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

Module - 1
Lecture - 2
Types and Functions of Geosynthetics

Hello students, let us continue our discussion on the different types of Geosynthetics and their applications.

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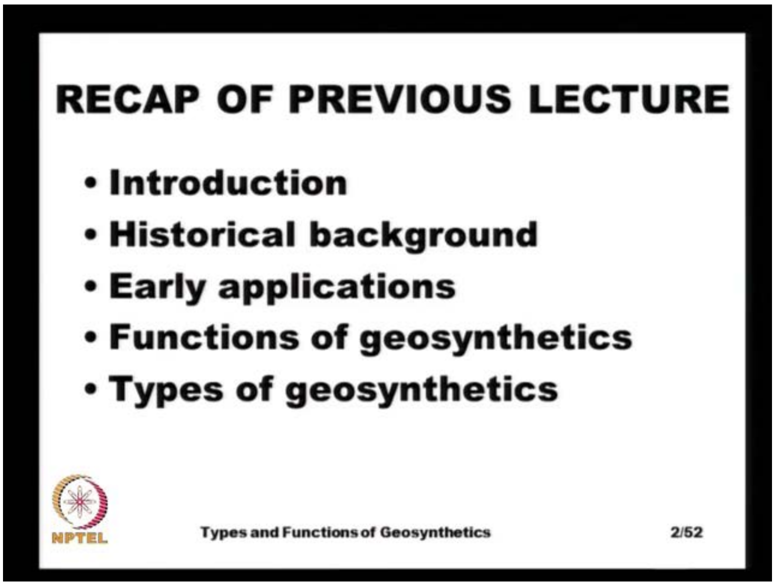

Just to briefly recap the previous lecture, we have discussed the brief introduction of the geosynthetics and the concept of reinforced soil and the need for geosynthetics. And we have seen the historical background, the early applications of the geosynthetics and the different functions of geosynthetics, and the types of geosynthetics.

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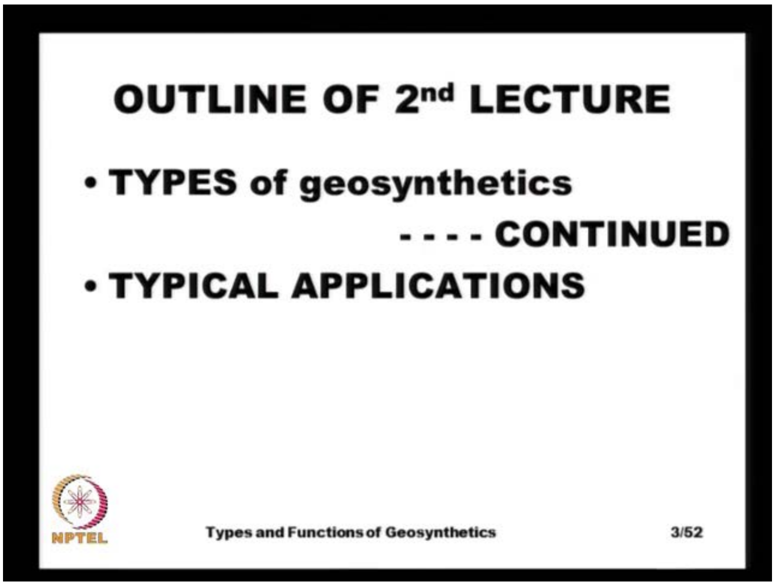

And in the this lecture is a continuation of the discussion on the types of geosynthetics.

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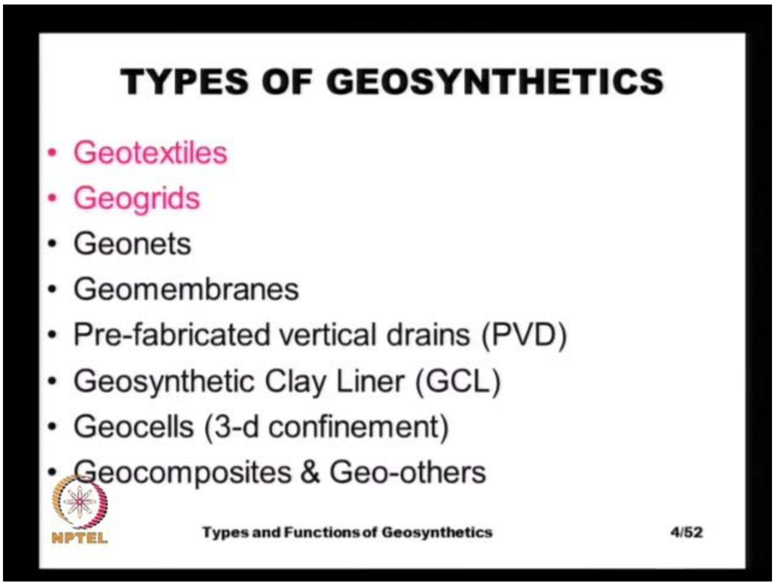

And in the previous lecture, we have already discussed the 2 types of geosynthetics, one is geotextile and the other is geogrid. And let us continue discussing the about the other types of geosynthetics.

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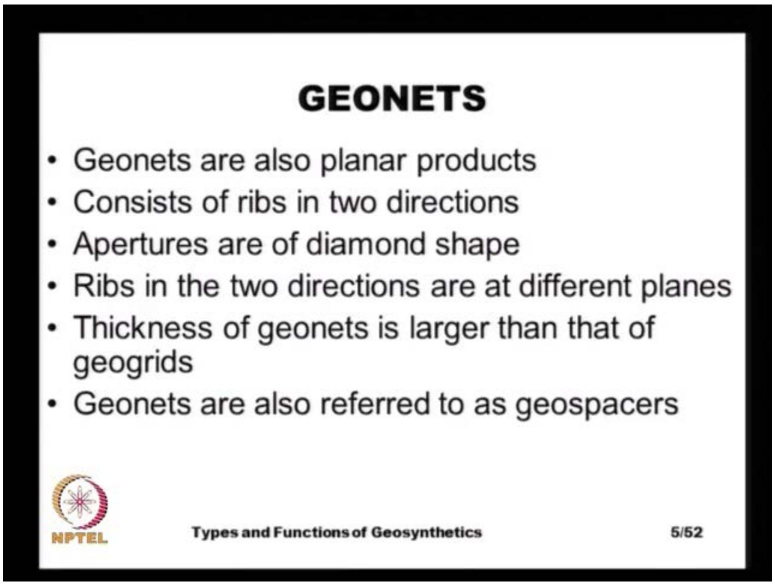

The geonets these are also planar products and they are very similar to geogrids and they also consist of ribs in 2 directions, but their aperture openings, they are not square or rectangular in shape, but they are more of diamond shaped. And the other major difference between a geonet and the geogrid is that the ribs, in the 2 directions, they are in 2 different planes. Say for example, the geonet there are ribs in 2 different directions, they are in 2 different planes, whereas in a geogrid both of them are in the same plane.

And the thickness of a geonet is much larger than that of geogrid, because the function of a geonet is very much different from that of the geogrid. And sometimes these geonets, they are also called as geospaces, because we want to creates, we need to create some space in some situations. So, that there is a flow of free flow of water or for some other purposes.

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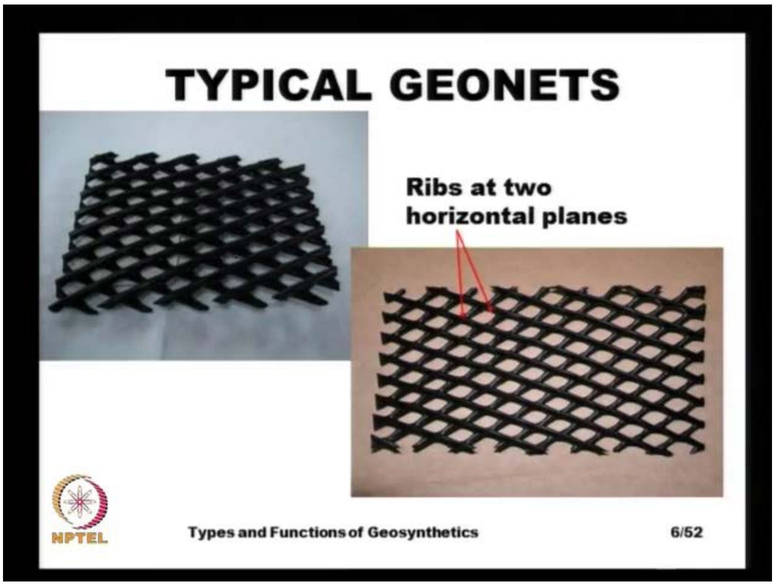

And these slide it shows typical geonets and we see that, the ribs or in 2 different planes and then the thickness of each of these ribs is very large, compared to that of a geogrid. And here, you see the close-up of the same thing, the ribs in 2 different directions and the aperture openings, they are more of diamond shaped and not square or rectangular.

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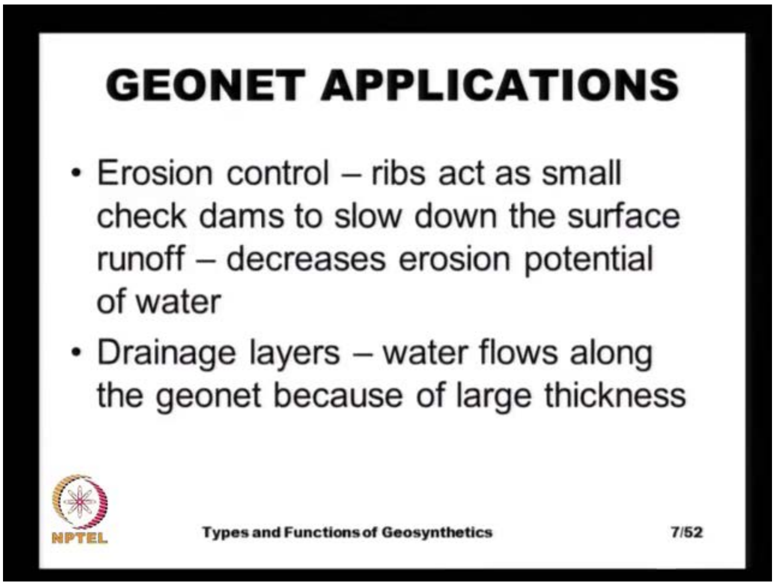

These geonet applications, they are mainly used for erosion control, because these ribs, because they are very thick, they act as small check dams to slow down the surface runoff. And once the rain water surface runoff is slow down, it reduces the erosion potential of the water and there by reduce the surface erosion of the soil. And the geonets can also be used as excellent drainage layers, because of the thickness of the geonet the soil in between the small diamond shaped openings is not very highly compacted and because of that, there is some flow path for the water to flow, through the geonet.

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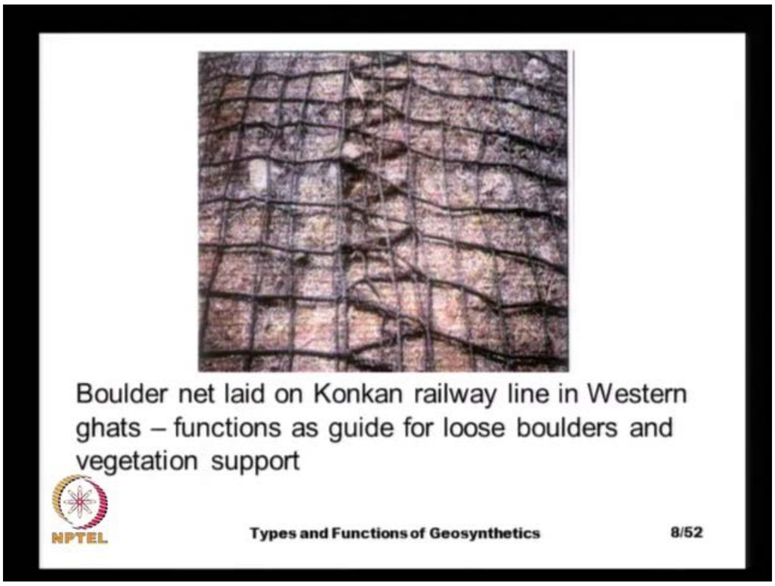

Here is a good application of a geonet is actually, this geonet is made of polymeric rope and this is called as a boulder net and this is used in the konkan railway in the western ghats. And the main function of this geonet is to act as a boulder and as a guide for the loose boulders.

So, that these loose boulders, they do not fall into the railway track, because most of the konkan railway is formed by cutting very deep gouges and the train passes through the very narrow gouge and when the boulders come loose during the heavy rainfall. The boulders come directly, they fall into the railway track and because of that there were several accidents for the past few years.

And you would have also read some newspaper reports or in the t v reports about the train accidents taking place at the konkan railway, because of the fall of the boulders. And the purpose of these boulder nets is to guide these loose boulders to fall into a trap, that is on both sides of the railway track. And in indirect manner, they also help in the growth of vegetation on the slopes

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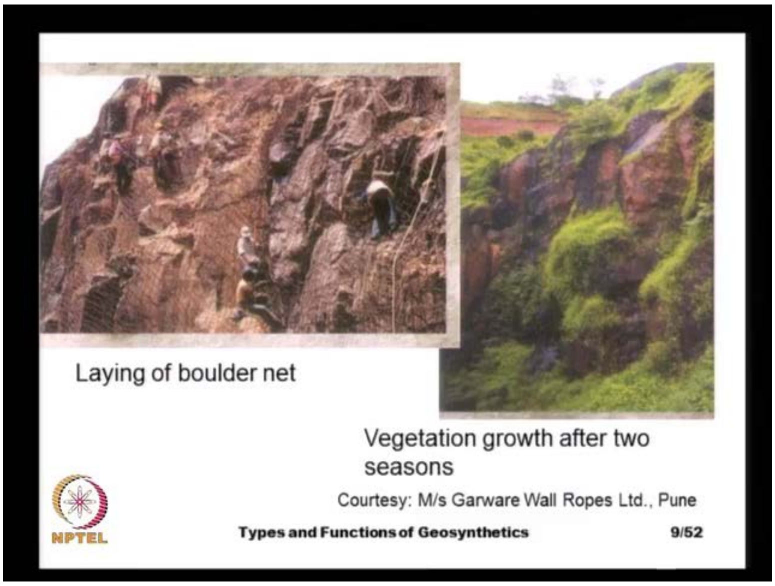

And here, we see in this slide, you see the laying of the boulder net on these cuts and on the right hand side, you can see the growth of vegetation after about 2 seasons and these 2 slides are the courtesy of misses garware wall ropes.

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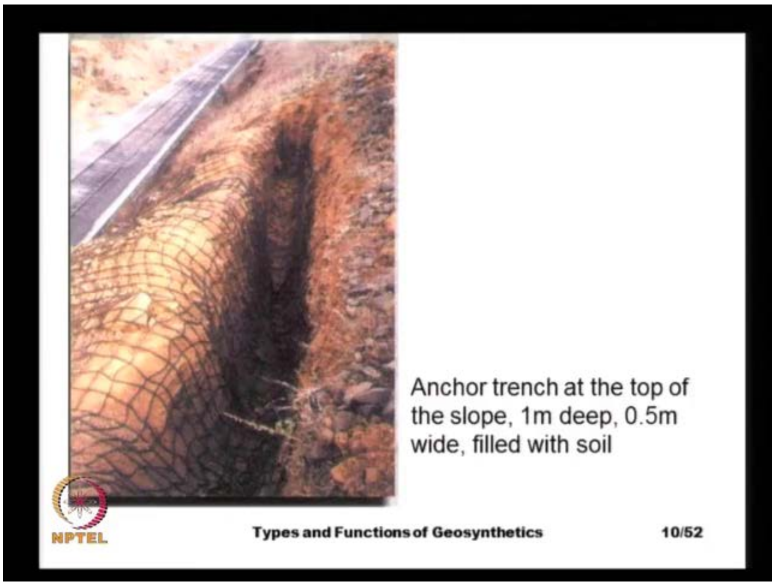

And this is how, we anchor the rope net top of the slope is actually, there is a 1 meter deep trenches and which is 0.5 meters wide. And it is the rope net is anchored in the trenches and the size of trench, especially the depth of the trench. And the width, they are decided based on the amount of tension, that is likely to be developed based on the size of the boulders, that are prevalent are this particular place. And here, you see the railway track going through a very narrow gouge and this is one typical application of a boulder net or a rope net in konkan railway.

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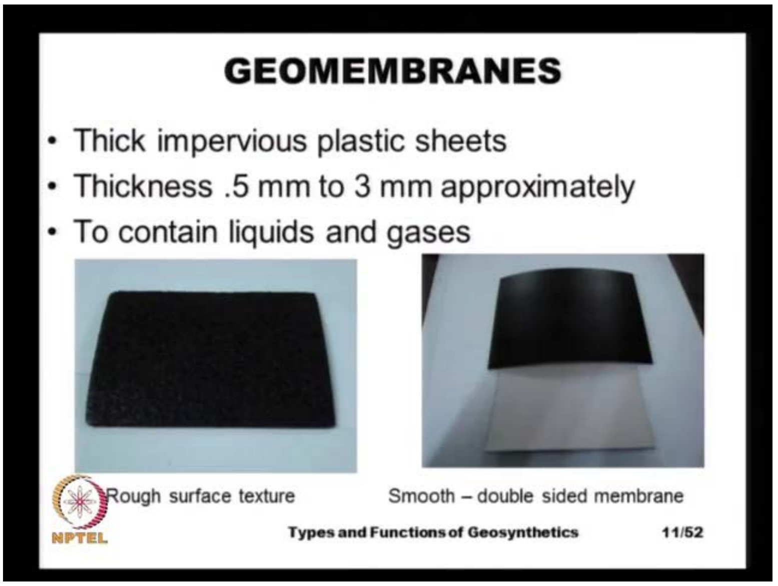

The other geosynthetic product is geomembrane, which is very commonly used for construction of landfills or for lining the canals or for lining some other water retaining structures. And these geomembranes, these are nothing but thick impervious plastic sheets and typically, their thickness can vary anywhere from 0.5 millimeters to almost 3 millimeters.

And these geomembranes are used to contain liquids or the gases and there are several varieties of geomembranes and the left hand side, we have a geomembrane with rough texture whereas, on the right hand side, we have a very smooth geomembrane. And depending on the necessity, we may use a smooth geomembrane or a very rough geomembrane.

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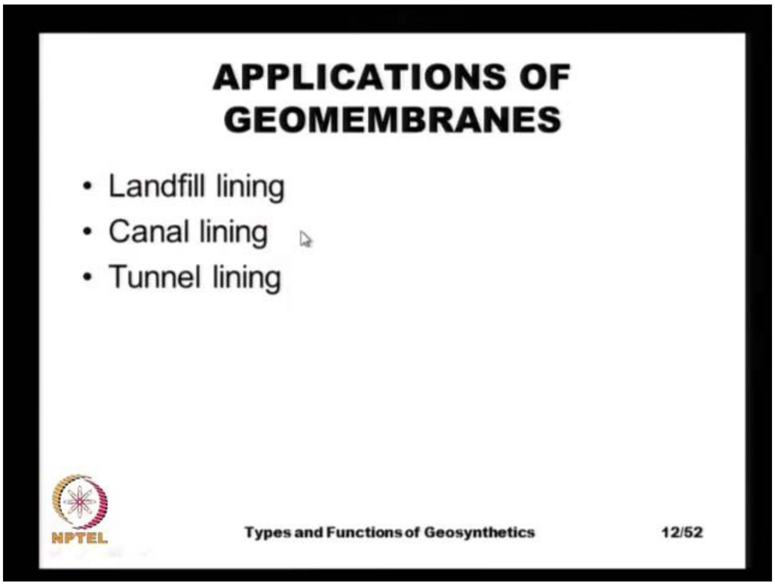

Some of the applications of the geomembranes, they are used in landfill linings and they can be used as canal lining materials or they can be used in the tunnels to prevent the rain water from flowing, through the tunnel or prevent the moisture from coming into the tunnel.

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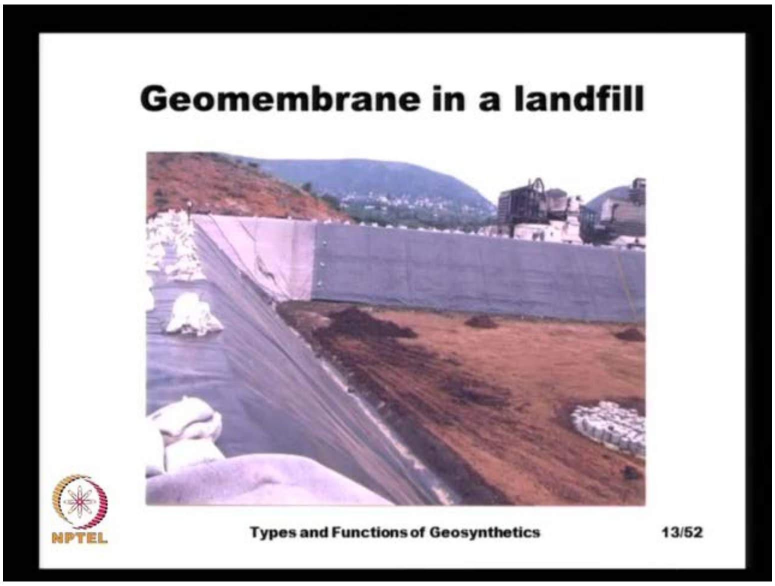

And here, we see the lining of a land fill with a geomembrane the main purpose is if there is a hassudust waste or a toxic waste the this the product of this toxic waste, they will not flow through the landfill and contaminate the ground water.

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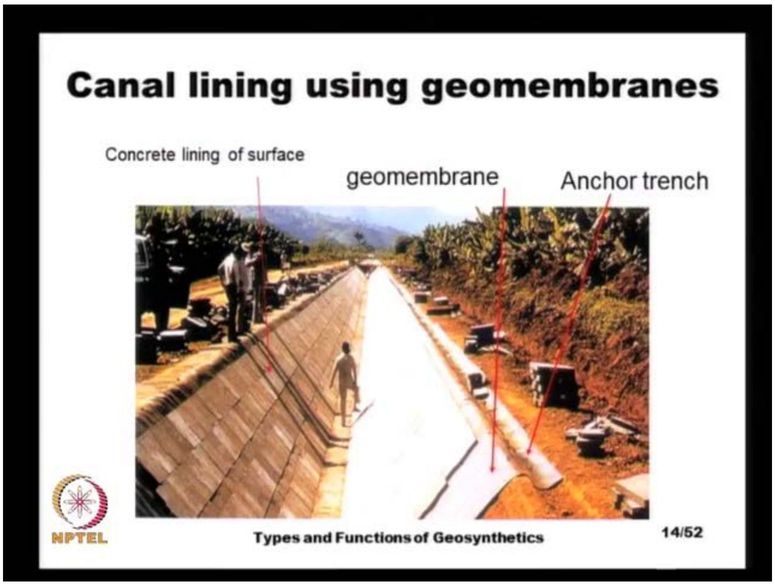

And here, we see the application of a geomembrane for canal lining and here, we see this the geomembrane, that is lined on the canal and the geomembrane itself is protected by concrete panels on the top. So, that the geomembrane is not directly exposed to the sun, because all these polymeric products, they have they get degraded, because of the exposure to light and the heat that is the sun. And the geomembrane, that is lined up, that is anchored at the top use using an anchor trench.

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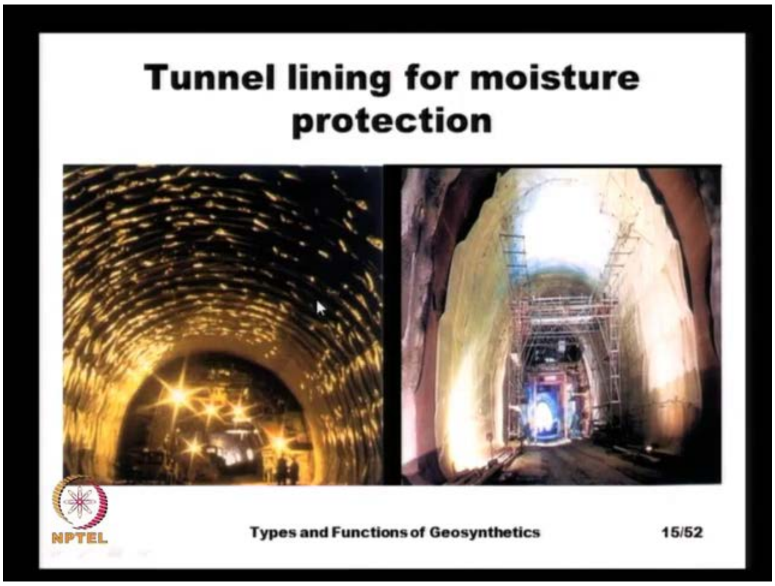

And here, we see the application of a geomembrane for canal lining to prevent the moisture from seeping into the inside of the tunnel.

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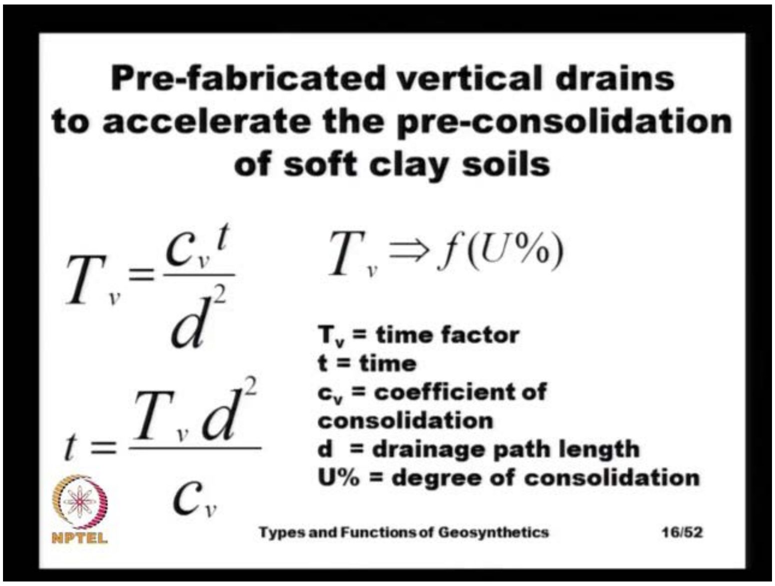

And another major application of the of the geosynthetic season, the form of a pre-fabricated vertical drain, that is used for accelerating the consolidation of a soft soils. Is actually, on the left hand side, I have given the equation for the time factor is a function of the coefficient of consolidation and the drainage path length d.

And then the time t and we know that the time T is directly proportional to the square of the drainage path length. And of course, the time factor and inversely proportional to the to the coefficient of consolidation and here, the only parameter that, we can change. So, that, we have a reduced time for consolidation is the drainage path length d, because the soil properties, we cannot change and then the T v is the time factor that is related to the degree of consolidation that, we want to achieve. And if you are able to reduce the drainage path length d by a factor of 2, the time for consolidation will reduce by a factor of 4, because of the time is directly proportional to the square of the drainage path length.

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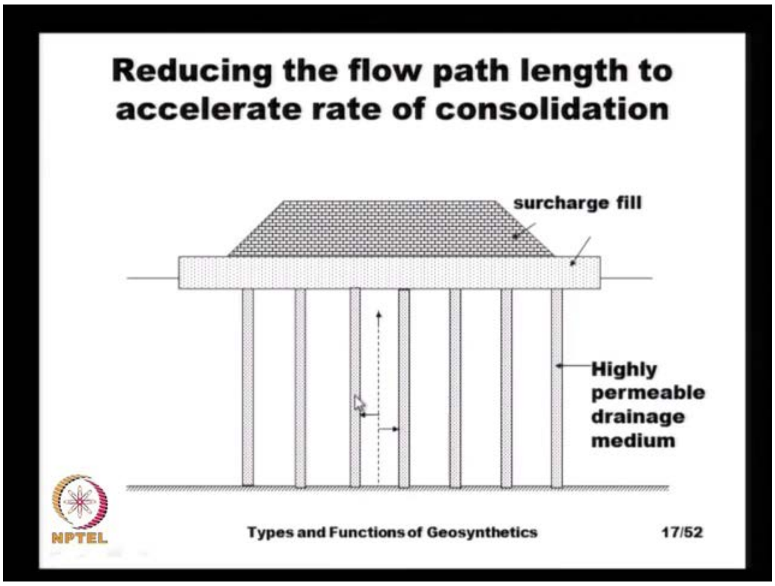

And here is a typical manner in, which we can apply the these drains and let us say that, we have a thick clay soil and if we do not put in anything the water has to travel this much length to escape from this soil. And it takes a very long time to consolidate the soil. And the other hand, if you introduce some highly permeable a members either sand columns or the pre-fabricated vertical drains and the length of the drainage path.

So, that the water can escape from the soil is very, very small, in this particular case, if the water particle travels the small distance, it can enter into this highly pervious column either sand column or a pre-fabricated vertical drain. And once it enters this drainage medium, it can escape very fast and that is the principle of the pre-consolidation somehow, we reduce the flow path length.

So, that our the time for consolidation is reduced and in the early days the sand was used for constructing these drains, and we all know what are the problems, that are associated with the sand columns, they can get contaminated by the soft clay or if there are some differential movements inside the ground. The efficiency of the sand columns will reduce tremendously and to overcome all these problems, we have come out with pre-fabricated vertical drains.

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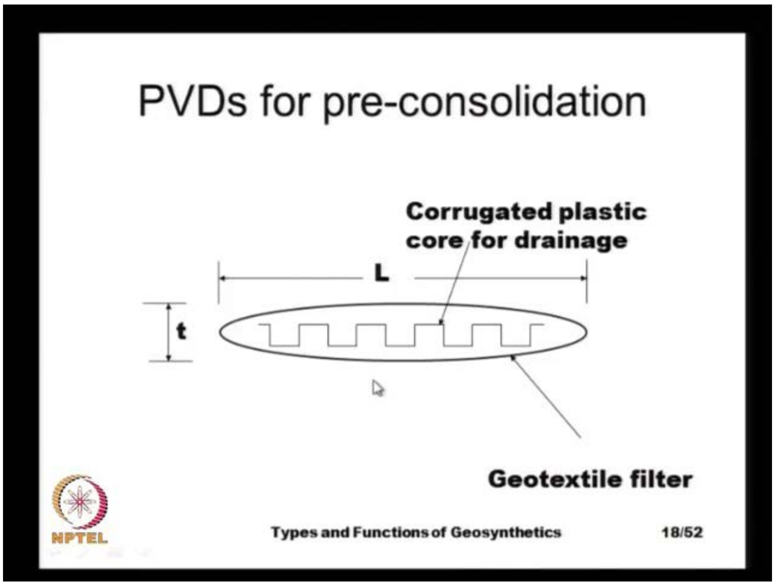

And in cross section a pre-fabricated vertical drain consist of an outer core of a geotextile that acts as a filter and there is an inner core that acts like the drainage medium. And this inner core could be made of in the simple P V D’s, it could be just corrugated plastic sheet, plastic core or in more complicated systems, we could have a geonet in as a core and at the outside, we could have a thick geotextile, that acts as a filter.

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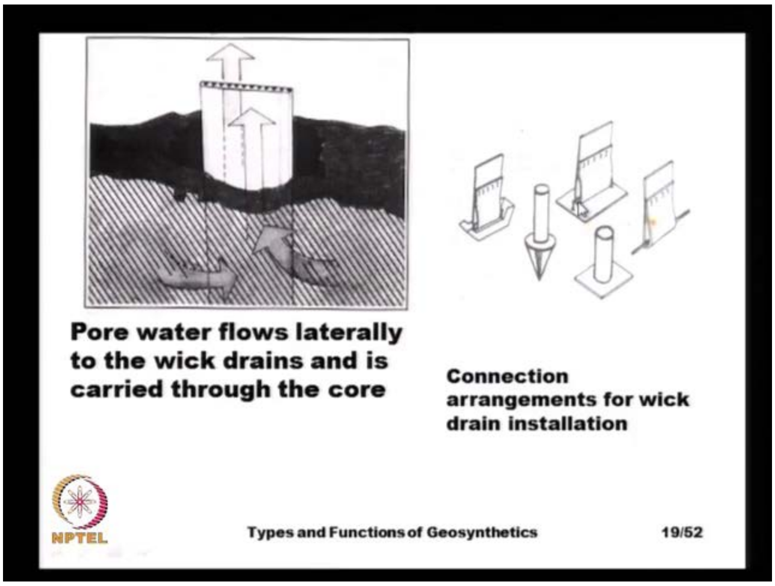

The concept is like this see, we introduce the pre-fabricated vertical drain into the ground by pushing, it by attaching it to some anchor like this and then we just simply push it and then allow the water to come out. And here, we see a schematically station of the water flowing through the geotextile filter and once it enters the core, because the core is highly permeable, the water comes out very fast.

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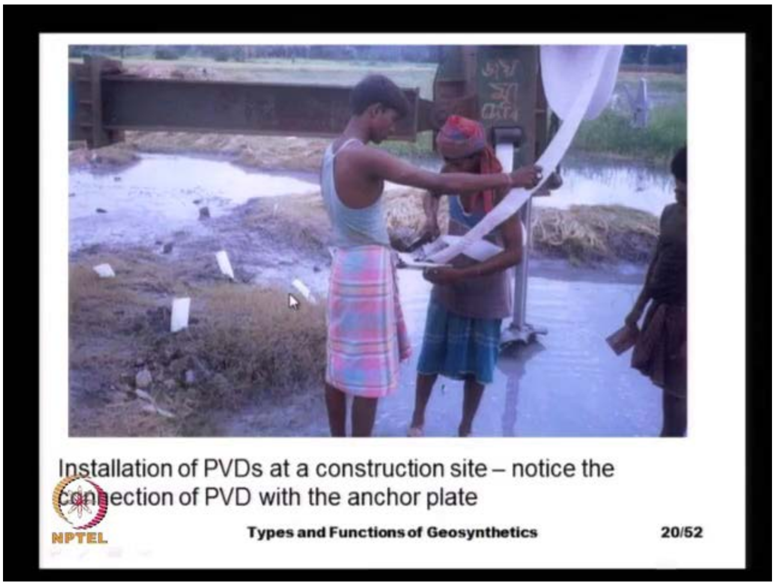

And here, we see the application of pre-fabricated vertical drains at a construction site with a very soft clay subgrade, soft clay foundation soil and here we see some P V D's that are already installed. And here, we see these 2 people attaching the P V D to an anchor plate.

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Is actually, here we see this another view of the same thing.

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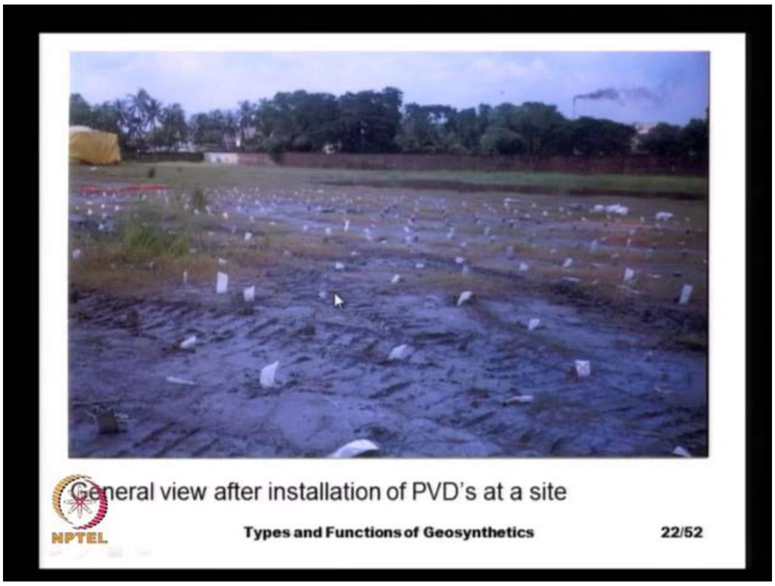

And once the entire ground is treated with pre-fabricated vertical drains, we can apply some surcharge on this and the soil. And the amount of surcharge that, we apply should be corresponding to the expected foundation pressures that, we have after the full construction takes place.

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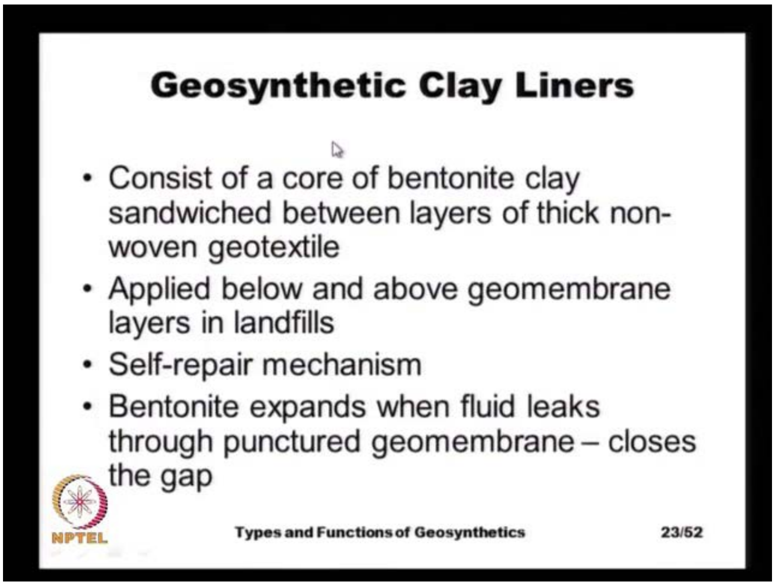

Another product geosynthetic product that, we have is geosynthetic clay liner is actually, this geosynthetic clay liner is an additional protection member that, we can that, we have in the landfills. And these G C L's, they consist of a core of a bentonite clay, that is sandwiched between 2 layers of thick non-woven geotextiles.

And this is applied below and above the geomembrane land in a landfill and the because of the provision of this GCL, there could be a self-repair mechanism. Because, for example, when there is a some damaged to a geomembrane. The fluid starts flowing and once the fluid starts flowing it comes in contact with the dry bentonite powder, that is placed in a geosynthetic clay liner, that is the GCL. And you know that once the bentonite clay comes in contact with water it expands once it swells, it can close the opening, because of this expansion and that, we call as a the self-repair mechanism and it can close the gaps, that are cause, because of the damage in the geomembrane.

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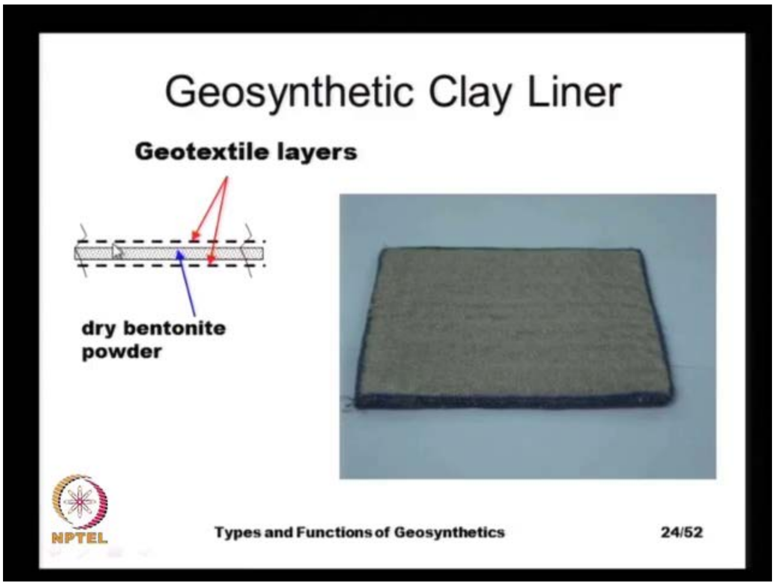

And Schematically G C L is something like this, we have a core of dry bentonite powder that is sandwiched between 2 thick geotextile layers. And the right hand side, we see a product of the G C L is actually, it is the same thing shown on the left hand side, we have a thick geotextile layer and the inside, we have the bentonite powder.

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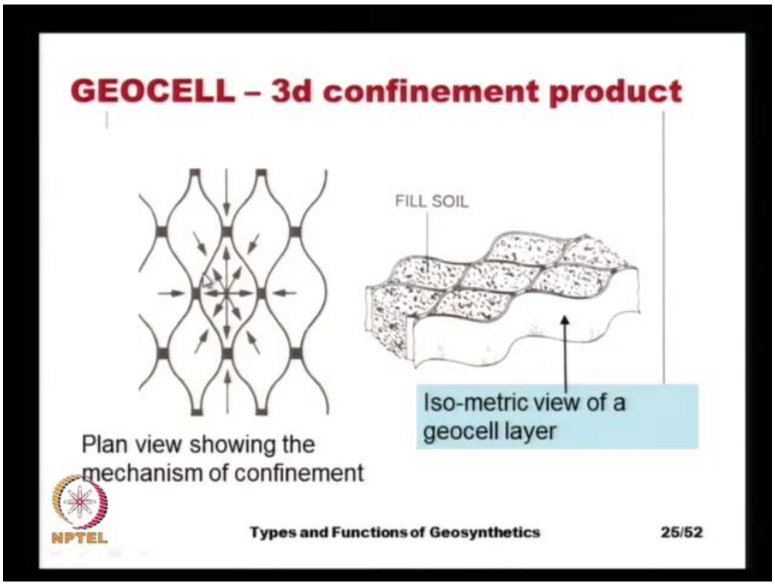

The geocell is different from all the other products that, we have seen, they are all planar products, that is they can provide reinforcement action or they can act as a separator or they can act as a filter whereas, a geocell, it has 3 dimensional effect on the soil. It can provide some confinement, because it has number of openings is actually, this geocell, it is more of a honeycomb structure where in, we take thin sheets of a plastic products, similar to a geomembrane and the weld it at several places at along the length like this. These plastic sheets, they are ultrasonically, welded and then the entire thing comes in a collapsed form in small rolls and once they taken to the site. They can be expanded and once you expand them, these pockets form and these pockets can be filled with soil to construct road base or several other things.

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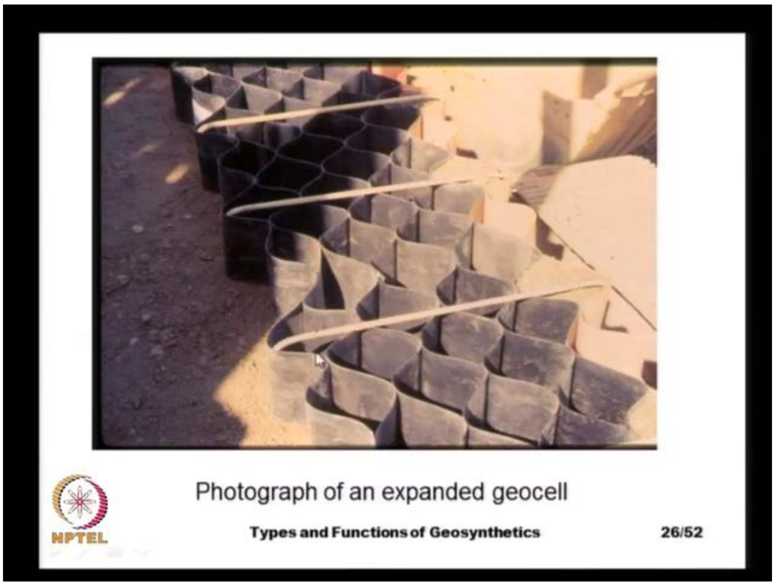

The expanded geocell is a something like this when the geocells first came into the market. This the geocells are made of plane plastic sheets like very similar to your geomembrane without any openings or without any rough surface. And now the more recent geocells, they are made with a either corrugated surface.

So, that they have a very good interaction with the in filled soil or with some openings. So, that the geocell layer can also act as a drainage layer, because this once this the geocell is made of a plastic sheet without any openings, it cannot allow the water to flow, the water can only go down and below that, below the geocell, we should have some geotextile or something, that can act as a drainage layer.

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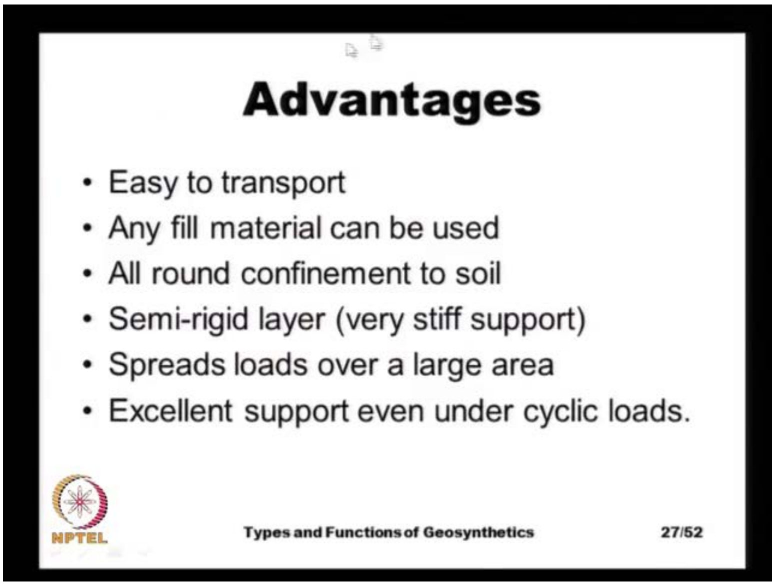

And some of the advantages that, we have with the geocells, these are easy to transport, because they come in a collapsed form. And then they occupy much volume and once these geocells are taken to the site and expanded, we can cover very large area, sometimes even has wide as about 4 meters wide and 10 meters long. In once it is collapse form may not occupy much space, it might be as compact as just a laptop bag. And we can use any fill material in these geocells and because of the all round confinement, that is given to the soil, it forms a semi-rigid layer providing a very stiff support to the loads, that we apply.

And because of the semi-rigid nature of the layer, it can spread the load over a very wide area, thus reducing the pressures that are transmitted into the subgrade and because of that, we have very good load dispersion and reduced settlements and reduced bearing capacity failures in the foundation soil. And this geocell layer, it can also provide excellent support even under cyclic loading, for example, under railway tracks or under high speed highways and so on.

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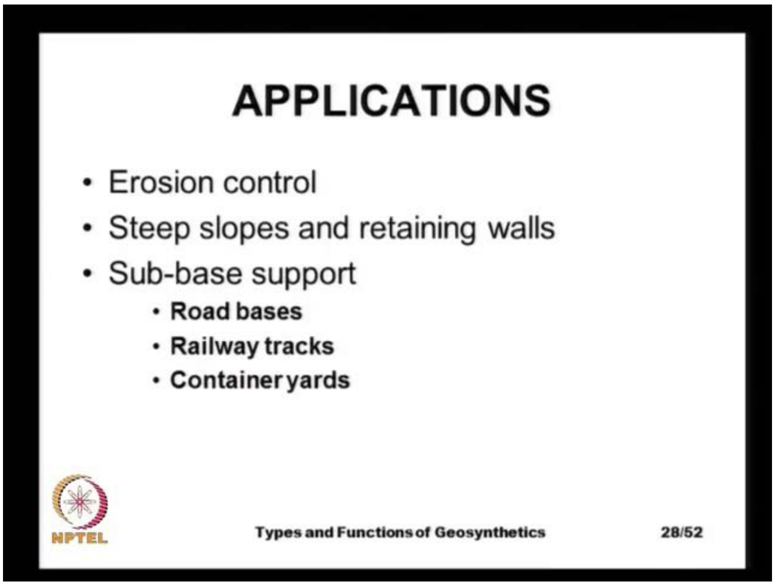

And some of the typical applications the apart from the load carrying functions, it can also be used as a erosion control product or for construction of steep slopes and retaining walls. And as a sub-base support it is an very excellent product, it can be used in road bases or it can be used in the railway tracks or it can be used for construction of the container yards and so on.

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And here we see the use of a geocell for construction of a unpaved road in a dairy factory and the ground is prepared on this left hand side preparation of the ground by leveling it and we can now lay this the geocell and then whenever there is a continuation of the geocell, we staple them. So, that they are joined together and here the geocells are filled with aggregates and then once it is filled with aggregate, we can do the compaction using our rollers. And then the entire surface, it can be just simply left as it is without any treatment, because of the surface, because of the confinement that is given by the geocell.

The soil is preserved and the and that road surface can have very good integrity and the main advantage with the geocells is that at a very low confining pressure, it provides excellent support excellent lateral support and because of that the soil behaves like a very stiff material. We know that when there is a good confinement the soil can be very, very strong and that is exactly what a geocell does.

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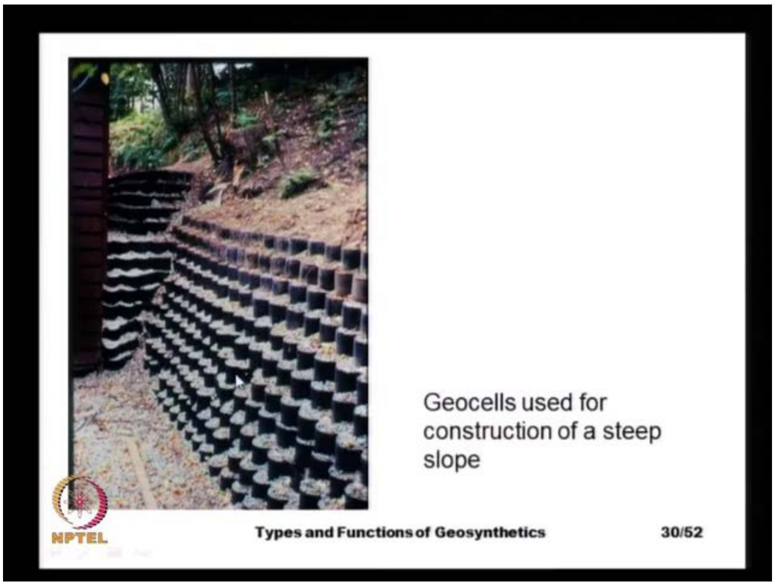

And here we see the application of a geocell for construction of a steep slope or for stabilizing the steep slope.

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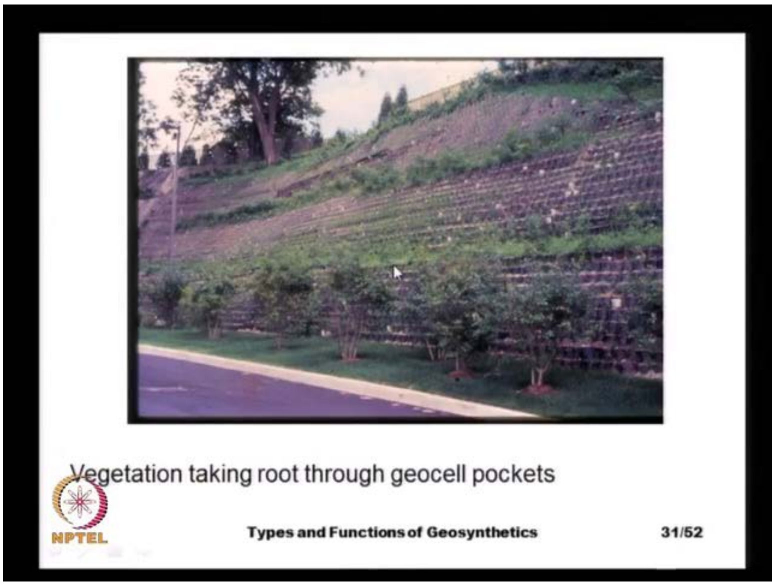

And here, we see the construction of a very steep slope using geocells and the and because of the open geocell pockets, we can promote the vegetation through this open pockets. And once these the vegetation takes root the entire thing could be a green color surface and we will not even see the that the geocells are applied for construction of the slope.

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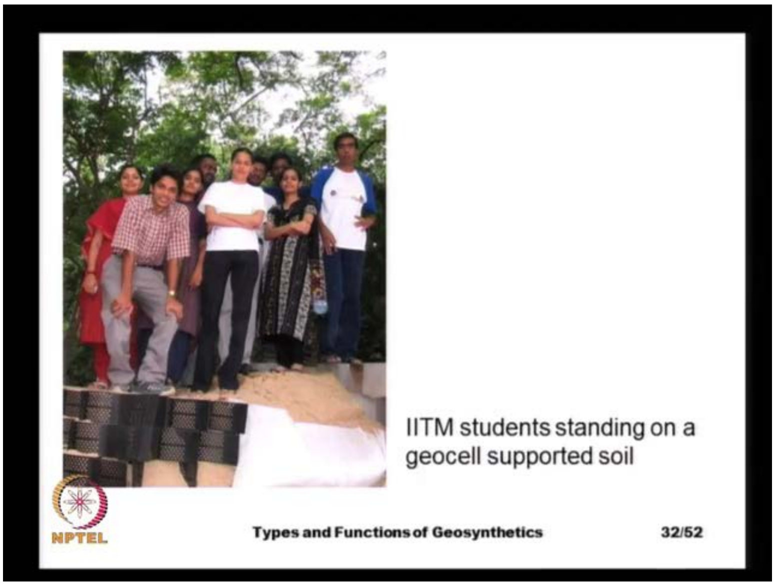

And here, you see some of the students at I I T madras standing on a geocell supported soil, which is about 1 and half meters tall. And here, you notice that these geocells are made of made with open structure the with number of openings in the geocell, that is to promote a good interaction between the soil inside the inside different pockets.

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And here, we see the application of a geocell, for a treatment of container yard, these container yards typically, they have very heavy loads, because of the movement of the of this the container vehicles and these are usually constructed on soft marine clays near the shore and. So, the problems are compounded, we have very heavy loads, but at the same time, we have very soft support, very soft subgrade soil and the result is like this.

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In fact, this particular container yard in Chennai was built on reclaimed land and the thickness of the soil, that is placed is about 1 and half 2 meters very very thick soil layer was placed and then that was stabilized by good compaction. And then on top of that there was about 500 millimeters thick pavement layer in the form of boulders then aggregates and then sand cement mix and so on.

In spite of that the deformations that are taking place in the soft clay, they get reflected back and we have a typical mud wave formation and once this mud waves form or they get reflected back at the surface, there is a problem. Because, all these container vehicles they are very heavy and is also dangerous for them to move on a on a highly regular surface, because there is a danger for these container to swing at a very fast rate. And so these container yards, they should be as smooth as possible and as flat as possible and this particular container yard was repaired by placing a layer of a geocell at the top.

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And here, we see the construction process, first we layer of geotextile, that can act as a separator.

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And then later it was the geocell was placed and it is filled with aggregate.

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And this constructed surface is actually, it is absolutely flat and these the photographs taken 3 years after the geocell treatment of the same area where, we have seen these mud waves, that were formed. And is actually, the entire yard is flat and the that allows the free movement of the of these container vehicles and another problem with the uneven ground is if these containers, they are stacked on uneven ground, they tend to get damaged by because of the bending action. And so we need flat support, so that these containers also, they do not get damaged.

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And here we see some close-ups of these this container yard, this was treated with geocell, except for some damage in the form of chipped paver blocks, there is no other damage and this entire thing was it has become. So, successful that, similar designs are employed in many other container yards, using the geocells for reconstruction of these of this container yards.

So, basically in spite of constructing this container yard, in an extremely soft soil is able to provide a good surface, because the entire geocell layer, it was it acted as a single layer and also as a semi rigid layer. And because of that the surface was very good and in fact, in some neighboring area, they had done with 150 millimeters thick concrete layer reinforced concrete layer.

But, unfortunately the reinforced concrete did not last for more than 2 years, it started cracking and then because of the marine environment the steel started corroding and the entire area could not be used, because of the corrosion of the steel. And because of excessive cracking of the reinforced concrete whereas, this the geocell being a polymeric product, it was highly stable and it was able to hold the soil together.

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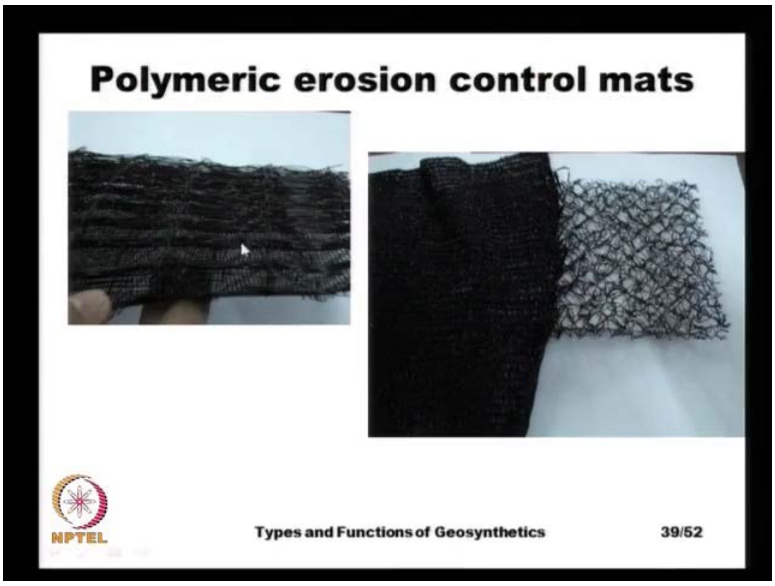

A some of the erosion control products are shown here is actually these are the trimped mesh the to once it is spread on the ground, it slows down the flow of water. And it prevents the erosion of soil, because it once it confines to the soil some extent, then it slows down the speed of the rain water on a slope. And once the rain water at the surface runoff is slowed down, it is erosion potential is reduced and then the soil is more stable.

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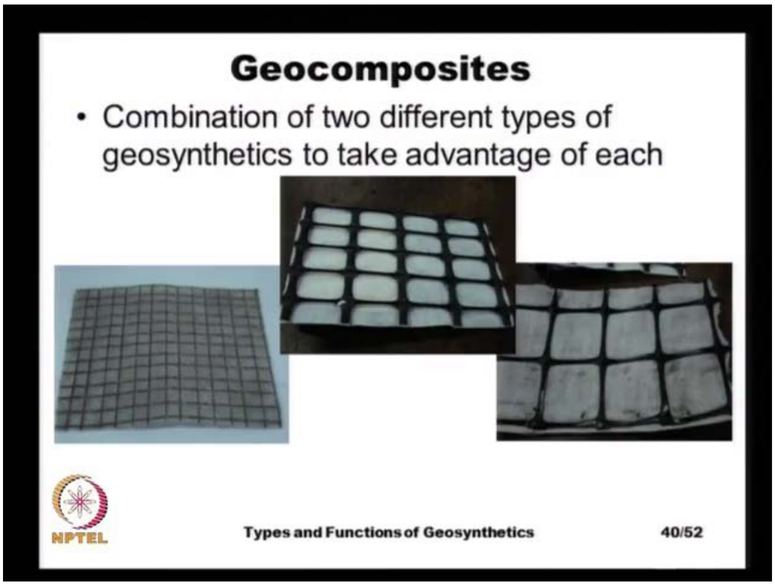

And another type of geosynthetics, they are geocomposites, we have several varieties of geocomposites. In fact, the prefabricated vertical grain is an example of a geocomposite wherein, we use a geotextile as an outer filter and inner core could be a geonet or a some other form of a corrugated the plastic sheet. So, that is one example of a geoccomposite and other examples are shown here, these are combinations of a geotextile and a geogrid they take advantage of the specific product properties of both the materials that are they like.

Geotextile it has excellent separation properties and also excellent filter properties whereas, the geogrid can have a excellent strength and stiffness. So, if you combine both of them they provide the reinforcement action they can provide drainage action, they can provide filter action. And here on the left hand side, we see another product, that is a combination of a geotextile and geogrid or and these are all in fact, this product it produces a very high force of the order of 200 kilo newton per meter at a very low strain of less than 4 percent. So, that is how strong the geosynthetics can be depending on the manufacturing process and depending on the materials that, we use they can be made to provide multiple functions.

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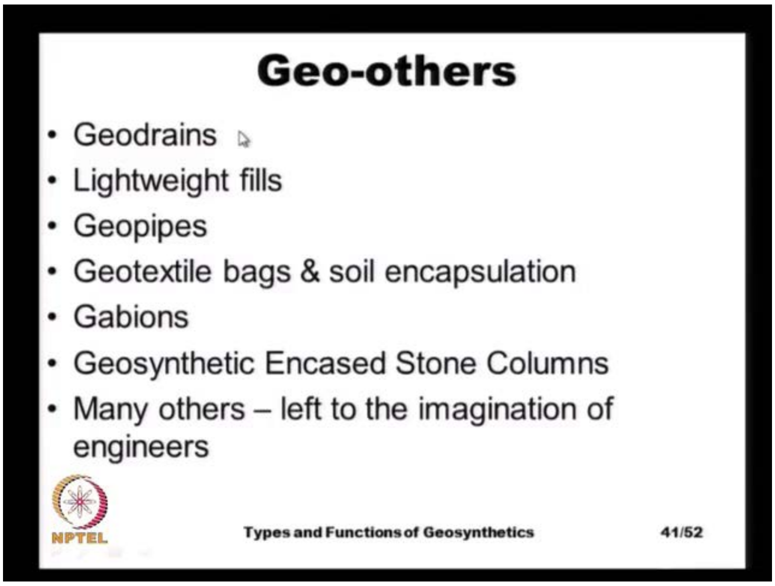

And there are several other geocomposites or water known as geo others, geodrains geodrain is nothing but a plastic pipe with perforations, once they are buried in the soil they can act as drains. Because, through the through this perforations in the pipe the rain water or the water in the soil can be collected and then it can be, it can flow through the pipe. And gets collected in a in some place and it can either pumped out or if you have any source of water, we can just lead all this rain water into some place.

And we have number of varieties of light weight fills, especially the lightweight fills made of polystyrene expanded polystyrene and so on. And we have geopipes, which is which are very similar to geodrains and then we have geotextile bags, one application that have already shown earlier for the construction of coastal erosion protection structures. And these geobags, they can be used as soil encapsulation, especially say if you are constructing in a very soft soil, we can use very large geobags.

And put in aggregate or soil and encapsulate the soil and the entire thing can act as a rigid mat and the gabions, they are once again, they can be categorized as geo others and these gabions, they can be either made of steel wire meshes or they can be made of rope nets and so on. And geosynthetic encased stone columns, these are of most recent origin and they are used for forming stiff columns in soft clays. And of course, there are so many other possibilities, these are left to the imagination of engineers. And every few months or few years, we see a new application of geosynthetics in a very innovative manner for construction in difficult soil conditions.

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Is actually, these are some examples of the of the geoboards or drainage boards, that are used behind retaining walls is actually here, we have a geotextile either a woven or nonwoven geotextile. And then we have a punched plastic sheet more like cotton that can act as a drainage layer and if this is fixed behind retaining wall, it can act as an excellent drain along the length of the along the height of the retaining wall. And in place of in place of a drainage layer, that is made by using aggregate very good quality aggregate, we can just simply stick one of these drainage boards behind a retaining wall to act as a drain.

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And we have number of light weight fills and these light weight fills, if they are made of small beads of polystyrene, they can also be made to act as good drainage medium and here, we see an example of a lightweight fill made by polystyrene beads. And the typical unit weight of these light weight materials is of order of the 0.3 to 0.4 kilo newtons per cubic meter comparatively, the weight of a soil typical soil could be anywhere from 18 to 20 kilo newtons per cubic meter.

And even the weight of fly ash could be of the order of 8 to 9 kilo newtons per cubic meter. So, you just imagine using these light weight fills as land fill material or for construction of road bases and so on. Absolutely, they will not result in any settlements and these lightweight fills could be made of stiff styrofoam or styrofoam or polystyrene blocks, for construction of road bases and so on or for embankments and so on.

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And here as we see the example of gabions and these gabions are nothing but baskets made of either steel wires, steel wire meshes or rope net meshes. And here in this particular case, we have rope net meshes and these gabions, they are packed with stones or they are filled with geotextile bags, filled with sand to act as to sea walls or as groin structures or to prevent to act as break waters and so on. And here, we see an example of a sea wall that was built using rope net gabions filled with stones.

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And here, we see an example of the gabion structures for breaking in the sea waves and the is actually, this instead of filling this gabions with stones, we feel them this was path of some research were going on at I I T madras. Here, we have these geobags, that are filled with bead sand that was readily available at the place where, we need to protect the beads and these are these bags are filled inside, these rope net gabions. And then we close them and we tie up several of these rope net gabions together and the weight of each of these sand bags is hardly about 20 k g's.

So, can be easily handles by people and they once, they have brought and assembled in a geobag, each one cubic meter of rope net gabion can accommodate about 50 k g's of these geobags. That means that, the weight of each of these rope net gabion could be as high as 1000 k g's or 1 ton and once all these similar bags, they are tied up together their combined mass could be very, very large. And they can be easily used for coastal protection works and here, we see the small break water, which is able to withstand about 1 and half meters wave that is shown here.

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And there are other products, that have made of used rubber tires and other industrial waste products, which are all cut to pieces and bounded together. So, that we provide some thick mass, some thick medium, that is highly porous and slightly compressible. So, that it can act as a cushion and also it acts, it can act as a drainage medium and behind retaining walls, if these are applied, they can be made to act as a as drainage medium or they can also be employed to reduce lateral earth pressures in the soil by promoting some yielding in the soil like. We know that when the soil expands laterally, the lateral earth pressures reduced and that concept is called as a controlled yielding and we will see the concept of controlled yielding and how these geosynthetics can be employed in some other lectures later on.

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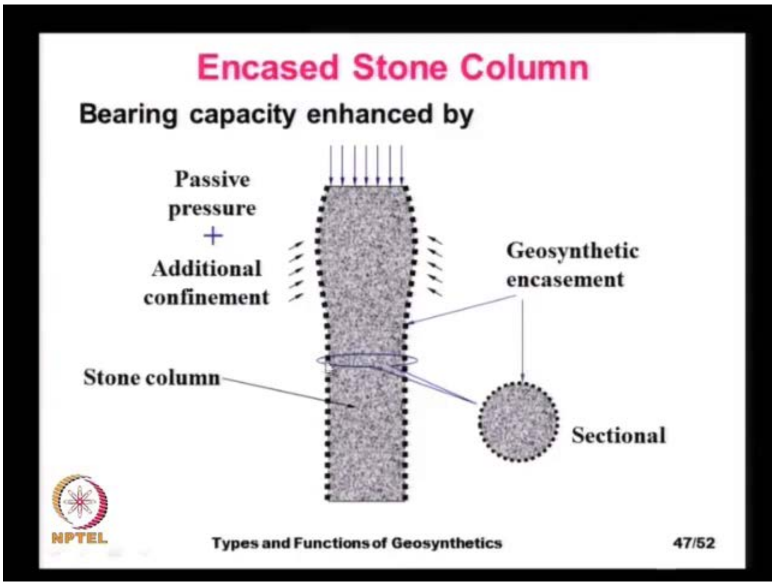

And one recent application of geosynthetics is in the form of encased stone columns. The stone columns are traditionally employed by geotechnical engineers for supporting of flexible structures like oil storage tanks or road way embankments and so on. And these stone columns, if they are constructed in a extremely soft clays, the main problem is it is difficult to form the stone column.

And there is not sufficient confinement given by surrounding the soft clay, because of that, these columns may not develop adequate strength to support the applied load and in most of these cases, the stone columns, they also act as excellent drainage mediums. But, then when there is extremely soft clay all around the stone column, the soft clay can contaminate the stone column and the stone column aggregate.

And in the process, it can clog all the openings in the stone column and once these aggregate materials, which are very good shear strength on by their own, but once they are contaminated, they will have very highly lubricate surfaces resulting in loss of shear strength of these aggregate, and once these problems can be easily overcome by encasing the stone column by a geosynthetic, in the form of a geotextile or a geocomposite and so on.

And the advantages that, we gain is we provide some additional confinement to the stone column and we prevent the contamination of the stone column material by the surrounding clays and its more easy to form the stone column. Because, many times, it is very difficult to the form the stone column in an extremely soft clay having a undrained cohesive strength less than about 10 k p a. That could typically, happen in marine clays and so on, in all such cases, we can easily construct the stone column by encasing them inside a geotextile tube.

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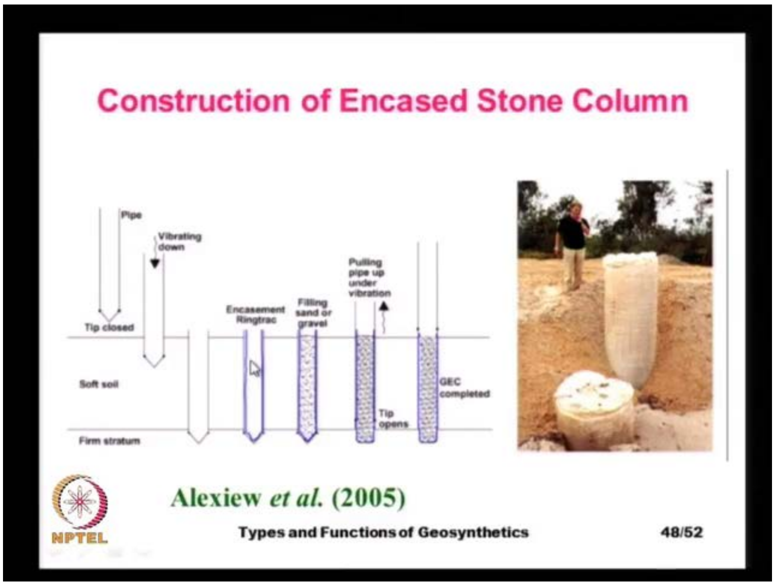

And here, we see an example of a geotextile column, geotextile reinforced sand column and the left hand side, we see how it is formed, we drive an open tube a pipe into the soil either by means of vibration or by water jet. Once this open tube is lowered to the desired depth, we lower tube of a geotextile and then we can fill it with sorry, then we can fill it with soil either sand or course material like gravel or aggregate. And then we can compact it by means of vibration when this tube is taken out, it can be vibrated to compact the soil and once the tube is taken out.

We have this geosynthetic encased column, either stone column or a sand column and these are used for constructing in extremely soft clays, for example, the airbus 8 3 8 factory germany was supported on this stone columns formed in this process, in this using this technique.

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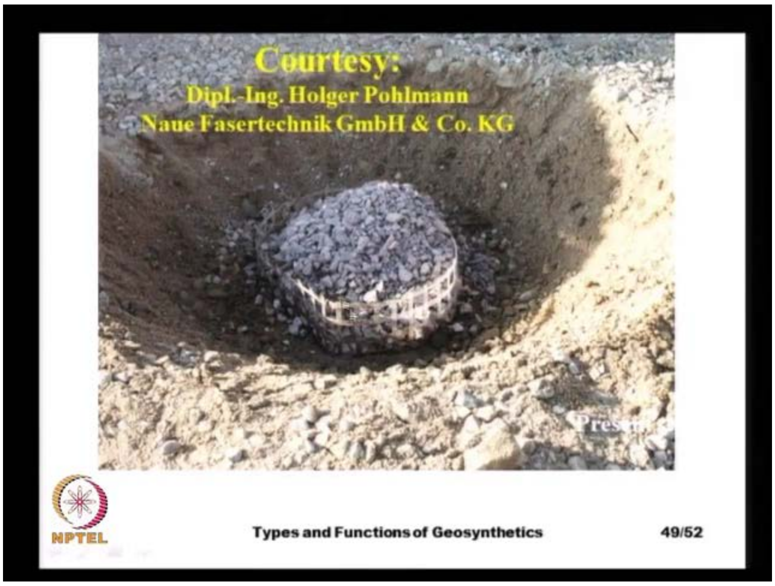

And here, we see an encased stone column using a geogrid is actually when geogrids can be used, because they have very high tensile strength and they can provide very good confinement and in areas where, we do not anticipate any contamination of the stone column material by the soft clays, we can use a geogrid.

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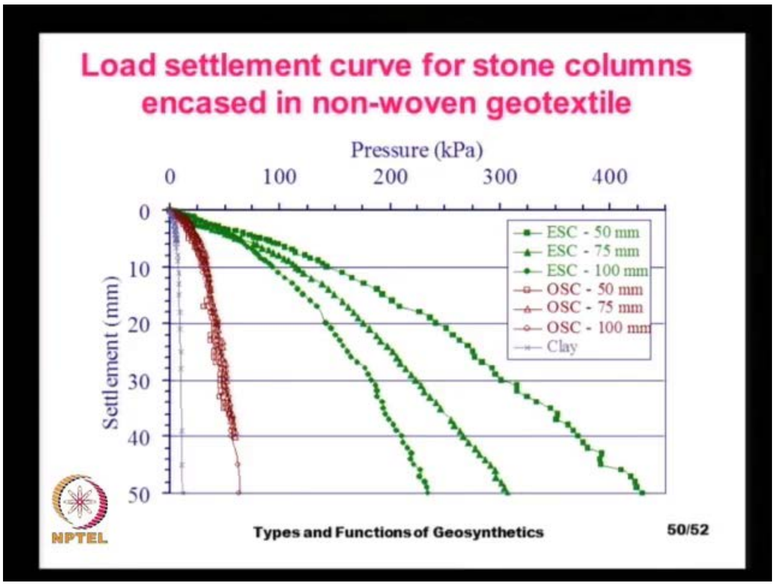

And here we see some test data from laboratory tests on encased stone columns, the pressures settlement data of the soft clay is like this.

The strength of the soft clay is of the order of about 3 to 5 k P a kilo Pascals, because this was this soil was prepared at a consistency very close to liquid limit. So, that there is a uniform constancy of the soft clay and when the stone columns were constructed, this is how the pressure settlement behavior is the soft clay it failed at very low pressure of the order of 10 to 15 kilo Pascals. And by inserting stone column O S C stands for ordinary stone column a 50 75 or 100 m m, the pressure capacity has increased to nearly 50 k P a and all these stone columns, they had similar pressure settlement data.

And when this the same stone columns were encased in a geotextile column, this is how they perform the 50 m m column. They had very high strength and the pressure as much as far 400 k P a could be applied, see the pressure on reinforced stone column was hardly 50 kilo Pascals and when the stone column was built using aggregate, the pressure could be increased about 50 k P a.

And when the stone column is encased in a geotextile in and fact this nonwoven geotextile, it has very low strength of the about 20 or 25 kilo newtons per meter, the compressive pressure of nearly 400 k P a could be applied. And more importantly, if you look at the slope of this graph, the slope represents the stiffness or the ability of the ground to support the loads without undergoing the settlements.

So, for example, even at a pressure of 100 k P a, the settlement of the stone column treated ground is hardly about 5 to 8 millimeters whereas, at a pressures of we could not even apply a pressure of 100 k P a on ordinary stone column. So, that is the advantage that, we gain with these stone columns and here interestingly as the stone column diameter increases like for example, this is the response of 50 sorry, the 50 m m diameter stone column and this is the response of 75 m m diameter stone column, this is the other one is for 100 millimeters. This is actually as the diameter of the stone column increases, the influence of the geotextile reduces the geosynthetic reduces, because as the diameter is increasing, the hoop strains or the hoop tensile forces, that are developed reduce.

And because of the reduction in the hoop tensile force the confinement the additional confinement, that is given by the geosynthetic reduces and consequently as the diameter is increased, we need to use a stiffer confinement material and in this particular case all the 3 diameters of the stone columns. They had the same geosynthetic material that, produces the same hoop tensile forces at a given strain and because of that we see the reduction in the stiffness and the pressure capacity as the diameter increases.

And is actually, in this particular case, I have not shown the data, but in some other lecture, I will show you the data from test perform and different diameter of the stone columns and with different stiffness of these geosynthetics. We see that, we can increase the pressure to very large values and imagine using this type of stone columns in extremely soft clays.

We can practically eliminate the settlements. In fact, the normal stone columns, they can reduce the settlements by about 40 to 50 percent. So, if in untreated ground undergoes settlement of let us say some 3 to 400 millimeters, even by providing the stone columns at very close spacing as much as 2 times the at a spacing of about let us say 1 and half to 2 times the diameter. The settlements reduce to only about may be 2 to 300 millimeters, but then of you use these encased stone columns, because they act almost like rigid piles.

The settlements are practical in negligible and because of the increased stiffness and increased strength, we can increase the spacing of these stone columns and that is the main advantage that, we gain by using encased stone columns. And the most recent technique is the encased stone columns, that are becoming very popular not only in India even in other countries.

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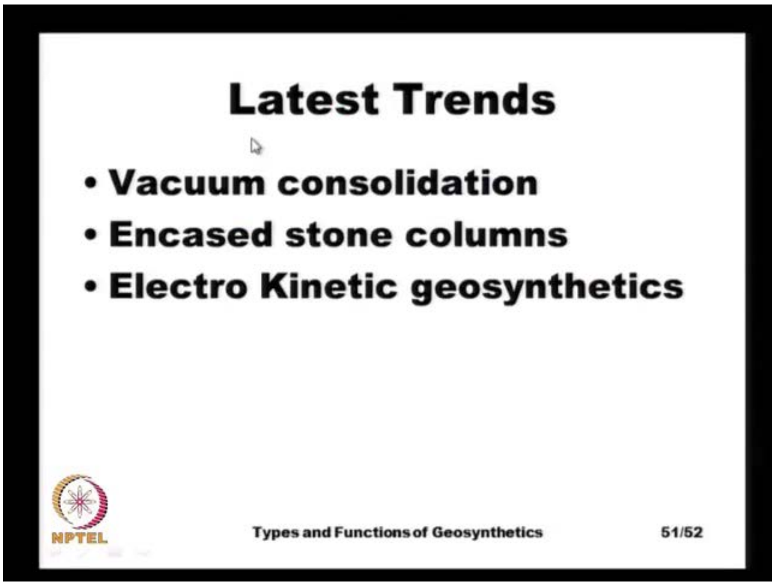

So, some of the latest trends that, we have in the geosynthetics, they are the applications of the geosynthetics for vacuum consolidation of soft clays and then of course, encased stone columns and the electro kinetic geosynthetics in here, we employ some copper wires along with a geotextiles or geogrids. So, that we can change the fundamental properties of the soft clays by polarizing the soil, because these techniques, we will see in some future lectures.

Thank you very much.