Geosynthetics and Reinforced Soil Structures
Prof. K. Rajagopal
Department of Civil Engineering
Indian Institute of Technology, Madras

Lecture - 37
Sustainable Infrastructure Development and Natural Geosynthetics

Very good morning students. In today's lecture, let us look at the sustainable infrastructure development and what role the natural geosynthetics can play in this development.

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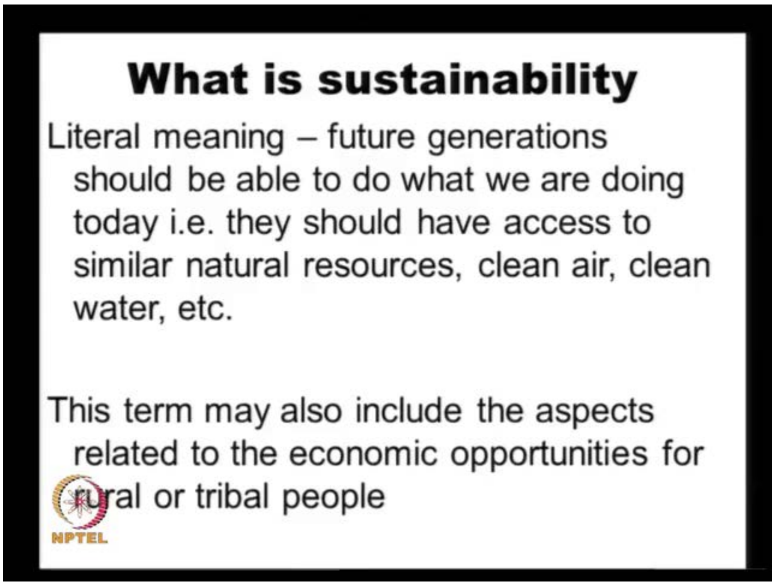

Well, before we go into the sustainability and how the geosynthetics can help in the sustainability let us look at what is sustainability? The dictionary meaning is very simple, any activity that enables the future generations to enjoy, whatever we are enjoying now in terms of the natural resources or the fresh air or the fresh water is called as sustainability or sustainable activity, because we are not utilizing the natural resources or destroying the nature so much. And now in this context, we can see how the geosynthetics can play a role in sustainable infrastructural development, because the world is expanding so fast, and especially India is developing so fast, that we are building thousands and thousands of kilometers of roads, and railway network and we should be able to reduce the utilization of natural materials.

So, that our dependence or the sustainability of the future generation is ensured. And the sustainability especially in the context of India should also include the aspects related to the economic opportunities that are provided for the rural, and semi skilled people because we bring in very hi-fi equipments that display all the people. And we do not make use of the human resources, that we have in our rural areas then that is also not good, because they will not have any employment, they will not have any economic opportunities.

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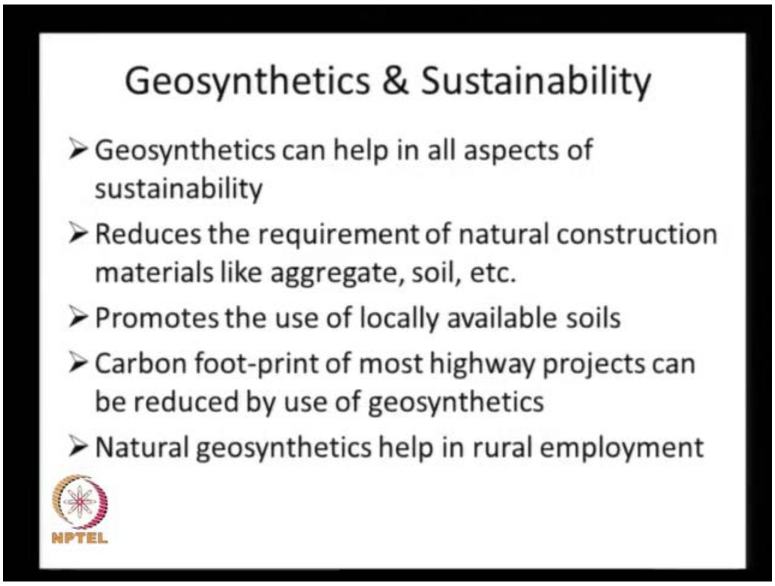

So, in that context both the geosynthetics and also the natural geosynthetics can play a very important role in the sustainability. And let us look at some aspects of how the geosynthetics can play a role in the sustainability. Well, in all aspects of construction and the sustainability the geosynthetics can play a role. And the geosynthetics we have seen that they can be used to reduce the consumption of natural construction materials, like aggregate soil and other materials. In the long run because of that our activities become more sustainable.

And these geosynthetics promote the use of local available soil, or marginal soils and the carbon footprint of most highway projects can be reduced by the use of geosynthetics. And this aspect we have seen few lectures back and how the carbon footprint can be reduced by reducing the transport of aggregate and other materials. And of course, these natural geosynthetics they help in rural employment because that is of the cornerstones of any national development.

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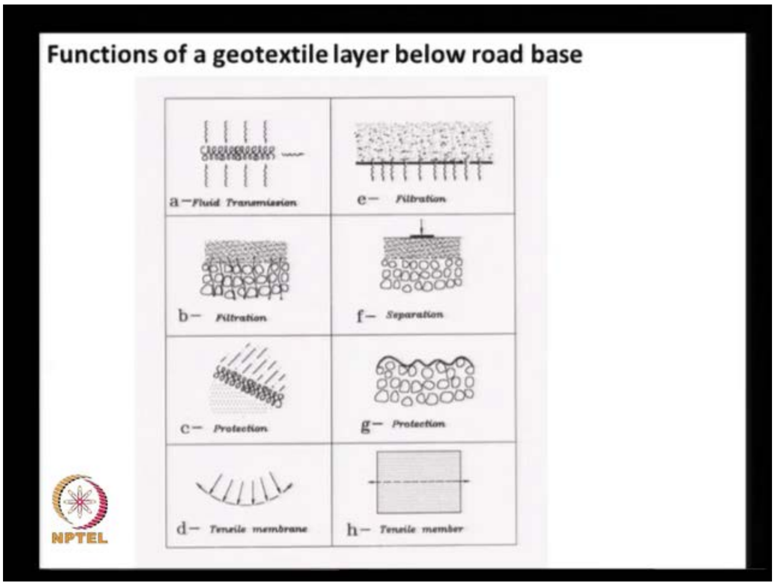

Well, let us look at how a geotextile performs when it is placed below a road base, it could act as a as an agent for fluid transmission that is for drainage purposes. It can act as a filter to prevent piping and another picture of the same filter. Then it can act as a good separator to separate out the aggregate from the sub grade soil, and it can act as a protector to prevent or to reduce the surface erosion. Also these geotextile, if there are very stiff they can also act as reinforcement materials.

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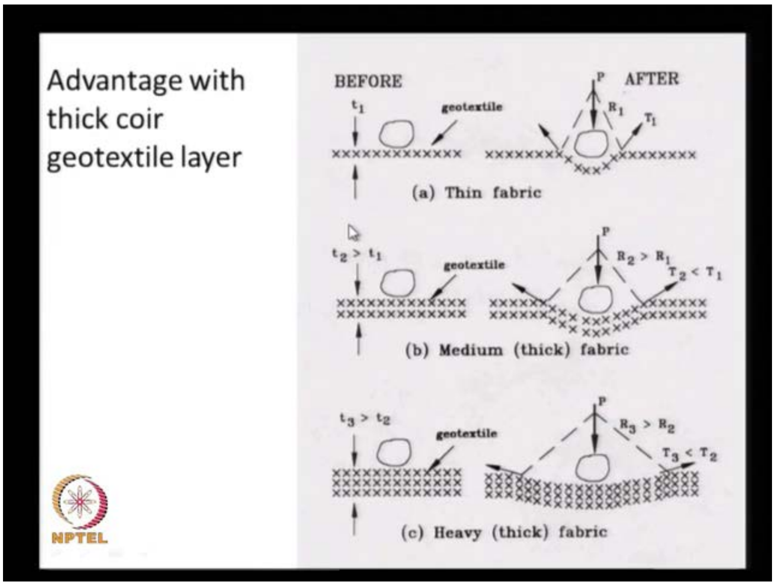

Well, in the context of applications, the natural textiles or the natural geotextiles, they tend to be much thicker as compared to their polymeric counterparts and that could in a way give us some advantage and that is illustrated here. So, when you have a very stiff thin geotextile, you require a large depression of the large retting to develop sufficient tensile force to counteract the applied loads. And if you have a thicker textile or a thicker reinforcement material, we require smaller retting to develop similar order of the tensile force.

And if you have even thicker geotextile, we require very small retting to mobilize the required amount of tensile force to counteract the applied forces. So, that means that the natural geotextiles if they are very thick, they can be made to promote the required tensile forces to counteract whatever applied forces. Let us go back to the different functions that are given by the international geosynthetics society.

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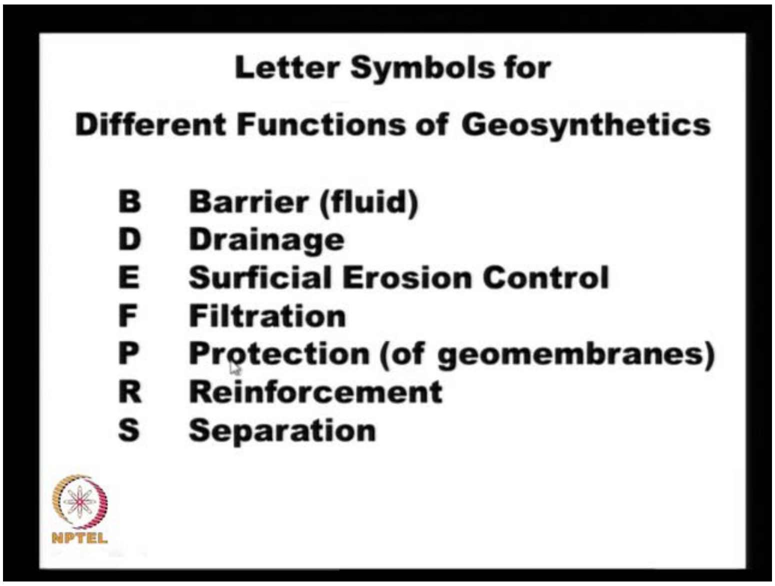

This we have seen in one of earlier lectures. These geosynthetics can play important role in most of the constructions they can act as a barrier. And the barrier function is exclusively reserved for geo membranes, and this is one activity were our natural geosynthetics cannot play a role. And the drainage application these natural synthetics can play a very important role because the thickness of the coir, and jute geotextiles is much more than that of synthetic fabrics, and so they can act as good drainage layers.

And in the surface erosion control, the natural geotextiles and other products they play very important role. And filtration it all depends on the pore size of these textiles and the natural geotextiles can also be fabricated to have a desired pore opening size. And protection of the geo membranes, the natural geotextiles can play a good role because of their thickness and their impact absorbed absorption capacity. And to some limited extent, the natural geosynthetics can also play a role as a reinforcement layer and also as a separator depending on the type of loads that we deal with.

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And here we see one innovative application of the geosynthetics for coastal erosion protection. Here this break water was made entirely by using the beach sand. The beach sand was filled in these geotextile bags, which are in turn placed inside rope net gabion and everything is tied together to form the break water units. And if it were not for beach sand, we need to input a large boulders and that is the typical solution that is adopted at most of the Indian coastal protection systems, we just simply bring large boulders and dump them, and to counteract the erosive forces. But here we can use the abundantly available local beach sand itself to construct our structures. And this is one application that is sustainable because we are not really destroying any natural resources in this construction.

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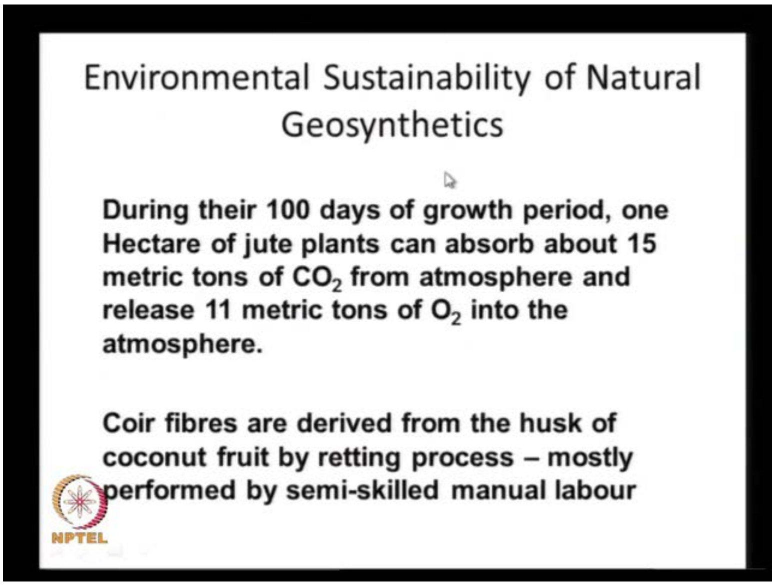

Well one advantage that we have with these natural geosynthetics is evident from this statement might have taken from one of the papers written by Mr. Sanyal of the jute board. During the hundred days of the growth of the jute plants per 1 hectare, the jute plants can absorb about 15 metric tons of carbon-di-oxide and release about 11 metric tons of oxygen into the atmosphere. And this is a very clear evidence of the advantage of the vegetation of course, all the plants they absorb carbon-di-oxide and release them oxygen as part of their natural process.

And the jute has more capacity to do this and the coir fibers that we use for making coir geotextiles or coir ropes these are entirely derived from the husk of coconut fruit by retting process. And it is mostly done by semi-skilled and manual labour, both the jute processing and the coir processing is a labour intensive, and it provides lot of employment for the rural people.

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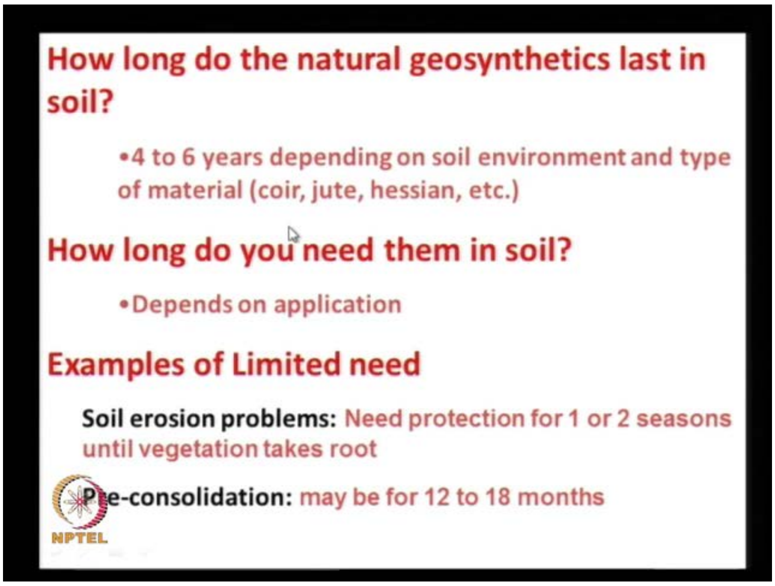

See one question that we need to ask ourselves is, our natural geosynthetics like the jute and the coir they have a limited life. They cannot stay in this soil for ever unlike, our synthetics counterparts like the geogrids and geotextiles made of say polyester or polypropylene or polyethylene, they can last for hundreds of years without any degradation whereas, the natural geosynthetics they have a limited life.

And the various studies they have shown that they can safely stay in the ground for about 4 to 6 years depending on the soil environment and the type of material, whether it is coir jute hessian and so long. And how long do we need the support from geosynthetics that are placed. It depends on the application say, if it is a below ground application level like ground improvement project or something, we may require them for about say 1 and half to 2 years until our the clay soil consolidates.

If it is a road base maybe for about 2 or 3 years until the sub grade gains, the strength or in some other application or in erosion control, we require the protection of the surface only for about 1 or 2 seasons until the vegetation takes root. Whereas, in some constructions like steep retaining walls or embankments, the requirement of the reinforcement is permanent. That means that as long as the structure is existing, we require the reinforcement to provide the reaction force. And in such applications the natural geosynthetics may not play a much role, but in all other applications where the need for the geosynthetics is limited, we can employ our natural geosynthetics very easily.

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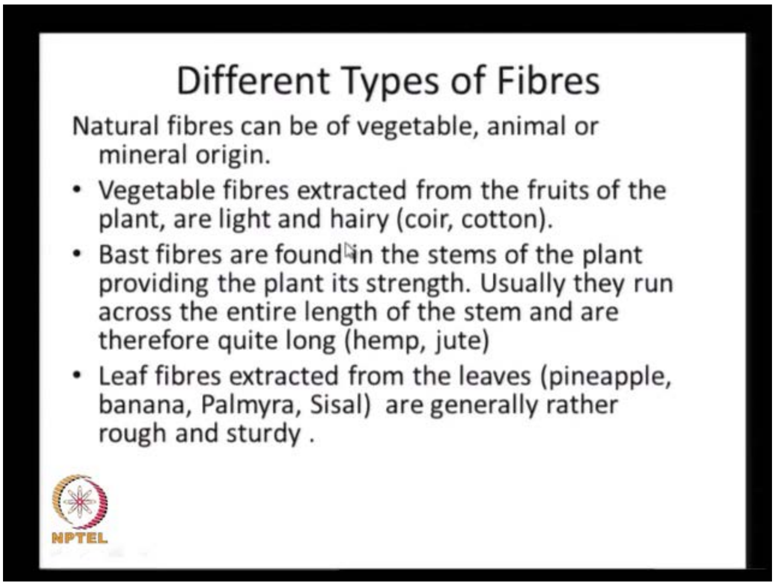

Well, what are the different types of fibres that we have for fabricating our geotextiles and geogrids. These natural fibres they can be of, they can have the argon of vegetative matter or animals or mineral origin. And vegetative fibres these are extracted from the fruits of plants and these are light and hairy and some examples are the coir and cotton fibres. And the bast fibres, these are found in the stems of the plants that provide strength to the plants. And usually they run across the entire length of the stem and are therefore, quite long. Some examples of the bast fibres at the hemp and the jute. And the bast fibres there are very long because they run along the entire trunk of the tree.

And there are also a leaf fibres, some examples are the pineapple, banana, palmyra, sisal and these are generally rather rough and sturdy and they can be used for several applications. The palmyra leaves they are used right from the ancient days in India, or writing our scripts and for other purposes writing purposes.

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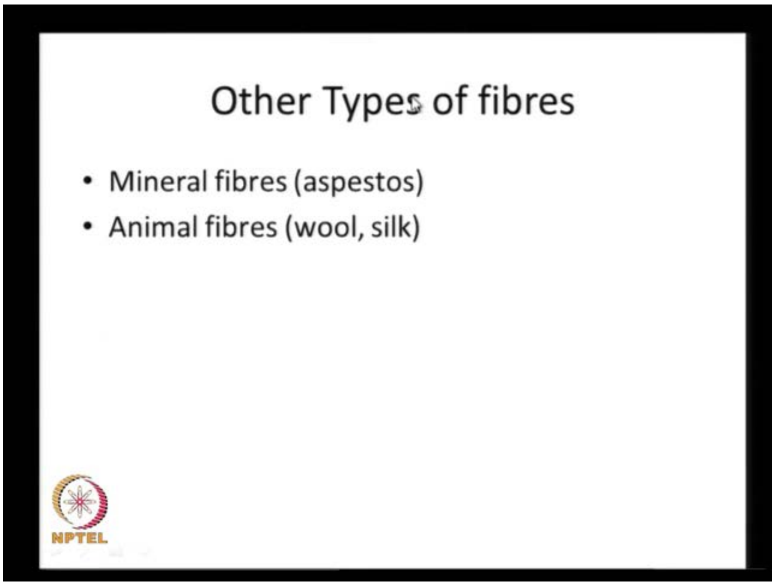

And the other type of fibers, what we have mineral fibers aspects, sorry there is a spelling mistake and animal fibers wool and silk.

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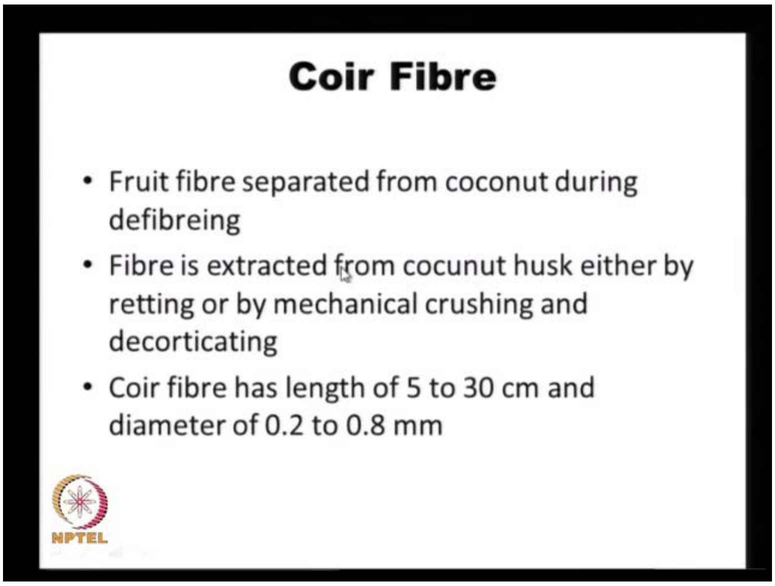

The coir and jute they are very important for the Indian economy because India is the largest producer of both coir and jute. And coir fibre itself is obtained from the coconut by defibreing operations and the fibre is extracted from coconut husk either by retting, or by mechanical crushing and then decorticating process. And the coir fibre can have lengths anywhere from 5 to 30 centimeters and diameter 0. 2 to 0.8 millimeters.

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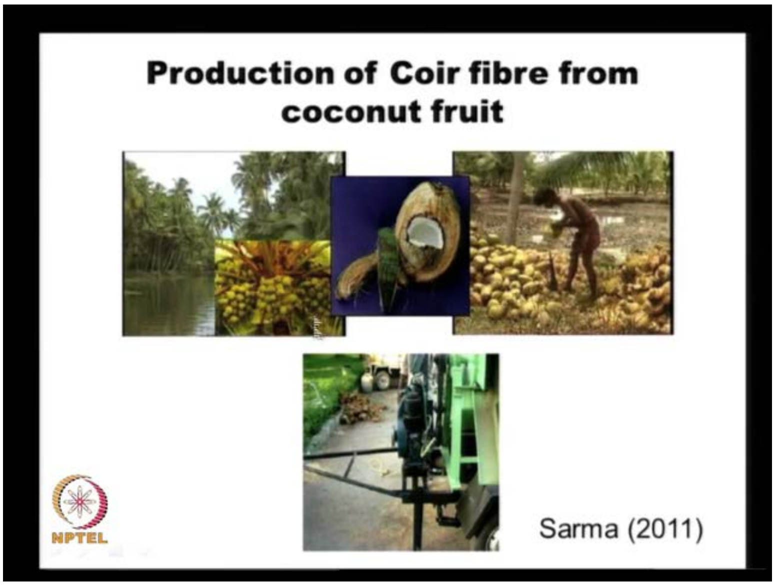

And the entire process is shown here, the coir fibre is obtained from coconut. And this is looks like this, husk surrounding the coconut fruit is the one that gives us the coir. It is mechanically the husk is removed and then by soaking in water that we call as retting process for about 6 months to 1 year period. The fibres separate out and then by some mechanical and labour intensive process the fibre is separated.

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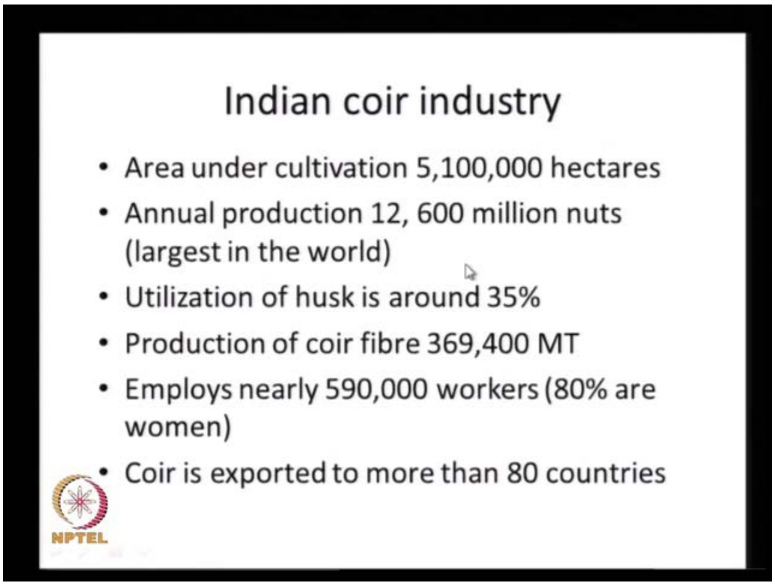

And then it is made into its made into textiles and ropes like this is actual, we can feed the individual fibres and spin them into coir ropes and nets. And here we see a needle punching machine that is producing the coir geotextiles. And the Indian coir industry is acquired quite large largest of its kind in the world. The coconut is under cultivation in about 5 million hectares of land, and the annual production of coconuts is about 12 thousand 6 hundred millions largest in the world. About 35 percent of the husk is utilized and the production of coir fibre is approximately 369,400 metric tons.

And it employees nearly 6000 workers and 80 percent of these workers are women because it is a labour intensive process and it does not require much of a skill. And the coir is exported to more than 80 countries mostly in the raw form. Just as how we are exporting the minerals, we are also exporting raw coconut fibres that are converted into useful products.

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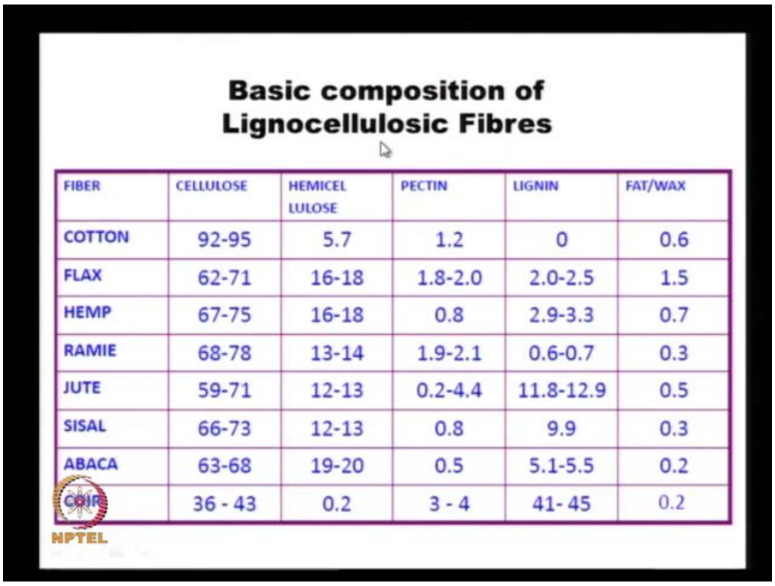
Basic composition of Lignocellulosic Fibres

FIBER	CELLULOSE	HEMICEL LULOSE	PECTIN	LIGNIN	FAT/WAX
COTTON	92-95	5.7	1.2	0	0.6
FLAX	62-71	16-18	1.8-2.0	2.0-2.5	1.5
HEMP	67-75	16-18	0.8	2.9-3.3	0.7
RAMIE	68-78	13-14	1.9-2.1	0.6-0.7	0.3
JUTE	59-71	12-13	0.2-4.4	11.8-12.9	0.5
SISAL	66-73	12-13	0.8	9.9	0.3
ABACA	63-68	19-20	0.5	5.1-5.5	0.2
COIR	36 - 43	0.2	3 - 4	41- 45	0.2

And the basic composition of these lignocellulosic fibres that is the fibres that have lot of lignant and cellulose content, cotton has very high cellulose content 92 to 95 percent. Then lignin is 0 then let us look at jute. Jute also has a very high cellulose content 59 to 71 percent lignin is very low. And the coir is got lower cellulose content and higher lignin content 41 to 45 percent and higher cellulose content gives the fibres more flexibility.

So, the cotton and jute there are more flexible and more smoother as compared to coir. At the same time a lignin gives them the life of the durability, when it is exposed to soil or water or other environmental factors. So, comparatively the coir has as a longer life span, but lesser workability because it has lesser cellulose content .

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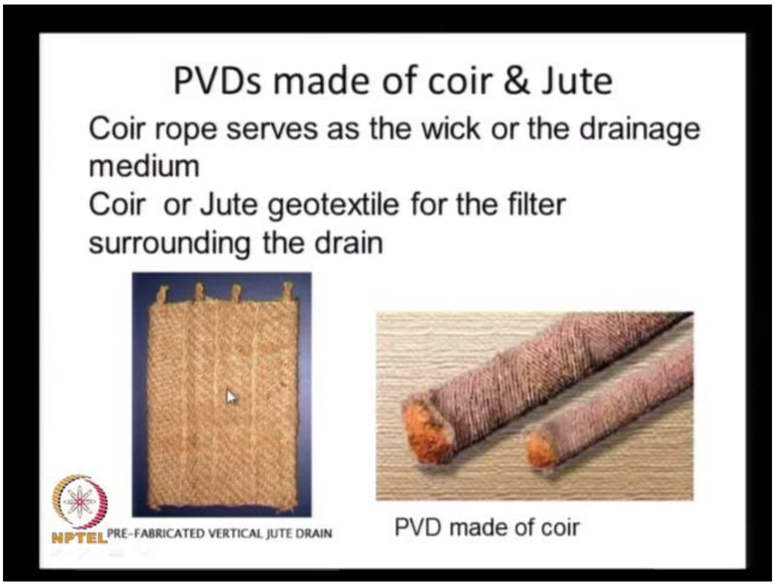

And the coir and the jute they can be employed for several applications. And here we see some products made for use in the pre-consolidation of soils and the PVDs prefabricated vertical drains. Here we see PVD made up of jute and coir is actual the coir wick is there that can transmit water and the jute filter cloth is surrounding this the drainage core to act as a filter.

And here we see another example of very large diameter coir rope that can act as a wick, that is surrounded by a textile made of jute or coir that can act as a filter. There were quite a few studies on applying these PVDs for pre-consolidation. And pre-consolidation is normally designed to consolidate this soil with an about 1 and half to 2 years. And for such applications the natural products they were shown to be excellent.

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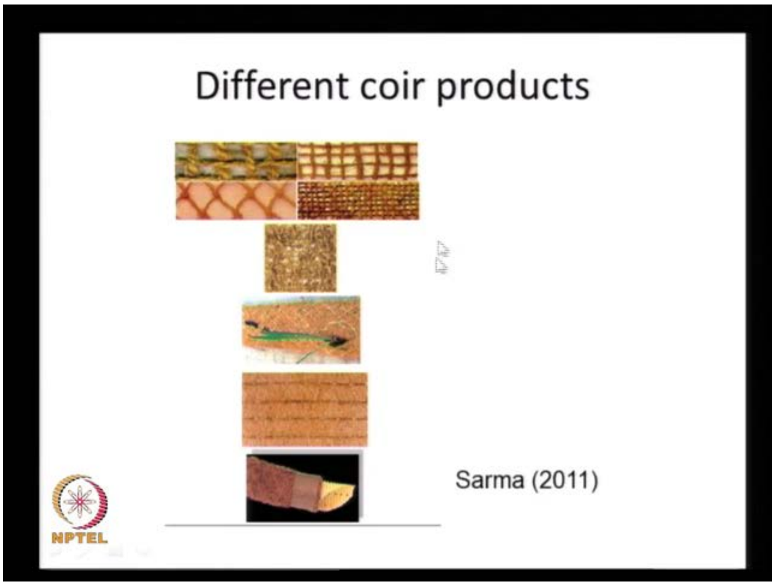

And some of the different coir products we can have nets or we can have a textile. This is a cocolog, this is a nonwoven textile and this is a pre-fabricated vertical drain.

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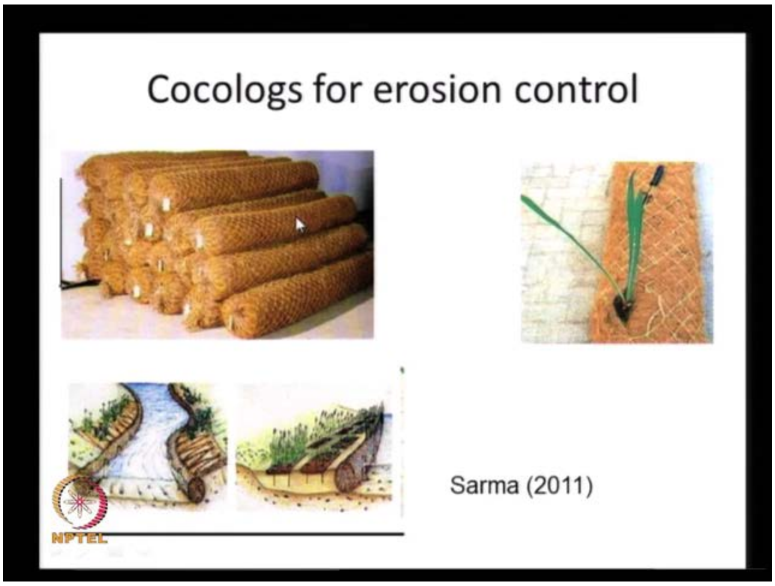

Cocologs is one of the more recent product. It is made in the form of a log, this entire log is made of coconut fibre and nonwoven or woven geotextile. And it floats in water and it can be employed in this systematic matter for river bank protection. If you provide it along the length of the river bank because of their flexible nature, they can take the shape of the river bank and absorb the way forces or water forces.

The main advantage is they can promote the growth of vegetation through them. And in no time because of the mulching action of this coir fibres and because they promote a good microorganism for the vegetation of the plants, the vegetation takes root. Once the vegetation takes root, we can solve most of the erosion problems.

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And another re-innovative application that we can think of is in the farm work of the concrete. So, these geotextiles here, we see one application of the coir geotextiles the coir and the jute geotextiles, they can help in moisture control. They can stabilize the moisture content along the edges of this. So, this are the coir geotextiles, they can distribute the moisture content so that the curing process of the concrete is good. These are called as permeable form works and it is catching up very fast all over the world.

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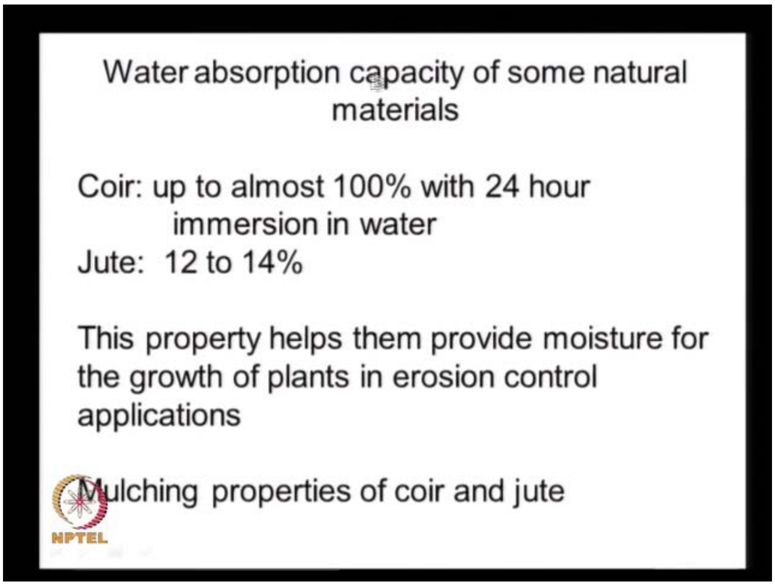

So, most of these natural fibres they have a very good water holding capacity. And the coir can absorb about almost hundred percent water, if it is immersed in water for about 24 hours. The jute they can absorb about 12 to 14 percent water by their weight. And this property of the water holding capacity is good because they can provide moisture for the growth of plants, when we employ the natural fabrics for the erosion control applications. Another advantage that we have with natural fibres is their mulching properties. Mulching is the gradually, they undergo the biological degradation and they produce some nutrients for the growth of vegetation.

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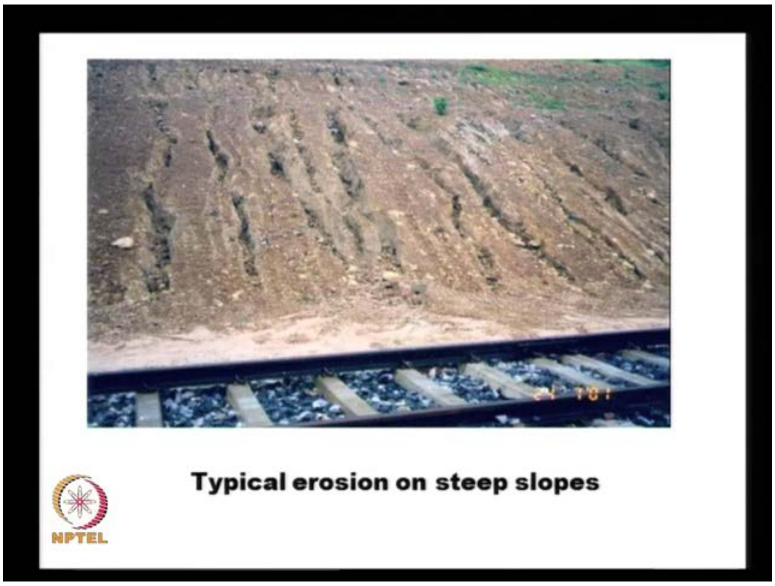

Typical erosion on steep slopes

And some example applications are shown here. This is a typical scene on most of the highway and the railway embankments because of the flow of the rain water, we have lot of gullies formed mainly because there is nothing to hold the soil together. If there is good vegetation, the roots of the vegetation can hold the soil together and prevent the erosion.

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And we can control the erosion by promoting the vegetation group. And here we see when coir carpet that is impregnated with seeds. And it comes in the form of a carpet; you just simply bring it and roll it on the area that we want to treat. This is a scene of one steep embankment that is grown with lot of vegetation. And here we can see one of the exposed coir geotextile. Within about 1 to 2 seasons, the vegetation grows and it takes a good root in the soil and that prevents the surface erosion.

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And here we see the application of coir mat to give a green finish for a landfill over one of the longest or the largest landfills in the world. In that was built in Visakhapatnam and the entire landfill was built above the ground level. And unless it is given some natural finish, it may look very ugly. We want this entire structure to blend with the surrounding green hillocks and other features of this area. And here by covering the entire embankment with a coir mat, we could grow the vegetation and now it looks very green and blends with the surroundings.

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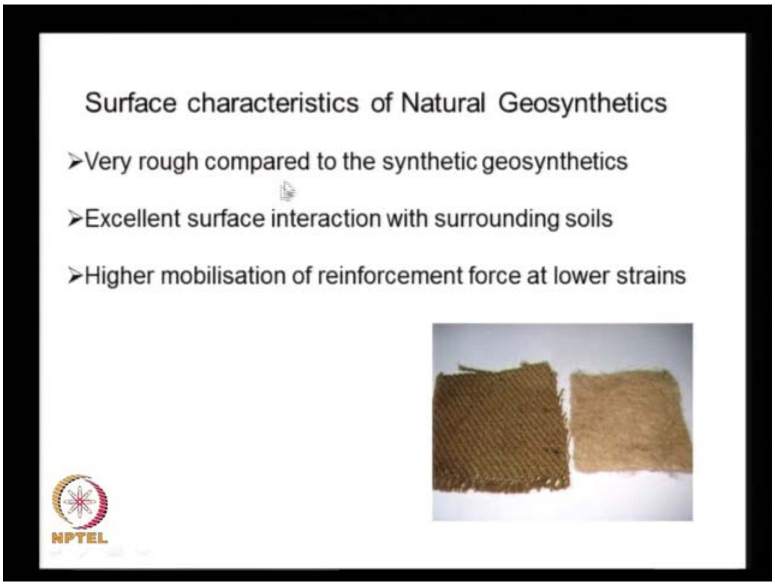

So, another characteristic of the natural geosynthetics that we can take good use of the surface character. The surface of most of the natural geosynthetics is very rough compared to their synthetic counterpart. And because of this roughness they have excellent surface interaction with surrounding soils, and that means that they can mobilize higher reinforcement force at a lower strain.

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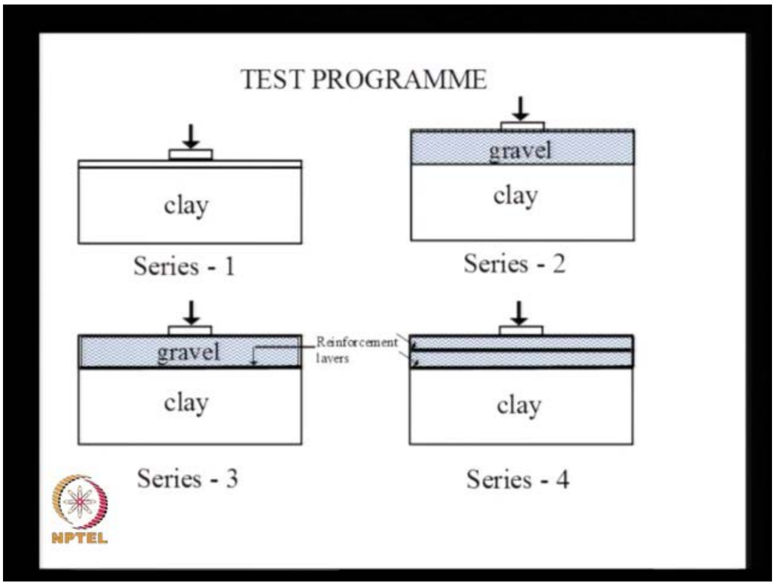

And I will illustrate that through some examples and here at I I T madras, some students have done some tests on the use of coir geotextile, similar to one that you have here for reinforcing soft clay and 4 series of tests were performed. The first series the play test done on clay soil alone, and the second series the clay soil with some murom soil layer and then the third series is the clay coir test, the clay plus gravel and with one base layer that is reinforcement layer that is at the base of the gravel. And the fourth series, there are 2 layers of reinforcement, one at the base of the gravel and another at mid height of this murom soil and let us see how they perform.

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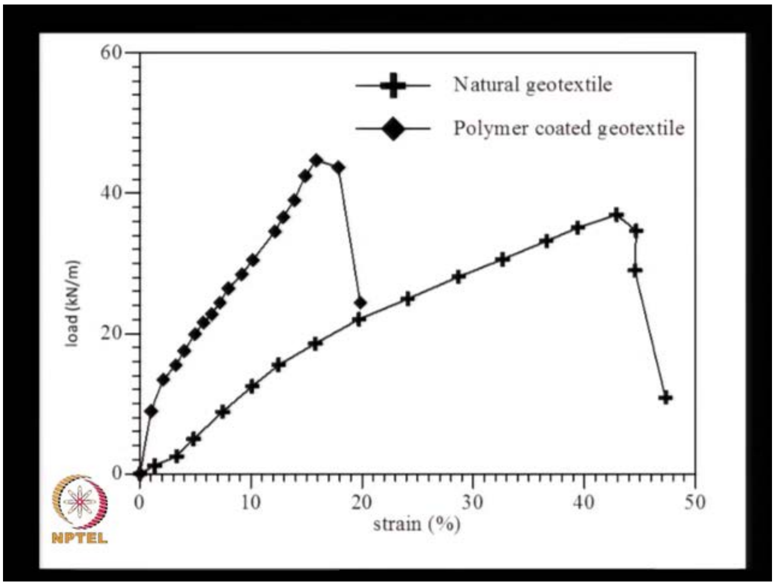

And this natural geotextile ((Refer Time: 27:25)) the geotextile, it is relatively soft textile. It provides or it develops maximum tensile force of about 36 to 37 kilo Newton per meter at a very large strain of nearly 40 percent, 42 percent and when it is treated with some polymer coating, we can make it stiffer. The strength as marginal increased to about 43 kilo Newton per meter and the strain at the peak load is about 16 percent.

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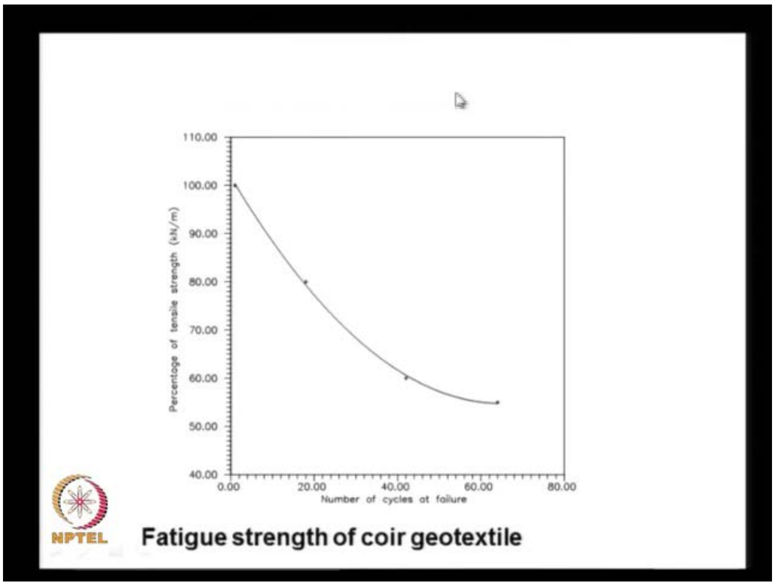

And the particular geotextile that we have it is susceptible to repeated load applications, and the strength reduces from 100 percent to almost 55 percent after about 60 load applications. So, the particular product that we are dealing with is a very soft product. And this particular result was obtained by applying nearly 90 percent of the ultimate strength. And it is not bad that even after of about 60 cycles, about 55 percent of the strength is still remaining in the coir.

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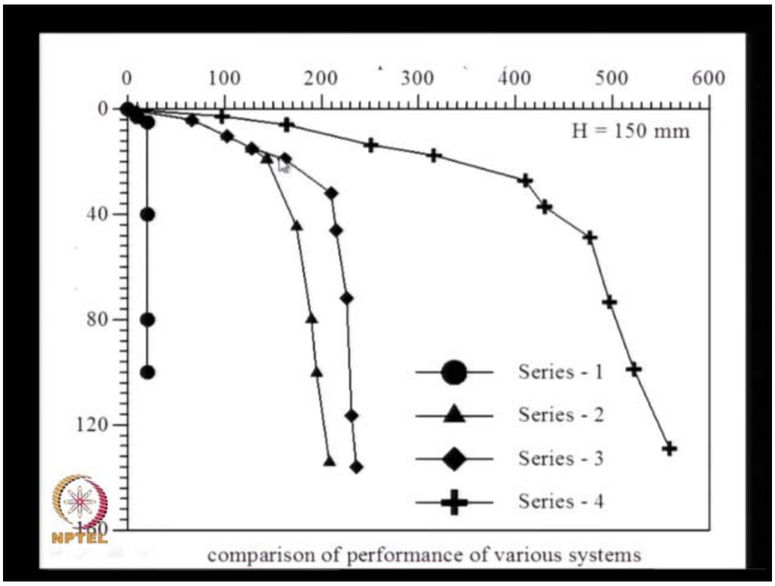

The result of this play coir test is like this. The x axis we have the pressure the y axis we have the settlement and the series one is the test that is performed on soft clay alone. It develops very low compressive strength of about 10 k p a and when there is a gravel layer of 100 millimeter thick, the clay pressure increases to almost the ultimate bearing capacity or ultimate pressure increases to nearly 200 k p a. When there is one layer of coir geotextile placed at the base of the gravel, the pressure increases slightly to about 225 or 240.

But then when we provide one additional layer of geotextile at the mid height of murom the result is phenomenal. The ultimate pressure is increased almost from about 200 to more than 500 or 550 k p a. This particular result can be only attributed because of the excellent interaction that is the taking place between the coir geotextiles at the murom. And because of the rough surface it is able to hold the soil together much better. That is resulting in mobilization of the higher capacity of the soil because ultimately, the soil is the one that needs to take the load.

And the coir that is provided in between the murom layer is able to hold it in place and allow it to develop a higher strength because actually, this particular geotextile is provided at a depth of 75 millimeters from the surface that means, that the earth burden pressure is very nominal. In spite of that we are able to get a very good increase in the strength of this system. And that can only be at the x plain by looking at the surface characteristics of this geotextile. These all data with different heights of the murom soil and these are all the results obtained for the unreinforced systems, and these are from tests from series 3 that is base l and reinforcement.

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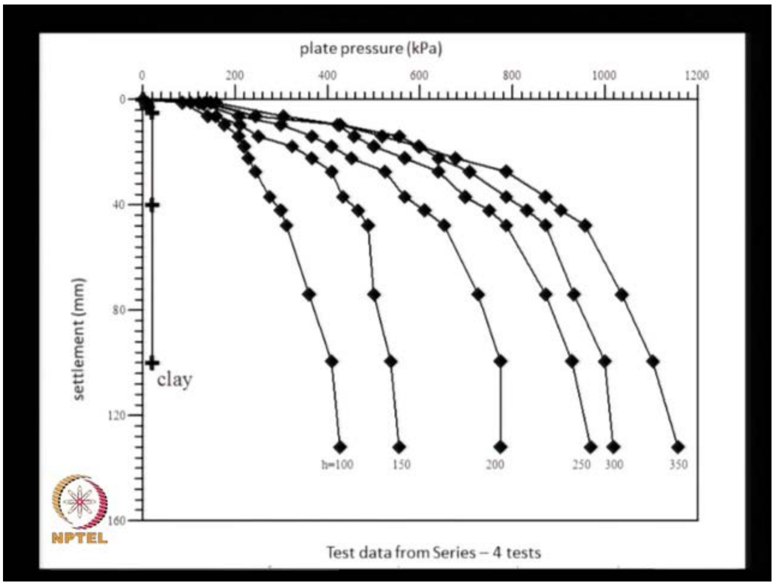

And this is the result from series 4 that is with 2 layers of enforcement.

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RESULTS

Ultimate pressure on clay bed = 20 kPa

Ultimate pressures (kPa) from plate load tests

Thickness of gravel layer (h)	unreinforced subbase layer	one layer of reinforcement	two layers reinforcement
100 mm	100	120	400
150	200	220	550
200	240	250	750
250	300	360	900
300	370	440	1000
350	400	500	1150

And the ultimate pressures that were obtained are like this, when the thickness of the gravel here is let us say about 20 millimeters. The maximum pressure that we can apply on the unreinforced system is 240 k p a, and with one layer at the reinforcement of the base it increases to 250 k p a so only a marginal increase and with two layers it increases to 750 k p a.

Say if you have a thickness of 350 millimeters, the unreinforced system can take a maximum pressure of 400 k p a, which increases to 500 with 1 bottom layer, but then when we provide one additional layer, this capacity almost doubles to nearly 1150 k p a. And this shows that we need a good interaction between the reinforcement and the soil to mobilize higher a capacities. Does this mean that we do not require a base a layer because we are not getting a good improvement.

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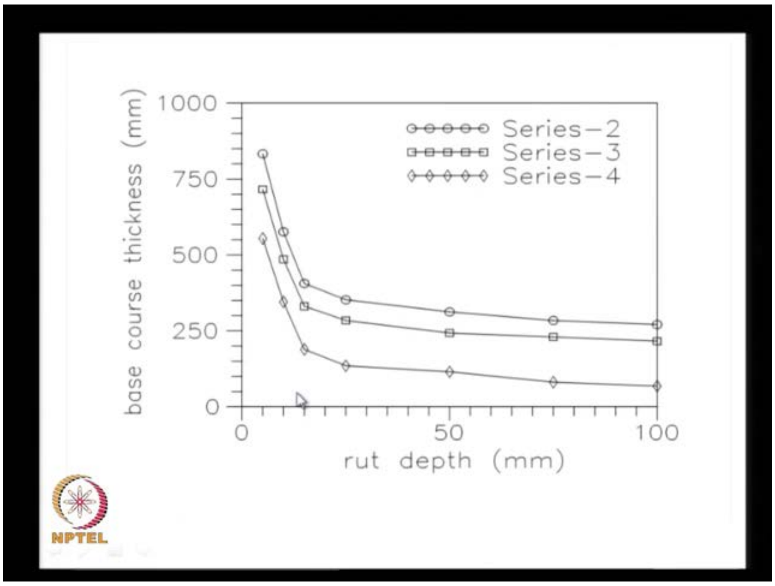

We should not think it like that because the base layer also plays a very important role in preventing the intermixing of good quality murom with soft clay soil. And that can only be achieved by placing the layer at the bottom at the place in the geotextile layer at the bottom of the murom soil. And that in turn helps in a long term performance whereas, the reinforcement layer that is placed at mid height of this murom soil can help in the short term performance, or it can immediately develop the force and increase the capacity.

And so we can think for the long term benefit, we need to provide one layer of reinforcement at the base of the Murom soil and for a short term performance, we require one additional layer of reinforcement at the mid height of this murom soil. The same data that is given in a different form corresponding to different rut depths. And what should be the base course thickness for unreinforced systems, and for with one layer of reinforcement at the base and with two layer reinforcement.

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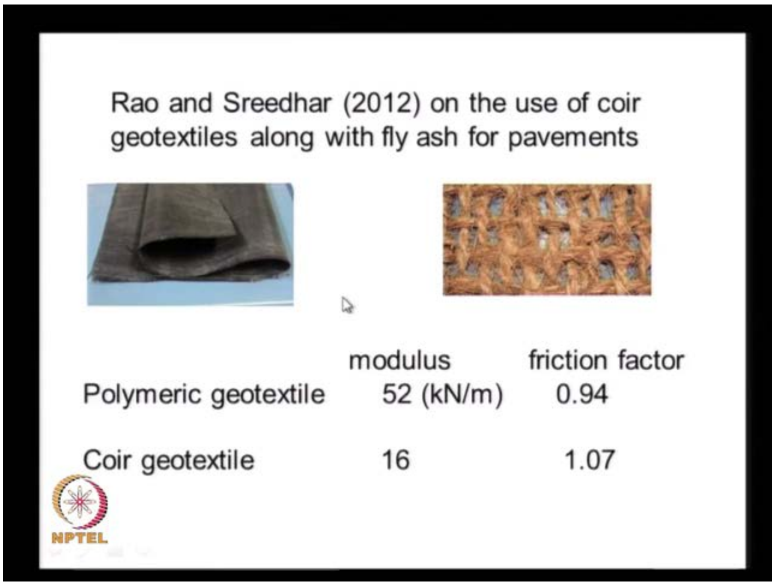

And the similar data was also published by other researchers. And one example is the paper by Rao and Sreedhar that was published in 2012. They compared performance of a coir geogrid, which is very rough like this with a geogrid made up of synthetic. The polymeric geotextile surface is very smooth like this, which has a modulus of about 52 kilo Newton's per meter and the coir geotextile, it has a modulus of 16 kilo Newton per meter, this is the secret modulus at 5 percent strain. And the friction factor is 0.94 from the modified direct ((Refer Time: 35:20)) whereas, for coir geotextile is 1.07.

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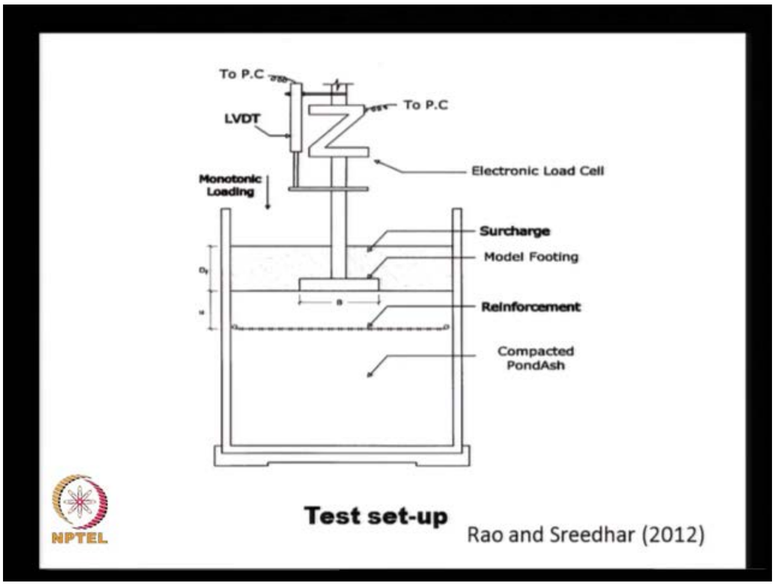

They have done a lot of laboratory test by using a compacted Pondash as the sub grid soil. And by placing the reinforcement at different depths, they have done this test.

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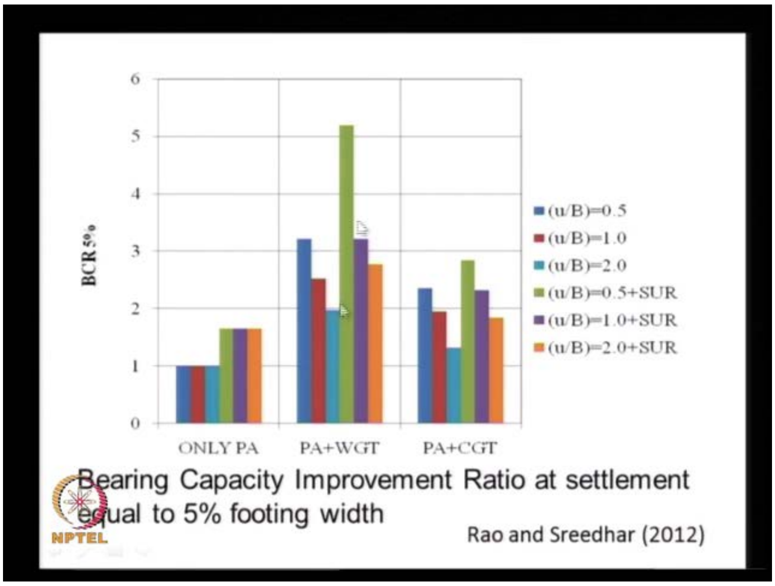

And their observations are here, the bearing capacity ratio. The bearing capacity of the unreinforced the soil in the denominator, and the bearing capacity of the reinforced soil in the numerator, just as how we have defined in the earlier lectures. With a different u by b that is the u by b is at a different depth, the reinforcement is placed.

Then the surcharge affect because they have placed the footing at different steps to get different surcharge effects. And the bearing capacity improvement ratio is maximum with polymeric type reinforcement. So, obviously this is the result at 5 percent settlement equal to 5 percent of the footing width and whereas, the benefit with coir is slightly better, but not as much as with the polymeric geotextile.

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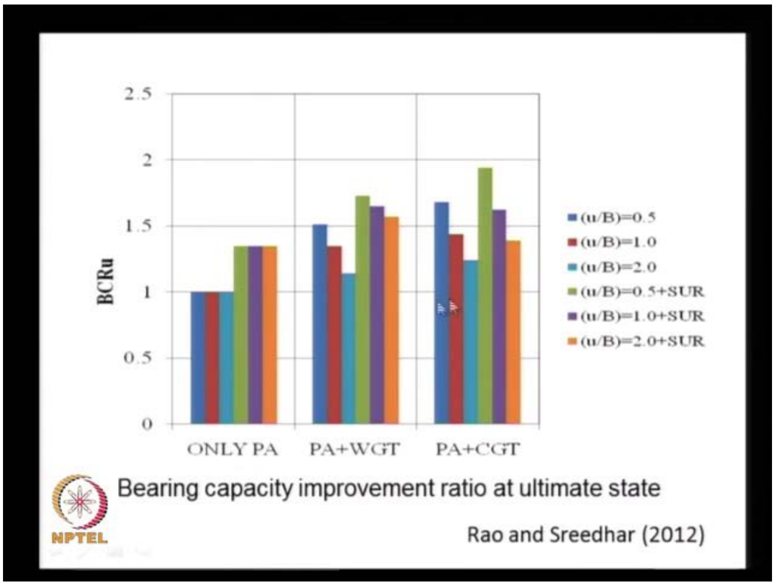

But if we see at the ultimate state where the retting is much higher, the coir geotextiles they have a higher bearing capacity improvement ratio as compared to the polymeric product. That is because at higher rut depths, the coir geotextiles is able to produce higher force because of better interaction it has with the surrounding medium.

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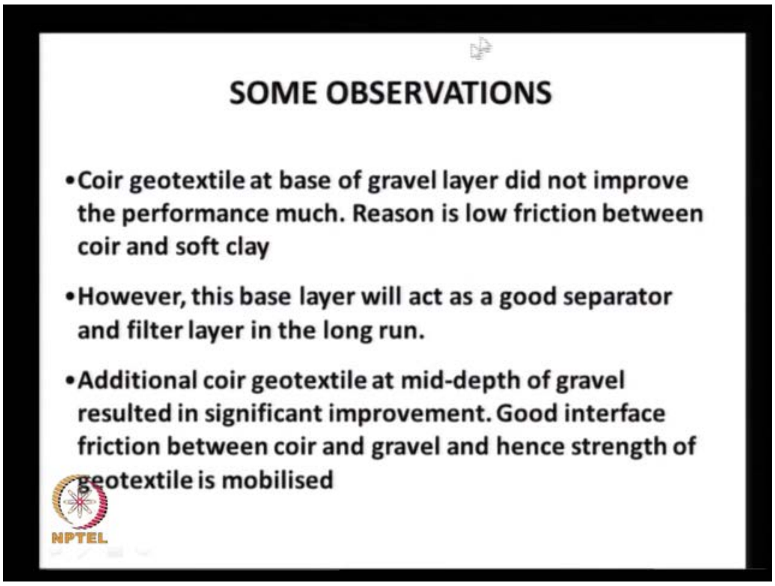

Some of the observations is that, the coir geotextile at the base of the gravel layer do not show much of the performance improvement because the surface is very smooth, because of the soft clay that we have. However, this base layer can act as a good separator and filter in the long run. Thus, improving the long term performance and the additional coir geotextile at mid-depth of the gravel layer, results in significant improvement because of the good interface real friction between the coir and the gravel. Hence, the strength of the geotextile and also the soil is mobilized in to a higher degree.

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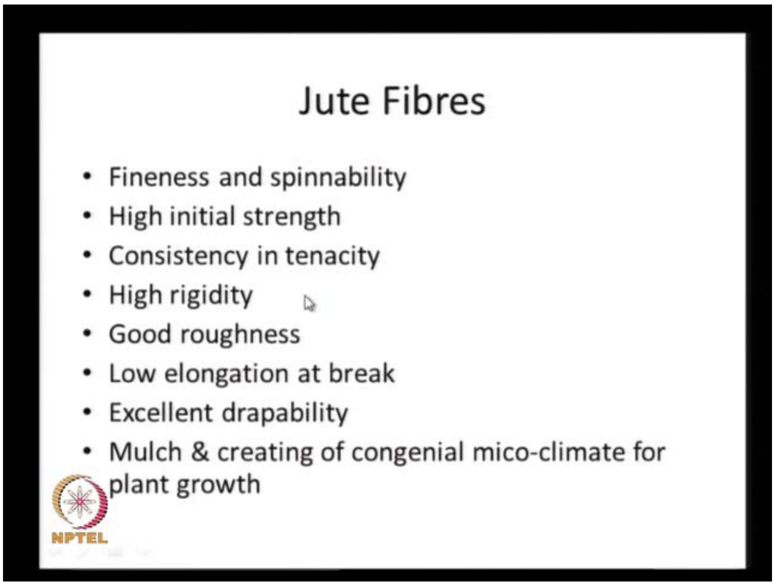

So, compared to the coir fibres, the jute fibres they are finer and they have better spinnability and the jute fibres have higher initial strength. And the consistency is more uniform in the case of jute fibres because these jute fibres are very long as compared to the coir fibres, and they have a higher rigidity, they have a good roughness, they have very low elongation at break, and they have excellent drapability. Drapability is a property that if you make a cloth out of these fibres and if you spread on a surface, they can take the contour of the ground more easily that is called as the drapability. And the jute fibres are also they have a mulching property and they create a congenial micro-climate for the growth of the plants.

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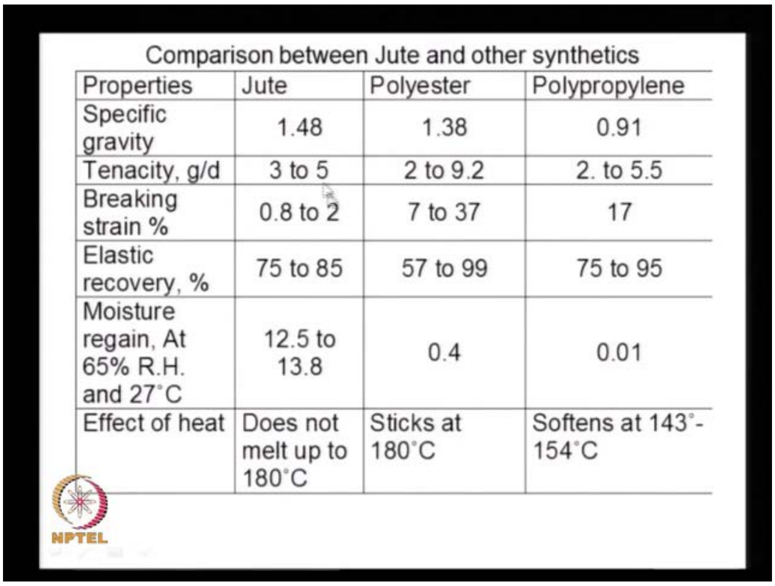

Comparison between Jute and other synthetics

Properties	Jute	Polyester	Polypropylene
Specific gravity	1.48	1.38	0.91
Tenacity, g/d	3 to 5	2 to 9.2	2. to 5.5
Breaking strain %	0.8 to 2	7 to 37	17
Elastic recovery, %	75 to 85	57 to 99	75 to 95
Moisture regain, At 65% R.H. and 27°C	12.5 to 13.8	0.4	0.01
Effect of heat	Does not melt up to 180°C	Sticks at 180°C	Softens at 143°-154°C

And some comparison between the jute and the other synthetic products specific gravity of the jute is 1.48. Whereas, polyester and polypropylene, they have these specific gravities of 1.38 and 1.91. And the breaking strain is very interesting and the jute, they have breaking strains of about 0.82 percent whereas, the polyester it has got 7 to 37 percent, polypropylene about 17 percent. The effect of the heat is quite significant in the case of polymers whereas, the jute it does not melt at even at 180 degrees centigrade. Whereas, the polyester at about 180 degree centigrade, it starts sticking to the hands.

And whereas, the polypropylene it softens in the range of 143 to 154 degrees centigrade. So, that means that the polypropylene and polyester type geotextile, they may not be used as ash fall to our lace because the ash fall is placed at high temperature at about 130 to 140 degree centigrade. Whereas, a jute textile because it does not melt even at 180 degree centigrade. It may be a good product that we can use as over layer fabric.

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And here we see an example of the vegetation growth after covering this area with a jute geotextile.

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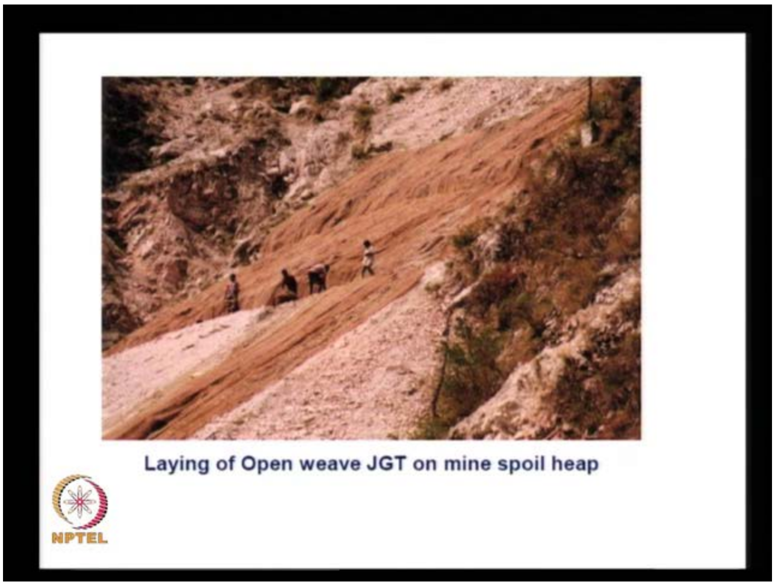

And here we see the application of jute geotextile being spread on a spoil heap mine dump to promote the growth of vegetation.

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And another form of natural product is the bamboo. Recently there were some studies on the use of bamboo as a reinforcement. And here we see tensile testing of a bamboo geonet and here we see a tube that is made of bamboo net. This picture shows the reinforcement of a soft clay soil using a bamboo grid that is filled with stones, and this is similar to geosynthetics encased stone columns. Here we have a bamboo net that is encasing the stone column to improve its performance.

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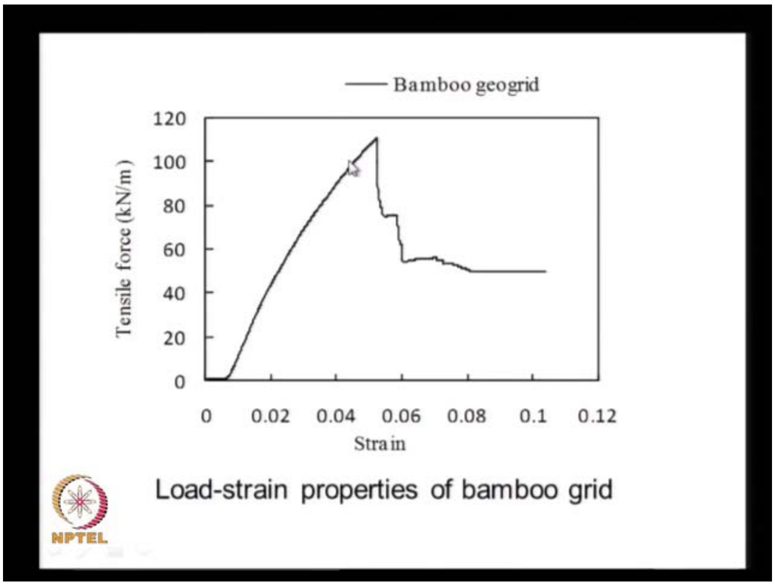

The tensile property of this bamboo geogrid is about 5 percent strain, it develops a force of about 110 kilo Newton's per meter. And it is a fairly good strength developed at relatively low strain and the result of encasement is quite substantial.

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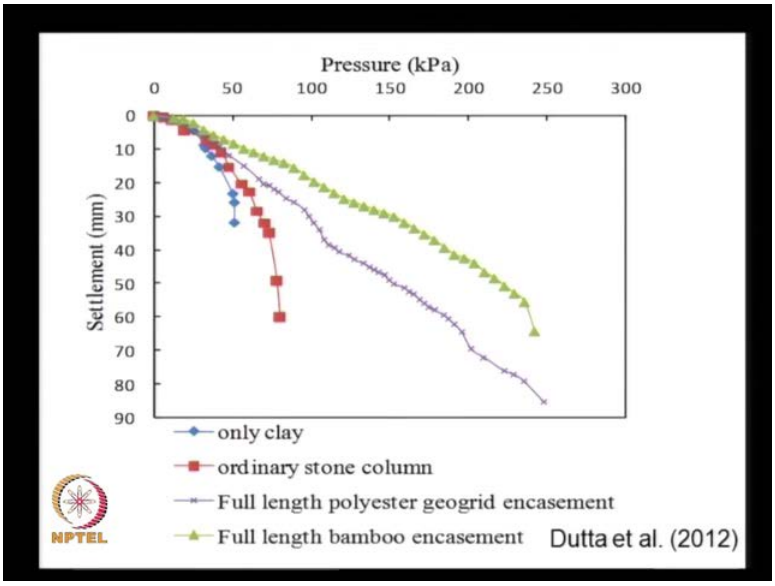

This is the pressure settlement data for clay soil alone, and this is with ordinary stone column. When the entire stone column is encased in a polyester geogrid, this is the type of response we have. And if it is encased in the full length bamboo encasement, there is a substantial increase in the pressure capacity. We see that both the initial slope and the ultimate pressure, they have increased by using the bamboo geoneotary enforcement.

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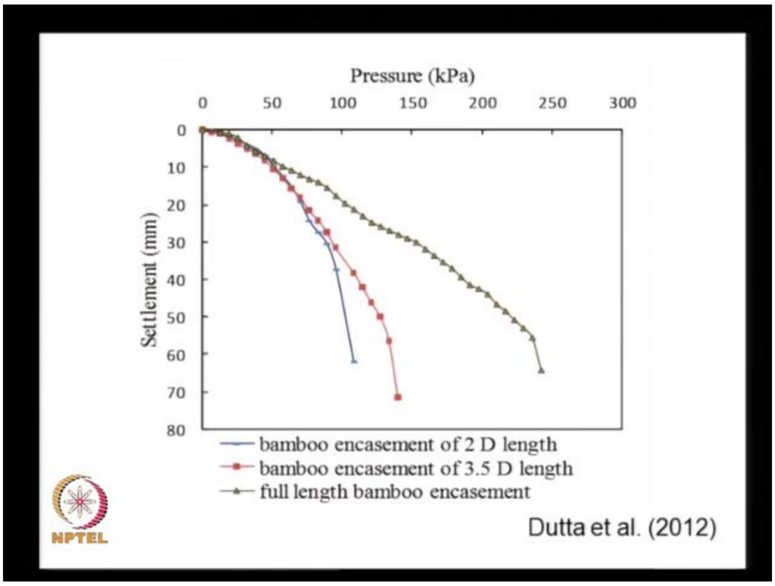

And here we see the comparison with different lengths of treatment. Sometimes we may not require the treatment of the stone column over the entire height. Actually this is the full length encasement whereas, with encasement or a length of 2 times the diameter and this is the type of response we have 3.15 the diameter. So, this is the response that we have so that means that even bamboo reinforcement can increase the stone column capacity. And wherever we need the stone column support for a limited period then we can utilize the bamboo, as a possible encasement to improve our stone column stiffness and also the ultimate capacity.

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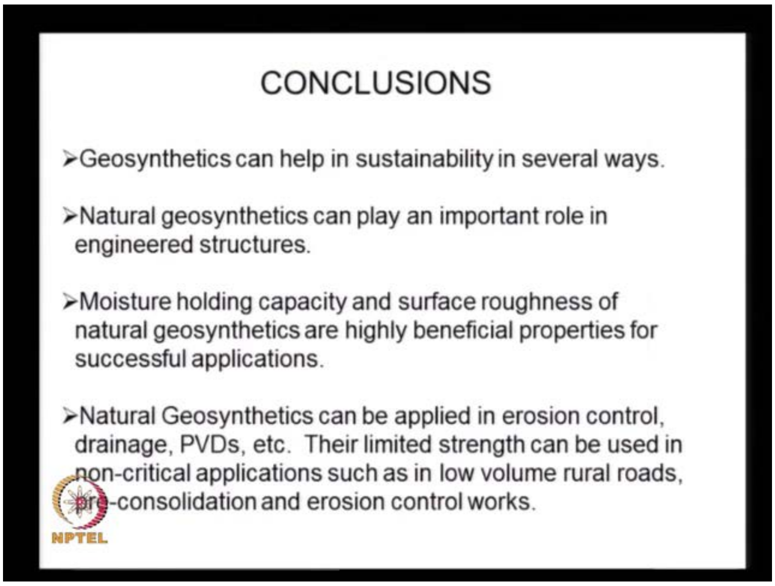

And just to conclude our geosynthetics can help in sustainability in several manners, as we have seen earlier and the natural geosynthetics can play an important role in engineered structures. And moisture holding capacity and the surface roughness of the natural geosynthetics are highly beneficial properties for successful application, not only in the reinforcement application and also in the surface erosion control applications. The natural geosynthetics can be applied in erosion control works drainage and in PVD applications. Their limited strength can be used in non critical applications such as in low volume rural roads and the other erosion control works.

So, thank you very much.