Geosynthetics Engineering: In Theory and Practices
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Lecture - 46
Geosynthetics for Ground Improvement

Dear student warm welcome to NPTEL phase two program video course on Geosynthetics engineering in theory and practice. My name is Professor J. N Mandal, department of civil engineering, Indian institute of technology Bombay, Mumbai, India. This is lecture number 46 module 9 geosynthetics for ground improvement.

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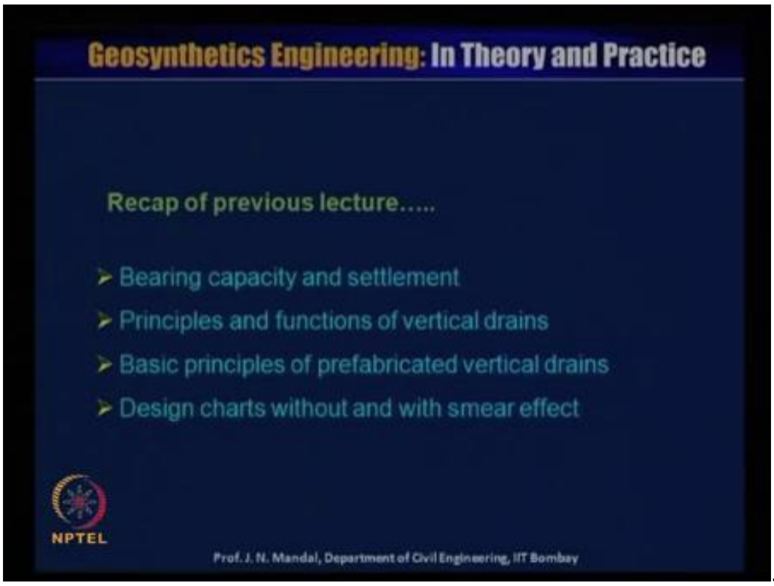

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I will now focus recap of the previous lecture, the bearing capacity and the settlement, the principle and function of vertical drain, basic principle of prefabricated vertical drain, design chart without and with smear effect.

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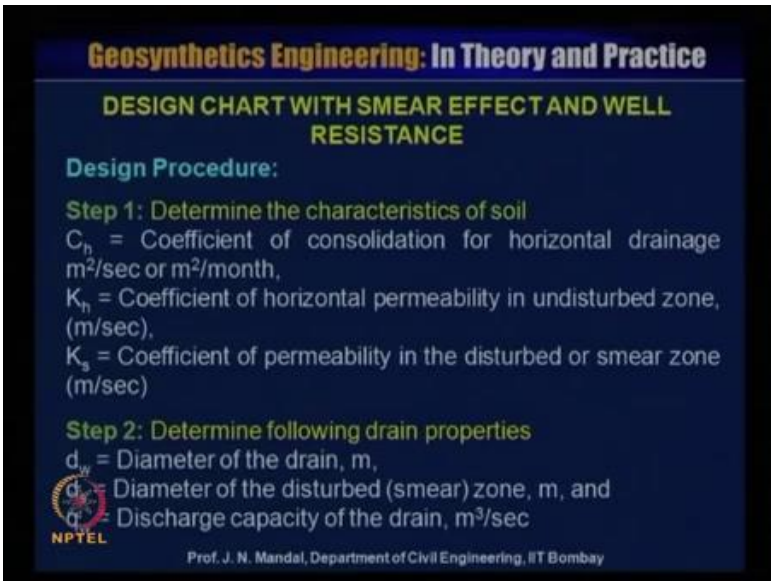

Now, we will continue design chart with smear effect and well resistance, what will be the design procedure? Step one, determine the characteristics of soil, that means you should know that what will be the Ch that is coefficient of consolidation for horizontal drainage, that is meter square per second or meter square per month. Kh - coefficient of horizontal permeability in undisturbed zone, that is meter per second and Ks coefficient of permeability in the disturbed or smear zone meter per second. Step two, determine the following drain properties, that is dw is diameter of the drain in meter, ds diameter of the disturbed or smear zone in meter and qw, discharge capacity of the drain, that is meter cube per second.

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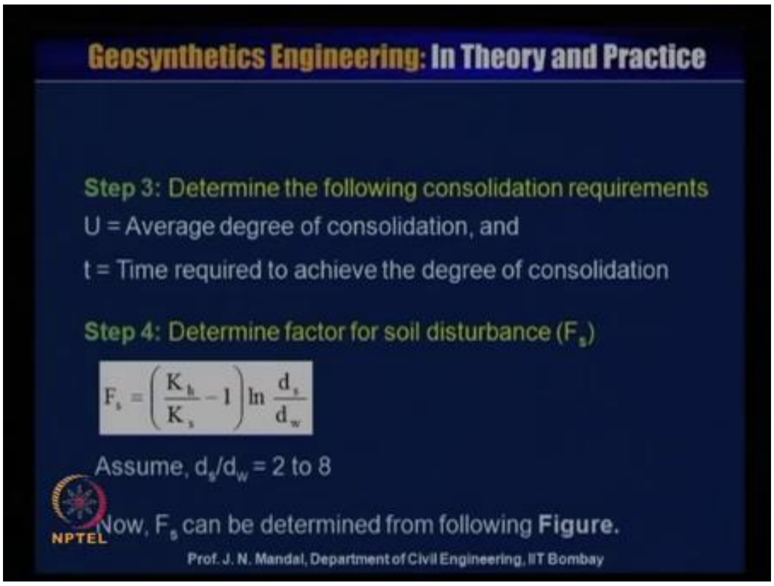

Step three, determine the following consolidation requirement that is, U is average degree of consolidation and t, time required to achieve the degree of consolidation. Step four, determine factor for soil disturbance, that is Fs so we will use this equation Fs is equal to Kh by Ks minus 1 into log ds by dw. Assume ds by d w is equal to 2 to 8 now, Fs can be determined from this following figure.

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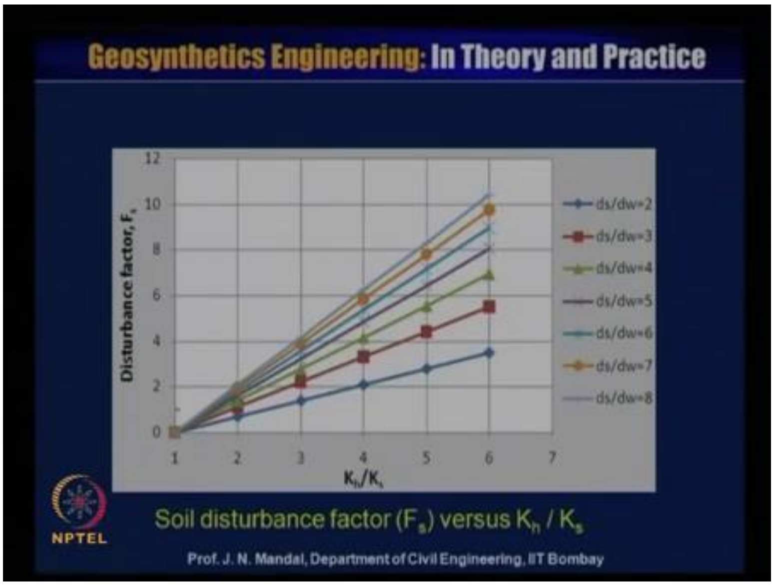

So, this is the figure, is shown that soil disturbance factor Fs versus Kh upon Ks. So, for the different value of ds by dw, so ds by dw may be 2, 3, 4, 5, 6, 7, 8 like this. So, for the different ds by dw, you can calculate that what should be the soil disturbance factor, that is Fs. So, you know now, what will be the ds by dw, if you know ds by dw, also you know what will be the Kh by Ks. So, knowing Kh by Ks and ds by dw then you can calculate what will be the soil distribution factor Fs, from this chart. So, I will give you later one example.

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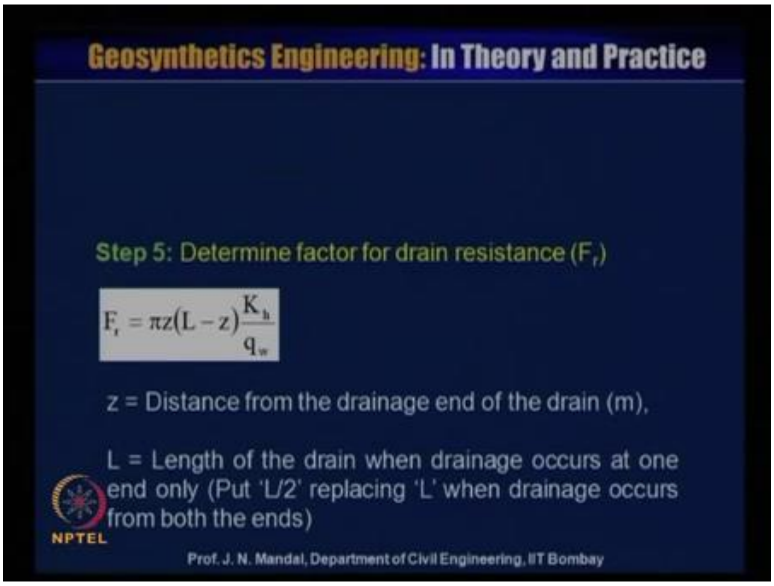

Now step five, determine factor for drain resistance that is Fr so use this equation drain resistance that is Fr is equal to pi z L minus z into Kh by qw. What z is equal to the distance, from the drainage end of the drain that is meter, L is equal to length of the drain when, drainage occur at one end only or put L by 2 replacing L when, drainage occurs from both the end.

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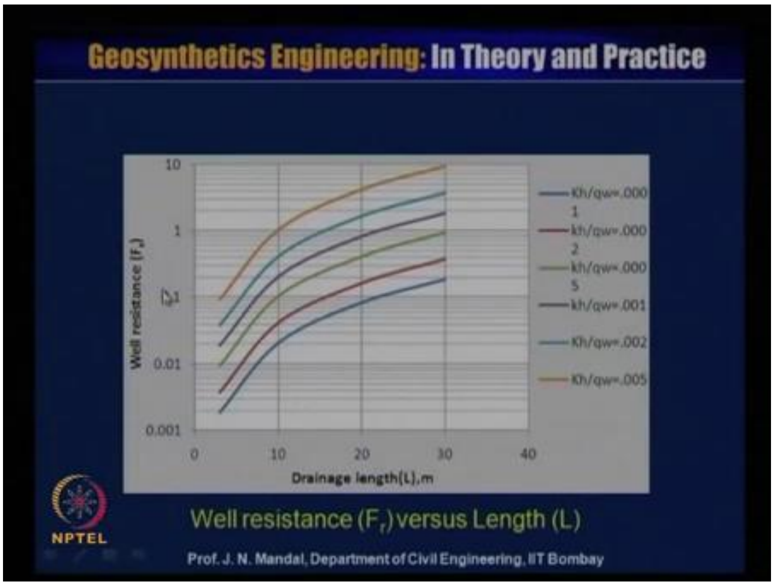

So, this is the chart well resistance versus the length, this is the length for different value of Kh by qw, Kh by qw 0.001, 2, 0.002, 0.005, 0.01, 0.02, 0.05. So, knowing the value of Kh by qw, Kh is coefficient of permeability in the horizontal direction and qw is the flow. So, if you know this ratio of this and what will be the drainage length so you know the drainage length, you know the Kh by qw then you can calculate, what will be the well resistance factor from this chart that is F of r.

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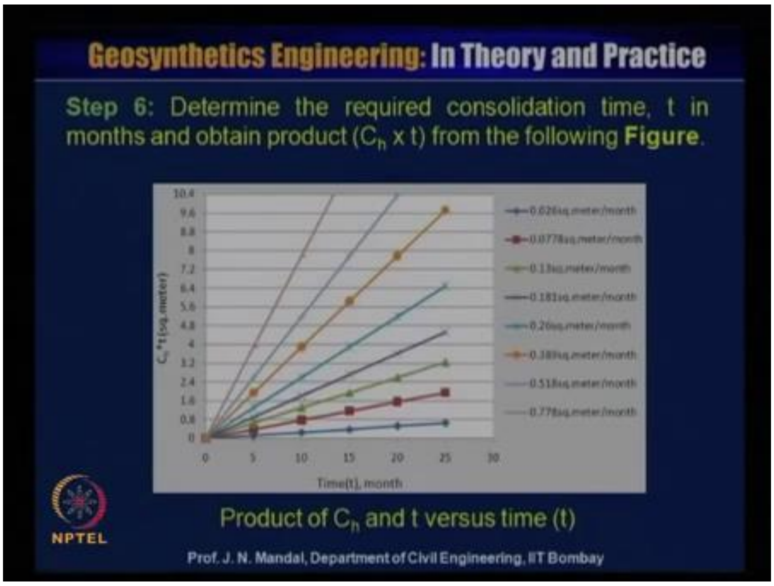

Step six, determine the required consolidation time t, in month and obtain product Ch into t, from the following figure. So, here is the product of Ch and t versus, the time t so you know the different value of Ch is this, given here 0.026 square meter per month. Like that, it is 0.778 square meter per month, so knowing that time and also this ratio you can calculate what is Ch into t from this chart.

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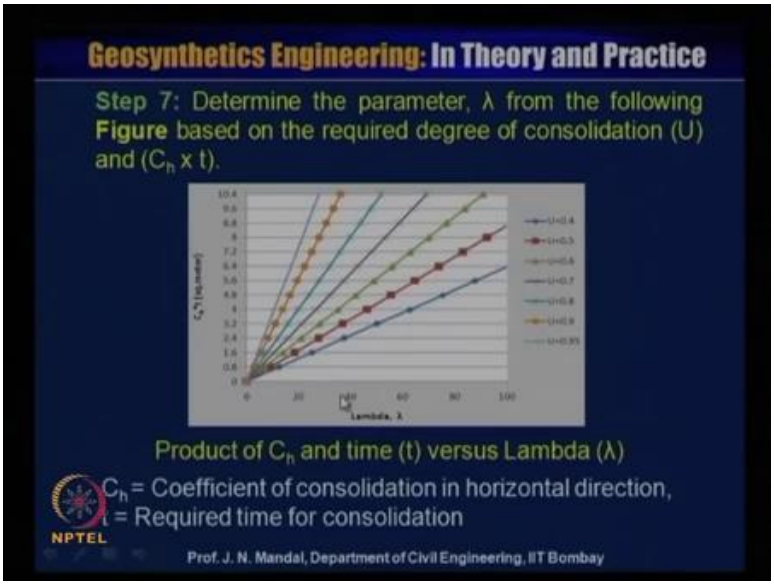

Step 7, determine the parameter lambda from the following figure, based on the required degree of consolidation U and Ch into t, so here product of Ch into and t, time t versus the lambda. This is lambda, for the different value of U that is required degree of consolidation, U value may be 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95. So, where that here Ch is coefficient of consolidation in horizontal direction and t is the required time for consolidation. So, this parameter lambda and knowing U and Ch into t, you can also determine this lambda value, from this design chart.

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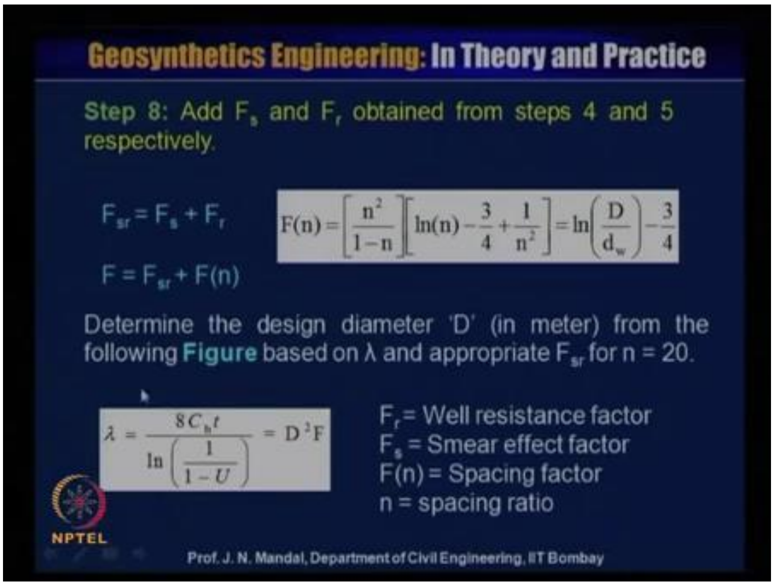

Now what is lambda, I will just explain also here that what do you mean by the lambda. So, step 8 add Fs and Fr obtained from step 4 and 5 respectively so total Fsr is equal to Fs plus Fr. Now, again f is equal to Fsr plus Fn, what is Fn, Fn is equal to n square by 1 minus n into log n minus 3 by 4 plus 1 by n square or is equal, is equal to log D by dw minus 3 by 4. Because this n is very small so n square will be very small. So, you can omit so you can directly write that log of n mean D by dw and minus 3 by 4 so omitting this value. So, determine the design diameter D in meter, from the figure I will show you based on lambda. And appropriate Fsr for n is equal to 20, here you know that F of r is equal to well resistance factor, F of s is smear effect factor or F of n is spacing factor, this is Fn spacing factor.

So, all combined is gives F is equal to Fsr that means Fs plus Fr plus Fn, Fn means spacing factor. So, it is a combination of the three factors that is F is equal to well resistance factor plus, smear effect factor plus, spacing factor. So, you have observed there are three equations for Fr, Fs and Fn, from these three equations, you can calculate the three different factors. And n is equal to spacing ratio, that is D by small d w and lambda can be expressed as 8 Ch t by, log 1 upon 1 minus U or is equal to D square into F.

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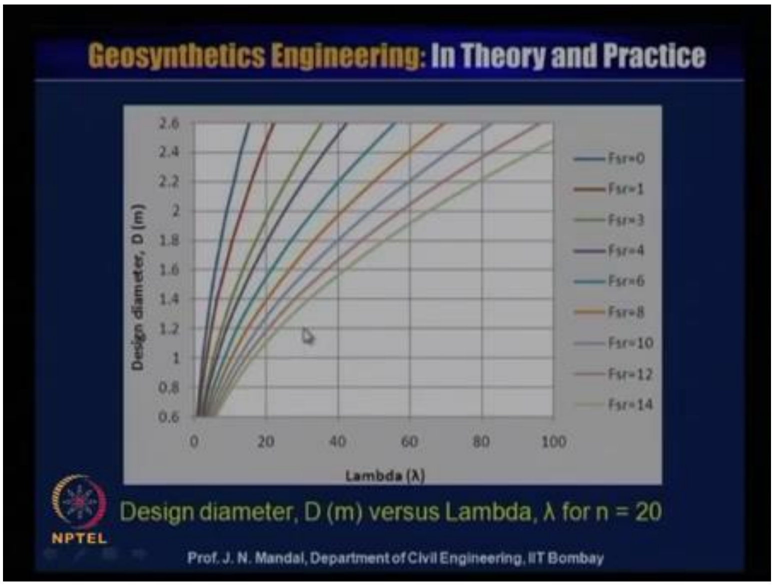

So, now this lambda here is the design diameter that is D in meter versus, the lambda for n is equal to 20. And here that Fsr is may be 1, 0, 3, 4, 6, 8, 10, 12 and 14 so different values. So, knowing also the lambda and Fsr so you can also calculate what will be the design diameter from this chart.

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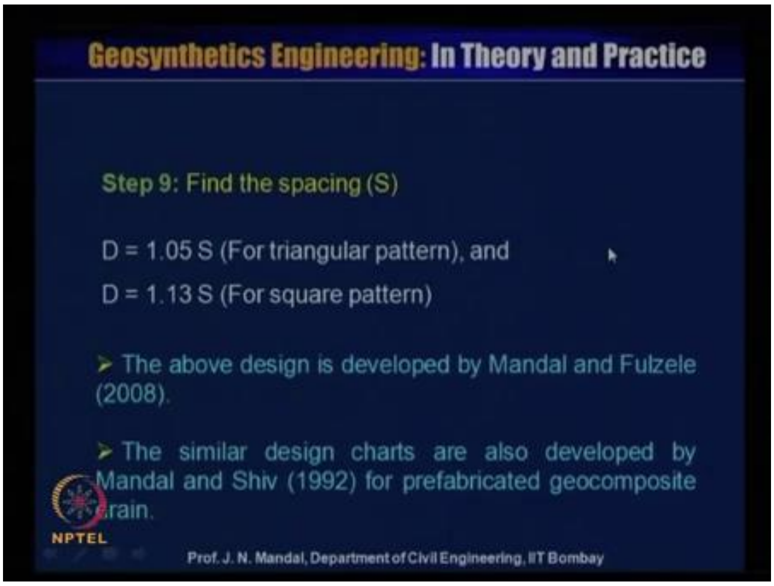

Step 9, now find the spacing that is S so you know that D is equal to 1.05 S for triangular pattern and D is equal to 1.13 S for square pattern. So, this above design chart is also developed by Mandal and Fulzele, 2008 and similar design chart are also developed by

Mandal and Shiv, 1992 for prefabricated Geocomposite drain. As I also mentioned you earlier that if you know that what will be the horizontal coefficient of the consolidation.

And then if you can select the time whether it is 1, 2, 3 or 4, 6 month and then you also know that what will be the degree of consolidation, that U value whether it is 80, 70, 90, 95 and then you can calculate the spacing S. So, there are different design chart also have been made and for the different prefabricated vertical drain including natural prefabricated drain. Now this is one example, let L is equal to length of the soil strata, about 20 meter.

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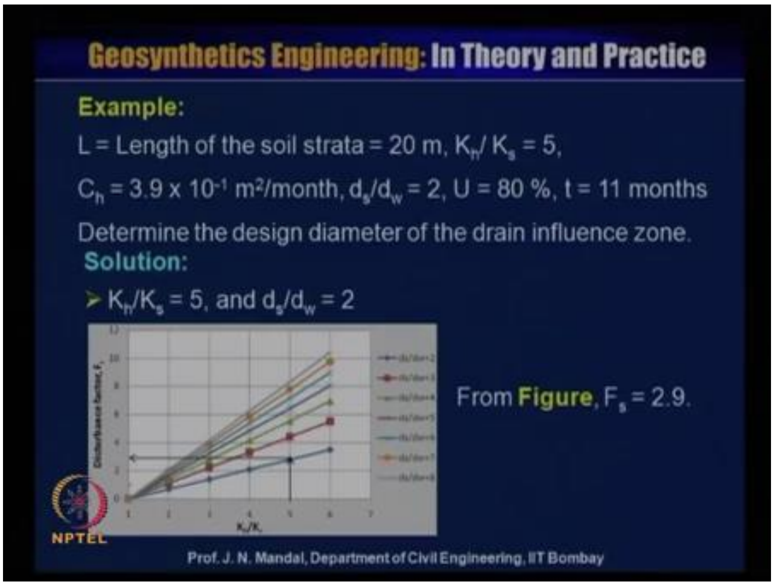

And Kh by Ks is equal to 5 and Ch is 3.9 into 10 to the power minus 1 meter square per month and ds by dw is equal to 2 and U is equal to 80 percent and time t is equal to 11 months. You have to determine the design diameter of the drain influence zone. Now solution you know, Kh by Ks is equal to 5 and ds by dw is equal to 2 given. So, from this figure you can see that you know Kh by Kw so Kh by Kw is equal to 5. So, here is the 5 and then you move up and then you can check the ds by dw so ds by dw is equal to 2. So, this is ds by dw equal to 2 and then you move horizontally towards left so you can calculate what is F of s. That means from this figure you can have Fs is equal to 2.9 so this is 2.9 so you can calculate Fs.

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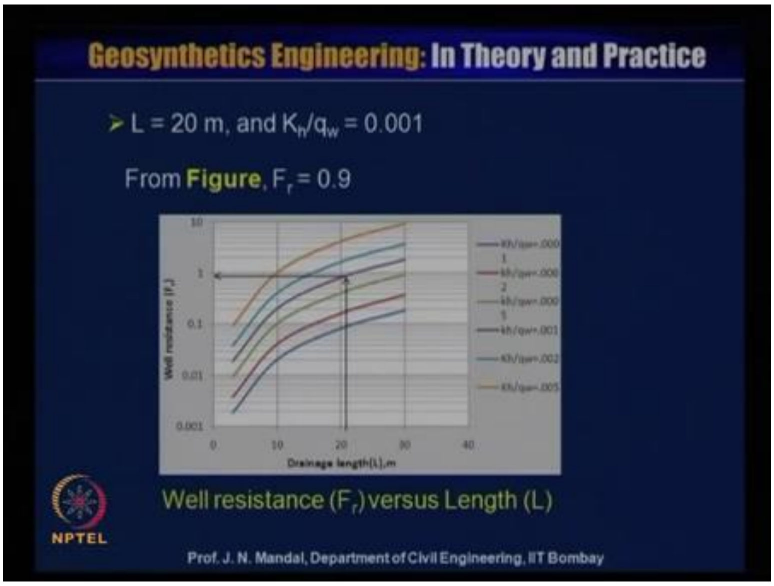

Now, you know the length is equal to 20 meter and Kh by qw is equal to 0, 0.001. So, from this figure you can calculate what is F of r so here is the design length, length is 20 meter and here is the Kh by qw that is 0.001 Kh by qw. So, this is 0.001 so if you know Kh by 0.001 then you move to the left and then you can calculate what is Fr. So, Fr is near about 0.9 so from this chart you calculate Fr.

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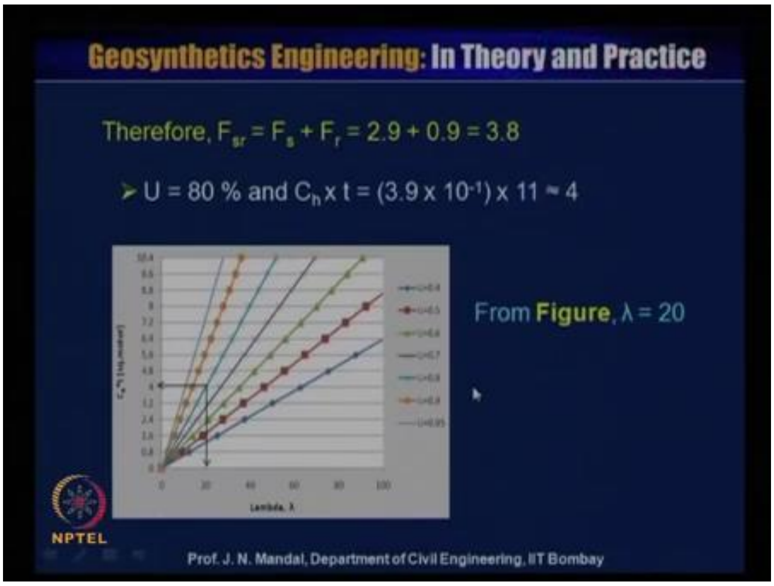

Now therefore, you know that Fsr is equal to Fs plus Fr, that means 2.9 plus 0.9 will be equal to 3.8. Now, U is equal to 80 percent given Ch into t also 3.9 into 10 to the power minus 1 into t is equal to 11 months. So, that is approximately let us say 4. So, from this design chart you can calculate this lambda so you know that, what is U 80 percent, you know. You know that what is the Ch into t, that is 4 so ,Ch into t it is 4 here then you move horizontally and you require, U is equal to this is 80 percentage and then you move down. And then you calculate what should be the value of lambda so lambda here is equal to 20, so that is why from this figure you can calculate the lambda, lambda is equal to 20.

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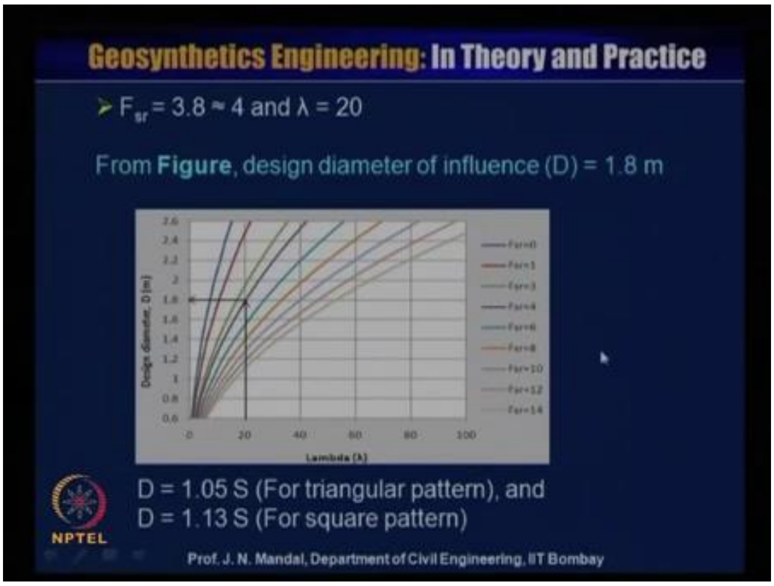

So, you know Fsr is about 3.8 or is equal to 4 and lambda is equal to 20. So, from this figure design diameter of influence, that is D you can calculate now, here that, what is the Fsr, that means Fsr is about 4. So, this is Fsr will be about 4, here Fsr 4 and you know the lambda is equal to 20 so lambda 20 then you move up, where Fsr is equal to about 44. And then you move horizontally here then you can obtain that what will be the design diameter D.

So, this design diameter of influence D is 1.8 meter, this is 1.8 meter. Now if you know the D though, you know the correlation between the D and the spacing S, for triangular pattern that is D will be equal to, 1.05 into S for triangular pattern. And D is equal to 1.13 S for square pattern so you can put this value of D and you can calculate the, what will be the spacing for the triangular pattern and what will be the spacing for the square pattern.

So, you know that how to design that, ultimately we have to design what will be the spacing between the two fabricated vertical drain. Whether it is a triangular spacing or the square facing, now it is very much essential for instrumentation of the embankment or soft soil with prefabricated vertical lane. When you are insulating the prefabricated vertical lane, it is required to some instrumentation to observe the behavior of the soil. So, one should know how to and what to place the instrumentation for the embankment on soft soil with PVD.

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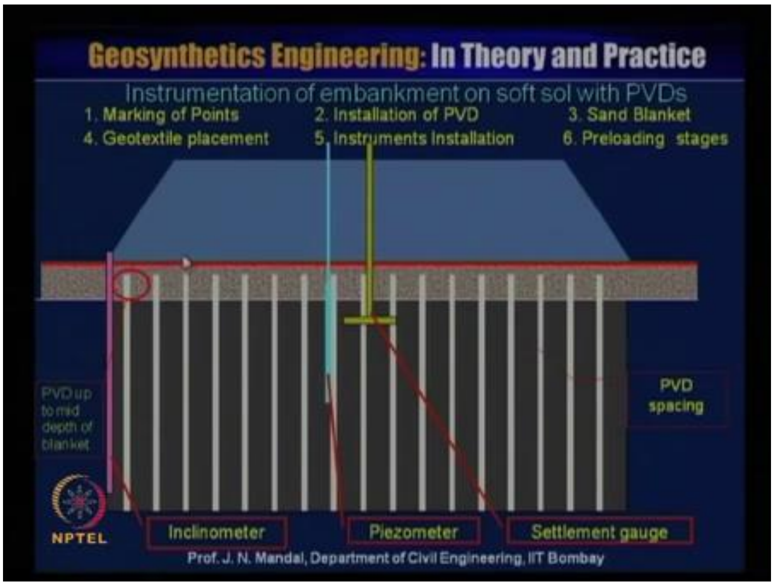

So, this is a initially this marking point and then you have to install the prefabricated vertical lane. So, this is the prefabricated vertical lane, you are installing like this so this is a soft soil foundation and you are insulating that PVD like this. So, at a particular spacing you know how to calculate the spacing between the two prefabricated vertical drain. So, you install and after that you can provide with the sand blanket so this is the sand blanket or you can place also Geotextile or Geocomposite material, which will act as a drainage. Then after this, you have to place the geotextile placement so you can place on the top of this geotextile material. Then after this, you have to give the instrument installation, you must provide that installation, here is the instrument you are providing. So, this is the settlement gauge so you can measure that what will be the settlement of the embankment.

So, we have to provide the settlement gauge next, you have to provide the piezometer here, to measure the pore water pressure. Then you have to provide with the inclinometer here then you have to need the preloading, you need preloading. So, you are putting the surcharge load then there will be distribution excess pore water pressure then preloading stage. Like 1, 2, 3 stage it is required so this is, I am telling that this is, this PVD spacing you know and this is the inclinometer and PVD up to mid depth of the blanket. You should provide mid depth of the blanket, here is a blanket, so at least that prefabricated vertical drain should reach to the mid depth of this blanket.

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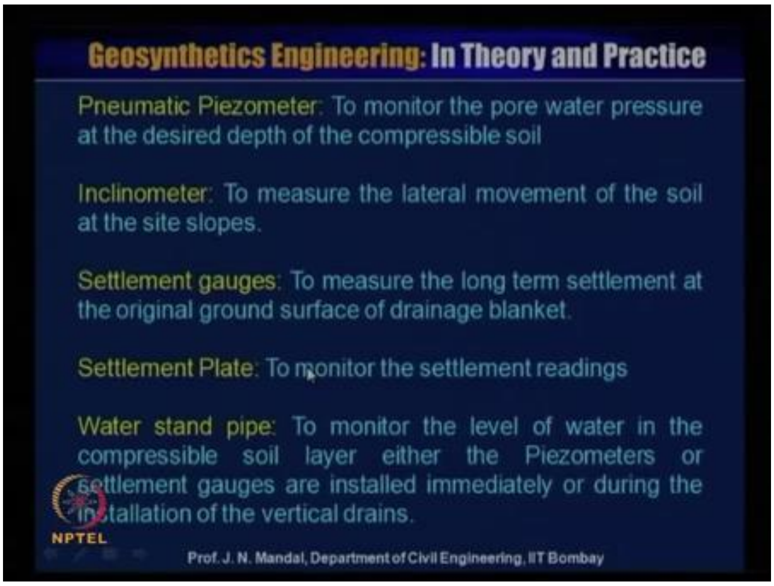

So, what will be the role of the pneumatic piezometer, to monitor the pore water pressure at the desired depth of the compressible soil. Inclinometer, you can measure the lateral movement of the soil at the site slope. Settlement gauge, to measure the long term settlement, at the original ground surface of the drainage blanket. Settlement plate, to monitor the settlement reading, water stand pipe to monitor the level of water in the compressible soil layer, either in the piezometer or settlement gauge are installed immediately or during the installation of the vertical drain.

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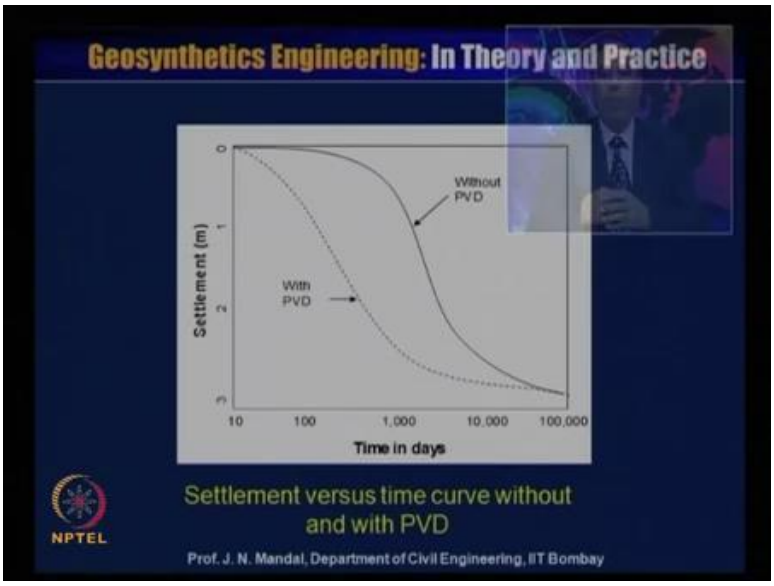

So, it is very important for the instrumentation and you can measure and then you can check up what will be the settlement versus time curve. Here, it has been shown the settlement versus this time curve, this is the settlement, this is the time and this is the, without prefabricated particles drain. And here with the prefabricated vertical drain so you can observe that, with a stipulated time this settlement is more, in case of prefabricated vertical drain, with respect to, without prefabricated vertical drain.

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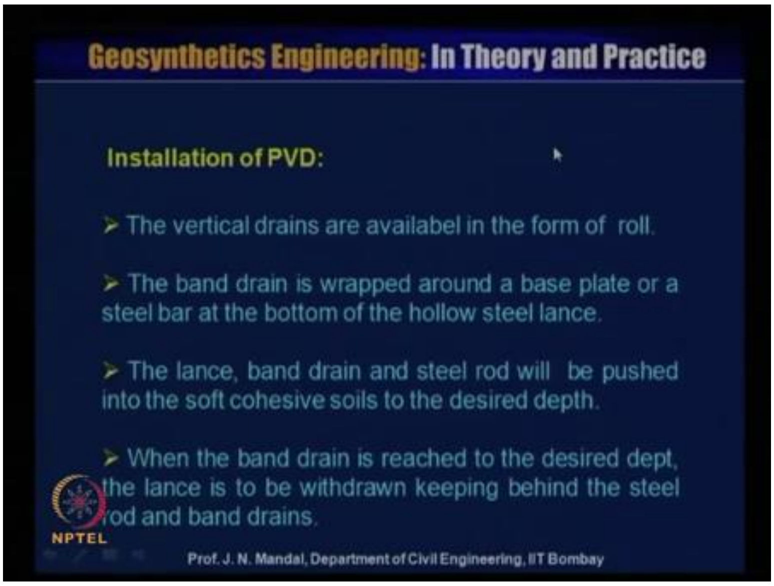

So, installation of PVD, the vertical drains are available in the form of roll, the band drain or the prefabricated band drain is wrapped around a base plate or a steel bar. I will show you later that, what is that steel bar and the base plate at the bottom of the hollow steel lance. The lance band drain and the steel rod will be pushed into the soft cohesive soil, to the desired depth. So, it is, it is like I will show this part that, will push into the soft cohesive soil to the desired depth. When the band drain or prefabricated drain is reached to the desired depth, the lance is to be withdrawn keeping behind the steel rod and the band drain.

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So, here you can see that installation of the prefabricated vertical drain, this is photo compliment to DBM Geotechnics. And this is the only, this one rig and this is very soft soil, where the prefabricated particle drain has been installed.

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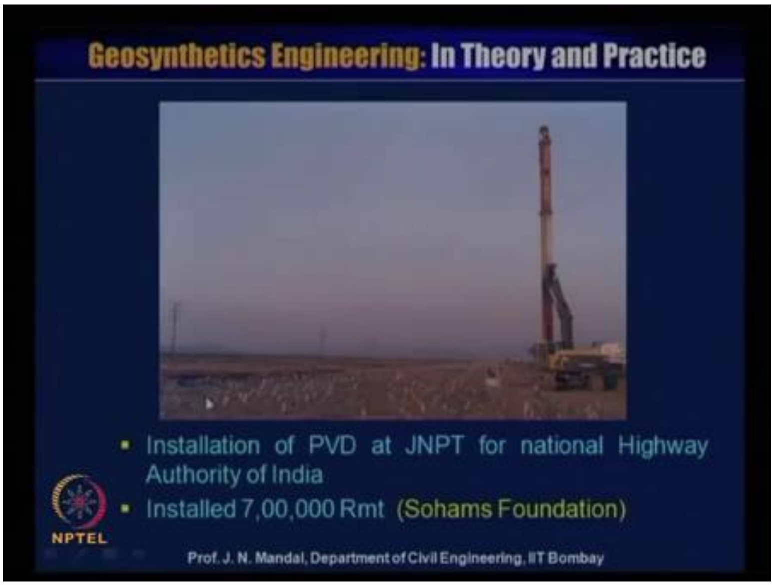

So, you can see more the installation of PVD at JNPT for national highway authority of India. And this is all white color here, this is prefabricated vertical drain has been installed. And this install about 7,00,000 running meter, this is Sohams foundation.

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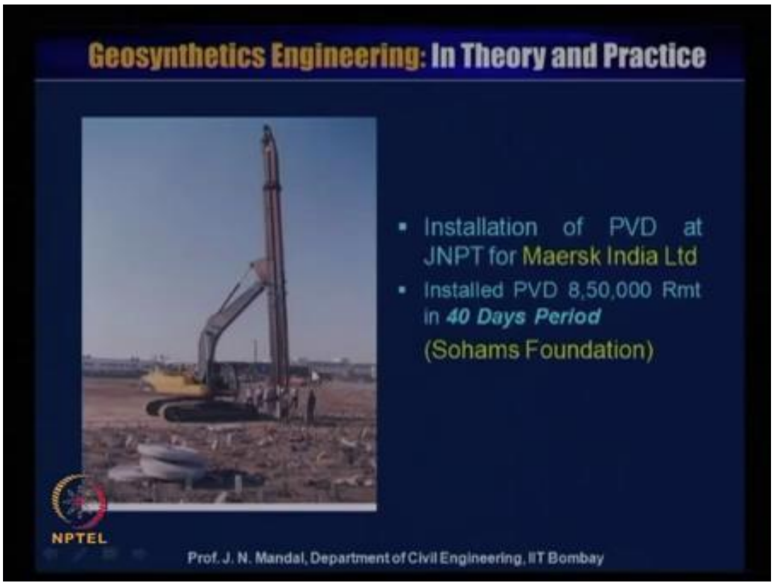

Here is also installation of the prefabricated vertical drain, you can see this is the, in the roll form like a roll of used toilet paper. So, this is the prefabricated particle with this crane, this prefabricated vertical drain inserted to the desired depth and then on the, from the top you can cut it, with the help of a scissors. So, this is the installation of PVD at

JNPT Maersk India limited and installation of PVD about 8,50,000 running meter in 40 days periods, this reported by Soham foundation.

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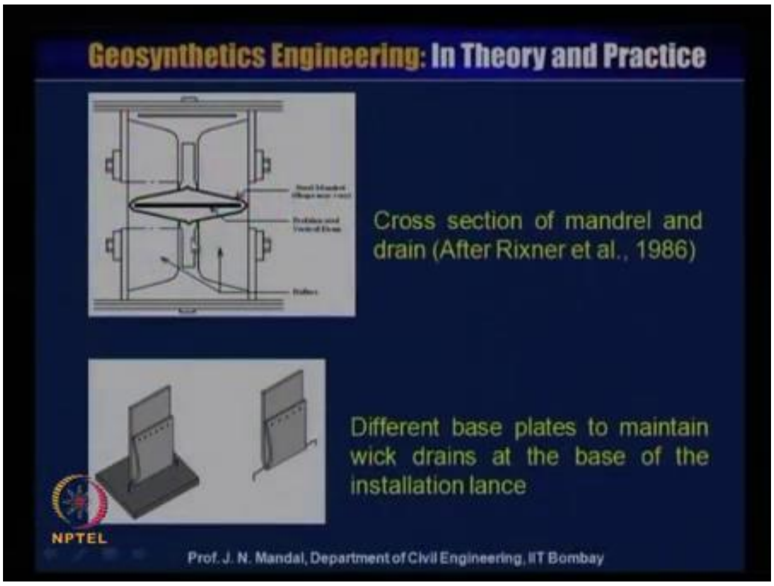

So, here is that how the PVD is joined with the rod or this the cross section of the mandrel and the drain, this is the prefabricated vertical drain. After Rixner et al 1986 or you can use the different base plate, this is the base plate and this prefabricated vertical drain is wrapped. And then you can stitch or pin or otherwise, you can use a rod so to maintain the base of the installation lance. So, this whole thing, this base plate or the rod with what this prefabricated vertical drain is attached and with the casing or the mandrel, the entire thing we inserted into the soft soil, to the desired depth. And then leaving behind this base plate or the rod and the prefabricated vertical drain then mandrel is withdrawn from the soft soil. So, this is the where, that prefabricated vertical drain is installed into the soft soil.

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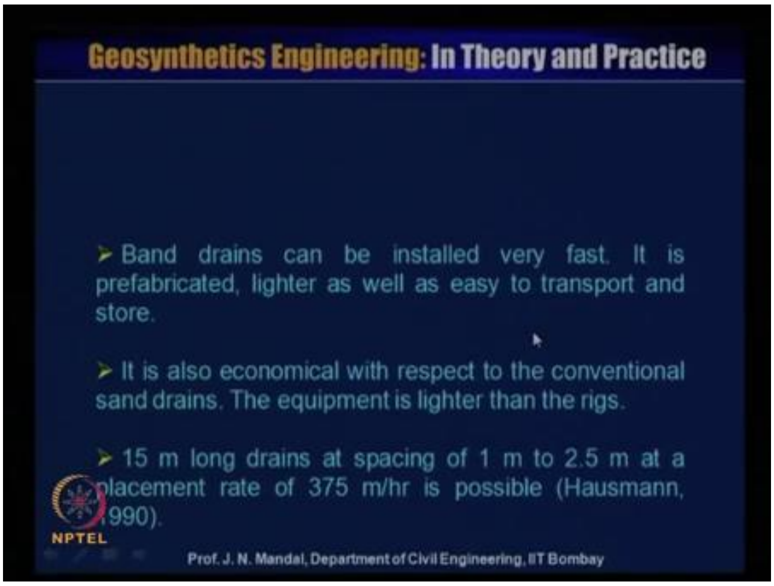

So, band drain can be installed very fast, it is prefabricated lighter as well as easy to transport and store, it is also economical with respect to the conventional sand drain. The equipment is lighter than the rigs, 15 meter long drain at spacing of 1 meter to 2.5 meter, at a placement rate of 375 meter per hour is possible, as mentioned Haussmann, 1990.

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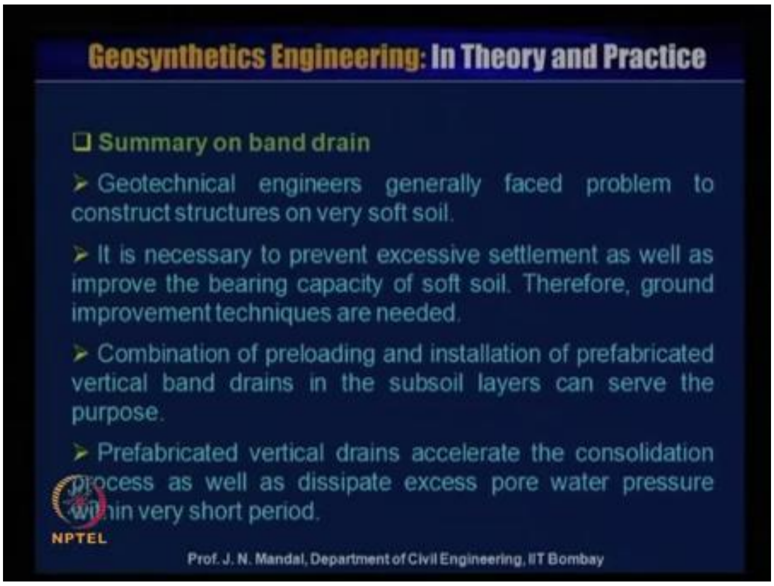

So, summary of the band drain, geotechnical engineer generally faced problem to the construction structure, on very soft soil. So, it is necessary to prevent the excessive settlement, as well as improve the bearing capacity of soft soil therefore, ground improvement techniques are needed. Combination of preloading and installation of prefabricated vertical drain, in the subsoil layer can serve the purpose. Prefabricated vertical drain, accelerated the consolidation process as well as dissipate excess pore water pressure within a very short period.

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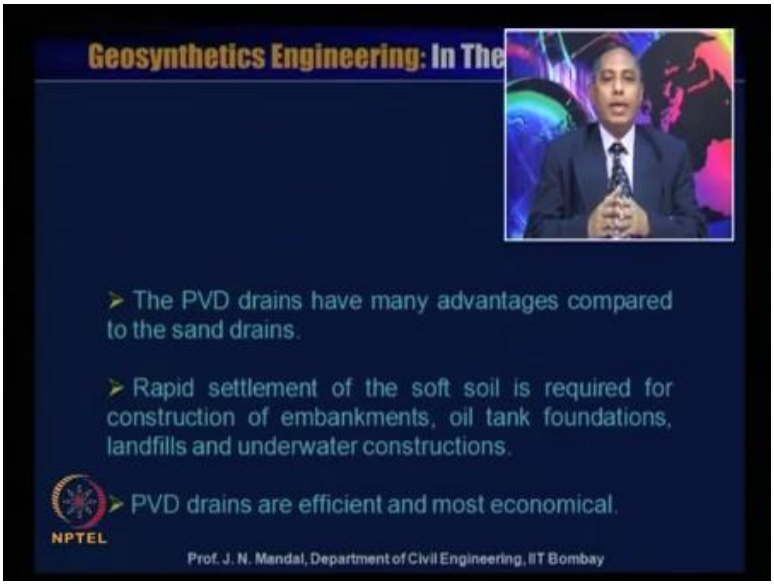

Now, prefabricated drain have many advantage compared to the sand drain. Rapid settlement of the soft soil is required for construction of the embankment, oil tank foundation, landfill and underwater construction. Sometimes that sand drain may not be continue, if the mandrel is withdrawn very fast. Apart from that, due to the surcharge load there is a possibility for the shear failure of the foundation soil. And in addition to that, as you know that small diameter of the sand drain, offer no shear resistance of the soil.

So, you require also initially very low surcharge load, in case of the sand drain so you cannot put the heavy surcharge load. And also it is very difficult and critical to obtain the material for surcharge, on to the spot and you may require about 10 meter height of the surcharge load and that is very common. But it is sometimes, the difficult to obtain the material on the spot and also it will be very expensive. Now PVD drains, but in case of the prefabricated vertical drain is efficient and most economical with respect to, the sand drain. Now, what is will happen between the polymer prefabricated vertical drain and the natural prefabricated vertical drain, when you will install into the job site. Now you can see that, some differences in the, in the installation technique that for the natural material prefabricated vertical drain, and also the polyester prefabricated vertical drain. In case of the polyester prefabricated vertical drain, when you install the dynamic load and there is a possibility, for the breaking of the core material.

But in case of the natural prefabricated vertical drain, if you apply the dynamic load then core material like a coil or jute will not break. And when you are insulating this prefabricated vertical drain, you do not know that, whether the prefabricated vertical drain has been installed properly, vertically or not or what is happening below the ground surface. So, this is the barrier possibility of the configuration of the vertical accommodation to the soil settlement.

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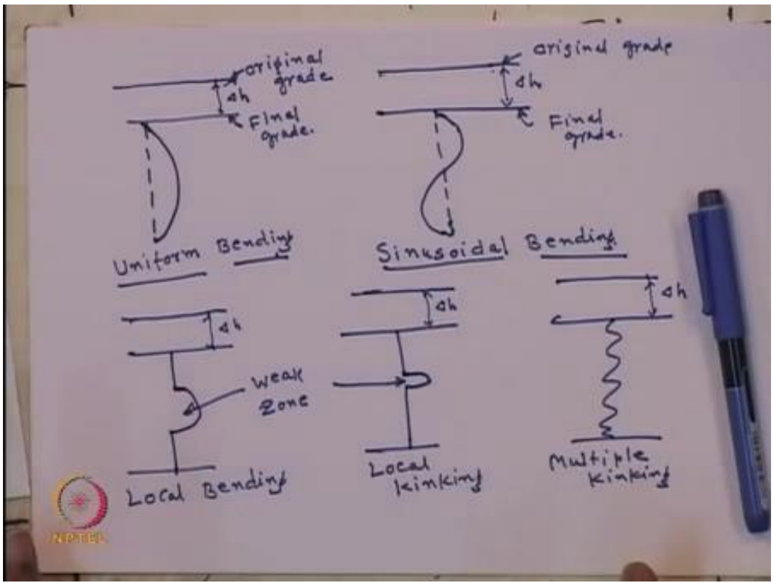

So, what may happen that in some cases, that if this is the drain and this is the original grade and this is let us say delta of h and here the relatively, the uniform soil mass and here is the final. So, this drain may be uniformly bending so there is a possibility for uniform bending or it may, if this is the drain so it may be like this, like this, that mean this is sinusoidal bending, this kind of the bending may occurs.

So, this is the original grade and this is the final grade so that may be the sinusoidal bending or there may be the uniform bending. You do not know, but this may happen or it may be, let us say this is delta of h and this drain may be like this or what you call that local bending, there is may be the local bending and this is the weak zone. Or it may be, this is delta of h or it may be like this.

So, here also this is weak zone and this may be local, called kinking or it may be, if this is the delta h or it may be like this. So, this you call the multiple kinking and this is given by Roland C and Cohen, 1988. So, these are the possibility for various configuration of the vertical accommodation, for the soil settlement. May be we do not know, but there is a possibility this kind of the configuration so this is all much more on the research oriented.

So, one can observe that what is happening and that way also, some ((Refer time: 37:12)) tests also have been conducted and find out some kind of the, kinking of the drain, has also observed. Because for the kinking, that flow of water will reduce because the cross sectional area also reduced so flow of water will be reduced. So, that way this drainage capacity also will be reduced. So, we do not know what is happening below the ground surface, but these are the some possibility for the ((Refer time: 37:15)). Now, we are showing one example.

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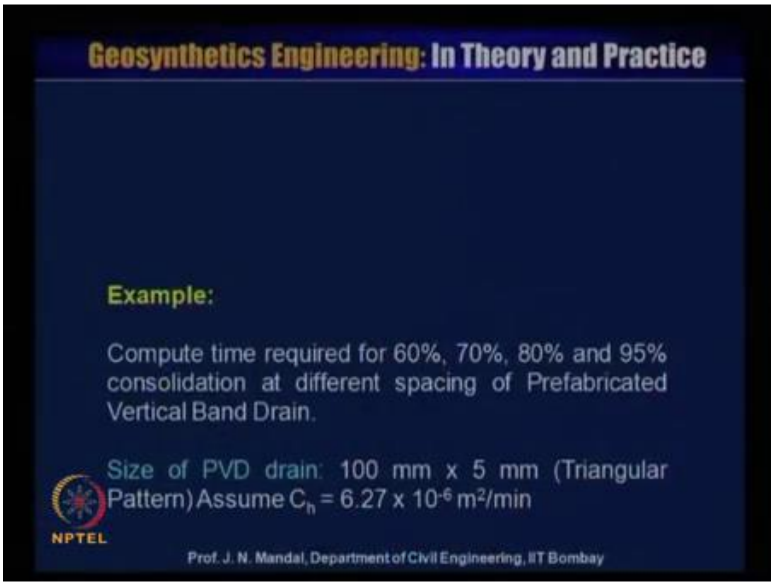

Compute time required for 60 percent, 70 percent, 80 percent and 95 percent consolidation, at different spacing of prefabricated band drain. Now, the size of the PVD drain is suppose given 100 millimeter into 5 millimeter and we are considering, this is a triangular pattern. And assume that Ch value is 6.27 into 10 to the power minus 6 meter square per minute.

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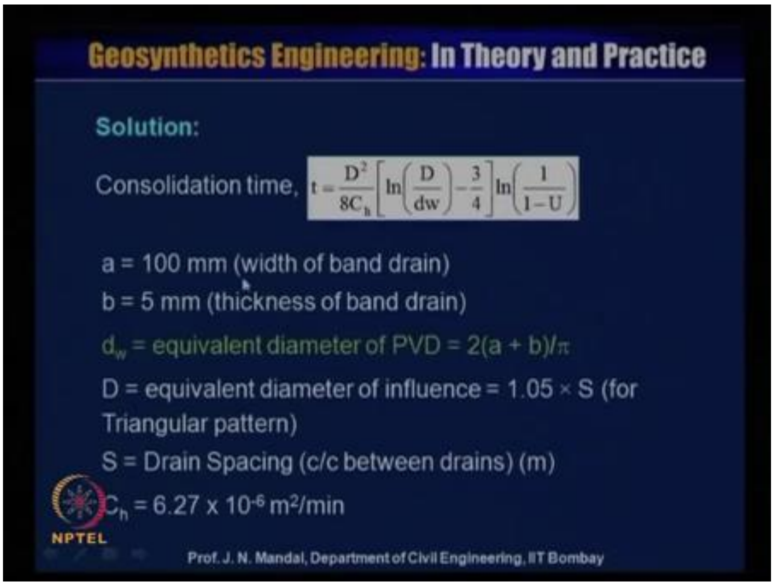

So, here is the solution you know consolidation time t is equal to, D square by 8 Ch l n D by d w minus 3 by 4 into log 1 upon 1 upon U. We know that size of the prefabricated drain, that is, a is 100 millimeter width of the band drain, b is 5 millimeter thickness of the band drain. And d w is a equivalent diameter of the PVD, that is 2 into a plus b divided by pi, means circumference by pi. So, you know a and b so you can calculate what is dw. So, 2 into 100 plus 5 by pi and D is equivalent diameter of the influence, that is 1.05 S for triangular pattern. Because, we have considered triangular pattern and S is drainage spacing from center to center, between the drain in meter. And Ch is given 6.27 into 10 to the power minus 6 meter square per minute.

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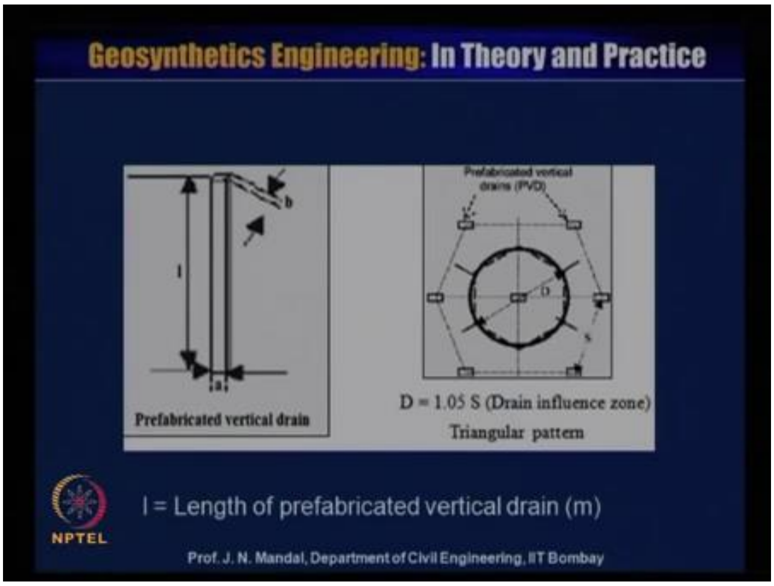

So, here you have shown that this, the prefabricated drain whose the length is L of the fabric drain and this is the a, that is width and this is the b, thickness. And here, this prefabricated vertical drain is placed in a triangular form, you can see this is the triangular form, this is a triangular form. Like this triangular form, this is a triangular form and this is a hexagonal and we assume, this as a equivalent diameter. This is hexagonal, almost you put it as equivalent diameter and that is what is D, what is D so these are the prefabricated vertical drain. So in case of triangular pattern, that is why D will take 1.05 into S and a lies, length of the prefabricated vertical drain in meter.

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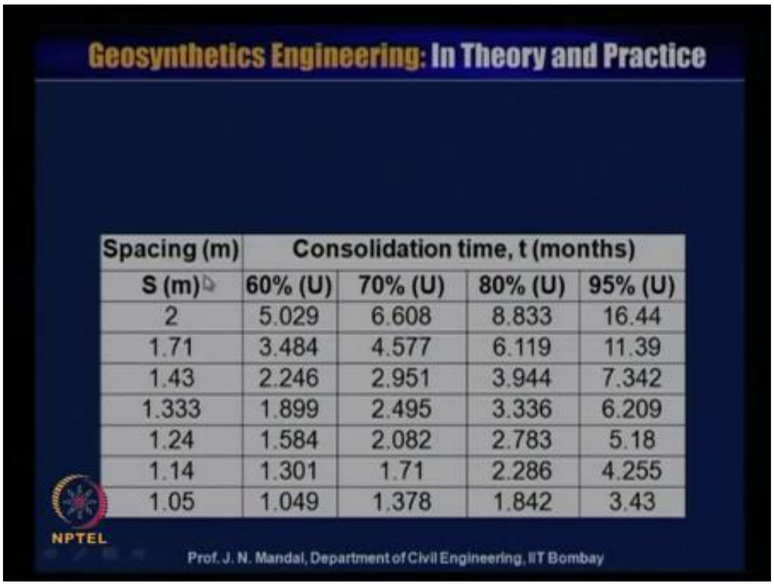

Spacing (m)	Consolidation time, t (months)			
S (m)	60% (U)	70% (U)	80% (U)	95% (U)
2	5.029	6.608	8.833	16.44
1.71	3.484	4.577	6.119	11.39
1.43	2.246	2.951	3.944	7.342
1.333	1.899	2.495	3.336	6.209
1.24	1.584	2.082	2.783	5.18
1.14	1.301	1.71	2.286	4.255
1.05	1.049	1.378	1.842	3.43

So, here is the spacing either D or S so you are assuming different value of D or S. Suppose these 2.2 meter spacing, 1.71, 1.43, 1.3, 1.24 so you are assuming different value of D, average spacing D, D is related with 1 point is here, you are put in S, but you can have in terms of the D. And you have to calculate consolidation time t, in months for let us say U is equal to 60 degree, I am telling you one factor suppose when, what will be the time for U is 60 degree so if we can see this equation here. So, we know what is D let us say, D is equal to 1.5 meter spacing so D you know Ch value is known 6.27 into 10 to the power minus 6 and d w value also you know. Because 2 into a plus b by pi then 2 into 100 plus 5 by pi so you know d w, you know D and you are considering for 60 percent consideration, then U is 60.

So, you know 60, you know D by d w, you know Ch, you know D so you can calculate t, what will be the time required, our target is what time required to reach the 60 percent degree of consolidation. So, here is the table source that what is the time in month to reach 60 percent degree of consolidation U, with this spacing. So, similarly same spacing if you reach to 70 percent U, you put those value, so you can obtain this value 6.608. For 80 percent U, you can have the consolidation time 8.833 months, for 95 percent U you can reach this consolidation time is 16.44 months.

You can see that degree of consolidation increasing also, that consolidation time is also increasing and here it has also shown, for different spacing, different spacing. You can see when you require the lower spacing, let us say 1.05 meters center to center, you can see to reach that 90 percent degree of consolidation within 3.43 month, 80 percent degree of consolidation 1.842. Whereas, if you keep the spacing more, also you can see your requirement for consolidation time is more so you require 16.44.

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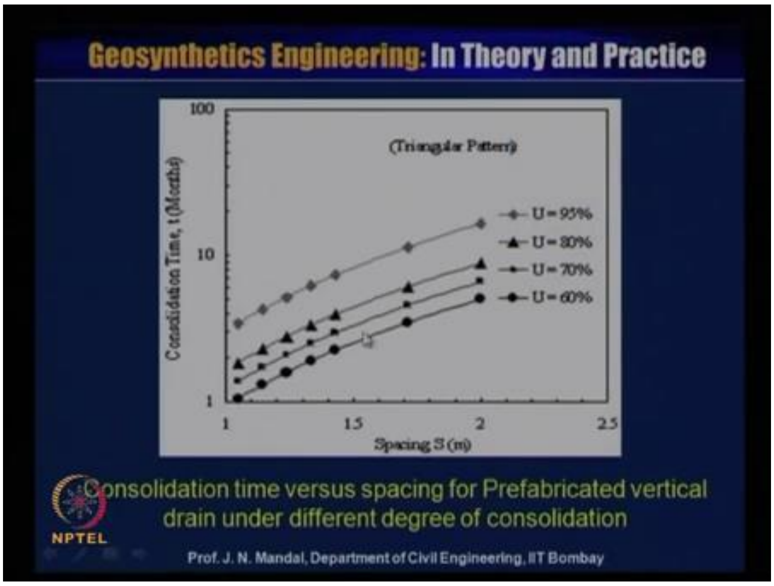

So, from this table you can also draw a relationship between the consolidation time versus spacing of the prefabricated vertical drain, under different degree of consolidation. These are main triangular pattern so this is the time, this, the spacing, this is the U value so U value 60, 70, 80, 95. So, if you want to know what will be the consolidation time required, if you fix up this spacing then if you want to reach the 95 percent consolidation then you will be knowing how many months you require. If you want to reach 60 percent degree of consolidation then you will be knowing what will be the consolidation time required. So, from this design chart also you can calculate that, what should be the spacing between the reinforcement.

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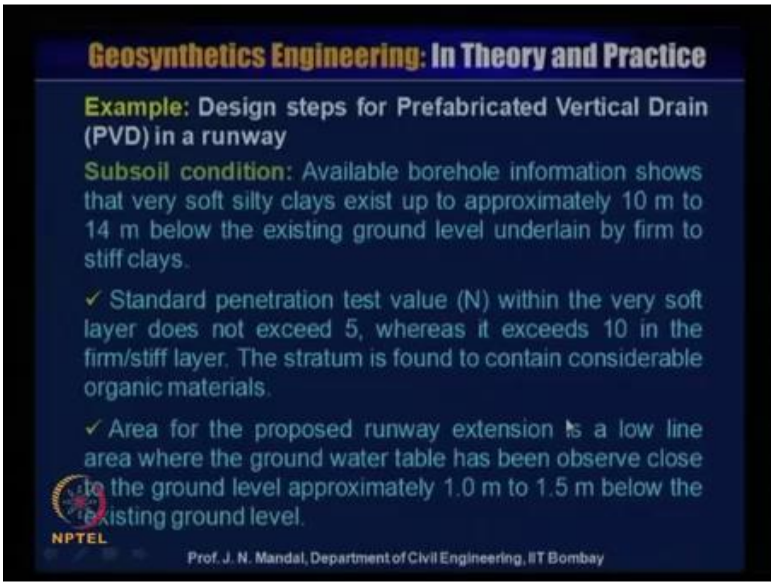

Here is one example is given, the design steps for prefabricated vertical drain PVD in a runway. So, this is one of the project, the subsoil condition available borehole information show that, very soft silty clays exist up to approximately 10 meter to 14 meter, below the existing ground level, underlain by firm to stiff clay. Standard penetration test value N, when the very soft layer does not exceed 5, whereas, it exceeds 10 in the firm and stiff layer. The stratum is found to contain, considerable organic material, area for the proposed runway extension is a low line area where, the ground water table has been observed close to the ground level approximately 1 meter to 1.5 meter, below the existing ground level. You can see that, what will be the silt local area.

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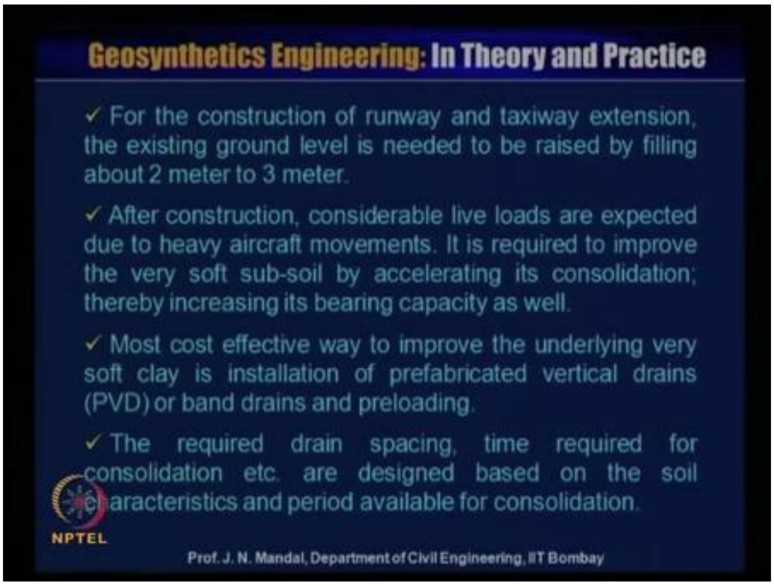

For the construction of the runway and taxiway extension, the existing ground level is needed to be raised by filling about, 2 meter to 3 meter. After construction, considerable live loads are expected due to the heavy aircraft movement, it is required to improve the very soft sub soil, by accelerating it consolidation. Thereby, increasing it bearing capacity as well, most cost effective way to improve the underlying very soft clay is, installation of prefabricated vertical drains or band drain and preloading. The required drain spacing, time required for consolidation etcetera are designed based on the soil characteristics and period available for consolidation.

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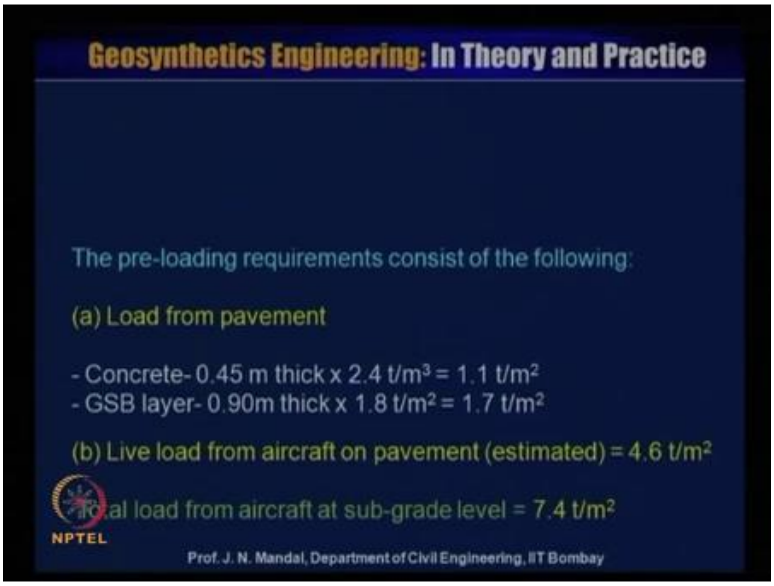

So, pre loading requirement consist of the following a, load from the pavement. So, concrete is 0.45 meter thick and density 2.4 ton per meter cube so this is 1.1 ton per meter square. So, this is the load coming on the pavement from concrete and GSB layer is 0.90 meter thick and density 1.8 ton per meter square. So, it will give 1.7 ton per meter square and live load from the aircraft of the pavement estimated is, 4.6 ton per meter square. So, total load from the aircraft at the sub grade level is 1.1 plus 1.7 plus 4.6, this will give 7.4 ton per meter square. So, this is the total load of aircraft at the sub grade.

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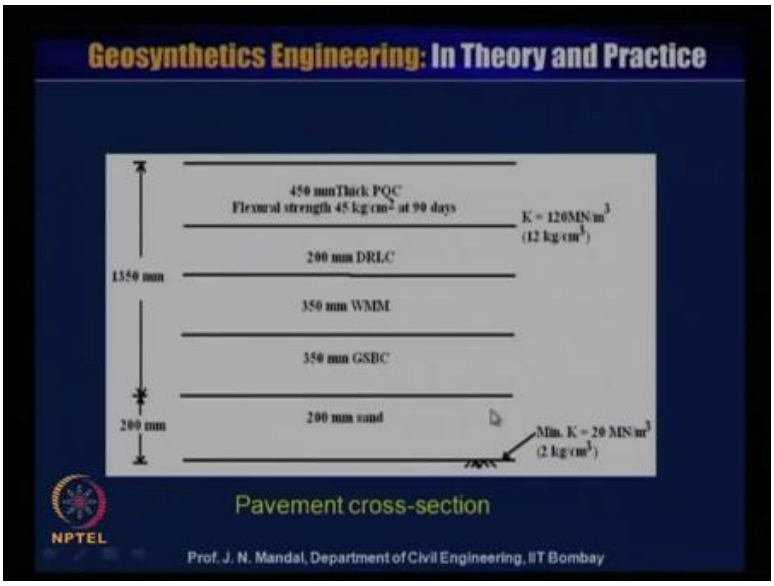

So, this is the pavement cross section so this is the 450 millimeter thick PQC, flexural strength is 45 kg per centimeter square at 90 days. And this k value is given 120 MN per meter cube, that means 12 kg per centimeter cube. And this is 200 millimeter DRLC, this is 350 millimeter that is WMM and 350 millimeter GSBC and 200 millimeter sand and here minimum k is 20 MN per meter cube or 2 kg per meter cube. This depth is about 200 millimeter from and here to here is about 1350 meter.

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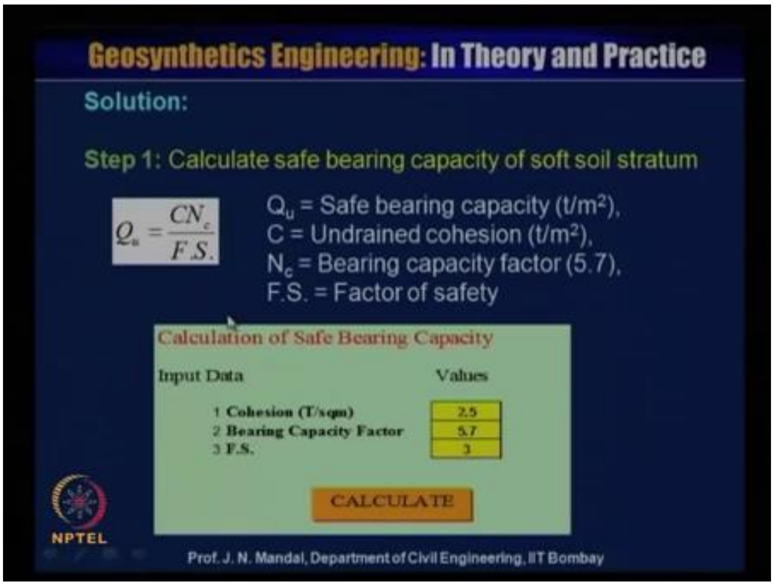

So, solution step 1, calculate the safe bearing capacity of soft soil stratum. You know the equation Qu is equal to, C into Nc divided by FS, that factor of safety Qu is the safe bearing capacity ton per meter square. C undrained cohesion value ton per meter square, Nc value bearing capacity factor value is 5.7 and FS factor of safety. So, you calculation of safe bearing capacity so you put input data 1, cohesion is 2.5 ton per square meter and bearing capacity factor is 5.7. So, factor of safety 3 so you can calculate and you can obtain this factor of safety.

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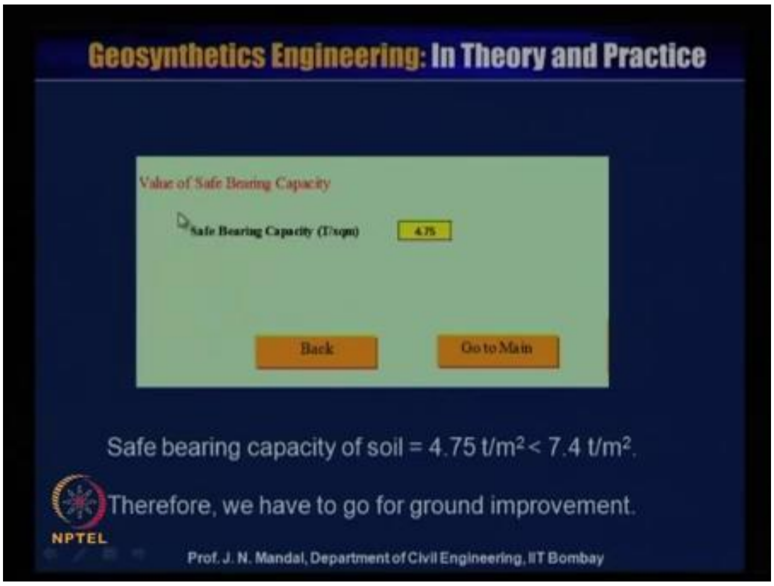

Now, this value of safe bearing capacity so safe bearing capacity is 4.75 ton per square meter. So, safe bearing capacity of soil 4.75 ton per meter square, but you have observed that your load coming is 7.4 ton per meter square. So, 475 ton what you say bearing capacity less than the 7.4 ton per meter square, what is required. Therefore, we have to go for ground improvement because it does not satisfied the bearing capacity of the soil.

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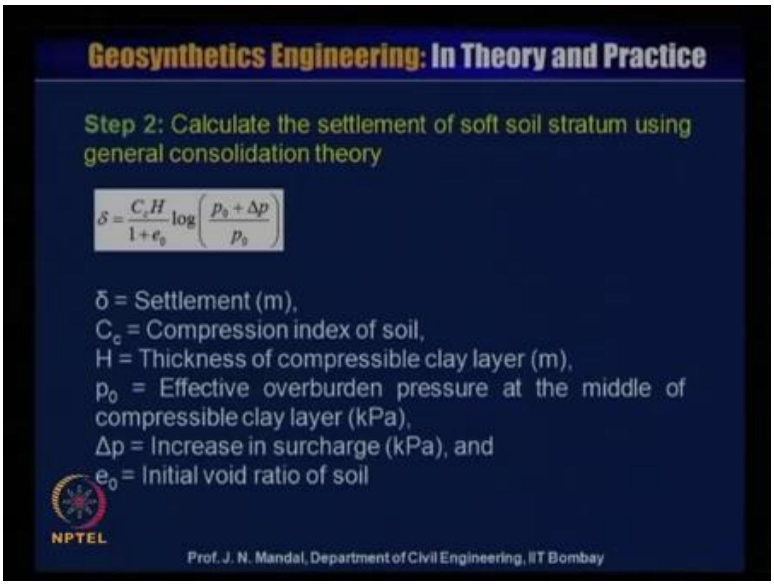

Now step 2, calculate the settlement of soft soil stratum using the general consolidation theory. So, you know that delta is equal to Cc H 1 plus e 0 log p 0 plus delta p by p0, while delta is equal to settlement in meter, C c compression index of soil and H is the thickness of the compressible clay layer in meter. And p 0 is effective overburden pressure, at the middle of compressible clay layer in kilopascal, delta p increase in surcharge kilopascal and e 0 initial void ratio of the soil.

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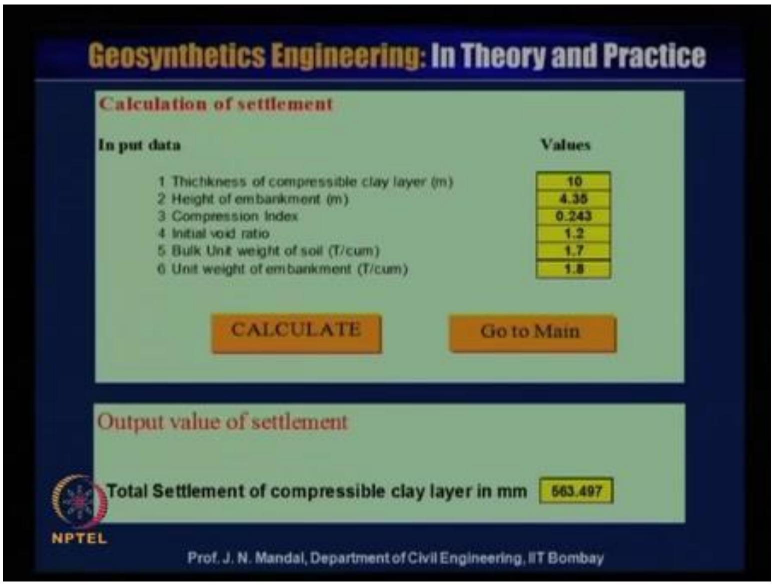

Now you have to calculate the settlement, you have to put the input data, thickness of the compressible clay layer is 10 meter, height of the embankment is 4.35 meter, compression index is 0.243 and initial void ratio is 1.2. And bulk unit weight of the soil in ton per meter cube meter is 1.7 and unit weight of the embankment ton for cubic meter is 1.8. So, if you calculate then you can obtain the settlement of the compressible clay layer in millimeter is 563.497 millimeter. So, this is the settlement you have calculated, you calculate bearing capacity, you calculate the settlement.

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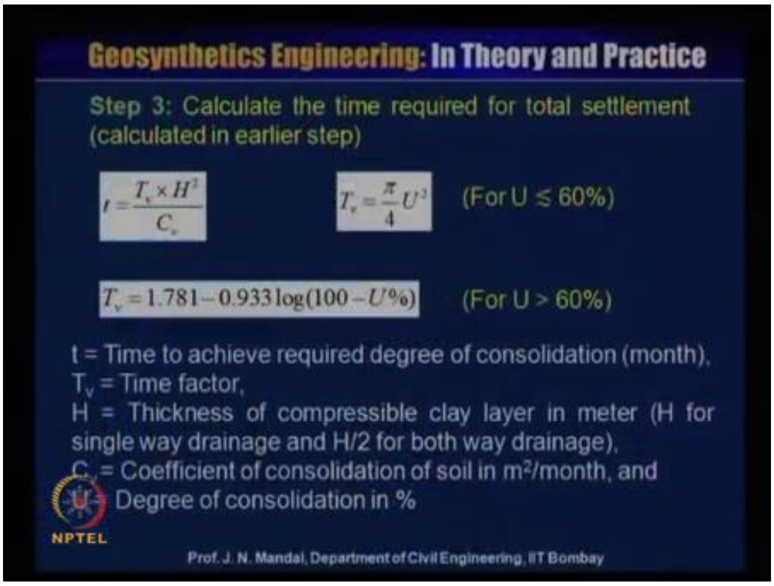

Step three, calculate the time required for total settlement so calculation in earlier step. So, you know that t time is equal to T v into H square by C v or T v is equal to pi by 4 into U square. Because U is less than equal to 60 percentage and T v is equal to 1.781 minus 0.933 log 100 minus U percentage, for u greater than 60 percent. While t is time achieved required degree of consolidation in month and T v is equal to time factor, H is equal to thickness of compressible clay layer in meter. And H for single way drainage layer and H by 2 for both way drainage and C v coefficient of consolidation of soil, in meter square per month and U degree of consolidation in percentage.

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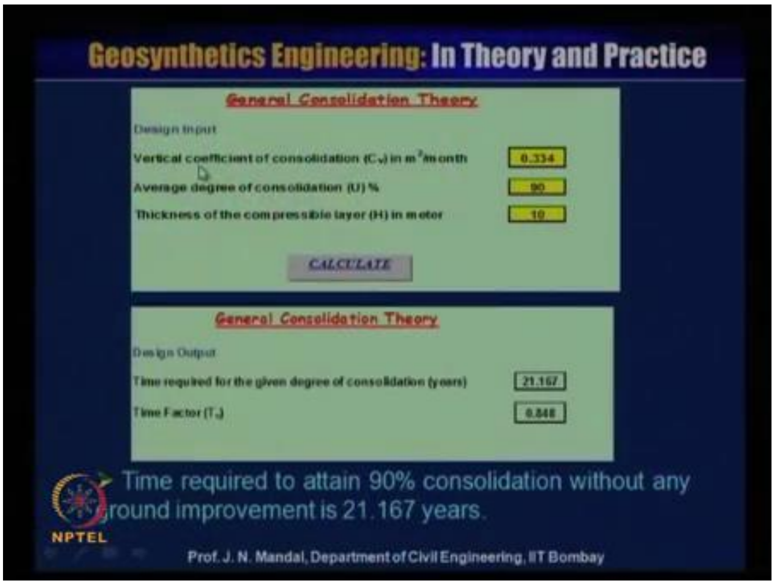

Here, you can put the vertical coefficient of consolidation that is C v in meter square per month, is 0.334 then average degree of consolidation that is U in percentage is 90 percent. So, thickness of the compressible layer H in meter is 10 so if you calculate using the general consolidation theory. So, you can have the design output that mean, time required for the given degree of consolidation in year 21.167 and time factor T v is 0.848. So, you see the time required to attain 90 percent consolidation without any ground improvement is 21.167 years. So, you have to wait more than 21 years to consolidate the soil, to improve the ground, so it is the very critical and difficult.

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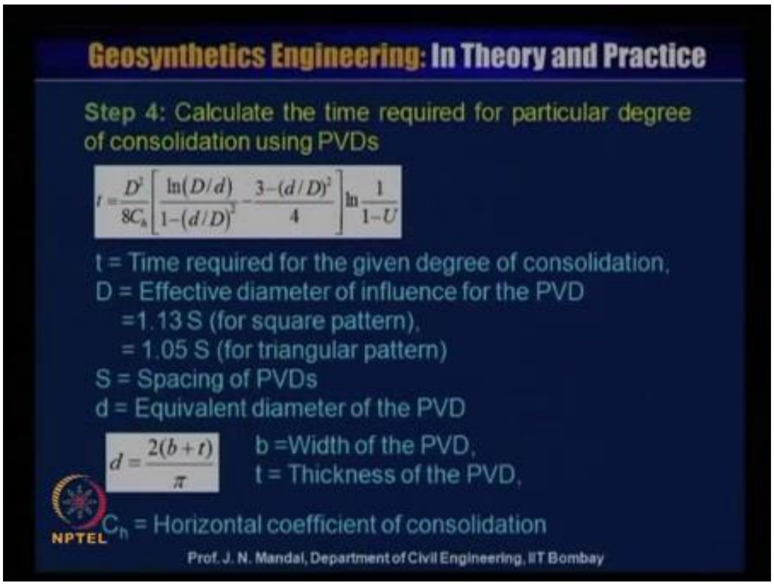

So step 4, calculate the time required for particular degree of consolidation using PVD. So, you know the t is equal to D square by 8 Ch l n D by d 1 minus d by D square minus 3 minus d by D square by 4 l n 1 upon 1 upon U. t is equal to time required for given degree of the consolidation and D is effective diameter of influence, for the PVD. That is 1.13 S for square pattern, 1.05 S, for triangular pattern, for S is equal to spacing of PVD and d is equivalent diameter of the PVD. That is d is equal to 2 into b plus t divided by pi where b is a width of the PVD t is the thickness of the PVD and Ch is the horizontal coefficient of consolidation.

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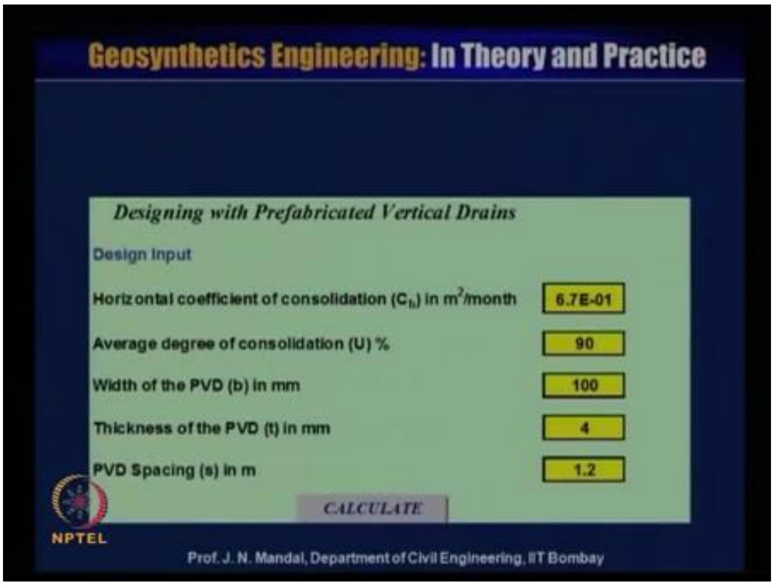

Now, design with prefabricated vertical drain you can put, the design input horizontal coefficient of consolidation Ch in meter square per month, 6.7 into 10 to the power minus 1. And average degree of consolidation U is, 90 percent width of the PVD in millimeter 100 millimeter, thickness of the PVD t in 4 millimeter so PVD spacing S in 1.2.

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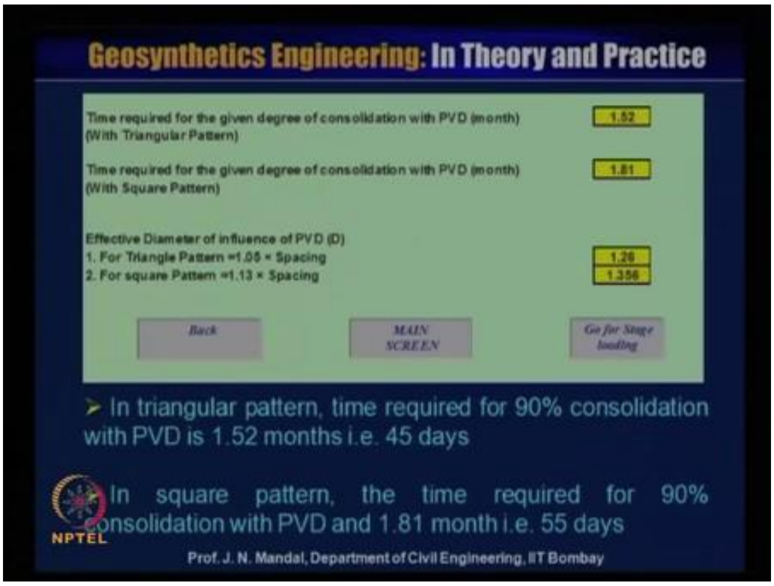

So, you can calculate so what will be the time required, for the given degree of consolidation with PVD in month 1.62. And time required for the given degree of consolidation, with PVD is 1.81 when, there is a square pattern and earlier one when, there is a triangular pattern. So, effective diameter of influence of PVD that is for triangular pattern is 1.05 into spacing, that is why it give 1.26 and for 2 for square pattern is equal to 1.13 into spacing that is 1.356.

So, in triangular pattern time required for 90 percentage consolidation with PVD is 1.52 month that is for 45 days, in square pattern the time required for 90 percent consolidation with PVD and 1.81 month that is 55 days. So, you can complete this consolidation using the prefabricated vertical drain within 45 days, if it is a triangular pattern and 55 days, if it is a square pattern.

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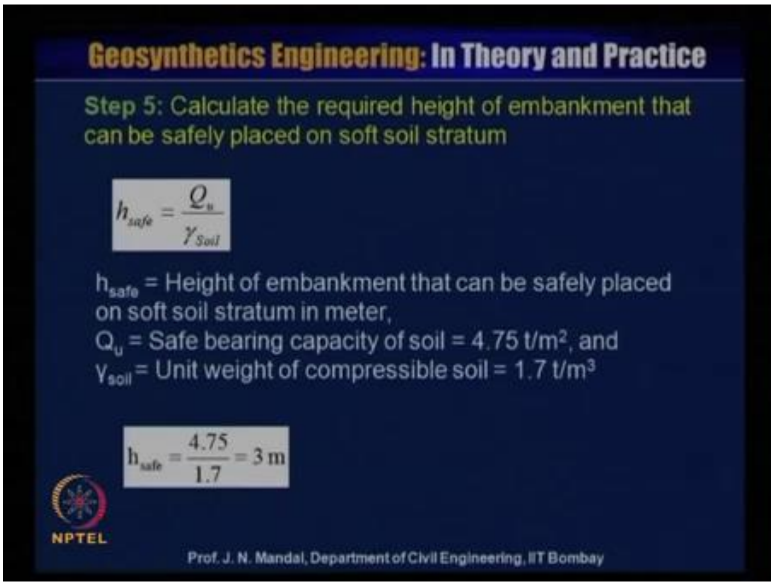

Step five, calculate the required height of embankment that can be safely placed on soft soil stratum. So, h safe is equal to Q u by gamma of soil, h safe is equal to height of the embankment, that can be safely placed on soft soil stratum in meter. And Q u is the safe bearing capacity of the soil is 475 ton per meter square and gamma soil unit weight of compressible soil is 1.7 ton per meter cube. So, you can calculate what will be the height of the embankment, that can save the place, that is height h safe is equal to 4.75 by 1.7 that means, that is 3 meter.

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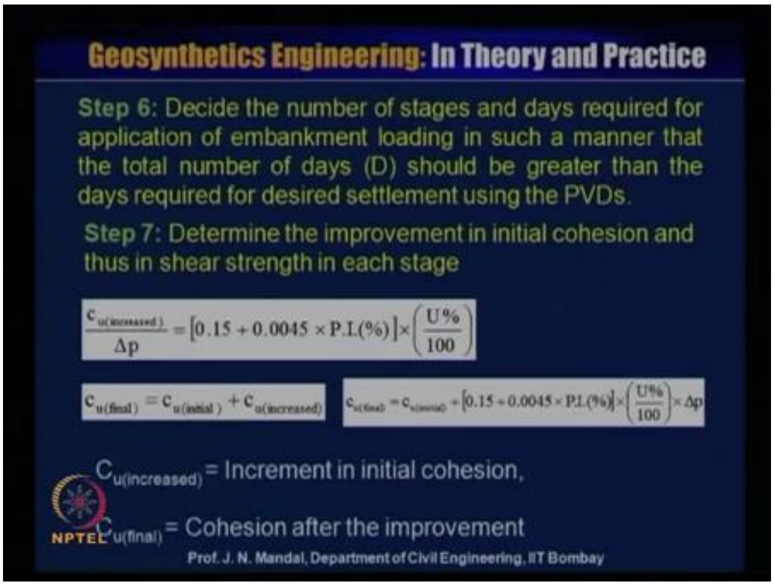

Step six, decide the number of the stages and days required for application of embankment loading. In such a manner that the total number of the days D, should be greater than the days required for the desired settlement, using the prefabricated vertical drain. Step seven, determine the improvement in initial cohesion and thus shear strength of in each stage. So, Cu increased divided by delta p is equal to 0.15 plus 0.0045 into PI in percentage, into U by 100 percentage.

So, Cu final will be Cu initial plus Cu, what is increased so Cu that final will be Cu initial and Cu increased will be equal to this into delta p. So, this into delta of p so what Cu increased is the increased in the initial cohesion, you know what will be the initial cohesion there. Then after that what will be the, cohesion after the improvement that is Cu of final. So, what will be the increased you know so you can calculate what should be the cohesion after the improvement.

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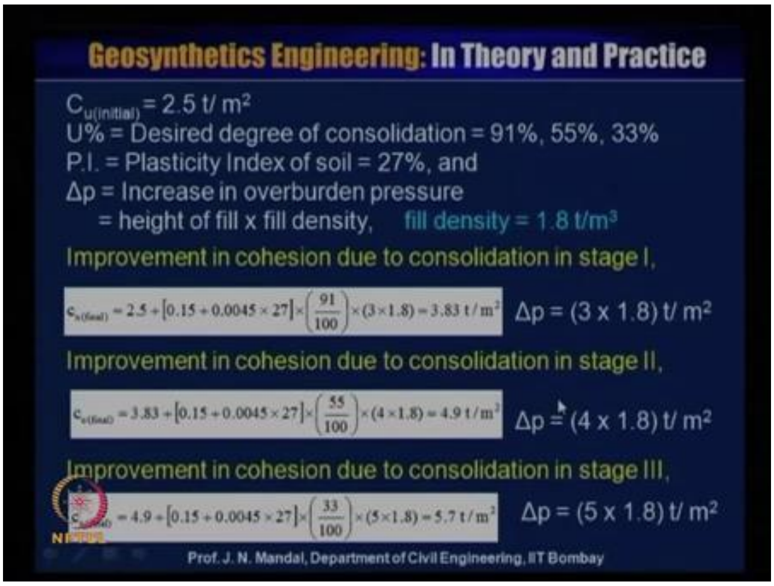

So, C u initial is given 2.5 ton per meter square where, U is desired degree of consolidation 91 percent, 55 percent and 33 percentage. PI is the plasticity index of the soil is 27 percent and delta p is the increase in overburden pressure, that means is equal to height of the fill into fill density. Fill density is given 18 ton per meter cube so improvement in cohesion due to consolidation in stage 1, that mean Cu final will be equal to 2.5.

That is initial cohesion value plus 0.15 plus, 0.0045 into this 27 that mean, plasticity index 27 into that U value 91 by 100, this into that is the 3 into 1.8 that means, 3 is the height. And density is 1.8, that is why 3 into 1.8 so this will give you that is delta p, that is delta p is equal to 3 height and density 1.8. So, 3 into 1.8 so C of u final will be 3.83 ton per meter square.

Now, improvement in cohesion due to consolidation in stage 2 so Cu final will be now initial is 3.83 plus 0.15 plus 0.0045 into 27 into now desired degree of consolidation 55, 55 by 100 into 4 into 1.8 delta p will be equal to 4 into 1.8. So, this will give the Cu final 4.91 ton per meter square now, improvement in cohesion due to consolidation in stage 3. So, Cu final is, this is 4.9 plus 0.15 plus 0.0045 into 27 into 33 the degree of consolidation, 33 by 100 into 5 into 1.8 delta p. So, this is delta p so this will give the 5.7 ton per meter square. So, you observe that that improvement of cohesion due to consolidation stage 1, consolidation stage 2 and the consolidation stage 3. So, with this I finish my lecture today. Let us hear from you, any questions?

Thanks for listening.