Soil Mechanics/Geotechnical Engineering I
Prof. Dilip Kumar Baidya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

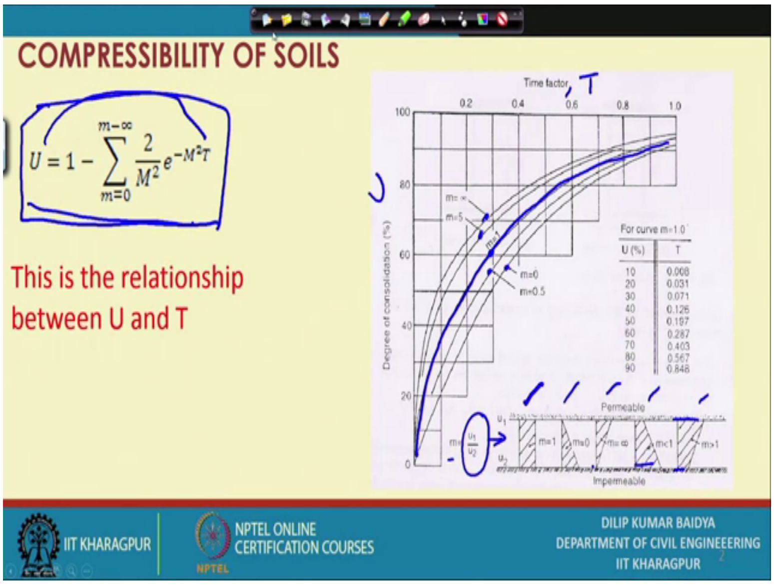
Lecture - 41
Compressibility of Soils (Contd.)

Let me once again continue from the point, where we have left in that in my last lecture. In my last lecture, I have shown just by applying consolidation one dimensional consolidation theory. We have a developed a mathematical expression or relationship between T and U, where T is the time factor and U is the degree of consolidation U is the degree of consolidation, what is degree of consolidation; that is actually suppose under certain loading it expected settlement is suppose 100, and if at any time settlement is to completed.

Suppose 20 millimetres, then degree of consolidation is 20 by 120 percent like that. So, degree of concentration U defined is like, that and another this time factor time factor is a non dimensional term again, which is equal to c v coefficient of consolidation time; T duration time duration T by h square h is the longest distance of the water particle to travel for dissipating the pore pressure.

So, that if T versus U relationship mathematically we have shown by applying one dimensional consolidation theory. Now let us see how to utilize this or how to for calculation of time settlement and also how to determine those c v value also which is very important in estimating the consolidation settlement particularly for pointing out the time consolidation consolidation settlement Cv is very very important. So, how to determine c?

(Refer Slide Time: 02:17)



So, this actually I have shown this expression, if the in the previous lecture which is obviously.

Relationship between U and T those m and other things they are actually something parameter defined there. And now this expression, if I use and in this actually there is a small m which is equal to 0 to infinity and for developing of this one dimensional consolidation settlement.

We assume m equal to 1 and what is m? Naturally, now I can show you schematically here we have shown different pressure distribution you 4 to 5 distribution this is one this is one this is one like that 4, 5 pressure distribution in pore pressure distribution you have shown. And this is the one we have said that we have assumed that uniform pore pressure distribution; that means, the top layer top of the layer and bottom of the layer, if I consider U y here and U 2 here the ratio of this m m is the ratio of this pore pressure at the top divided by pore pressure at the bottom U 1 by U 2 and that is taken as 1.

And for these expressions, but this similar treatment can be done with different values of m and m equal to 0, when it will be m equal to 0, when this is the one ; that means, it is a newly deposited soil. So, pore pressure will be 0 at the top at the bottom, it will maximum the ratio becomes 0 the m equal to 0, then it can be another relationship where loaded foundation at close to the surface it will be maximum and at a particular depth is 0. So, here actually m will have the value infinity.

So, that we will get another set of relationship and then in normal case that a at a embankment loading, then in that case we will have lesser value of pore pressure here and more value of pore pressure at depth. So, this one m equal to less than 1. So, if I applied that one you will get another set of solution and here actually at a particular depth thick layer is there. In that case pore pressure will be here maximum and at a greater depth it will be very less.

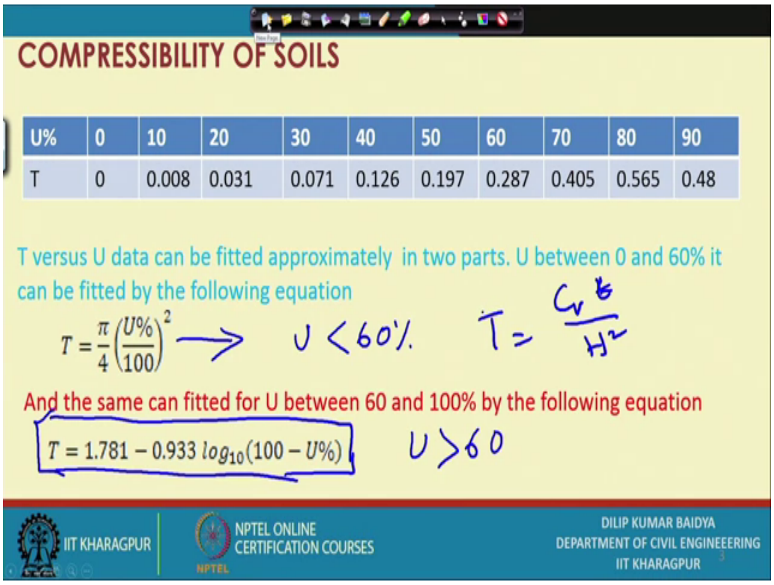
So, in that case ratio will become ratio of m a ratio of these two pressure switch defined as m will be greater than 1. So, if I use that m we will get another solution, but. So, far we are actually for undergraduate level particularly we are actually it would be enough actually if you can understand.

The case with m equal to 1; that means, purpose at distribution uniform within the layer and that will this is the case and if this is the case then you can see there are different plots are given time factor this is U or T and this is degree of consolidation U T versus U plot by mathematically develop the solution.

And finally, protecting versus U and this is giving one different values of U can see m equal to 0.5 m equal to 0 this is for 0.5 this is for 0 this is for 1, this is equal to 5, this is equal to infinity, but we will be working with 1. So, this is the on1 this is the T versus U corresponding to m equal to 1. So, we will work with that again if you read this value.

And graphically if you put then you can see U versus T there are certain values. So, which I will show you the next slide also you can see here.

(Refer Slide Time: 06:00)

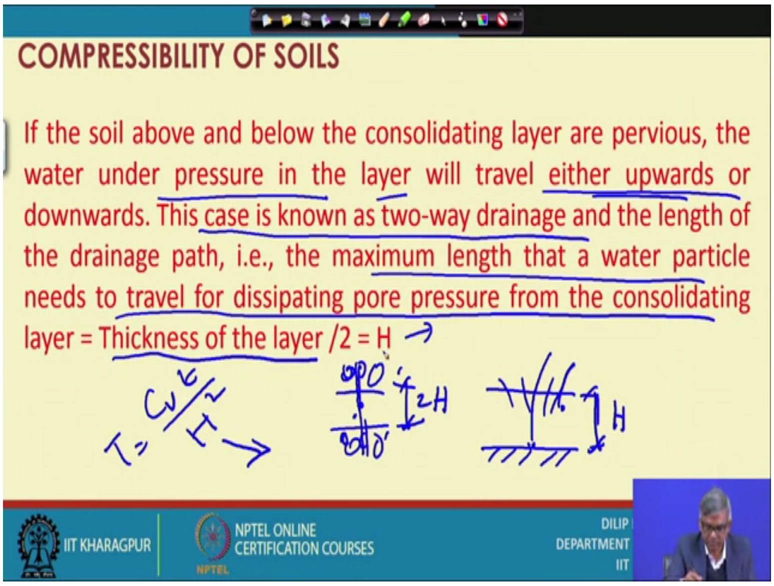


I have written once again U and T U is 0 equal to 0 U equal to 10 T equal to 0.008 U equal to 20.0031 U equal to 30.071 U equal to 40 percent. Actually 0.126 50 percent, 0.197 60 percent, 0.287 70 percent, 0.405 80 percent; 0.565 90 percent 0.48; so this is the T versus U data; these data if you try to fill it actually approximately feet in to equation up to 60 percent ; that means, less than 60 percent the T can be approximately treated by this equation T equal to pi by 4 U square this is 1 up to 60 percent, when U less than 60 percent.

And another equation when U greater than 60 percent; this equation do longer valid it will give error. So, we have another equation for U greater than so this is the m 1 1.681 minus 0.933 log 10 bears 100 minus U. So, these two things actually you need to remember time to time for calculation and this may be required, because you know the U from U you have to find out the time factor and once you get the time factor T you know Cv T by a square.

So, if you know the soil property if you know the thickness of the layer. So, T how much time will it take to consolidate that much percentage of degree that much degree of consolidation we can find out. So, this equation this, these two points are two three ways can be used one actually directly one can read the chart. You know that degree of consolidation of 50 percent from the chart you find that what is the T another way generate data for T versus you then you fit. So, if you can directly use the equation to find out the T; if you know the U find out T from this equation. And so these two ways actually one can find out in versus U and now the whether is a layer, then we have a situation.

(Refer Slide Time: 08:37)



At the only one side is rock and one side is pervious soil. So, water will flow in to one direction sometime there will be the layer this side this side both side actually pervious soil. So, pro will be in the both direction. So, accordingly whatever equation we have used T equal to Cv t by H square, this H actually the longest distance the water particle to move to dissipate the pore pressure.

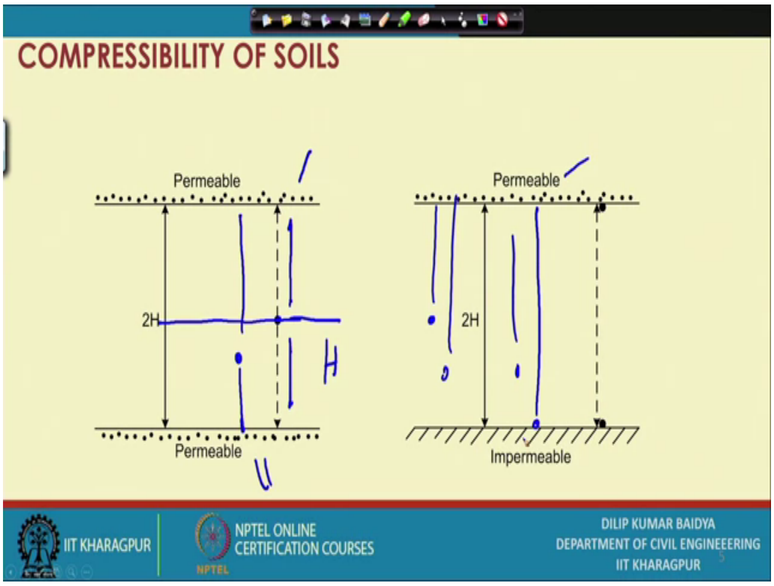
So, if this is impervious, then to dissipate pore pressure from here the water particle has to move this much distance so this way. So, in that case H becomes this; so longest though soil particle here to this that will travel this much distance, but at this point whether it is travelled this much. So, longest path is h so; that means, if there is a, drainage is like this; that means, the one way is impervious and other ways.

The other side is pervious the longest path will be the thickness of the layer whereas, if you have both side drainage then the longest part the water particle to remove for dissipating the pore pressure will be half, because if water particle is here it will try to go these directions instead of going this direction. So, there was be more than half. So, maximum point at the midpoint either it can go this side or go this side. So, because of that when drainage is in the both side then the longest distance water particle to travel for distributing the pore pressure is half the thickness of the layer.

So, that is the thing is mentioned here, if the soil above and below the consolidating layer are pervious the water under pressure under pressure in the layer we will we will travel either ah; that means, water under pressure, because you did this because pore pressure because, why; because it is in the under pressure because of that pore pressure is developed.

So, layer will travel either upwards or downwards this case is known as two way drainage so; that means, when pervious layer at both the top and bottom that is called two way drainage and when there is a two way drainage the maximum length that a water particle leads to travel for dissipating pore pressure from the consolidating layer, that is equal to thickness of the layer divided by a 2. And we in our analysis we have consider thickness of the layer as 2 H.

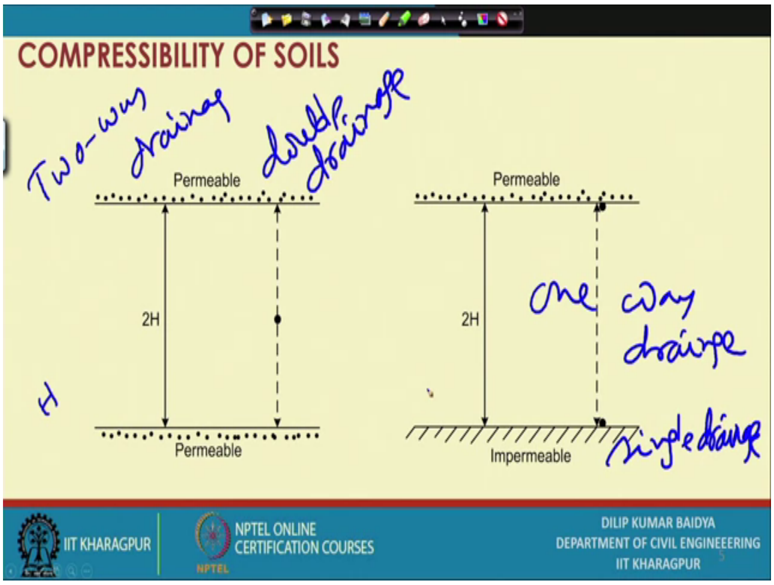
(Refer Slide Time: 11:41)



So, your drainage path will be H and this is schematically shown in this; you can see this is permeable and this is also permeable. So, water particle from here maximum distance travelled, if it goes whether it goes this way or this way that distance is still H, but if the water particle is here it will never go this way, because before that if it goes there it will be faster. So, they will try to release faster, because it is under pressure.

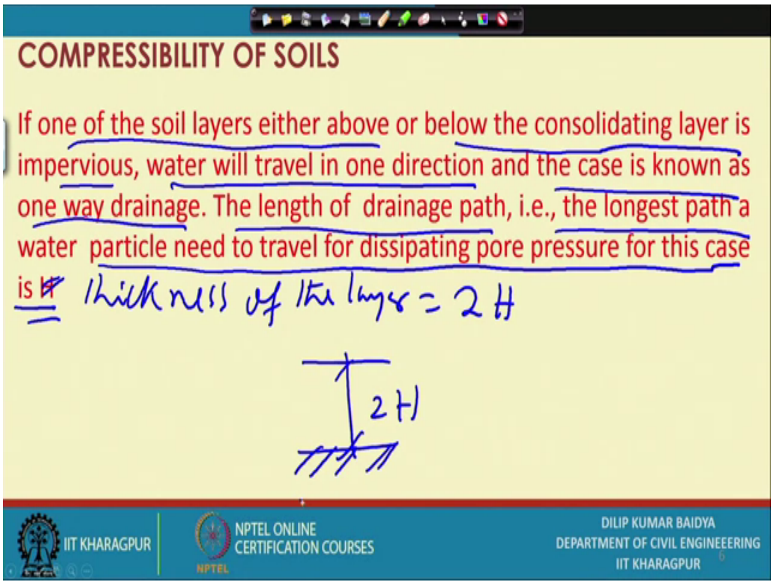
So, always because of these you have maximum or longest travel path for water is the thickness half the thickness of the layer whereas, if one side is impervious and other side is pervious permeable, then water particle is disparate from different points only the one direction, but maximum distance to travel from here to here actually. So, that is the one; that means, that is called one way that is and for one way that is your longest path water particle to travel to dissipate the pore water pressure is that equal to the thickness of the layer.

(Refer Slide Time: 12:54)



So, that is the thing that, these two symmetrical diagram two ways drainage or it is all this called double drainage. And this is one way drainage or sometimes called single drainage ok. So, double drainage actually there are H will become half the thickness of the layer, when single drainage that it will be like thickness of the layer itself will be the H.

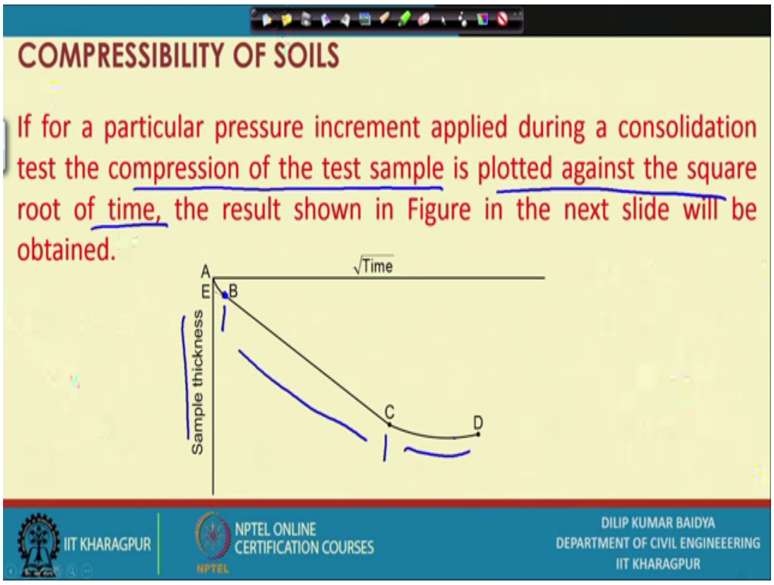
(Refer Slide Time: 13:36)



So, this is same thing repeated here, whatever I had just told if one of the soil layers either above or below the consolidated layer consolidating layer is impervious water will travel in one direction and the case is known as one way drainage.

The length of drainage path, that is the longest path a water particle need to travel for dissipating pore pressure for the, for this case is H, it will it should be 2 H; actually since we have considered or. it would be thickness of the layer you can say thickness of the layer which will be equal to 2 H, because we have consider this thing is as 2 H and if it is one way drainage; that is closed here.

(Refer Slide Time: 14:33)

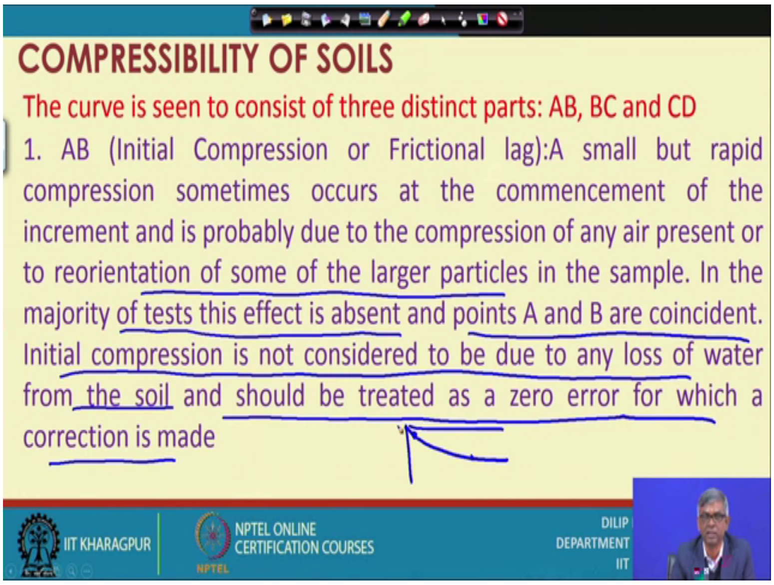


Now, T versus U you know now T versus sample thickness observation it is seen that for a particular pressure intimate applied during a consolidation test. The compression of the test sample is plotted against the square root of time square root of time versus sample thickness, if it is plotted, then we get a curve like this initially a small curve portion.

Then for a solution in long straight portion and then again there is another curve portion. So, they have different name different location, this is actually initial compression either it is elastic there say or particle adjustment, because of particles etcetera, because of that this small portion and when those adjustment is established; then consolidation will take place B to C, this is the consolidation.

And primary consolidation and this one will be secondary consolidation and many other things can happen here. So, see if there are four parts.

(Refer Slide Time: 15:51)



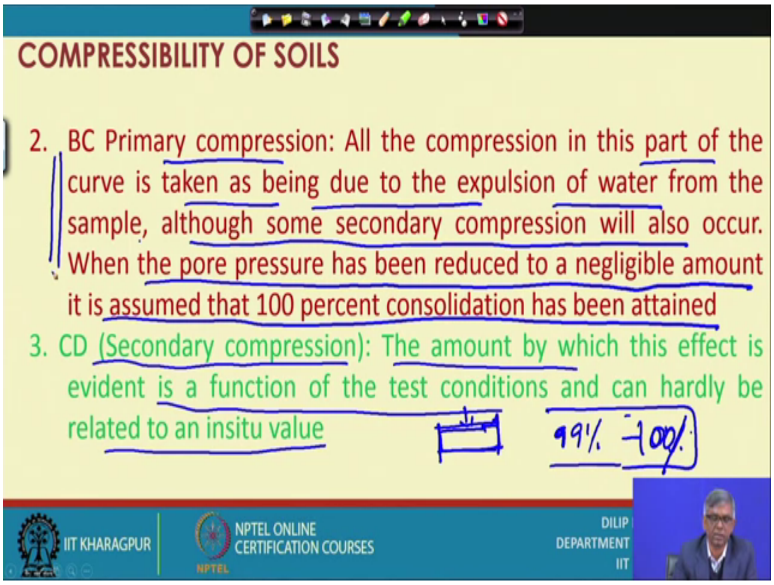
So, we will explain one by one what are those you can see the car was seen to consist of three distinct part AB, BC and CD and AB is the initial compression or frictional lag. So, because of this it is a it is at a ring sample will be prepared and it will load and then compression will be observed.

So, initially we will have a slower rate a initial compression this is a small, but rapid compression sometime occur at the at the commencement of the increment. And is probably due to the probably due to due to the compression of any air present or to reorientation of the some of the larger particles in the sample in the majority of the stage this effect is absent and points A and B are considered.

The initial compression is not considered to be due to any loss of water from the soil and should be treated as a 0 error for which a correction is made ; that means, you have the curve like this; initial portion v and then it will be stayed.

So, this portion you can be you can be taken as a error or correction. So, this is this is what is happening; consolidation means when the volume changes taking place same amount of volume of water is going out ok. Here, actually up to this B point we are conserving, it is there is a no movement of water it is, because of many other things which is listed here and BC is up.

(Refer Slide Time: 17:32)



Primary compression that is, whatever consolidation mechanism we have explain. All the compression in this part of the curve is taken as being due to the expulsion of water from the sample, although some secondary compression will also occur.

When the pore pressure has been reduced to a negligible amount it is assumed that 100 percent consolidation has been has attained; that means, here a in the in the consolidation set up you have applied load; and by definition of completion of consolidation is work where we apply the load.

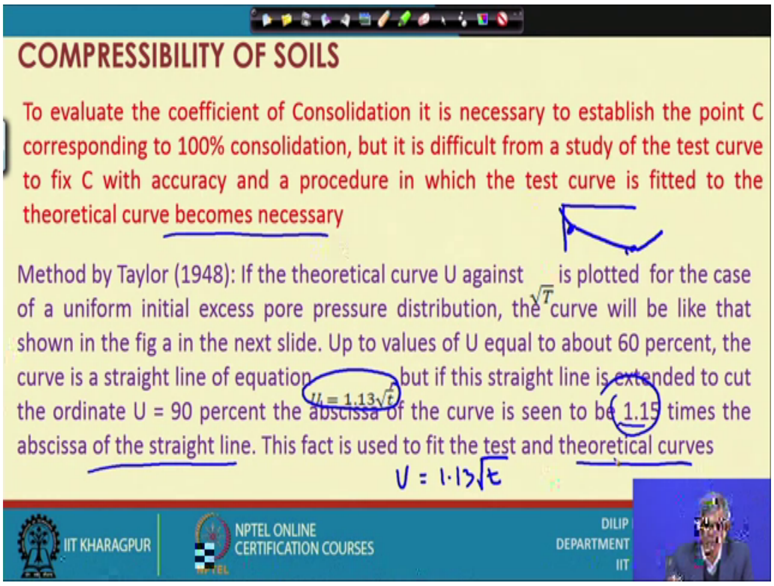
Then, within the soil pore pressure will develop and when the after that we will keep it for a longer time. The pore pressure will dissipate and slowly pour pressure excess pore pressure will be reduced and when the excess pore pressure is coming to 0; that time we say it is a completion of pore pressure compression of personal reason.

But here that sometime probably 99.99 percent to a pore pressure have 00 percent to 0 percent or 100 percent dissipation 99 to 100 percent dissipation they take very long time. So, because of that sometime when it become poor pressure become negligibly small some of 98 percent 97 percent; still we may have consider as a compression of consolidation.

Otherwise you have to do wait for a long time and then this is BC part a CD part is a secondary compression the about by which this expect is evident is a function of the test condition and can hardly be related to an value. So, this is secondary compression theory is different we will not discuss right.

Now we will try to discuss this handling that primary consolidation settlement, how to this observation; how to utilize for finding some soil parameter into relate into compressibility of soil.

(Refer Slide Time: 19:50)



So to evaluate the coefficient of Consolidation it is necessary to establish the point C ; that means, we have shown there that, sorry; we have showed that this is the point there is this one that, then these one and then this one. So, we could be to see that is this C point has to be established, why; because the end of 100 percent consolidation, correspond to 100 percent also, but it is difficult from a study of the test curve to fix C with accuracy and a procedure in which the test curve is fitted to the theoretical curve becomes necessary.

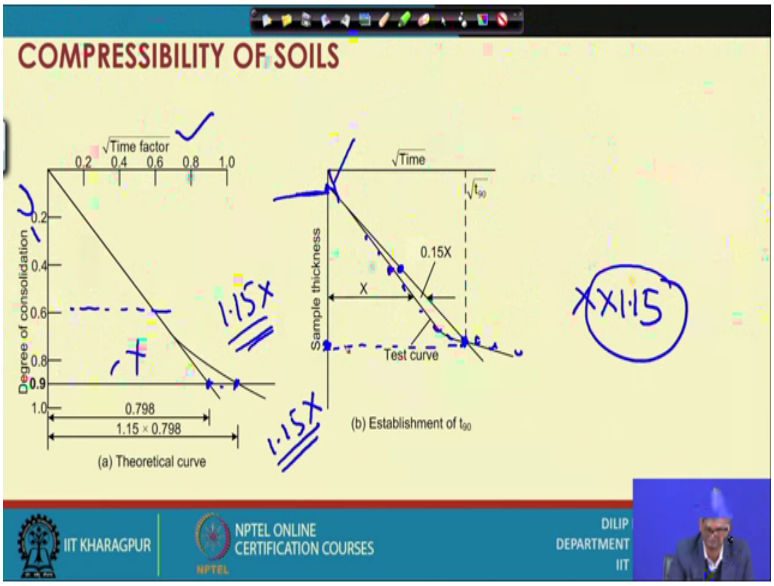
So, theoretically we observe the, and based on that some adjustment can be done to find out; approximately this behaviour at this value. So, one such technique was proposed by Taylor who first observed a theoretical curve U against root T plotted U versus root T is plotted or an uniform initial excess pore pressure distribution, the curve will be like that is what in the figure a in the next slide.

So, I will I will come to that figure U up to values of U equal to about 60 percent; the curve is a straight line of equation. So, that is equation is this U equal to 1.13 under root T up to values of U equal to 60 percent, the U versus T is a straight line, but if this straight line is extended to cut the ordinate of U 90 percent the abscissa of the curve is seen to be 1.15 times the abscissa of the straight line.

This fact is used to fit the test at theoretical curve. So, we have observed something with test results. Now it is observed with theoretical curve U versus T root T and then it is seen that up to 60 percent is a straight line and beyond straight line is a 60 beyond 60 percent is a curve one, but at 90 percent which is close to the 100 percent that point we have seen there is a relationship between this original curve at their straight line.

So, it is this shows is 1.5 1.15. So, this point is of these observations will be utilized. So, to fit the curve and find out C v you can see here.

(Refer Slide Time: 22:40)



This is the one observation is given; initially the root time factor versus degree of consolidation U plotted like this, and up to 60 percent is perfect straight line and then started deviating from the straight line.

But it is 90 percent consolidation you see the abscissa, whatever value was here and whatever value of the curve actual curve it is one point times the abscissa of the straight line and this straight line at 90 percent; whatever the initial curve you have got up to 60 percent that one in the extend up to 90 percent; whatever value you need.

Suppose X then actual curve on that point will be 1.15 times X this is the important observation to be used for utilizing for to utilize and find out the coefficient of consolidation Cv. So, you can see now the test curve in the test curve.

So, generally initially there will be a curve one and then this will be like this it will cover route time versus sample thickness, if you plot and then if there is a curve. Then we can the straight portion can be extend that this one can be taken as a zero possible start part of the consolidation and if the soil does not have this initial portion, then you are getting correctly zero point, but if it is not if then the curve that this state portion can be extended to X axis X axis here that will be the starting point of the consolidation and now this curve is whatever test data we have based on that you can draw the curve and like this like this you can draw the curve.

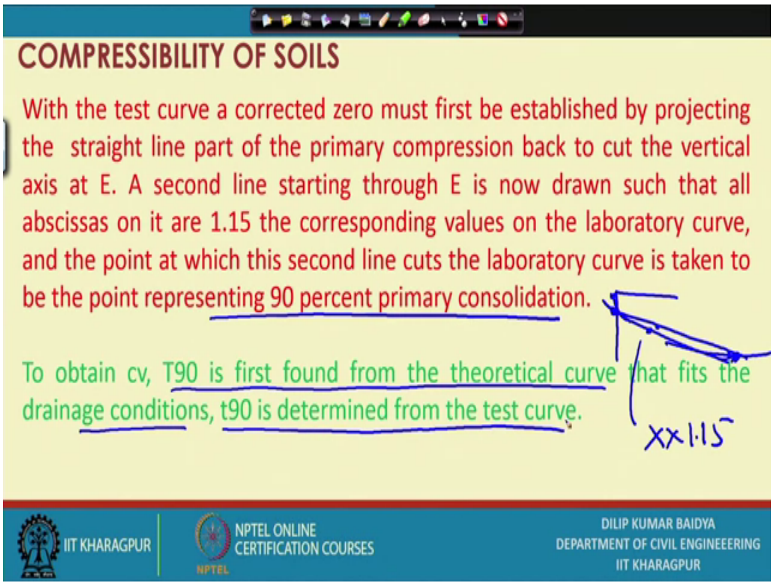
And after drawing the curve; what you can do since whatever observation we have made that abscess out of the straight line will be equal to will be, but the abscess of the curve will be equal to 1.15 times the abscises on the straight line. So, we can take 1 or 2 points from here and you can take 1 or 2 points on these suppose this is one and we need value X you multiply by 1.15 and establish a point here. They joined these two these and extend it ok, then after the extending this one it will intersect the original curve somewhere here.

Once the intersect somewhere here that since it is a 90.90 percent, that is; the observation we have seen 1.15 time and now we are doing reverse best of you have observed this one. Now we considered these as a fact. So, we have taken a value on the curve and we have multiplied by 1.15 intersect the curve.

So, that intersect is part what will happen here actually 90 percent consolidation; we have got this observation. So, when you have reverse we have done and intersected here that with that point will represent the 90 percent degree of consolidation.

So, this point so this, become corresponding point to 90 percent consider. So, I can now I can find out this is original thickness and this is 90 percent. So, from here actually you can find out; this 90 percent. So, degree of consolidation is 90 percent. So, T 90 you can find out and then get and, then we can find out the C v by using the relationship we have; now based on these, so, this point ; that means, you are you are getting here by this construction we are getting your U 90 once you get the U 90.

(Refer Slide Time: 26:52)



So, once again whatever I have mentioned and just repeat with the test curve we corrected zero must be must first be established by projecting the straight line part of this so; that means, if you have the curve like this. So, you extend this straight portion we will gets though the curve started here, but you can yeah consider start of constellation here line of the primary compression back to cut the vertical axis at E. So; that means, this is the point E.

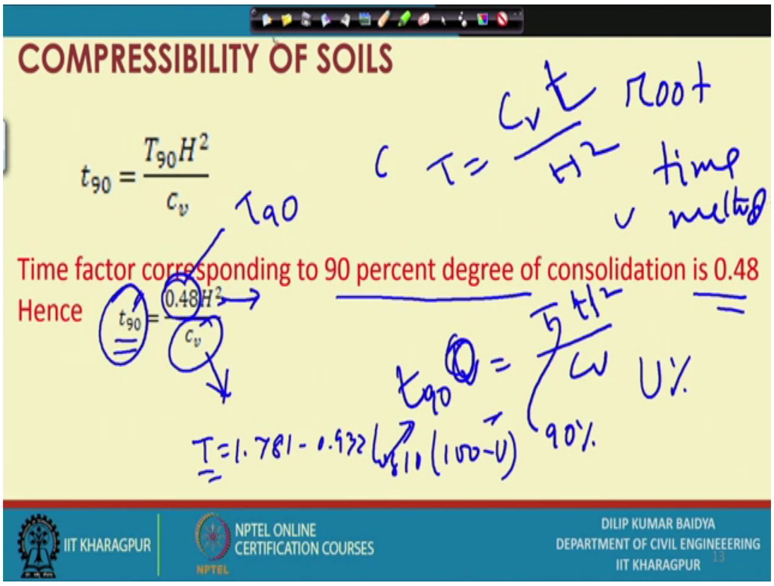
A second line starting through E is now drawn such that the abscissa on it are 1.15 time corresponding value on the abscissa on the curve; that means, from here I will read the value. Suppose this is X and then, I multiplied by 1.15 and then I will get the point here from here to here I joined and this curve will intersect somewhere here.

So, that is the thing is done abscissa on it are 1.15 the times the corresponding value on the laboratory curve, at the point at which the second line curves the laboratory curve is taken to be the point representing 90 percent primary to consolidation.

So, these lines when intersected, because previously you have observed that at 90 percent this is the thing happening. So, now, we are reverse we are doing we we are drawing the line intersecting the curve where it is intersecting that we are considering as 90 percent consolidation. So, U 90 you are getting.

So, to obtain C v T 90 is first found from the theoretical curve that fits that drainage condition, T by T is determined from the test curve. So, you can see now sorry you can see now.

(Refer Slide Time: 28:50)



This is the relationship we know you know you know T equal to C v T by H square. So, if I want to find out C v C v equal to TH square by C v and C we want to find out C v which can be considered as the constant and we have got this I consider sorry this is not capital T.

This is small t. So, T into H square by C v sorry this is actually T this is small t. So, this t corresponding to 90 percent since we have already got a t this also 90 percent. So, t 90 that mean time required for completing 90 percent consolidation you can find out from this expression.

So, for this what we need? We have to find out t90 t. So, t 90; how you have; how we will get you have got U 90 percent and from there corresponding t 90 percent we can get. So, either way so, if you read from the graph t 90 and if you get t 90 and if you know the; that thickness that he can find out the Cv.

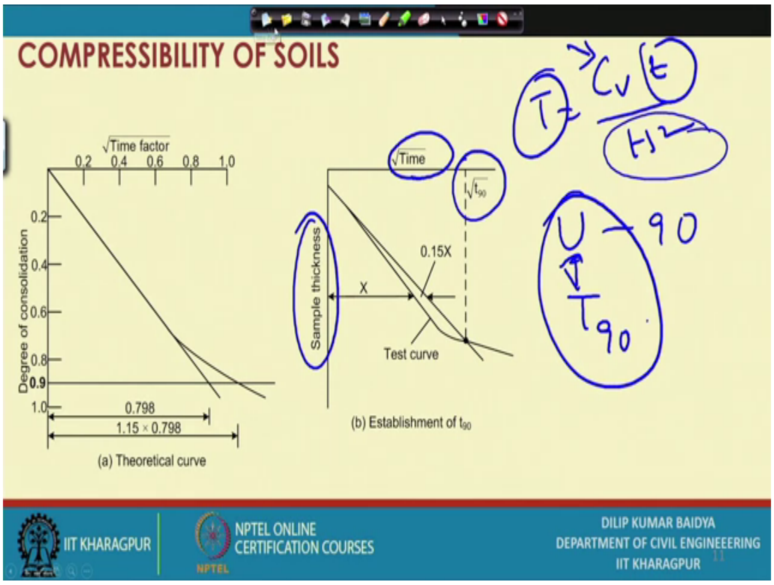
So, time factors corresponding to 90 percent degree of consolidation is 0.48, if you go back to the chart you will see that, when U is 90, then T equal to 0.48 or you can use second equation that T equal to 1.781 or something minus 0.933 log 10 base 100 minus U. If you use this equation also in this equation U equal to 90 percent, then T will become 0.48. So, you can be express the 90 percent.

Since you have used 90 percent correspond t corresponding to 90 percent degree of consolidation. So, this is t 90 is 0.48 H square C v and this is t 90. So, t 90 can be read from the graph. So, C v can be obtained from this. So, this is the one way that is called root time method.

So, determination of C v value from the consolidation test there are number of methods are there this is called to root time method this is called root time method ; that means, I can show you the previous slide this is actually you can consider.

This is as a laboratory data and this side is square root of time and this side is a sample thickness.

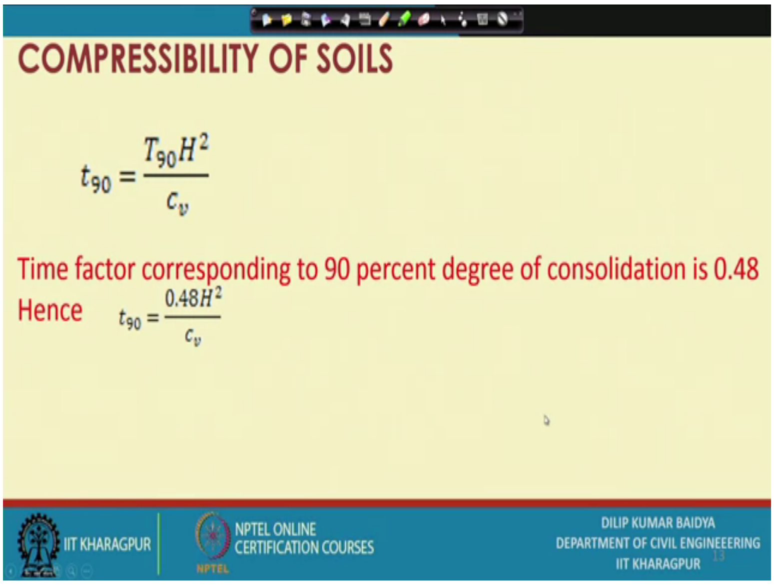
(Refer Slide Time: 31:57)



So, from here actually from this plot we can read. So, we have got intestine. So, T 90 we will get from that test here and U 90, then corresponding T 90 I can get from the relationship between T and U. So, once you get T equal to C v T by H square. So, when you carry out contest H is known T we are getting from here and T you are getting from this relationship. So, only unknown is Cv. So, C v can be determined like this that is by root time method and so, this is one method.

And of course, I will discuss one or two methods again later on. So, this is the way one can find out the Cv.

(Refer Slide Time: 32:49)



And of course, this relationship can be utilize to find out the time consolidation; that means, we know how much you know the sudden total consolidation amount, but if you want to know time required to find out a time required to consolidate 50 percent or 60 percent or 70 percent, then we need to utilize those expression how to utilize that we will see the next class I will stop here.

Thank you.