Geosynthetics Engineering: In Theory and Practices
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Lecture - 45
Geosynthetics for Ground Improvement

Dear student warm welcome to NPTEL phase two 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. Now, lecture number 45 and module 9 geosynthetics for ground improvement. Very often the civil engineer is faced with the site that is width to support the soil. That means when the soil is very soft and also cannot support the load, it is required to improve the bearing capacity, and reduce the settlement.

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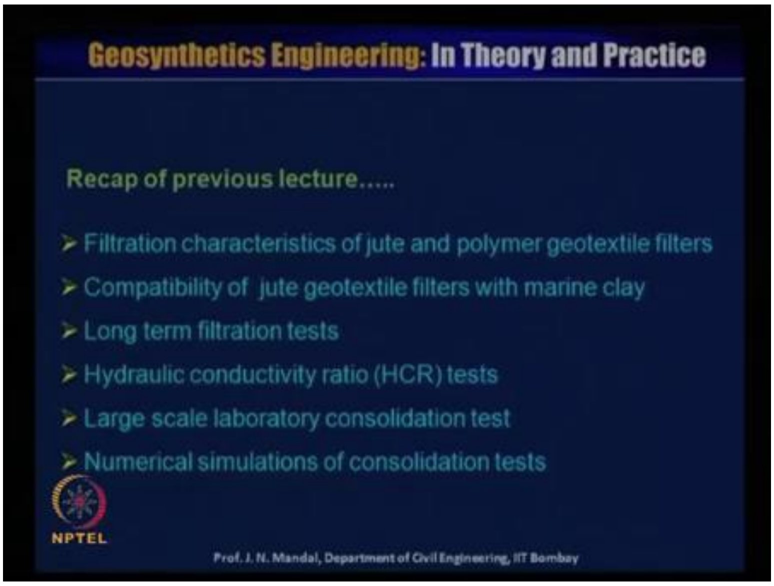

Before this ground improvement, I wanted to show the recap of the previous lecture what we have covered. Filtration characteristics of jute and polymer geotextile filters, compatibility of jute geotextile filters with marine clay, long term filtration test, hydraulic conductivity ratio test that is HCR, large scale laboratory consolidation test and numerical simulate of consolidation test. So, there are various kinds of the ground improvement techniques are available, but most of the time that civil engineer has to face the problem, when the soil is very weak or compressible soil and when the bearing capacity of the soil is very low.

Also the potential large settlement, so it is essential to improve the soft ground it is also required to improve the bearing capacity, and to reduce the settlement. So, how can you improve the bearing capacity and reduce the settlement. So, we will first go for the settlement analysis and also the bearing capacity how you can calculate the bearing capacity, and how you can calculate the settlement. And then we will talk about what will be the principle and the function.

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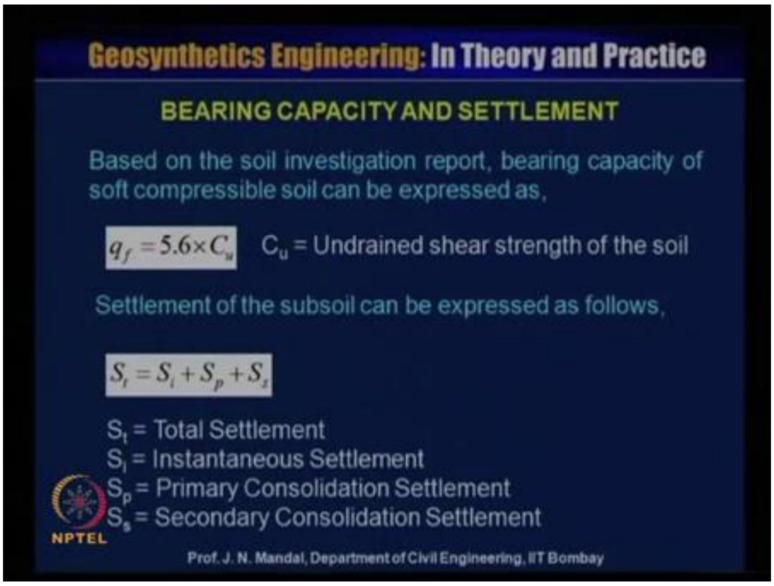

Bearing capacity and settlement based on the soil investigation report bearing capacity of soft compressible soil can be expressed as q f is equal to 5.6 into C u where C u is equal to undrained shear strength of the soil. Settlement of the subsoil can be expressed as follows S of t is equal to S i plus S p plus S s. Here, S t is equal to total settlement, S i is equal to instantaneous settlement, S of p is equal to primary consolidation settlement and S of s is equal to secondary consolidation settlement. So, if you know the undrained shear strength of the soil, then you can calculate that what would be the bearing capacity of the compressible soil.

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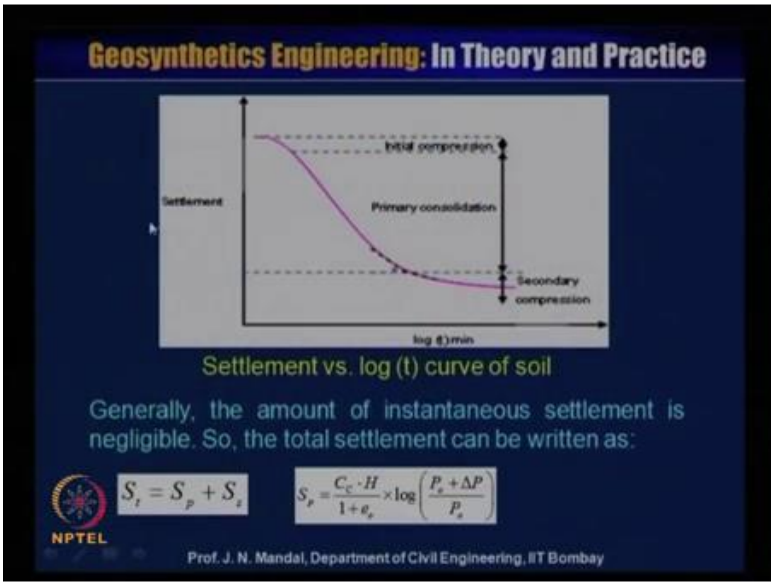

Now, in case of the settlement you can see that here is the diagram between the settlement and this is the time in minutes in log scale, you can have a nature of curve like this. So, this is the part which call the initial compression and then this is the primary consolidation and after that the secondary consolidation starts. So, generally the amount of instantaneous settlement this part is negligible, so the total settlement can be written as S of t is equal to primary consolidation, S p and then this is the secondary consolidation. So, primary consolidation you can determine from this equation you know that S p is equal to C c into H divided by 1 plus e 0 into log of p 0 plus delta p by p 0.

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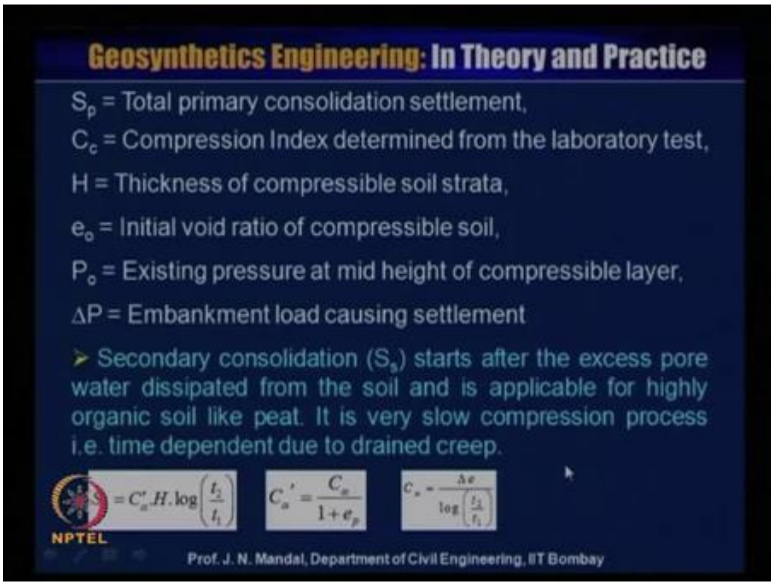

Here, S p is equal to total primary consolidation settlement, C c is compression index determined from the laboratory test, H is thickness of compressible soil strata, e 0 initial void ratio of compressible soil, P 0 existing pressure at the mid height of compressible layer and delta P is embankment load causing the settlement. Now, you have also to calculate the secondary consolidation that is S s.

So, secondary consolidation start after the excess pore water dissipates from the soil and is applicable for highly organic soil like peat. It is very slow compression process that is time dependent due to the drained creep. So, secondary consolidation can be expressed with this equation, S s is equal to C alpha dash H log t 2 by t 1 where C alpha dash is equal to C alpha divided by 1 plus e of p and then C alpha again is equal to delta e by log t 2 by t 1.

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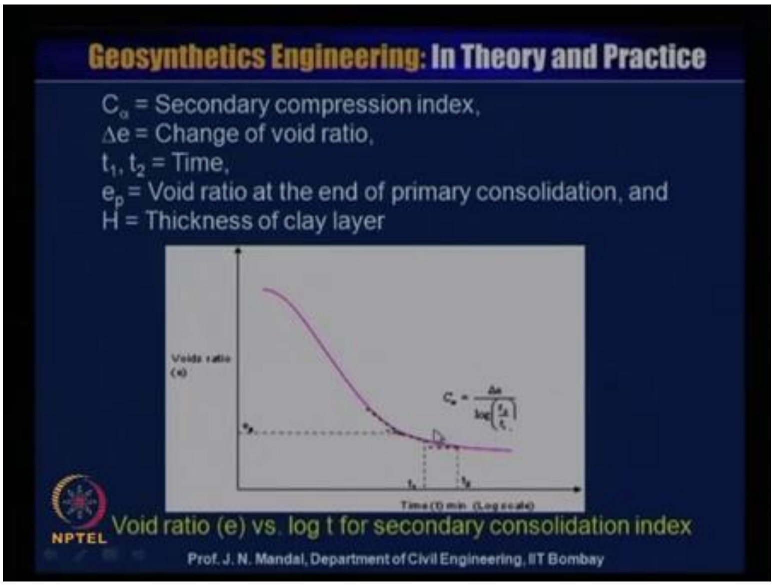

So, this you can see can be determined from this curve this is the void ratio e versus this is log t for secondary consolidation. So, where here this C alpha is secondary compression index and delta e is the change of void ratio and t 1 and t 1 is the time and here e p is the void ratio. At the end of the primary consolidation, here this is e p and h is equal to thickness of the clay layer. So, you can calculate what should be the C of alpha, that is you know this is the change in the void ratio that means this part is delta of e and this is the time t 1 and t 2. So, you know this C alpha and then you can substitute this value here then you can calculate what is C of alpha dash. So, if you substitute the value of C of alpha dash here, then you can calculate the secondary consolidation that is S s.

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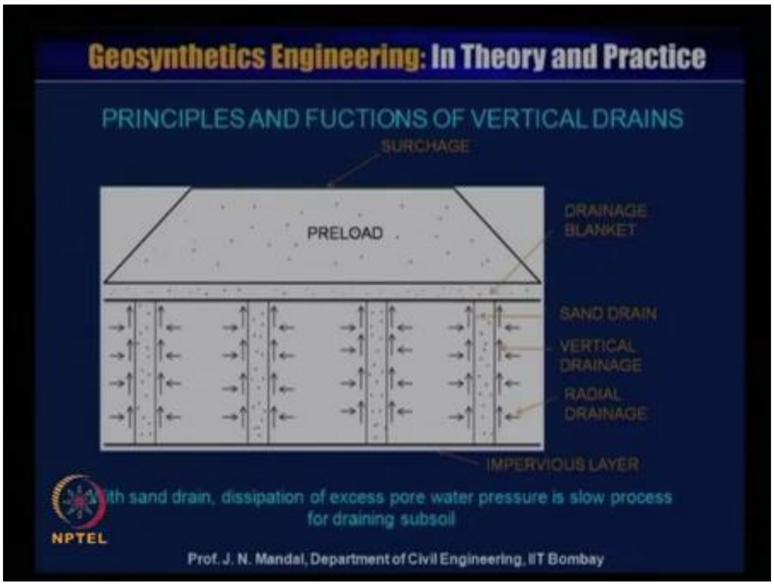

Next, we will talk about the principle and function of the vertical drain, now why we wanted to use the drain? So, very often civil engineers are required to build on the site which consists of very fine grain and saturated soil that have the poor drainage. It is a difficult and critical that all excess water be removed from the soil, here all the excess pressure are to be removed from the soil before the construction of a new infrastructure building or for any amenity structure. Now, presently there are various methods or the system available to improve the soft compressible soil.

So, here I am showing you that sand drain which is very conventional method has been used at a particular spacing. So, with the sand drain there would be also dissipation of excess pore water pressure and this is the radial drainage or the horizontal drain and this is the vertical drain. On the top of the sand drain you provide with drainage blanket and due to this preload or surcharge load then water can be drained out to the drainage side. So, this kind of the system is very slow process for the drainage, therefore you require very fast dissipation of the pore water pressure.

Now, this consolidation process you have applying the load from the top of the soil. There will be the increase of the pore water pressure and this dissipate slowly as the pore water drain up in saturated soil. The large percentage of the void of pore usually filled with water and this settlement process will be lengthy because the saturated soil has a low coefficient of permeability. So, it is more difficult and time consuming for water drained it out, therefore drainage time also depend upon the number of the factors. It depends upon the distance of the drainage path, also it depend upon what will be the spacing of the drain.

Now, this consolidation when accelerated then volume of the void is reduced and then the settlement occur, so this is the conventional system which is very time consuming now alternative to this conventional system what we can adopt. So, you can see with the conventional system, what performance of the vertical drain the vertical drain accelerated the consolidation. It is almost important that drainage performance or you have to select the proper kind of the vertical drain, but also you have to remember that failure can severely jeopardize the project construction schedule and the structural stability.

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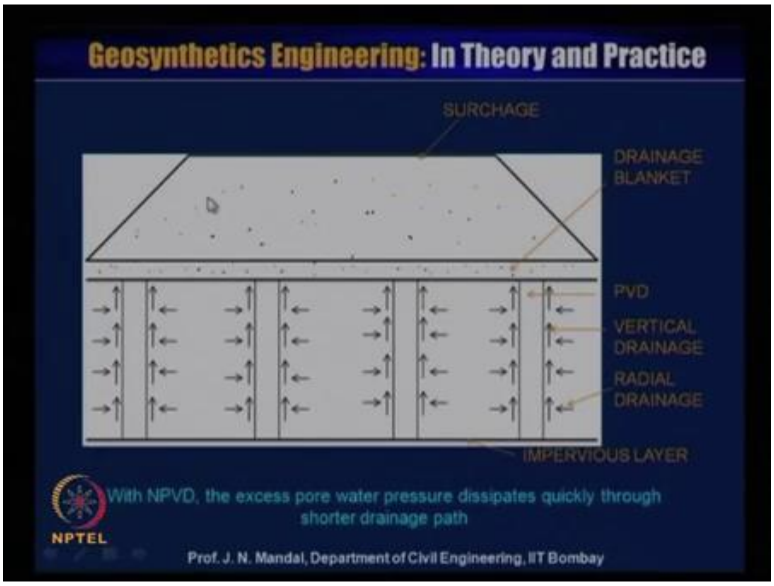

Therefore, the alternative to the sand drain we can adopt this natural prefabricated vertical drain. So, this is the natural prefabricated vertical drain, you can use because this natural prefabricated vertical drain is among the most economical and suitable method. Also, you can use the suction, then also it can reduce the time for acceleration, here this is the natural prefabricated vertical drain and there is a radial drain also the vertical drain.

You can provide with drainage blanket or any geotextile or geocomposite material on the top of the natural prefabricated vertical drain.

Then you can provide with the surcharge load or preload also with the N P V D, the excess pore water pressure dissipated quickly through the shorter drainage path. So, in case of sand drainage it is a slow process. So, it takes time to consolidated, but in case of the natural prefabricated vertical drain or the polyester prefabricated vertical drain, the excess pore water pressure dissipate very quickly through the shorter drainage path.

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Now, this is a system that suppose this is the natural prefabricated vertical drain and this has a drainage body a unique core this is the core material and this is the jacket. Now, this unique core material made of coir rope this is coconut coir rope. It is specifically designed to provide the high discharge capacity, high tensile and compressive strength and this is the filter jacket. This is the strong and durable jute geotextile with good tensile strength. Also, it has a high permeability and effective filtering property. Now, if you combine both the the core material and the filter jacket, this will give you the unique combination and it provide also very effective fast and reliable performance for soil improvement.

So, what you can that achieve from this kind of this material if you introduce into the very soft clay. So, it will reduce the settlement and increase the bearing capacity, also decrease the permeability and it also change the dynamic response and reduce the risk of liquefaction. Now, one of the interesting things to note here that when we will use the natural prefabricated vertical drain, where you are inserting the natural prefabricated vertical drain into the soft ground and you can apply the dynamic load.

If you apply the dynamic load, this material will not crack, it may bend, but it will not cut, both the material either the jute geotextile or the coir geotextile. So, it will not break, but if we use this polyester prefabricated vertical drain and this is the core material and this is the jacket material, it is spun bonded nonwoven geotextile material. This is the core channel, it is a plastic, but when you apply the dynamic load on the natural prefabricated vertical drain and this may break, this plastic may break. So, its discharge capacity also will reduce, so this is one of the good advantages between the natural prefabricated vertical drain as well as the polyester prefabricated vertical drain.

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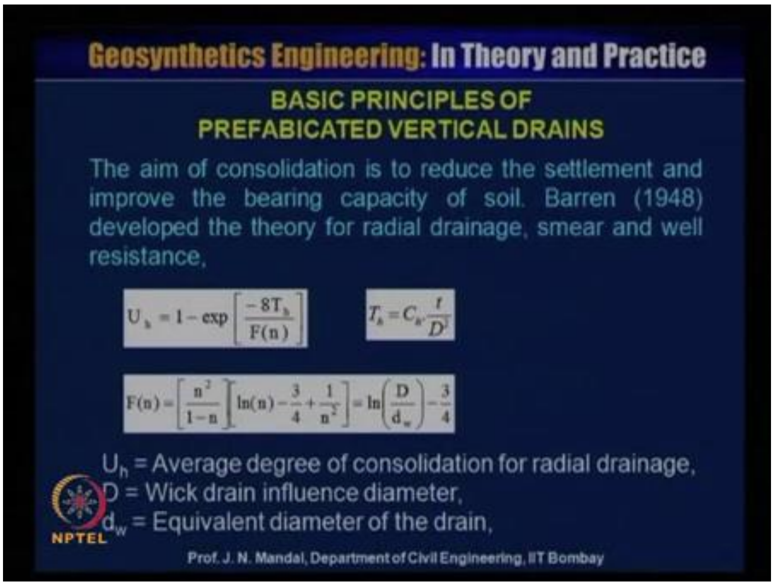

Now, what are the basic principle of prefabricated vertical drain the aim of consolidation is to reduce the settlement and improve the bearing capacity of soil barren 1948 developed the theory for radial drainage smear and well resistance. This is the equation U h is equal to 1 minus exponential minus 8 T h divided by F n. this T h is equal to C h into t by D square. This F n is equal to n square by 1 minus n l n n minus 3 by 4 plus 1 by n square is equal to l n D by d w minus 3 by 4 where n is equal to D by d w. So, U h is the average degree of consolidation for radial drainage and D is the wick drain influence diameter and d w is equivalent diameter of the drain.

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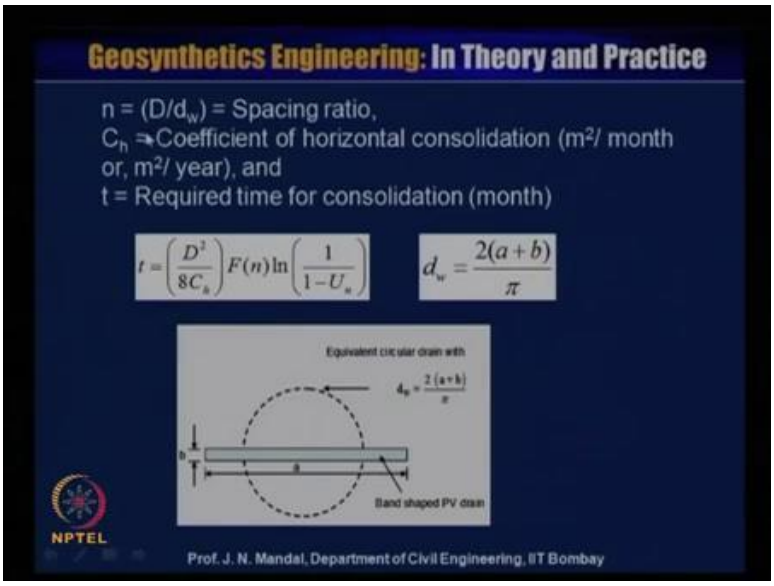

So, n is equal to D by d w which is called the spacing ratio and C h coefficient of horizontal consolidation that is meter square per month or meter square per year and t is equal to required time for consolidation in month. So, we can write this t is equal to D square by 8 into C h F n into l n 1 by 1 minus U h. Here, that d of w, this is d of w, so this is the band drain or the prefabricated vertical drain which this is the width is a, and this is the thickness is b.

So, equivalently it will be like a equivalent circular drain, so which is designated at d of w, so d w will be equal to circumference by pi that means 2 into a plus b divided by pi. So, you can determine that what will be the equivalent diameter of this drain prefabricated drain, so you can calculate d w so you know that what will be the value of d w. Now, this is a drain you can place in the triangular pattern and also as a square pattern.

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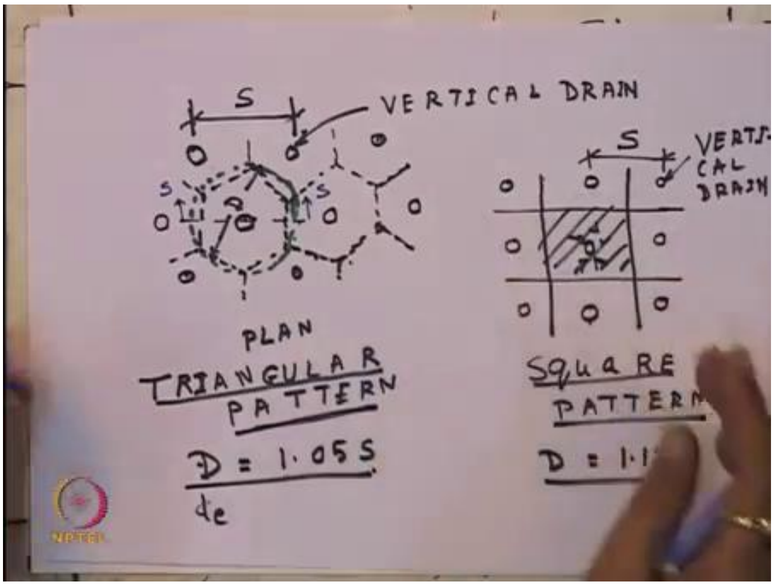

So, for example this is the drain this the prefabricated drain, so this are the vertical drain, so let us say this is the vertical drain and this is in triangular pattern like this. This is triangular pattern, so you have placed in a triangular pattern and the spacing between this drain let us say S. So, you can define the spacing between this vertical drain which can be defined as S and this is the plan this is different drain pattern for equivalent cylinder, so here making like a hexagonal and ultimately you can consider is as a equivalent like this equivalent cylinder.

So, it is like a circle so this diameter can be expressed as d or also you can sometimes equivalent diameter also you can express as small d e also so this is the d. Now, this D if it is a triangular pattern, then has a correlationship that this D will be equal to 1.05 of S. If it is a triangular spacing you can also draw for the square spacing if it is a square spacing. So, this is the vertical drain, also this has a spacing S, so this is I say that triangular pattern, this is triangular pattern and this is square pattern like this. This is the vertical drain, this is square pattern like this, it can be drained it like this.

So, this is the square pattern, so this is square pattern and this d if it is a spacing basically, so this has a relation with the spacing between the drain that is S, that mean this d or sometimes also we write something D is equal to 1.05 S. In case of square spacing this d will be equal to 1.13 S, so this is the plan for the triangular spacing. Now, if I draw a cross section of this, if I take a section from here, I am taking section, this is let us say S and S I am taking the section of this, this is the plan I will take the cross section of this part.

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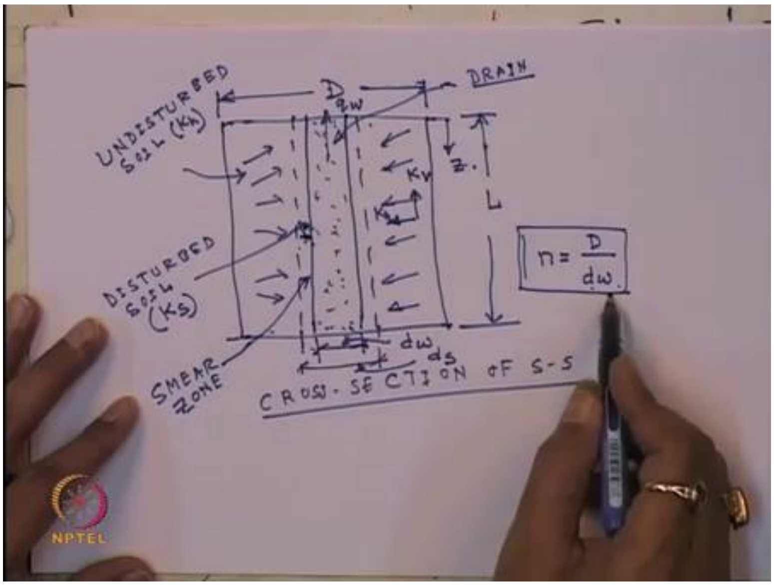

So, if I draw a cross section of this, so you can have this is the drain and this is the smear zone, so this is the drainage and this is cross section of S s. This cross section of S s, so this is the drain, so this is the drain we are showing here, now this drain also has a diameter of the well drain let us say this is d of w. Also, this is the smear zone, this part, so this also has a diameter let us say due to smear zone this diameter is d of s. This equivalent diameter of the zone that is d, this is d or you can say small d u also, this is for here this equivalent diameter of the drain is this d, this d, this d, this d, this d. So, here the water flow like this from both side there will be a radial zone, now what is this smear zone, when you are inserting the sand drain into the soft clay by the weight of the mandrel, or the casing and then when you casing is pulled it out from the soft soil.

Then soil around this drain will be disturbed, so that is why this zone is the disturbed soil. So, here is the disturbed soil disturbed soil and this also has a coefficient of permeability of the soil. Let us say this coefficient of permeability of the disturbed soil is K of s whereas this portion of the soil is undisturbed soil. This is undisturbed soil and this also has a coefficient of permeability let us say K h and let us say this length of this drain is l the drainage may be impermeable here or it may be permeable for both the side.

At any depth you can say z and it has also coefficient of permeability in the horizontal direction as well as coefficient of permeability in the vertical direction and this I say that this is the drain so this is the flow will be along this, this is q of w. So, this is the schematic diagram of the vertical drain including the well resistance and n that is the ratio of D divided by d of w or sometimes we write small D by d w. So, this is also important to us, so D means this and d w means what will be the diameter of the well drain d w, so n is equal to D by d w, so this is the section of the equivalent the cylinder.

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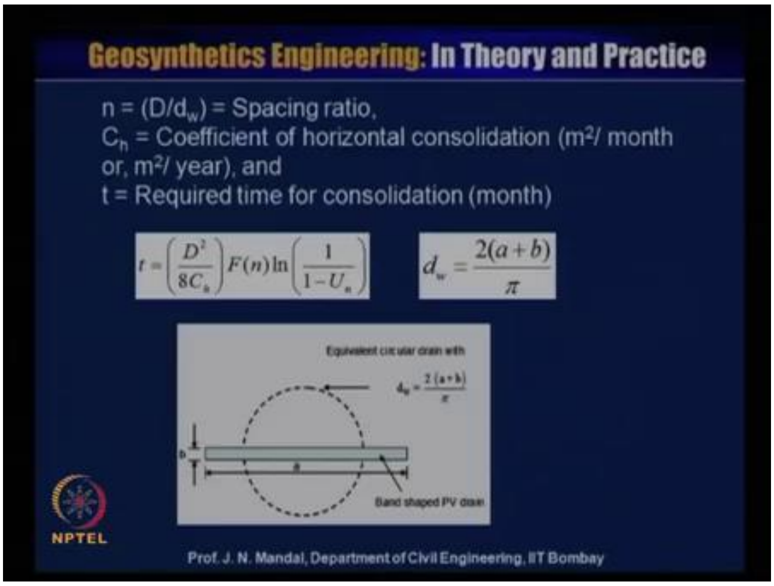

Now, here I show that what is n is equal to D by d w, that is spacing ratio and C h is coefficient of horizontal consolidation meter square per month or meter square per year and t time required I mentioned d w also I mentioned.

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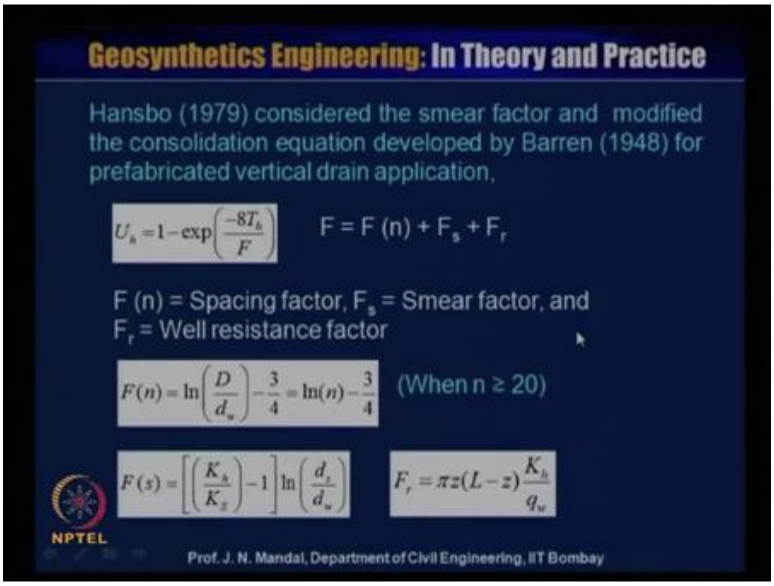

So, you know what is n now Hansbo 1979 considered the smear effect factor and modified the consolidation equation developed by Barren 1948 for prefabricated vertical drain application. So, U h is equal to 1 minus exponential minus 8 of T h divided by F where F is equal to F n plus F s plus F r. Now, F n is spacing factor and F s is smear factor and F r is well resistance factor. Now, F n again is equal to that means spacing factor is equal to l n D by d w minus 3 by 4 is equal to l n n minus 3 by 4 when the n value, the ratio that is d by small d w should be greater than equal to 20.

Now, what is smear factor, smear factor you can use this equation that is F s is equal to K h by K s minus 1 into l n d s by d w. This is diameter for this smear and this is d w is the diameter of the well drain and for F r, that means well resistance factor will be equal to pi into z into L minus z. L is equal to length of the drain at any depth is z l minus z into k h by q w q w is the flow of water through the drain and K h is coefficient of permeability in the horizontal direction. So, you know that total f will be equal to F n spacing factor plus F s that is smear factor plus F r well resistance factor.

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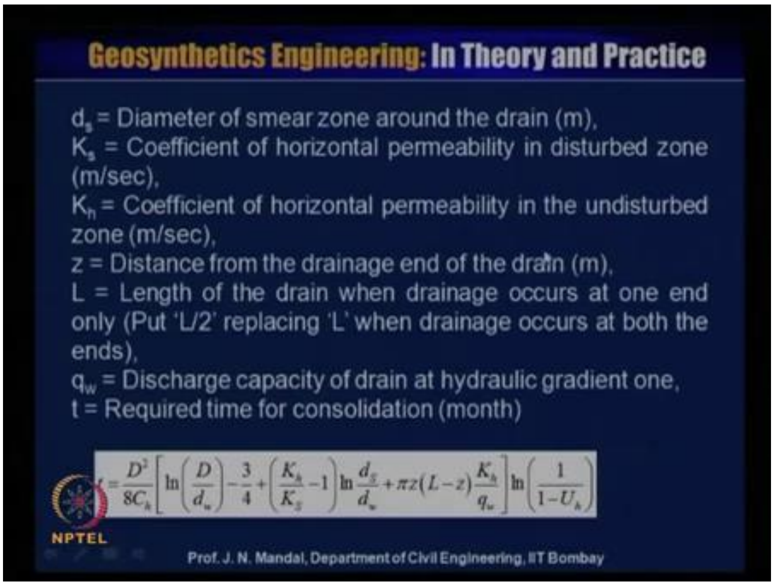

So, here again that d s is diameter of smear zone of the drain in meter K s coefficient of the horizontal permeability in the disturbed zone meter per second K h coefficient of horizontal permeability in the undisturbed zone meter per second z. Distance from the drainage end of the drain in meter, L is equal to length of the drain when drainage occur at one end only put L by 2 replacing L, when the drainage occur at both the end q w is the discharge capacity of the drain at hydraulic gradient 1. So, t required time for consolidation month can be expressed as t is equal to D square by 8 into C h l n D by d w minus 3 by 4 plus K h by K s minus 1 l n d s by d w plus pi z L minus z K h by q w into l n into 1 by 1 minus U h. So, ultimately you have this equation considering all these factors.

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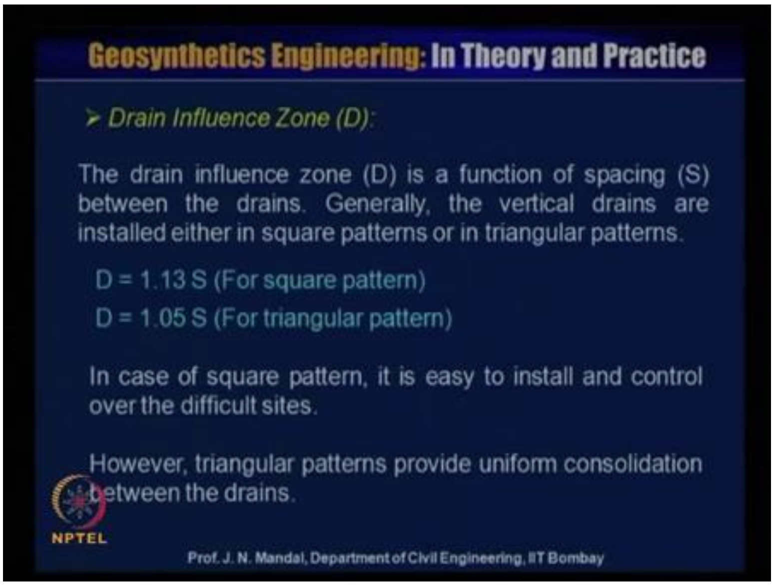

Now, this I mention the drainage influence zone D drainage influence D is a function of spacing between the drain. Generally, the vertical drain are installed either in the square pattern or in triangular pattern I mention d is equal to 1.13 S for square pattern and D is equal to 1.05 S s for triangular pattern. In case of the square pattern it is easy to install and control over the difficult site, however triangular pattern provide uniform consolidation between the drain.

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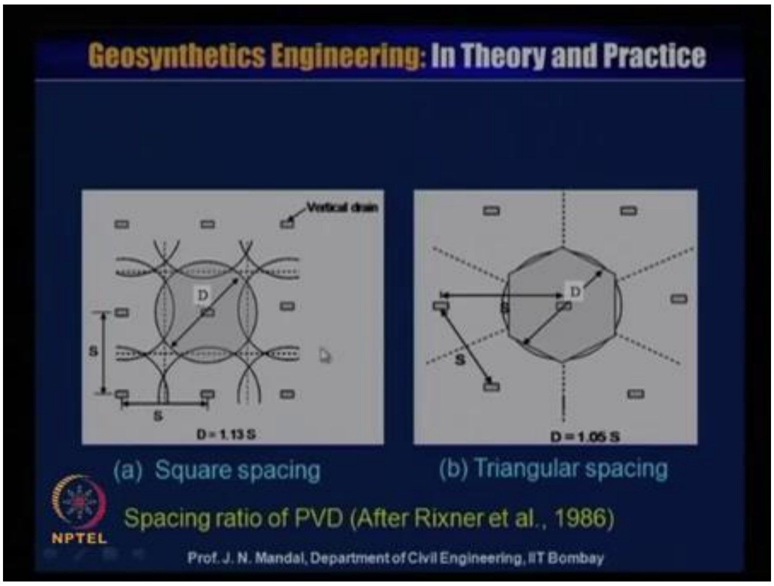

Here also spacing ratio of prefabricated vertical drain this is square after Rixner et al, this I have shown that what is that D this is also the triangular pattern this is the vertical drain and D is equal to 1.13 S. Here also for the triangular pattern the like this, so here also D is equal to 1.05 S.

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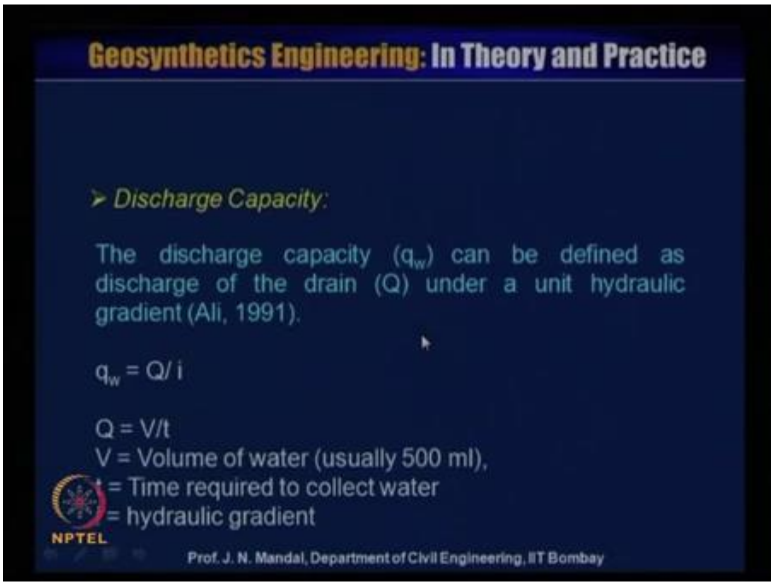

Now, how to calculate the discharge capacity, that is also very important that discharge capacity q w can be defined as discharge of the drain Q under a unit hydraulic gradient that what Ali has mentioned. In 1991 he gave the equation q w is equal to Q by I, where q is equal to V by t, where V is equal to volume of water usually 500 milliliter and t is equal to time required to collect the water and i is equal to hydraulic gradient. So, you can calculate what will be the discharge capacity you know the will be the volume of water at a particular time. So, you can calculate that q discharge and then you know what hydraulic gradient is so you can calculate what the discharge capacity q w is.

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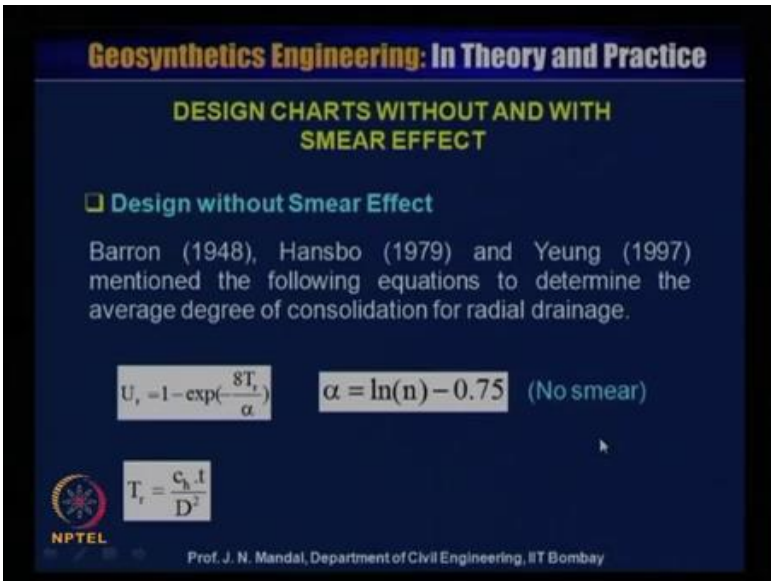

Now, where design chart without and with the smear effect, so you can also from that initial equation, you can also draw the design chart.

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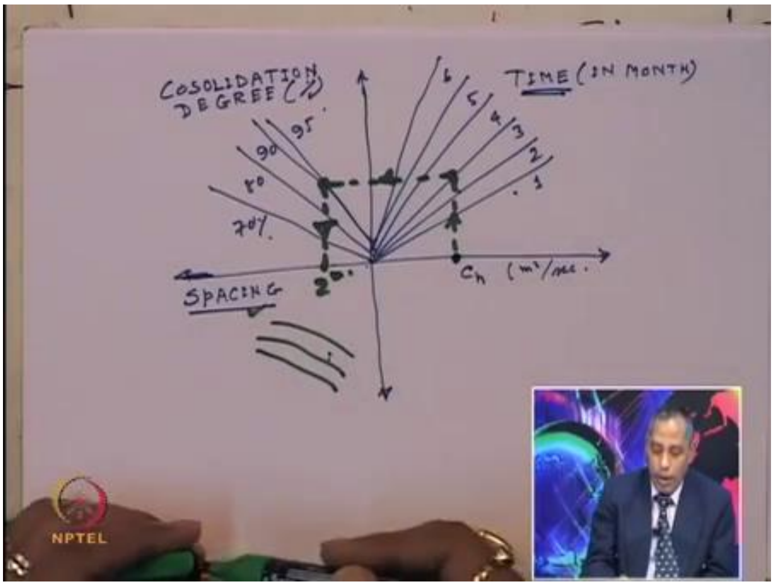

So, for a particular P V D also you can draw this design chart I am just showing here that if you know that what is the horizontal consolidation coefficient is meter square per second. Now, this part is the time, so you can draw the number of line, let us say you want to do time in month, you want to finish one month, two month, three month, four month, five month, even then six month like that you can go eight month one year. So, this part is the time and here is the consolidation degree that is in percentage.

So, you have to show that what degree of consolidation you want to take, so whether it is a 70 percent, 80 percent 90 percent or 95 percentage and this site is give the spacing this is the spacing this this will give the spacing. So, from that earlier equation, so you can make a design chart for P V D suppose from the site you know that what should be the consolidation coefficient or C h. So, if you know the coefficient of consolidation, then you can choose that you what time you want to finish the project two month, three month, four month, five month, six month, like this.

Let us say you wanted to finish within the three month, so you know from the soil report what the consolidation coefficient is then you can move up. Let us consider for three month, so three month then what percentage of consolidation degree you wanted to achieve 90, 95 percent, 80, 75 percent. Let us say you want to achieve 95 percentage, so you move that horizontally and you want to achieve 95 percentage and then you go down and here is the spacing.

So, you will know spacing let us say this is 2 meter spacing, so ultimately from this design chart you will be able to tell that what should be the spacing you require for the prefabricated vertical drain. When you make a design chart, so this design chart is a for a particular natural prefabricated vertical drain, or polyester prefabricated vertical drain because discharge capacity varying from drain to drain.

So, you have to select proper kind of the drainage, so for each case the drainage chart will be the difference even then you can draw that what should be the length of the drainage. From here you will know what should be the length of the drainage so you can make a number of design charts.

So, now design chart without and with the smear effect design without smear effect Barron 1948 Hansbo 1979 and Yeung 1997 mentioned the following equation to determine the average degree of consolidation for radial drainage. So, this is for radial drainage that is why U r is equal to 1 minus exponential minus 8 t r by alpha, alpha is equal to log n n minus 0.75, no smear and t r is equal to C h into t by D square.

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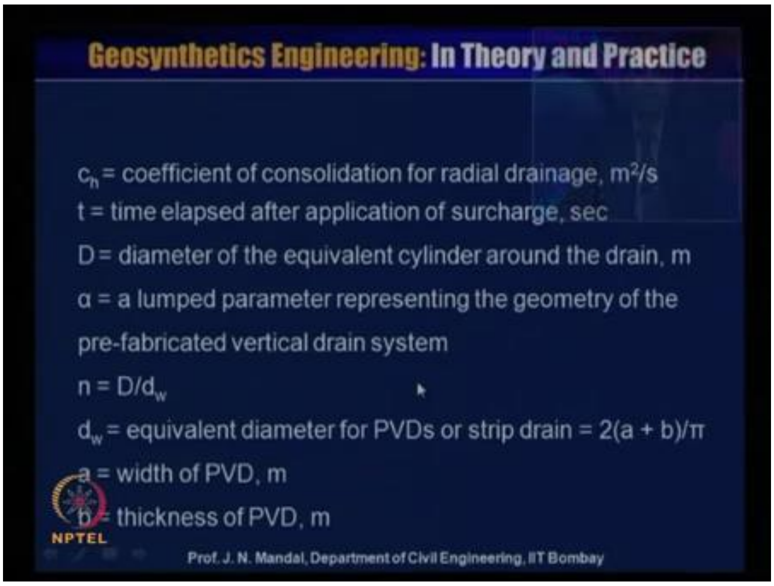

So, c h is coefficient of consolidation for radial drainage meter square per second t time elapsed after application of surcharge. This is second D diameter of the equivalent cylinder around the drain in meter alpha a lumped parameter representing the geometry of the prefabricated vertical drain system n is equal to d by d w, d w is equal to equivalent diameter of P V D or strip drain. You know it is equal to 2 into a plus b by pi where a is equal to width of the prefabricated vertical drain in meter and b is thickness of prefabricated vertical drain in meter.

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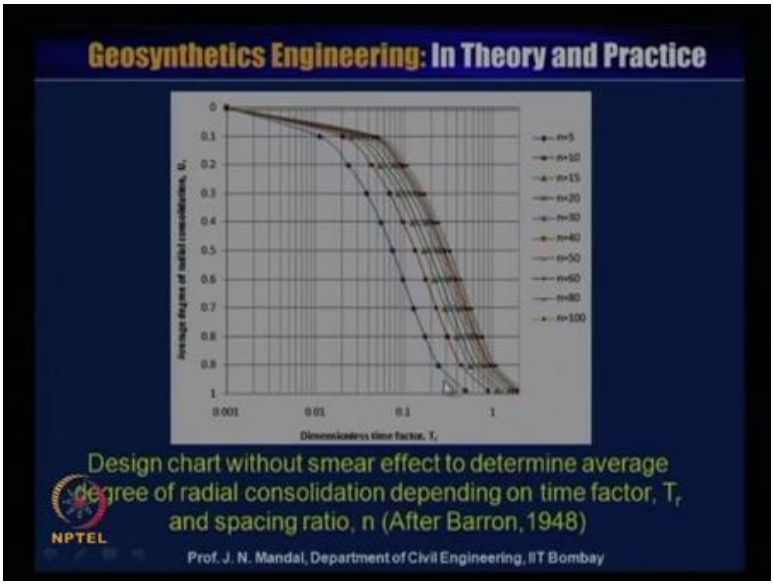

Now, here is the design chart without smear effect to determine the average degree of radial consolidation and this depending on the time factor the T r and the spacing ratio that is n this is after Barron 1948. So, you should know that what is n is equal to capital D by d w, which means equivalent diameter by what will be diameter of the diameter of the well drain. So, n may be 5 10 15 like this 20 80 100 like that. So, you have drawn different curve for various values of spacing ratio n is spacing ratio, so from this design chart if you know that what is the time factor that is T r what you can calculate from this equation T r C h t by D square. So, you know that n value, then you can calculate what will be the average degree of radial consolidation that is e 1 from this chart.

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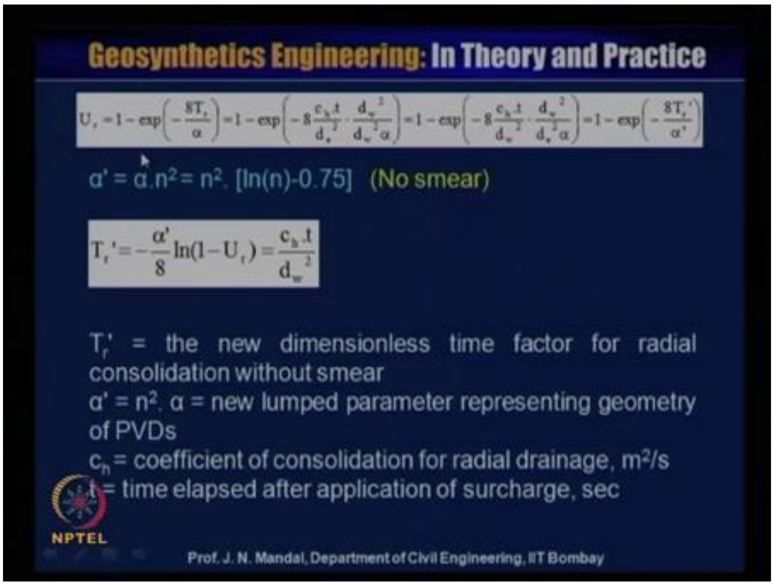

Now, U r is equal to 1 minus exponential minus 8 T r by alpha, that means 1 minus exponential minus 8 C h into t by C h into t by d w square into d w divided by d w square into alpha is equal to 1 minus exponential minus 8 of C h into t by d w square into d w square divided by d e square alpha is equal to 1 minus exponential minus 8 T r dash by alpha dash, where alpha dash is equal to alpha into n square or equal to n square into l n n minus 0.75 when no smear.

T r dash is alpha dash by 8 l n 1 minus U r that is equal to C h into t by d w square, where this is t r dash is equal to new dimensionless time factor for radial consolidation without smear. Alpha dash is equal to n square alpha that is new lumped parameter representing the geometry of the prefabricated drain. And C h is coefficient of consolidation of radial drainage that is meter square per second and t is time elapsed after application of surcharge that is in second.

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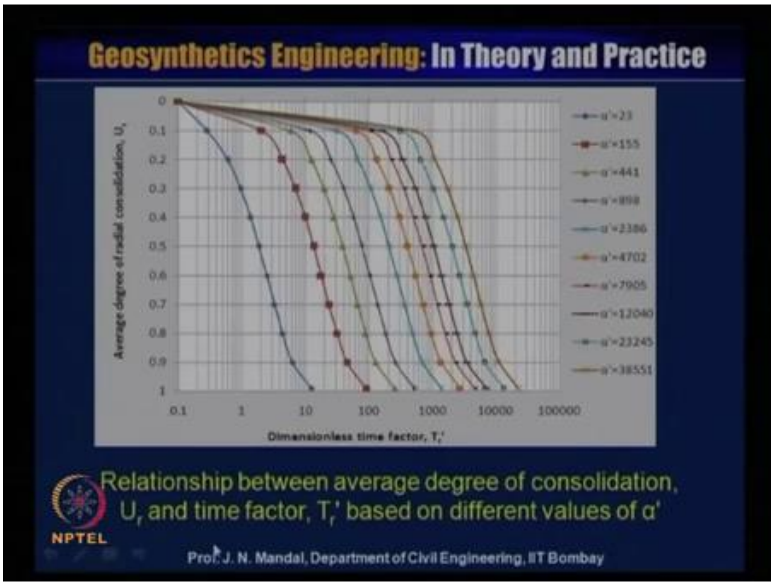

Now, this is a chart show the relationship between the average degree of consolidation this is U of r and the time factor that is t r dash and based on the different value of alpha dash I mentioned here that what is that your alpha dash. So, different value of alpha dash, so from that equation, you can calculate whether alpha dash is 23 155 etcetera like this. So, different value you can have of alpha dash and you know that what is dimensional factor that is T of r dash. And then from this design chart knowing the value of time factor and the alpha dash, you can calculate what will be the average degree of radial consolidation that means U of r.

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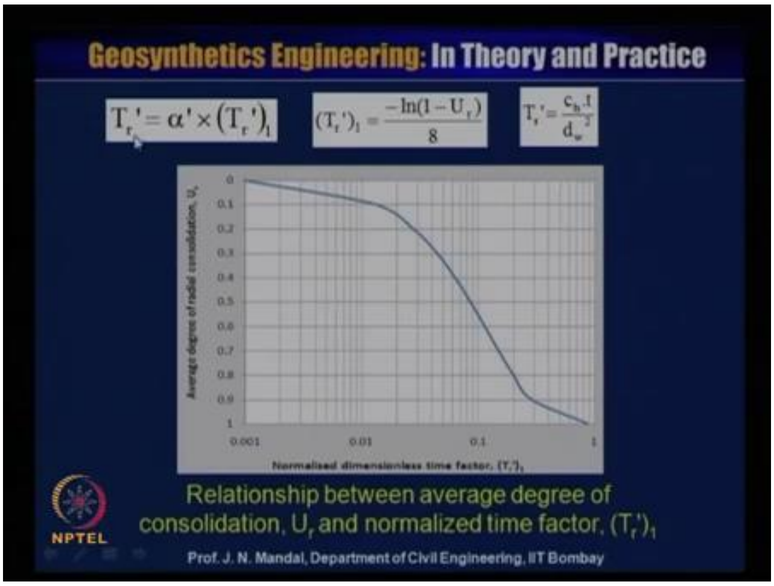

Now, again the t r dash is equal to alpha dash into T r dash 1 that means T r dash 1 is equal to minus l n 1 minus U r divided by 8 or T r dash is equal to C h into t by d w square. So, here is relationship between the average degree of consolidation U r and the normalized time factor T of r dash. So, you can directly also determine from here because this is normalized time factor, you know what is below normalized time factor t r dash which you can determine from this equation.

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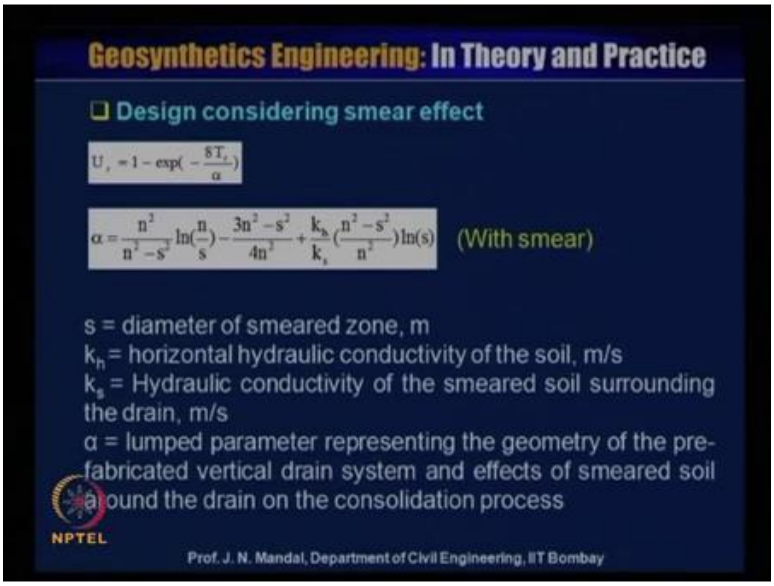

Then you can calculate that what should be the average degree of radial consolidation from this chart, so design considering the smear effect. Now, U r is equal to 1 minus exponential minus 8 T r by alpha where alpha is equal to n square by n square minus s square l n n by s minus 3 n square minus s square by 4 n square plus k h by k s into n square minus s square by n square into log n s.

Now, we are considering the smear effect earlier we did not consider the smear effect. So, where s is here s is equal to diameter of the smeared zone in meter k of h is horizontal hydraulic conductivity of the soil in meter per second and k of s is the hydraulic conductivity of the smeared soil surrounding the drain that is meter per second. This alpha is the lumped parameter representing the geometry of the prefabricated vertical drain system, and effect of smeared soil around the drain on the consolidation process.

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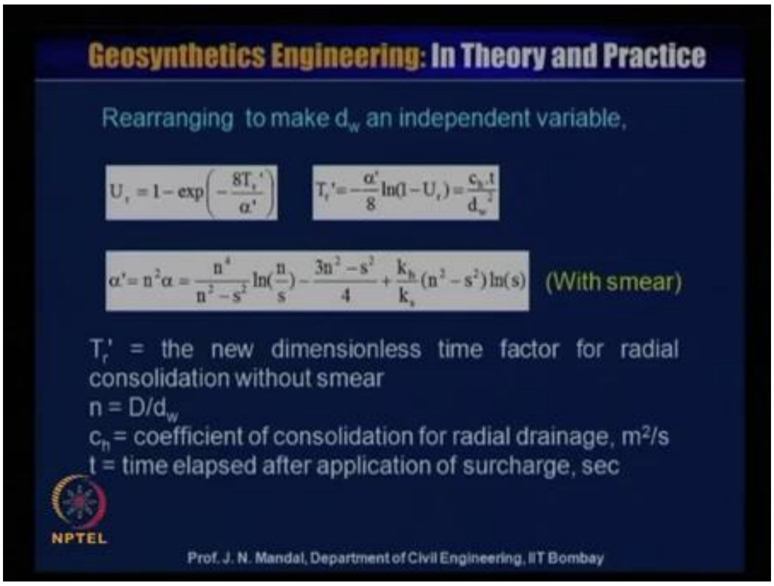

So, rearranging to make the d w an independent value that is U r is equal to 1 minus exponential minus 8 T r dash by alpha dash again T r dash is equal to alpha dash by 8 into l n 1 minus U r is equal to C h into t by d w square. So, ultimately we can have alpha dash is equal to n square alpha that means n to the power 4 divided by n square minus s square into l n n by S minus 3 n square minus s square by 4 plus k h by k s n square minus s square l n s with smear.

So, here the T r dash is equal to new dimensionless time factor for radial consolidation without smear and n is equal to D by d w and C h is equal to coefficient of consolidation for the radial drainage that is meter square per second. And t is time elapsed after the application of surcharge that is in second.

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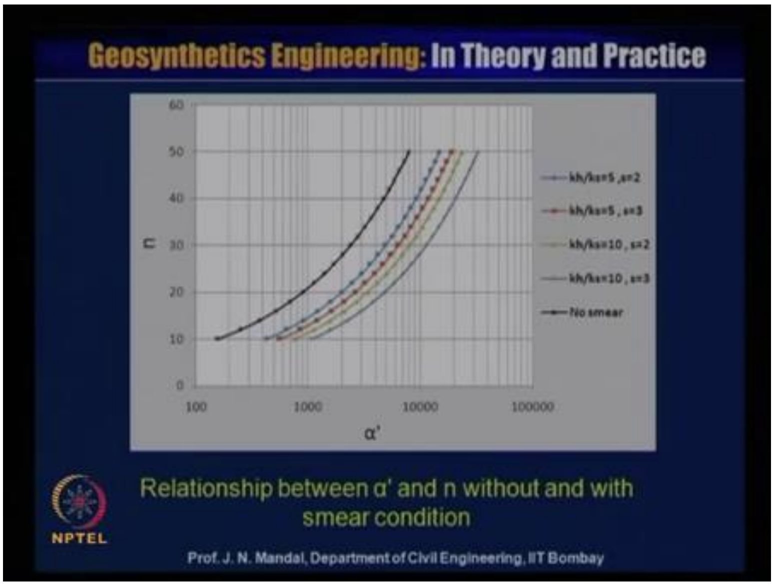

So, this is the relationship between the alpha dash and this n without and with smear condition, so here is the K h by K s. This is the coefficient of permeability for smear and this coefficient of permeability horizontal, so here you can have the different value of K h by K s. It may be 5 5 or 10 10 and where this S is equal to the 2 or 3, S is equal to 2 again S is equal to 3 and this one is the no smear. So, this is no smear and this is for the different S value may be 2, 3 what will be the K h by K s ratio you can see here. So, from here also you can establish a relationship between alpha dash and n dash, if you require alpha dash, if you know this value or this value for you known then also we can calculate this alpha dash or n.

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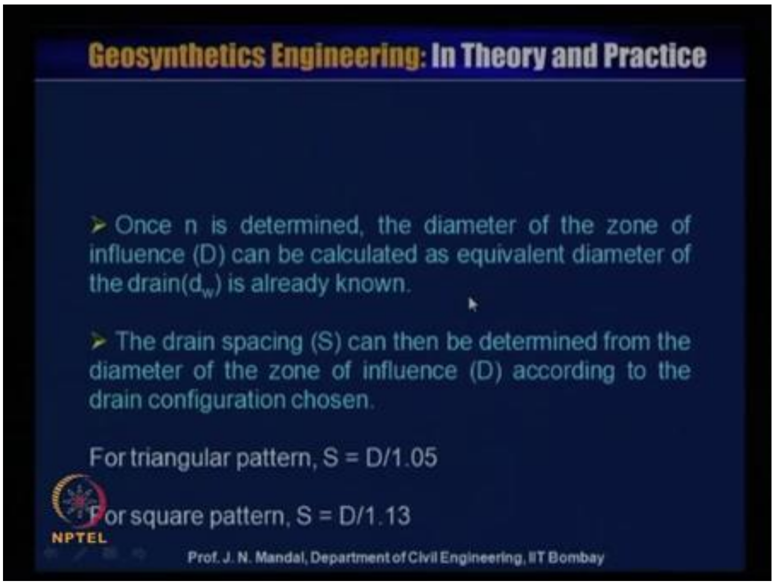

Once n is determined from this chart, then diameter of the zone of the influence D can be calculated as equivalent diameter of the drain d w is already known. So, drain spacing S can be determined from the diameter of the zone of influence that is capital D according to the drain configuration is chosen. If we chose for triangular pattern then S will be equal to D divided by 1.05. If you chose square pattern though S will be equal to D divided by 1.13, so when you know that n value and then you can have a correlation from this correlation, so you can determine what will be the spacing between the two drains. This means what will be the S value, so from like this you can calculate the spacing between the drain what we require.

So, from this study you have followed what will be the theory for the consolidation to determine the bearing capacity of the soil when the soil is very fine grain saturated soil. Also, you can calculate that primary consolidation settlement and secondary consolidation settlement, and also you can also make this design chart for the prefabricated vertical drain or natural prefabricated vertical drain. So, if you know what will be the spacing ratio that means if you know what will be the equivalent diameter of the drain and also the diameter of the well drain is? So, you can calculate these, also these n value and from that n value also we can calculate the spacing, so with this I finish my lecture today. Let us hear from you, any question?

Thanks for listening.