Ground Improvement
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Lecture – 33
Preconsolidation (contd.)

Hi everyone, we are in preloading chapters. And perhaps I have taken already two lectures. Today is the third lecture, and the last class perhaps I have shown that through the problem, particularly when a compressible layer is there and for that if, within a time period if you want to achieve certain degree of consolidation whether without drain, vertical drain is possible or not, if not possible then how to design sand drain, that we have discussed.

And through one problem and all steps perhaps I have shown and again, once you, almost similar concept and similar steps will be used. But, to you stop making sand drain, sometime to make the process of installation faster, nowadays, there is another type of vertical drains are available, which is available in the, in the form of strip.

And in the role, it is available and it can be just pushed into the soil. And that will, this will have satisfied some criteria. And based on that, it will be used as a vertical drain. And that is quite popularly used nowadays. And about that actually I will, certain aspect of that PVD that means pre-fabricated, vertical drain.

That is actually pre-fabricated, that means available. And that can be taken in the site and then rig and through that it can be pushed in the ground. And if surcharge is required after pushing the ground, surcharge will be applied. And then through that, water can come out. So, that is and once water comes out then consolidation will happen. That today's topic because of that is with PVD.

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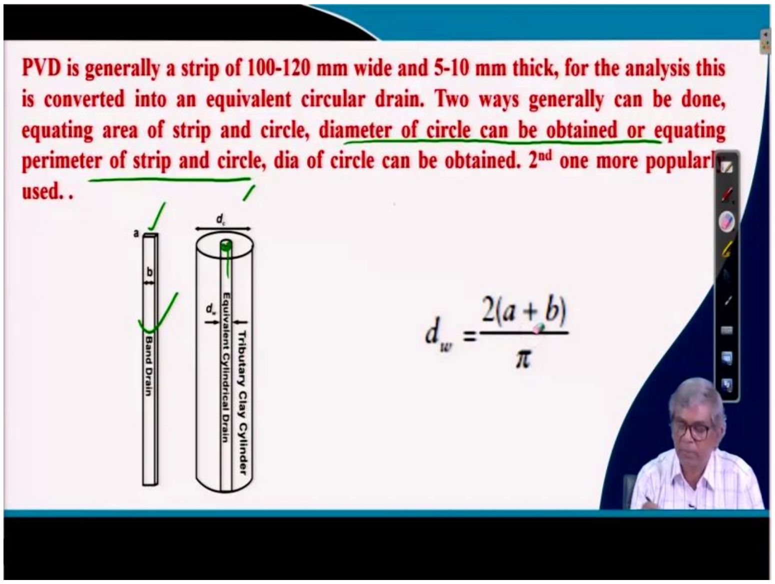

And let me go to the, so PVD, what is PVD actually? PVD is actually, is a strip and it is generally 100millimeter to 120millimeter wider, wide and your and about 5 to 10millimeter thickness. And for the analysis purpose generally, if you have. So, if you have this one, this is the strip suppose and it will have dimension a, b and it will have thickness. So, a is the thickness, b is the width.

$$d_w = \frac{2(a+b)}{\pi}$$

And then if I push inside the ground suppose, this is a PVD location, this is a PVD location. This PVD as sand drain also it will have, area of influence. Like that, through one PVD that another PVD will be going like this, another PVD will be going like this. Area also that is why, because water will be entering to that in all directions. Because of that circular entrance area, we can imagine.

That circular entrance area, so de, what is the equivalent? Actually, we are using strip, but you have to assume that it is a cylindrical vertical drain. If I think or if I consider this as an equivalent circular, then how to find out the equivalent? They are actually, concept used the equivalent perimeter. What about perimeter for these and in this a circle of d_c, if I consider and then what is the perimeter?

These two perimeters to be equated. Sometimes we consider area equations some, some calculus, some application. We, for making equivalent we consider the area. But here actually, it is seen that perimeter equivalence will be the better one. And that is the one suggested. And you can see, pi times d_w is the, the area and pi d is the perimeter of this one and of course dw or here actually dc is written.

It is d_w we can say, well are, and then this will be equal to, and this perimeter of these twice a plus b. From here I can find out. And this will be used in future, which I will be showing one by one. There are actually two ways generally can be done, equating area of strip a circle, another one way. And another way is, diameter of circle can be obtained or equating the perimeter of the strip. And as I have mentioned already, this is the method generally used.

We will discuss in with respect to that only. This actually the from this strip, from this strip we are getting an equivalent, this dw is correct because this dw is this one, d_w, this is the one. This is also correct sorry, I did mistake. This is correct, that will be not dc, that is d_e, in fact, I will show you later on. This is de and this is d_w, d_w is the diameter of the drain or oil. And, here equivalent how we are getting?

Perimeter of this and perimeter of this one to be equated and from there we are getting. How to get this one? That the perimeter for the circular area, perimeter for the strip equating that we are getting equivalent diameter of the pre-fabricated PVD. By using this one will be used in subsequently, that to be remembered. Let us go to the next slide.

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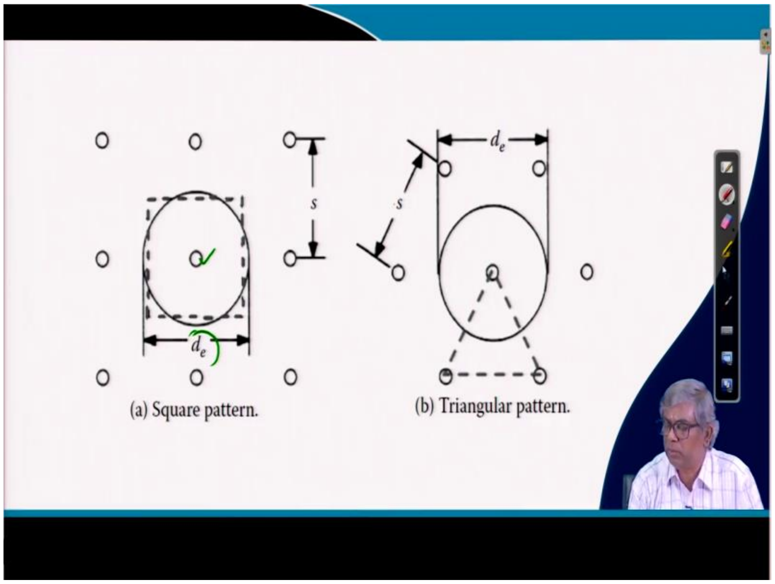

And here actually, already I have done this. Once again, I repeat that this is the PVD and this is the area of influence. And if there is there, then with respect to spacing, if this is the de, equivalent diameter and this is actually diameter of the well and if the square pattern, this is the one. And in the triangular pattern, this is the way actually done. And using these, already I have shown what is the relationship. Same thing, I will show you again in the next one. And that will be, sorry that will be used. Only sometime this notation is changed, otherwise they are same.

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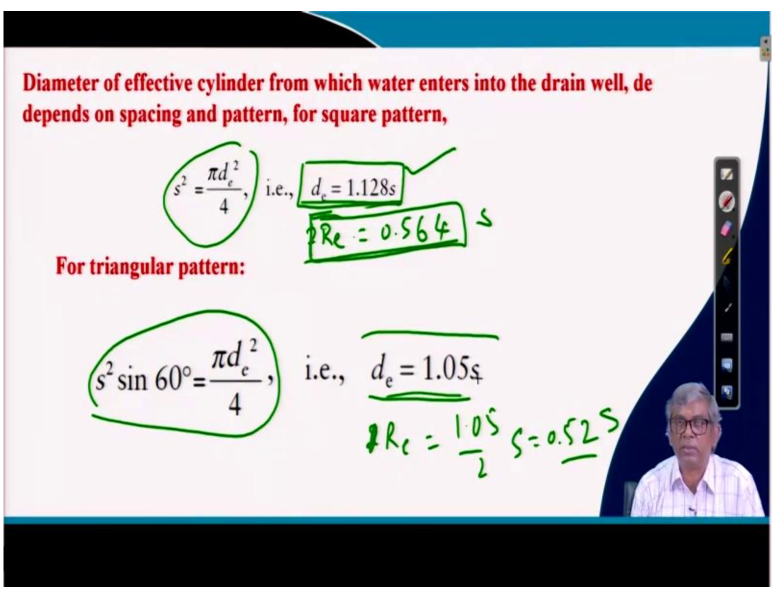

$$S^2 = \frac{\pi d_e{}^2}{4} i.e., d_e = 1.128s$$
$$R_e = 0.564$$
$$For\ triangluar\ pattern:$$
$$S^2 \sin 60^0 = \frac{\pi d_e{}^2}{4} i.e., d_e = 1.05s$$
$$R_e = \frac{1.05}{2}$$
$$S = 0.525$$

You can see that; this area is equated. And from there actually we have got de equal to this, nothing but, de is nothing about twice I can say Re. And so, that means, R_e equal to it will be 0.564. This is the one we have already established, when it is a square pattern, Re equal to 0.564 s. same thing is to if R_e, if you De is mentioned, it is twice of that. So, one pound 2 s, this has to be, if it is a square pattern.

Similarly, when it is a triangular pattern and then we have seen that previous one that, that previous one that your, there will be 12 total number of I have shown that previously, little differently they have done here. One triangle they have considered from here actually, from there actually they have got de equal to this one. Again, if I consider this is actually 2 Re and then actually it will, it will be equal to 1.05 by 2 s, which is already we have done is equal to 0.5, 2, 52 s actually, which I, we have done.

Here actually since we are talking about in terms of de, it is become twice of that. This, relationship we have to remember, de equal to 1.128 is, what is the square pattern. D_e equal to 1.05 s, when it is a triangular product. These two things are required, because some calculation this will be required. Otherwise also one can derive any time. Let me go to the next one.

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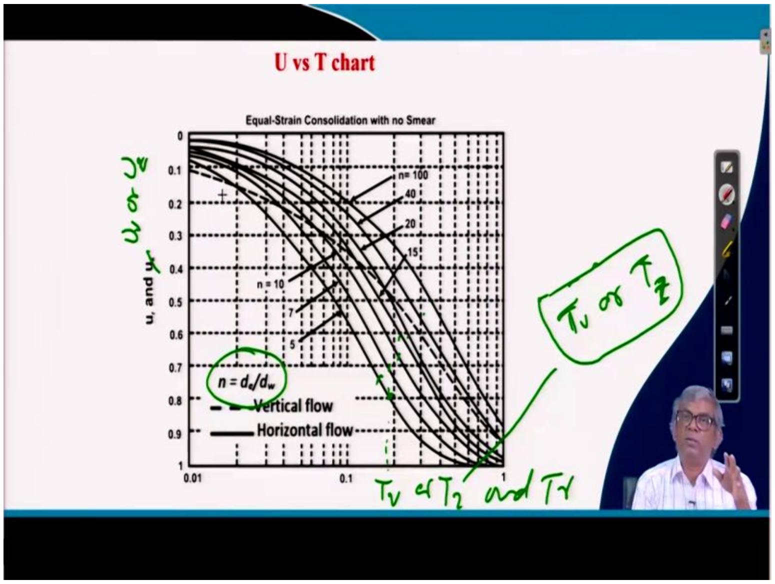

And you can see that already, this is of course, this is instead of Ur, it may be U_v or U_z. And this is Ur, so Ur actually when it is a three-dimensional problem that consolidation problem is solved, then additional parameter will come in. N is the de by dw. And you can see that n equal to de by dw. So, this can be because depending upon your spacing, it can be n can be many, many. So, because of that this chart is prepared. So, n equal to you can see 5 7 10 15 20 40 and 100. So, different values of n this chart is given.

And this x is actually your U versus I think this is T. So, this is T_v or T_z and T_r. So, this one, two, three, four, five, six lines are for Tr. And this dotted line, dotted line, the dotted line is for Tv or T_z. T_v vertical or T_z, z is for vertical direction and v will be vertical. So, the both notations are used. Sometimes you use Tv, sometimes we can use as T_z. So, that means, this, this dotted line actually the T versus U if suppose, U is 90 percent, what is the T?

$$T_v \text{ or } T_z$$

You can read from here, dotted line from here actually. Similarly, if U equal to 80 percent and n equal to suppose 5, then from here actually, you can find out what is the value of T_r. you can find out from here. Like that this chart can be used, used directly, whatever three-dimensional consolidation problem we have shown, equation we have shown, but solution in detail we have not gone for.

But I have mentioned that finally, this solution is having too many mathematical steps, it may take several classes. Instead of that, solution is already obtained and it has been presented in the form of chart, which actually can readily be used in design. This is the chart actually; in this chart it has given U_v or U_z and U_r. U_r actually again is function of n. Because of that one, two, three, four, five, six, seven curves are given, for n equal to 5, 7, 10, 15, 20, 40 and 100.

Whereas, U is independent, that is no n. The U is, U_v or U_z is only curve that is dotted is given. And what, if you know that degree of consolidation to be achieved, suppose 90 80 70 then you can produce on that curve, from there you can read the here, what is the value of time factor. That time factor again can be used for calculation that I will come to the next slide.

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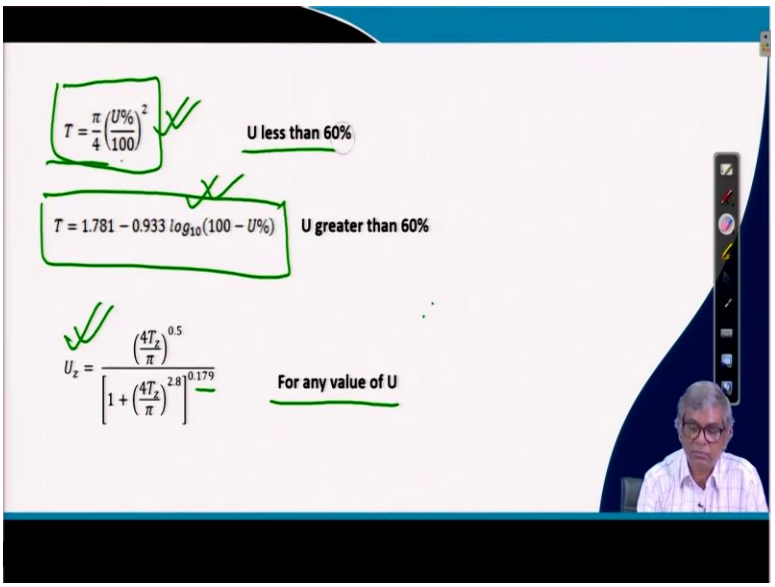
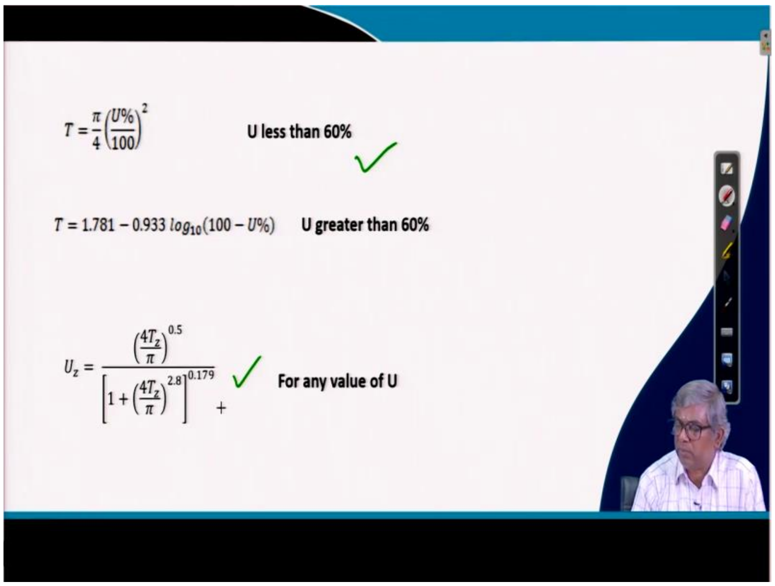


$$T = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 \text{ U less than 60\%}$$

$$T = 1.781 - 0.933\log_{10}\left(100 - U\%\right) \text{ U greater than 60\%}$$

$$U_z = \frac{\left(\frac{4T_z}{\pi}\right)^{0.5}}{\left[1 + \left(\frac{4T_z}{\pi}\right)^{2.8}\right]^{0.179}} \text{ For any value of U}$$



So, here actually you can see in soil mechanics, you might have learned. That though U versus, U versus T, or vertical, one-dimensional consolidation in the form of chart is available, also in the form of table it is available. But in the exam actually neither chart nor table is available. And sometimes it is not given.

$$T = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 \text{ U less than 60\%}$$

$$T = 1.781 - 0.933\log_{10}\left(100 - U\%\right) \text{ U greater than 60\%}$$

$$U_z = \frac{\left(\frac{4T_z}{\pi}\right)^{0.5}}{\left[1 + \left(\frac{4T_z}{\pi}\right)^{2.8}\right]^{0.179}} \text{ For any value of U}$$

You have to either remember or if there is any way to calculate that is better. Because of that, in the soil mechanics, since long these expressions are available, this and this, these two expressions are available T versus U equation, empirical equation and this equation applicable when U is less than 60, less than equal to 60 percent.

And when U become greater than 60 percent, generally these equate. So, the T versus U as given in the form of two empirical equation 1 up to 60 percent U. And another is when the U greater than 60 percent. The two equations can be used, but whereas, now, it is available in another form of equation, empirical equation you can see here.

For any value of U, so U_z, actually that directly is given $4T_z$ by pi 1 plus $4T_z$ pi power, to the power 2.8 and whole to the power 1.0, 0.179. So, but by using this equation, one can directly whether it is 60 percent, 70 percent, 80 percent or 40 percent whatever maybe so, by this equation, one can find out the value of U. Or if you know the value of U, you can find out the T. So, this is one equation, we will prefer to use for this.

Because R, if you are comfortable with two equation, one can, you remember this equation also. Either way, it can be used. The previous page, our previous slide I have shown T versus U that curve. If that is available, one can use it, if that is not available, one can use again, these two equations for two parts or one can use the universal equation this, and they can calculate wherever required T or U when other is, another one is known, next one.

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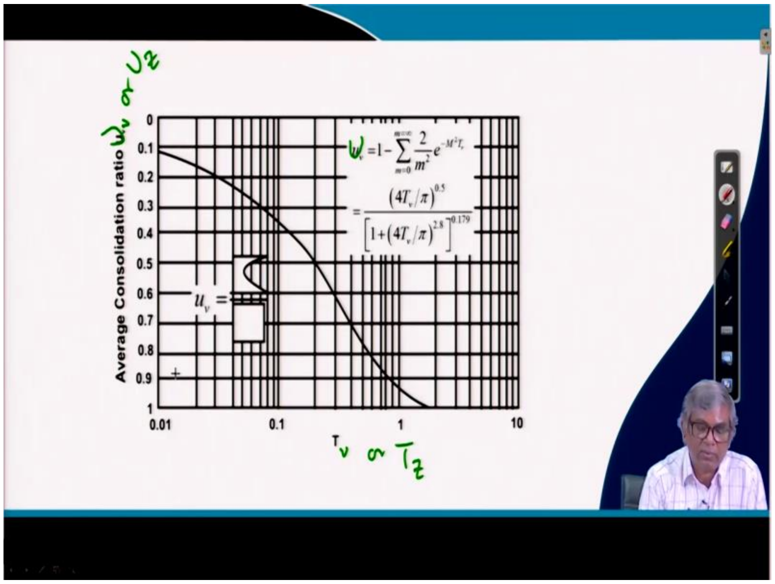

This is the one, same thing is given here, you can see U_v versus T. So, this is basically capital U, this is actually capital U capital U v or U_z both are useful. And this is T_v or T_z, both are useful. And this is actually, this expression equal to this or equal to this. This is capital U. So, this is the way one can find out either by using chart or by this equation.

This equation exactly if you calculate, it will fall in this line. If you use U equal to different values 0.1 put it here, you supposed to get whatever value T is there correspondingly. These two equations already I have discussed. Let me go to the next slide.

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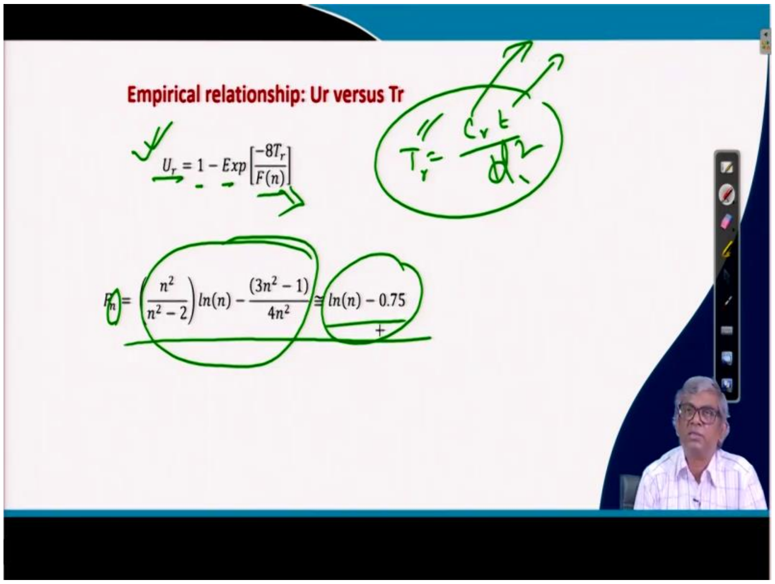

And you can see here, that empirical relationship Ur versus Tr. Though I have shown in the, in the other one curve, where both T_r is there, T_r versus U, U_r is there. And T_v versus U_v is there. So, that you can, from the chart itself we can use it, but in the exam or some other application when chart is available, not available with you then we can use a simple equation. You can see here that empirical U versus T, U_r equal to 1 minus exponential minus 8 T_r by F_n.

This everything T and U, either any one of them will be used. T equal to C_v T or T_r, C_r versus T by H square or d square. This is the equation. Generally, if you know the coefficient of consolidation in radial direction, if you know the time over which that particular degree of consolidation to be achieved. And if you know the diameter, influence the diameter then I can find out T. And if I find out this T, and from there I can find out e, U.

Empirical relationsship: U_r vs T_r

$$U_r = 1 - Exp\left[\frac{-8T_r}{F(n)}\right]$$

$$F_n = \left(\frac{n^2}{n^2-2}\right)\ln(n) - \frac{(3n^2-1)}{4n^2} \cong \ln(n) - 0.75$$

$$T_r = \frac{c_r t}{d^2}$$

So, these again you can see that everything this, these are known, but the only another unknown is introduced here, that is fn. And what is this Fn? This is Fn, Fn is this is the function. And though actual equation is this, but suppose again based on calculation, it is checked for different values of n, if I use this link the equation whatever result we get and if I do this equation, also we are getting same result.

SLn n minus 0.75 by this also one can find out, either can be used this or it can be used by using this. This is a little error will be there, but that error will not cause much problem in actual results. This can be used, without any difficulty and is easy to remember also. So, that means, though we have a chart, in the form of charts T versus U, T_v versus U_z and Tr versus Ur, but also simultaneously we have some empirical equation, which can be used quite easily.

And of course, whether you are using chart or whether you use this equation, everywhere there will be some approximation, there is some error. Actual if you want to find out then you have to go to the mathematical equation and you have to solve and then finally numerically find out the exact value. And finally, it is seen whatever chart is prepared or whatever equation is fitted, they are quite close and whatever difference will be there, that will not much difference in the end result. So, that is why it can be used without any difficulty.

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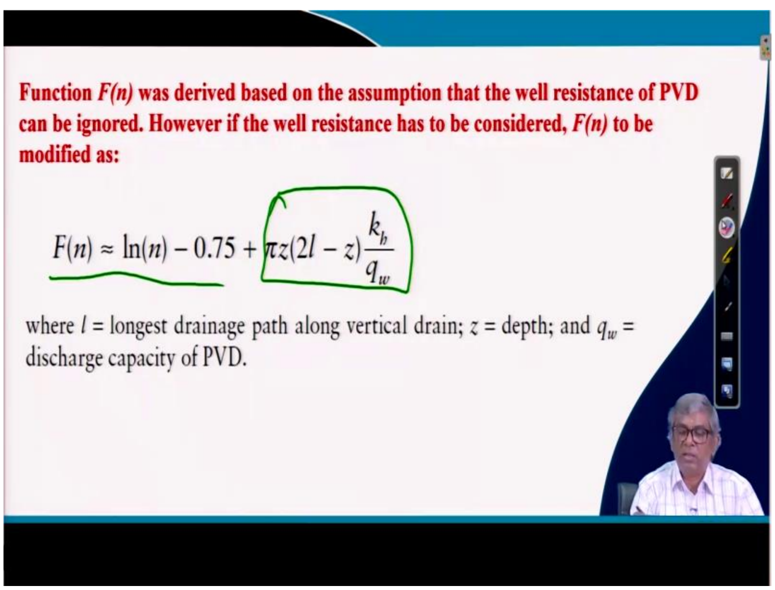

$$F(n) \approx \ln(n) - 0.75 + \pi z(2l - z)\frac{k_h}{q_w}$$

where $l =$ *longest drainage path along vertical drain*; $Z =$ *depth*; *and* $q_w =$ *discharge capacity of PVD*

Now, a function F_n was derived based on the assumption, that the well resistance of PVD can be ignored. Well resistance mean, whenever we do, has either a sand drain or a PVD drain. Then the when water is flowing, that flow is not free. There will be some resistance will be there obviously. So, that resistance is ignored. Considering that, that derivation is done.

And how if the well resistance is considered, then there will be another equation for Fn instead of last line, last page whatever previous slide whatever seen, in addition to that this can be added. Where L is the longest drainage path along vertical drain, z is the depth and q_w is the discharge capacity, capacity of the PVD. So, this is the additional part, but it is seen that if the quantity of flow is large, is a quantity of flow is large, which I will show you in the next slide, then this part this entire part contributes a very small value.

Because of that sometime if you can make sure that seepage quantity is very large, then automatically I can use this equation itself, whatever, whether you have ignored the resistance or not, automatically ignored if the flow is more. Flow is more means resistance is less. That is why it is reflected, it is reflecting in the result also.

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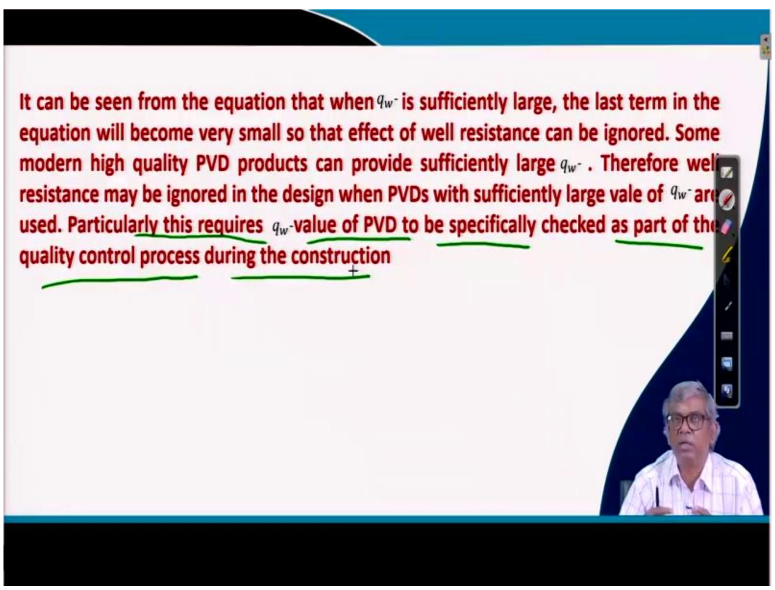

In this equation when q is large, then automatically this explanation is given here you can see that it can be seen from the equation that when q_w is sufficiently large, the last term in the equation will become very small. That the effect of well resistance can be ignored. So, some of, some modern high quality PVD products can provide sufficiently large q_w. Therefore, world resistance may be ignored in the design, when PVDs with sufficiently large value of q_w are used.

Particularly this requires q_w value of PVD to be specifically checked. So, we design a particular, chosen some particular PVD and use those equation where q_w is assumed significantly large. So, because of that in the checking initial check that means, quality control that we check. So, before using you have to check how is the flow in it? Whether, whatever assumption we made, whether it is satisfying or not that to be checked properly.

That is why this you can ignore, that through logic, we can show that in the calculation we can ignore the second part. But if you do that, then you have to make sure that the q_w is really large. For that particular this requires q_w value PVD to be specifically checked as part of the quality control process during the construction.

Before installing the, installing the PVD, one has to check what is the quantity of flow actually is happening? That you can ignore that well resistance and use the simplified equation. Otherwise, of course entire equation can be used there is no issue. But always in the, in the design we try to make the calculation simple, and that is the purpose.

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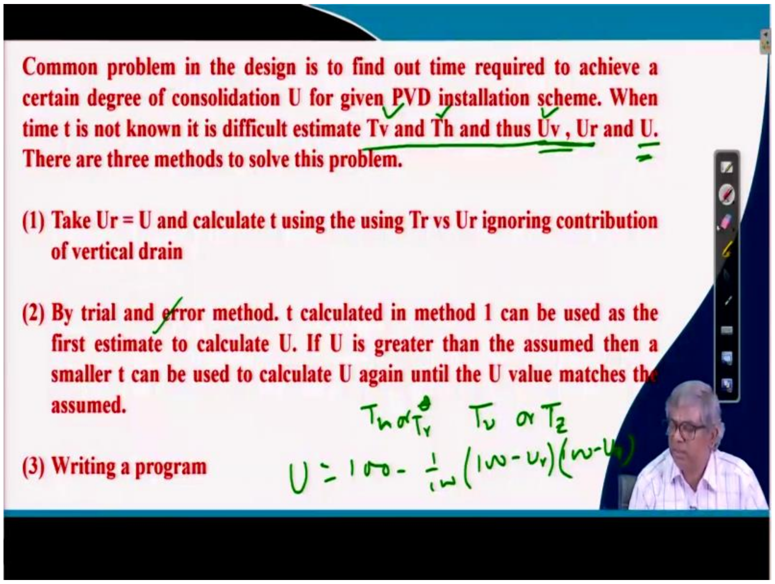

So, now, a common problem in design is to find out time required to achieve a certain degree of consolidate U for a given PVD installation scheme. When time T is not known, it, it is difficult to estimate T_v, T_h and thus U_v. So, already we have shown the equation. You know the Th, you know T_h or, or T_r both are used. And another is T_v or T_z, T_z. If I know then combined U can be obtained that 100 minus 1 by 100 1 by 100 minus Ur and then 100 minus U_z something like that equation we had.

$$T_z \ or \ T_v$$

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

That means, that common problem in the design is to find out time required to achieve a certain degree of consolidate U for a given period installation scheme. When time is to, time T is not known it is difficult to estimate Tv and Th and thus U_v. So, that is what T is not given then these two is difficult to estimate, then this also obviously difficult to estimate, U_v and so but time is not there, then T_v, T_h will not be there.

Then if T_v, Th is not there U_v, U_r will not be there. If U_v, U_r are not there then you difficult to find out U also, that is combined degree of consolidation. So, there are three methods to solve these problems. So, how actually we solve these in the, in the mind practice. So, generally we consider Ur equal to U.

That means, if you see any calculation when PVD is used for draining purpose or pre consolidation purpose, we will see that, that degree of consolidation, contribution from horizontal or radial consolidation is much higher than the U_v or U_z. And U_v or U_z maybe 10 to 15 percent, whereas, it will be sometime 85 to 90 percent. Because of that to get an approximation as shown or take Ur equal to U calculate t.

And calculate T using the Tr versus Ur ignoring contribution of vertical drain. This is that means, you can, U_r equal to U and then you go to the curve T_r versus U_r. And ignore the contribution of vertical drain. This is the one way you can find out the t. Now, by trial and error method, another alternative. This, first alternative that one. Second alternative by trial and error method, T calculated in method one can be used as the first estimate to calculate U. So, this is the one, first method whatever you are getting that can be taken as trial one.

And then based on that, you can that is a time you take and then first trial then you find out U. If U is greater than the assumed, then the smaller t can be used to calculate U again until the U value matches the actual. So, the trial and error but, whatever time you are required and whatever U we are getting that to be matched actually. So, this trial and error, any trial and error problem you know, towards the end it has to converge.

That convergence actually, so, you need you can either you can do this, here also you can assume something else instead of whatever time you are getting, that time as a, as a first trial instead of that something else can be used. But, better to use that one. And then to converge whether you can increase the t or decrease the t, so that you can get the targeted value of U until and um less you are getting that.

You are assuming some t, you are getting U actually 95, but you required, Ur required is 90. Again, it can be changed to degree of consolidation. Generally, suppose, another t you assume, each degree of consolidation 85 percent. But you require 95 percent, then you can change the t, then again calculate and see it is reaching to 90 percent, still not satisfied. Then again change the t, find out what is the value of that then coming suppose, 96 percent that means it is satisfied.

If you want to further to make, make it quite close to 95, we can make another trial. But when it crossed 95 percent, you can consider that is satisfactory design and that 80 can be considered as a time required to reach that much consolidation. And this is the way it can be done. And then, this trial and error calculate, trial and error method of calculation generally will take little time.

And of course, nowadays you have a computer, we can write a simple program and by using that simple program, we can iterate it as many times as possible required. And you can converge really and get the correct value of t. So, this is the way of calculation we generally do.

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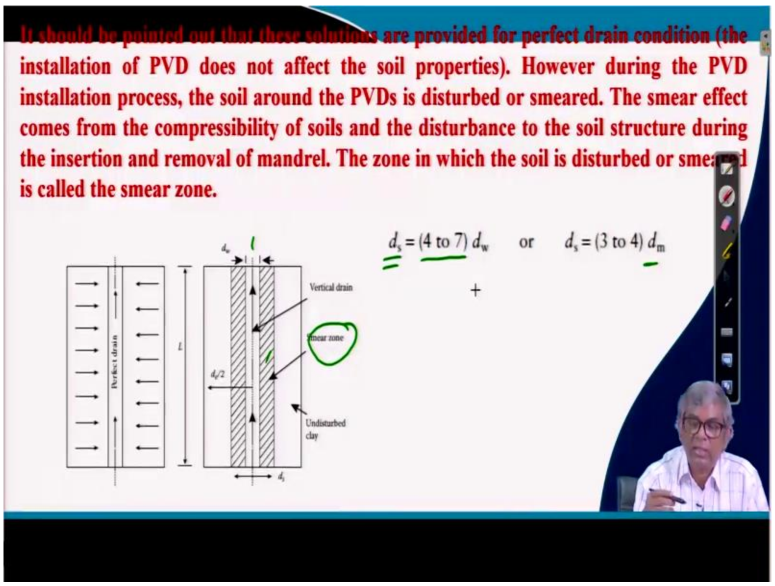

And then there is a smear effect that means, when you dry the PVD, through the soil, then surrounding soil will be disturbed. And that, because of that disturbance whatever permeability we have assumed, Ch or Cr, that is actually highly get affected. So, because of that sometimes and how much area actually you can see here, this is the drain and this is a drain and you can see that this much distance, this, this hatched portion is called smeared zone. And that, d_h is the smear diameter, and it is 4 to 7 times d_w.

$$d_s = (4to7)\, d_w \text{ or } d_s = (3to4)\, d_m$$

So, this is dw and this is 4 to 7 times of dw is the ds. And our, ds equal to 3 to 4 times of dm. Undisturbed plain and all. This is the things are available actually, this can be used. So, that means you should, it is known that, when PVD is installed and water supposed to flow from around direction and enter into the PVD. But during the installation process the soil gets disturbed, that is called smearing effect.

And because of that swearing effect, permeability value change and that change actually how much that is some quantification, some recommendation is there. And that has to be taken, you can see in the next slide, I will show you how it is incorporated.

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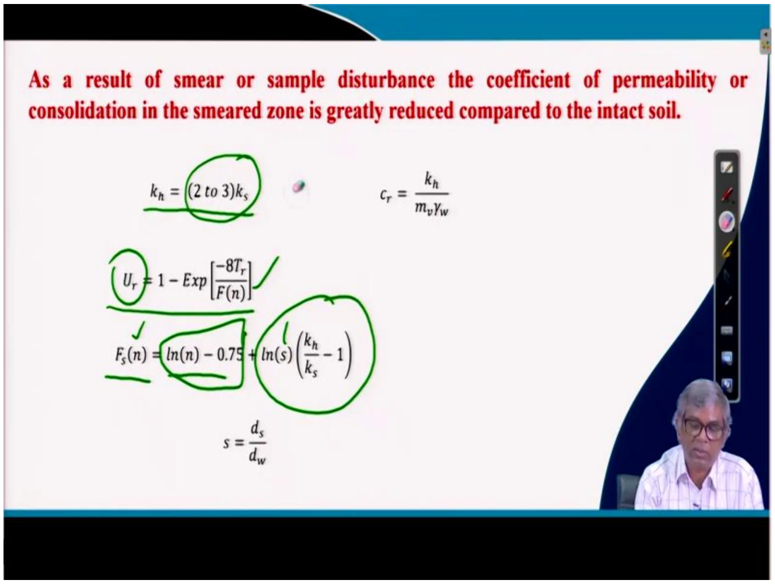

you can see now, here you can see kh is actually or k_r, it is 2 to 3 times of ks. The smeared zone, the k value will be reduced. And then Ur can be calculated, again same equation. But F_{sn} when it is a smear, that k is actually F_{sn}. And that can be calculated when smearing effect is consider, the equation, our equation was previously up to this but additionally, this portion to be added. Ln s multiplied by k_h by k_s minus 1.

Where s equal to ds by dw, and so, from there actually the s is here. That s is ds by dw. So, k_h by k_s, will not be, k_h and k_s supposed to be same. Because of smearing effect, the k_h becoming k_s. How much it is? If it is 3 4 2 4 or more, accordingly this value will change. And accordingly, the function will change. And according to this, U will also change. That has to be taken into consideration that is the effect of smearing zone to be taken into calculation.

$$k_h = (2 to 3) k_s$$

$$U_r = 1 - Exp\left[\frac{-8T_r}{F(n)}\right]$$

$$F(n) = \ln(n) - 0.75 + \ln(s)\left(\frac{k_h}{k_s} - 1\right)$$

$$s = \frac{d_s}{d_w}$$

$$c_r = \frac{k_h}{m_v \gamma_w}$$

And of course, this is actually by a large how we use PVD for calculation of pre consolidation calculation. And of course, while doing this, or as we have mentioned that, we can use graphical chart, we can use empirical equation. And finally at the end, sometime we can do without smearing effect and with smearing effects. Initial part I have mentioned without smearing effect. And final part, towards end, I have shown the smearing zone and how it is affecting the calculation, that also same.

With this actually, the PVD calculation is discussed. I may see now some problem, where I can show that PVD actual calculation, how find out, how to find out depth spacing. And then if I take smearing effect again how it is affecting that also can be shown. With this, I will close here maybe in the next lecture, I will take those problems. Thank you.