Advanced Foundation Engineering
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Lecture - 13
Shallow Foundation: Settlement Calculation – III

In last class, I have discussed about the settlement calculation for granular soil by using the field test data, then I have discussed how to calculate the settlement for the by using plate load test data, then for the SPT test and for the CPT test or static confrontation test.

Now, this class I will explain a few other techniques to determine the settlement for the granular soil, and then I will solve couple of problems to show how to use those; how to calculate the settlement by using various field data.

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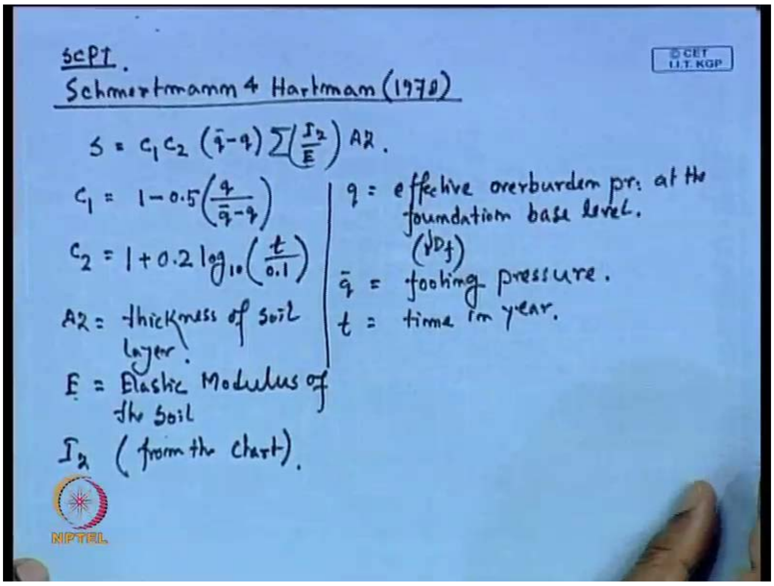

Now, first that I have discussed about the technique for the using the CPT. So, there is another technique by using the SCPT data, so by using the SCPT data. So, this technique is proposed by Schmertmann and Hartman 1978, well according to their procedure that your settlement that we will get, the settlement calculation that is c 1 c 2 this is q bar by q minus q into summation of I z by E into del z.

So, this is the expression, where c 1 is given by this expression 1 minus 0.5 by q minus q bar minus q, and c 2 is another expression that is given 1 plus 0.2 log 10 t divided by 0.1.

Now, here this q is the effective overburden pressure, where q is overburden pressure at the foundation base level or basically we can say that q is basically gamma into D f. Now, q bar is the pressure or the coming as a load; that means the footing pressure, which is coming from the super structure.

Now, here t is the time in year. So, suppose if we want to determine the settlement at one year, then we will put t equal to 1 if we want to put at settlement at 5 years, then t will be 5 now z del z is a thickness of soil layer.

So, where del z is the thickness of the soil layer, E is the elastic modulus of the soil layer and I z that value will use by the we will get one value that we will get from the chart. So, this I z we will get from the chart. So, this chart we have to prepare I will explain how to prepare this chart.

So, that means thus the settlement the total settlement that we will get for the different layer soil if this layer soil and c 1 into c 2 into q minus q bar minus q into summation of I z, E and del z, where del z is the thickness of each soil layer, E is the elastic module of the soil layer, I z that will prepare this chart. And then from there we will get the I z value and c 1, we will get by using this expression and c 2 by using this expression where t is the time in year, q is the effective overburden pressure at the foundation base level and q bar is the footing pressure.

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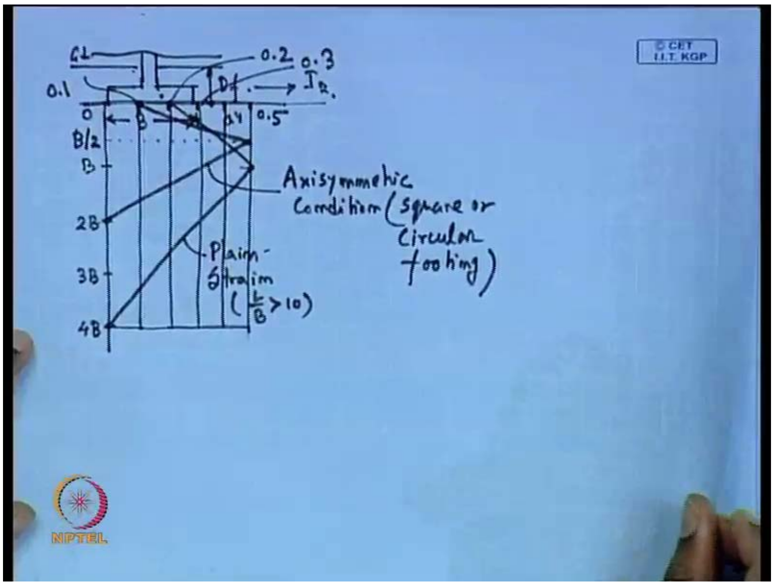

Now to determine the I z; so suppose this I z will get at the base of the footing, suppose this is the footing base; this is the ground surface, ground level and this is footing base and this is D f is a depth of the footing. So, at this level and this is the B is the width of the footing, D f is the depth of the footing, D is the width of the footing and this is at the footing base.

Then here below this footing base, if we draw this line suppose this is for the B; this is for the 2B; this is for 3B; and this is for 4B. So, this is B; this is 2B line; this is 3B line and this is 4 B line. So, we will get this chart suppose this is 0.1; this is 0.2; this is 0.3; this is 0.4 and this is 0.5; 0.1, 0.2, 0.3, 0.4, 0.5. So, that means, here this is 0; this value is in this direction; this is I z that coefficient this is 0.5; this is 0.4; this one is 0.1 so that means, this is 0.1; this is 0.2; this is 0.3; this is 0.4 and this is 0.5.

Now, this one is the point at the B distance, now for the axisymmetric condition this graph we have to draw from 0.1 to this 2B and for plain strain condition this will be the graph that means this is for the plain strain condition, where L by B is this greater than 10 and this is for the axisymmetric condition, similarly for the square or circular footing.

So, we will get the two graphs; one that is starting from 0.1, I z and then this is the maximum at B by 2 distance that is for the axisymmetric graph this is corresponding to B by 2 distance, then up to 0.2B if up to 2B this is minimum and then for the plain strain condition this is graph to start from 0.2, then at B this is maximum, then it will go up to 4B. So, this is plain strain condition this is axisymmetric condition.

So, now from this graph we will get the I z value suppose the for at any distance because the we will we have to consider the center point of the each soil layer, then at that point what will be the I z that we have to determine. So, now if we solve one example and then we will get how to calculate or how to get the this value suppose this is the one footing that we are getting this value this is the footing width.

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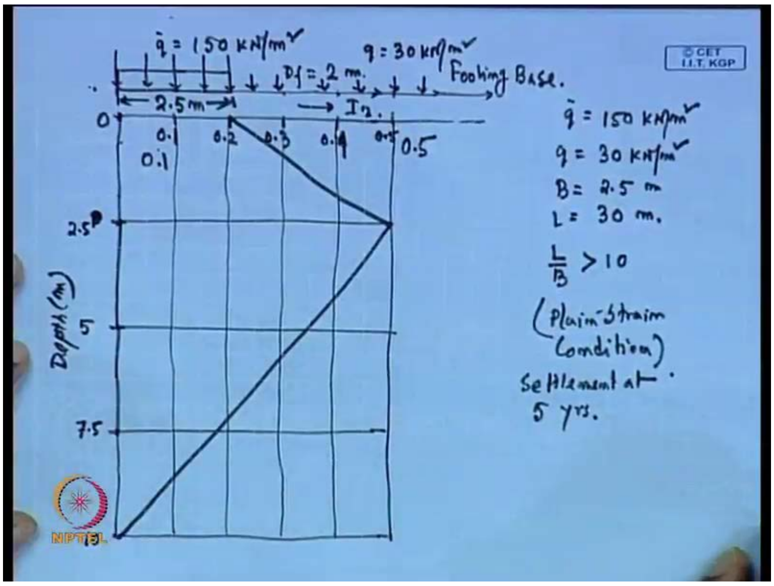

So, footing width is we are considering that this footing width is D. So, suppose this is the footing width we have footing we have to place it here. So, this is the B which is footing width now here that intensity of the loading that we are applying here for the footing that intensity is q bar at the footing base we are talking over this is the footing base this line is basically the footing base.

So, intensity that suppose this is 150 kilonewton per meter square and this depth of the footing depth of the footing is 2 meter and that due to this 2 meter soil the intensity of the footing of the load that is coming at this point that means q is 30 kilonewton per meter square, that means q bar is 150 kilonewton meter square, that means the footing pressure at the base of the footing that is 150 kilonewton per meter square. And this q effective overburden pressure at the base of the footing that is gamma D f is it coming out to be 30 say this is 30 kilonewton per meter square, where D f is 2 meter and that footing intensity is 150 kilonewton per meter square and depth we are getting.

So, this is the footing width is taken the given is 2.5 meter. So, the B of the footing width of the footing is 2.5 meter and L of the footing is 30 meter. So, this is we can say L by B is greater than 10. So, we have to go for the plain strain condition. So, this is for plain strain condition strain condition.

Now, first we will consider I will calculate and we have to calculate the settlement at 5 years. So, now what are the soil that I will give later on first to prepare that chart to determine the I z. So, suppose this point if I take from this point. So, this is say 0 0. So, this is B, 2B; this is 0, B, 2B, 3B. So, this is B where B is 2.5 meter this is 3B, 2B that is 5 meter; this is 7.5 meter and this one is 10 meter. So, these are the this is the depth in meter. So, this is B, 5B, 7.5B, B, 2B, 3B and 4B. So, we have to go for up to 4B depth. So, this is 4B.

Next suppose this point is 0.1; this is 0.2; this is 0.3; this is 0.4 and this is 0.5. Now as this is plain strain condition, so that means that means at this condition we have to go for B depth starting from 0.2, then if I go for up to the B and then from here up to 4B. So, this is the chart from here this is showing the I z; this value is 0.1, 0.2. So, this is 0.1; this is 0.2, 0.3, 0.4 and this one is 0.5.

So, once we have prepared this chart, now we will give the. So, this chart we will use to determine the I z value. So, this is this B, 0 is the base of the footing from here it will start B, 2B, 3B and 4B, because for this we have to go for the 4B depth.

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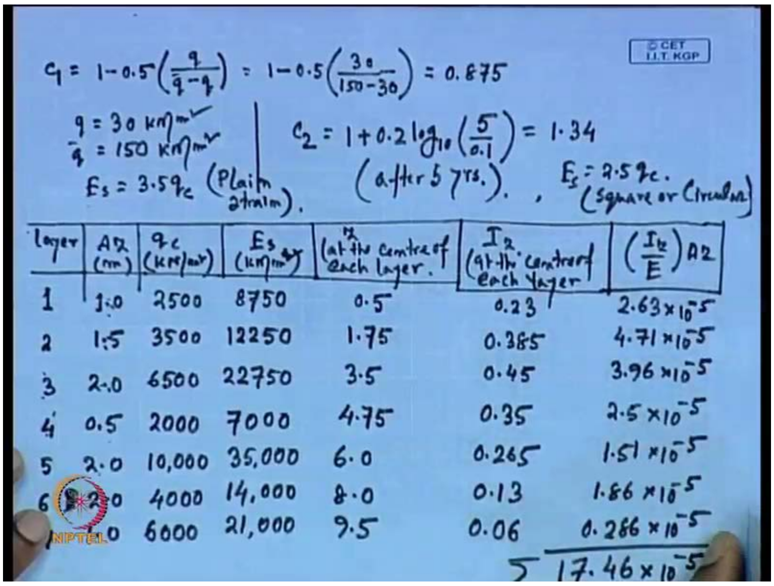

Now, if I give the other properties that now first we have to calculate the c 1 and c 2 value that c 1 value is 1 minus 0.5 into that c 1 value that value that will give this is in terms of q by q bar minus q. So, this value is coming 1 minus 0.4 q is here 30 q bar 150 q is 30 because q is 30 kilonewton per meter square and q bar is 150 kilonewton per meter square.

So, c 1 value is coming 0.875. Similarly, that c 2 value 1 plus 0.2 log 10 because we are calculating at the 5 year this is 5 by 0.1; this is coming 1.34; c 1 and c 2. So, this is after 5 years.

Now, we have to prepare one table. So, suppose this is the table we have to prepare the first column is the layer, this is layer; this is the del z or the thickness of the each layer in meter; this is the q c value q c is the static cone resistance value the each layer E s is kilonewton per meter square elastic modulus, then z value at the of each layer.

So, z is the; z at the center of each layer and I z that we will get at the center of each layer and then we will calculate I z by E and del z for the each layer. So, this is the total table that we will prepare this is I z by E into del z. So, this for this for the first one for the layer one the thickness that is given is thickness of the soil for the layer soil first layer is 1 meter whose q c is 2500, because these are the measured value 2500 kilonewton per meter square.

And one thing that it is mentioned that how to calculate the E at the base is the aspect of q c, now if this q c we will E we will get E s it is 3.5 q c for plain strain condition for plain strain plain strain condition. Now, E s will give this value so that means, the E s and similarly, we will get E s equal to 2.5 into q c for square or circular footing. So, q s equal to 2.5 q c for the square and circular and q c is the 3 point q c for the plain strain. So, here the recommendation this year; this is for the circular or for the square; this is 2.5 q c for the square and circular and q c is 3.5 into q c that E s for the plain strain.

Here this is for the plain strain. So, we will use this 3.5 into q c. Now, here q c value is given 2500. So, if I multiply the 3.5 we will get 8750 is the E value kilonewton per meter square. So, this is kilonewton per meter square.

Similarly, at the center because this is the first layer whose thickness is 1 meter. So, the center will be 0.5 meter this is the center of the first layer that is 0.5 meter. Now from the chart that I have prepared, so this is the chart now here this is 2.5. So, this distance; so that means, this will be 0.15, 0.5. So, 0.5 corresponding I this value is around 0.23. So, this is the 0.5 depth corresponding to this I z value this is 0.5 corresponding to this graph; this I z is 0.23.

So, in this shall we will get the I z value 0.23 and then we will calculate this term; this is coming 2.63 into 10 to the power minus 5. Now, we will go for the second layer whose thickness is given 1.5, q c value the measured value 3500 now if I consider three 0.5 q c. So, this is coming 12250 is the E s value, then z center this will be. So, this is for center of this layer is; that means; this z value we have to measure from the top.

So, this is 0.5 meter from the ground surface or from the base of the footing. So, this will be center will be 1.5 by 2.75 plus 1. So, this will be 1.75 from the base of the footing.

So, corresponding I z we will calculate here, so 1.75. So, this somewhere here, so one 0.75 corresponding value will be 0.385. So, here this will be 0.385 corresponding value this is 0.385. So, this value is 4.71 into 10 to the power minus 5.

So, similarly for the third layer this thickness is 2 meter q c value 6500. So, this is coming 22750 the thickness will be 2.5 plus 1; 3.5 the z value form the center the I z from the graph is 0.45. So, this value is 3.96 into 10 to the power minus 5.

Similarly, for the fourth layer this is 0.5 say and for the fifth layer this thickness is 2 meter for the sixth layer the thickness thickness of the layer is 2 meter, and seventh layer the thickness of the layer is 1 meter.

So, this is the 7 layers are represent 1, 2, 3, 4, 5, 6. So, first layer is 1 meter, second layer is 1.5 meter thickness, third layer is 2 meter thickness say, fourth layer is 0.5 meter thickness, fifth layer is 2 meter thickness, sixth layer is 2 meter thickness, seventh layer is also 1 meter thickness.

Now, corresponding q c value here this value is 2000 say and E we will get into 2000 into 3.5 this is 7000 for this 2 meter layer this is 10000 q c. So, this E value is with 35000 for the sixth layer this is 4000 corresponding E will be 14000 kilonewton per meter square for the last layer this is 6000 corresponding E will be 21000.

And the center for this thing this will be 1.5, 2.5, 4.5 plus 0.25. So, 4.75 this will be 4.75. Similarly, this layer this is 1, 2.5, 4.5, 5 plus 1 this is two layer thickness. So, center will be one. So, 5 plus 1 this is 6 meter similarly, this is also 8 meter and this will be 9.5 meter.

Now, corresponding I z value we will get from the chart is 0.35 this is 0.265; this is 0.13 and this is 0.06. So, this value we will get from the chart this is the center z thickness from the base of the footing at the center of each layer at the center of each layer this is the thickness.

Corresponding this value is coming 2.5 into 10 to the power minus 5; this is 1.51 into 10 to the power minus 5; this 1.86 into 10 to the power minus 5 and this is 286 into 10 to the power minus 5; 0.286 into 10 to the power minus 5. Now, if we sum this last column and if I sum this last column value now the summation of this last column value this will give us the value 17.46 into 10 to the power minus 5, the summation of this last column the summation will give us 17.46 into 10 to the power minus 5.

Now, next here now we will know the c 1 value; we know the c 2 value; we know this summation term. So, this z, so now we will put. Now, we will calculate the settlement.

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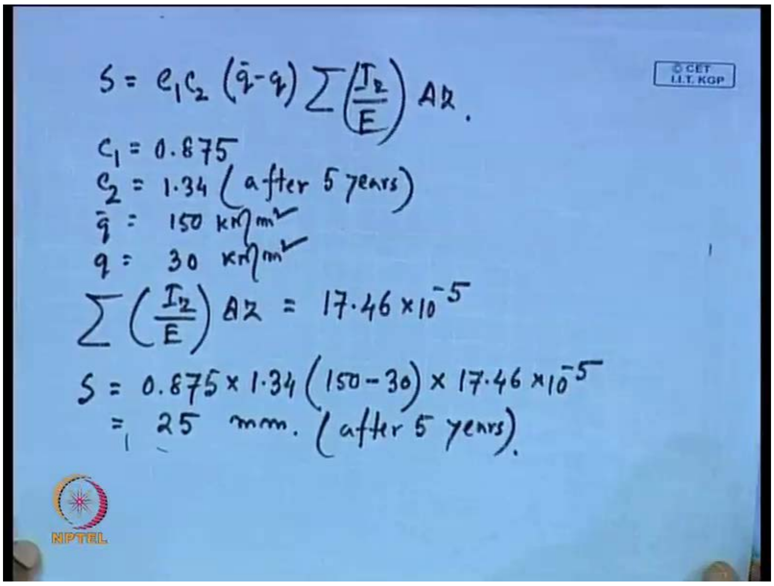

Now, the settlement that we will get, so this settlement is c 1 into c 2 into q bar minus q into summation of I z by E into del z. Now, c 1 value is 0.875 c 2 is 1.34 this is after 5 years q bar is 150 kilonewton per meter square q is 30 kilonewton per meter square and summation of I z; E into del z that is equal to 17.46 into 10 to the power minus 5.

Now, if we put this value here S is 0.875 into 1.34 this is 150 minus 30, then into 17.46 into 10 to the power minus 5. So, this value is; that means, 25 millimeter. So, the settlement of this total soil layer under this loading condition is 25 millimeter after 5 years.

Now, by using this difference, so suppose if I want to calculate the settlement after one year, then we have to put this we have to modify the c 1, c 2 coefficient by putting t equal to 1 year, then we can multiply this settlement by this new c 2 and divided by the old c 2 then we will get the settlement of the soil and the one year also.

So, this is the calculation and then how there this measure this is the another method by where you are using SCPT value and we are getting the settlement for the granular soil.

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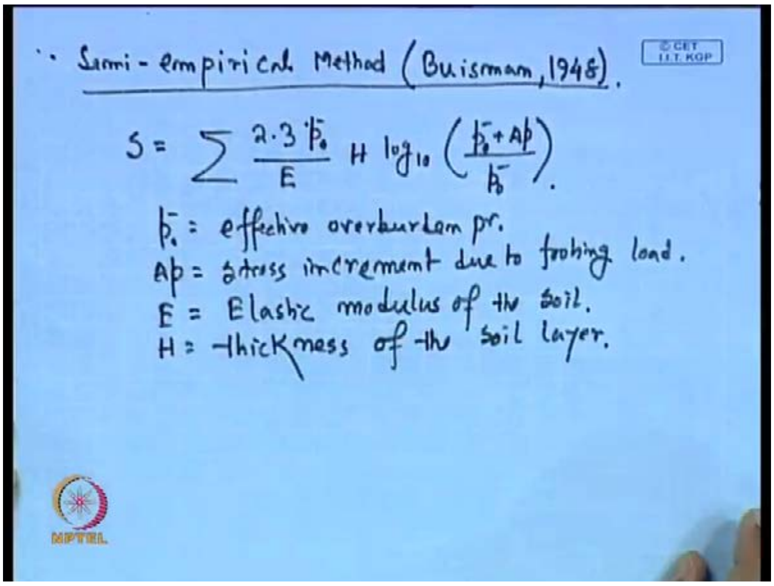

Now, the next method that we want to discuss that is another method which is this is the semi-empirical method that is presented by Buisman, 1948.

Here the settlement is calculated as a summation of 2.3 into p 0 bar by E into H into log 10 p 0 bar plus del p by p 0 bar or we can say this is sigma 0 bar or del sigma p both are same, where p 0 bar is effective overburden pressure and del p is the stress increment due to footing load.

E is the elastic modulus of the soil and H is the thickness of the soil layer. So, by using this expression also we can determine the settlement of the granular soil by using this semi-empirical expression. So, these are all for the granular soil.

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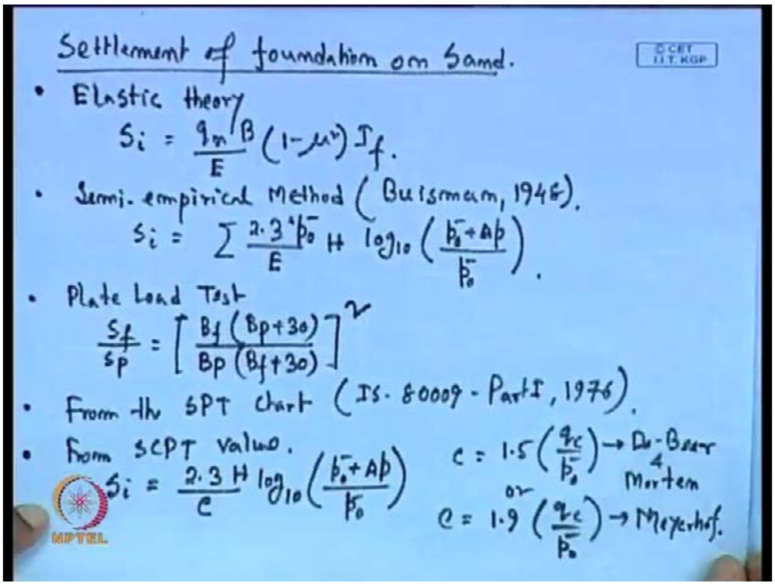

Now, if we summarize the different techniques to determine the granular soil settlement calculation, then we can say that the settlement of foundation on sand or granular soil the first one method is by the elastic theory method. So, by this method we calculate the settlement is by using q n, B, E, 1 minus mu square into I f.

So, this expression I have already given when we discussed about the immediate settlement. So, this is the immediate settlement or the by using the elastic theory this q n is the net footing pressure this is the net footing pressure B is the width of the foundation E is the elastic modulus mu is the Poisson ratio I f is the influence factor now I have presented one table and here I have explained how to calculate this I f value.

The next method that is the semi-empirical method that I have just now what I have explained it is a semi-empirical method and this is given by Buisman, 1948. So, this is the where S i we can calculate summation of 2.3; this is p 0 by E into H log ten p 0 bar; this is also p 0 bar into del p 0 bar. So, next one is the plate load test, where this expression we are using S f by S p equal to B f, B p plus 30 into B p, B f plus 30 to the power whole square this is for the granular soil.

Now, next method that we are using that from the from the SPT chart it is presented in I s 8009 part one 1976, by using the SPT chart also we can determine the settlement and then the from SCPT value. So, here the expression S i we can calculate by 2.3 into H divided by c into log ten; this is p 0 bar plus del p into p 0 bar, where c we will get by using this expression 1.5; q c by p 0 bar; this is proposed by De-Beers this expression is proposed by De-Beer and Morten or we can use c equal to 1.9; q c, p 0 bar that is proposed by Meyerhof.

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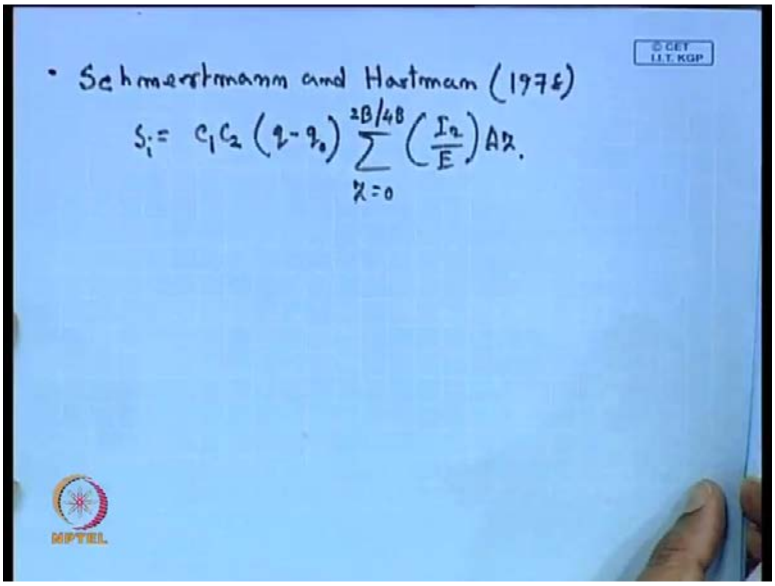

So, now the last method or the next one is given by; this is also based on SPT value Schmertmann Schmertmann and Hartman; this is 1978. So, here we will get this value by c 1 into c 2 this is q minus q 0 as the footing base the summation of z equal to 0 to 2B or 4B. So, this is summation of I z; E into del z.

Where this is 2B or 4B and for if it is axisymmetric condition that is square of circular, then this z is from the base of the footing from 0 to 2B the summation up to 2B if it is a plain strain condition, then we have to go for 0 to 4B up to 4B condition, then we will get the if I sum these things it we will get this value of the settlement.

So, these are the methods by which we can determine the settlement of the granular soil under different loading condition. Now, if in the next section that now we will solve one problem and then we will compare the we will determine this value or settlement value by using this different techniques, then we will compare about the what is the settlement that we are getting by using this different methods.

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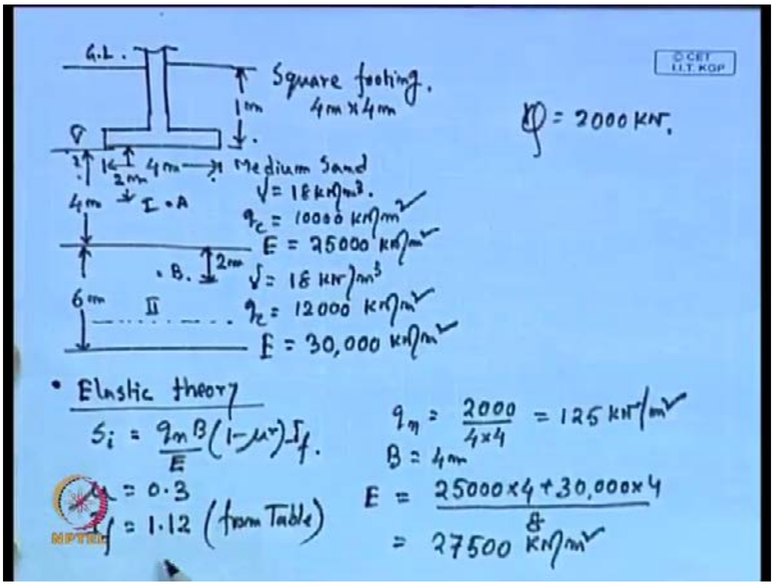

Now, first if I the settlement calculation for this different methods and there is a problem that we are taking. So, suppose this is the foundation; this is ground line; this is the foundation width say 4 meter; this is square foundation, square footing with dimension 4 meter cross 4 meter.

Now, the this depth of foundation is 1 meter and the position of the water table is as the base of the footing. Now, this is the layer one and this is layer two; this is for the medium sand that gamma we are taking 18 kilonewton per meter cube, q c value we are taking 10000 kilonewton per meter square, E value for the first layer we are taking this is 25000 kilonewton per meter square.

For the second layer also we assume the same gamma it is 18 kilonewton per meter cube, q c value we are taking 12000 kilonewton per meter square, and E for the second layer is 30000 kilonewton per meter square. Now, the total load that is coming, the total load or load Q is 2000 kilonewton.

So, this is the layer. So, this layer here the up to the, this layer thickness first layer thickness is 4 meter and second layer thickness is 6 meter. So, we are taking the influence zone if we use the different method and all the method because it is in square footing even in the last method also the influence zone will be up to 2B

So, here up to 8 meter that means, up to this 2B this will be influence zone. So, we are taking two points the center of the each layer because this is the influence zone up to 2B so; that means, this layer is 2 meter from the base of the foundation and this layer is also 2 meter from the end of the first layer.

Now, we will use those different methods; first we will use the elastic theory. So, we will use the elastic theory first. So, here the E value elastic theory the S i settlement that is q n B by E into 1 by mu square into I f influence factor.

Now, q n here we can calculate this is 2000 divided by 4 cross 4 this is; this value is coming out to be 125 kilonewton per meter square, similarly B is here 4 meter E we are taking the weighted average value because here 4 meter influenced on 4 meter for the first layer and 4 meter for the second layer. So, we can take the average one or this E value that we are taking that is 25000 into 4 plus 3000 into 4 divided by 8 or we can simply take the average of two layers. So, this is coming out to be 2750 kilonewton per meter square.

Now, here we assume that mu value is 0.3 for this tan and I f, we can calculate this I f is value is one 0.12 from the table; this table I have already given. So, from this table this I f value is coming 1.12.

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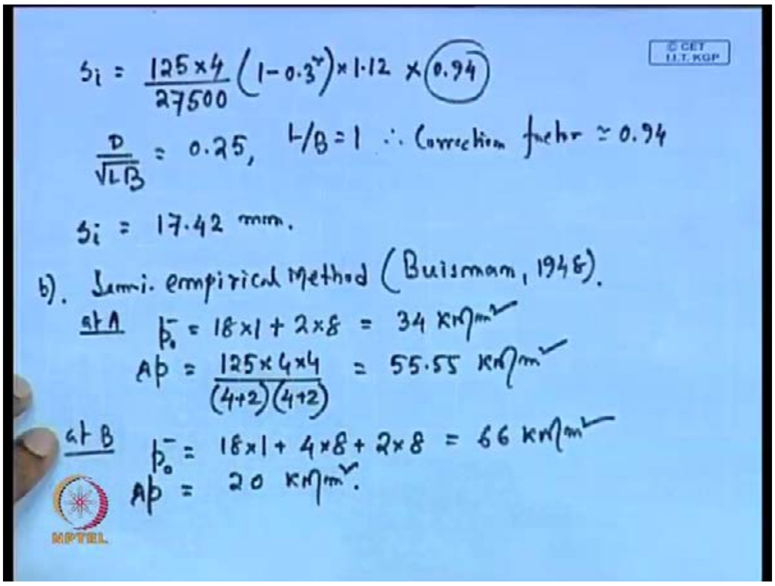

So, now this if I put this all the calculation value this then we can get the S i will be 125 into 4 divided by 27500 1 by 0.3, 1 minus 0.3 square into 1.12. Now, in this calculation we have to use the correction factor because here this is the isolated footing. So, this is rigid this is not rigid. So, rigidity correction is not required. So, this is a sandy soil. So, consideration correction due to the consolidation that is also not required. So, only the depth correction we have to apply here.

Now to calculate the depth correction, so far the depth correction or the fox correction. So, now the D root L B that value is 0.25 here and L by B equal to 1. So, the correction factor is around 0.94 that will give from the chart. So, if L by B equal to 1 and D this value 0.25 we will get 0.9.

So, now we have to multiply here 0.94. So, we will get the corrected value. So, S i immediate corrected that is 17.42 millimeter. So, this is the settlement by using the elastic theory approach. Now, this settlement is coming 17.42 up to the correction because we have applied the correction factor this is the correction factor we have applied. So, this will coming 17.42 millimeter.

Now, the next method is by the semi-empirical method if I use the same expression same problem by using the semi-empirical method. So, here we are taken two points because this is the two points or the two center of this two layers; this is for the first layer thickness is 4 meter and the center is A point the first second layer thickness up to the influence zone it is we have taken the 4 meter and this is of the center.

So, A and B two points, so now the we have to calculate the sigma 0 at A that is p 0 or sigma 0 bar is 18 plus 1; 18 into 1 plus 2 into 8 because for the below ground water table we have the base of the footing. So, this is 8 into 2. So, this is coming 34 kilonewton per meter square.

Now, del p if I consider one is to two distribution del p will be 125 into 4 into 4 divided by 4 plus 2 into 4 plus 2 because we have considered one is to two distribution. So, this is coming 55.55 kilonewton per meter square.

Similarly, at point B; p 0 bar is 18 plus 1 18 into 1 plus 4 into 18 plus 2 into 8 4 into 8 plus 2 into 8. So, this is 66 kilonewton per meter square and del p by using same one is to two distribution this is coming 20 kilonewton per meter square.

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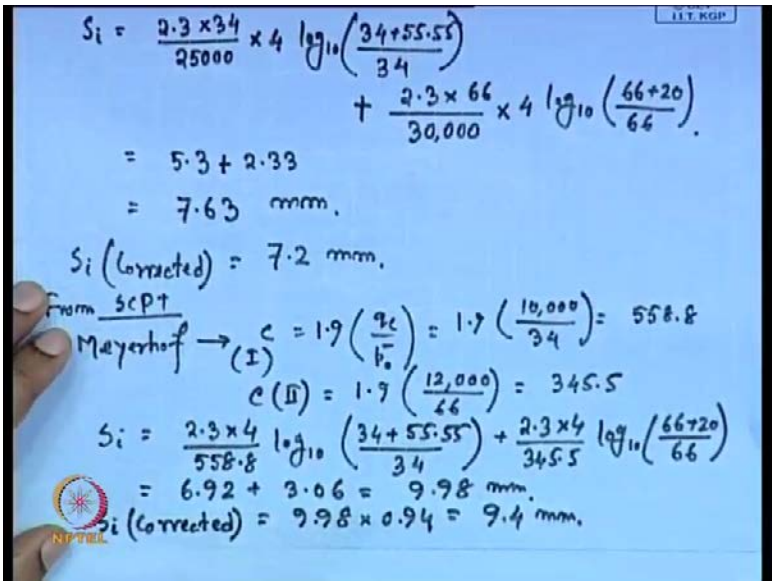

So, now the final expression for this method S i we will get this is 2.3 into 34 is the p 0 bar E is 25000 for this layer E and 4 is the thickness of this layer, then log 34 plus 55.55 divided by 34 plus 2.3 into 66 divided by 3000, because this is the elastic modulus of the second layer thickness is 4 meter for this second layer also this is 10; 66 plus 20 divided by 66.

So, here we will get the settlement 5.3 plus 2.33. So, the total settlement is 7.63 millimeter, and after the correction is been multiplied the depth correction here that is 0.94 the S i after correction this value is coming 7.2 millimeter.

Now, if I go for the next method that is from this SPT value that is from this is method from SCPT value. So, here first we consider the Meyerhof expression, where c for the first layer first layer this is 1.9, then this is this value is q c by p 0 bar. So, 1.9 is 10000 E 0 bar is 34. So, this value is 558.8.

Now, see for the second layer is also 1.9 q c is here 12000 and this value is 66. So, this is 345.5 now if I calculate this S i the expression is 2.3 into 4 that is the h by c by c 558.8 for the first layer into 34 plus 55.55 divided by 34 plus 2.3 into 4 divided by 345.5 into log 10 66 plus 20 divided by 60.

So, this value after the calculation we will get this value is coming 6.92 plus 3.06. So, that is 9.98 millimeter after correction if I apply the correction if I multiply the depth correction factor that is 0.94. So, this is 9.98 into 0.94 this is around 9.4 millimeter.

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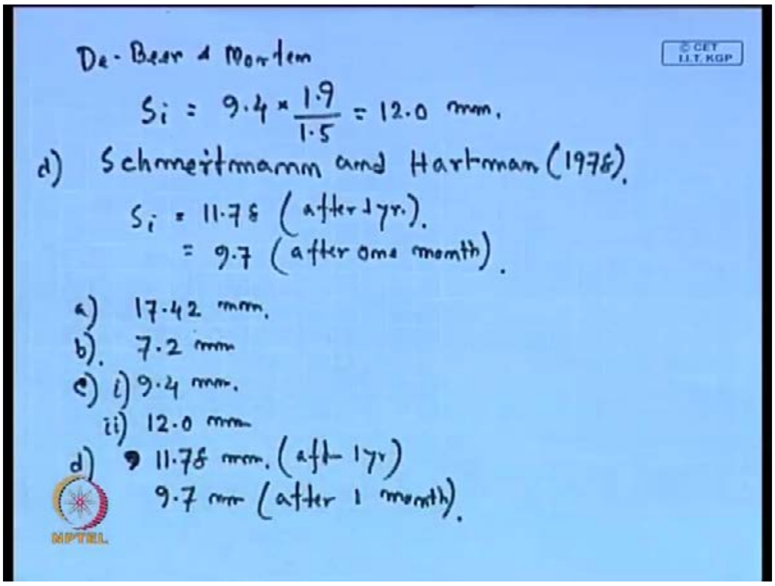

So, now if I convert this is by this De-Beer’s method and Morten method, then this settlement is 9.4 into 1.9 divided by 1.5. So, this is 12 millimeter. Similarly, by using the next technique that is the D technique using the Schmertmann and Hartman technique Hartman technique in 1978, that we have done this is by because here this is the axisymmetric condition; this is square footing though it will vary the graph that we have to draw this will start from 0.1, then up to B by 2 this will give the maximum, then it will go up to twice B.

Now, if the because this method I have already explained how to use this method, then calculate the this I have explained for the plain strain condition, here it is the axisymmetric condition and the only difference is that here instead of this graph when we calculate the influence this factor I z, then this point will start from the 0.1 then it will maximum at points maximum that value is 0.5 at B by 2, then it will go 0 at 2B. And then by using the at the center it is two points at the center it is one center is point is at the B, A another center is at the B and they are, so this we have to calculate the I z value, then c 1 value, c 2 value here.

We have calculated the c 1 at the one year. So, this value at this S i is coming out to be 11.78 this is after one year, and this coming say 9.7 meter this is after one month. So, we can if I compare the value. So, so far the elastic method method one this value for the elastic method the value this is coming out to be this is 17.42 millimeter, for the second method or semi-empirical method this value that is coming 7.2 millimeter, and for the c for the Meyerhof this is coming 9.4 millimeter, this is one and for De-Beers and Morten it is coming 12 millimeter and d method is coming 9.7 or you can say this is 11.78 millimeter for the one year and 9.7 millimeter after one month.

So, from this things we can say that this elastic theory is giving higher settlement; that means, it is overestimate this the meeting the settlement value; this is the giving the higher settlement value and the b method by using the semi-empirical method that is giving the lower settlement value. And other values are more or less same, but only the maximum one is given by the elastic theory and minimum is given by the semi empirical method, and whereas the CPT by using SCPT value these values are almost same, and although this it is expected that it is obvious that the Meyerhof theory is giving lesser settlement by if I consider the c for the De-Beers or Morten, but the maximum was given by the elastic settlement elastic theory.

So, in the next class I will discuss that how to calculate the how to calculate the bearing capacity and the settlement of the foundation and based on this bearing capacity, and settlement council here, until now we have considered the settlement calculation we have done the settlement or either bearing or settlement.

In the next class, I will consider the how to using the, this both criteria and then how to design or choose the dimension of a footing or the depth of a footing by using the considering settlement and bearing criteria both. And then I will also explain how to apply the depth correction when we will calculate the settlement based on SPT or based on plate load test data.