Foundation Engineering

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Lecture – 16
Shallow Foundation - Settlement I

So, in this class first I will discuss a problem where I will show, how we can incorporate the bearing incorporate the water table effect in the bearing capacity equation and then, we will discuss about the settlement criteria for the foundation design.

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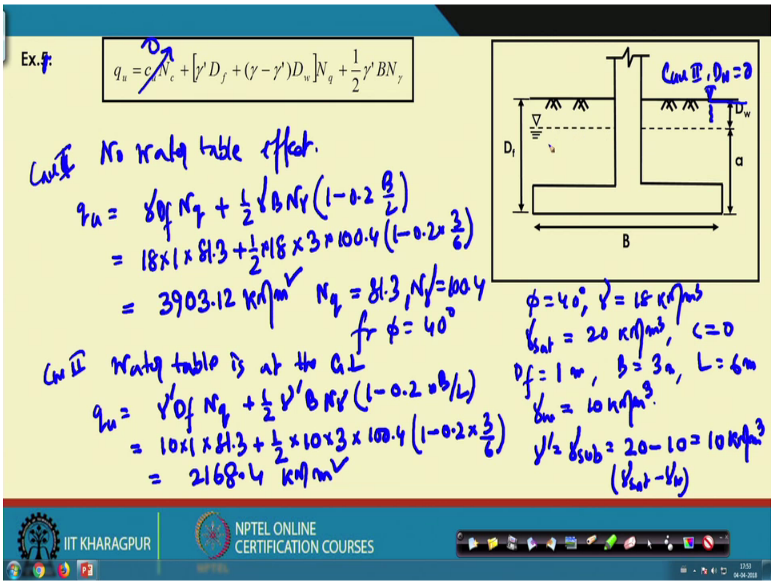

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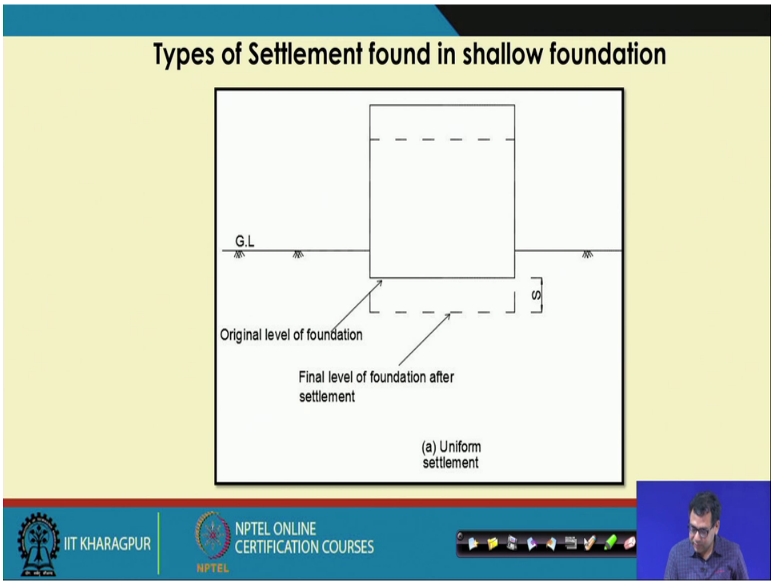

So, first we are taking the same problem that we took in the previous class that we have to taking the foundation where homogeneous soil phi value is equal to 40 degree, then unit weight of the soil above the water table is 18 kilo Newton per meter cube, then water table unit weight of the saturated water is 20 kilo Newton per meter cube, then it is equation value is 0 and this is homogenous soil depth of foundation is equal to 1 meter, B is equal to 3 meter, L is equal to 6 meter and then, the unit weight of water that you are taking 10 kilo Newton per meter cube

So, as it is phi value is greater than 36 degree. So, degree there will be a general shear failure. So, we can use the bearing capacity factor that we used in the last class and for this, because we are using only Terzaghi's bearing capacity equation. So, as but Terzaghi's bearing capacity equation the in the first case in the one, we are taking no water table effect. So, our this is N c c u is 0. So, our q u will be that gamma D f into N q plus half into gamma B N gamma then correction one minus point 2 B by L this is the factor.

So, gamma is 18 because there is no water. So, we are taking 18 kilo Newton is the gamma D f is 1 and if N q is equal to 81.3 and N gamma is equal to 100.4 for phi is equal to 0 as per Terzaghi. So, this is equal to 81.3, then plus half into 18 into B is equal to 3 then 100.4 1 minus 0.2 into 3 divided by 6. So, this value is coming out to be 3903.12 kilo Newton per meter square

So, this is the case 1, you are taking the no water table effect. So, this is without water table. Now the case 2, we are considering this water table is at the ground surface. So, in the case 2 where D w value is equal to 0. So, in the case 2 the water table is at the ground surface, the case 2 water table is at the G L or ground level. So, in that case you are here the equation q u will be gamma dash D f because D w is equal to 0. So, into N q plus half gamma dash B N gamma 1 minus point 2 into B divided by L.

So, gamma dash is the is equal to gamma sub is equal to 20 minus 10 that is gamma sat minus gamma w that is equal to 10 kilo Newton per meter cube. So, this will be 10 D f is 1 N q is 81.3 plus half gamma dash is 10 B is 3 N gamma is 100.4 1 minus 0.2 into 3 divided by 6. So, these value is coming out to be 2168.4 kilo Newton per meter square. So, we can see there is a around 4000 kilo Newton per meter square that is reduced to 2168.4. So, value is almost fifty percent reduction if the water table is located at the ground surface.

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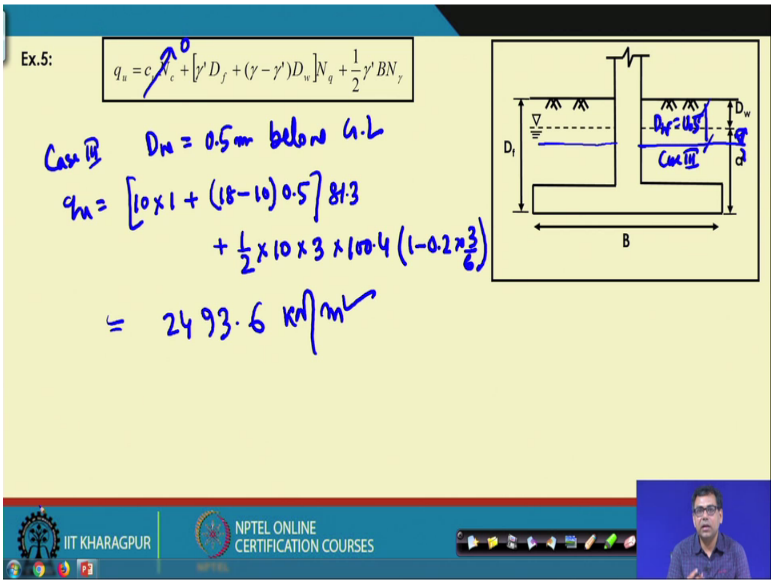

So in that case 3, we are considering the in the case 3 we are considering the water table is here with the depth of your D w is equal to 0.5 ok. So, water table is here that is case 3. So, in the case 3 that water table D w is located depth of 0.5 below G L ok

So, now in this case the q u will be again this is 0. So, q u will be the gamma dash is 10 into D f is 1 plus gamma is 18 minus this is 10 into D f is 0.5 that whole is equal to this is the 81.3 then plus half gamma dash is 0 into B is gamma dash is 10 into B is 3 N gamma is 100.4 into 1 minus 0.2 into 3 by 6 and this value is coming out to be 2493.6 kilo Newton per meter square. Because you can remember this in these 2 cases in water; case 2 and case 3, the second third term I mean second gamma is always gamma dash because it is always the soil below the water table is always under submerge condition.

So, what you can see that because this the bearing capacity is increase in case 3 as compared to case 2 because if we lower down the water table, then our bearing capacity value will again increase and then if we place the water table is the greater depth in this effect will vanish.

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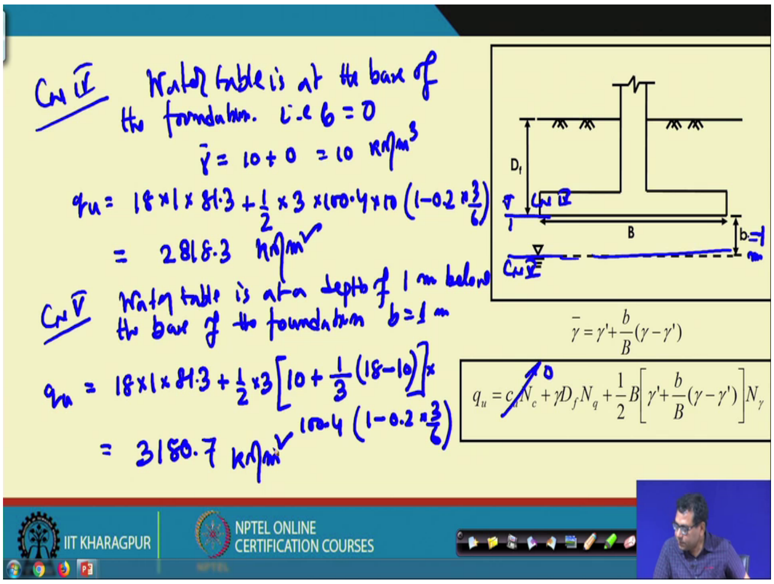

So in the next case, that we are doing is suppose in the case 4 in the case 4, when we are placing water table is at the base. So, my case 4 the water table is at the base of the foundation. So, from this equation, then you have to use this equation in this equation that is b is equal to 0. So, in the case 4, if it is water table at the base of the foundation, then gamma bar will be gamma dash is 10 plus 0 because the b is equal to 0. So, this will be 10 kilo Newton per meter cube.

So, my this is 0 q u will be because the now the what soil above the water table is there, the soil above the base of the foundation there is no what else we have to consider that you need to it is 18 and then D f is 1 into N q is 81.3, then plus half into B is 3 meter B is 3 meter, then N gamma is 100.4 and then gamma bar which is 10 then 1 minus 0.2 into 3 divided by 6. So, these value is coming out to be 2818.8 kilo Newton per meter square. So, bearing capacities further increased.

Now in the case 5, we have this is case 4 and in the case 5 we consider, thus b value water table is at a depth of 1 meter below the footing. So case 5, water table is at a depth of 1 meter below the base of the foundation. So, my B value is equal to 1 meter. So, I can write the equation q u is equal to this will be the again 18 into 1 into 81.3 plus this equation half b is 3 then gamma bar is 10 plus b is 1 meter capital B is 3 meter then gamma is 18 minus gamma bar is 10, then the total is 100.4, then the correction factor 1 minus 0.2 into 3 divided by 6

So, this will be the equation and the final value is 3180.7 kilo Newton per meter square. So, bearing capacities further increased if I place the water table at a depth of 1 meter below the foundation. So, in this way, we can see that that the ground water table if you place the ground level, so that will give the worst condition and lowest bearing capacity.

Now, then the next for here I am finishing the bearing capacity part, now I will I will start the next part that is the settlement criteria of the foundation design. So, as I have already mention that the foundation design has two criteria's; one is bearing capacity, another is a settlement.

Now, in the settlement first we know that what are the different types of settlement. This different types of settlement or they are been there is the first one is the total settlement or if you are foundation is the settle uniformly, then this type the because this is your original level of the foundation and the after the settlement, this is the final level of the foundation. So, this is the uniformly the you are foundation is settle so; that means, this settlement is called the uniform settlement where or you considered this is the total settlement also. So, that is the uniform settlement.

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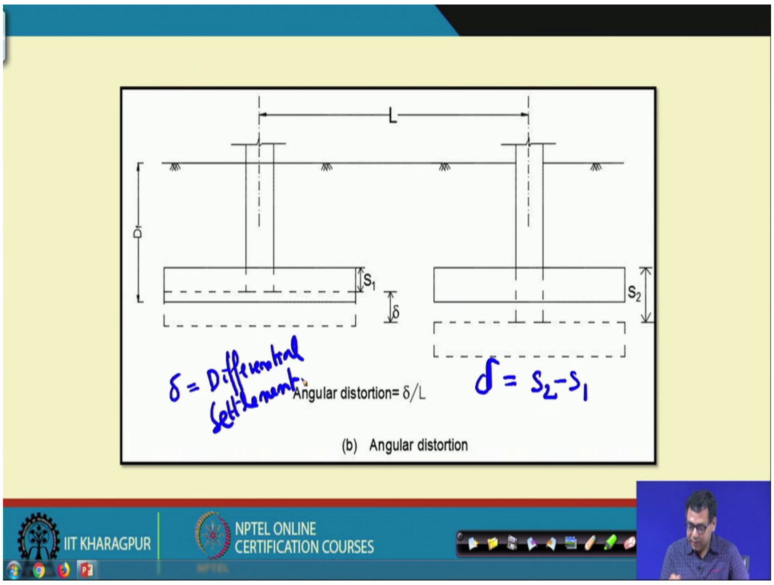

The next one, if you have 2 columns and you have 2 individual foundation for the column so, there is the possibility because we are load on the 2 columns are not same. So, there is the possibility that both the columns may deform in different way. So, in that case if the 1 column deformation is S 1, so suppose this is the original position of the foundation top and this is the final position of the foundation top, then this is the S 1 and then this is the S 2 for the second column; then there will be angular distortion or this is this angular distortion you can see, this is the delta is the difference of you are settlement so; that means, you have this is the your delta value is delta value is the basically S 2 minus S 1 which is the difference of the settlement and then if I divided to the spacing between 2 columns or 2 foundation then that will give you the angular distortion in.

Now in sometimes this delta is also called the differential settlement. So, now when you design the this foundation, then you have to check the total settlement, then you have to check the differences settlement because you cannot have a excessive amount of the total settle settlement as well as the excessive amount of the differential settlement also; because then you will be problem in your structure. So, that mean we have to make foundation such that the total settlement and the differential settlement should be within the permissible limit. So, that mean this is the differential settlement or the in other way the angular distortion that you have to check.

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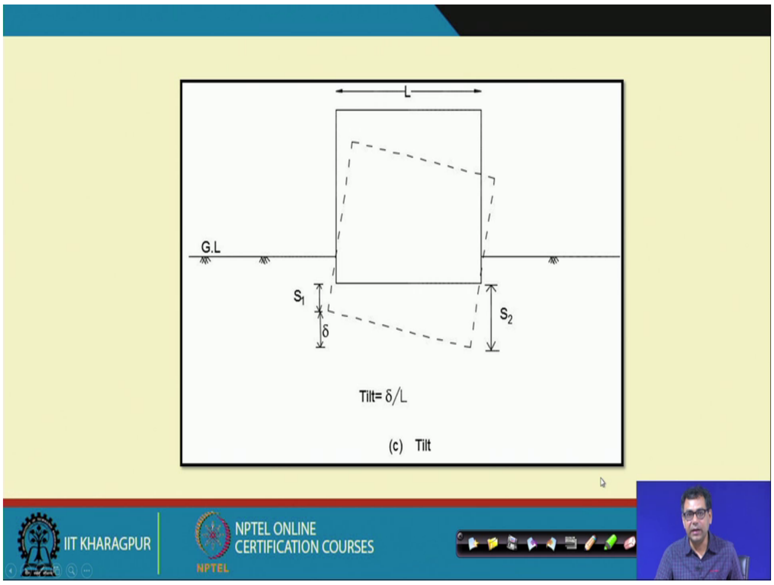

Now the mix type of thing is that the tilting. Now in the previous case, so there will be difference between the angular distortion or the differential settlement and the tilting is that. In previous case, you are two foundation has the differential or the differential settlement, but here your settlement this is also differ due to the differential settlement, but the differential settlement in such that that one side of the building is deform more compared to the other side of the building, then the total building we will tilt because of this differential settlement. So, that we settle settlement difference. So, that tilting that means, when the total system total building we will tilt so, that also we have to take care.

So, there is there is basically this type of settlement there. There will be uniformly settlement uniform settlement or the maximum settlement; there will be the differential settlement or the angular distortion or there will be the tilting. So, all these things you have to take care during the design of the foundation.

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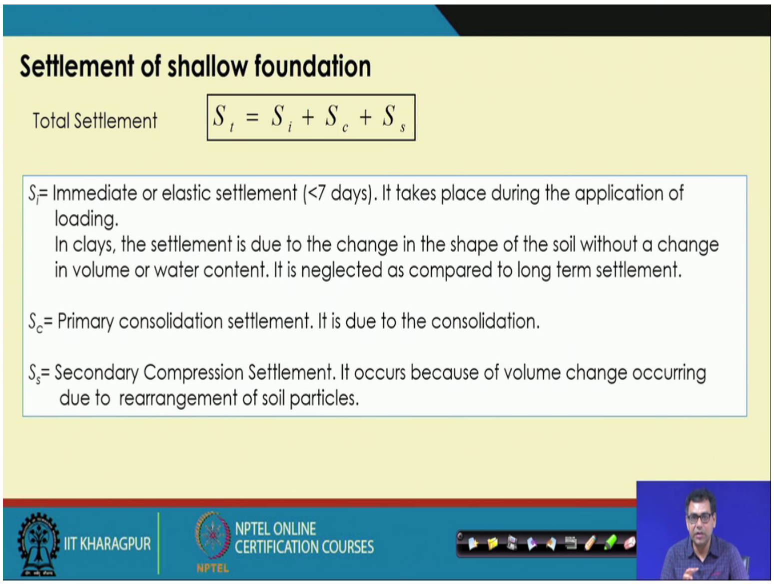

Now, the settlement of the shallow foundation is basically three types. So, that mean the this is the summation of the three types of settlement. The first settlement that is S t total settlement is S i S c and S s. So, S i is the immediate or the elastic settlement generally you get immediately after application of the load and it takes place during the during the application of the loading and in the in clay, this the settlement is due to the change in the shape of the soil without the change in the volume of the what or the water contain. It is neglected as compared to the long term shape settlement.

So, in the in case in case of sandy soil, the majority of the settlement is the immediate settlement. So, or you can say the total settlement is the immediate settlement because it is the sandy soil if you app if you apply the load, then the settlement will be happen immediately. But in the clay soil, this is the immediate settlement is the settlement that we will occur due to the shape change of the soil. It is not the volume change of the soil or the water content change of the soil because when they will be changed in the volume or when you apply the load the water will dissipate, so volume your water ratio you will reduce and they will be settlement; that settlement in the consultation settlement that is not the immediate settlement. But the immediate settlement in the clay, it is due to the change in shape of the soil.

So, in that in case of clay, the immediate settlement is the negligible amount. So, the most of the settlement will be the consideration settlement or the third type of the settlement so; that means, in the sand the most of the settlement is the immediate settlement, in the clay the immediate settlement is negligible compared to the long term settlement because immediate settlement immediate is the short term settlement.

Now, S c is the primary consolidation settlement due to happen due to the consultation or due to the x desperation of the water, the volume reduces and settlement occur. And S c is the secondary compression settlement, it occurs because of the volume change occurring due to the rearrangement of the particle so; that means, when there is a volume change there will be particle rearrangement because of that there will be also a settlement. So, that is the S.

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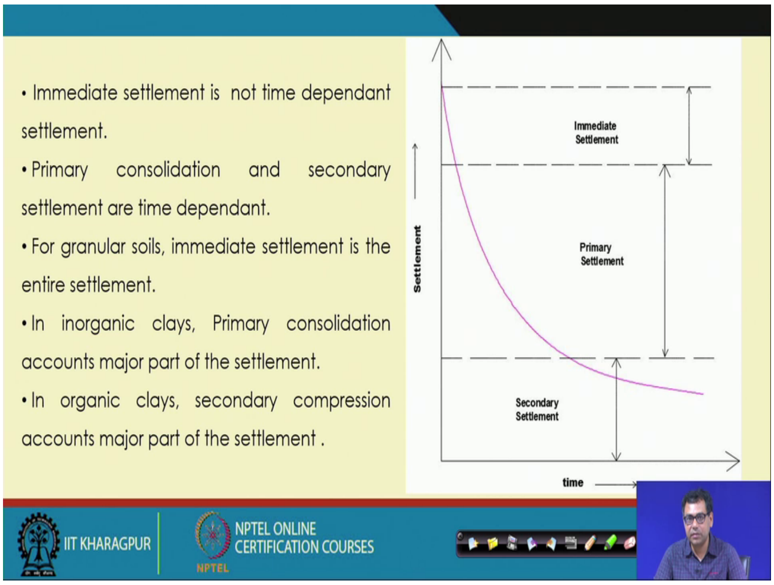

So that means, if I draw the graphs the 3 types of settlement; immediate settlement, primary settlement or primary consolidation settlement and or the secondary settlement which is called as the secondary compression so; that means, here the primary consolidation and secondary settlements are the time dependent settlement, but the immediate settlement is not the time dependent settlement; immediately after application of the load the settlement will occur.

So, now the granular soil, the immediate settlement is the entire settlement because the other two settlements are negligible because most of the settlement will occur immediately. But for the inorganic clay, the primary consolidation accounts the major part of the settlement and for the organic clay, secondary compression accounts major part of the settlement.

So now for the organic clay, it is the third part we will take the major 1 but the for the in organic clay, so primary consolidation will take the major part. So, and then what the long short time settlement for the clay soil also negligible compared to the long term settlement. So now, when you design this thing when settlement calculation, so you have to take care all these things; if it is sandy soil you have to take the immediate settlement, if it is a inorganic clay, then you have to take the primary consolidation settlement.

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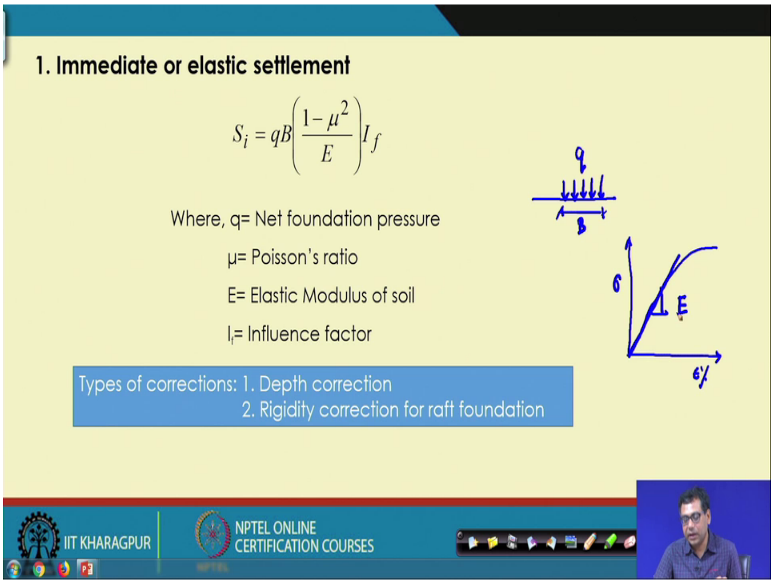

Now, how I will calculate the immediate settlement because is a immediate or the elastic settlement because when we apply it is elastically immediate ok. So, that mean the elastic settlement we can use using this equation, so where q is the net foundation pressure so; that means, the q value is the if it is the foundation base, so how much net pressure is acting at the foundation base. So, that is called the q, B is the width of foundation or this is the width of foundation mu is the Poisson ratio of the soil and E is the elastic modulus or Young's modulus of the soil. So, how we will calculate the we will get the elastic modulus? If you have a stress strain, this is the axial strain and this is the stress diagram. So, in the soil we have this type of stress strain curve

So, elastic means the slope of this stress strain curve in the in the initial straight portion though this the slope of this curve will give you the elastic modulus of the soil. So, basically it is the stress divided by the strain and this is the elastic zone that mean the straight portion of the stress strain curve and then I f is the influence factor and then, when you calculate the elastic settlement then you have to apply two corrections, then the depth corrections; one is the rigidity correction that you have to apply for the raft foundation.

So, now if depth correction is required all the expression, so develop for the surface footing, but you will place the found foundation that a depth below the ground surface. So, you have to apply the correction in the settlement. And the rigidity correction is that that if you are you are designing a foundation which is isolated footing, then that is flexible kind of kind of foundation.

Now, if you are applying or designing a raft foundation which is the rigid kind of foundation in that type of foundation, you have to apply rigidity correction. So, immediate settlement you have to apply two corrections; one is the depth corrections, another is the rigidity correction.

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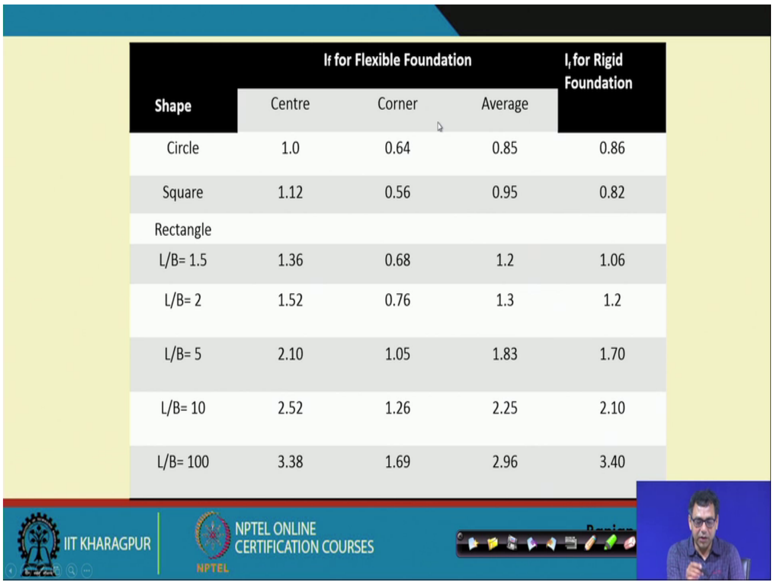

Shape	If for Flexible Foundation			Ir for Rigid Foundation
	Centre	Corner	Average	
Circle	1.0	0.64	0.85	0.86
Square	1.12	0.56	0.95	0.82
Rectangle				
L/B= 1.5	1.36	0.68	1.2	1.06
L/B= 2	1.52	0.76	1.3	1.2
L/B= 5	2.10	1.05	1.83	1.70
L/B= 10	2.52	1.26	2.25	2.10
L/B= 100	3.38	1.69	2.96	3.40

Next one, so these are the inference factor for factor values for the flexible foundation and the rigid foundation or the raft flexible foundation or the isolated footing. So, this is for the circulars square rectangular all L by B value; L is the length, B is the width of the foundation. So, at the center at the corner and this is the average and this is the rigidity correction for the rigid foundation rigid foundation these are the I f value.

Now, if you look at this values, so these I f values for the rigid foundation is almost 80 percent of the I f value that you are getting at the center of the flexible foundation. So, what we do that, that is why what we do that we use the I f value for the center at the center because that is the maximum at the center for the flexible foundation in case of rigid foundation design, then we apply a rigidity correction of point 8 for the rigid foundation.

So; that means, we will use only the I f value of the we will use the I f value of flexible foundation at the center; both flexible foundation and the rigid foundation. So, for the flexible foundation, we will not apply any correction, but the rigid foundation over this settlement, we will apply rigidity correction which is 0.8

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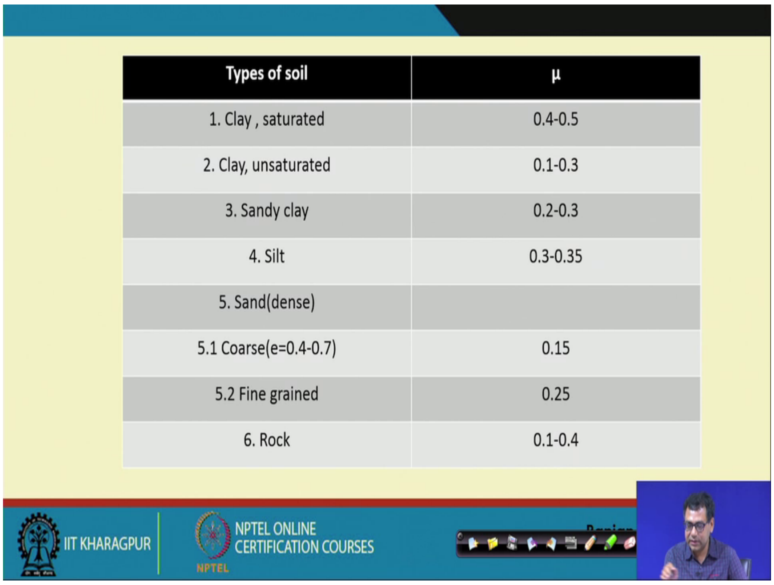

Types of soil	μ
1. Clay , saturated	0.4-0.5
2. Clay, unsaturated	0.1-0.3
3. Sandy clay	0.2-0.3
4. Silt	0.3-0.35
5. Sand(dense)	
5.1 Coarse(e=0.4-0.7)	0.15
5.2 Fine grained	0.25
6. Rock	0.1-0.4

So, now typical value of the mu Poisson ratio of the soil is given in this chart. So, this chart you can use for your reference purpose. So, these are the all Poisson ratio values are given for the different soil. So, you can see for the unsaturated it is 0.1 to 3; but for the saturated clay, it is close to the 0.5. So, that is we generally take 0.45 for the saturated clay and sad it is 0.25 2.15, silt it is 0.3. So, these are the Poisson ratio value.

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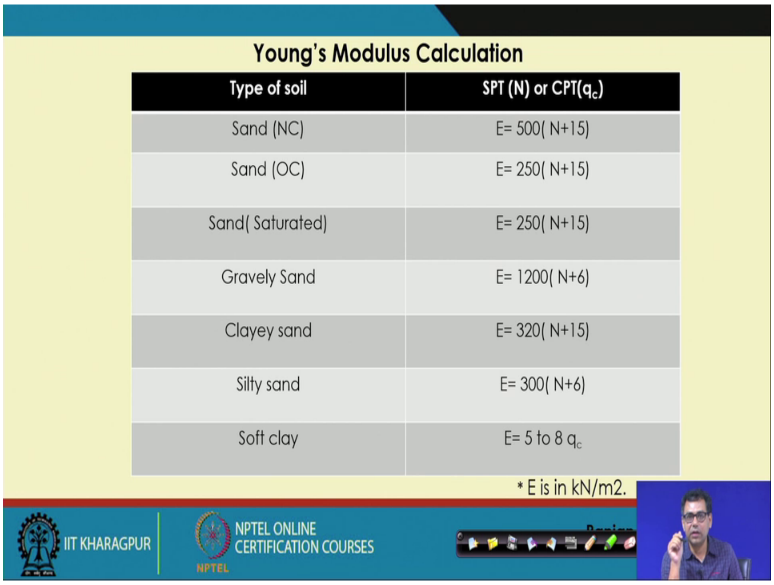

Similarly, we can get the Young's modulus or the elastic modulus of the soil by using this equation. This is E value is the elastic modulus and these are the equation that so, we will use this equation when you solve the problem and then I will discuss this how you will use this equation in that when you solve the problem, but these are the value n value is the S P T value and for the soft clay, why using cone resistance also we can get the E value that elastic modulus by using this expression. Remember that E is in kilo Newton per meter square.

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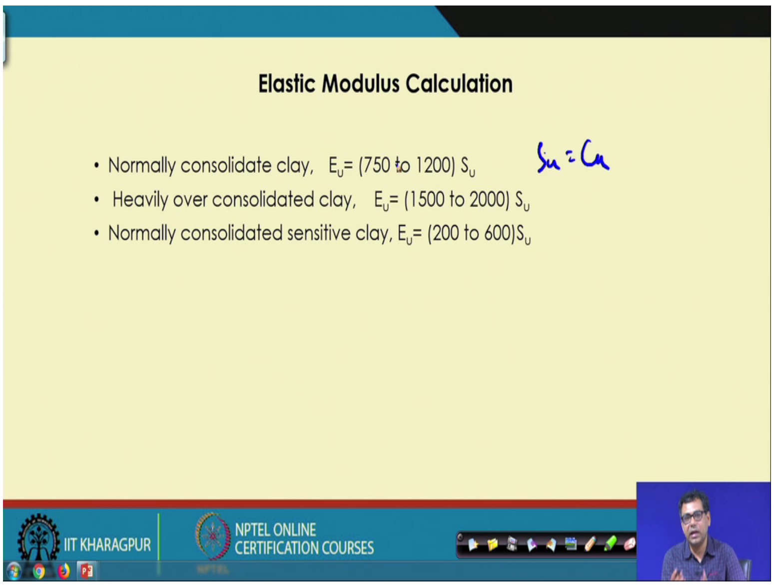

And for the clay soil also we can use we can use the undrained equation or the undrained strength of the soil S u. So, that is your for the normally consolidated clay, you will get E elastic modulus and for the over consolidated clay, so I am discuss what is normally consolidated what is over consolidated. And for the sensitive clay, generally we will consolidated in these two over consolidated and normally consolidated or heavily over consolidated normally consolidated. So, you will get this S u is nothing, but for this case is S u is equal to C u, undrained coefficient. So, that if you know undrained coefficient, then you will get the E value from this range.

Generally if you know the C value, you take the average value of this range and that you can is nothing is mentioned. You take the average value at this range and then you use for the elastic modulus calculation for the clay.

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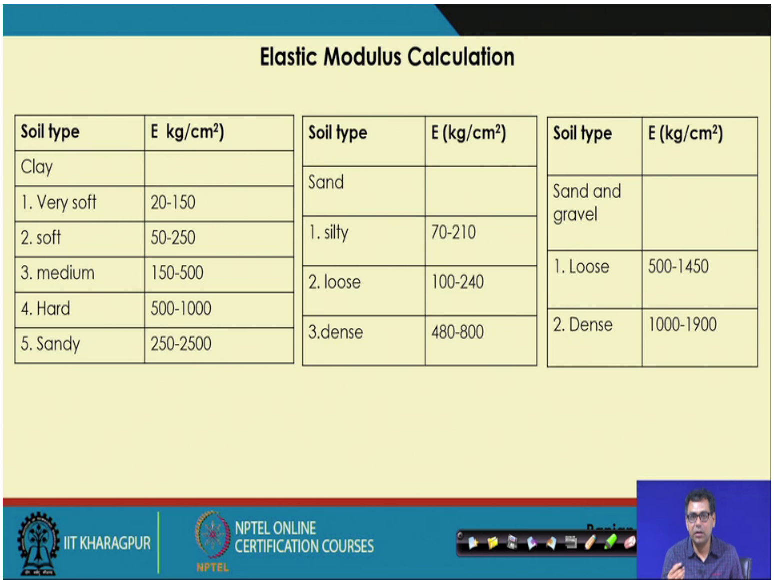

Now so, elastic modulus for the another tables are given to if this is the range of elastic modulus. So, you are elastic modulus that you are you are you are taking that should be in this range. So, there are number of ways you can determine the elastic modulus. So, for the clay soil and the sandy soil so, but this should be used in this range that table is given.

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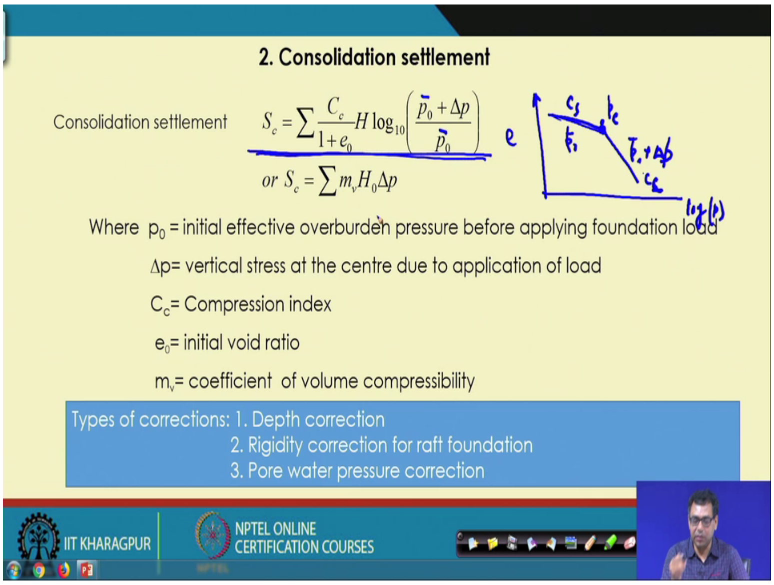

So, next one is the consolidation settlement. So, consolidation settlement you can calculate in, this is the for the normally consolidated soil. So, that is the settlement equation and you can do it in two ways and what are the values are given, based on that C c is the compression index and m v is the coefficient of volume compression. So, if you have volume compression compressibility value and then you have to use the second equation; you have if you have the compression index value, then you have to use the first equation.

And remember that this p 0 is the initial effective overburden pressure before applying the foundation and del p is the additional stress that is coming due to the foundation load or the load that is coming on the to the foundation from the superstructure and from the foundation to the soil so; that means, the del p is the is the is the stress that at a point in the soil is induced due to the applied external load and p 0 bar is the soil pressure which is effective overburden pressure.

And here we have to apply three corrections. So, what are these three corrections? Say for the depth corrections, for the rigidity corrections and for the poor water pressure corrections because depth correction is common for flexible footing and the rigid footing or the raft foundation, but rigidity correction is applicable only for the rigid footing or the raft, but it is not applicable for the flexible foundation, but the poor water pressure correction is applicable for both raft flexible and the rigid footing.

So, isolated footing there are two corrections; depth correction and the poor water pressure correction, but for the rigid footing or the raft foundation, there are three corrections that you have to apply in the consolidation settlement; that is the depth correction, rigidity correction and the poor water pressure correction

Now the so, I will discuss that as I mentioned the this is for normally consolidated case. In the second lecture discuss that form the e log p curve you will get the p consolidation pressure. So, if this is your log p and this is e y ratio and the this is the p c value. So now if you are so; that means, you have two stresses; one is the p plus p 0 or p 0 bar which is the initial effective over in pressure because it is bar effective. So, p 0 bar plus del p.

So, now if you are both the pressure are within this range, then it is the normally consolidation case where the slope is C c compression index. So, if then you have to use these expression and if your p p 0 bar plus del p in this range, then you have to use instead of c c this will be c s soil in index. So, these things I have discussed in the second lecture. So, you can go through that lecture and you can see that where we have to use C s where you have to use C c; C c is for the normally consolidation soil and consolidated soil and C s for the over consolidated soil, if you are del p plus p 0 range is here; I mean beyond I am less than p c, then you have to use C s. If this total value is greater than p c, then you have to use this C c.

Another option is there you have p 0 bar is here, but p 0 plus del p is in this range that mean the p 0 is less than p 0 bar is less than p c, but p 0 bar plus del p is greater than p c. So, then you have to use the third equation that have given in that that lecture. So, but here most of the problem that I will solve in this course is normally consolidated soil. So, you will use these equation which is the further normally consolidated soil. So, mainly I will use this equation and if the values are given in this form, then we can use these equation also where wither this or this that we will use.

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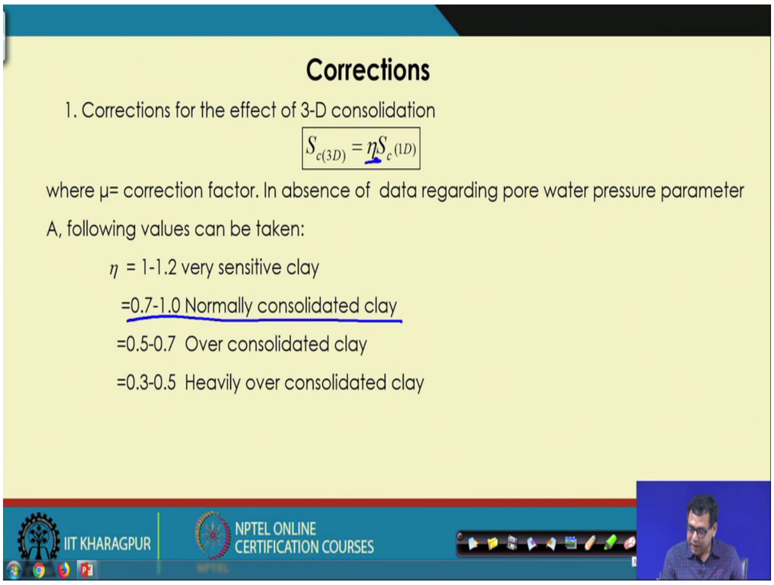

Now, the we are talking about the rigidity correction you know that if the foundation rigid, if depth correction is also you know that if because these are equation are develop for the surface footing, but we are placing for footing as some depth. So, it apply the depth correction, but why we have to go for the poor water pressure correction? Because poor water pressure correction is required the all these equation that I am talking about this Terzaghi 1D consolidation equation so; that means, here it is assume that the soil will deform in one directional and only in the vertical direction, but actually the consolidation is the 3D problem because you are soil can flow not only the vertical direction, it can flow in any direction x y z so; that means, it is actually 3D problem, but the they equation that we are using that is derive for 1D problem.

So, that is why you have to apply a correction that is poor water pressure correction. So, that is the correction is value is correction factor is this one and this one. So, these are the range of these further, what is the range of this correction factor for different clays. So, we are talking about you will consider here. So, normally consolidated clay it is 0.721. So, you have to first we will calculate the consolidation settlement for considering 1D equation, then we multiply with this correction factor to convert it for the 3D problem. So, this is the normally consolidated clay and this is for the over consolidated clay and this is for the heavily over consolidated clay.

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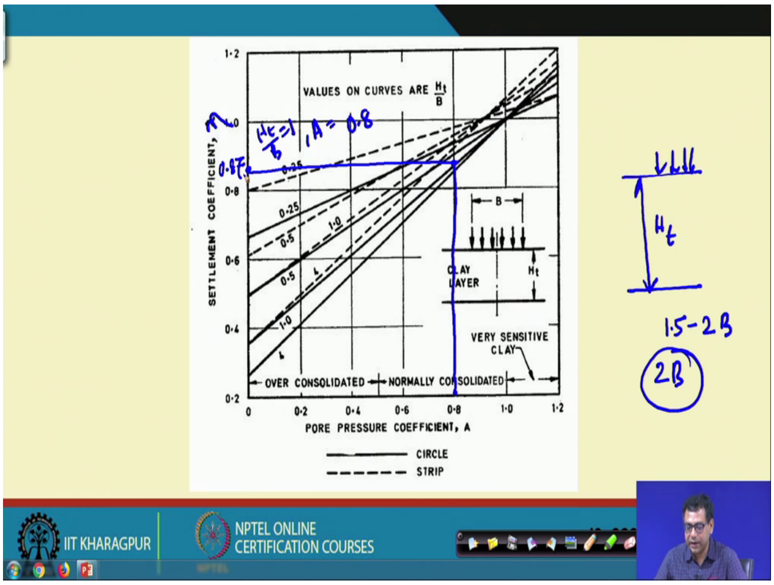

And then if we have the poor water pressure parameter A so, now from the soil mechanics course you know that this is 2 poor water pressure parameter one is A and one is B. So, if we have A parameter value, then by using this chart which is proposed by I s code so, we can you calculate the correction this is settlement coefficient; so which is nothing, but the value that we are using for the correction factor. So, that is for you can use for this. What is this chart? Because if we have a this is the foundation base and this H t is the thickness of the soil layer that you are talking or you are considering for the founda settlement calculation.

So, remember that when you are I am talking about that bearing capacity, then the influence zone was taken as B; but when we are calculating the settlement, then you have to go for a bigger influence zone, then the influence zone is generally taken as 1.52 twice B. So, for the bearing capacity calculation, we will consider the soil parameter up to the B from the base of the foundation, but for the settlement calculation we will considered the soil up to a depth of 1.52 to B from the base of the foundation, but I will prefer I will always use twice B as the influence zone when it is settlement calculation.

So, I will use a soil up to the depth twice B from the base of the foundation during the settlement calculation. So, here so this is this is the H t there is the influence zone, but there may be some rigid bade also there you cannot go up to twice B. So, you have to restrict tilt within the twice B if there is a hydroxide. So, in those case in so; that means, the actual H t is the thickness of the soil layer that you are considering during the settlement calculation and B is the width of foundation. So, if you know H t by B values and if you know the A, so from here for the different H t by B is values; so we have this is normally consolidated range, this is over consolidated range.

Now with very sensitive clay if you know for example, if our A value is 0.8 and we have a circular footing so; that means, the form line and strip footing the dotted line. So, we will go for the form line and H t by B say one. So, H t by B this is the H t by B 4, this is 1 this is 0.5, this is 0.25. So, H t by B 1 is this one and then corresponding correction factor will be around 0.87. So, our correction factor will be 0.87, if H t by e B is 1 and this is for H t by B e is equal to 1 and A value is equal to 0.8.

So, if you are a value is given and if you are design H t B is; obviously, given and H t you have to decide how much influence zone you will consider and then, corresponding correction factor you will get from this chart and that value is 0.86. So, similarly for the other case also we can determine what will be the correction factor for poor water pressure.

So, here I am finishing this class for this class. In the next class, I will discuss about that how I will apply these theories and then calculate the settlement. And then how we will what are the procedure you will apply for the settlement calculation of the clay and what are the procedure or the mythology we will we will choose. So, settlement calculation for the sand and then you will discuss about the plate load test also that is the load test that we will do in the field to get the settlement and the bearing capacity from the plate load test. So, these those things will discuss in the next classes.

Thank you.