Soil Mechanics/ Geotechnical Engineering I
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Lecture – 39
Compressibility of Soils (Contd.)

Once again let me continue to compressibility of soil; till the last lecture what I have various aspect of compressibility I was discussing and I have discussed normally consolidated soil and now I will take a the another actually since normally consolidation is there. So, it will be over consolidated also will be there. So, I will see what is over consolidated soil.

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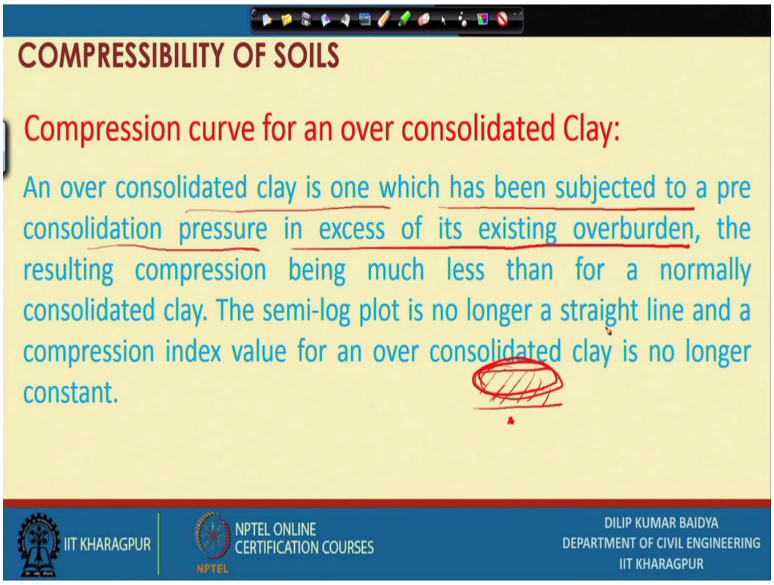

This is so, how and how will be what is the over consolidated soil and how will be the compression curve of a over consolidated clay and let me first define what is the over consolidated clay. And over consolidated clay is one which has been subjected to a pre consolidation pressure in excess of its existing overburden; that means, suppose at a particular depth at a at or at any point say all at any point.

Suppose at even close to surface that is some overburden pressure, but if you look back and see the entire history of this deposit and you may find that this layer was subjected to a higher pressure than the pressure present (Refer Time: 01:37) measure that that is called overburden. How it happens actually, suppose this soil was initially this much thick and under this loading suppose this soil is consolidated and because of some construction issue and etcetera maybe soil this much soil is removed and maybe several years back and this much soil remove then; that means, at present condition this soil at this point will not have the highest pressure it has been subjected to be 4 it is been much lower.

So, that is what an over consolidation clay is one which has been subjected to a pre consolidation pressure in excess of its existing overburden pressure that is the example actually because of some reason soil maybe removed eroded and then overburden pressure is released. That means, before that the soil is compressed by a higher pressure and the resulting compression being much less that for a than for a normally; that means, if it is a pre consolidated soil; that means, already it was consolidated then now if I calculate apply certain amount of load that compression is expected to be much lower than the normally consolidated soils.

So, the semi log plot is no longer is straight line; that means, if I now over consolidated soil; that means, if I now if I calculate e versus p and then finally, if you plot a e versus log p then it will not be a straight line, it will be. In fact, it will be a continuously a curve, but we can divided into two straight lines for a convenient of calculation analysis that I will show you in the next slide.

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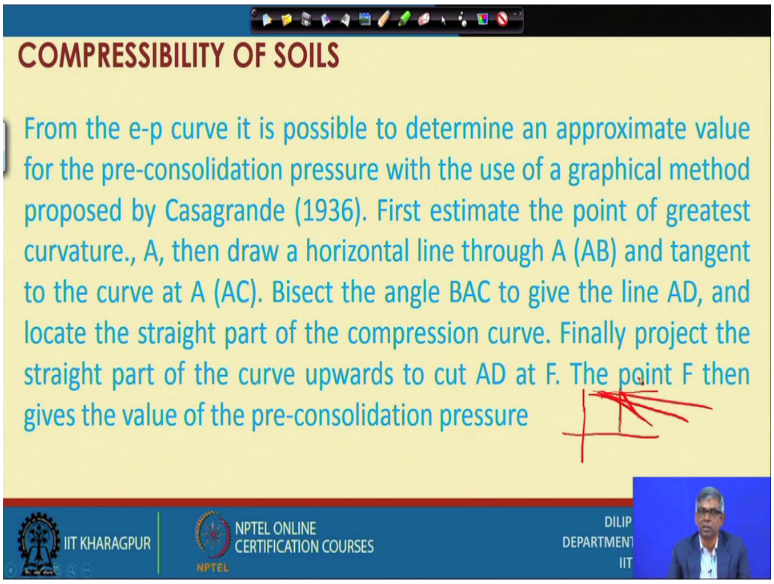

And from the e-p curve it is possible to determine an approximate value for the pre consolidation pressure.

So, e-p curve actually if you plot I will show in the next slide there we it is important to find out pre consolidation pressure; that means, in the any calculation to estimate the total consolidation settlement you need to know what all the if it is a over consolidated soil you need to estimate what was the over consolidation pressure. So, that is a graphical method given by a Casagrande and in that actually using the e-p curve you have to first estimate the point of greatest curvature on the on the curve that I will show in the next slide it is like that, if you do e-p curve a e log p curve it will be something like this.

So, you have to find out point of greatest curvature that is the point a suppose then from there you have to draw an horizontal line and then a tangent, you have to draw an tangent and then you have to and bisect the angle BA; that means, this angle we have to bisect and then from this the original straight portion of the curve or to be extended to intersect this bisector, that point actually will be your pre consolidation that I will show you in the next slide also.

And this is the actually a there is no theoretical backing for this. In fact, people in the past or what they have done they have conducted several test and they have plotted and try to find out different ways and finally, they got this is the generalized method by which if you do we get approximately a pre consolidation pressure this is exactly this is totally a graphical method there is no theoretical basis. So, based on observation only and practice people develop this method and these methods are still working quite well.

And so, if we go to next slide and in a better a clean figure I will let me show.

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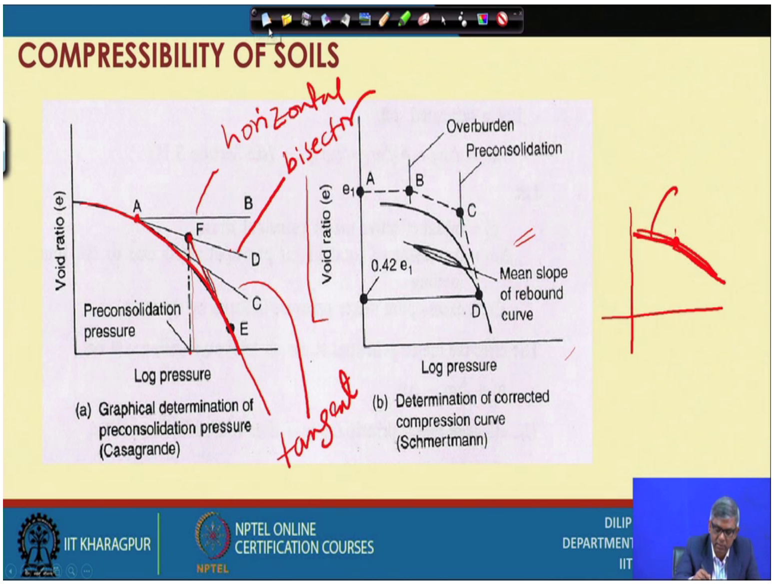

So, this is the one actually we can show you this is the log E versus log pressure curve is this suppose this one and then the point have greatest curvature suppose you have to find out say this is the point and from there you suppose to draw a horizontal, this is horizontal and from this point this is tangent and then you have got a angle BAC and this is bisector, this is actually bisector and then once you got this bisector and this curve is continuously curve and, but towards the end it becomes straight by this original this straight portion of the curve if you extend and by meeting the bisector.

So, this is extended this is the extended to bisect ultra sect the bisector and that point actually if you drop only x axis the value read will be your pre consolidation pressure. So, now, this is the graphical method and a laboratory from the test data you can find out this, but while this is a field compression, field test sometime we can do or actual pre consolidation pressure from the field; that means, the field method is there I am discussing this one I am keeping because maybe undergraduate level may not be required.

So, I am just keeping away this one field determination of corrected compression curve; that means, correct because of the sampling and testing in the laboratory this is actually not that is all a virgin consolidation curve. So, because of that there is some correction I am not discussing that I am just concentrate only if you know the e-p curve from there how to find out the pre consolidation curve pressure that is a method I just want to mention here.

So, this is the method then what is a pressure, if you have e versus pressure e versus log pressure curve find out the point of greatest curvature though horizontal thought a tangent from those points and then the angle we get because of this drawing with a by drawing this two lines at point A you divide that a bisect that one, by a line and then a step portion of the e log p curve is extend that to insect intersect the bisector and that point from that intersecting point you vertically draw up to the x axis. That means, log pressure axis and then it will intersect the x axis that is at point you read the value of pressure that become the pre consolidation pressure and for most of the practical case.

Suppose if you have a e log p curve for practical purpose suppose this is the curve and if this is the consolidation pressure we generally consider two straight line, this is a one straight line this is one straight line. So, this is recompression curve and this is normally consolidated curve. So, this two part actually you can you use while doing calculation so, that I will show you in the next few slide.

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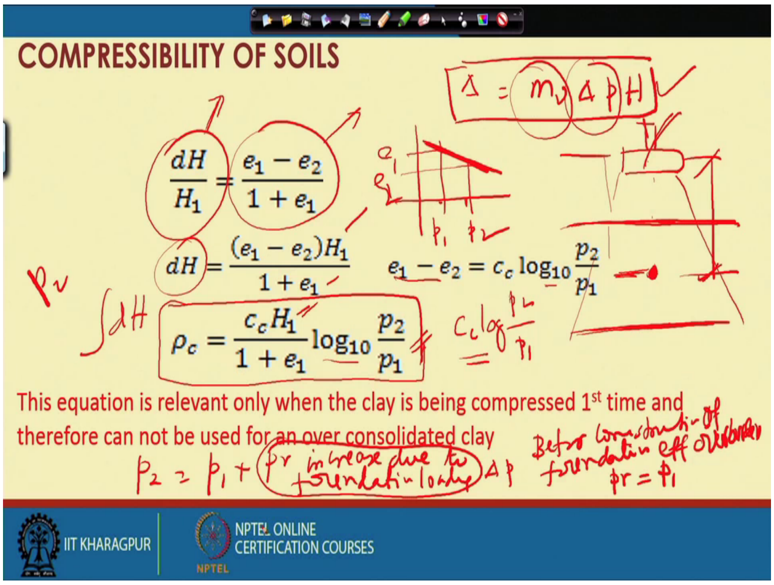

And you can see now observing this e versus log p curve this is a straight line and then you can utilize that to find out the compression we have already developed we have shown one calculation for how to find out that the total consolidation settlement, delta will be equal to mv multiplied by del p multiplied by H this way that is called mv method and.

So, we can calculate the settlements suppose if there is a 10 meter thick layer and because of a construction of foundation that will be increase of pressure on the soil and because of this increase of the pressure on the soil what will be the total consolidation that can be estimated by using this equation, how this equation will be first we mv to be estimated based on e versus pressure plot and del p; that means, if you have a clay ah.

If you have a soil and on the on that if you a construct a foundation from the foundation at the middle of the clay layer how much pressure is transferred that to be calculated, that is actually already we have discussed that bossiness method, trapezoidal method many other method we have discussed. That means, if you apply a load through a footing like this and then suppose clay layer is somewhere here and this much thickness.

So, because of the loading here what is the pressure at this point. So, that to be find found out by using bossiness and many other method we all discuss already we can see go back and see that so; that means, by that way one can find out the consolidation settlement mv method and there is another method that is called log method.

So, we have already observed that e versus pressure plot data, if you plot in a semi log plot; that means, pressure is a log scale and e is the natural scale then we have seen that it accept the initial portion the curve is a straight line. So, if you do that and if you recollect whatever we have learned before that dH by d 1 we have shown dH by d 1 is nothing, but de by v this is the original volume and this is delta e by; that means, volumetric chain this is a volumetric chain one way destination this is another way of determining volumetric chain.

So, this will be equal. So, if you consider that then dH will be equal to e 1 minus e 2 into h 1 by 1 plus e 1 and now. So, if I want to find out the delta; that means, integral of dH integral of dh; that means, if I have the e log p curve like this. So, from here to here I have to integrate. So, integrate if I do integration if I do then ultimately you can see dH equal to this is nothing, but e 1 minus e 2. So, this is e 1 and this is e 2 and this is p 1 and this is p 2. So, e 1 minus e 2 from this line I can write Cc into log Cc into log p 2 by p 1 ok.

So, this e 1 minus e 2 is nothing, but c to log p 2 by p 1. So, if you substitute that one then you are getting a equation Cc into h 1 by 1 plus e 1 log p 2 by here actually log. So, when we plot a semi log plot that, log actually 10 base log. So, this will be 10 base log 10 base p 2 by p 1. So, this is one formula that is called log formula to find out the total consolidation settlement suppose this is the same one if I consider, this is the foundation and it is applying some load on the soil and suppose consolidating layer is here.

So, because of this load what is the pressure here you have to find out. So, we can see Cc into a Cc means compression slope of this line, Cc is the slope of this line the then only you can write this one in this form. So, e 1 minus e 2 equal to Cc into this from here only this coming. So, the Cc is the slope of this line and this is known as compression index and another thing is. So, Cc will be obtained from this graph H is known what is a thickness e 1 initial vertices is known.

So, what is required actually p 2 by p 1 what is p 2 and what is p 1 p 1 is before applying this before constructing this foundation what was the effective overburden pressure at this level that become p one before construction of foundation effective overburden pressure effective overburden pressure which will be equal to p 1 and what is p2, p 2 is p 1 plus pressure increase due to foundation loading, foundation loading and of course, you have to find out at the middle of the clay layer.

So, there are 2, 3 ways one can do directly one can find out the pressure increase here or one can find out pressure increase here and pressure increase here average of this can be obtained or and that can be obtained by bossiness or by trapezoidal distribution all those thing I will discuss later on. the further time being you have to understand this meaning of this equation total settlement of a particular layer because of this loading will be equal to Cc into by 1 plus e log p 2 by p 1 what is Cc if I collect a sample from there.

And if I do a test in the laboratory and then e versus pressure if I plot in the semi log curve then you will get a straight line the slope of the straight line will be Cc that is obtained from the laboratory of course, to find out a Cc there are many methods available empirical method people actually conduct a test on different types of soil and finally, courier to a liquid limit plastic limit many other things there are many equations are available. But otherwise those are applicable sometimes particular soil otherwise you can sample it do the test then e versus p data generate then from there you plot e versus log p and from the slope of this you get the value of Cc.

So, Cc is obtained and e e naught also e initial vertex are to be obtained and then log p 2 by p 1. So, to find out p 2 and p 1, p 1 is actually before applying any load what was the originally effective over burden pressure at the middle of the clay layer. So, that is just weight of the soil above this weight of the soil above this if we are considering this point weight of the soil above these to be consider as effective overburden pressure then. Obviously, if there is a water table then you have to subtract pore water pressure that method we have discussed several many times.

So, once again; obviously, we will repeat same otherwise if I do again and again only you will remember otherwise there is a chance of forgetting or doing mistake. So, again while doing problem I will again this type of thing I will take saturated or with water table. So, that how to find out effective overburden pressure that I will show you again and that is effective overburden pressure before application of the or applying the load is p 1.

And once load p load is applied through the foundation then what is the increasing pressure in the middle of the clay layer that can be obtained by different methods, bossiness method can be used corner formula can be used which is nothing, but bossiness formula of course, from way we are using bossiness formula or approx method approximate method; that means, if I draw if I construct a foundation and applying load and you we can visualize that when you go deeper and deeper the load will be dispersed.

So, that dispersion 2 is to 1 to be considered and by you can assume that there are trapezoidal distribution and by that the width of the foundation is increasing you are going deeper and deeper by that how to find out the a pressure we have discussed and I will show you once again so; that means, there are several ways to find out del p or. So, p 2 is nothing, but p 1 plus a pressure increasing loading and this is typically you can say del p actually.

So, because of the foundation whatever load is coming that is del p. So, p one to be calculated del p to be calculated. So, p 2 will be p 1 plus del p once you know all those thing you can calculate the total consolidation settlements. So, now, let me see one problem very simple problem the problem will never be so simple.

But to illustrate the they formula I will just take this problem and you can see.

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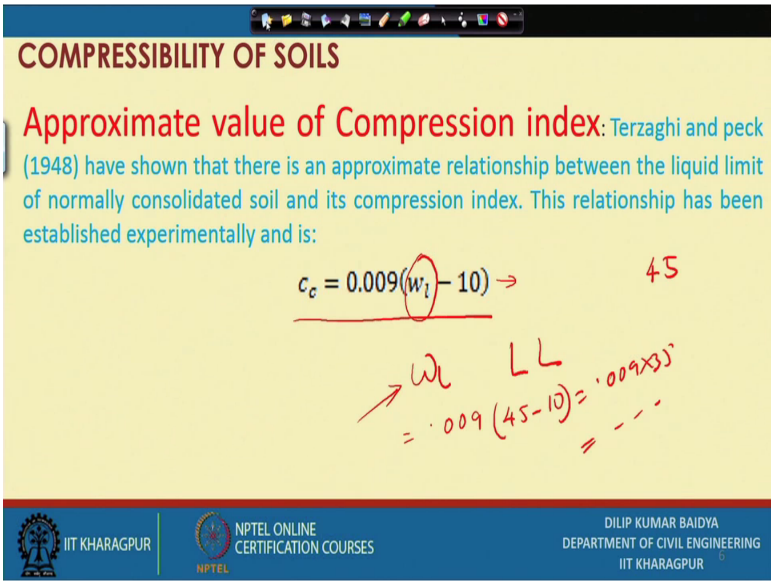

So, before going to that problem let me as I have mentioned that Cc is the slope of the e log p curve, but I also I have mentioned that there are several methods available to find out Cc one such method is given by Terzaghi actually Cc equal to 0.009 into liquid limit minus 10.

So, liquid limit is written sometime this you give sometime for water we use for water content. So, when you use with l; that means, it is liquid limit otherwise liquid limit also sometime ll. So, different ways people will write.

So, either you write this or this it is nothing, but liquid limit. So, 0.009 liquid limit minus 10. So, by this actually you can find out also compression index suppose a particular soil is having liquid limit equal to 45. So, your Cc will become, Cc will become 0.009 45 minus 10. So, it is 0.009 into 35. So, whatever value it comes that is your Cc.

So, this is a very approximate generally it you get a the very conservative side, but it is generally recommended that when your practice you have to say collect the sample do the test plot it and then from there you get the value of Cc.

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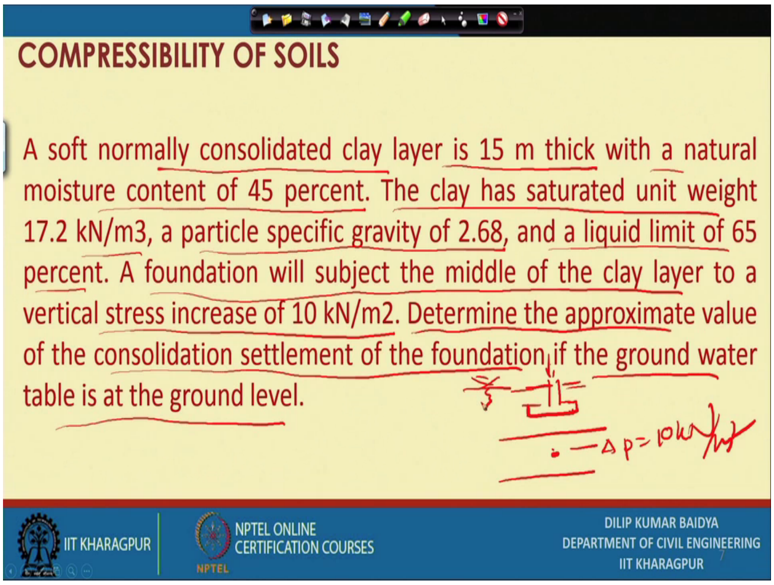

As I have mentioned that very to illustrate the appeal your problem a equation what you have used there is a simple problem we have taken here you can see the problem you saw normally consolidated clay is 15 millimeter thick, with a natural moisture content of 45 percent, the clay has saturated unit weight of this a particle specific gravity 2.68 and in liquid limit of this is 65 percent.

A foundation will subject the middle of the clay layer to a vertical stress increase of 10 kilo Newton meter. So, generally this is never be given, but here it is given suppose you have a foundation, this is the foundation and some amount of load applied through this and clay layer is here the middle of the clay layer what is the pressure because of this foundation load you need to calculate, but here actually it is given that a foundation will subject the middle of the clay layer to a vertical stress increase of 10 kilo Newton because of this foundation del p is 10 kilo Newton per meter square that is given.

So, a part of the calculation is not, you do not do not have to do otherwise in actual practice problem or actual problem you generally have to find out first del p and p 2 a p 1 and then find out p 2. So, this is given. So, calculation is reduce. So, determine the approximate value of the consolidation settlement of the foundation if the ground water table is at the ground level. So, this is another point is given. So, so; that means, your ground water is here ok.

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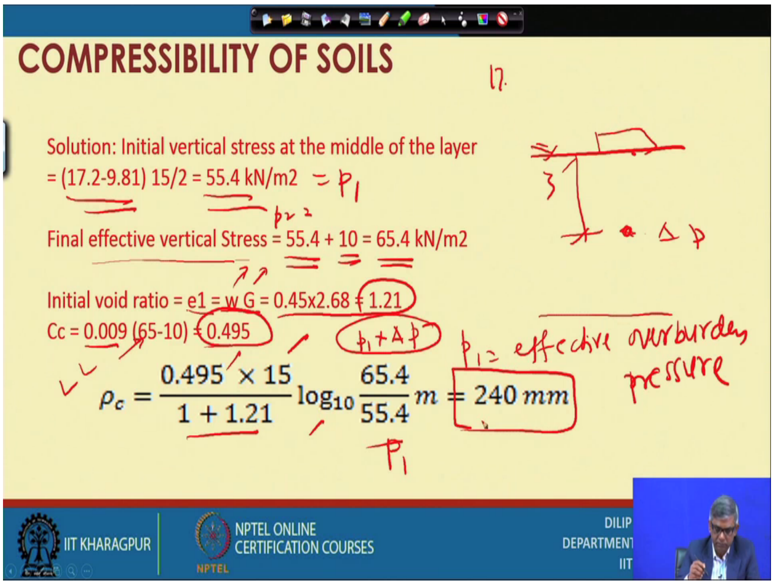

So, based on that let us see the calculation. So, the clay layer thickness was something 15 meter. So, 15 meter thick layer and water table is here and. So, you can see the because of this foundation at the middle actually del p is given, but what you have to find out p 1, p 1 is nothing, but effective overburden pressure ok; So, effective overburden pressure.

So, you can see initial vertical stress at the middle of the clay layer it will be how much. So, unit weight is given 17.2. So, 6 is a water underwater. So, your effective unit weight will be 17.2 minus 9.81 into middle of the clay layer; so, into 7.5. So, that become 55.4 kilo Newton per meter square, but. So, this is effective overburden pressure and a final effective vertical stress will be that is this is p 2 this is actually nothing, but equal to p 1 and this is actually p 2 p 2 will be this effective p 1 plus this is delta p.

So, 65 and initial void ratio was w 1 equal to; that means, now saturated that can be obtained w into g w is a natural overburden content g is the specific gravity. So, from there I get 1.21 was the initial void ratio then Cc again 65 percent is liquid limit is given liquid limit is 65 percent. So, 0.009 into 65 minus 10 in that is gives you 0.495 was the Cc so; that means, your Cc into h 1 plus e 1 log p p 2 by p 1 or p 1 plus delta p that is also sometime we write p 1 plus delta p by p 1.

And if you do this you will get a settlement of 240 millimeter for this now I will show if it is a over consolidation consolidated clay how to find out the consolidation settlement and you can see that.

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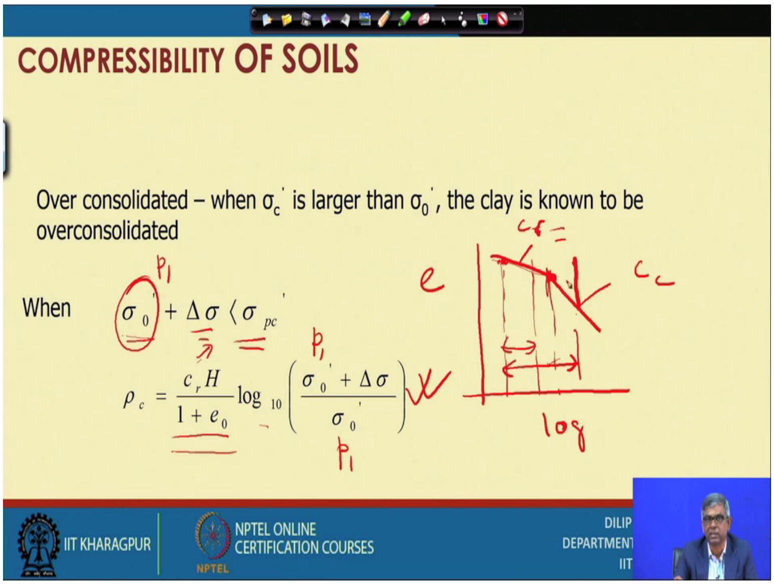

As I have mentioned before that e versus log p curve we generally take if this way this is e and this is log p and this is cr and this is Cc this is actually p consolidation pressure this is the way we take.

And now actually we are using literally different symbol otherwise it is same everything is same this is initial effective pressure this is nothing, but p 1 and this is delta sigma.

So, initial effective pressure is suppose, suppose somewhere here initial effective pressure is somewhere here and you have applied delta p in such way it is delta p you applied this much, then this consolidation is only in this within this curve along this only.

So, if we if I you want to find out the consolidation settlement because of this loading then what will happen slope of this curve is the cr, cr is actually decompression, coefficient of curvature for recompression; cr actually coefficient of curvature compression index for recompression ok, so it is a over consolidation. So, a settle soil this portion is decompression.

So, compression index for recompression so; that means it is still it is recompression zone. So, your formula will not change. So, cr into h instead of Cc you will be using cr into h 1 plus e naught corresponding to this void ratio is e naught log this is suppose p 1 and this is suppose delta p and this is p 1. So, same formula to be used only instead of Cc it will be cr and p 1 to p 1 to be calculated and p 2 delta sigma to be calculated.

So, this formula for over consolidation though the soil is over consolidated, but during construction if you load in such a way that your present effective overburden pressure per delta sigma does not in increase or exceed the over consolidation pressure, this is a much below the over consolidation pressure in that case your compression will be much smaller.

So, before that pin consolidation pressure. So, this is the formula to be used and if it is a delta p is applied in such a way that suppose delta p is here then the you delta p is in this range because of this to this is delta p then the soil is compressing from here to here by some way and from here to here another way.

So, there are two parts; that means the recompression and there will be a compression part. So, from here to here from 0 to or initial weight pressure to pre consolidation pressure that is recompression and for pre consolidation the pressure to next level of pressure that is actually compression.

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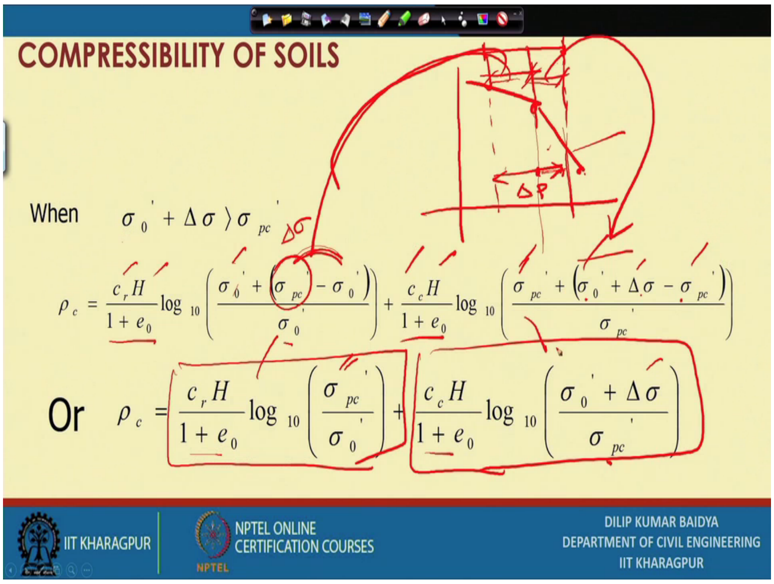

So, if I see this on next slide let me see and you can see this one suppose this is the curve is something like this and your p naught is somewhere here and delta p is this is delta p. So, what I will do I will calculate for this and calculate for this. So, for calculation for this I can see this is decompression. So, cr into h 1 plus e log here it was sigma naught and here actually this is actually nothing, but delta sigma minus this is original effective pressure here. So, this is actually delta; so, delta sigma naught plus this.

So, what I will do you know the pre consolidation pressure at this point. So, pre consolidation pressure minus initial pressure that is delta pressure pre consolidation pressure minus this will be the delta pressure. So, sigma naught plus this by this and if I simplify cr into h by 1 plus e log ultimately sigma pc the pre this is sigma pc is nothing, but pre consolidation pressure by sigma naught.

Now, to find out this portion from here to here you can see, since it is compression is the actually compression virgin compression. So, it will be Cc to be use Cc into h 1 plus e naught log and here actually starting compression is sigma pc and delta sigma will be how much this to this.

So, from here to here how to find out, I can find out p naught plus delta sigma p naught plus delta sigma that I am reaching up to this p naught plus delta sigma that I am reaching here now already I have taken the effect after this then I have to subtract the sigma pc. So, you can see sigma naught plus delta sigma minus sigma pre consolidation so; that means, I will get this portion separately, this portion is for the for this portion is this and for this portion is this and if I simplify this Cc into h by one plus e sigma naught plus del sigma by sigma pre consolidation.

So, it will be having two parts 1 is because of the recompression and 1 will be the normal compression this two part to be calculated separately if it is over consolidation pressure and cr value will be much smaller than the Cc if not given or not estimated then it is approximately one fifth of the Cc can be taken as value for calculation and. So, that means, if it is a over consolidated soil to find out the consolidation settlement 2 ways you have to you have to see after the application of the delta sigma you have to see whether you are crossing pre consolidation pressure or not.

If it is not crossing then only cr portion to be applied and normally consolidated equation to be used and if your application of delta sigma its cross the pre consolidation pressure then it will be having two segment, one is for recompression another is a compression. This two together will be the total consolidation of the soil for the over consolidation soil.

So, this much actually I wanted to cover here next class I will text some application of this problem etcetera and further rate of consolidation etcetera I will take a take subsequently.

Thank you I stop here.