Ground Improvement
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Lecture – 32
Preconsolidation (contd.)

Hi everyone, let us continue with preconsolidation topic. And in the previous lecture, just we have discussed about the application of vertical drains to consolidate in advance. That means, when there is a fine grain saturated soil and it has to be used and then after construction, then the, we too much of settlement expected but most of the structure has specified settlement, if we cannot allow more than that.

Because of that we need to consolidate before constructing or using that land for the interest or for construction purpose. And that is a preloading is the method and preloading in conjunction with vertical drain. All the preloading also can help to allow certain amount of load is applied on the soil, then over time consolidation will take place and it will consolidation will happen.

But the amount of time required is very long. So, in many constructions, actually after according the land, land and if you plan to construction, plan to construct after consolidation then that project time also is an important thing. Suppose a road to be constructed within one year and if preconsolidation takes two years, then that project is not viable actually. What you have to do? You have to design in such way, that entire project will be completed by one year.

That means, for preconsolidation maybe three months or six months, remaining time for rest of the construction. That is the way to be planned. To accelerate the consolidation process, what we have seen that, we can use vertical drain. And this vertical drain of course, different types of vertical drains will be there. And initially of course, we will discuss about a particular type of drain that is sand drain.

Later on, there are some artificial drains. They are not really drain, it is some sort of material, which can be vertically pushed inside. And that can be used as a drain, the water can come out through that actually. We will discuss that, I will some details later on. For the time being we are discussing that, that vertical drain, the application of vertical drain to accelerate the consolidation.

There actually we have shown that, there is a governing for three-dimensional consolidation. And there are different parameters and in between, there are parameters actually then sand drains, then we spacing. The spacing between the sand drains if a and then each sand drain will have an influence R, then what is the relationship between the influence area, radius of influence and the spacing?

And again, these two are different when you are using in square pattern or in a triangular pattern that much we have shown. Now, we are trying to, we are not going to detail mathematical solution, but what solution is given for three-dimension consolidation, and how to use it to solve this sand drain problem, we will discuss that.

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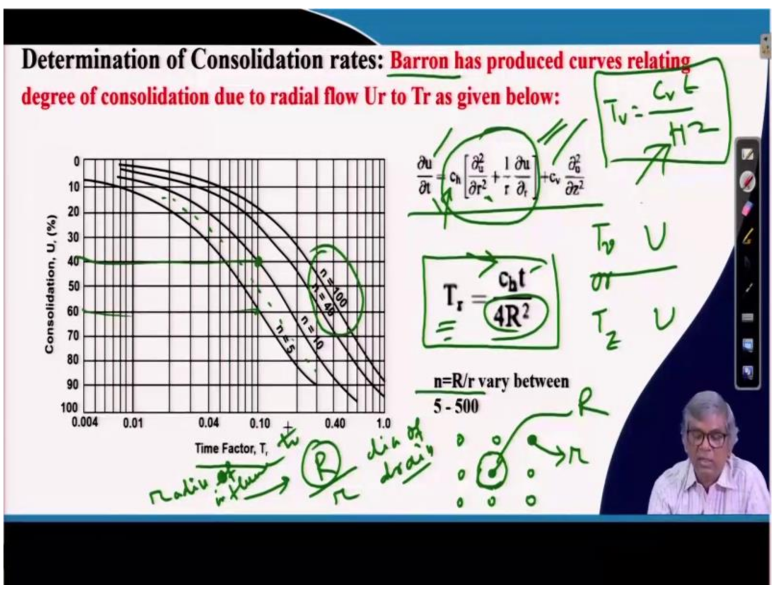

let me come to this one. This is the one we have, we have shown before. This is the equation you can see; the time and you use the pore pressure. And you can see that the other thing C_v is there, coefficient of consolidation, z is there, the direction and r is the radial direction. C_h is the coefficient of pressure horizontal direction. And C_v is the coefficient of consolidation in vertical direction.

$$T = \frac{C_v t}{H^2}$$

Three-dimensional consolidation equation is

$$\frac{\partial u}{\partial t} = c_h \left[\frac{\partial_u^{\ 2}}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} \right] + c_v \frac{\partial_u^{\ 2}}{\partial z^2}$$

$$T = \frac{C_v t}{H^2}$$

$$T_r = \frac{C_h t}{4R^2}$$

$n = R/r$ vary between 5-500

And you can see, this one if it is a one-dimensional consolidation, this part was not there. Only this, this equal to this. And that solution we have already in, shown in the soil mechanics. Similarly in the advance soil mechanics, we will get the solution of this equation, I am not coming to this. Finally, what happens that this different people, that is called Barron most likely. They have Barron actually name is given here.

They have solved the, he has solved this and finally, similar to the vertical consolidation then there is a chart T versus U like in the normal consolidation, one dimensional consolidation. We have a chart T versus U. So, that T_V, T can be written as T_V or T_Z versus U. Similar to that, this Barron actually this problem, this problem is solved has presented an equation of a chart, that is actually Tr, radial degree of consolidation Tr time factor, radial time factor T_r versus U.

And this is again, is given for three or four different the n value. And you can see that, n equal to 5, 10, 40, or 100. And in between of course, you can interpolate. And n is nothing but what? R by r, what is R by r? N is R by r, what is small r? what is capital R? So, that means, if I have a sand drain like this, sand drain like this, sand drain like this, then this sand drain will have influence area, so, this much.

So, radius of from here to here that is actually capital R and radius of each sand drain is the small r. So, capital R by small r that means influence area, radius of influence. That means radius of influence to that diameter of drain, to dia of drain, so this ratio. Now, these ratio actually can be a bigger number, because we have mentioned that already that 1.5 meter to 4.5 meter is the spacing of the, of the drain.

And, and then your diameter of the sand drain is only 300 to 600millimeter. Obviously, the ratio will be always greater than 1, it will require generally a large number. So, that's why it is given, starting from 5, 10, 40, 100. Generally, these numbers are never be used, 5, 10, most of the design.

Of course, it will be used maybe somewhere in other design, but sand drain design, generally these two curves actually are in between will be useful, that I will show you. And like your Tv I, already we have an equation T_v equal to C_v t over H square that was the equation. And here similar to these, you have Tr, that is time factor in the radial direction, radial drains, C_h t by 4R square. Because the distance is 2R.

Because of that, it is taken 4R. The drain distance actually, the diameter actually it would have been D square. D actually equal to 2R. Because of this 2R squared, it is become 4R square. This is a formula to be used, that for T_r calculation and this is the formula to be used for vertical drain calculations, a vertical type factor calculation.

But again, this H is again it can be of thickness of the layer or it can be half the thickness of the layer. When one side drain is there, that when bottom is impervious, the only drainage is there on the top. In that situation, you have to consider the entire thickness as H whereas, if there is a below the comprehensible layer, if there is a gravel or something where draining is possible. And at the top also draining is possible, in that case that H will become half the thickness of the layer.

That of course perhaps you all learn in the soil mechanics quite well. I need not repeat that. This is the equation to find out time factor for vertical drainage. And this is the equation for time factor for horizontal drainage. In that case actually c H is the coefficient of consolidation in the horizontal direction or radial direction, T is the time and R is the radius of influence of particular drain, vertical drain.

That is what already we have calculated, if you know the spacing, from there, I can find out the radius in terms of spacing. Those things to be used. That means, for example, if you find that T_r equal to 0.1 and n equal to 5 and then I can find out what is the degree of consolidation, 60 percent. Similarly, if I say your time factor T_r is 1 and n equal to 10, then what is the degree of consolidation, it is 40 percent.

Like that I can find out from this chart. And if it is in between supposed, 7 or 8, I can imagine a parallel line between that proportionally. And from there I can project. This is the way we have to do the design using this chart. Let me go to the next.

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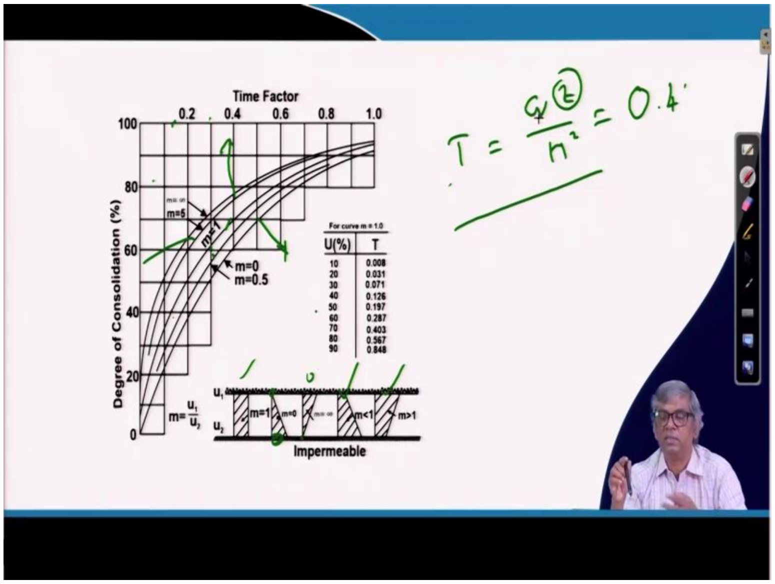

And here actually you can see, that this is the solution for radial drainage. And this is the solution for vertical drainage. This is, I have not, this one I have not shown because this is done in soil mechanics. Only thing actually here actually there are too many curves, but all may not be useful. You can see here, that when there is a load is applied, pore pressure within the soil can be assumed uniform.

And if it is uniform, u1 u2 ratio is 1. Then actually you can see in the middle curve that is the important curve which will be used by us. And there may be different field condition, where immediately after loading the pore pressure will be 0 here. But pore pressure will be quite high here. In that case, ratio will be u1, u1 by u2 0 by 1 or something, it will be 0. So, you can see for, for corresponding to that, this this curve will be this.

And suppose somewhere, there is a load applied here. Then immediately pore pressure will be significantly high. But if you go deeper and deeper, where pore pressure maybe negligible and have a 0. So, u1 by u2, that means some value divided by 0 that means n infinity. And you can see for infinity m equal in, this is the curve. M equal to infinity to this one, 0 this one and middle is the 1.

And there can be in between, some variation, the surface, close to the sharpest or loading area U is small, but at actual bottom U is quite large. And in that case, ratio become less than 1. Here actually that is the curve and if that situation were, the close to the surface pore pressure immediately after low application, there pressure will be more. And if you go deeper, it will be less actually. That means u_1 by u_2, the ratio will be greater than 1.

In that case, you can see 5, m equal to 5. There is a curve here, this is the 15. There are five different types of fills situation can be there. But, soil mechanics mostly we do for uniform pressure. If the load is applied, we assume that throughout the clay layer or foil layer, the pore pressure development is uniform. And if it is uniform, that means m equal to 1 and the, if this m equal to 1. Then you can use the central curve, that middle one.

And this is the curve, can we use for time factor and configure, degree of, if the degree of consolidation is required, 40 percent. Suppose, this is a 40 percent, then what is the time factor? Time factor is around 15 percent, if the degree of consolidate is 60 percent, time factor is required almost like 30 percent. And time factor T_v, equal to C_v t over H square, I know.

And it is, this value is known suppose 0.4 or 0.5 or something, from here I can find out the time required. That is the way we generally solve the problem in soil mechanics. Similar to that, based on that u, we can find out how much u to be achieved? 90 percent, 80 percent, 70 percent then corresponding to u, corresponding to that u what is the time factor required we can find out.

And time factor equation can be here in terms of C_v t and s and that can be obtained and from here I can find out the time. It is already you know, in the soil, from the soil mechanics. This is about vertical drainage vertical consolidation equation, this also to be used together when you will be trying to find out sand drainage problem or vertical drain problem. How it will be done that step I will explain here, maybe next slide let me explain to you.

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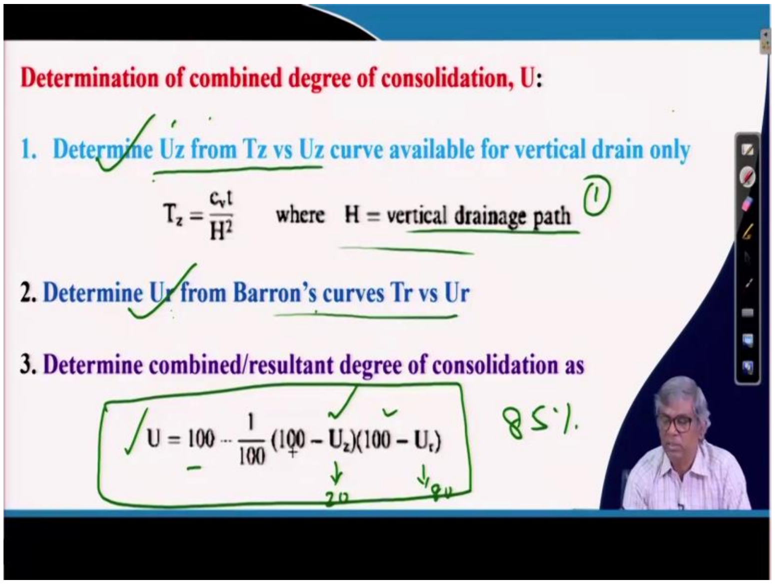

You can see here, for finding out the consolidation problem, in with radial drainage, at any time how to find out the Tv of consolidation you can see here, that step one that determine U_z from T_z versus U_z. Determine U_z versus T_z. So, how much a settlement actually required or how much, how much settlement, total settlement will be there, how much do we achieve? From there you will be getting U, and from U, and U_z versus T_z curve you can find out T_z.

1.Determine U_Z from T_Z vs U_Z curve available for vertical drain only

$T_z = \frac{C_v t}{H^2}$ Where H=vertical drainage path

2.Determine U_r from Barron's Curve T_r *vs* U_r

3.Determine combined/resultant degree of consolidation as

$$U = 100 - \frac{1}{100}(100 - U_Z)(100 - U_r)$$

So, Tz will be these, where H equal to vertical drainage path. This can first part you can do. And first of all, in some problem you can first find out, whether at all sand drainage is required? If I apply certain amount of vertex, whether it is possible or not that to be checked. By this way, if I see that degree of consolidation you know these values and based on that you find out T, from the T you can find out U and that U is less than desired U, then that means with that without vertical drain that cannot be done.

If you use a vertical drain, next is that you determine Ur from Barron's curve or Tr versus U. you know the degree of consolidation required. And then from here, you can find out Tr and from Tr actually you can find out Ur. And finally, you can find out U from where? Finally, U from here and then combine U will be 100 minus 1 by 100, 100 minus Uz multiplied by 100 minus Ur.

U_z means this maybe 20 percent, this may be 80 percent and then finally, if you combine them, it may come something like 85 percent or something like that. This is the final equation that is when you use sand grain, that time also vertical consolidation will be there, with respect to vertical consolidation, what is the degree of consolidation?

U_z, and then when you apply sand drain, then you can find out what is the degree of consolidation, radial consolidation. The U_r usually you know, then by using this equation you can find out the combined degree of consolidation U, we can say. This is the procedure actually. Now, I can take one problem to explain this one.

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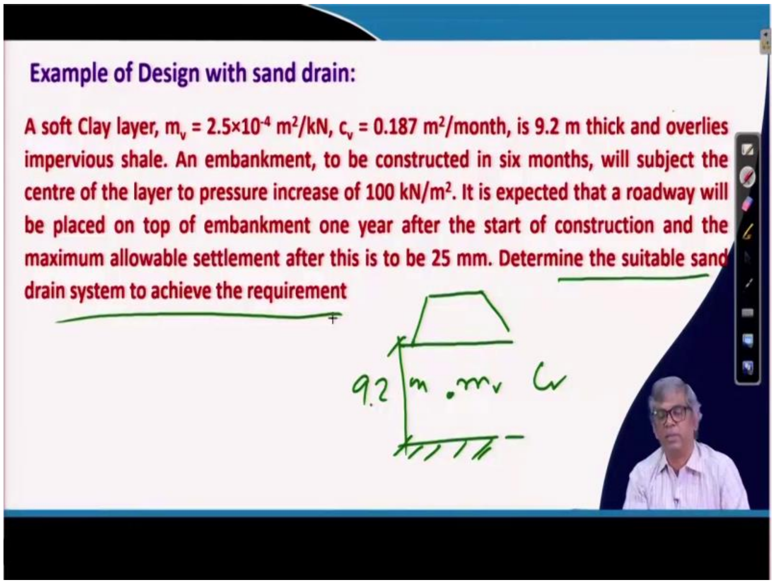

You can see that, this is the one. A soft clay layer which is having mv equal to 2.5 into 10 to the power minus 4meter square per kilonewton and C_v equal to 0.87meter square per month, this is actually two soil parameters are given. And that is clearly, its thickness is 9.2 meter thick. And overlies impervious shale, impervious shale. That means one direction drain.

So, the suppose if there is a clay layer is this, this one here there is an impervious layer. And this thickness is 9.2 meter. And its value is mv is also given, Cv also is given, and these two parameters are there. And an embankment to be constructed in six months will subject the center of the layer to pressure increase of 100 kilo newton per meter square. You have to make an embankment over that, by which it will give a pressure increase of about 100 kilonewton per meter square.

It is expected that a roadway will be placed on top of the embankment one year after the start of the construction. And the maximum allowable settlement, after these is to be 25 millimeters. That means after doing this construction, after making the embankment, it will be kept one year. And then after one year, you can apply the actual pavement and that pavement after construction can go, undergo or settlement maximum of 25 millimeters.

That means after finished embankment, you can select, settle only 25millimeter. If we more than that, then there will be danger, so that is the requirement. The maximum allowable settlement after this is 25. To determine the suitable sand grain system to do this achieve the requirement. So, this problem we will try to do, let me create one page.

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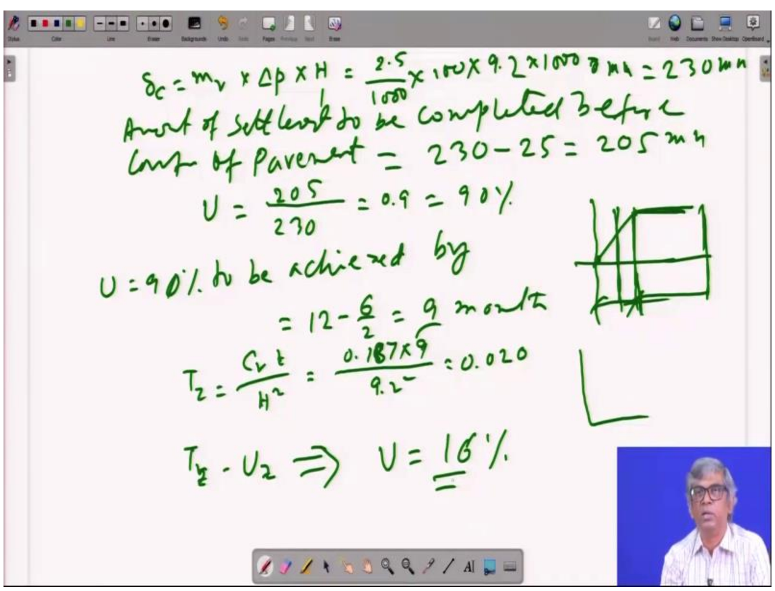

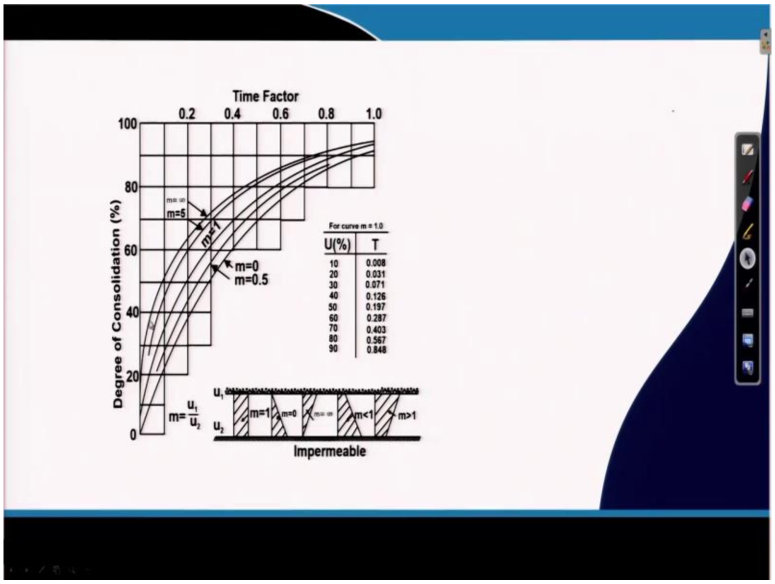

So, so, you can see the, from the theory we have seen delta c equal to what? Mv multiplied by delta p multiplied by H. So, these values are known. So, mv value actually is given 2.5 multiplied by 10 to the minus 4. So, divide by this one, multiplied by delta p is 100 kilonewton per meter square. And your thickness of the layer is 9.2 since it is one direction.

$$\delta_c = m_v \times \Delta p \times H = \frac{2.5}{1000} \times 100 \times 9.2 \times 1000 = 230mm$$

$$Amount\ of\ settlement\ to\ be\ completed\ beforeconstructioonofpavement = 230 - 25 = 205mm$$

$$U = \frac{205}{230} = 0.9 = 90\%$$

$$U = 90\% to\ be\ acheived\ by$$

$$= 12 - \frac{6}{2} = 9months$$

$$T_Z = \frac{C_V t}{H^2} = \frac{0.187 \times 9}{9.2^2} = 0.020$$

$$T_z - U_Z\ \ U = 16\%$$

So, directly I can take full thickness and since it is in millimeter, so, I can multiply it by 1000, which I will get, I will get in millimeter. So, if I put this one, then it will be coming 230 millimeter total. So, that means, that whatever arrangement is there in the embankment, total expected settlements 230 millimeter.

And that means, so, the so before cross section the amount of settlement to be completed before pavement, before construction of pavement will be how much? We know, we have seen that after pavement construction, it can settle only 25 millimeters. You have already 230 total minus 25, it will be 205millimeter.

So, 205millimeter settlement is has to be completed before pavement construction. So, from here I can find out U equal to 205 is the settlement to be completed and actual, actual 230 feet gives you around 0.9 or it is 90 percent. And so, the cost embankment construction will be there over a six months period.

So, we can assume that settlement will start, suppose, as I have shown you that diagram, the loading time loading time to these, these loading it takes about six months. I can take, neither can I take starting of settlement these, nor I can take the starting of settlement these. I can take in between, so from the three months time. So, I can take the settlement time taking place from three months. So, time to so, ultimately your time that means U equal to 90 percent to be achieved, to be achieved by what time?

Actually, you will be keeping one month, we will actually be leaving, and so twelve months minus 6 by 2, that is nine months. After one year it will be constructed. Six months is a construction, that means I could have taken six months loading. But if I take that will what design actually. What I have taken, so here actually with this loading six months will be there. This is six months, and this is also six months.

Instead of taking only this six-month loading, I am taking six months plus this three, nine-month loading. So, that means, T become nine months. Now if I look at your, if I go back to our T vs Cv, now I can find out Tz equal to Cv t over H square. And this gives you 0.187 multiplied by 9, 9 sorry 9 months divided by H square, actually 9.2 square. So, it gives you 0.020, 0.20 is actually Tz. Now, I can Tz versus U curve if I refer, I can refer actually Tz versus U curve.

You can see, T_z versus U curve actually if it is T equal to 0.2. So, 0.02 somewhere here and if you put over this, if you put over these, if you put over these it comes actually 16 percent. So, that means from your, So, that means you T_z, versus U_z curve from there you get U equal to only 16 percent, Tz versus U only 16 percent.

That means, by nine months time, only if you do not provide a new vertical drain, only degree of consolidation will be 16 percent. That means, whereas you have to achieve 90 percent. So, that means, the only preloading will not work. You have to provide sand drain.

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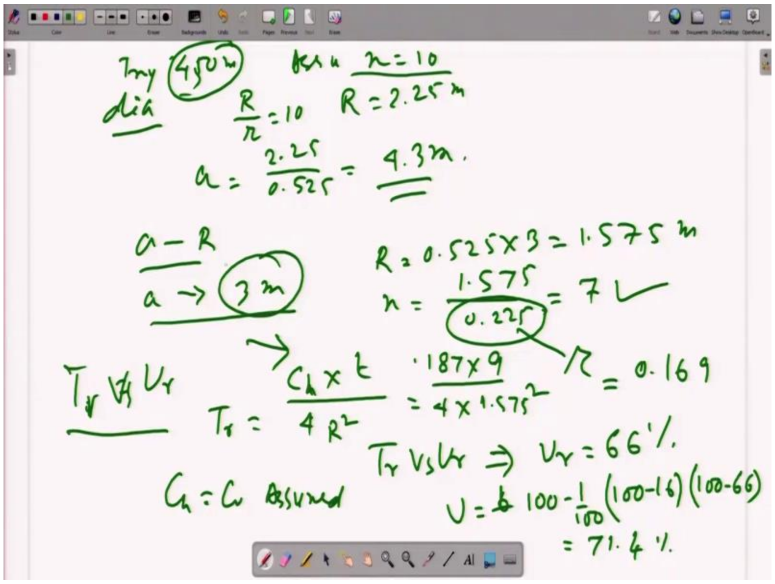

To provide sand drain, so to provide sand drain actually, we try with 430millimeter sand drain. And assume, assume initially n equal to 10, then your R by r, R by r equal to 10 from there actually R become 2.25 meter. And a become a become 2.25 divided by 0.525 become a R, a and R there is a relationship from there I am getting this. This gives you around 4.3 meter.

If I use n equal to 10, then n 450, that this, it is coming, like this. But instead of that, let me try with grid spacing of 3 meter and triangular spacing I will assume, a choose actually 3meter. And if I assume a equal to 3 meter then R become, R become 0.525, 0.525 multiplied by 3 it become 1.575 meter. And your n become 1.575 divided by 0.225. So, this gives you, because I have, this is how it has come?

I have a diameter of drain, try dia of drain 450. D is 450, so, this is r, that is small r is 250, 225. So, it gives you 7, now if you go back to Tr verses, Tr verses Ur curve from there actually, we have n equal to 7. And next thing we can find out Tr, next part we can by Ch, Ch multiplied by t divided by 4R square. And if I put all those things Ch value separately is not given. So, I assume Ch equal to Cv.

So, Ch is equal to Cv is assumed. In that case, point 187 multiplied by 9 divided by 4 multiplied by 1.575 square. So, this gives you a value 0.169. And if, if you have these Tr equal to 0.169 and so from Tr versus Ur curve does gives you, Ur equal to gives you 66 percent, Ur gives you 66 percent. And then combined U can be calculated, 100 minus 1 by 100, then 100 minus U, U was, Uz was 16 multiple 100 minus this is 66.

$$
\begin{aligned}
&Assume\ \mathrm{r} = 10\\
&R = 2.25m\\
&\frac{R}{r} = 10\\
&a = \frac{2.25}{0.525} = 4.3m\\
&a \rightarrow 3m\\
&R = 0.525 \times 3 = 1.575m\\
&r = \frac{1.575}{0.225} = 7\\
&T_r = \frac{C_h t}{4R^2} = \frac{187 \times 9}{4 \times 1.575^2} = 0.169\\
&C_h = C_v\ assumed\ T_r\ vs\ \mathrm{U}_r \Rightarrow \mathrm{U}_r = 66\%\\
&U = 100 - \frac{1}{100}\left(100-16\right)\left(100-66\right) = 71.4\%
\end{aligned}
$$

These value if you calculate, then it will give you 71.4 percent. U become 71.4 percent. But you have to achieve actually 90 percent that means this design is not enough. We can think of another alternative, that means try with a a equal to 2.25. Initially here actually we have assumed these become 4.3. But we have started a with 3.3 meter, spacing we have assumed 3meter.

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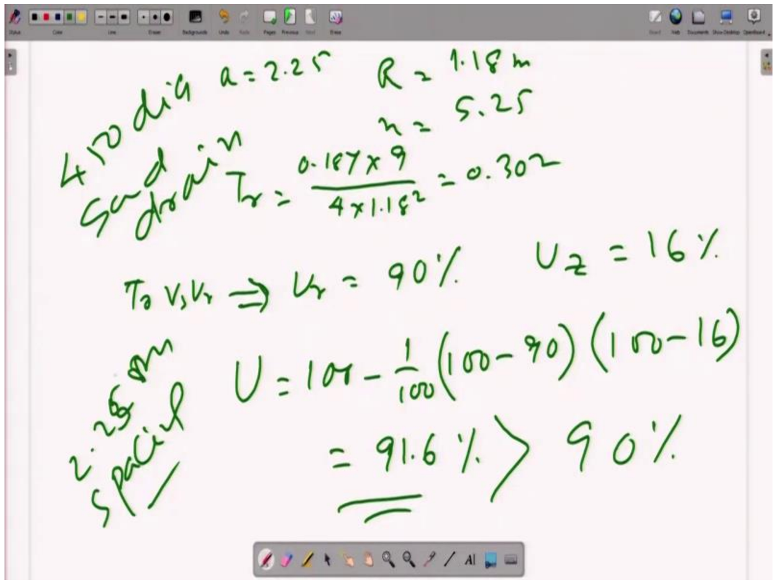

And now, we can assume a, we call 2.25. So, now we can assume equal to 2.25. And then R become 1.18 meter and then n become 5.25, and then you can, T_r actually, T_r equal to C_h, actually 0.187 multiplied by 9 divided by 4 multiplied by 1.18 squared. This gives you 0.302. Now, T_r verses U_r curve, that gives you, U_r equal to this Ur gives you, if I go back, it will be around 90 percent, U_r become 90 percent, U_z is 60 percent, 16 percent already done.

So, U actually 100 minus 1 by 100 100 minus 90 100 minus 16 and this one if you calculate and then you will see the value will come 91.6 percent and which is greater than 90 percent, which is required to be achieved. So, that means, this design is, that means, with a spacing with 450 millimeter dia. sand drain and 2.25 5 meter spacing, it gives you a 91.5, 91 point, 91.6 percent U over a after one year.

$$a = 2.25 \text{ R=1.18m}$$

$$\text{r=5.25}$$

$$\text{T}_r = \frac{0.187 \times 9}{4 \times 1.18^2} = 0.302$$

$$T_r \ vs \ U_r = 90\% \ U_z = 16\%$$

$$U = 100 - \frac{1}{100}(100-90)(100-16) = 91.6\% > 90\%$$

This design can be kept, still if you want to improve little you can try with, instead of 2.25 you can, 2 meter you can try and see how it is coming, still if it is 90 percent then you can adopt this

a. These are the by and large, what I wanted to show, that steps in calculation of degree of consolidate, consolidation when both radial drainage and your vertical drain both are taking place together, then how to find out U which is targeted actually.

And that target has to be satisfied. So, with this actually perhaps I can stop today. This solution also I kept at the end, also I have kept it. If you while solving I have explained how we are doing. Otherwise, entire solution also in the scan at the end, it is added. We can both we can go through for, it will be easy to understand, I hope.

Now I will take some more things, different types of drain and then when you will provide the drain, there is some damage in between. Because of that permeability will not be the actual permeability. All those things are there. I will try to take some more aspect of preconsolidation in the next class. Thank you.