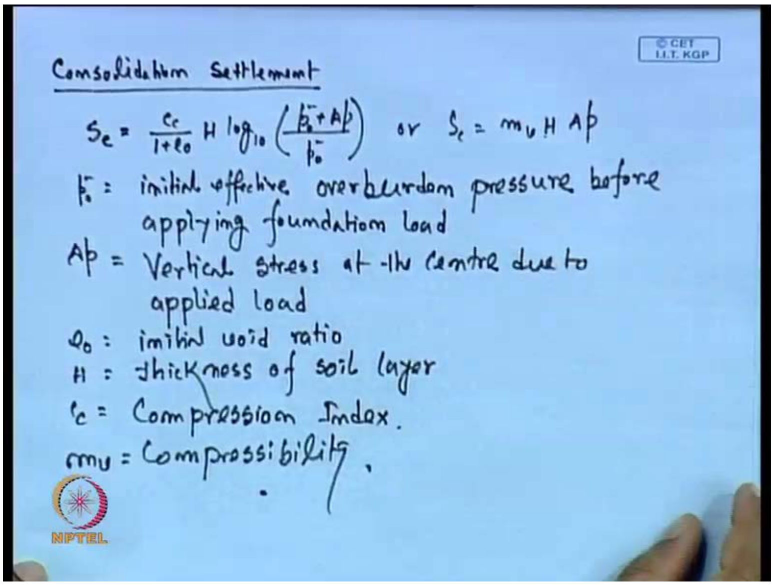

So, now next we will go for the consolidation settlement calculation; that how to calculate the consolidation settlement. This is consolidation settlement by consolidation... So, for the first class I will explain that how to calculate this consolidation settlement.

So, C c by 1 plus e zero into H, is the thickness of the layer, log ten. Then del p 0, a p 0 bar plus del p by p 0 bar. Or, we can calculate that S e by m v into H into del p. So, you have p 0 bar is the initial effective overburden pressure before applying foundation load; and del p is equal to the vertical stress at the center due to applied load; e zero is the initial void ratio; then H is the thickness of soil layer and C c is equal to compression index.

So, either we can use this expression to calculate the consolidation settlement or we can use this expression to calculate the consolidation settlement; where m v is equal to compressibility of the soil of the soil. So, here also H is the thickness of the soil layer and del p is the vertical stress at the center due to applied load.

So, if it is the single layer, then we calculate this way or if it is a multilayer, then we can calculate this settlement at different points. Then we can sum all the settlement, then we will get the total settlement of the soil layer. Now that means, using this expression, these two expressions we can calculate the consolidation settlement as well as the… And the immediate settlement.

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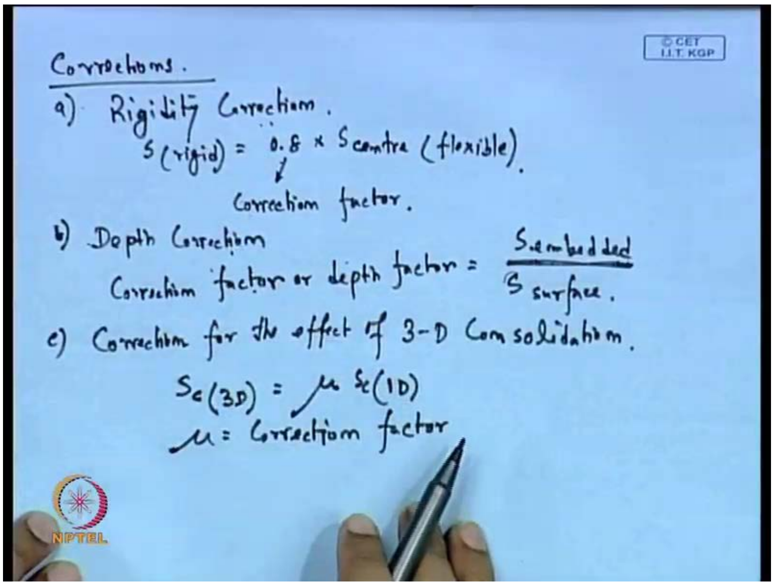

The next one that we will apply is the E value or the corrections. So, what are the different corrections that we will apply? The first one as I have mentioned that if it is a rigid foundation, then we will apply the rigidity correction. So, S rigid is equal to 0.8 times into S center flexible. So, as I have mentioned that settlement of the rigid foundation is, first we calculate this center settlement of the flexible foundation, then we will multiply it by 0.8, then we will get the settlement of the rigid foundation. That means this 0.8 is the correction factor.

So next one… and this correction we will apply only for the rigid foundation. Next one, we will calculate the depth correction. So, this depth correction is the correction factor or depth factor. That is equal to settlement at embedded, then settlement at surface. That means, that settlement that we are calculating that considering this is; that means at the, if it is embedded settlement, then that means, if first you calculate the settlement, that is the surface settlement, and we will apply the correction factor for the depth, then we will get the settlement for the embedded condition. Actually, we will place this putting at a below the foundation depth. So, that is in the embedded condition, but the settlement that we are calculating by using those expression that will give us the surface settlement.

So, as the footing is placed at the depth below the ground surface; though that means, we have to apply some depth corrections. So, that correction factor is S embedded by S surface.

So, that means we will first calculate the surface footing, surface of calculation of the surface, then settlement, placing the footing at the surface, then we will get the… calculate the settlement, then we will apply the correction factor. Then we will get the settlement at the embedded condition.

And, the next correction is factor. This is the correction for the effect of three-dimensional three-dimensional consolidation; because of consolidation expression that we are using that is for one dimensional consolidation theory. Now actually in the field, there is the three directional consolidation; so the x, y, z. But here we consider only the z-direction consolidation. But it will go for the x and y direction also. So, that means they incorporate that, three dimension consolidation effect we have to apply from consolidation correction factor

So that means, the S c consolidation for three dimensions is equal to the correction factor mean into S c for one dimension; where mu is the correction factor. So, that means here we will get the consolidation, so that corrections also. So, these two corrections, these here will… this correction factor is 0.8. But what will be the correction factor for depth and consolidation?

So, and it is noted that this consolidation correction, we will apply only for the consolidation settlement, not for immediate settlement. But for the rigidity correction and depth correction, these two corrections we will apply; so these two corrections; so a and b. We will apply for the immediate settlement calculation, but this consolidation correction factor we will apply for the consolidation settlement calculation. That means a, b, c; this three we will apply for calculation of consolidation settlement. But for calculation of immediate settlement, we will apply only a and b; these two corrections.

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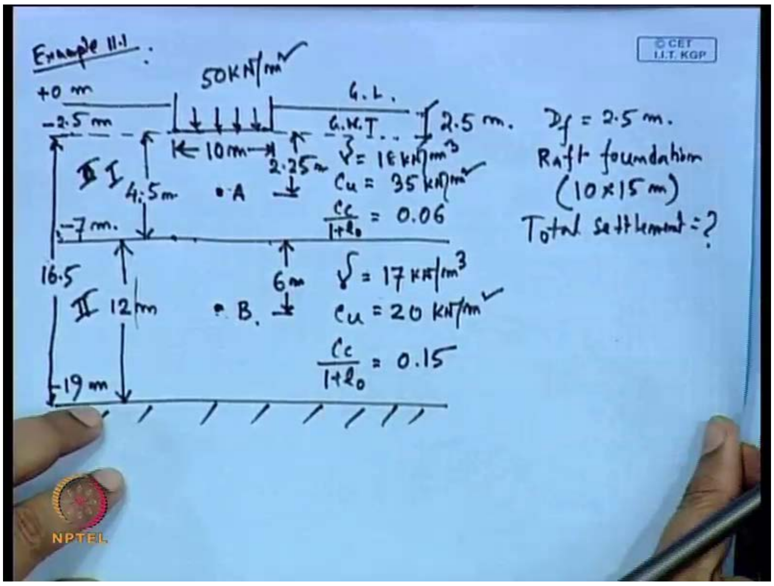

Now, next we will solve one problem, then then we will get how to calculate this consolidation correction factor. So, this is the example eleven point one. So, a raft foundation; so first we place a raft foundation. So, this is the raft foundation loading; that is coming is 50 kilo Newton per meter square meter square. So, this is ground surface. So, this is plus zero meter level. Now, water table is placed at the base of the foundation. So, that means this is minus 2.5 meter.

So, water table is placed at minus 2.5 meter. So, that means this depth is 2.5 meter. So, one layer depth is minus 7 meter, minus means in the, below the ground surface, and another layer is minus 19 meter depth. So, the depth of this second layer; so this is layer one, this is layer two and the position of ground water table. This is ground water table, which is 2.5 meter below the ground and that is the position of the footing base also. So, that means D f is 2.5 meter and the dimension of the raft, that is the raft dimension is 10 meter cross 15 meter.

So, that means the width of this raft foundation is 10 meter and length of the foundation is 15 meter. So, now we have to calculate the total settlement. And, what would be the total settlement? Now, first we will that means this total layer, first layer one is 7 meter thickness and layer two is 12 meter thickness. So, this is 19 minus 7; that is 12 meter. And, the properties that we will get, thus for the layer one gamma is 18 kilo Newton per meter cube. C u is 35 kilo Newton per meter square and C c 1 plus e 0 for the layer one is

0.06. And for the layer two, this gamma is 17 kilo Newton per meters cube; C u is 20 kilo Newton per meter square and C c 1 plus e 0; that is 0.15. So, this is soft clay, this layer. So, this means we can say this is layer one and this is layer two.

Now as I have mentioned, therefore settlement calculation will go for... So, that means that the thickness of this, here this is one is the hard strata or the rock. So, that means this soil. So, that means the influence zone for the settlement calculation is twice b. and, b is here is 10 meter. So, influence zone will be 20 meter, but below the base of the foundation. So base of the foundation, this total thickness of the soil layer is 16.5. So, this total thickness of the soil layer from the base of the foundation. This is 16.5.

So that means, and and the influence zone is 20 meter. So, that means we will consider this total soil layer. Now if influence zone is within that, suppose this width of the foundation is 4 meter, then the influence zone for the settlement calculation would be 8 meter. So, that means up to 8 meter soil, we have to consider if the width was 4 meter, but here this is 10 meter. So, 20 meter as this portion is hard strata.

So, we will neglect the settlement calculation for this portion. We will consider only these two layers, settlement contribution because as this total thickness 16.5, which is less than the 20 meter. So, we will consider the total if this 16.5, which is more than the influence zone, then we have to consider the only that influence zone. Suppose, if it is the 4 meter, then only 8 meter we have to consider to calculate the settlement. So, here we will consider the total soil. And here, as we will consider the approximation method to calculate the stress due to this footing load, so now you consider one point as the center of this first layer; below that means center of this portion, below the footing.

So, this portion is 4.5 meter. and another point, we will consider at b point, which is say center of this second layer. So, as if we consider more points, then we will get further accurate result. for this calculation, we will consider only the one point and that is sufficient to calculate this total settlement. So, that means this b is 6 meter from the top of the second layer and A point is at the depth of 2.25 meter from the base of the footing.

So, there we have considered the two points. One is a and b. here these two points we will calculate the consolidation settlement and this four, this a point is 2.25 meter from the base of the footing and b point is 6 meter from the top of the second layer or 10.5 meter from the base of the footing 6.4 meter; this base of the footing to disc top layer, top of the second layer, and the top of the second layer, this is 6 meter. So, there will… total will be 10.5 meter from the base of the footing.

So, first we will calculate the immediate settlement, then we will calculate the other settlement. So, first we will calculate the immediate settlement of this foundation, then then we will calculate the consolidation settlement and then the corrections.

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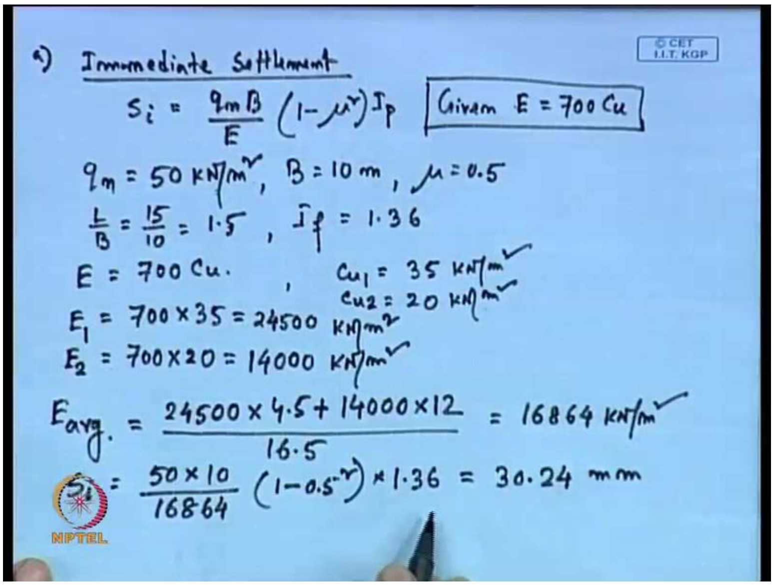

So, first we will calculate the immediate settlement. So, if the immediate settlement calculation expression is q n into B divided by E 1 minus mu square into I p. So, in this question it is also given that, E for this layer one and layer two is equal to 700 Cu; because we will get various relations in terms of E and C u. That means, we will get the… If you know the C u cohesion and then cohesion of the soil, then it can calculate the E for (( )) for this particular problem is mentioned that is 700 C u.

Now, that means from q n is equal to 50 kilo Newton per meter square for this particular condition; B is equal to 10 meter; mu, consider for the clay it is 5 meter; 0.5. So, mu is also considering it as 0.5. And now we will calculate the influence factor. So, we will calculate the… Consider the flexible foundation influence factor at the center, then we have applied the correction factor 0.8 for the rigid foundation. As it is raft foundation, so it is the rigid foundation. Now for this L by B, this value is 15 divided by 10. So, this is 1.5.

So, if it is a… So, from this table we can see that for the rectangular footing; if L by B is equal to 0.5, then for the flexible foundation, this I S value is 1.36. So, we will consider first 1.36, then we will multiply when we calculate the settlement; immediate settlement as well as consolidation settlement. Then we will multiply it by 0.8 to get the settlement for the rigid foundation.

So, this is 1.36. We will consider. So, our I f will be 1.36. Now, as E is 700 C u, so here there are two soil layers. So, now first layer, we will consider the first layer value; that means, C u one is given 35 kilo Newton per meter square and C u two is 20 kilo Newton per meter square. Now as this influence zone is within that two layers, so we will get the E value as the weighted average.

So, that means E 1; if we calculate E 1 for the first layer; that is 700 into 35; so this will be 24500 kilo Newton per meter square. Then the E 2 will be 700 into 20; that is 1400 14000 kilo Newton per meter square.

So, this E 1 is 24500 kilo Newton per meter square and E 2 is 14000 kilo Newton per meter square. So, E average would be… now, the total thickness of this layer from the base of the foundation is 16.5. And first layer; so that means this is the figure, here we can say the total thickness of this layer is 16.5 and first layer influence is 4.5 and second layer is 12 meter and total is 16.5 meter. So, we can take the weighted average in this fashion, thus this for the first layer 24500 and that is for 4.5 meter plus for the second layer into that is 12, then divided by 16.5 meter.

So, we will get this value; 68 16864 kilo Newton per meter square. So, weighted average value is 16864 kilo Newton per meter square. So, this weighted value, weighted average value we will consider when we calculate this immediate settlement.

So, immediate settlement S i will be; q n is 50, B is 10, E is 16864, 1 minus 0.5 square, influence factor is 1.36. So, after the calculation we will get; this value is 30.24 millimeter. So, this is the immediate settlement amount is 30.24 millimeter without any corrections.

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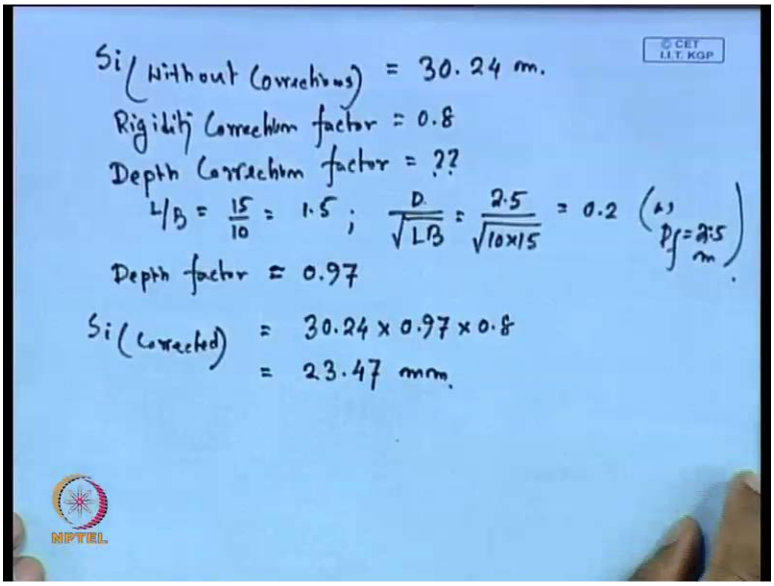

Next, we will apply the corrections for the immediate settlement. So, that means S i without corrections is equal to 30.24 meter. So, here immediate settlement calculation; we will consider only two correction. That is, one rigidity correction if it is the rigid foundation. As it is a mat foundation; that means, here we have to apply the rigidity correction. and then we have to apply the depth corrections. So, the rigidity correction factor is equal to 0.8. Now, what will be the depth correction factor? So, how we will calculate this depth correction factor?

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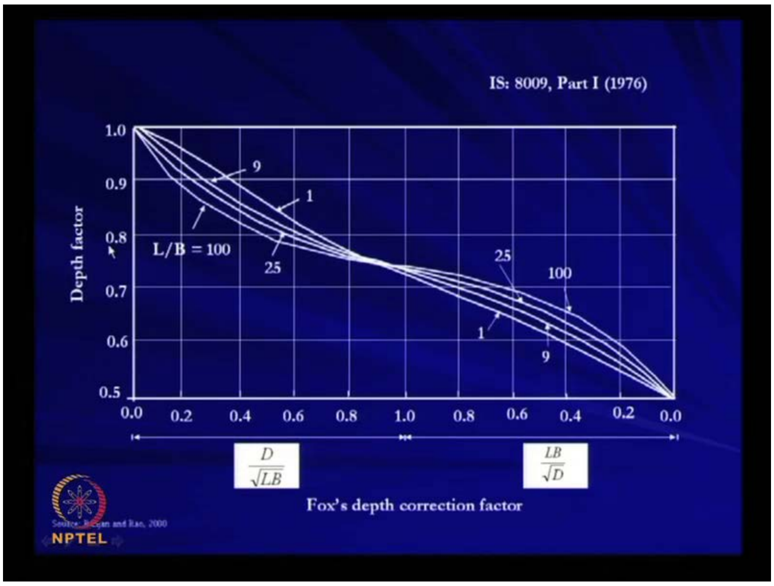

Now, from this figure this IS code recommends that how to calculate this depth correction factors. So, the depth factor this I, by using this IS recommendation we can calculate; so this is IS: 8009, part I 1976. Here, these are the different charts available for L by B value. And, this is the D by root over L B. This part from 1 to 0 and this is L B root over D from this part.

So, now if we consider this part where we need L by B value and we need D by root over L by B. So, once we get these two values, so by using these charts, this value, we will get the depth factors. Now, this is what called Fox's depth correction factor.

So, now to get the depth factors, so we need this L by B; let value is 15 divided by 10; 1.5. And, another is D root over L B. So, these value is D at is 2.5 and root over l. So, this means this is 10 into 15. So, this value is coming 0.2; so as D f is equal to 2.5 meter, D f equal to 2.5 meter. So, now here we will get L by B equal to 1.5 and D root over L B is equal to 0.2

So corresponding to this figure if i go, that is, so D by root L B is 0.2 and L by B is 1.5. So, this chart is for one, this is for nine. So, this will be around this region. So, this is 0.2. So, corresponding to this 1.5, this graph, so this value is depth factor is around 0.97. So, this is the depth factor value. This value is 0.97. So, we will get that depth factor. It is coming around 0.97. So, S i corrected; that would be 30.24, then 0.97 for the depth correction and 0.8 for the rigidity correction. So, this value is coming to be 23.47 millimeter. So, 23.47 millimeter is the corrected immediate settlement value, after you correct the depth factor and the rigidity factor. So, next we will calculate the consolidation settlement. Then how to calculate this consolidation settlement; that part we will discuss. So, first we will go for the consolidation settlement.

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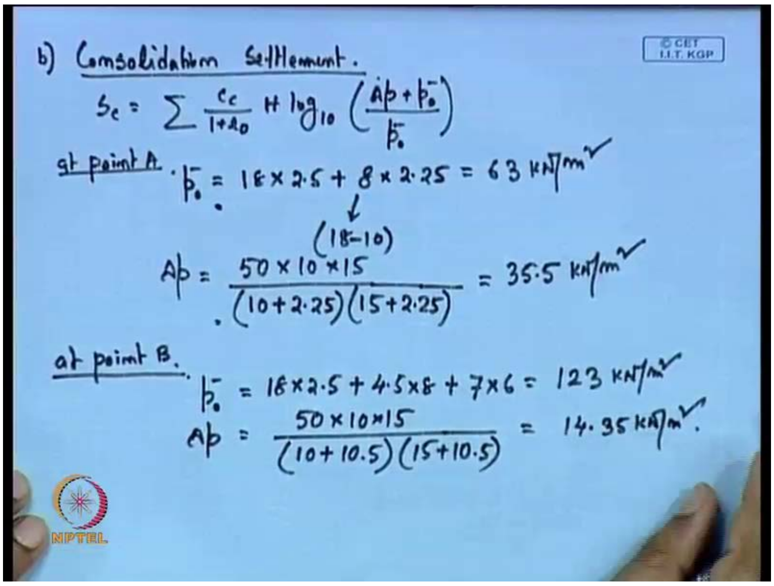

So, next one is the consolidation settlement. So, we have this consolidation settlement expression; that is summation C c 1 plus E 0, then H log 10 del p plus p 0 bar divided by p 0 bar. So, we have two points; point A and point B. So, we will calculate first the point A; at point A. Now at point a, p zero bar that is equal to... So, this is the figure. So, at point A p zero bar, effective overburden will be 2.5 into 18, then 2.25 into 8; because here it is below the… And we consider if the saturated density is 18 and consider this is the bulk unit weight also. So, this is the bulk unit weight and saturated unit weight; both are same. Consider this is 18. So, here this will be 18 and here this will be 18 minus 10; so 8.

So, when we calculate the effective overburden pressure at A, p which is 2.25 meter below the base of the footing. So, this will be 2.5 into 18 plus 2.25 into 8. Similarly, when we calculate the effective overburden pressure at point B, so this will be 2.5 into 18 plus 4.5 into 8 plus 6 into 7, here also we will consider 7 because 17 minus 7. So, this will be 6 into 7 plus 4.5 into 8 plus 2.5 into 18.

So, that will give you the, give us the effective overburden pressure at point B. And similarly, we get the point A calculation. Similarly, the depth of this A point is 2.25 meter from the base and 10.5 meter. The depth of B from the base of the footing is 10.5 meter. So, this p zero for at A point, this will be this p zero value; this will be 18 into 2.5 plus 8 into 2.25; this 8 is coming, this is 18 minus 10.

So, this value is coming 63 kilo Newton per meter square. Similarly del p, if I consider the 2:1 dispersion of the load, so del p will be 50 into 10 into 15 divided by 10 plus, z is to 0.25, this will be 2.25 into 15 plus 2.25.

So, del p value is coming 35.5 kilo Newton per meter square. Similarly at point B, we calculate this p zero bar, this is this p zero bar at b; this will be 18 into 2.5 plus 4.5 into 8 plus 7 into 6. So, this is the value having 123 kilo Newton per meter square. Similarly, del p at B point is 50 into 10 into 15 divided by 10 plus, this is 10.5, into 15 plus 10.5; so that the total, this stress is 14.35 kilo Newton per meter square. So, this way we will get the p 0 at A point is 63 and del p is 35.5 kilo Newton per meter square; p 0 at B point is 123 kilo Newton per meter square and del p is 14.35 kilo Newton per meter square at B point.

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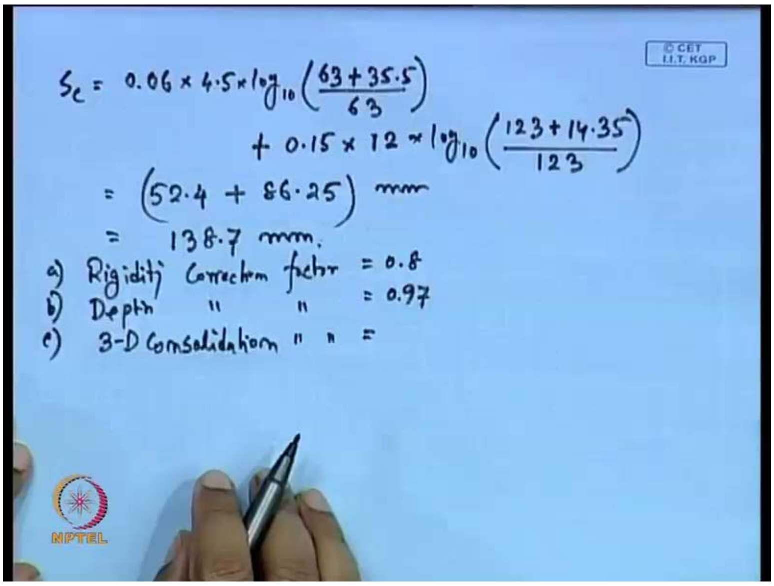

So, now if we put these values at this consolidation expression; so S c, that will be this. Since for the first layer C c by 1 plus E 0 is 0.06, thickness will be 4.5 meter, then log 10 63 plus 35.5 divided by 63, then plus C c by 1 E 0 1 plus E zero plus second layer is 0.15, thickness is 10 point... This thickness is 12 meter; the thickness of the second layer is 12 meter into log 10 base 123 plus 14.35 divided by 123. So, this value is coming out to be; so 52.4 millimeter plus 86.25 millimeter; so total value is 138.7 millimeter. So, this is the consolidation settlement of the soil. This is without any corrections.

Now, here what are the corrections that we apply again for this? First one correction is the rigidity correction; that is equal to 0.8. Then the second correction is the depth correction factor. That we have already calculated. That is 0.97. Then the next correction factor that the third one that we have to apply for this consolidation correction; that is, for the correction factor for the three dimension consolidation. This is for the three-dimension consolidation correction factor. So, then how we will calculate this three dimension consolidation correction factor?

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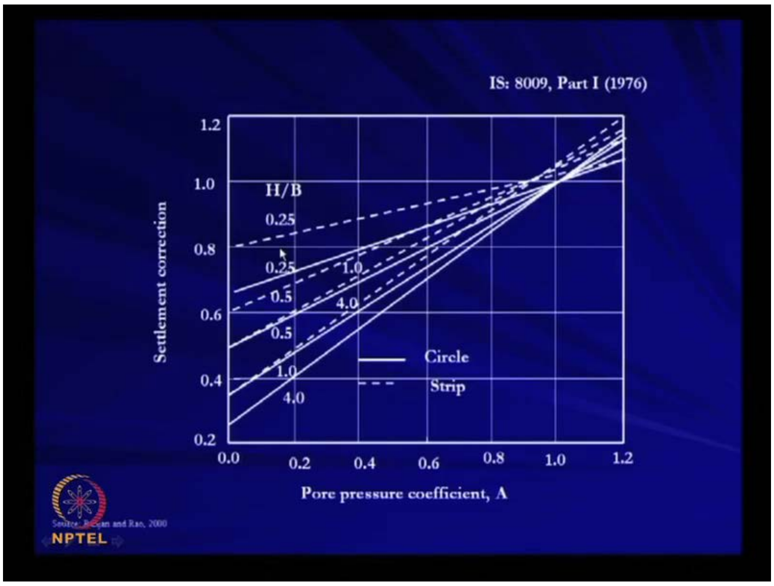

So, here also this I s code, this IS: 8003 part I suggested a chart by which we can calculate the consolidation correction factor; that, here this is the chart for this different H by B value; where h is the thickness. Total thickness of the soil layer, B is the width of the foundation. This is point and this is dotted lines, this represents the strip footing and the circular line. This represents the, this form line represent this circular footing.

So, that means the dotted line represent the strip footing and the form lines represent the circular footing. And, this x axis is values pore water coefficient. This is A. and then we calculate the H by B.

So, according to difference footing condition and this different HB value, if we for the for the particular soil condition or for the soil, this if we know this pore water coefficient A value, then we will get this settlement corrections factors. So, these are settlement correction factors. So, this is for the dotted line, this is for 0.25, this is for 0.5, this is for

1 and this is for 4. Similarly for the five form lines, this is 0.25, this is 0.5, this is 1 and this is 4.

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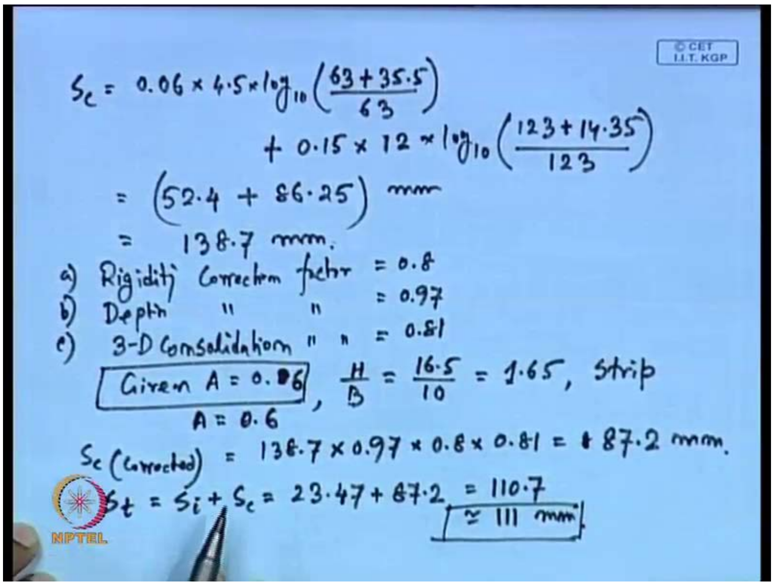

Now for these questions that, this is given that A value. We can take 0.8. So, this is given that A value; we will take 0.8 and H by B value that we will get the total thickness. If I consider 16.5 and B is 10 meter, width of the footing is 10, total thickness is 16.5 meter. So, this is 1.65. So, that means A value is 0.8 and H by B is 1.65 and it is thus we can consider it as a strip footing; as as because in this chart only this circle and the strip, these two are given.

So, here we consider as a strip one and here the A value is 0.8. So, this is the 0.8. And, H by B value is 1.65. So, this is the dotted line; 1.65. So, it is in between dotted lines. So, this is 1 and 4. So, this will be in between 1 and 4 and 0.8. So, this value will be in between this. So, this value is point, sorry, this is, this value is A value. So, this value is taken as 0.6; not 0.8. So, this given value A is 0.6; not 0.8. So, this is the 0.6.

So, that means the A value is 0.6 H by B is 1.65 and this is the strip footing. So, if it is given A is equal to 0.6, so now from this chart, this is 0.6 and this is in between 1 and 4. So, this is is around here. So, this is 1.65. So, corresponding pore water correction factor value is 0.81. So, that means corresponding corresponding to A is equal to 0.6 and this is 124 and this value is around 0.81. So, this pore water correction factor; we can say this is 0.81. So, now the S c corrected is equal to 138.7 into 0.97 for depth correction; 0.8 for rigidity correction and 0.81 for pore water pressure correction or this three-dimensional consolidation correction. So, this value is coming out to be 87.2 millimeter.

So total settlement, that is the S immediate settlement plus consolidation settlement. We are considering only the immediate settlement and the consolidation settlement here. So, this part is 23.47 plus 87.2. As I have mentioned for the clay type of soil, this consolidation settlement is more compared to the immediate settlement. So, this is 87.2. So, this is coming out to be 110.7; so 111 millimeter.

So, this will be the total settlement of the foundation; that is 111 millimeter. So, in this way we can calculate the immediate as well as the consolidation settlement of the foundation.

So, next class I will discuss that other different techniques to calculate the settlement of the foundation. And then by field field test or that is a plate load test, we can also calculate the settlement and the bearing capacity of the soil directly in the field, that thing also I will discuss in the next class.

Thank you.