Geosynthetics Engineering: In Theory and Practices

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Lecture - 44
Geosynthetics for Ground Improvement

Dear student, warm welcome to NPTEL phase 2 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 lecture number is 44 and module 9 Geosynthetics for ground improvement.

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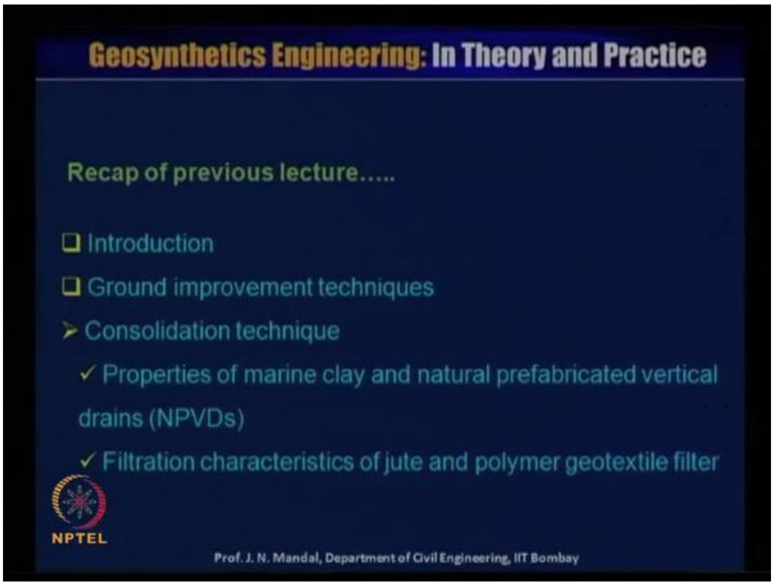

Now, I will address the recap of the previous lecture. That is introduction, ground improvement technique, consolidation technique, properties of marine clay and natural prefabricated vertical drain NPVDs, and filtration characteristics of jute and polymer geotextile filter.

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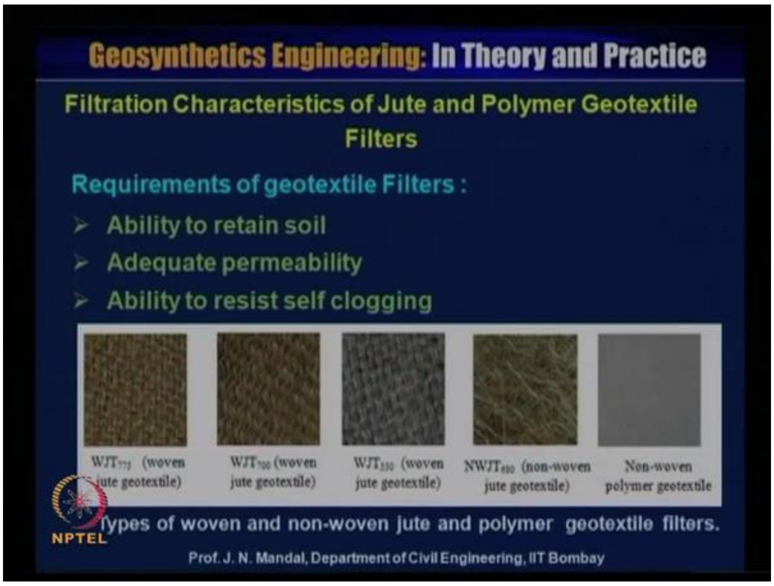

Now, filtration characteristics of the jute and polymer geotextile filter. Most important requirement of geotextile filter is the ability to retain the soil, adequate permeability, and ability to resist self clogging. These are the very important parameter for the filtration and drainage for any kind of the material. Here, we have shown that four natural prefabricated vertical drain, either woven jute geotextile or nonwoven geotextile and the polymer geotextile material. So, these are the various type of the geotextile filter.

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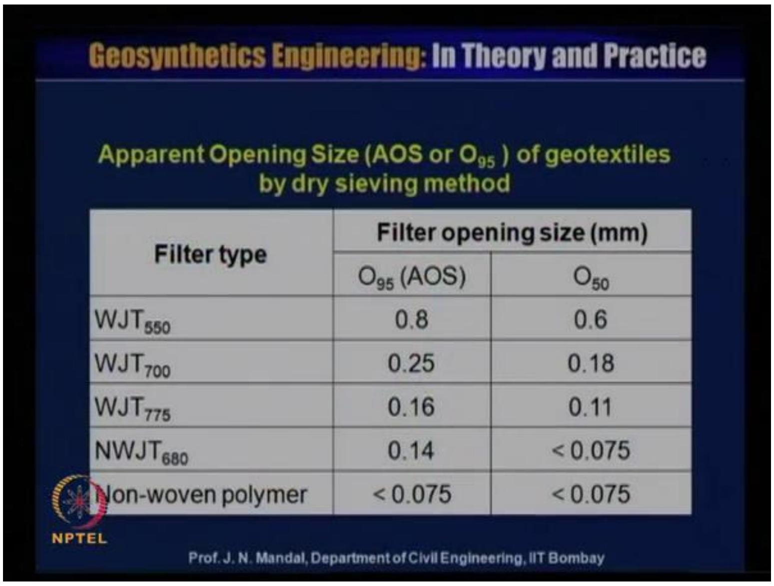

Filter type	Filter opening size (mm)	
	O_{95} (AOS)	O_{50}
WJT_{550}	0.8	0.6
WJT_{700}	0.25	0.18
WJT_{775}	0.16	0.11
$NWJT_{680}$	0.14	< 0.075
Non-woven polymer	< 0.075	< 0.075

Now, apparent opening size of the geotextile, this is very important that one should know what will be the apparent opening size or the equivalent opening size of the geosynthetic material. Now, this apparent opening size geotextile material A O S or O 95 of geotextile has been performed by dry sieving method. So here is the filter type, this is all jute material 550 and A O S or filter opening size which is designated as O 95 or equivalent opening size, this is 0.8 millimeter and this is 0.6 millimeter O 50.

Similarly, for the W J T 700 that O 95, 0.25 millimeter and O 50 is 0.18 millimeter, then W J T 775 that O 95, 0.16 and O 50 is 0.11 and then in W J T 680 these are all gram. So, O 95 is 0.14 millimeter and O 50 less than 0.075 millimeter whereas, Non woven polymer this O 95 is less than 0.075 millimeter and O 50 also 0.075 millimeter. So, this apparent opening size of the different geotextile material is important because here we have to observe how the water can pass through the geotextile material.

What should be the required equivalent opening size or apparent opening size, this also depend upon that what will be the uniformity coefficient of the soil. So, we have already studied it that how to design the filtration and drainage, here for the natural and the prefabricated vertical drain. The one of the important parameter is the apparent opening size of the geotextile that has been shown. Now, apart from the apparent opening size of the geotextile, we should also study that what will be the permeability of the geotextile filter that is also very important factor for the case of the drainage and the filtration.

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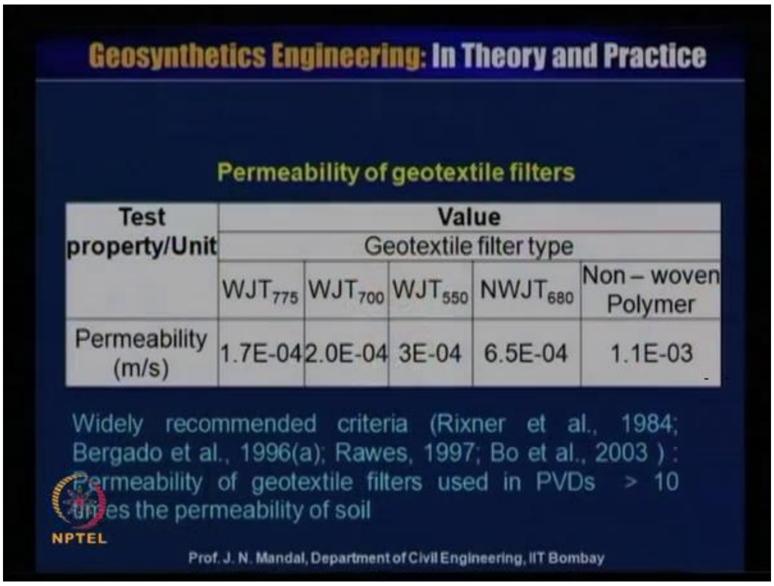

Now, permeability of the geotextile filters, due to its stress property or the unit this is geotextile filter. This permeability value for W J T 775 is 1.7 into 10 to the power minus 0.4 meter per second, W J T 700 is 2.0 into 10 to the power minus 0.4 meter per second and W J T 550 is 3 into 10 to the power minus 0.4 meter per second n W J T 680 is 1.1 into 10 to the power minus 0.3 meter per second.

Whereas, non woven polymer geotextile that permeability value is 1.1 into 10 to the power minus 3. So, this is widely recommended criteria that are given by Rixner et al 1984, Bergado et al 1986, Rawes 1997, and BO et al 2003 that permeability of geotextile used in the prefabricated vertical drain should be greater than ten times the permittivity of the soil. So, if it satisfies these criteria, so you can make use of this natural prefabricated particle drain. So, these two criteria should fulfill what are the apparent opening size of the prefabricated vertical drain as well as the permeability of the prefabricated vertical drain.

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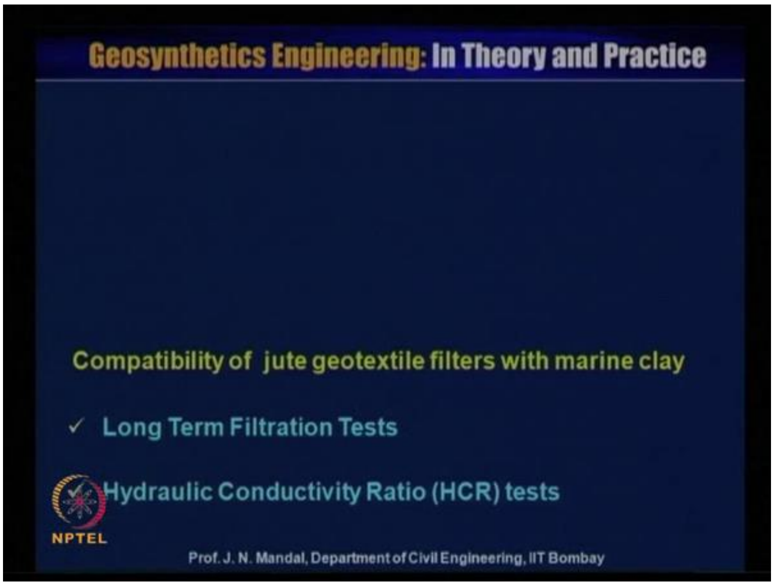

Then some compatibility of jute geotextile filters with marine clay because the jute geotextile has to come in contact with the marine clay when you install this prefabricated vertical drain. So, what is required that long term filtration test you require hydraulic conductivity ratio test that is called the HCR test.

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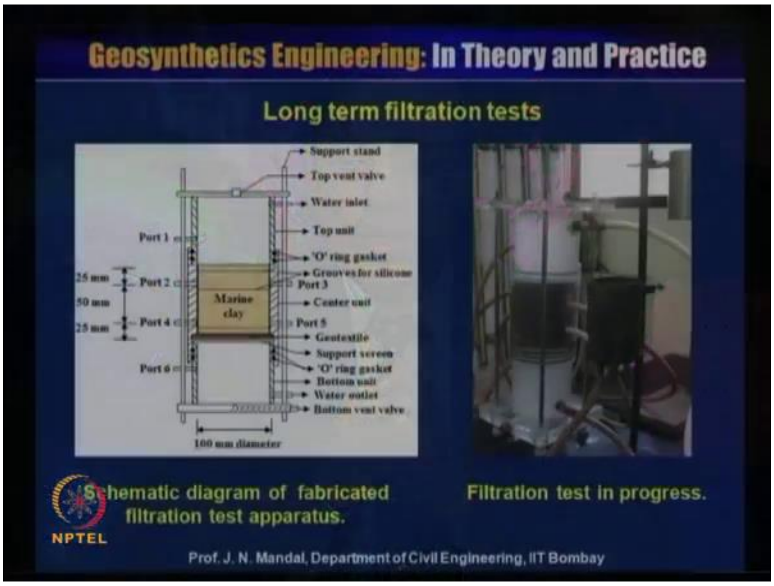

So, for the long term filtration test and this is the schematic diagram is fabricated for filtration test apparatus in IIT Bombay by doctor Asha and this is the filtration test is in the progress. So, this I have already discussed in detail, the earlier chapter when I talked about the filtration drainage and erosion control system chapter. So, here is a geotextile material and this is the marine clay like this, here filtration test is in the progress and you can measure that what will be the water level. Then you can find out that what should be the filtration characteristics of the material.

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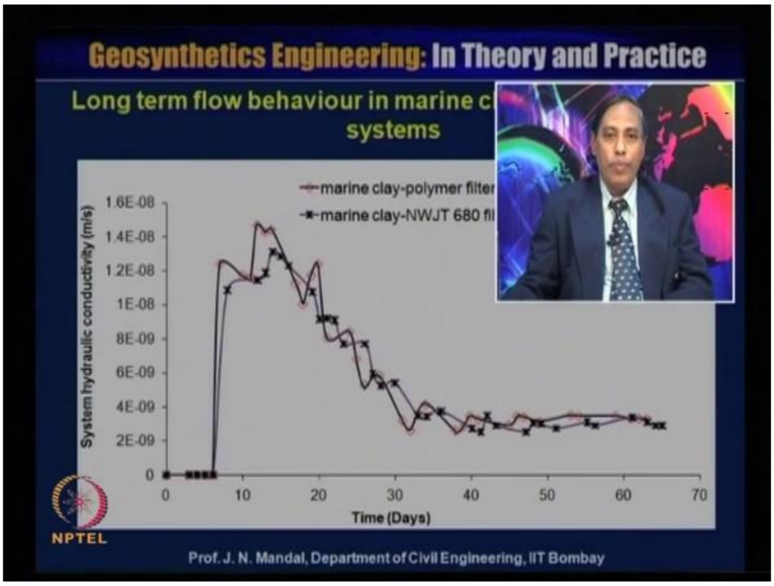

So, from this test you can correlate the relation between the system hydraulic conductivity that is meter per second to time in days. So, these are the marine clay polymer filter whose apparent opening size is less than 0.75 millimeter and also the marine clay with the natural woven jute textile 680 filter whose apparent opening size of filter is 0.14 millimeter system. So, with these two systems you can see that it is almost the matching and also the hydraulic conductivity.

You can see that here increasing is reached to this top and then it is coming down and almost this constant after 30 days 46 it is remained the constant. So, with time passes, how you can see that hydraulic conductivity behaves and these two the material one is the polymer material another is the natural prefabricated vertical drain. Both also almost giving the same result therefore, we can conclude that natural prefabricated vertical drain also can be used. And it satisfies the long term behavior of the marine clay in geotextile filter system.

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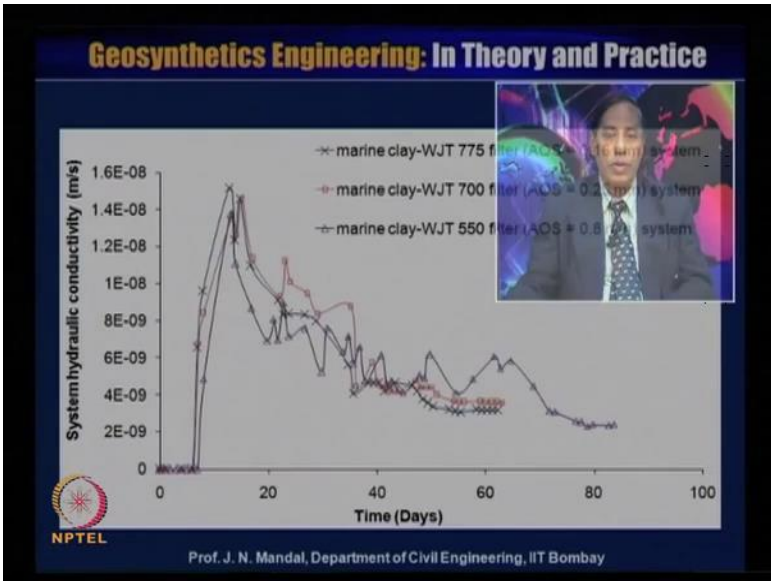

Another curve for the relationship between the systematic hydraulic conductivity versus the time in days, here marine clay and woven jute geotextile 775 filter whose apparent opening size is 0.16 millimeter system. Marine clay W J T 700 filter and apparent opening size of geotextile is 0.25 millimeter system and marine clay woven jute textile 550 filters and apparent opening size 0.8 millimeter system.

So, you can see all these system, you can see that nature of the curve with increasing this is the time versus the early conductivity. It is increasing then it is after may be the 10 or 15 days and then it is decreasing after 30 40 days 50 60. Then almost remain constant, that means it will be in a state of equilibrium position, and it is in a state of stable, so within a short period of the time.

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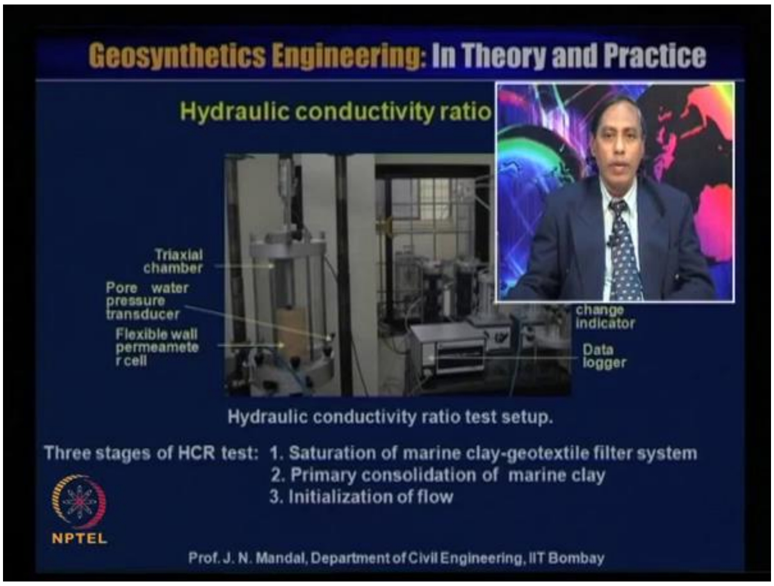

Now, apart from this we have performed hydraulic conductivity ratio test, H C R test. So, this also we have described in the filtration drainage and erosion control chapter and this is the hydraulic conductivity test ratio. The setup and here is a triaxial, the chamber this is pore water pressure transducer, this is flexible wall perimeter cell and here is the volume changes indicator. Here, is the data logger and this is back up pressure system and this is cell pressure system. So, when you perform this hydraulic conductivity ratio test, there are three stages of H C R test. First, saturation of marine clay geotextile filter system, second primary consolidation of marine clay and third the initialization of flow, so this also have been described here.

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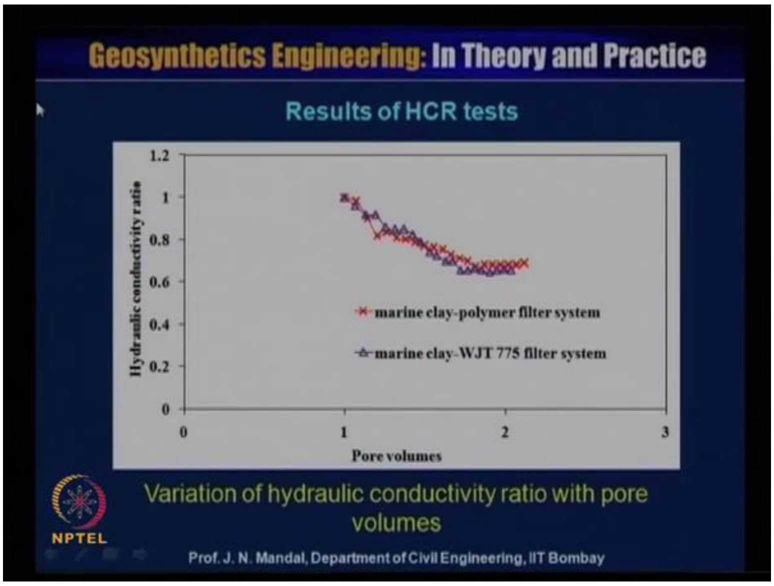

I am just showing some result of the H C R test this is the hydraulic conductivity ratio versus the pore volume, so this is the variation of the hydraulic conductivity ratio with the pore volume. So, this is marine clay, the rate this is marine clay polymer filter system and this is marine clay woven jute geotextile 755 filter system. You can see here that how the hydraulic conductivity ratio is also decreasing with increasing that pore volume and then after two or like that it is almost it is constant. This is also similar nature of the curve for both the polymer filter system as well as natural woven jute geotextile 775 filter systems. So, it also satisfies these criteria that what should be the pore volume or the hydraulic conductivity of the ratio of the pore volume.

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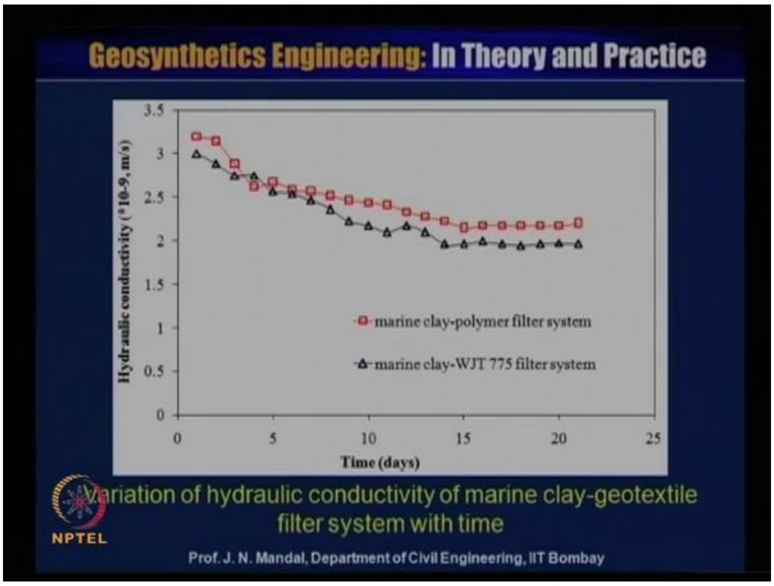

So, next also this is the variation of the hydraulic conductivity of marine clay geotextile filter system with time. So, here also the same the marine clay polymer filter system and the marine clay. Then woven jute geotextile 775 filter system as we shown you can see here that how the hydraulic conductivity here decreasing and with increasing the time in days and then almost after 15 days it remain also the constant. So, this also satisfy this criteria for both cases for polymer filter system, as well as the natural prefabricated vertical drain system where in both the cases marine clay also have been used.

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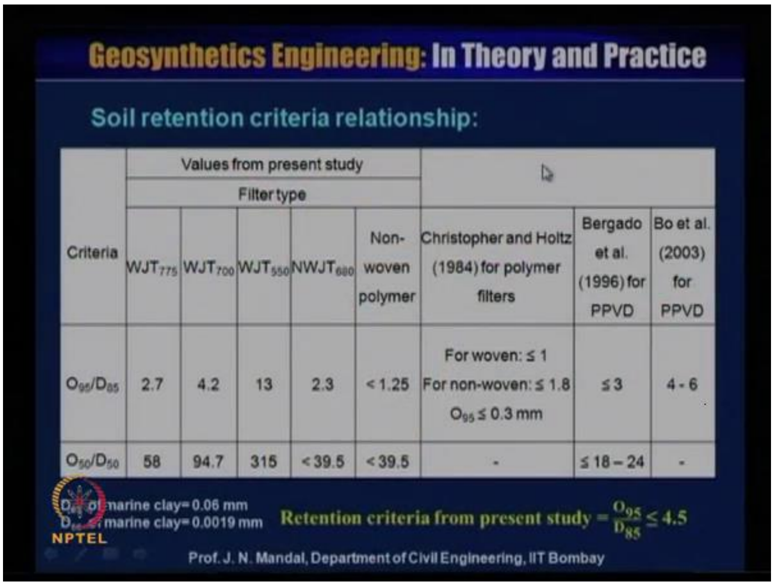

So, soil retention criteria relationship, this is very important soil retention criteria. So, from the present study you have the criteria that O 95 by D 85 and O 50 by D 50. So, this is the filter type, this is the all natural pore geotextile prefabricated vertical drain and this is the nonwoven polymer drain. You can see that ratio, O 95 by D 85 for natural this case is 2.7 for W J T 700 is 4.2, W J T 550 is 13, and in W J T that is 680 is 2.3. For non woven polymer it is less than 1.25 and O 50 by D 50 for W J T 775 is 58, W J T 700 is 94.5 and W J T 500 is 315 and in W J T 680 is less than 39.5 and non woven polymer is less than 39.5.

So, here that Christopher and Holtz 1984 for polymer filter material defined for woven, this will be less than equal to 1. For non woven, it is less than equal to 1.8 and O 95 is less than equal to 0.3 millimeter. For Bergado et al 1996 for the prefabricated vertical drain this value is less than equal to 3 and also this is less than equal to 18 to 24. BO et al 2003 for the polyester prefabricated vertical drain and this value is lies 4 to 6.

So, here that D 85 of marine clay is 0.06 millimeter and D 50 for marine clay is 0.0019 millimeter. But, what is the criteria retention, criteria for this present study. So, retention criteria for this present study that O 95 by D 85 should be less than equal to 4.5. So, you can see that some cases, here also this ratio is less than equal to 4.5 this is the criteria you require, so it is satisfying the soil retention criteria.

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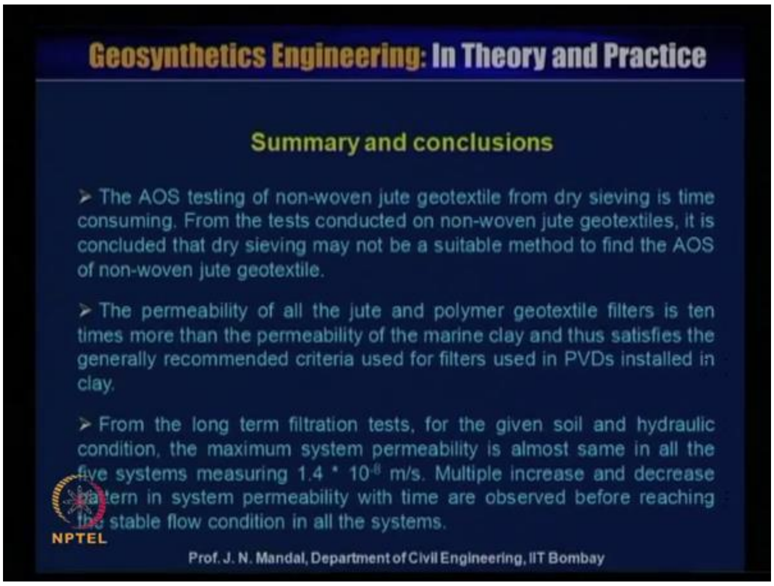

So, here because soil retention criteria also very important, so wherever you will design for any filtration and drainage, so you should go through the gradation ((Refer slide: 18:20)) properly because D 85, D 50, these are the data or parameters are very important. Now, summary and conclusion, the apparent opening size testing of non woven jute geotextile from dry sieving is time consuming from the test conducted on non woven jute geotextile. It is conducted that dry sieving may not be a suitable method to find the apparent opening size of non woven jute geotextile.

But, majority of cases, we have performed the dry sieving case the permeability of all the jute and polymer geotextile filter is 10 times more than the permeability of the marine clay. Thus satisfies the general recommended criteria used for filter used in the prefabricated vertical drain install in clay. From the long term filtration test, for the given soil and hydraulic condition the maximum system permeability is almost same in all the five system measuring 1.4 into 10 to the power minus 8 meter per second. Multiple increase and decrease pattern in system permeability with time are observed before reaching the stable flow condition in all the system.

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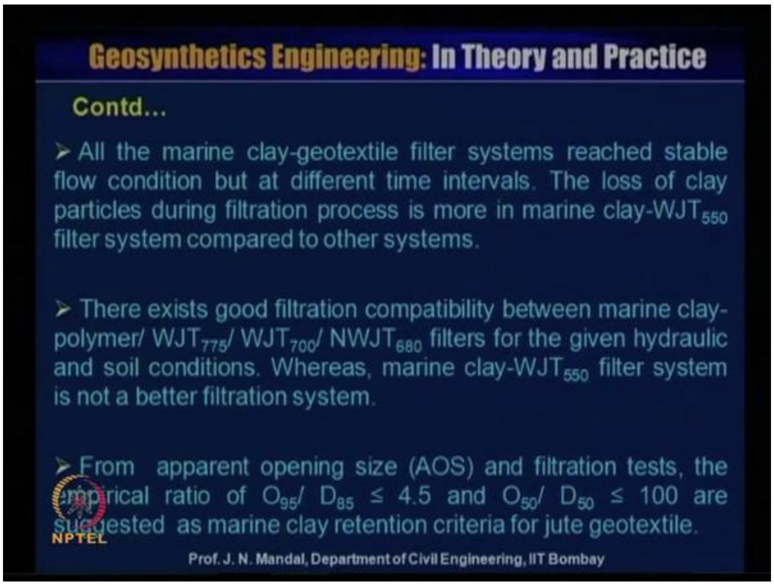

All the marine clay geotextile filter system reach stable flow condition but at different time interval, the loss of clay particle during filtration process is more in marine clay and W J T 550 filter system compare to the other system. There exist good filtration compatibility between the marine clay polymer, or natural woven jute geotextile 775 woven jute geotextile 700, and non woven jute geotextile 680 filter for the given hydraulic and soil condition. Whereas, marine clay woven jute geotextile 550 filter system is not a better filtration system. From the apparent opening size or A O S, and the filtration test the empirical ratio of O 95 by D 85 less than equal to 4.5 and O 50 by D 50 less than equal to 100 are suggested as marine clay retention criteria for jute geotextile.

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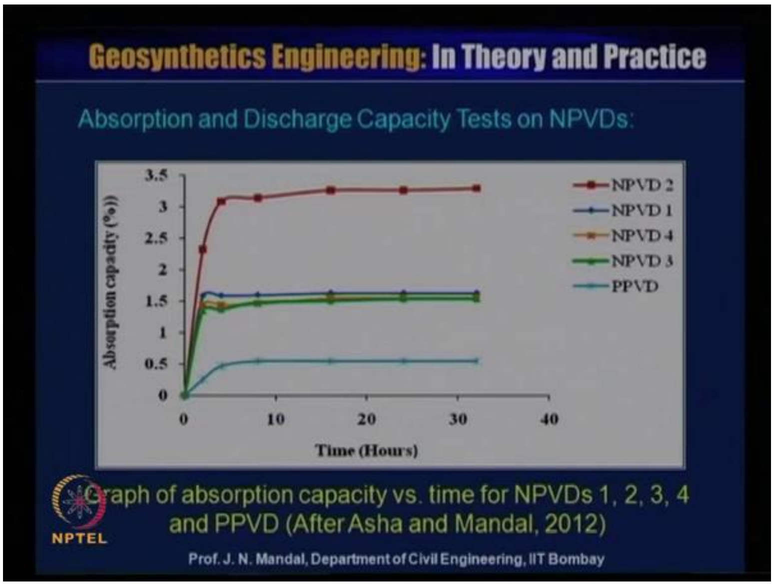

So, next is some absorption or discharge capacity test on the natural prefabricated vertical drain. So, it is very important to understand that what should be the absorption capacity of the natural prefabricated vertical drain with time. So, we have the platform as per Asha and Mandal 2012, this is the 4 different types of natural prefabricated vertical drain that is 1 2 3 4 as well as the polyester prefabricated vertical drain.

So, here graph shows that absorption capacity in percentage versus the time in hour for both the natural prefabricated vertical drain, 1 2 3 4 and the polyester prefabricated vertical drain. So, in case of the polyester prefabricated vertical drain you can see here that that water absorption capacity is less and the time passes, then water absorption capacity remain constant with the time.

Whereas, in case of natural prefabricated vertical drain in case of 2 N P V D 2, you can see that absorption capacity is too high. In terms of percentage and within a short time and then remain constant and for other case, 1 4 3 this is almost that constant water absorption capacity with time, and drain remain constant with passage of time. So, naturally we can say that natural prefabricated vertical drain has a good absorption capacity.

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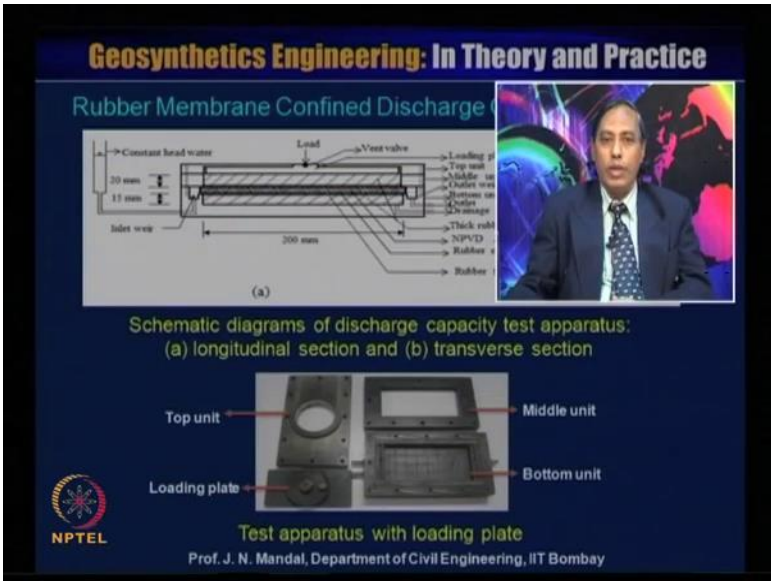

Now, they have also performed rubber membrane confined discharge capacity test, so this is the schematic diagram of the discharge capacity test apparatus. This is the longitudinal section and this is transverse section which we have also covered in the filtration and drainage chapter. Here the test apparatus with the loading plate this is the loading plate and this is the top unit, this is the middle unit and this is the bottom unit. You have to place this geotextile material somewhere here or here and then top and bottom is that any impermeable material. Then the water can flow pass through this geotextile material along the plane of the geotextile and drain under the different application of the load.

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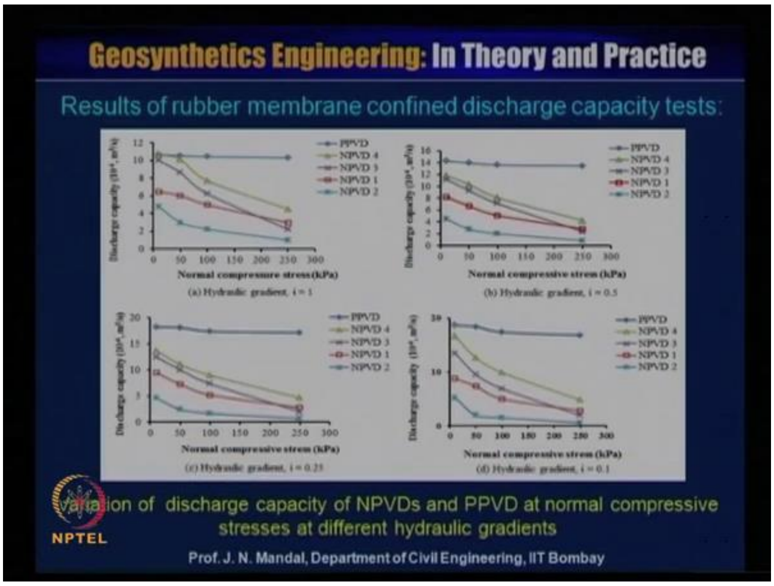

So, then you can calculate what will be the discharge capacity, so these are the some result of rubber membrane confined discharge capacity tests because water should not pass the top and the bottom. That is why it is provided with the impermeable material and from this tests here variation of discharge capacity of the natural prefabricated vertical drain.

The polyester prefabricated vertical drain and normal compressive stress at different hydraulic gradient, this is very important that hydraulic gradient value because sometimes you can see the hydraulic gradient value is given 5 10 15. If the hydraulic gradient is high your discharge capacity also will be the high but it should obey the Darcy's law, it should be in the laminar flow condition not the terminal flow condition.

So, here from this discharge capacity test this relationship between the discharge capacity and this is the normal pressure. You can start with 50, normal pressure and a particular time you are collecting the water what will be the quantity of water at a particular time. Due to the applied load are 50 and then you calculate what will be the discharge capacity?

Similarly, the next is 100 normal compressive stresses, 100 Kilo Pascal, then water is passing through the geotextile material and you are measuring what will be the discharge capacity at a particular time. Like that you are continuing 250 and even then more and then you are shown the relationship between discharge capacity and the normal compressive stress for a hydraulic gradient i is equal to the 1.

So, you can see that discharge capacity is decreasing with increasing the pressure and then it will be in a stable condition. But, in case of the P P V D polyester prefabricated vertical drain, you can see that discharge capacity almost remain constant. So, all such cases have also performed under different hydraulic gradient, here suppose hydraulic gradient is 0.5 here hydraulic gradient 0.25 here hydraulic gradient is 0.1. So, all cases you can observe that discharge capacity is decreasing with the increasing the normal compressive stress.

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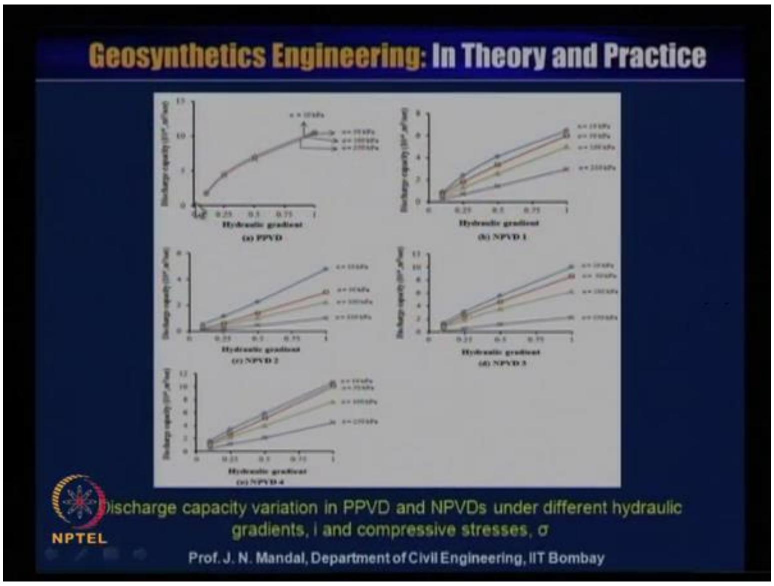

Here, also this curve discharge capacity variation of polyester prefabricated vertical drain and the natural prefabricated vertical drain under different hydraulic gradient. You are considering here, is the different hydraulic gradient 0.25, 0.50, 0.75 or 1 and or a compressive stress. So, you can see here 10 Kilo Pascal 50, 100, 250 like that. So, you can see that what should be this value, so you can see it is increasing and like this you can have a curve like this for case of P P V D. So, all the curve you can have the relationship like this, so what will be the discharge capacity for the different hydraulic gradient and under this different compressive stress value.

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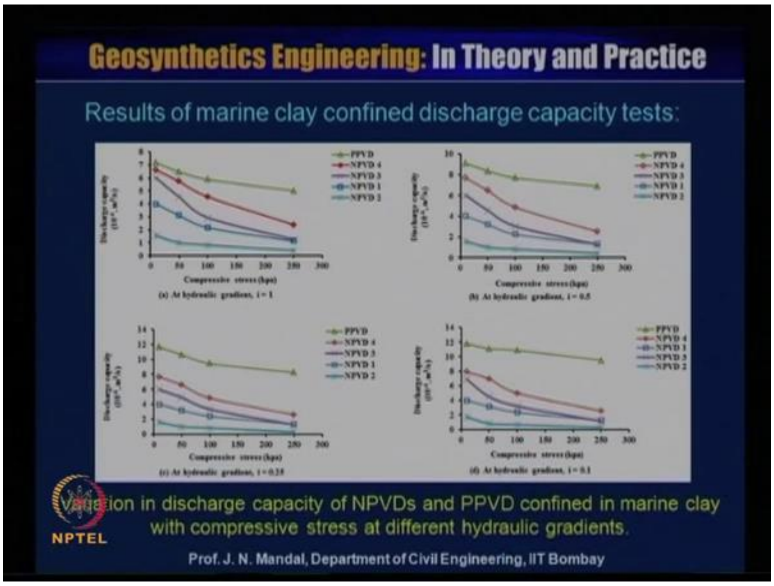

Here, also the result for the marine clay confined discharge capacity test. So, this is the variation in the discharge capacity of natural prefabricated vertical drain. The polyester prefabricated vertical drain confined in marine clay with compressive stress at different hydraulic gradient. So, this is hydraulic gradient 1, this is for 0.5, this is 0.25 and this is 0.1. You can see that how there discharge capacity is decreasing with increasing the pressure. So, either it is a natural prefabricated vertical drain or the polyester prefabricated vertical drain.

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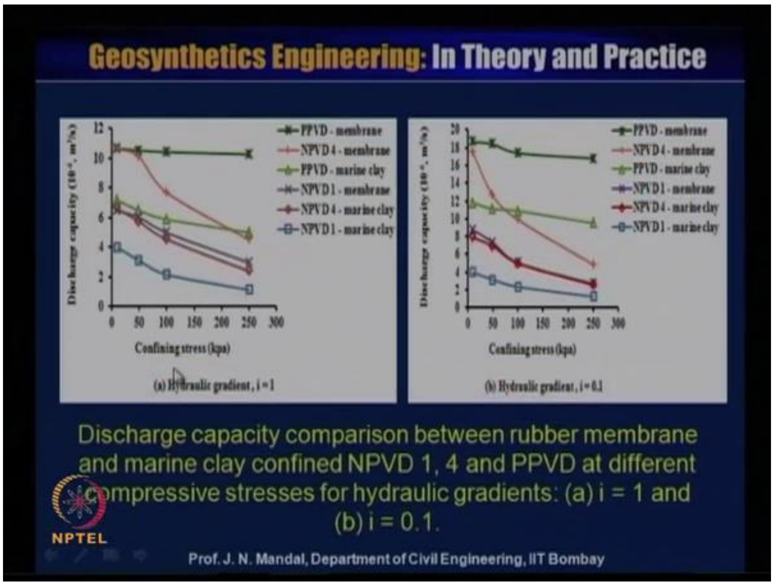

The nature of the curve is the same here also the discharge capacity comparison between the rubber membrane and the marine clay confined N P V D 1, 4. Polyester prefabricated vertical drain at different compressive stress for hydraulic gradient a for 1 and for hydraulic gradient i is 0.1. So, here you can see that in case of the membrane prefabricated vertical drain you are having the discharge capacity almost that constant with the different confining pressure. Here, also almost similar nature of the curve, but in case of natural prefabricated vertical drain with the marine clay, you can see that discharge capacity is decreasing with increasing the confining pressure. Here, also for all other cases it gives the similar in nature.

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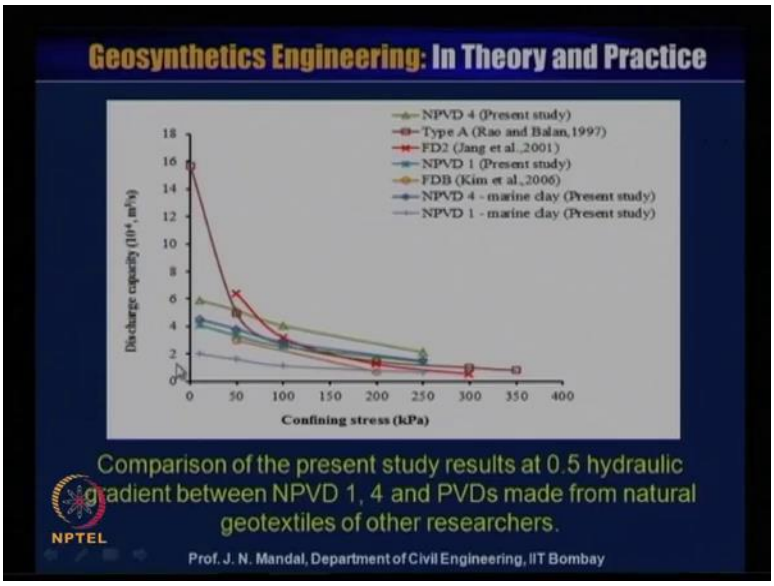

Here, the comparison of the present study result at a 0.5 hydraulic gradient between natural prefabricated vertical drain 1, the 4 and prefabricated vertical drain made from the natural geotextile of other researcher. And you can see this is the natural vertical drain 4 in this present study, and whatever the other study have been done type a Rao Balan 1997 f d two also Jang et al 2001, and natural prefabricated vertical drain that is also, one in the present study and f d b Kim et al 2006. Natural prefabricated vertical drain 4 marine clay, and in the present study and N P V D 1 marine clay in the present study. So, here also we can see that how the discharge capacity decreasing with increasing the confining pressure and it has been compared with the all other authors.

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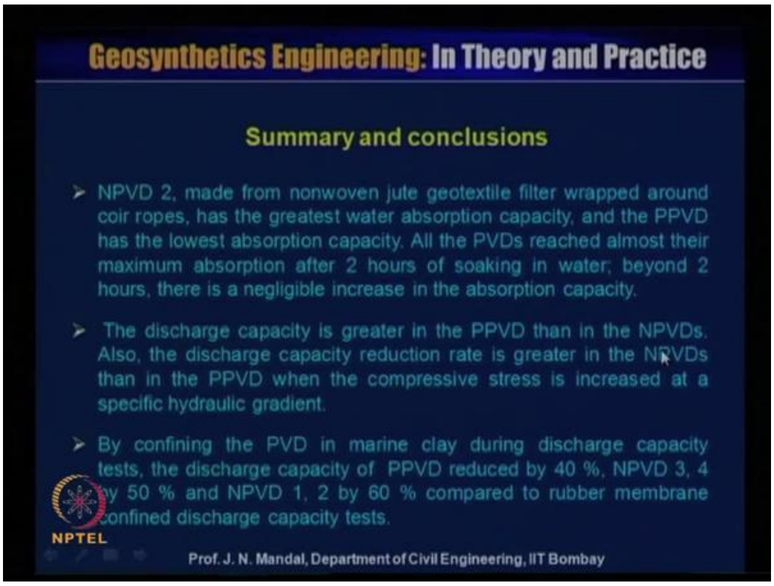

So, we come to some summary and conclusion that natural prefabricated vertical drain 2 made from nonwoven jute geotextile filter wrapped around coir rope has the greatest water absorption capacity. The polyester prefabricated vertical drain has the lowest absorption capacity you have observed that from the curve. All the prefabricated vertical drain reached almost their maximum absorption after 2 hours of soaking in water, beyond 2 hour, there is a negligible increase in the absorption capacity.

The discharge capacity is greater in the prefabricated vertical drain than in the natural prefabricated drain. Also, the discharge capacity reduction rate is greater in the natural prefabricated vertical drain than in the polyester prefabricated drain when the compressive stress is increased at a specific hydraulic gradient. So, you should maintain that hydraulic gradient by confining the prefabricated drain in marine clay during discharge capacity test. The discharge capacity of prefabricated drain is reduced by 40 percent, natural prefabricated vertical drain 3, 4 by 50 percent and natural prefabricated vertical drain 1, 2 by 60 percent compare to rubber membrane confined discharge capacity test.

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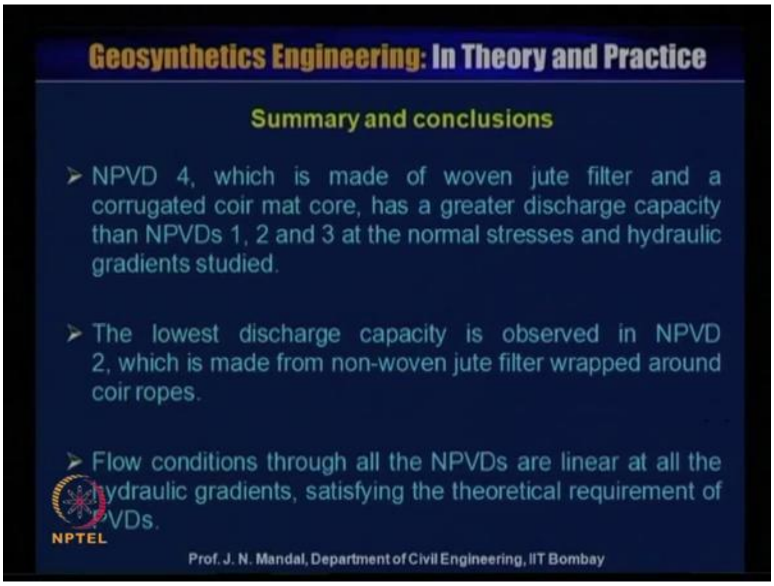

So, some summary and conclusion from this result that natural prefabricated vertical drain 4, which is made of woven jute filter and corrugated coir mat core has a greater discharge capacity, than the natural prefabricated vertical drain 1 2 and 3 at the normal stresses and hydraulic gradient studied. The lowest discharge capacity is observed in natural prefabricated drain 2, which is made of nonwoven jute filter wrapped around coir ropes. Flow conditions through all the natural prefabricated vertical drain are linear at all the hydraulic gradients, satisfying the theoretical requirement for prefabricated vertical drain.

So, which you observe that the natural prefabricated vertical drain which satisfy this all the criteria your discharge capacity, your clogging criteria, your permeability criteria as well as the apparent opening size of the geotextile criteria. So, it satisfies all the criteria, so one can make use of this kind of nonwoven prefabricated vertical drain for the construction purpose. Now, you have also studied some large scale laboratory consolidation test that what is happening if you use this material in a large scale consolidation test.

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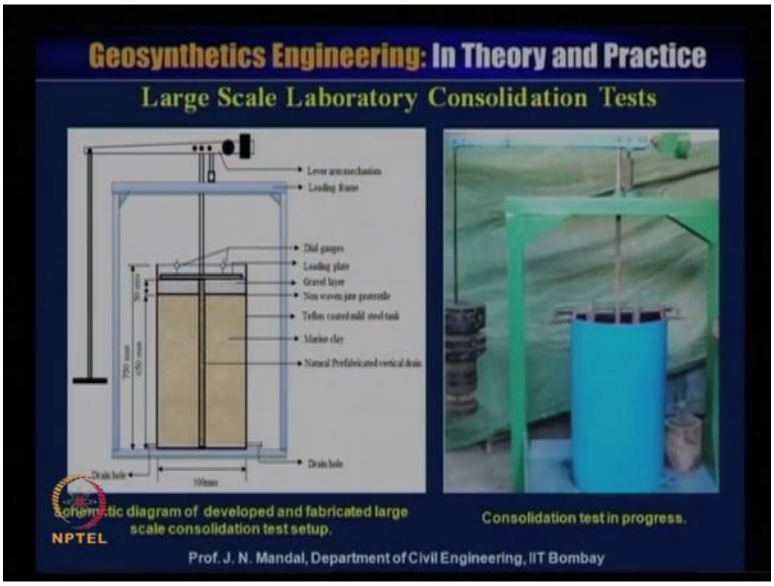

So, this is the right side, this is the large scale consolidation test is in progress and this is the schematic diagram developed and fabricated large scale consolidation test data by doctor Asha. What here is the natural prefabricated vertical drain and here also the drainage system there is a drain and also at the top of this is the marine clay. The top of this we are provided with the non woven geotextile material then the layer gravel layer then the loading and then by the dial gauge reading we are measuring. You are applying the load and you can measure from this large scale consolidation test.

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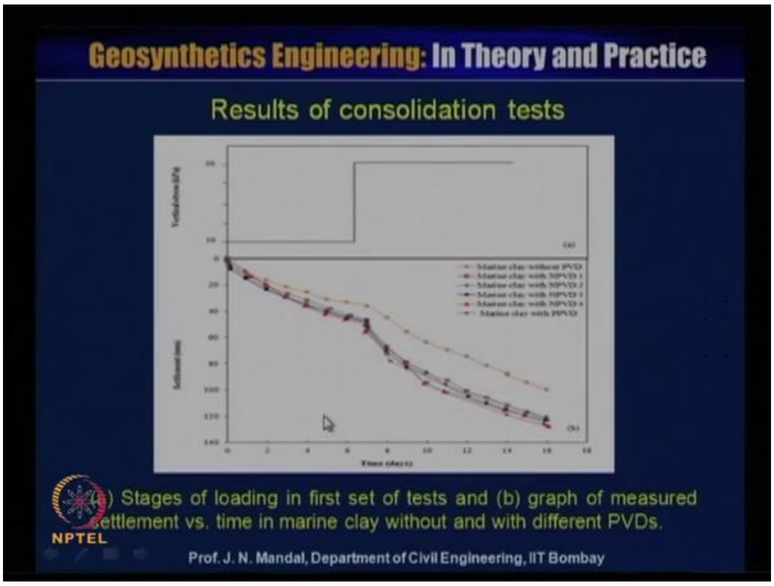

So, this is the stage of loading first set of test and we will show later the graph measure settlement versus also the time curve. Here, without and with the different prefabricated vertical drain, so this is you can see that what is happening with the time stress. Loading in first set of tests, it take this time you can see that with the time what is happening in the settlement then again that after the loading of this 50 and then with respect to the time. Here, you can see how it is with respect to the time this settlement is occurring and then after a sometime, it will be also stabilized. But, you require may be very large scale consolidation test, we can give you the much more the equilibrium state of the soil or it will be stabilized at a what time barriers seems to be for the limitation of this equipment. So, it will be able to say up to this these days the settlement may be occur that maximum work you can obtain from this curve.

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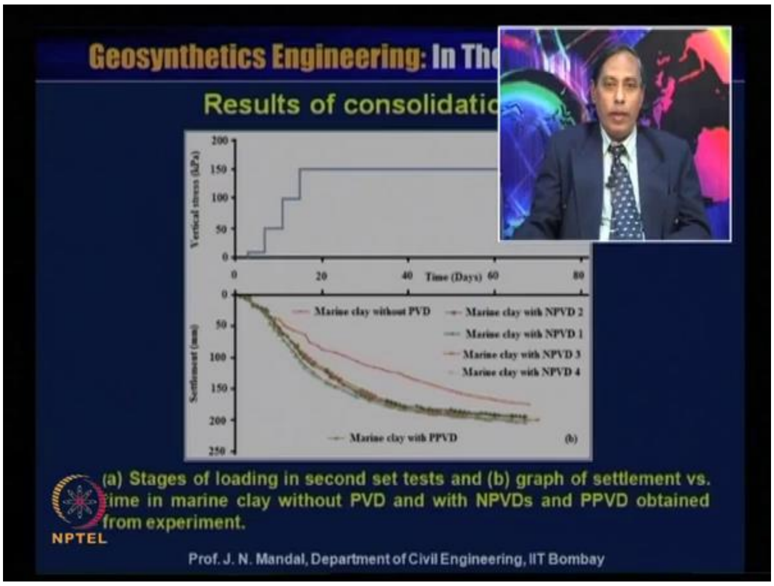

Now, here also the stage loading for the second set of test and here is the curve the graph settlement versus the time for the marine clay. So, this is the vertical stress in Kilo Pascal this is the time in days, so this is a stage loading you are giving this stage loading like that, like it takes time then again load it, takes time like this. You can see that after 1 up to 150 Kilo Pascal the vertical stress and these days passed is constant after the 20 like that near are relative constant.

Similarly, that settlement curves with the time for various prefabricated drain natural prefabricated drain, and also marine clay without this prefabricated drain without prefabricated drain you can see this is the nature of the curve. Whereas, that with the prefabricating drain, you can see that settlement is more with the P V D that means consolidation time within a short time it can give the better settlement.

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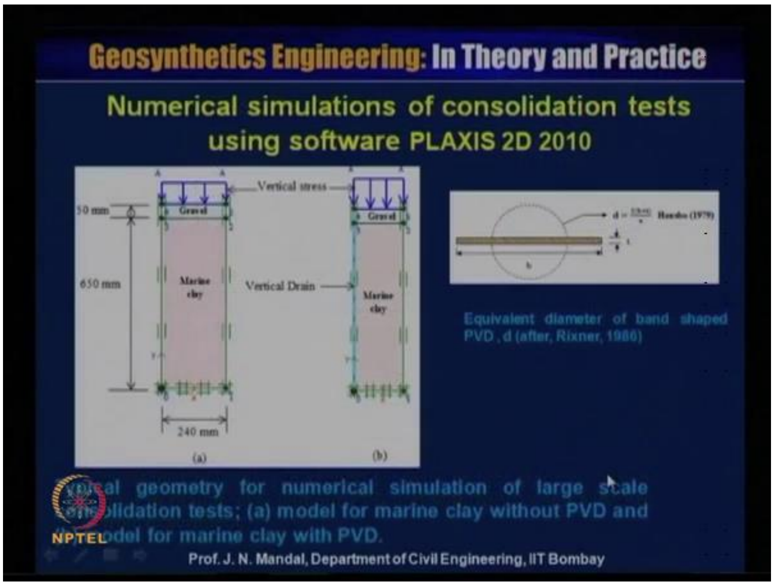

So, some numerical simulation of consolidation test using the software PLAXIS 2 D 2010 I have performed. So, here the typical geometry for the numerical simulation of large scale consolidation test, this is the model of the marine clay without the prefabricated vertical drain. This is the model for marine clay with P V D drain, they are provided P V D drain is here and this size is about 240 millimeter. This is 650 and there is gravel about 50 millimeters and then you are applying the vertical stress and you will see and this is the vertical drain here ok.

So, you want to see that behavior of the prefabricated vertical drain when it come contact with the marine clay. Another important points that equivalent diameter of the band in shape that is P V D this is after Rixner 1986. If this is the width of the prefabricated drain, if this is the width is equal to the D and this thickness of the prefabricated drain is T then equivalent diameter D will be equal to 2 into V plus D divided by phi which is given by Hansbo 1979. So, here what I want to mean is that most of the cases that it has been observed that, in general the sand drain the diameter of the sand drain is about that 66 millimeter.

For example, that if you find that width of the prefabricated vertical drain is 100 and this thickness of the prefabricated vertical drain is 5 millimeter. So, if you can substitute this value that means H 2 into 100 plus 5 divided by phi, so 105 into 2 that means almost 210 divided by phi, so this will give almost this value about 60 65. So, that the way that equivalent diameter of the sand drain has been considered, so I will, may be later on tell about more about this.

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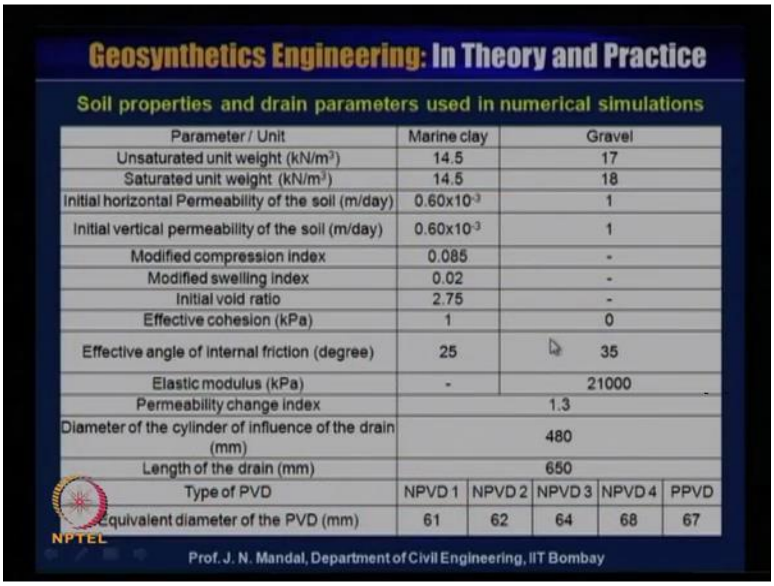

Parameter / Unit	Marine clay	Gravel			
Unsaturated unit weight (kN/m^3)	14.5	17			
Saturated unit weight (kN/m^3)	14.5	18			
Initial horizontal Permeability of the soil (m/day)	0.60×10^{-3}	1			
Initial vertical permeability of the soil (m/day)	0.60×10^{-3}	1			
Modified compression index	0.085	-			
Modified swelling index	0.02	-			
Initial void ratio	2.75	-			
Effective cohesion (kPa)	1	0			
Effective angle of internal friction (degree)	25	35			
Elastic modulus (kPa)	-	21000			
Permeability change index	1.3				
Diameter of the cylinder of influence of the drain (mm)	480				
Length of the drain (mm)	650				
Type of PVD	NPVD 1	NPVD 2	NPVD 3	NPVD 4	PPVD
Equivalent diameter of the PVD (mm)	61	62	64	68	67

So, from this soil property and the drain parameter used in this numerical simulation, so this is the parameter used for the marine clay. This is the gravel that unsaturated unit weight in Kilo Newton per meter cube, for marine clay 14.5 gravel, 17 saturated unit. Weight for marine clay 14.5 and this is the 18 like initial horizontal permeability of the soil meter per day 0.60 into 10 to the power minus 3. Here, is the one initial vertical permeability of soil meter per day 0.60 into 10 to the power minus 3 and for gravel 1 modified compression index is 0.085, modified swelling index is 0.02.

Initial void ratio, 2.75, effective cohesion is 1 Kilo Pascal and effective angle of internal friction 25 degree in case of gravel 35 degree. So, these are the properties has been included in the computational analysis for simulation. Apart from this, you have to provide with the elastic modulus that is for gravel 21000 Kilo Pascal. Permeability chain index is 1.33, diameter of the cylinder influence of the drain is 480 millimeter length of the drain is 650 millimeter and type of the P V D. So, equivalent diameter, this I was trying to tell you that equivalent diameter P V D for natural prefabricated vertical drain 1 is 61. Natural prefabricated vertical drain 2 is 62, natural prefabricated vertical drain 3 is 64, or natural prefabricated vertical drain 4 is 68 and polyester prefabricated vertical drain is 67. So, this is important that how you can calculate equivalent that diameter, that is D of E, so as I said for this sand drain we used about 65 66 millimeter and that equivalent diameter has been determined. Using that ideal equation and then you can obtain these are the values of equivalent diameter of the prefabricated vertical drain.

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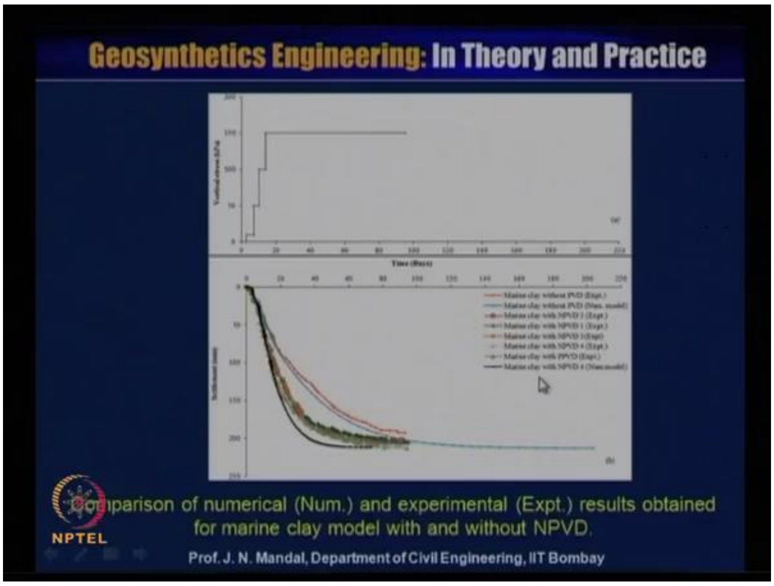

So, after this input you can have this comparison of numerical and the experimental result obtained from the marine clay model with and without natural prefabricated vertical drain. So, here is the vertical stress versus this time, here the settlement versus this time. You can see that earlier also it has been shown like this the vertical stress with the time and here you can see the settlement for the different natural prefabricated vertical drain and polyester prefabricated vertical drain. Even then only the marine clay without prefabricated vertical drain, you can see that nature of curve is like this, so with days passes also it stabilize.

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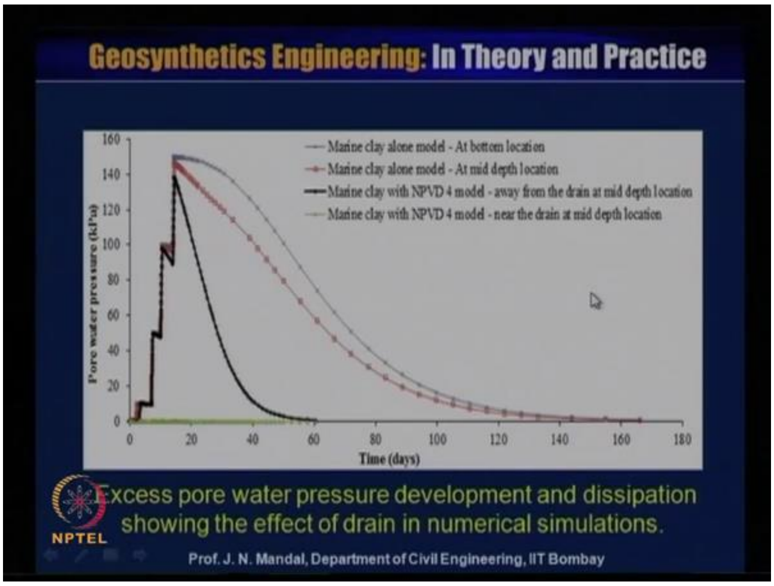

So, here the excess pore water pressure development and dissipation showing the effect of drain in numerical simulation, here is the pore water pressure with the time. So, this is for marine clay alone model and then marine clay alone model at mid depth of the location and marine clay with N P V D 4 model away from the drain. At the mid depth of the location and marine clay N P V D 4 model near the drain, at the mid depth of the location you can see for the different location.

Even then if you take and you find that what will be the pore water pressure variation with respect to the time? So, you can see the pore water pressure is increasing with up to may be 20 days and then it abruptly is decreasing with increasing the time. So, you can have the idea how the pore water pressure running with the time also, me computation with the excess pore water pressure dissipation pattern in the numerical simulation.

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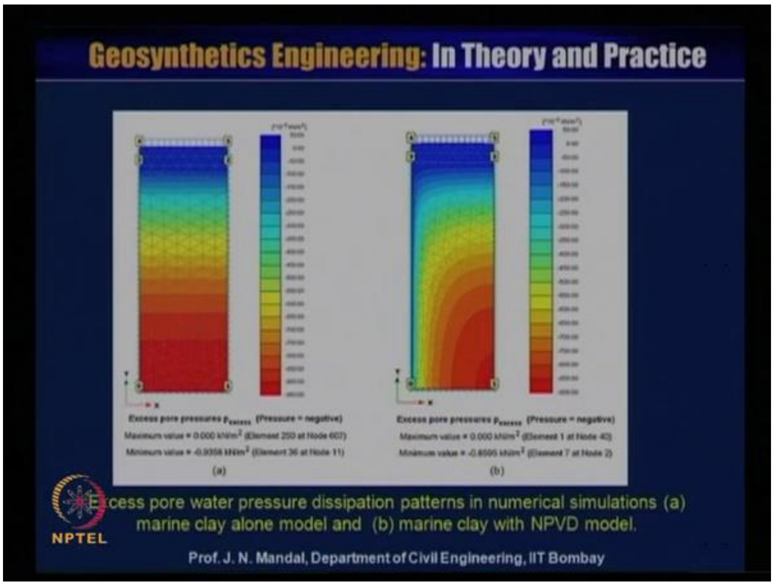

Air with the marine clay alone model and B with the marine clay, with the natural prefabricated vertical drain, so we can see that here what will be the excess pore water pressure. This is developed under the different that pressure, so you can see here that what will be the excess pore water pressure here, and you can see that how the excess pore water pressure dissipated.

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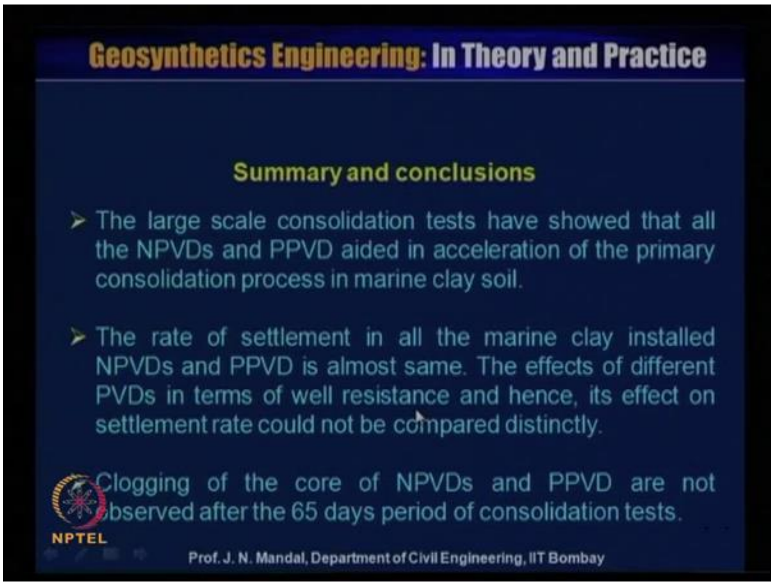

So, what are the summary and the conclusion that large scale consolidation test have shown that all the natural prefabricated drain, the polyester prefabricated drain aided in acceleration of the primary consolidation process in marine clay soil. The rate of settlement in all the marine clay install natural fabricated drain and the polyester prefabricated drain is almost same. The effect of different polyester prefabricated drain in terms of well resistance and hence, its affect on settlement rate could not be compared distinctly. Clogging of the core on the natural prefabricated drain and the polyester prefabricated drain are not observed after the 65 days period of consolidation test, which we can only perform.

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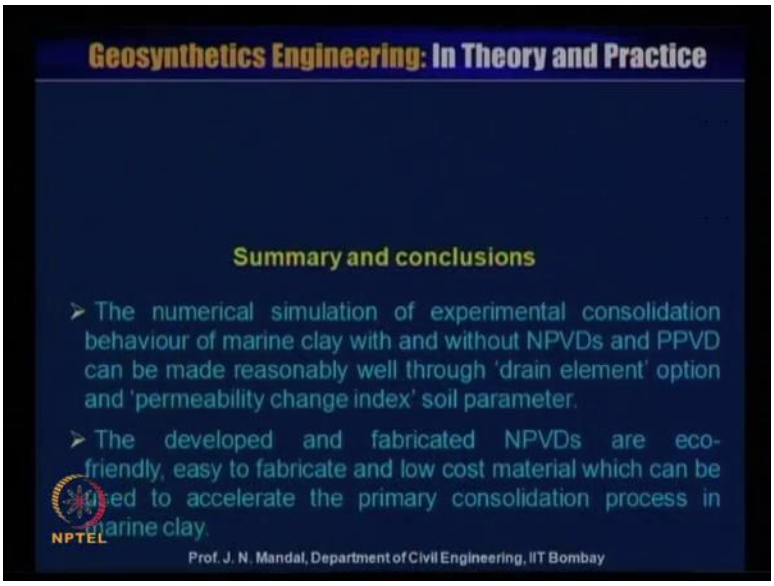

Now, main summary and conclusion from the above test that numerical simulation of experimental consolidation. Behavior of marine clay with and without natural prefabricated drain and the polyester prefabricated drain can be made reasonably well through drain element option and permeability chain index soil parameter. The developed and fabricated natural prefabricated drains are eco friendly, easy to fabricate and low cost material which can be used to accelerate the primary consolidation process in marine clay.

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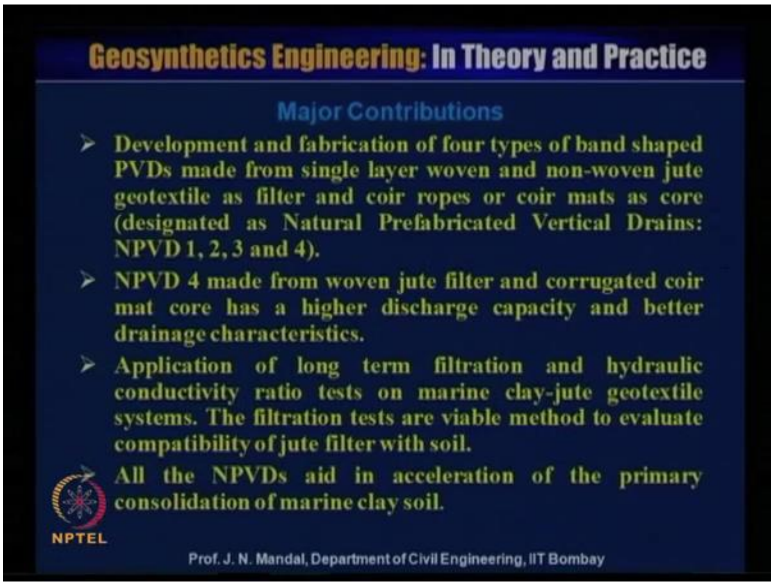

Now, what are the major contributions from this test? The development and fabrication of e types of the band shape prefabricated drain made from single layer woven and non woven jute geotextile. As filter and coir ropes or coir mat, as core designated as natural prefabricated drains or N P V D 1, N P V D 2 3 4. N P V D 4, made from the woven jute filter and corrugated mat core has a high discharge capacity and better drainage characteristics. I say that discharge capacity also very important application of long term filtration and hydraulic conductivity ratio test on marine clay jute geotextile systems. The filtration tests are viable method to evaluate compatibility of the jute filter with soil, all the natural prefabricated drain aid in acceleration of the primary consolidation of the marine clay.

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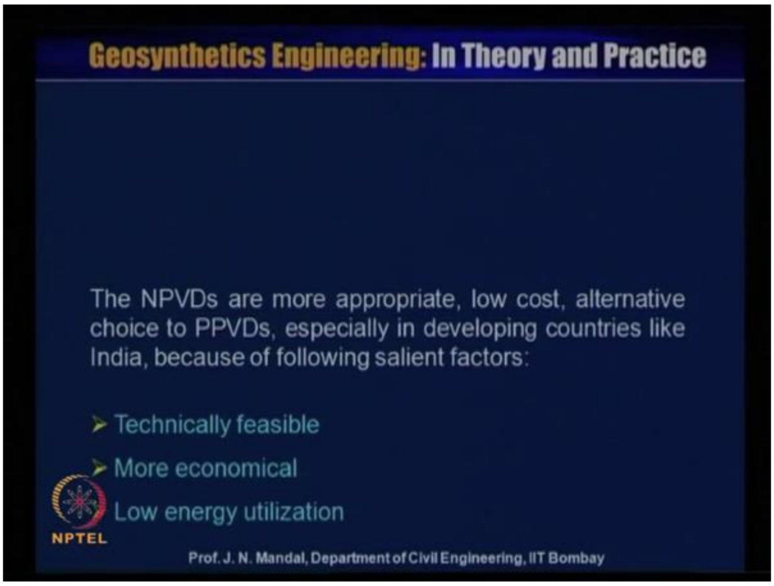

Apart from this, the natural prefabricated drain are more appropriate, low cost, alternative choice to polyester prefabricated drain, especially in developing country like India because of the falling saline factors. The natural prefabricated vertical drain is technically feasible, it is more economical, low energy utilization and it is a sustainable material and also it is eco friendly and environmental friendly. So, you can make use of the natural prefabricated vertical drain because it satisfies all the criteria like the polyester prefabricated vertical drain.

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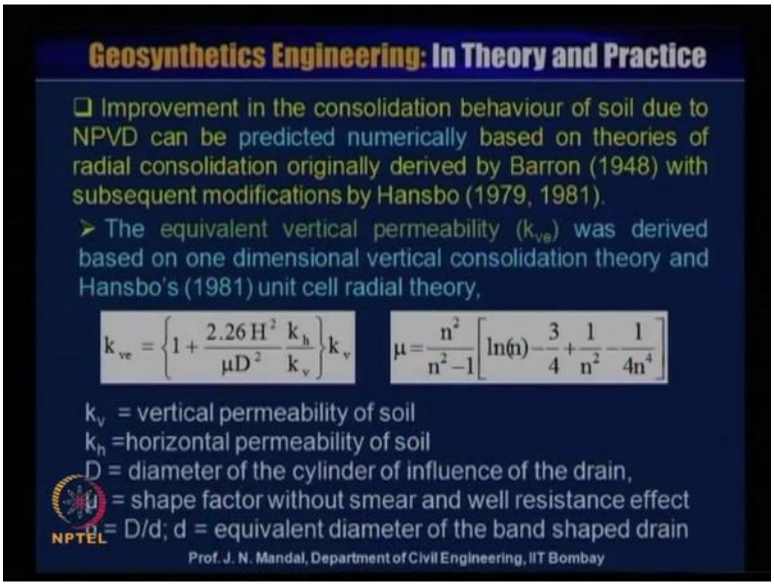

Now, how to this design and what are the equations we can adopt to design the prefabricated vertical drain. Improvement in the consolidation behavior of soil due to the natural prefabricated vertical drain can be predicted numerically based on the theory of radial consolidation. Originally derived by the Barron 1948 with subsequent modification by Hansbo 1979 and 1981.

The equivalent vertical permeability K V e was derived based on the one dimensional vertical consolidation theory and Hansbo 1981 unit cell radial theory. So, here K V e is the vertical permeability of the soil is equal to 1 plus 2.6 into H square divided by mu into D square into K h by K v into K v, or mu is equal to n square divided by n square minus 1 into l n, n minus 3 by 4 plus 1 by n square minus 1 by whole n to the power 4, where K v is the vertical permeability of the soil, K h is the horizontal permeability of the soil, and D is the diameter of the cylinder of influence of the drain. And mu is the safe factor with smear and well resistance effect and n is equal to D by d, where this small d is the equivalent diameter of the band shaped drain.

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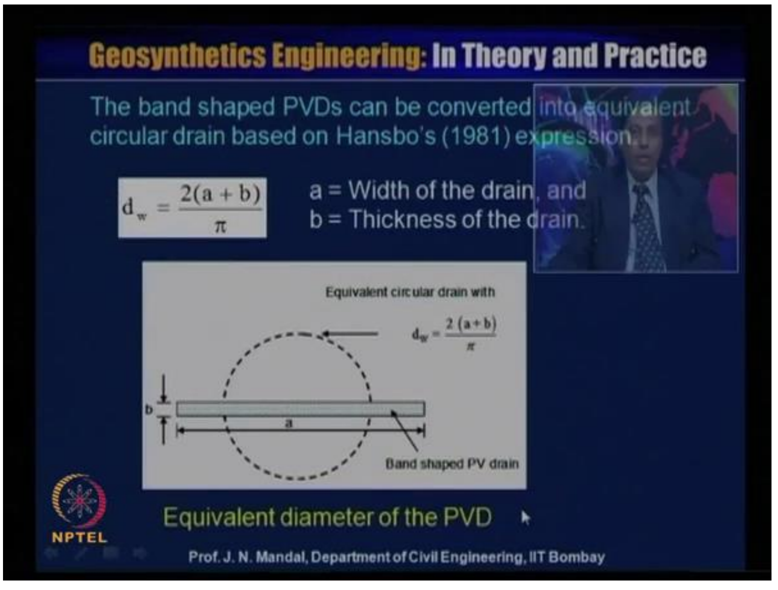

So, here capital D is the diameter of the cylinder of influence of the drain and small d equivalent diameter of the band shape drain. So, here what I was trying to say that equivalent diameter of the drain, the band shape, the prefabricated drain can be converted into equivalent circular drain based on the Hansbo 1981 expression. So, this equivalent diameter d W will be 2 into a plus b by pi, where this is a that means width of the drain and this is the b, is the thickness of the drain. So, d W will be equal to this is the equivalent circular drain, so d W will be equal to 2 into a plus b by phi. So, this is the band shape prefabricated drain, so this is important that how you can calculate the equivalent diameter of the P V D. So, if you know that what is the width of the P V D if you know what should be the thickness of the P V D.

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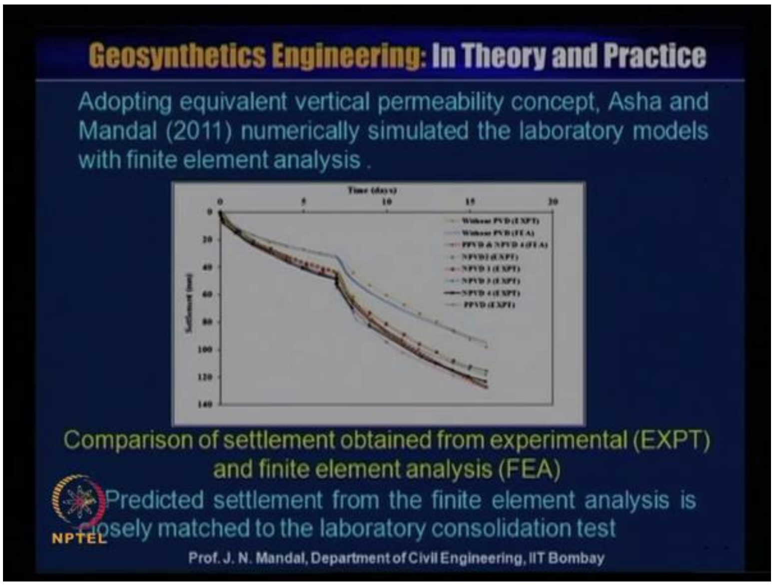

So, then you can calculate that what should be the equivalent diameter of the P V D, so adopting the equivalent vertical permeability concept, Asha and Mandal 2011, numerically simulated the laboratory model with finite element analysis. This is the comparison of the settlement obtained from the experiment and the finite element analysis. So, you can see here the time versus the settlement for various prefabricated vertical drain.

So, you can see that how the settlement is increasing with the time then after a certain time again the settlement is increasing like this for all this P V D you can see. You can match between that what will be, you have, obtained from the experiment and also the finite element method. So, it has been observed that it is quite good matching between the experimental, and finite element method. And the predicted settlement from finite element method is closely matched to the laboratory consolidation test. So, we can have that we have performed the different type of the test and also we have performed that numerical analysis using the fluxes as a finite element method, and it has been observed that it is matching well. So, natural prefabricated vertical drain can be used for the ground improvement. With this, I finish my lecture today, let us hear from you any question?

Thanks for listening.