Ground Improvement
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Lecture – 35
Preconsolidation (contd.)

Hi, everyone, so let me continue again on the preconsolidation. And already I have given four parts of it. And this is the last and concluding part of reconsolidation. And here are basically some details about PVD. And then the construction steps and what are the parameters soil, parameters etc required and what is the quality control etc has to be done. So, about all those things totally, I will try to spend in this lecture.

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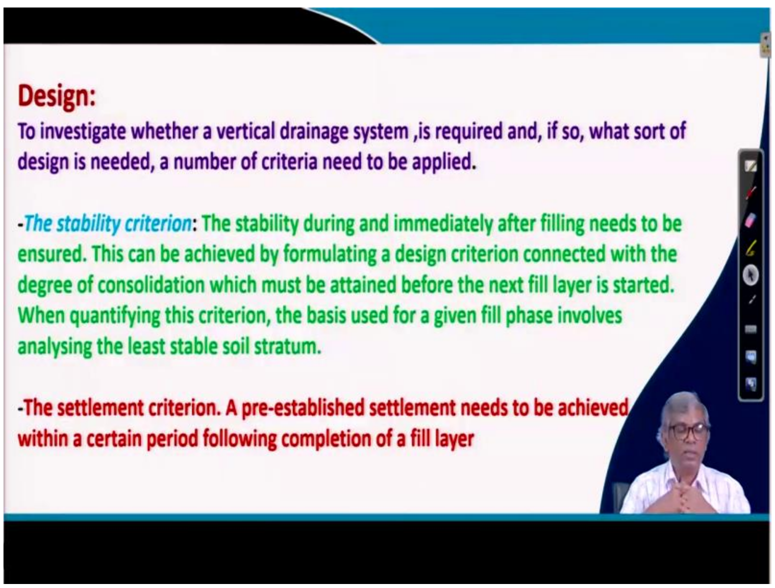

And, let me see first that, when we design a PVD or, or any preconsolidation. What are the steps actually there to investigation, to invest whether a vertical drainage system is required? And if what sort of design needed, a number of criteria need to be applied. This is the one, that means particular soil is known suppose, and you want to make embankment over a period of one year, whether that is sufficient for consolidating the layer or not.

First of all you have to find out whether before construction you have to do consolidation or not, that one. And if you decide, then if you get that information then you have to design properly. And while designing, what are the different criteria to be followed? There are three important criteria is there, one is a stability criteria. Stability criteria means actually, there actually the, in between multiple, multiple stage actually you can put a surcharge.

And in between the, if you put together the whatever surcharge required, then soil may not be able to sustain or it will fail. Because of that, you have to make it stages that to we check. So, here what is actually given? Stability check means, it is a criteria means exactly here, the stability during and immediately after filling needs to be ensured.

This can be achieved by formulating design criteria, connected with the degree of consolidation which must be attained before the next fill layer is started. Suppose I want to targeted a 50 percent consolidation of first level of filling. That has to be, if it is not ensured, then when you make the next level of surcharge, then soil may fail. That is the one that we checked actually. That is the stability check, stability criteria to be verified.

When quantifying this criterion, the base is used for a given fill phase involves analyzing the least stable soil stratum. That is the, the stability means that is the one that we, you have to target and you have to achieve that one. Before going to the second one I will explain through the problem later on. And settlement criteria actually, there are pre established settlements need to be achieved within a certain period following completion of a fill layer.

Settlement criteria that we can calculate settlement, actually there are theories available and then how much after construction, how much before construction, that is known and that has to be satisfied. And because of that, suppose 35 millimeter after construction and before construction you need to total settlement is suppose estimated 100 or 130 or maybe 150 and only 25 years after construction is permitted. That means remaining that 150 minus 25 has to be carried or completed by preconsolidation. That is the one and how to do that, that design has to be done that is actually settlement criteria.

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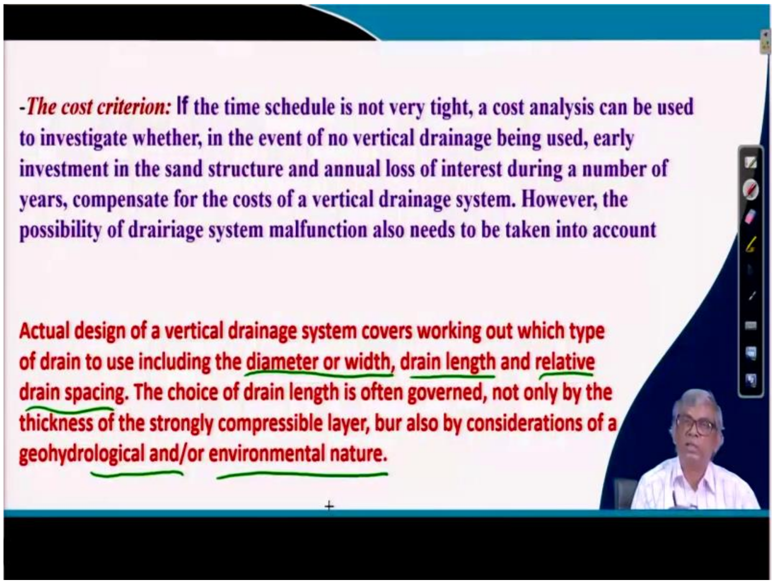

Next one is actually, the cost criteria. This is very important actually. Cost suppose, without doing any vertical drain, maybe it is possible to consolidate in five years time. But if you consider that the five years time in the cost, it may make a huge difference. So, instead of that, you will spend some amount on vertical drain and then finish it in one year and saving four years actually it gives you a lot of advantage.

That is what the cost criteria, whether you at all required vertical drains or not, that actually dictated by the, the cost effect actually. So, that is why the, if the time schedule is not very tight, a cost analysis can be used to investigate whether in the event of no vertical drainage being used. That means, if you do not use then that also satisfactory, there and early investment in the, in the sand structure, an annual loss of interest during a number of years compensates for the cost of a vertical drainage system.

That analysis has to show, you make a vertical drain, finished within one year. Or you wait without vertical drain for five years and that cost has to be included and then you have to see which one is better accordingly, it should be decided. However, the possibility of drainage system malfunctioning also needs to be taken into account. So, that is also another important, that means you have designed a vertical drain.

But suppose it did not work, and then in that case actually use cost involved and finally, you have not got the result. The double cost. Once vertical drain is designed, you make, one has to make sure that it is, it is working. That is also important. This is, these are cost criteria. Cost is very important at the end. It is though at the end we think, we consider, but it is the most guiding factor.

What we have to do finally? It dictates. And actual design actually though there are three criteria, actual design will be actually vertical drainage actually. We will be covering the number of things you can see here, the diameter or width. When it is a sand drain, you have to find out diameter. And if it is a PVD then width is to, has to be designed.

Drain length, actually how long actually you have to do the drains actually depends on mostly the, the thickness of the compressible layer. Sometime any other factor also it can influence. Then relative drain spacing, what spacing we will be using, all those things actually design means, it has to be, do that. There are three criteria to be followed. And in between what you have to do?

You have to adjust this diameter width or drain length and relative spacing etc. The choice of drain length is often governed not only by the thickness of the strongly, that is why as I mentioned already, but also considered, consideration of a geohydrological or environmental nature. These are the things, mostly it is the best on thickness of the compressible layer. Some other factors may be there, that we consider to decide the length. Let me see the next one.

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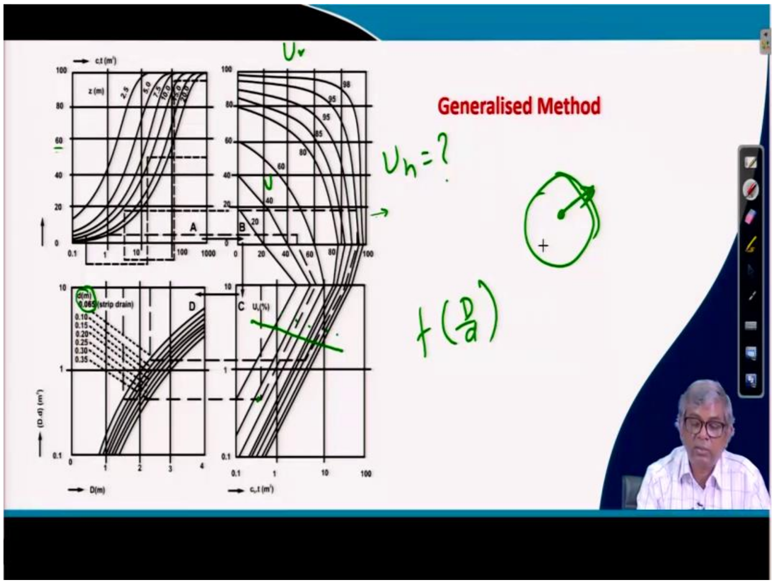

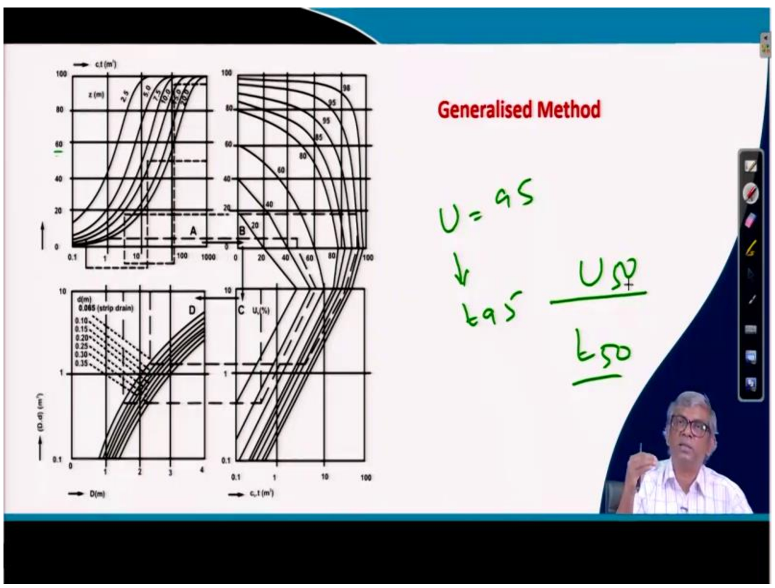

And this is actually, a we have mentioned settlement criteria, we have mentioned that, what is a stability criteria? Stability criteria means, before applying the second level or third level of surcharge, it has to achieve certain design. So, there is a generalized design, here I will explain now, by using these one can find out the, the spacing and other things, that diameter and spacing of the your what is that? Drain and, and simultaneously the stability check also can be done.

This is a very generalized design chart. And this design chart can be used. Here in these some of the things missing. This is U_v and this is U and I will just explain that. And here actually first of all, if there is a particular soil thickness is known and then you know the Cv and if you know the time, so Cv into T, you can calculate. And, and thickness actually, these are actually thickness, z actually is given. Suppose, the 10 meter thickness, so 10 meter.

So, Cv multiplied bt T is some value, and it is 10. So, from here actually you can find out, Uv here actually, this is UV. The degree of, degree of consolidation actually 90 percent. So, here based on soil Cv, and time and thickness whatever U you get and you can see. And if you see that, that U is getting less than the targeted value, that means by normal whatever, if you time, if you fix the time and, and the clay layer is fixed.

And in the, Cv also is fixed, then whatever, based on that calculation, whatever U you are getting, that U is not equal to the targeted value. That means, sand drain will be required. So, this is the first chart, will give you whether the chart is required, drain is required or not. And so, and second chart actually and the, from the first chart you are getting U. And from the second chart, corresponding for that U value and, and for targeted U 90.

So, this is the U value, whatever value you are getting from here. And whatever the targeted value U, of suppose is here, combine U is given here. These two from there actually will get Uh, this is Uh. On this, on this curve, finally, you will get from this chart, you will get Uh, from this chart. So, you know target, you know the targeted U and you are calculating the, without vertical drain, what is the degree of consolidation is vertical direction.

So, Uv and U is known, from there actually from this chart you can get Uh. And from this chart actually, what we can get? First corresponding value of, you can by, you can find out Cv here actually. Ch, Ch T that you can, Ch into T you can find out, that is known value. And also you can, Uh already got, you will get from U from this graph, we will get Uh. So, Uh and T, and from there actually will get a, these are Uh value.

Uh actually this, the different values of Uh. So, Cv T you project on that from here. And then you will get a value, That is actually function D by d. And that actually from there again we can project using fourth chart. Actually again, it is given for different values of, actually D, this is actually, this is actually your f D by d. And f by D by d can be produced two different charts actually 0.3 5.3 0.25 accordingly.

If we choose stiff, then this is decolonize D. Then from there you can find out what is the, diameter, from here actually we are getting the value. And from there actually what is the diameter, actually is required equal in diameter. That means this is actually diameter and this one So, you will get this one. And you, if you get this one from there you can get the spacing also.

So, that is the way it has to be used. I will better, some of the things actually somehow missed. Because of that is difficult to maybe I will be adding correcting in the document later on, here. So, one or two things are missing, so I will correct that one.

And for the time being what I will show you, I will take one example problem from where actually it will be clear, how this chart can be used both for design purpose and for stability check purpose. So, whatever we have done here, suppose time, U is given sorry, U, U is given, suppose 95 percent. And corresponding time I can say T 95. Similarly, if is U is 50 percent is given. So, corresponding time can be considered as T 50.

So, so, that means, to find out, suppose degree of consolidate U 50 percent is given, and then how much time it is taking? And if it is within it is supposed to be completed by six months, if it takes more than that, that means it is not satisfactory. So, that check can be done here also. So, that is what, through the problem I will try to explain, let me go to the next slide.

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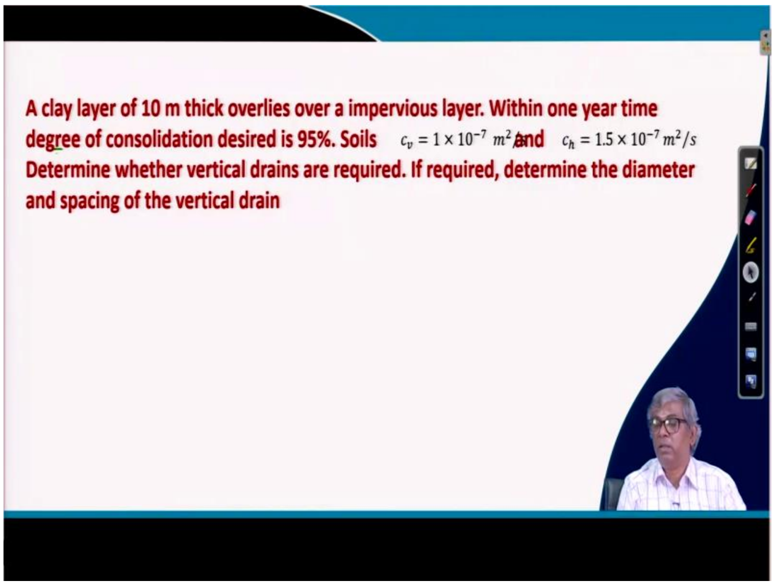

The problem is like this, a clay layer of 10 meter thick overlies over a impervious layer. Within one year time, degree of consolation desired is 95 percent. And soils Cv value is 1 into 10 to the minus 7 meter square per year, a meter square per second. And Ch value is equal to 1.5 multiplied by 9 ,10 to the power minus 7 meter square per second. Determine, whether vertical drains are required. If required, determine the diameter and spacing of the vertical drain.

So, this is the problem, this chart can be used I just how chart A B C D to be used. I will, I will just explain that.

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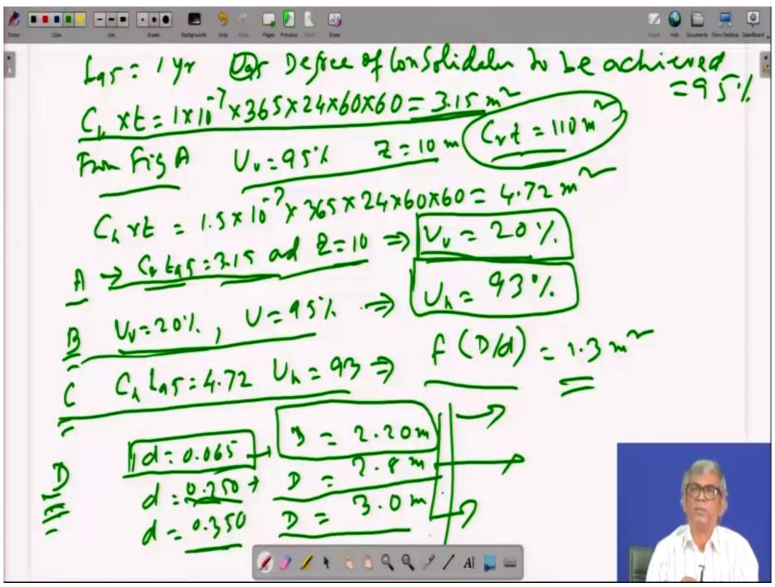

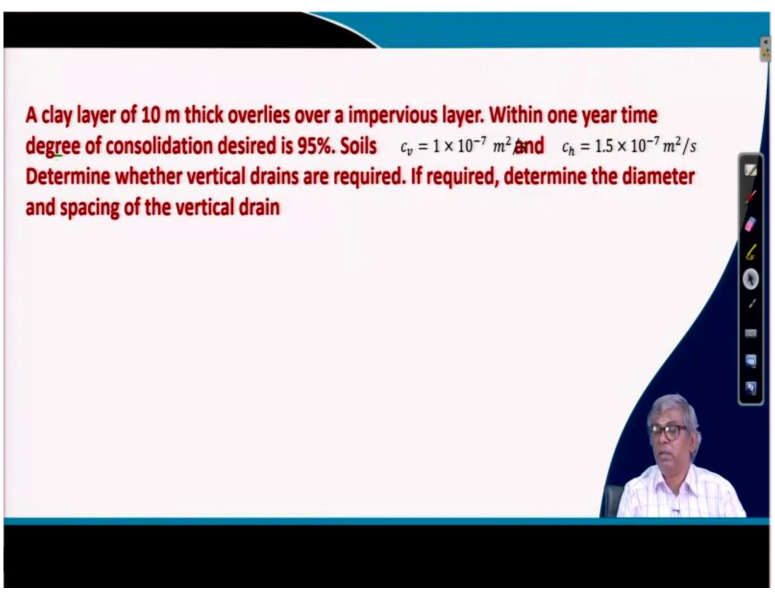

So, here actually your value of Cv is given, and T 95 also given suppose one year. That means, in one year time 95 percent to be obtained. T 95. So, T 95 is one year and U 95 actually is given already, 95 percent U degree of consolidation to be used. Degree of consolidation, degree of consolidation to be achieved is 95 percent. So, in that case, so, Cv multiplied by T, how much it is coming?

It is 1 multiplied by 10 to the power minus 7 multiplied by 365 multiplied by 24 multiplied by 60 multiplied by 60. Why I have done that? Because it is given in second. I have converted in second. So, these value come, this value comes actually 3.15, 3.15 meter square. Now, from figure A out of four figure, if you refer figure, one side is given actually Cv T. And other side, the other side is given U.

$$t_{95} = 1yr$$
$$\textit{Degree of consolidation to be achieved} = 95\%$$
$$C_h \times t = 1\times10^{-7}\times365\times24\times60\times60 = 3.15m^2$$
$$\textit{From FigA } U_v = 95\%$$
$$Z = 10m\ C_v t = 110m^2$$
$$C_h \times t = 1.5\times10^{-7}\times365\times24\times60\times60 = 4.72m^2$$
$$A \to C_h \times t_{95} = 1\times10^{-7}\times365\times24\times60\times60 = 3.15m^2, Z = 10m \Rightarrow U_v = 20\%$$
$$B \to U_v = 20\%, U = 95\% U_h = 93\%$$
$$C \to C_h t_{95} = 4.72\ U_h = 93\% \Rightarrow f\left(\frac{D}{d}\right) = 1.3m^2$$
$$D \to d = 0.065 \to D = 2.20m$$
$$D \to d = 0.250 \to D = 2.8m$$
$$D \to d = 0.350 \to D = 3.0m$$

And in there are four different values of z, jet means thickness. So, thickness is 10 meter you can pick up. And you can plot and we will get that, for Uv, Uv equal to 95 percent and, and z, and z equal to, z equal to 10meter. Your Cv T comes around 10, 110meter square, this is 110 meters. Which is actually, actual Cv T is only 3.1. Whereas, if you want to achieve within one year so, it is actually it, it is required this much, this is higher.

This is higher means actually what? That means only vertical drain, it will not do to achieve 95 percent degree of consolidation by one year. That means vertical drain is required. Now, we have to, if required vertical drain, the vertical drain is required then you have to find out the spacing and diameter. So, for that actually, what I will do now, you can find out now Ch multiplied by T 95 again, you can do that is 1.5 multiplied by Ch is 1.5 multiplied by 10 to the minus 7 multiplied by 365 multiplied by 24 multiplied by 60 multiplied by 60.

This gives you a 4.72meter square. Here actually from figure A, from A, there are A, B, C, D four figures are there. From figure A, we are getting that Cv multiplied by T 95 equal to 3.15. And, and z equal to 10 from the chart using that you are getting U_v equal to, U_v equal to only 20 percent. If I refer the figure chart, there are three parameters in one chart. These two parameters are given, the third parameter is obtained.

Now if you go to the figure B, figure B again three parameters are there. Uv is there, combined U is there and there is a Uh also there. So, Uv equal to 20 percent and your, U equal to 95 percent. And there are third unknown, there are three parameters based on these two parameter I can identify third parameter, which is Uh. That will be called to 93 percent. And now, if you refer figure C, then, then again there are three functions.

And they are actually C_h multiplied by T 95 equal to 4.72, this is one value. And U_h equal to 93 and there are a third parameter which can be identified from there, f D by d. And then going to the four figure, figure D. The f D by d, we will get a value which will be equal to 1.3meter square. And, and for now from this is actually these are, from figure D you will, you can choose diameter d equal to 0.065.

Then capital D will be equal to 2.20 meter. Similarly, if I assume d equal to 250, 0.250, this D comes 2.8 meter. If d equal to take an 0.35, then this D is coming 3.0 meter. So, you can see here, that if I use that means, I have now several options, I have to design finally, diameter and spacing. I can choose this diameter, if I choose this diameter, this is nothing but PVD. And if I use this PVD, then our spacing become 2.2 meters.

Now, I can choose that if I use sand drain, the sand drain diameter generally varies between 250 to 450 or something. So, I the chart there are many other diameters also there, I have taken only 250 and 350. If I use 250 spacing, then D become 2.8. And if I use 350meter, a millimeter diameter, then you are getting spacing in 3.0 meter. You can see the smaller diameter, closer spacing, larger diameter, wider spacing.

That is obvious that. So, this is a, the chart whatever I have shown that is a very generalized chart there is A, B, C, D. First A can make sure that whether vertical drain is required or without vertical drain whether you can achieve your target, that will give you some decision. And if, if you can decide that and based on that you can go, if is drain is required then you can design by using subsequent BCD.

How actually first figure will give you first of all, whether drain is required or not, that is to be decided. And then, finally quantitative whatever soil property is there, whatever depth, the based on that, time is required, based on that what we can find out? Degree of consolidation from figure A. Figure B, I can find out degree of horizontal consolidation I can find out. Figure C, I can find out, D by d ratio.

And figure C, you can find and figure D, there are different diameter corresponding chart is given. So, if I choose one diameter, corresponding other diameter, spacing we will get, capital D we will get. From there I can pick up, so accordingly I can either choose this one, I can choose this one, I can choose here.

This is the designer choice of course, which one is convenient, cost convenient everything together. One can design this is a quite generalized method and of course in between, the same chart can be used for stability, satisfying stability criteria also. With this problem, let me some more things are there. Let me take that.

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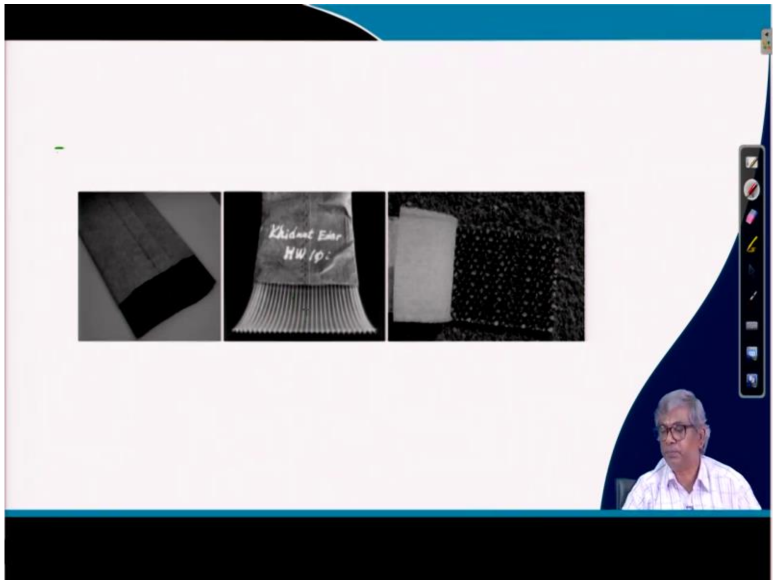

So, as my previous problem, I have kept of course I have not kept this problem here. I hope it is enough. Now we are talking about PVD, how it looks like? PVD actually looks like, we can see that will be inside, the outside there will be a cover. And then there will be inside. So, this is of course porous, highly porous. And water actually can easily pass through, there are different shape is available actually.

So, for outer core, almost similar. The inner part, actually is different in different PVD. So, depending upon your quantity of floor, require and all, strength is required. One can pick up, whatever available in the market.

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Then how it installed? You can see here, that this is the PVD installtion rig. And Static Ocean type one. So, it is actually you can see, these are here and this will be holding and you can see these are the extended portion black points. Whatever black points are there actually already installed, these are all installed, these are all installed.

So, like that one after one it can be installed and very quickly it can be done actually. Because that is the advantage, very quickly this can be. Otherwise, sand drain it takes a significant amount of time, that is the only advantage disadvantages between these two. Let me go to the next slide.

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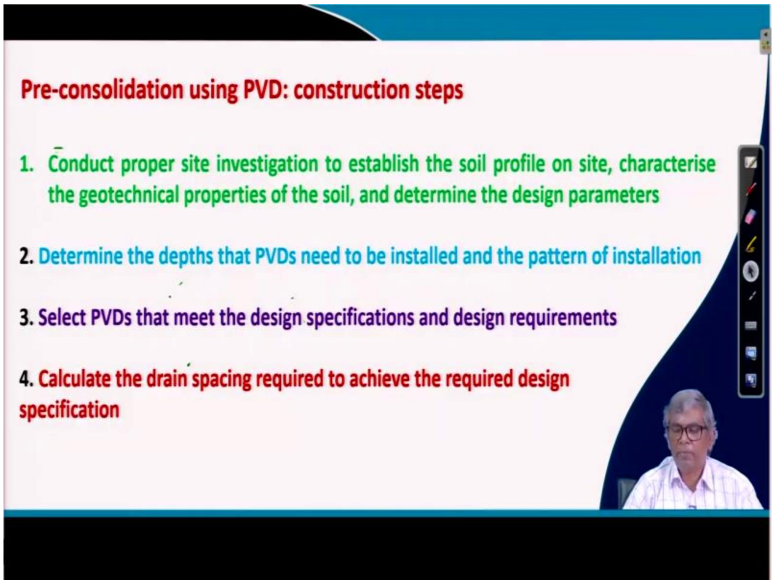

Preconsolidation using PVD when you do, then what are the construction steps? You can see the first step, to conduct proper site investigation to establish the soil profile on site. Then characterize the geotechnical properties of the soil, and determine the design parameters. So, this is actually first step. That means, you have to, you have to do soil investigation and you have to design the soil parameter.

Then determine the depth, that PVD is needed to be installed. And the pattern of installation. That means, already, we have mentioned triangular pattern, square pattern, that we, so you have to decide which pattern. And also what depth, and depth how it is decided by the depth? Depth is decided by the thickness of the comprehensible layer and sometimes some environmental and mother effect.

Then detail, decide select PVDs, that meet the design specifications and design requirements. So, flow and other things, filter criteria and flow criteria all those things. Calculate the drain spacing required to achieve the required design specification. That is the spacing, first of all you have to find out to achieve 95 percent or 90 percent, you can make the spacing accordingly. If wider spacing will be taking longer time, closer spacing.

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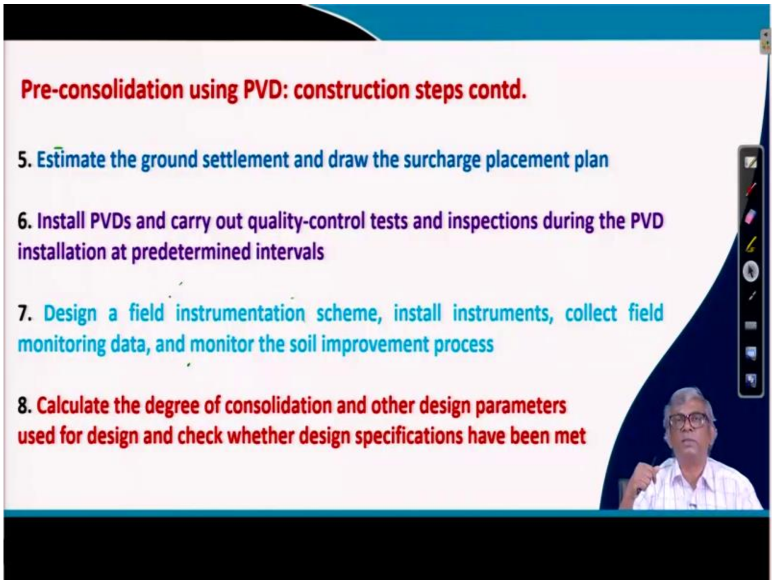

Similarly, then estimate the ground settlement and draw surcharge placement plan. So, how much settlement is by preconsolidation will be done? And accordingly you have to surcharge whether you do single stage, double stage, triple stage like that you have to plan. Then install PVDs and carry out quality control test, inspect during the PVD installation as predetermined intervals. You have to install and same time you have to maintain some quality control.

Quality control means what? Why the flow is proper, then what is the piezometer? Sometimes you can put, we can find out the change of pore pressure all those things. Then design a field instrumentation scheme, installed instruments, collect field monitoring data and monitor the soil improvement process. This is also having to be done.

And then calculate the degree of consolidation and other design parameters used for design and check whether design specification have been met. Whatever you do, finally, whether it is achieved or not that has to be checked.

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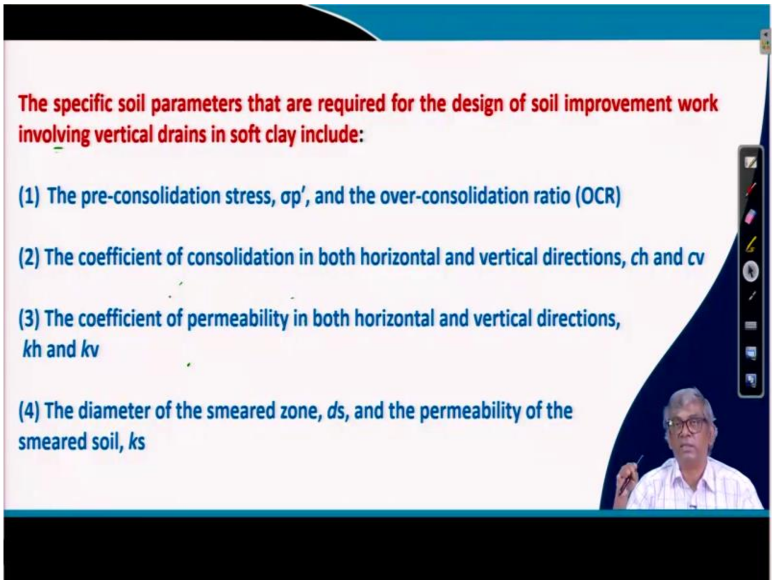

Then out of these design step, one most important perhaps is the soil investigation part. Other things readymade you have to select and put it and when you do soil investigation, what are the things to be soil parameters. So, about soil what have to, one has to know? There are number of things preconsolidation stress, actually to be determine. Then over consolidation ratio is determined.

Then the coefficient of consolidation in horizontal vertical direction Ch and Cv to be determine. The coefficient of permeability in the horizontal or vertical direction, C, K_h, K_v to be determined. The diameter of the smeared zone, the ds and the permeability of the smeared soil ks, that also has to be determined, if you want to consider and if you know that particular installation process and soil type, it may cause a significant amount of smear.

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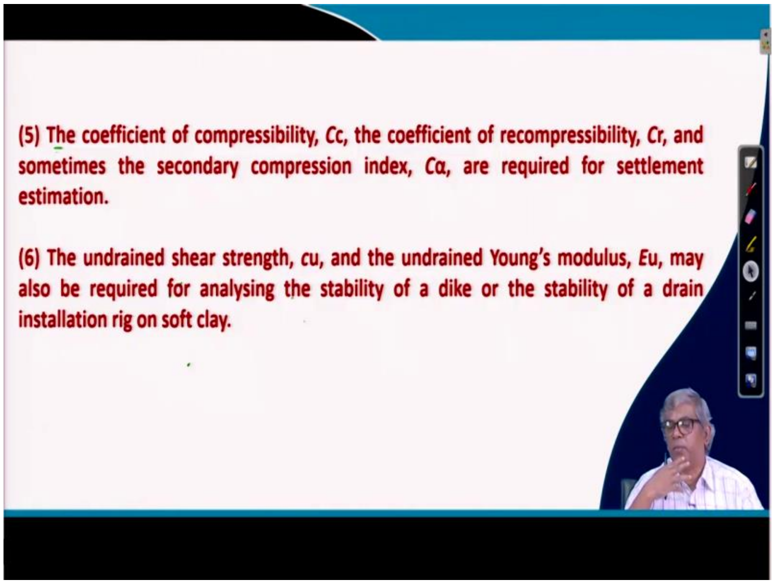

Then coefficient of compressibility, Cc, coefficient of compressibility, recompressibility Cr and sometimes secondary compression index C alpha. These are the things also determined because otherwise you will not be able to estimate the what is the total settlement actually and for that you have to plan the preconsolidation.

The undrained shear strength cu also is required and the undrained Young's model, Eu may also be required for analyzing the stability of the dike or stability of the drain installation rig on soft clay. So, these are the soil parameters by and large required when you do the soil investigation.

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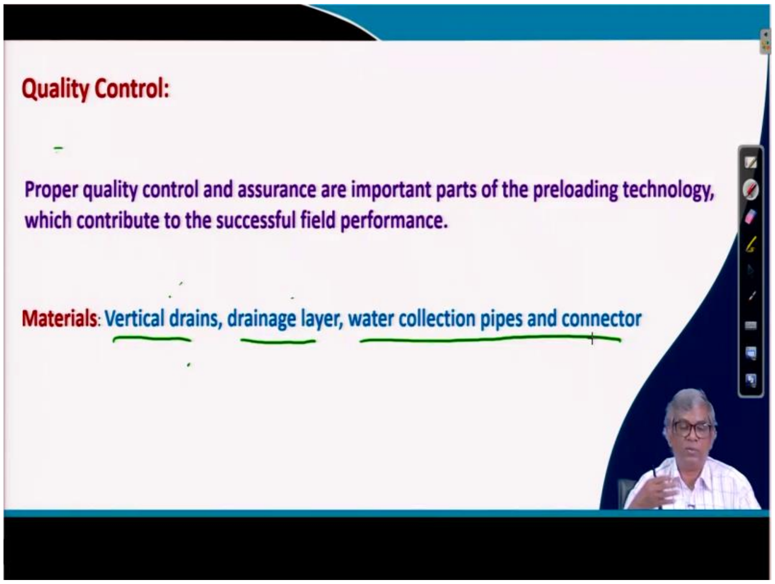

Then quality control, under these like many other ground improvement already I have discussed. Everywhere there is a quality control, here also quality control with there. By proper quality control and assurance are, important parts are now, for proper quality control, control and assurance are important parts of the preloading technology. Which contribute to a successful field performance.

And what actually pre con, quality control means what you will do? In the material part actually, there are a lot of control. One is actually vertical drains, whatever we are doing vertical drains first of all, for gradation etc your, it has to be proper. And filter criteria and all those things has to be satisfied, then drainage layer, then water collection pipes and connectors.

So, these are the things actually has to be checked, that whatever plan is done, the plan actually workable and it can achieve the target. These are the things drain, then layer all those things has to be. These are the quality, components of quality control.

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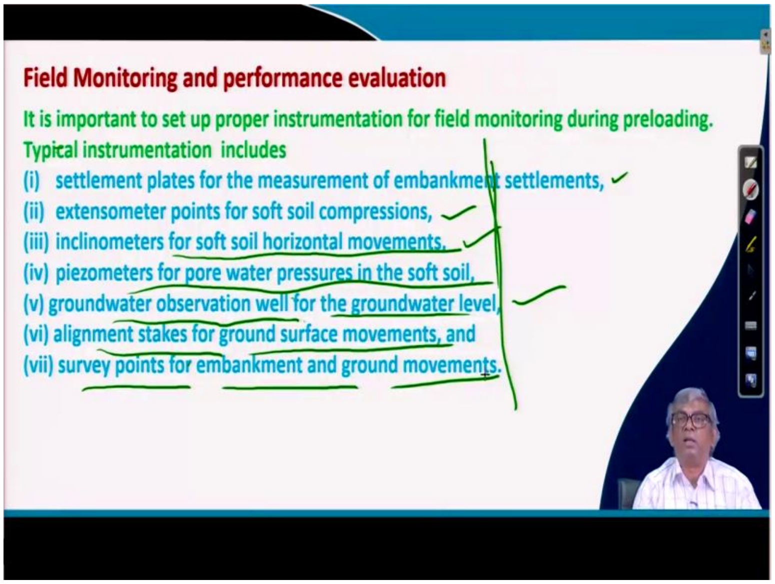

Next part is then, field monitoring and performance evaluation, under these it is important to set up proper instrumentation, instrumentation for field monitoring during preloading. And typical instrumentation, what we can generally we can use during preloading there are a number of them. One is settlement plates, for the measurement of embankment settlement. So, this can be installed and see over the time how it is scribbling.

Extensometer points for soft soil compression. Extensometer by that soil compression can be. Inclinometers for soft soil horizontal movements, that also can be installed, then piezometer to pour water pressure in the soft soil. The groundwater observation well for the groundwater level, then alignment stakes for ground surface movement. And survey points for embankment and ground movement. So, these are things can be done actually. These are the list of things.

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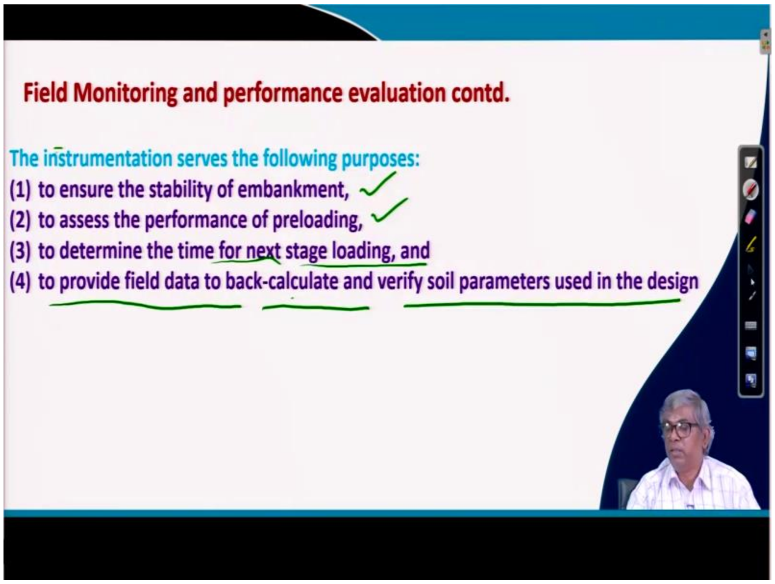

Next is the field monitoring but same continuing the, that by using field instrumentation, what we can achieve actually? We can ensure the stability of the embankments and to assess the performance of the preloading. So, we have designed something whether it is working or not that can be assessed actually by this monitoring, to determine the time for next stage of loading. You until you are monitoring, suppose you have targeted in two months 40 percent consolidation, but you do not monitor, it may achieve early also sometime and it may take longer time also. That monitoring only helps you to know exactly, where actually we have to that target is reached and then if you satisfactory, see that the target is reached, then next course of action can be started.

That is, to determine the time for next stage of loading. That is also going to provide field data to back calculate and verify soil parameter used in the design. Some time, some for the monitoring also we collect a lot of data and sometimes we can do back calculation and see whatever, in the preliminary soil investigation whatever data we have used, whether they are matching or not.

If there is a mismatch of course, you have to take care, because otherwise everything may go wrong. That you have to in between, you have to do some modification in the system. That ultimately the project become successful.

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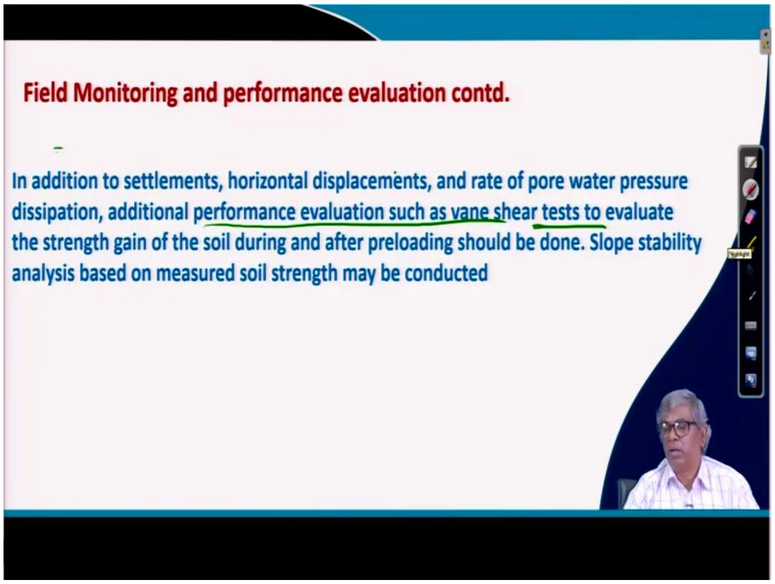

So, field monitoring again, performance evaluation. Here actually in addition to settlement, and horizontal displacement and rate of pore water pressure dissipation, these measurements whatever we do, additional performance evaluations have, to be sometime is required. Such as, vane shear test, to evaluate the strength gain of the soil during and after preloading.

Whatever monitoring we are doing, simultaneously some sort of performance evaluation has to be done. That means, what is that actually? For example, it is by, it is a soft soil actually. you how to use in the field vane shear and see the strength before preloading how it was, after preloading how much it is based on that you can also judge something. So, that also from time is required.

And so, that in addition to settlements, horizontal displacement and rate of pore water pressure, dissipation additional performance evaluation such as vane shear test to evaluate the, evaluate the strength gain of the soil during and after preloading should be done. Slope stability analysis based on measured soil strength may be conducted. So, that is also, whatever you are getting based on that stability analysis also.

These are the, by a large some quality control and monitoring work one has to do, when this type of work is undertaken in the field. As engineer actually these are the things one has to carry out. With this completed the preloading. Whatever there, preloading of course, there are plenty of things are available still, but minimum what is required for the design of a sand drain system or PVD system.

And what are the precautions or what are the things has to be taken into consolidation to make the design successful. And what is the monitoring scheme or performance as soon as scheme is required by a large very briefly, I have done here. I think this will be useful and if we want to do further of course you can see all recent, recent literature from which were recent work whatever going on.

Through those we can we can learn additionally if required. Otherwise, briefly about preloading whatever essential I could cover here, with this I will thank you all I close here. Maybe I will in the next class, I will start something new topic. Thank you.