Geosynthetics Engineering: In Theory and Practices
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Lecture - 43
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.

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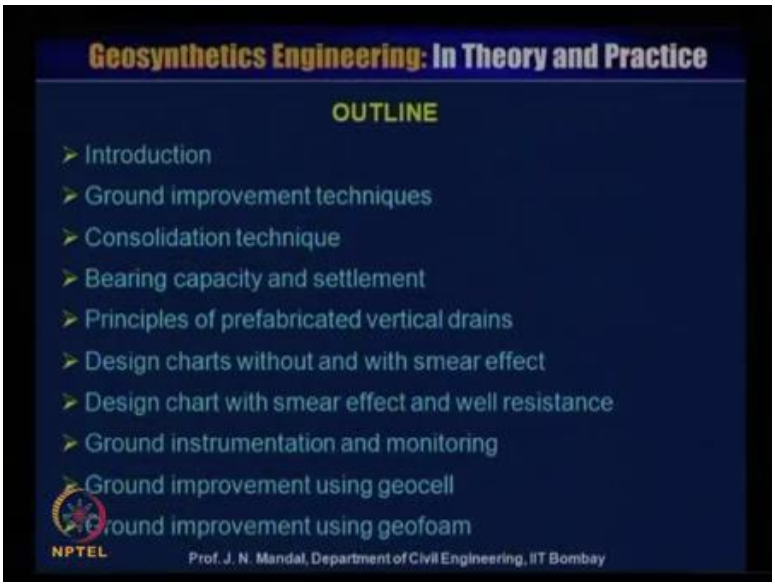

Now, this lecture number 43, this module 9 lecture 43, geosynthetics for ground improvement, so for the ground improvement, the outline of this course is introduction ground improvement technique. Consolidation technique, bearing capacity and settlement principle of prefabricated vertical drain design chart without and with smear effect, design chart with smear effect and well resistance, ground instrumentation and monitoring, ground improvement using geo cell, and ground improvement using geo foam.

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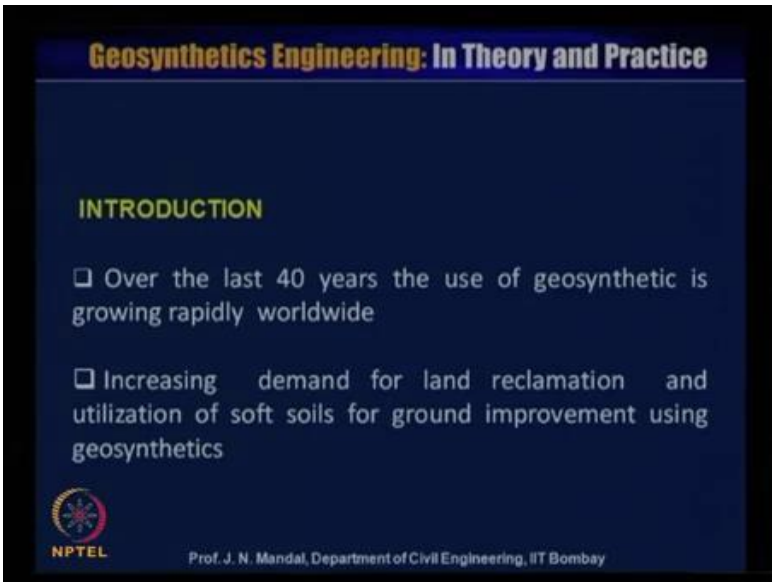

So, in most of the cases in the soil mechanics, we face three problems and that is the strain problem and then the deformation problem and the sewage problem. The strain problem means it is related with the total stress effective stress, and also that load at any depth where you know that what will be the unit weight of the soil and the depth, then you also can calculate what will be the load due to the unit weight of the soil. And secondly that deformation problem, and that deformation problem depend upon what will be the steepness of the soil. You can say what will be the either, what will be the E value, what will be the G value, that means what is elastic modulus of the soil, what is shear modulus of the soil and the seepage problem.

It depends upon what will be the coefficient of permeability of this soil. So, all these three problems can be combined to the consolidation problem, and that combined that, what should be the steepness as well as the seepage. The most important concept of the soil mechanics is that mechanical behavior, that of the soil that means that is the change in the strain value and that depend on only the effective stress. So, its behavior depends on the forces between the particle and that depend upon effective stress, not the total stress because for any ground improvement effective stress is very important parameter. So, with this background I will start this introduction. Over the last 40 years, the use of geosynthetics is growing rapidly worldwide, and the increasing demand for land reclamation and utilization of soft soil for ground improvement using geosynthetics material.

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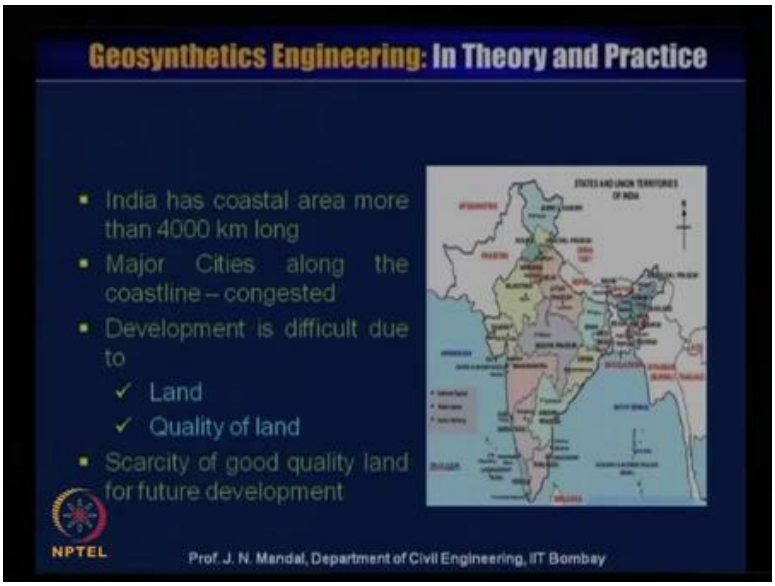

Now, India has a coastal area more than 4000 kilometer long, the major cities along the coastline congested and development is difficult due to the land and quality of the land. So, there is a scarcity of good quality land for future development, even then in the city you can see that there is a problem for the land. Most of the infrastructure has been completed with the good soil and now you can find there is a soft soil and in that case also you can improve the ground. There are many conventional systems are there and we will study here, that how the alternative ground improvement or modification system will be adopted in this course.

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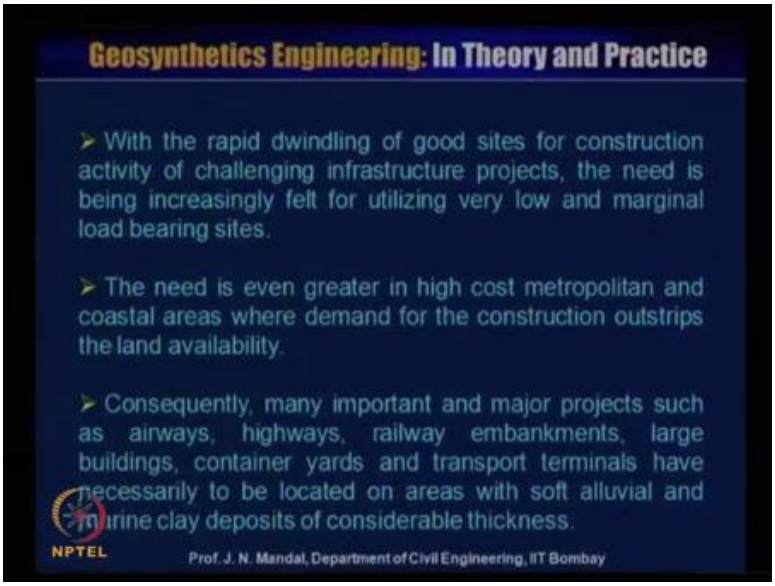

With the rapid dwindling of the good site for the construction activity of challenging infrastructure projects, the need is being increasingly felt for utilizing very low and marginal load bearing site. The need is even greater in high cost metropolitan and the coastal area where demand for the construction outstrip the land availability. Consequently, many important and major projects such as airways, highways, railways embankment, large building container yards, and transport terminal have necessarily to be located on area with the soft alluvial and the marine clay deposit of considerable thickness.

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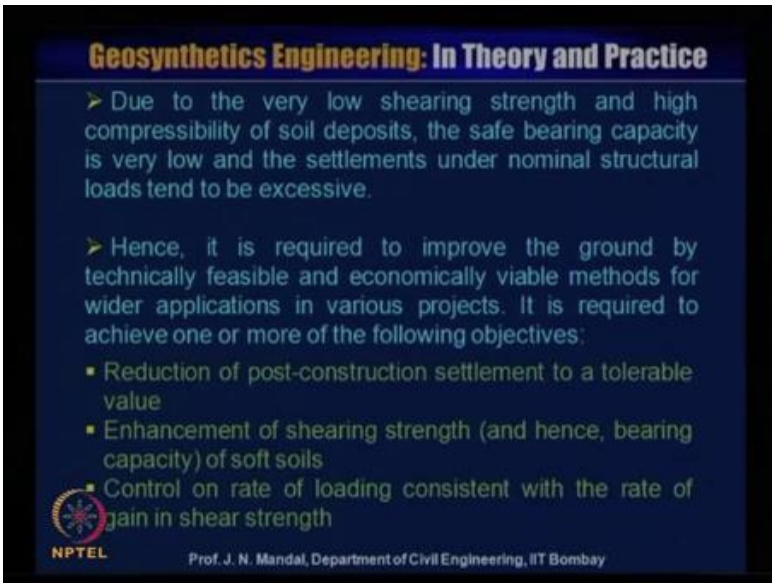

So, due to the very low shearing strength and high compressibility of soil, deposit the safe bearing capacity is very low and the settlement under nominal structural load tends to be excessive. Hence, it is required to improve the ground by technically feasible and economically viable method for wider application in various projects. It is required to achieve one or more of the following objective, reduction of post construction settlement to a tolerable value. Then enhancement of shearing strength and hence, the bearing capacity of soft soils, control on rate of loading consistent with the rate of gain in shear strength. So, these are the objectives you have to keep in mind and it should satisfy for the ground modification.

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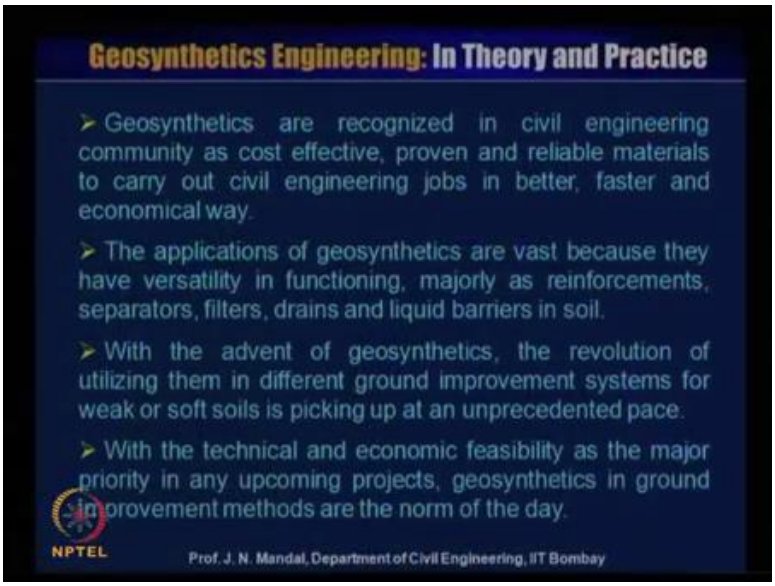

Now, geosynthetics are recognized in civil engineering community as cost effective proven and reliable material to carry out the civil engineering job in better, faster and economical way. The applications of geosynthetics are vast because they have versatility in functioning, majority as reinforcement, separator, filter, drain and liquid barriers in soil. So, these are the main function what we will study that how you can use the geosynthetics material as a separation, as reinforcement, as a filtration, as a drainage and even then as a liquid barrier. With the advent of geosynthetics, the revolution of utilizing them in different ground improvement system for weak or soft soil is picking up at an unprecedented pace. With the technical and economic feasibility, as the major priority in any upcoming project, so geosynthetics in ground improvement method are the norm of the day.

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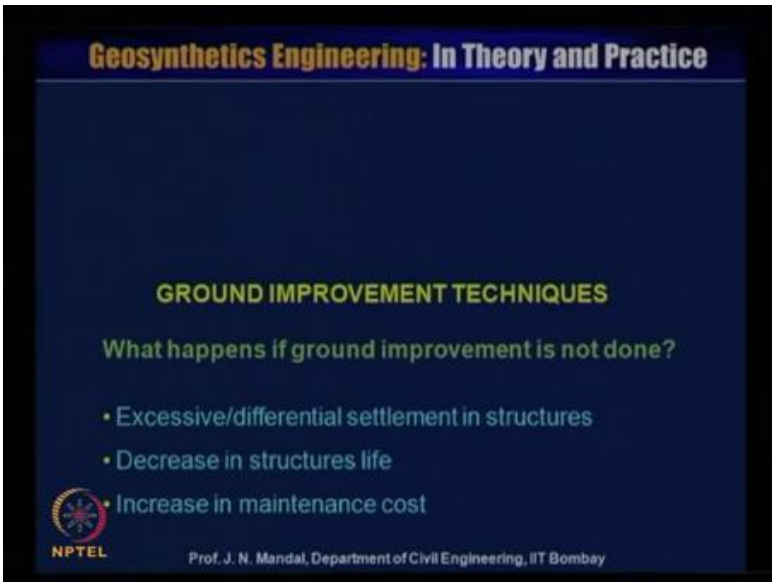

Now, ground improvement technique, what happen if ground improvement is not done? So, you see there will be excessive or differential settlement in structure decrease in structure life increase in maintenance cost, so we require how to solve this kind of the problem.

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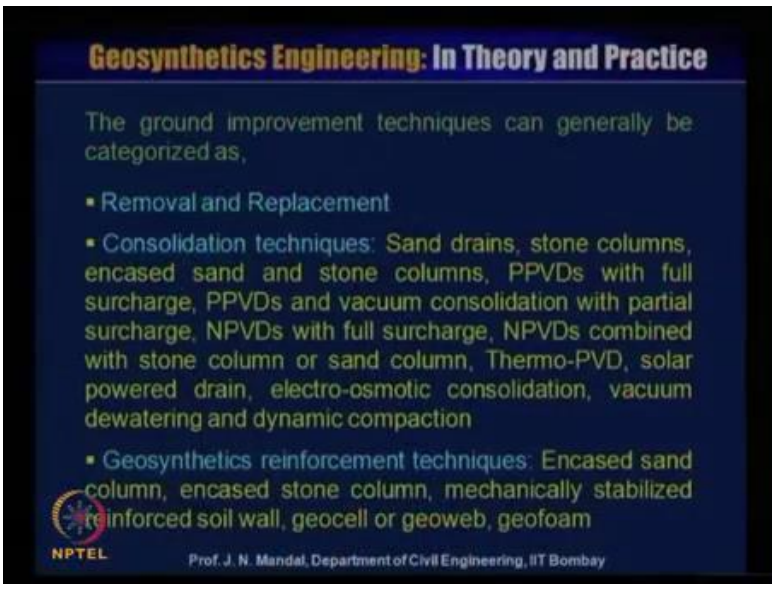

The ground improvement technique can generally be categorized that, you remove and replace, and we use the different consolidation technique that is we use the sand drain stone column. Encased sand and stone column then prefabricated vertical drain with full

surcharge and vacuum consolidation with partial surcharge and prefabricated vertical drain, natural prefabricated vertical drain with full surcharge. Natural prefabricated vertical drain combined with the stone column or sand column thermo prefabricated drain, solar powered drain, electro osmotic consolidation vacuum dewatering and dynamic compaction.

Geosynthetics reinforcement technique, that is encased stone column, encased stone column mechanically stabilized reinforced soil wall geo cell or geo web or geo foam. So, you find that different types of the ground improvement technique, and we have to observe that what kind of the system will be more suitable in Indian condition. Some of the system will be very expensive and time consuming in Indian condition, so we have to adopt the proper kind of the ground improvement technique. So, we will focus later on detail about that, apart from this ground improvement you can go for the densification. Let us say, pile RCC wooden steel composite dynamic compaction vibro compaction grouting.

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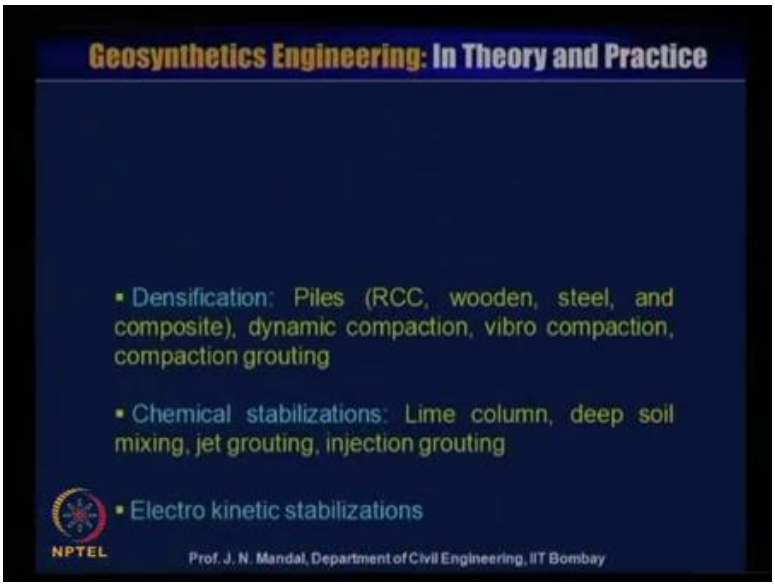

These are all very expensive chemical stabilization. We can go lime column, deep soil mixing, jet grouting, and injection grouting then electro kinetic stabilization.

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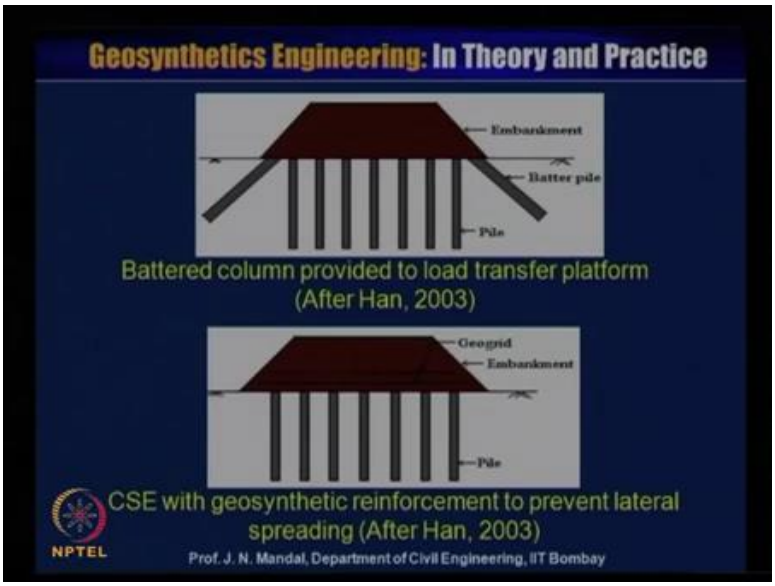

So, these are some of the systems which we adopt now a day, but most of the cases what we adopt for the sand drain and now the alternative to the sand drain. So we can use the prefabricated vertical band drain. So, what is prefabricated vertical band drain also we will study and also we have developed some natural prefabricated vertical drain. How the natural prefabricated vertical drain also compare the polyester prefabricated vertical drain because natural prefabricated drain is available, and it is much more cheaper than the polyester prefabricated vertical drain. I will now show you some of the structure where you need the ground improvement. So, this is the embankment, what we do that some cases that battered column are provided.

You can see here, battered pile in water that loads can be transferred to this platform and this is the pile, this is given After Han 2003. So, now a day also in some of the project where you are using the pile and then we can place the layer of the geo grid material. Here, in between the embankment and the top of the cap of the pile and this geosynthetics reinforcement can prevent the lateral spreading, this is also After Han 2003. So, you do not require any battered pile, you can simply provide with the layer of geo grid material in between the pile and this embankment which can prevent the lateral spreading.

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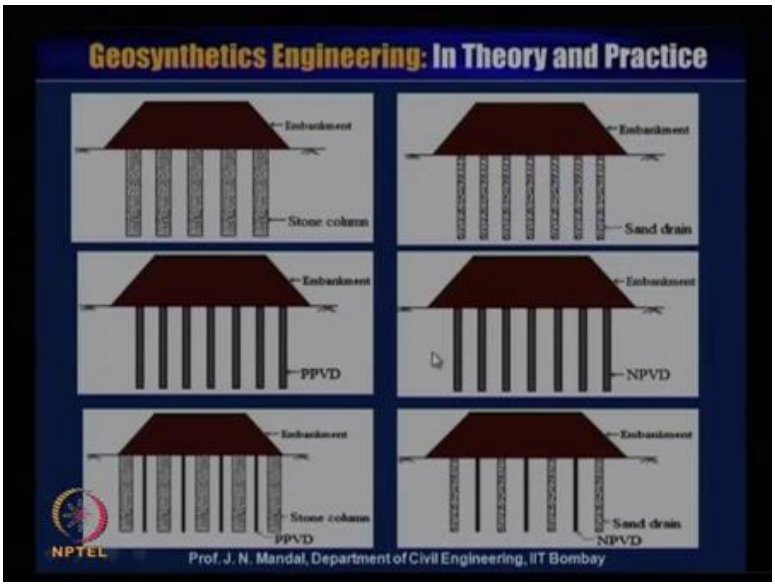

Now, there is various combination of the use of the stone column or the sand drain also prefabricated vertical drain and natural prefabricated vertical drain. So, here you can see embankment has been constructed with the stone column here this embankment is construction on this sand drain. So, this you have to install the band drain or casing and push into the soft soil and then you can fill up with the sand and then pulled out the casing. So, you can form the sand drain here, so alternative to the stone column and the sand drain. So, you can adopt that this is polyester prefabricated vertical drain and apart from this polyester prefabricated vertical drain you can alternative you can do the natural prefabricated vertical drain. So, suppose this is the polyester prefabricated vertical drain.

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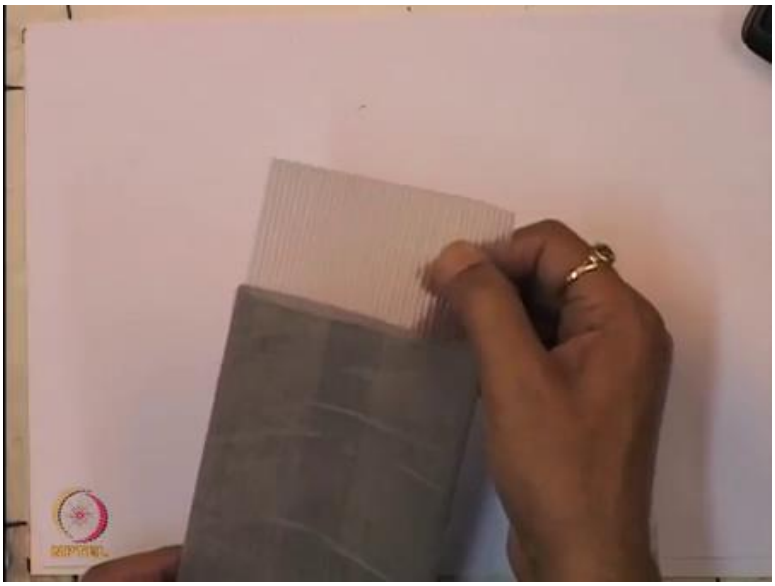

So, this is the core and this is the jacket and this polyester prefabricated vertical drain, alternative to this you can use the jute or natural prefabricated vertical drain. So, this is the jute and this is the coir has a core and jute it may be the woven, or it may be the nonwoven here it is a nonwoven jute material. So, non woven jute material will act as a jacket and this will act as a core and also you can construct this woven jute geotextile material as a jacket. Also, this material or the coir also as a coat alternative to this you can use the coir as a coat.

So, I will show you more about the different type of natural prefabricated vertical drain and now you can see here that, you can use stone column and prefabricated vertical drain you can use sand drain with the natural prefabricated vertical drain. Now, you can see sometimes that when you want to use the stone column, and also either the natural prefabricated vertical drain or the polyester prefabricated vertical drain. So, this kind of the system what we call the multiple system because you are providing the stone column and as well as the natural prefabricated vertical drain. So, natural prefabricated vertical drains will accelerated consolidation is very fast.

So, there will be a development of excess pore water pressure with the jute or natural prefabricated vertical drain can absorb and can translate on the top of the embankment. That means, the natural prefabricated vertical drain can take care for the settlement,

because distribution excess pore water pressure has been reduced in the effective stress it will increase.

But, the stone column is very good material to improve the bearing capacity that means stone material can take care for the load carrying capacity. So, if you can use combination of the stone column and the natural prefabricated vertical drain, so one will take care of the settlement and other will take care for the bearing capacity. So, this kind of the system also is applied in India.

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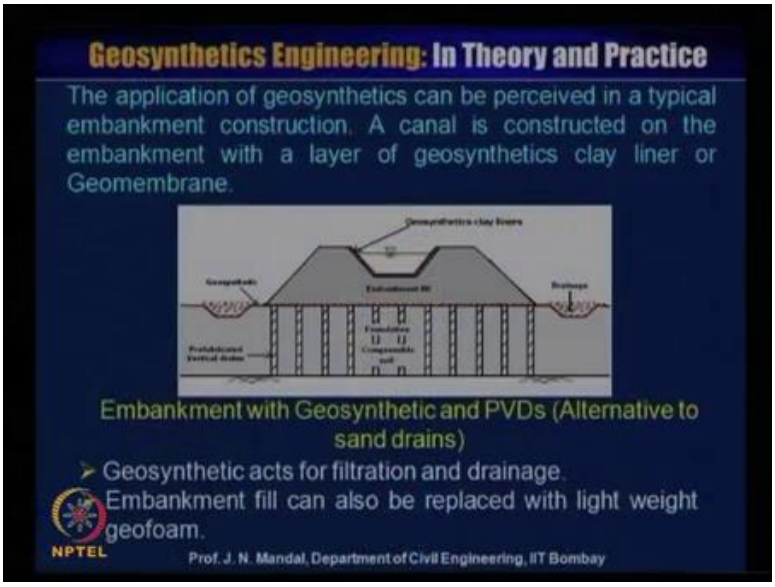

Now, application of geosynthetics can be perceived in a typical embankment construction. A canal is constructed on the embankment with a layer of geosynthetics clay liner or the geo membrane sometimes. You can see that if this is the embankment and this is the ground improvement have performed with the prefabricated vertical drain. This is a foundation compressible soil and on the top of this embankment you require suppose some canal. So, you can place here the geo membrane clay liner or the geo membrane even then sometimes you can place the geo membrane and also geo cell. So, here this geosynthetics material act as a filtration and drainage and embankment fill can also replace by the light weight material. You can also replace with the light weight material like geo foam.

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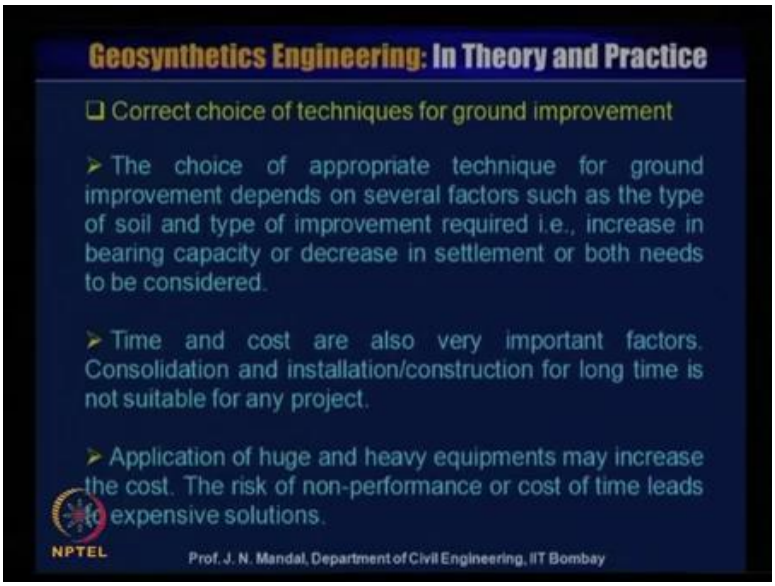

So, correct choice of technique for ground improvement, the choice of appropriate technique for ground improvement depends on several factors such as the type of soil and type of improvement required. That is, increase in the bearing capacity or decrease in settlement or both need to be considered. Time and the cost are also very important factor consolidation and installation, and construction for long time is not suitable for any project. Nobody like that, you should continue for a longer time to consolidate the soil, everybody wants to finish the project at the earliest also because time is money. Application of huge and heavy equipment may increase the cost the risk of nonperformance or cost of time lead to expensive solution.

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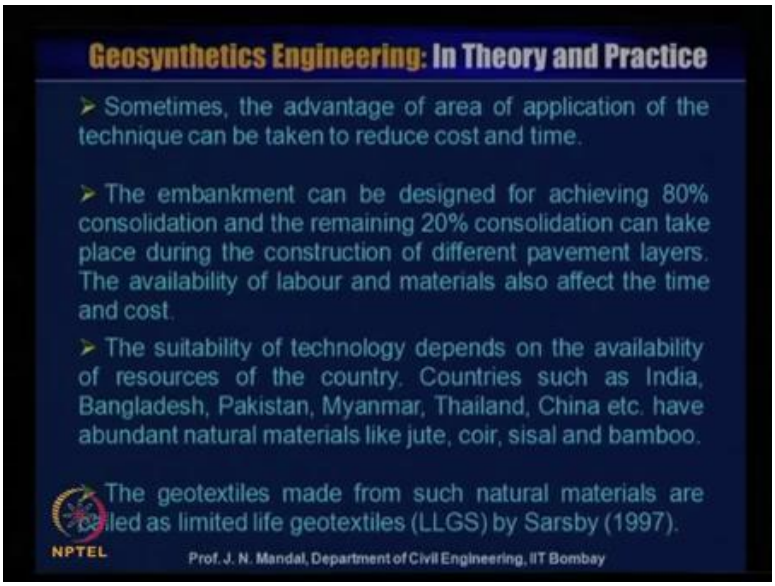

Sometimes, the advantage of area of application of the technique can be taken to reduce the cost and time. The embankment can be designed for achieving 80 percent consolidation and remaining 20 percent consolidation can take place during the construction of different pavement layer. The availability of labor and the material also affect the time and cost. Suitability of technology depend on the availability of the resources of the countries such as India, Bangladesh, Pakistan, Myanmar, Thailand, China etcetera have abundant natural material like jute coir, sisal and bamboo.

The geotextile made from such natural material are called as limited life geotextile or LLGS reported by Sarsby 1997. So, here are two issues is that when you wanted to construct the embankment on a soft soil and you use any natural prefabricated vertical drain it takes time to consolidate. You have to achieve the 95 percentage consolidation, so you should even then you can go for the 80 percent. When the structure is constructing, remaining the 20 percent or the 15 percent can be completed, so this will act as a stress loading. Here, that most of the cases we use this polyester prefabricated vertical drain, here as I mentioned that abundant natural material like jute and coir are available in India. So, we can manufacture the natural prefabricated vertical drain, I will also address that some of the natural prefabricated vertical drain also.

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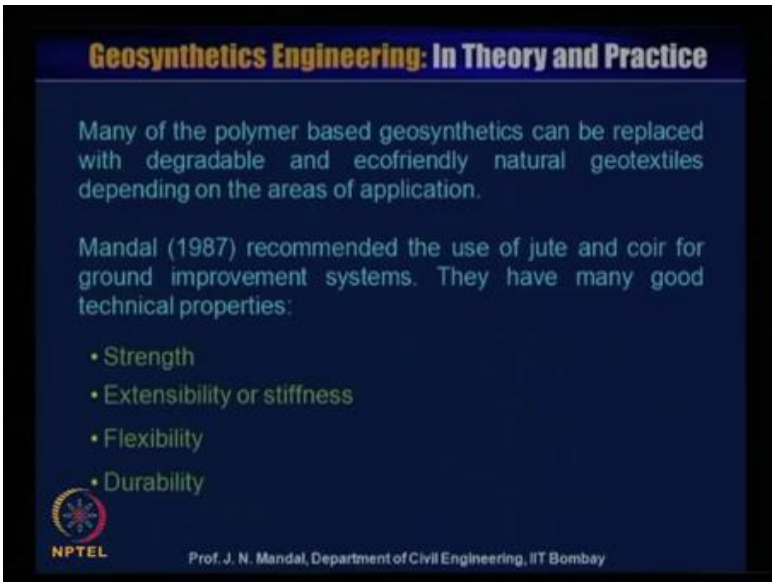

Now, many of the polymer based geosynthetics can be replaced with degradable and ecofriendly natural geotextile depending on the area of application. Mandal 1987 recommended the use of jute and coir for ground improvement system and they have the many good technical property. You can see this paper also in international journal geotextile and geo membrane, so they will give this good property like strength extensibility or the stiffness and flexibility and durability.

So, most of the cases you can see when you talk about the natural material and jute and the coir then everybody ask about what is biodegradable what is life. So, that is why that doctor Sarscy mentioned it is a limited life because jute is very good water absorption capacity, 300 400 percentage water, no other material polymer material cannot absorb that much percentage of the water.

Secondly, for the installation of the prefabricated drain, do not take the major strength tensile strength of the material because it is required initially only for the installation and because jute absorb water and consolidation is very faster. So, stabilization will be very faster even then jute deteriorated, that means is water absorption capacity also increases, so consolidation also will be very faster it accelerated very fast. So, that was the main reason that where you can use the jute and the coir as a natural material for the ground improvement.

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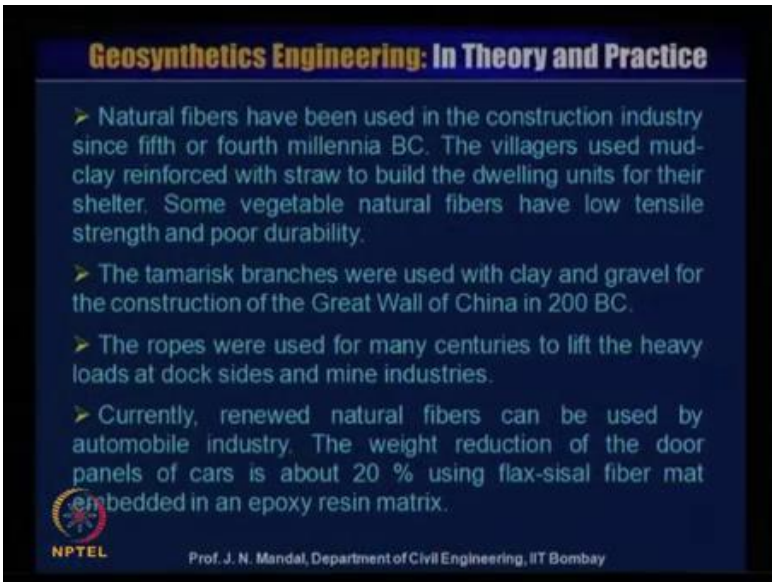

So, natural fibers have been used in the construction industry since the fifth or fourth millennia BC. The villagers used mud clay reinforced with straw to build the dwelling units for their shelter some vegetable natural fibers have low tensile strength and poor durability. The tamarisk branches were used with the clay and the gravel for the construction of the Great Wall of China in 200 BC, the rope was used for many centuries to lift the heavy load at dock side and mine industries currently renewed. Natural fiber can be used by automobile industry the weight reduction of the door panel of car is about 20 percent using the flax, sisal fiber mat embedded in an epoxy resin matrix. So, you can see that how the natural material can be used in various applications even then in the automobile industry natural fiber can be utilized.

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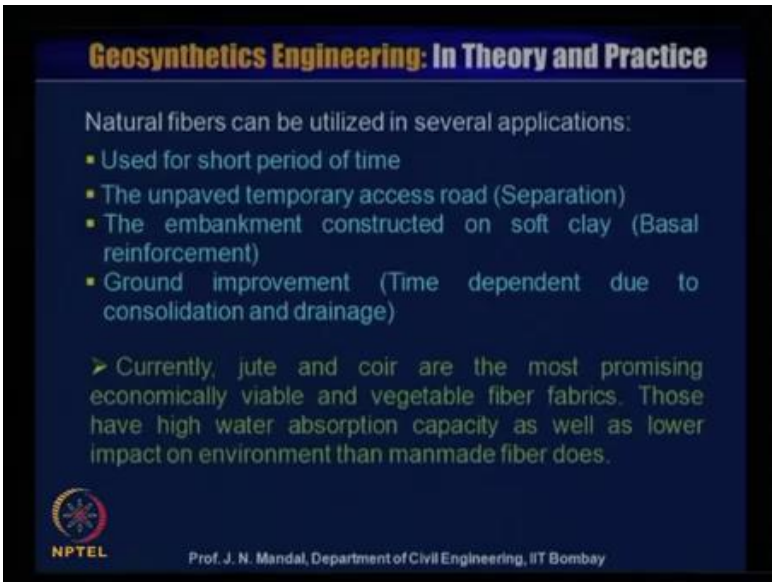

The several applications used for short period of time unpaved temporary access road that is separation. The embankment construction on soft clay that is basal reinforcement ground improvement time dependent due to consolidation and drainage. Currently, jute and coir are the most promising economically viable, and vegetable fiber fabrics those have high water absorption capacity, as well as the lower impact on environment than manmade fiber does. So, here you can see that how the natural material is much more suitable for the ground modification and it is environmental friendly also.

The natural material can be used for temporary for any purpose if it is a very soft soil it is very difficult to cross. So, you can place the natural material and then you can walk on the soft soil using the natural material where in many army places where they have to cross and they have to build up very temporary some. Let us say, mechanically stabilized reinforced soil wall or reinforced soil slope for time being. So, you can construct temporary road where soil is very soft, so you can make use for temporary for any places even then I am telling that army where we use, so where we can make use of this natural material.

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Indigenous natural geotextile have certain major advantage and play significant role in developing countries like India. The raw materials are environmental friendly, renewable resources and available abundantly India is the second largest jute producer in the world. Thus, making sustainable construction industry and Bangladesh is the first that jute manufacturing country and natural, bio degradable nourishes soil and return to the ground without pollution. Low unit cost production and conversion cost low provide competitive cost, and economical create new market to agriculture product support agro industry and job for the local people.

This is very important that how we can make use of the natural material like jute and coir. So, common people can survive, elevate this pore. This also can be used for the mulching in the agriculture, you can use the jute and coir material for the erosion control and grass can grow. Jute has been used for many, many years for the erosion control because the grass will grow, and if you pour the water jute is a very good water absorption capacity and it retains.

So, grass can survive for a longer time and also the grass from grow the roots and it stabilizes, so jute has a very important role for the soil erosion. Even then for the agriculture you can use jute and coir like a pipe and then then water can pass through this pipe through the jute material and because the jute also has an opening side and water can be spread through the plant and plant can grow. It is not necessary that you have to

provide the water often on because water absorption capacity is more than any other material. So, it has also used in various like this agriculture industry.

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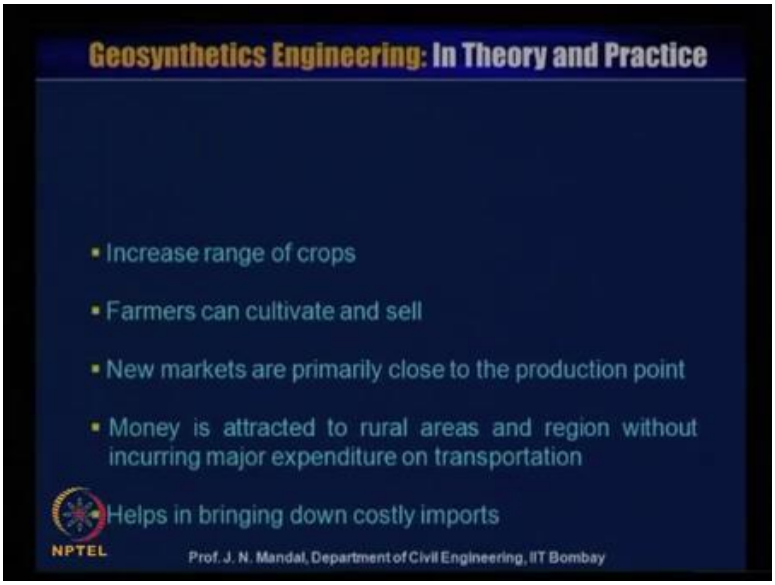

So, that is why is increase the ranges of crops farmer can cultivate and sell new market are primarily close to the production point. Money is attached to rural area and region without incurring the major expenditure on transportation help in bringing down costly import. So, you observe that how we can make use of the natural material jute and coir and how the common people also will be the benefited. How the different type of this infrastructure we can use the natural material jute or the coir.

Now, we will talk about some consolidation technique and what is happening. What is the mechanics and mechanism of the natural prefabricated vertical drain, how you can improve the ground using this natural prefabricated vertical drain or the polyester prefabricated vertical drain. So, before that we should know what is happening and what we adopt, so let us study some consolidation technique.

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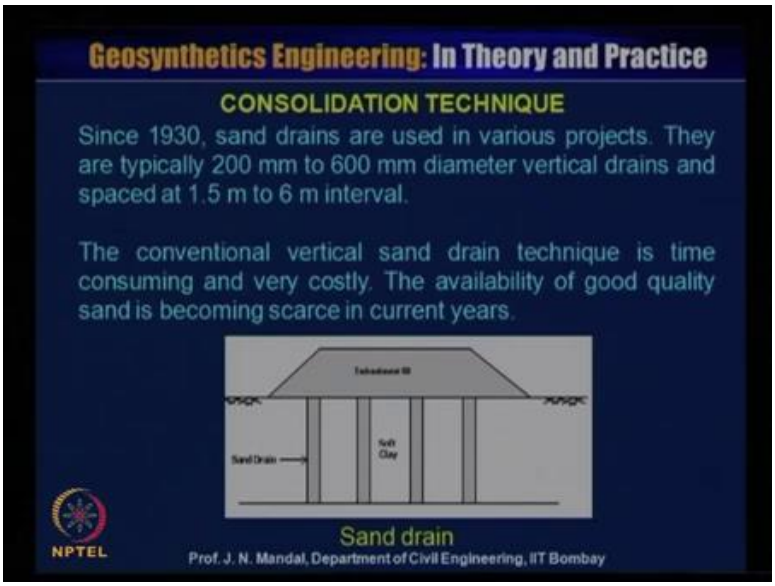

Since 1930, sand drains are used in various project and they are typically 200 millimeter to 600 millimeter diameter vertical drain and spaced at 1.5 to 6 meter interval. The conventional vertical sand drain technique is time consuming and very costly. The availability of good quality sand is becoming scarce in current years. Here, you can see that this is the sand drain. This is the very soft clay, you install the sand drain and then you are find this embankment. And in case of the sand drain, you require what will be the diameter of the sand drain, what will be the spacing of the sand drain. And when you will use the sand drain, it takes to consolidate about 2 years, 3 years, 7 years, even then 22 years. So, one cannot wait for so many years when the embankment or the building will come up on that area because time is money.

So, everybody wants to complete the project at the earliest. Even then natural prefabricated vertical drains also have been used in the Singapore and five Storey constructions building also have been completed. So, many years back, even after that 5 years, it has been observed it is giving very good drainage. So, you can see that how the natural prefabricated vertical drain have been used. It is unfortunate in India that nothing natural prefabricated vertical drain have been used, but we have used plenty of the polyester prefabricated vertical drain, and we have the production of the natural jute. Geo textile material is the second largest in the world in production after the Bangladesh. So what is happening that if we use this sand drain, so it takes lot of time?

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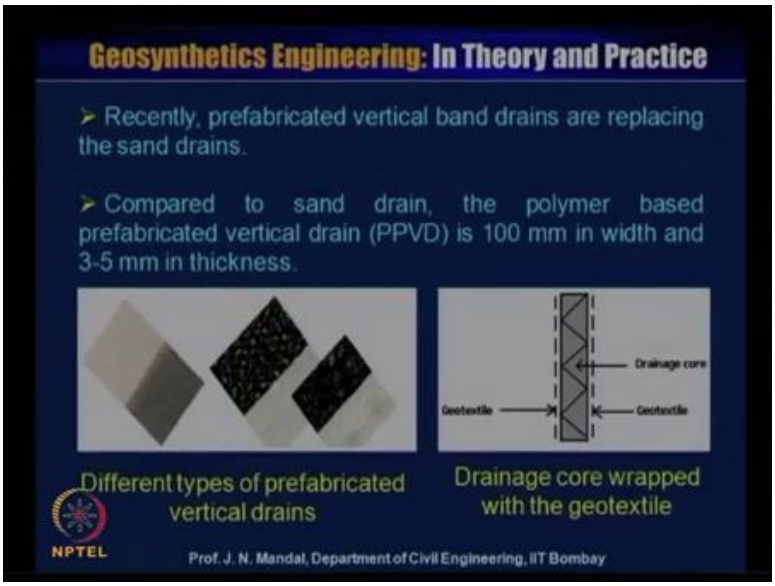

Also as I say that, sand also is scarce not available because you need that kind of the gradation of the sand to build sand drain. So, even then that initially any type project also they do not want to go for the sand drain system, I am sorry the natural prefabricated vertical drain system or prefabricated vertical drain. So, then I presented in Delhi for the use of the prefabricated vertical band drain and then it has been also implemented. It has also been implemented in JNPT in Bombay and many places, I will show you later on some of the case history where the prefabricated vertical drain also have been used.

So, now recently the prefabricated vertical drain are replacing the sand drain and compared to the sand drain, the polymer based prefabricated vertical drain is 100 millimeter in width and 3 to 5 millimeter in thickness. It is like this kind of the material you can see that this is 100 millimeter in width and its thickness may be 3 to 5 millimeter. It may be polyester or it may be the natural material also like this, so it is width about the 100 millimeter and this thickness may be about 5 millimeter.

So, compared to the sand drain, polyester based prefabricated vertical drain is 100 millimeter in width and 3 to 5 millimeter in thickness. So, here you can, I have shown you the different types of the prefabricated vertical drain, and this drain has a core wrapped with the geotextile material. In case of polyester and in case of the natural material, this core material is the coir and this wrapped with the jute material. Either, it is

a woven jute geotextile material or the nonwoven jute geotextile materials, the prefabricated drain have many advantage with respect to the sand drain.

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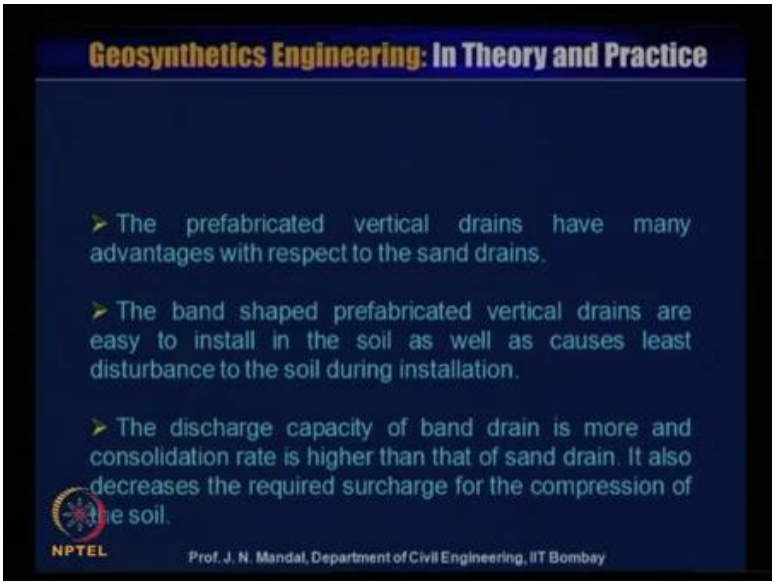

The band shaped prefabricated vertical drain are easy to install in the soil as well as causes least disturbance to the soil during installation. The discharge capacity of the band drain is more and consolidation rate is higher than that of sand drain. It also decreases the required surcharge for the compression of the soil. So, you can see that because the jute is very good absorption capacity, so discharge capacity is more than the sand drain. So, because discharge capacity is more acceleration is very fast, so consolidation is very fast, so it takes minimum time to consolidate.

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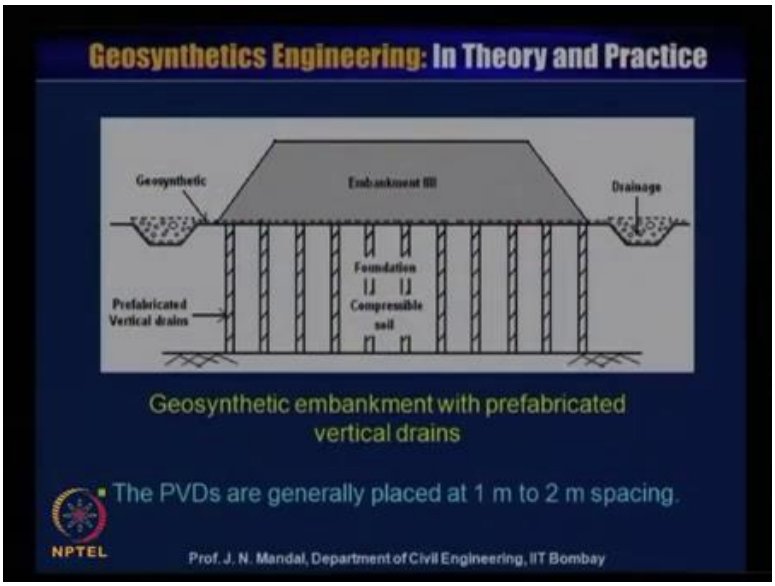

So, here on geosynthetics embankment with prefabricated vertical drain. So, this is the PVD are generally placed through 1 meter to 5 meter in spacing. You can see, you can provide with the proper kind of the drainage in order that the water, there will be a radial drainage and also vertical drainage, then water can pass through this drainage.

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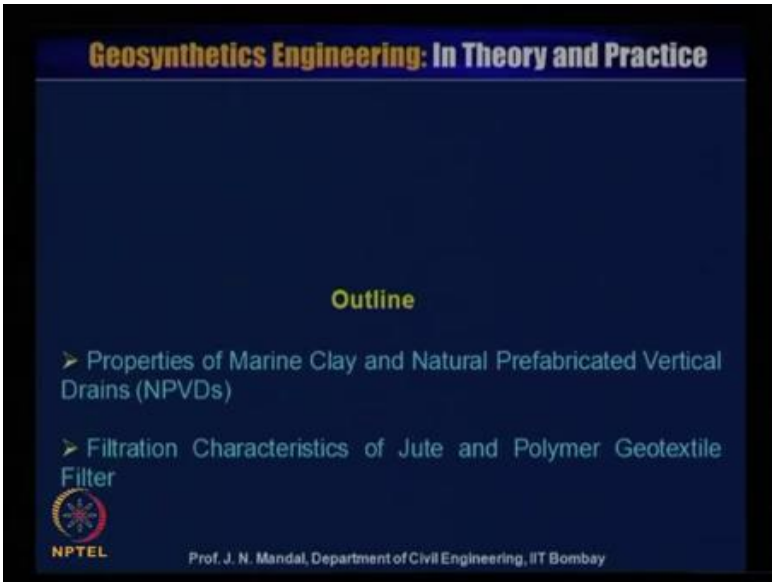

So, some outline that we have developed, some prefabricated natural drain. So, we should know what will be the properties of the marine clay and natural prefabricated vertical drain, where you can use the natural prefabricated vertical drain in marine clay.

All of the most important factor, also filtration characteristics of the jute and the polymer geotextile filter.

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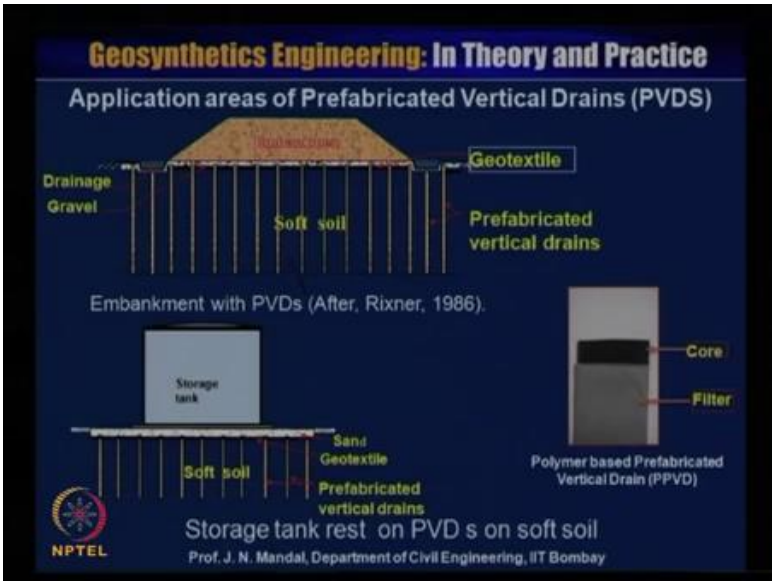

So, this is the application area of prefabricated vertical drain. You can see this is soft soil where this is prefabricated vertical drain and you can place a geotextile material here because you provide with the 3 to 400 or 500 millimeter thickness of the sand. As a drainage material, you sometimes may not be required, you can provide with the geotextile or the geocomposite material then water can be drained it out. It can be used for the storage tank, this also type of the storage tank has been used in India and this is the polyester based prefabricated vertical drain. I mention this is the filter and this inside is the core.

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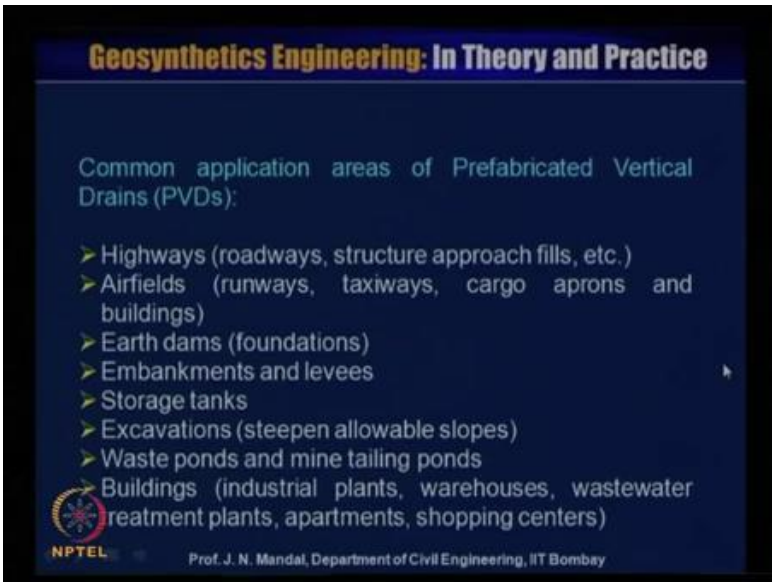

Now, common application area of prefabricated vertical drain PVDs, it can be used for the highway, that is roadway, structure application fill etcetera, airfields that is runways, taxiways, cargo apron and the building. Earth dam that is foundation, embankment and levees, storage tank excavation that is steepen allowable slope. Waste pond and mine tailing pond, building that is industrial plant, warehouses, waste water treatment plant, apartment and shopping center.

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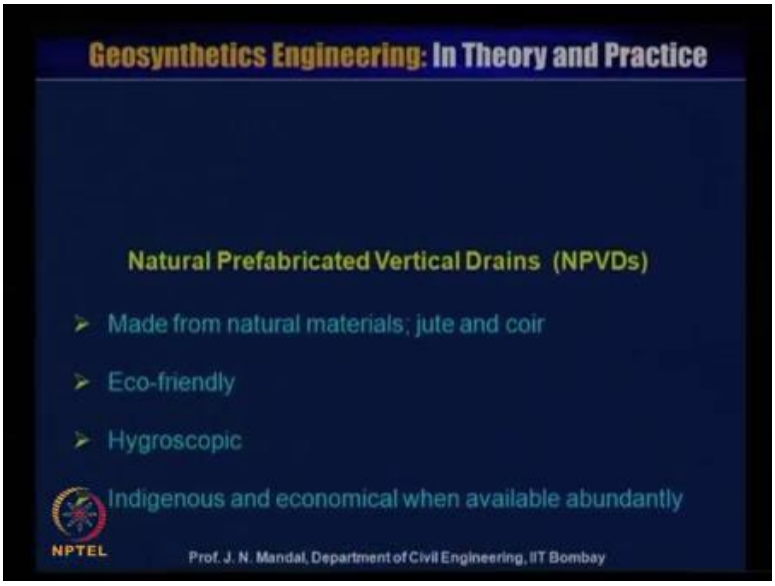

So, these are the places where you can use this kind of the natural prefabricated drain. One of the most important, in case of the natural prefabricated vertical drain this is made from natural material like jute and coir and it is ecofriendly. It is hygroscopic, and it is indigenous and economically and when it is available abundantly.

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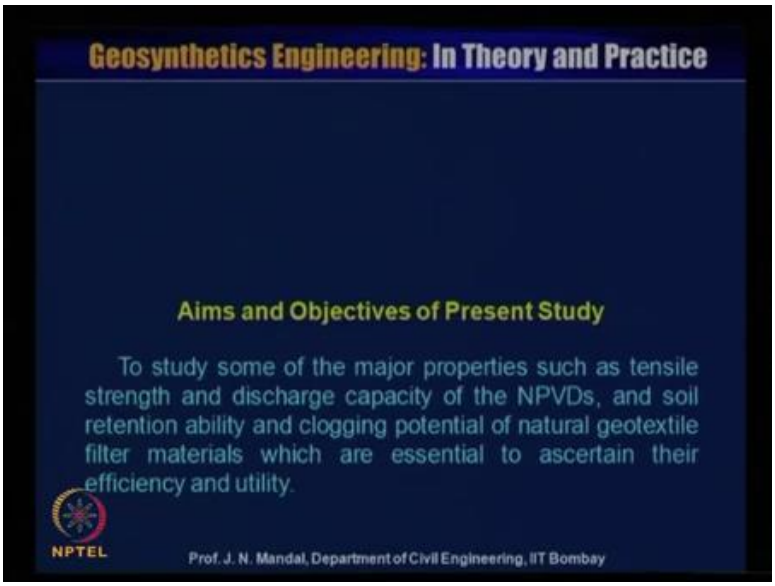

So, it is not so much costly and also it is environmental friendly and also it is abundantly available. Now, some study has been performed in IIT Bombay by doctor Asha, and this is the sum that aim and objective of this present study, that to study some of the major property such as the tensile strength, and the discharge capacity of the natural prefabricated vertical drain. Soil retention ability and clogging potential of natural geotextile filter materials which are essential to ascertain their efficiency and utility.

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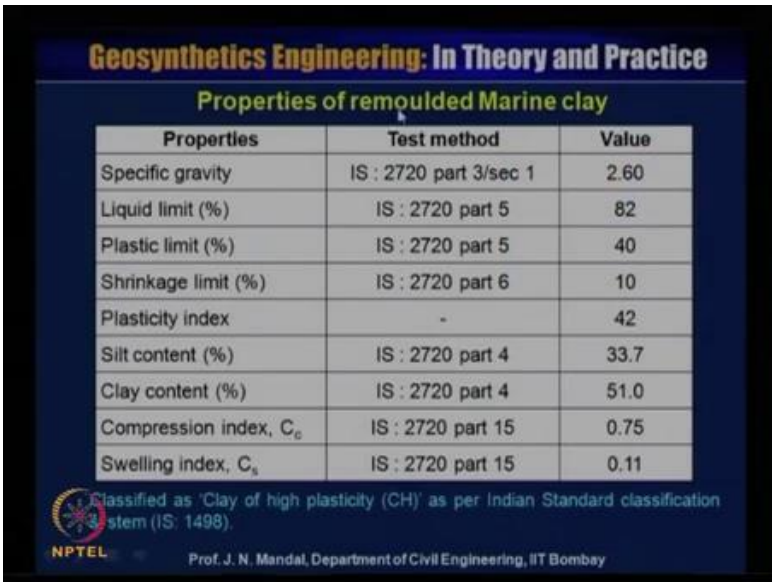

So, here are the properties of the remolded marine clay, you can see this property what are the test method as per I S and these are the value. So, here this specific gravity 2.60, liquid limit 82 percentage, plastic limit 40 percentage, shrinkage limit 10 percentage, plasticity index 42, silt content 33.7 percentage, clay content 51.0 percentage. Then compression index C 0, 0.75 swelling index CS 0.11, so this classifies as clay of high plasticity that is CH, as per Indian standard classification system IS 498.

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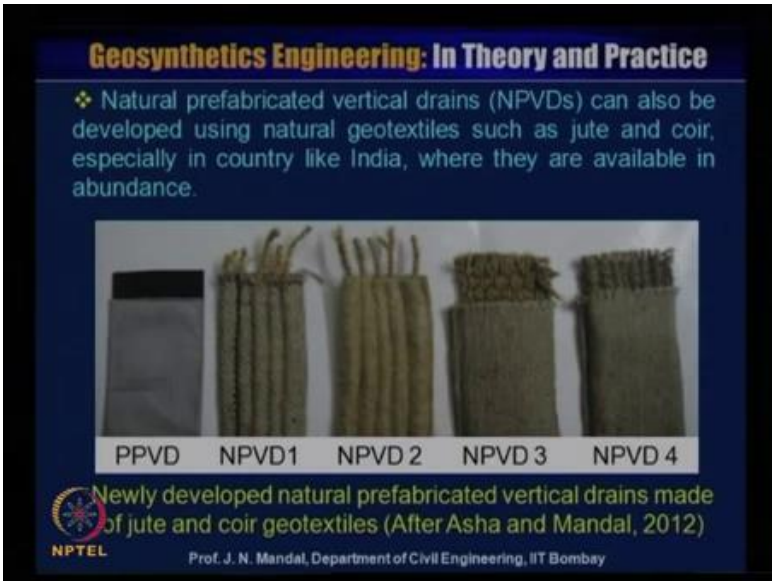

So, this is the natural prefabricated vertical drain can also be developed using the natural geotextile such as jute and coir specially in country like India, where they are available in abundance. You can see this is the polyester prefabricated vertical drain and these are the different types of the natural prefabricated vertical drain have been developed. So, this is the natural prefabricated vertical drain, one where it is a jacket is the woven geotextile material and then coir is act as a core material. This is natural prefabricated vertical drain 2 where the jacket is made of non woven jute geotextile material and the coir as a core material.

Here, again the natural prefabricated vertical drain 3, here you can see that jacket is made of the woven geotextile material and this coir is like a mat coir mat has been used. So, this is natural prefabricated vertical drain 3 and then also this natural prefabricated vertical drain 4 with the different pattern of the mat. It also depend on that what will be the pattern of the core material then how can water can flow through this core material, how the discharge can take place through this core material. In case of here also there will be, it will act like a filament and it is act like a composite material. So, this is the newly developed natural prefabricated vertical drain made of jute and the coir geotextile Asha and Mandal 2012.

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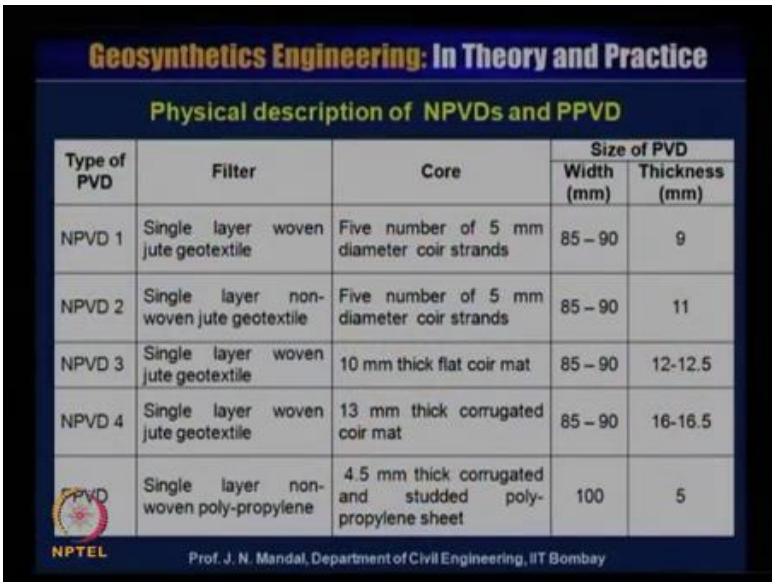

So, you have performed some test on this natural prefabricated vertical drain. We have determined that what will be their physical properties for both the natural prefabricated

vertical drain and also polyester prefabricated vertical drain. Then you can compare and can observe whether it is a suitable that whether we can use the natural prefabricated vertical drain or not.

Whether it satisfies all the requirements or all the properties and criteria, so here is the physical description of the prefabricated. This is natural prefabricated vertical drain type 1, this is single layer woven geotextile material and core 5 number of 5 millimeter diameter of coir strands and width is from 85 to 90 millimeter and thickness of the PVD 9 millimeter.

In case of NPVD 2, this is a filter is single layer nonwoven jute geotextile material 5 numbers of 5 millimeter diameter coir strand and width is 85 to 90 millimeter and thickness is about 11 millimeter. NPVD 3 that is single layer woven jute geotextile and coir is 10 millimeter thick flat coir mat and width is 85 to 90 millimeter and thickness is 12 to 12.5 millimeter. Now, NPVD 4 that is filter, is single layer woven jute geotextile material and core is 13 millimeter thick corrugated coir mat and the width is 85 to 90 and thickness about 16 to 16.5 millimeter. Whereas, polyester prefabricated vertical drain, this is a single layer nonwoven polypropylene and core material is 4.5 millimeter thick corrugated, and studded polypropylene sheet.

And the width is 100 millimeter and thickness is 5 millimeter also it vary from 95 to 100 and thickness also vary from 3 millimeter to 5 millimeter. So, you can see that what is the variation of the width and the thickness. So, width and thickness are also very important because we have to check up that equivalent diameter of the sand drain. Then if you can calculate you can find that equivalent diameter is the same, almost the same with respect to the sand drain and when we will design, I will explain more about this.

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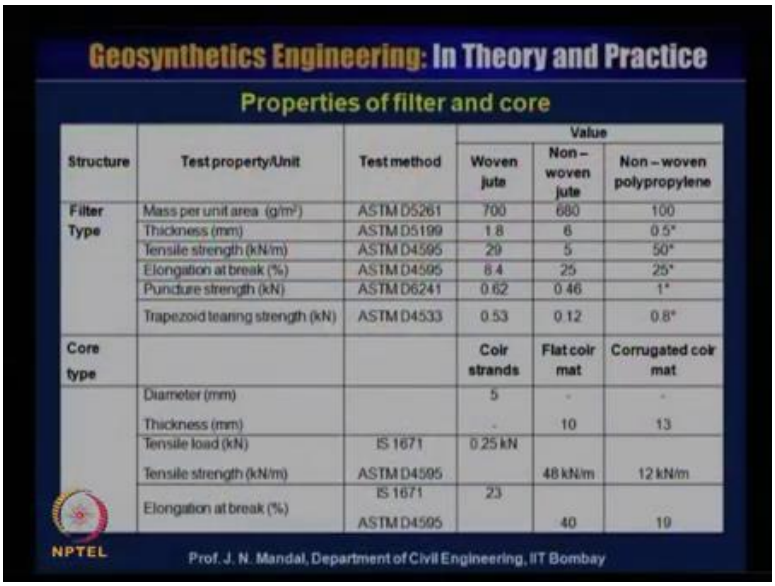

Structure	Test property/Unit	Test method	Value		
			Woven jute	Non – woven jute	Non – woven polypropylene
Filter Type	Mass per unit area (g/m²)	ASTM D5261	700	680	100
	Thickness (mm)	ASTM D5199	1.8	6	0.5*
	Tensile strength (kN/m)	ASTM D4595	29	5	50*
	Elongation at break (%)	ASTM D4595	8.4	25	25*
	Puncture strength (kN)	ASTM D6241	0.62	0.46	1*
	Trapezoid tearing strength (kN)	ASTM D4533	0.53	0.12	0.8*
Core type			Coir strands	Flat coir mat	Corrugated coir mat
	Diameter (mm)		5	-	-
	Thickness (mm)		-	10	13
	Tensile load (kN)	IS 1671	0.25 kN		
	Tensile strength (kN/m)	ASTM D4595		48 kN/m	12 kN/m
	Elongation at break (%)	IS 1671	23		
		ASTM D4595		40	19

Now, properties of the filter and core, so you have to also have to determine what will be the property. You can see this is the structure the filter type and this is the test method woven jute, this is the nonwoven jute geotextile material and this is the nonwoven polypropylene material and this all the test has been performed as per ASTM and also IS. So, here as per unit area in case of woven 700 gram per meter square and nonwoven is 680 gram per meter square, where as nonwoven polypropylene is 100 gram per meter square thickness.

In case of woven jute, this is 1.8 millimeter and nonwoven is 6 millimeter and this in case of polypropylene this is 0.5 millimeter. Now, tensile strength is 29 kilo Newton per meter for nonwoven jute is 5, 5 kilo Newton per meter and nonwoven polypropylene is 50 kilo Newton per meter. Now, elongation for woven is 8.4 percent for nonwoven jute is 25 and this nonwoven polypropylene is 25 percentage, then puncture strength in kilo Newton, it is woven jute is 0.62 kilo Newton nonwoven jute is 0.46 kilo Newton. This non woven polypropylene is 1 kilo Newton trapezoid tearing strength this is woven jute is 0.53 kilo Newton and nonwoven 0.12 and nonwoven polypropylene 0.8.

Similarly, coir type that is diameter for coir strand is 5 millimeter. Thickness for flat coir is 10 millimeter and corrugated coir mat is 13 millimeter and tensile strength is for the nonwoven geotextile material is 44.8 kilo Newton per meter. This is 12 kilo Newton per meter elongation at break is for non woven jute material is 40 percentage woven jute

materials is 23 percentage and non woven polypropylene geotextile material is 19 percentage. So, these are the properties of the material that what is the core material and also what is the jacket material.

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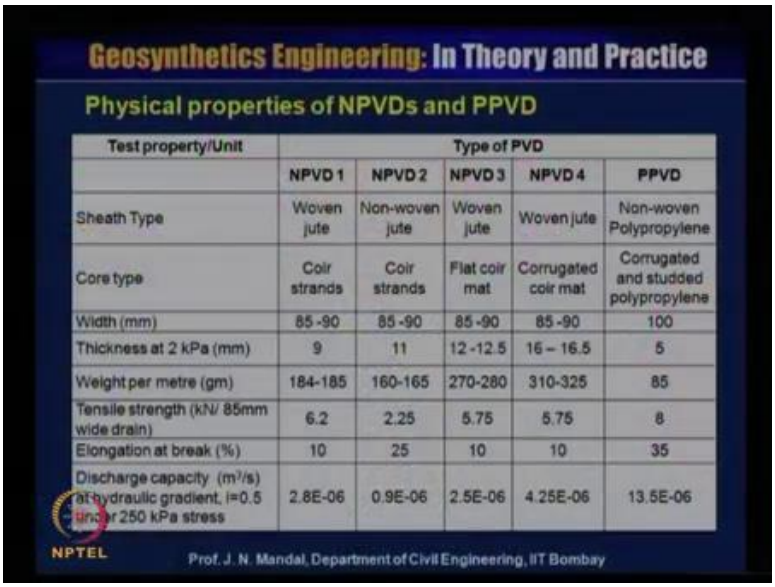

Test property/Unit	Type of PVD				
	NPVD 1	NPVD 2	NPVD 3	NPVD 4	PPVD
Sheath Type	Woven jute	Non-woven jute	Woven jute	Woven jute	Non-woven Polypropylene
Core type	Coir strands	Coir strands	Flat coir mat	Corrugated coir mat	Corrugated and studded polypropylene
Width (mm)	85 -90	85 -90	85 -90	85 -90	100
Thickness at 2 kPa (mm)	9	11	12 -12.5	16 – 16.5	5
Weight per metre (gm)	184-185	160-165	270-280	310-325	85
Tensile strength (kN/ 85mm wide drain)	6.2	2.25	5.75	5.75	8
Elongation at break (%)	10	25	10	10	35
Discharge capacity (m^3/s) at hydraulic gradient, i=0.5 under 250 kPa stress	2.8E-06	0.9E-06	2.5E-06	4.25E-06	13.5E-06

Now, some also that physical properties of the NPVD and PVD, this is the type that sheath type. You can see that for the natural material 1 2 3 4 what we have used you know this is the coir type, you know what you have used and what is the thickness at two kilo Pascal for the woven jute 9 millimeter, nonwoven jute 11 millimeter, woven jute 12 to 12.5 millimeter and this is woven jute 16 to 16.5 millimeter. In case of the PPVD this is 5 millimeter width per meter this for NPVD 1, 184 to 185 NPVD 2, 160 to 165 gram and NPVD 3, 270 to 280 and woven jute is 310 to 326 and for PPVD is 85 tensile strength kilo Newton per 85 millimeter wide drain.

So, this is for NPVD 1 is 6.2, NPVD 2 is 2.25, NPVD 3 is 5.76 and NPVD 4 is 5.76 and PPVD is 8. Elongation at break for NPVD 1 10 percentage, NPVD 2 25 percentage, NPVD 3 10 percentage, NPVD 4 10 percentage and PPVD is 35 percentage. Another important parameter that is discharge capacity that is meter cube per second, at the hydraulic gradient I is equal to 0.5 under 250 kilo Pascal stress. So, here for NPVD 1 is 2.8 to 10 to the power minus 6, that is meter cube per second and NPVD 2 is 0.9 into 10 to the power minus 6 meter cube per second. NPVD 3, 2.5 into 10 to the power minus 6

meter cube per second and NPVD 4 is 4.25 into 10 to the power minus 6 and for PPVD is 13.5 into 10 to the power minus 6.

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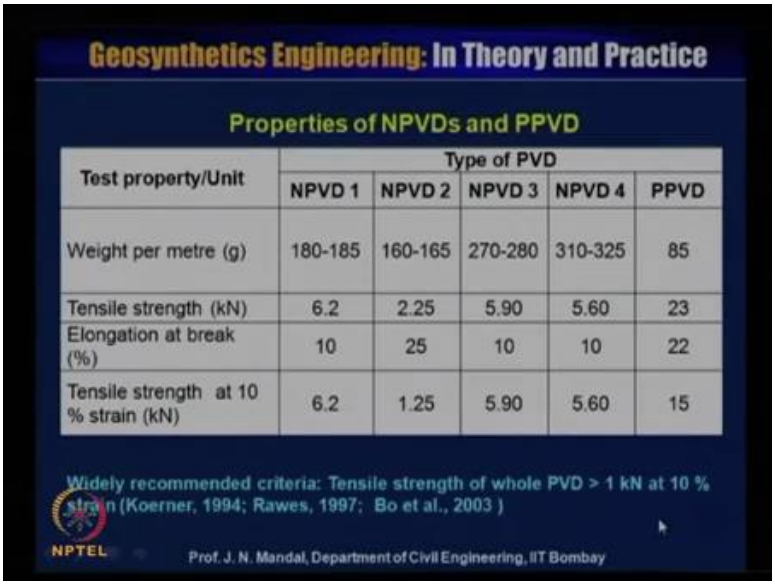

So, you see that, what the property of this natural material is. Now, this we can say that some test properties for weight per meter it vary 180 to 185 for NNPVD 1, NPVD 2 160 to 165, NPVD 3 270 to 280 and NPVD 4 310 to 325 and PPVD is 85 tensile strength which also lies between 6.2 for NPVD 1, 2.25 for NPVD 2, 5.90 for NPVD 3, and 5.60 for NPVD 4 and PPVD is 23. Elongation for NPVD 1 10, NPVD 2 25, NPVD 3 10, NPVD 4 10 and PPVD 22 tensile strength at 10 percentage, this is also important because we require that what will be the tensile strength at 10 percent strain for NPVD 1. This strength is 6.2 kilo Newton for NPVD 2, 1.25 kilo Newton and for NPVD 3, 5.90 for NPVD 4 are 4.60 and PPVD is 15 kilo Newton.

Generally, widely recommended criteria tensile strength of the whole prefabricated drain should be greater than one kilo Newton at 10 percent strain. So, as per Koerner 1994 and Rawes 1997 and BO et al 2003, so we observe that that if the PVD value is greater than 1, then it satisfy the criteria. So, here we observe that tensile strength of the natural material is satisfying the criteria. So, we can make use of this natural material as a prefabricated vertical drain for the ground improvement.

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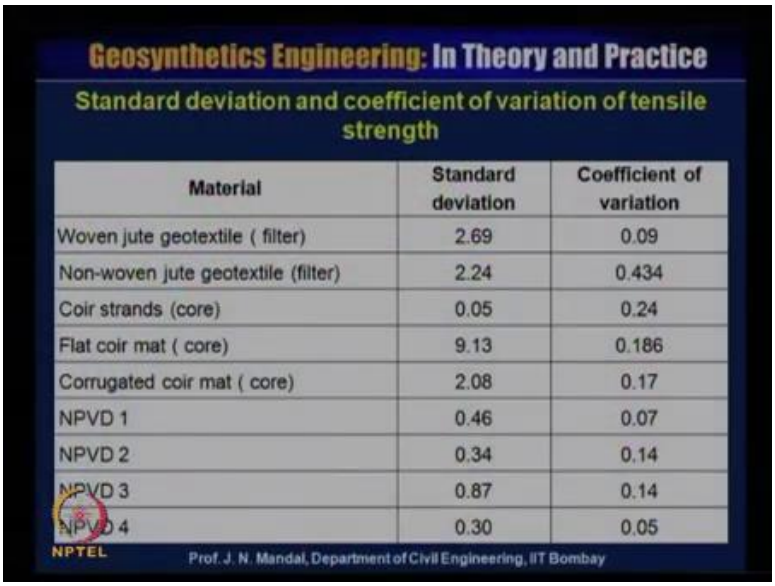

Standard deviation and coefficient of variation of tensile strength, these are the material woven jute geotextile filter the standard deviation 2.69 and coefficient of variation 0.09. Nonwoven jute geotextile filter, standard deviation 2.24 and coefficient of variation 0.434, coir strand as a core material, standard deviation 0.05 and coefficient of variation 0.24.

Flat coir mat as a core material, standard deviation 9.13 and coefficient of variation 0.86, corrugated coir mat core, standard deviation 2.08 and coefficient of variation is 0.17. NPVD 1, the standard deviation 0.46 and coefficient of variation 0.07, NPVD 2, the standard deviation 0.34 and this is factors 0.14, NPVD 3, standard deviation 0.87. This coefficient factor is 0.14, NPVD 4, the standard deviation 0.30 and coefficient factor is 0.05.

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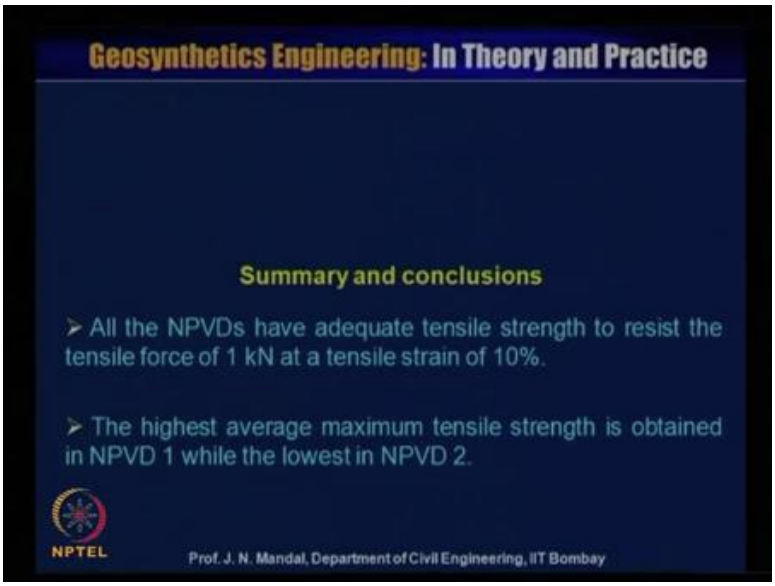

So, what we can do summary and the conclusion from this study that all the natural prefabricated vertical drain has the adequate tensile strength to resist the tensile force of 1 kilo Newton at a tensile strain of 10 percentage that what we require. The highest average maximum tensile strength is obtained in natural prefabricated vertical drain 1, while the lowest in natural prefabricated vertical drain 2. With this, I ended up the lecture today. Please let us hear from you any question?

Thanks for listening.