Geosynthetics and Reinforced Soil Structures

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Lecture - 34
Filtration of Soils Using Geosynthetics

Very good morning to you all, in today's lecture let us look at how to use geosynthetics for filtration applications.

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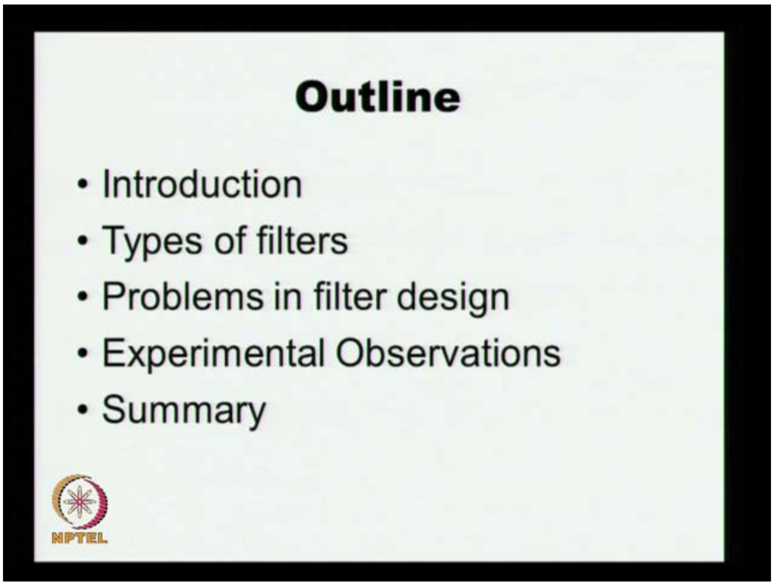

A brief outline of today's lecture is, will have a short introduction and then let us look at the different types of filters, and then what are the issues that we need to consider in the in the filter design. Some experimental observations and then a summary of this today's lecture.

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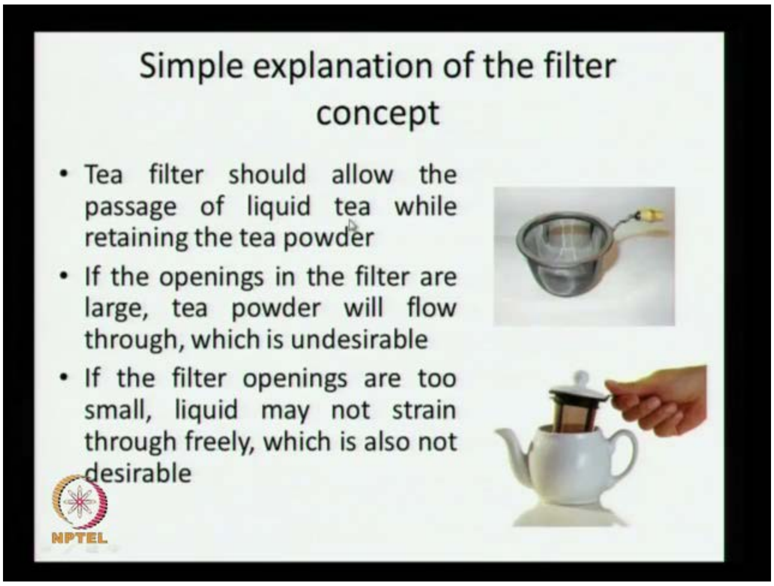

Well, to explain it in a very simple manner, the filter is that, that we use in a soil applications is very similar to the tea filter that we see on everyday usage. See, if this tea filter allows the tea powder to come through will you like it, obviously not. So, the tea filter should only allow the tea water to come through and retain all the tea powder on the filter, so for that to happen the openings in the tea filter should be small enough. So, that only the water comes through and then the tea powder gets retained on the on the filter.

But, then if the filter openings are very, very small. What happens? See, the tea may not strain properly or it might take too long and we will have to wait for instead of 5 minutes, we may have to wait for 10 hours and that also is not desired. So, the openings in the tea filter should be so optimal that it allows the tea to strain freely, at the same time does not allow the tea powder to come through.

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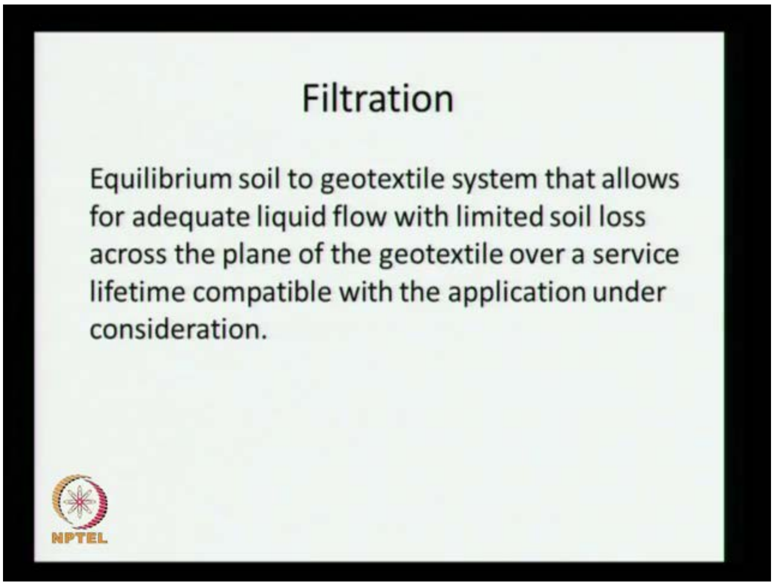

And the same concept we can also apply in our geotechnical applications and we come across the requirement of filters. In several situations, wherever we have a lightly piping problem, we want only the water to come out and the soil particles to be retained in the sub grade. So, the filtration to define it in a very simple manner, see it is an equilibrium soil, soil to geotextile systems that allows for adequate liquid flow, with limited soil loss across the plane of geotextile. Over the service lifetime, compatible with the application under consideration see it is actually, it is a system. It is not just simply the soil or not it is simply the geotextile because once you place a filter fabric and during the course of water flow we form. What is known as a filter cake and together with the filter cake, and the flowing water the whole thing should be a under stable equilibrium that only fresh water comes out, without bringing along with the any soil particles.

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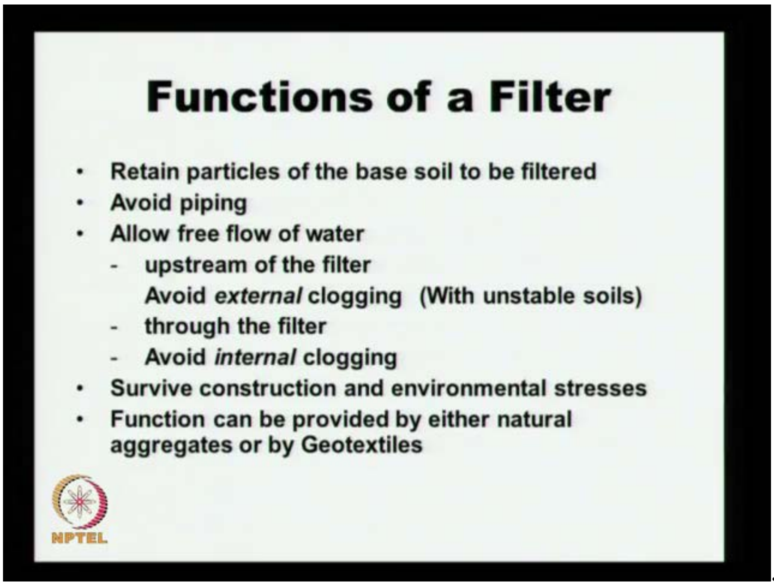

Well, let us look at the different functions of a filter. Obviously, the first requirement is, it should retain the particles of the base soil to be filtered and that means that it should be able to avoid piping. As we know, it is the loss of fine soil particles from the sub grade l because of the gradient of flow and while avoiding the piping the filter should allow for the free flow of water upstream of the filter and avoid external clogging. That is, see when you have some type of unstable soils that are highly upgraded and there could be some internal movements of the particles within the soil medium may not be through this the filter.

But, within the soil medium also the small soil particles might come and occupy the voids in between the bigger particles as impairing the flow of water, and that also should be avoided. It should allow the water, free of flow of water through the filter and also it should avoid any internal clogging, internal clogging is sometimes the fine. So, fine soil particles will come and fill up the voids within the filter and unless the water is continuously flowing, these fine soil particles might remain within the filter.

The long run it could cause clogging and the filter whatever we are providing it should be able to survive the construction and other environmental stresses. The filter could be made of either natural aggregates or by a geotextile natural aggregate is that is traditional way of constructing the filters. We provide layers of soil aggregate consistent with the properties of the soil or in other, in the more recent cases we just simply provide a geotextile in place of the natural aggregates.

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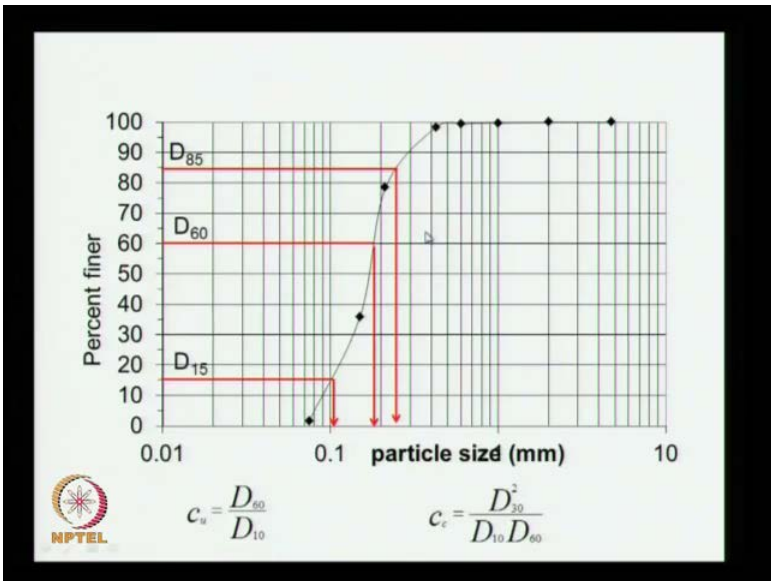

Well, for the purpose of design of filter, we should properly analyze the grain size distribution of the base soil and the grain size distribution typical one may look something like this. On the x axis, we have the particle size and then on the y axis, we have the percent finer. So, for example, here the x axis given in terms of log scale, so it is actually this is 0.1, 0.2, 0.3, sorry 0.1, 1 2 3 4 and so on. So, at a particle size of 0.1, 0.2, 0.3 4 5 0.6 that is 600 micron, 100 percent of the particles flowing through and we call the 100 percent finers is 600 microns and similarly, we have other particle sizes D 85, D 60, D 15, D 10, D 30 and so on.

How we get the particle sizes, we draw a horizontal line at the desired person finer and then see where is this horizontal line intersects, this grain size distribution curve and draw a vertical line and then get the particle size on the in the x axis. For example, D 85 is approximately 0.25 or something, whereas D 15, it is nearly 0.1. Based on the different particle sizes, that we get from the grain size distribution analysis, Cu is D 60 by D 10. The Cu is the coefficient of uniformity and the Cc is D 30 square by D 10 times D 60 and sometimes we may draw a linear line instead of a curve. We can get D covalent D 60 and D 10, corresponding to that linear line and we call it as a linear Cu.

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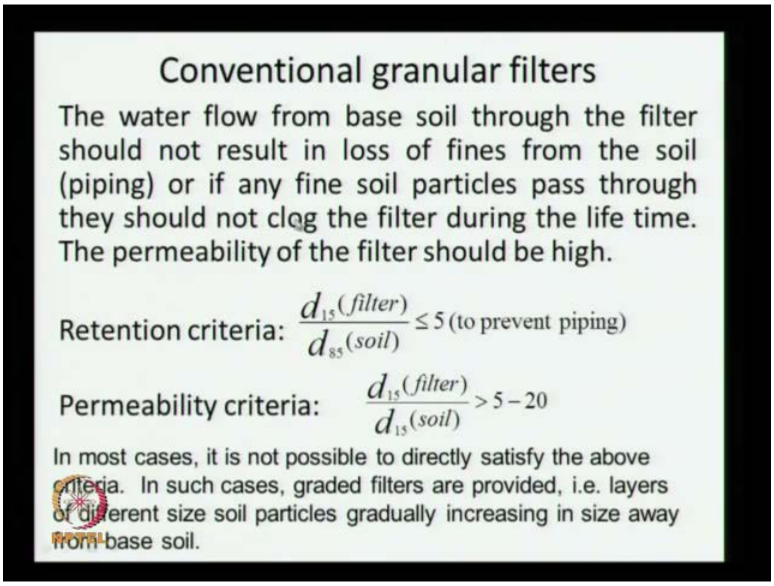

Briefly, let us look at the design of the conversional filters, these were originally given by Terzaghi and modified later by several other geotechnical engineers. The water flows from the base soil through the filter should not result in loss of fines from the soil or in other words, piping should not happen. If any fine soil particles pass through, they should not clog filter during the service life, during the lifetime of the filter. The permeability of the filter should be high enough that the water flow is freely happening and the retention criteria is D15 of the filter divided by D85 of the soil.

That is, D15 diameter allowing for 15 percent fines passed though divided by D85 that is, 85 percent of the soil particles pass should be less than or equal to 5. This is required to prevent piping and the permeability criteria is D 15 of the filter divided by D 15 of the soil should be about 5 to 20. In the range of 5 to 20, that means that the filter particles should be much coarser than the base soil particles so that the water can flow freely.

In most cases, it is not possible to directly satisfy the above criteria because it is very easy to design. But, then the practical implementation depends on the availability of the nearby quarry from where we can get the desired aggregates. If we are not able to get the desired aggregates, what we do is we go in for a graded filter. That is, we provide different layers of uniformly graded soil particles to gradually achieve our filter criteria, and that is called as a graded filter. Usually, in these graded filters the particle sizes goes on increasing as we go away from the base soil.

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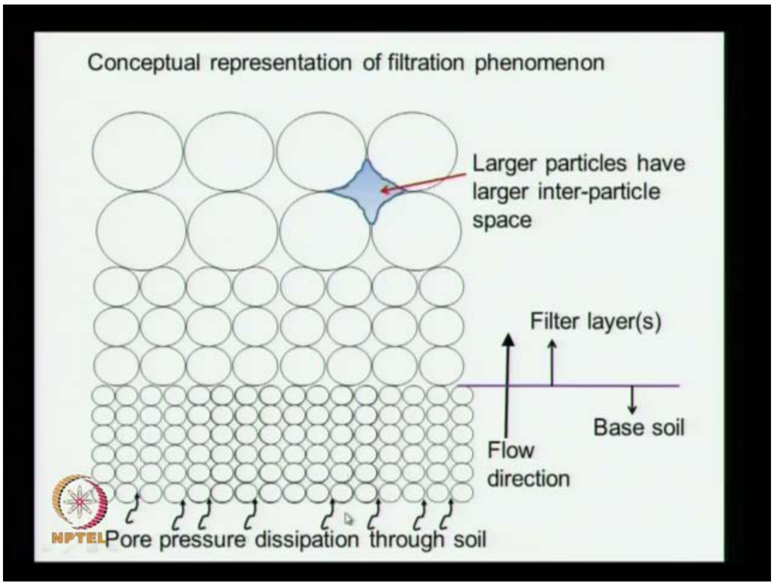

The typical illustration is given here, is actually I have considered a uniformly graded soil and then they are so nicely arranged with the maximum wide ratio, that is one particle sitting directly on top of the other particle. Let us say that, this is our base soil and then we want to construct a filter and then what we notice is the opening size between the particles is related to the to the particle size.

Say for example with these larger particles, this is the opening that we have and when we have a very small particle, this is the small opening that we have. These small particles, they should not come and sit inside one of the openings to clog the filter and let us say that we have full saturation because of rainfall or something. Whenever there is a traffic flow at the water inside or within the base soil, we will get pressurized and it would like to come out.

A pore pressure goes on dissipating through the base soil filter and in the process, it should not deposit any of these fine soil particles in these wides and that we call as the free flow of water. At the same time, none of these fine soil particles should be lost into the atmosphere that we call as piping, and the filter that we provide, it should be able to allow for the free flow of the water and also retain the fine soil particles within the sub grade soil.

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See here, I will show you one small video and its very common practice in India to see number of part holes that happen on the roads immediately after the rains. Here, we see a pool of water on top of a pavement because of lack of drainage let us see what happens.

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Here, just notice this water bubble how it comes out. When I play this video and we have the traffic going all around and of captured the water bubbles that are coming out and that typical illustrates the effect of the moving traffic and the pore pressure generated. The pore pressure is getting dissipated by gushing out of the water and in the process of the water coming out, it might come out with fine soil particles. Now, just see this video, yeah see these bubbles are forming and they are coming out of this soil, so this is of the one phenomenon that leads to loss of fine soil particles and piping.

The conventional method to overcome that type of problem is to provide a nice filter, nicely designed filter either in one layer or in multiple layers. That is, the graded filters to avoid the piping problem and as the experience shows it is easy to design, but when it comes to construction it is not that simple because the it is not easy to satisfy all the relations. That is, D 15 of the filter divided by D 15 of the base soil, in certain range and say D 15 of the filter divided by D 85 of the soil in some other range and so on.

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To overcome them, we can use the geotextiles as the filters. As we have seen, these geotextiles they are manufactured products or fabrics with different opening sizes and we have number of these geotextile. So, we have the woven fabrics and nonwoven fabrics and some of them, you can see here and we have the thin fabrics and very thick fabrics and usually the thin fabrics, they are used as filters. Whereas, the thick fabrics they are used for drainage purposes and the thin fabrics, they could be either woven geotextiles or nonwoven geotextiles, and there is a certain criteria that these fabrics should not get damaged during the construction process.

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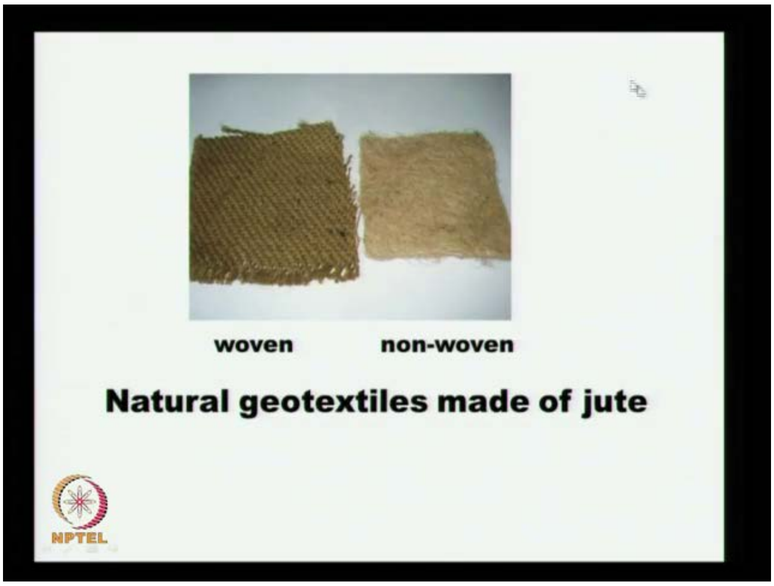

We also have number of natural products, the woven and non woven jute products and chord products and so on.

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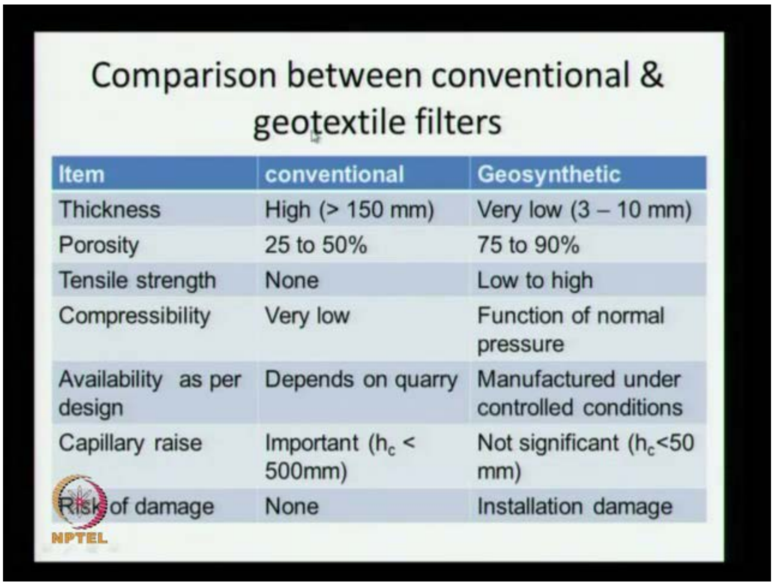
Comparison between conventional & geotextile filters

Item	conventional	Geosynthetic
Thickness	High (> 150 mm)	Very low (3 – 10 mm)
Porosity	25 to 50%	75 to 90%
Tensile strength	None	Low to high
Compressibility	Very low	Function of normal pressure
Availability as per design	Depends on quarry	Manufactured under controlled conditions
Capillary raise	Important (h_c < 500mm)	Not significant (h_c<50 mm)
Risk of damage	None	Installation damage

Well, let us see a brief comparison between conventional filter and then the geotextiles filters. The main difference comes out in the thickness, the thickness of the conventional filter is always more than 150 millimeter because it is not easy to just simply, provide one thin layer of filter. Assume that, it will function as a filter and also not be, not clog during the service life, whereas a geosynthetic liner is very thin about 3 to 10 millimeters.

The porosity of the soil filters is about 25 to 50 percent, whereas the porosity of the geosynthetics is very high, 75 to 90 percent and the tensile strength. There is no tensile strength in the natural or the aggregate filters, whereas the geosynthetics can be designed. They can have a low tensile strength or very high tensile strength depending on the requirement and the compressibility, the aggregate filters they do not undergo any compression. Whereas, the geosynthetics depending on their thickness and then depending on their nature of the fabric, whether it is woven or nonwoven, the compressibility is function of the normal pressure.

As we have seen earlier, the woven fabrics they do not undergo any compression because their initial thickness itself is very small. Whereas, the nonwoven fabrics, they can undergo large compressions and in the process of compression they also undergo the loss of permeability and the change in the pore size and so on. The availability as per the design, well the conventional aggregate filters depends on the quarry that we have, if we have a nice portable quarry nearby we can get the aggregate of the required sizes. If not, we may have to use a graded filters or going for some other alternatives, whereas the geosynthetic fabrics because these are manufactured under controlled conditions.

They can always be purchased readily off the shelf depending on our requirements the capillary raise is an important phenomenon especially in the cold countries because of the capillary phenomenon water table raises. In the case of aggregate filters or the graded filters is very important and the capillary raise could be very high. It should be designed so that the capillary raise is not higher than about half a meter. In the geosynthetics, it is not very significant because the layer of fabric that we provide is very thin of the order of 1 millimeter to 2 millimeters.

At the maximum and the capillary raise, maximum capillary raise that was observed is less than 50 millimeter and the risk of damage, there is no damage in the case of natural aggregate filters. Whereas, the geosynthetics filters, they undergo, they could undergo lot of damage depending on the type of fabric and depending on the construction procedures that we adopt.

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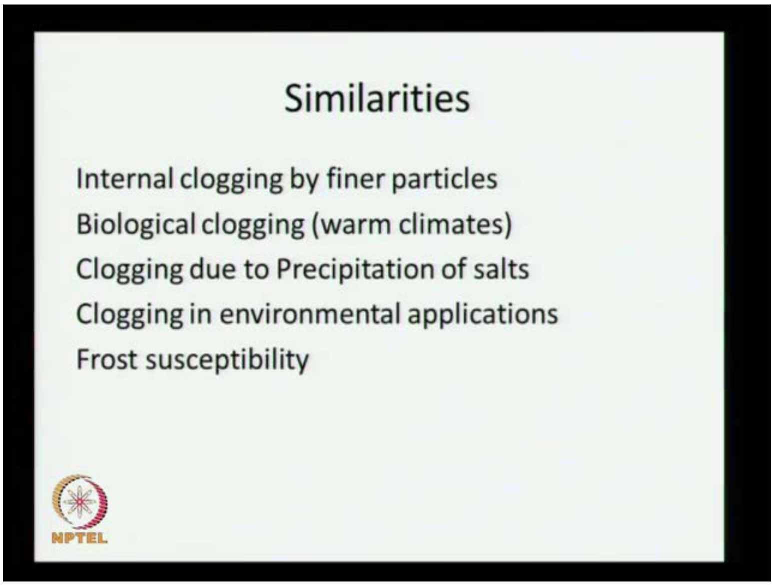

Both these filters, whether it is natural or artificial geotextile filters, both of them are susceptibility internal clogging by fine soil particles and there could be some biological clogging. Especially, in the case of warm climates because of the microbial activity, we could have some clogging and then the clogging due to the precipitation of salts. Especially, if the ground water is highly saline or it is laden with some iron or some other chemicals, the sulfates and the calcium, they could leave behind or the salts and that could clog the filter and then at the clogging in environmental applications.

Whenever we apply the filters, either natural aggregates or the geotextile filters in the land fields, we should be ready for the flow of lichet through the filter. Whenever there is a lichet, it carries along with a lot of suspended particles or some chemicals that could be left behind and that may be a potential cause for the clogging. Then the frost susceptibility is actually, the frost is something that is the frozen soil or the frozen water. The top soil or during the winter and both of them or susceptible to frost and when the frost happens, the filters cannot function because the flow of water is stopped.

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The one property of the geotextile that we require is the apparent opening size and as we have seen earlier, one method of a determining the apparent opening size is by the glass beats method. We just simply shake the glass beats of different sizes through the fabric and then depending on the weight or the mass of the glass beat that come through. We determine the apparent opening size and here we see this glass beats this is the filter fabric that is stretched in the sieve. Then we put it in the conventional sieve, and then shake it for 10 minutes and then after shaking it, we collect the glass beats and take their mass.

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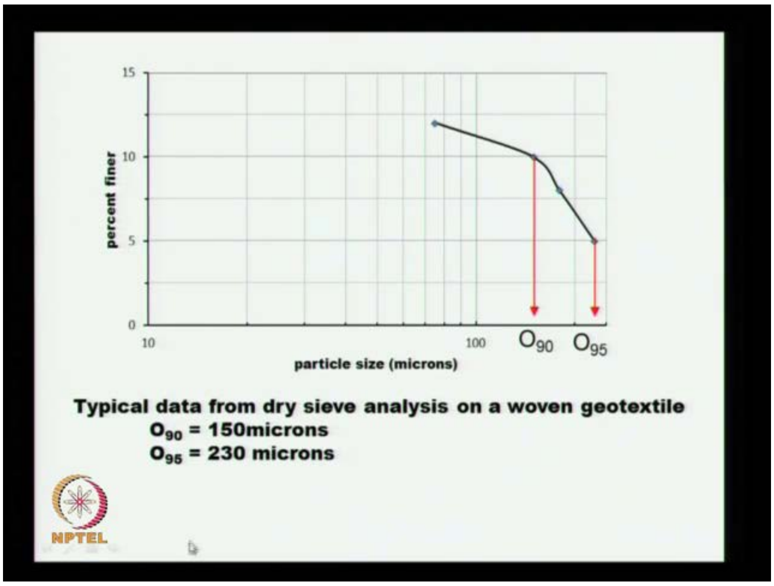

If you plot a graph between the particle size and the percent finer graph may look something like this, and O 90 size is corresponding to 10 percent finer size. Then on 95 is corresponding to 5 percent finer, that is less than 5 percent of the particles pass through and here the O95 is nearly 230 microns. Whereas, O90 is about 150 microns, and these opening sizes they are related into the particle sizes, the soil particle sizes for our design purposes.

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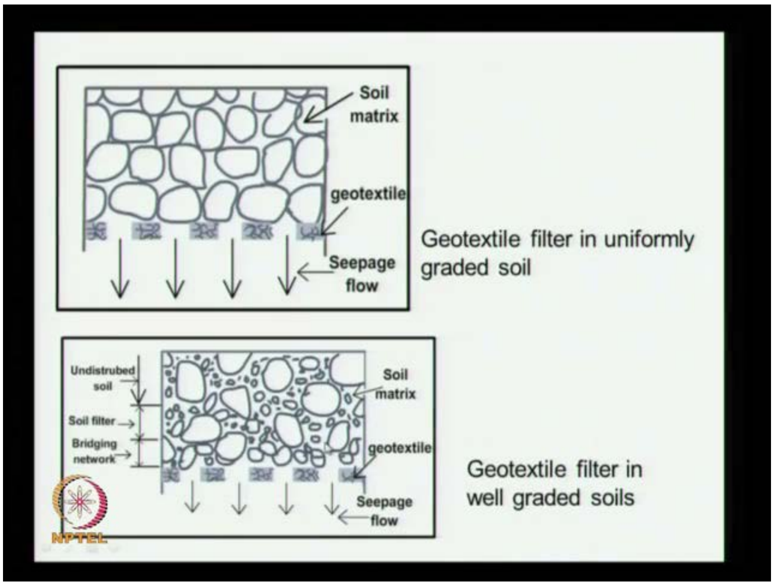

How does geotextile function when it is installed in the soil to act as a filter? This is how the geotextile may help in preventing the pipe in the uniformly graded soils. This is a schematic sketch, we may have some soil particles that are directly edged across the openings or in some cases if you have two small particles, they could bridge this opening by just simply in contact with each other like this. Based on these observations, numbers of empirical guidelines have been developed on what should be the opening size of the textile.

So, that the soil particles are retained while allowing the water to pass through and in one of the requirements the opening size is given as two times the average particle size. With the assumption that these particles, they will bridge over the openings after sometime and in the case of well graded soils, we have a nice filter cake forming at just above the geotextile. This is actually, this is the under step soil and the soil filter is under formation and a bridging network that is just as how the soil particles are bridging over the aperture. Similar thing would happen here, and usually it is noticed that we require some float takes place before the filter cake is formed.

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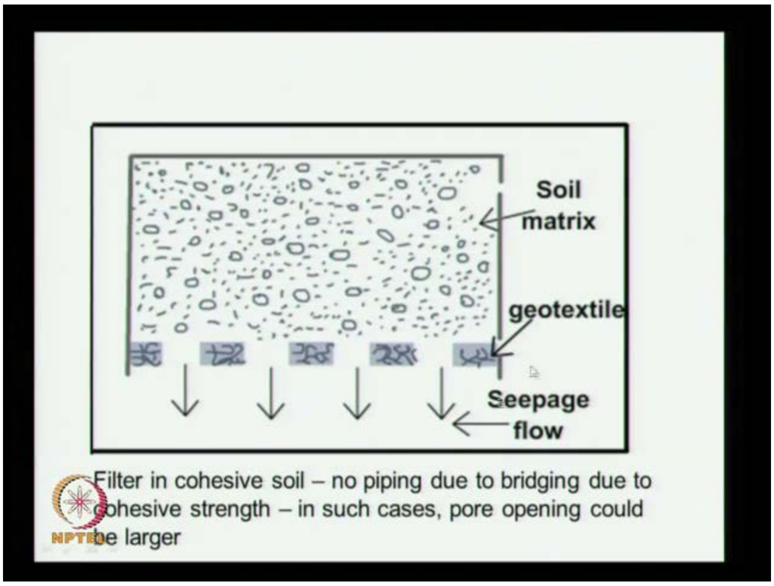

How the fabrics perform in the case of clay soils, is something like this the clay soils. As you know, they have very fine soil particles and whatever type of geotextile we provide the soil, the clay soil particles are so fine that they can just simply pass through. But, then during the experimental observations they have seen that the soil particles do not really come out, even when the opening size is very large. This happens because of the cohesive strength, because of the cohesive strength the openings in the geotextile or bridged very nicely. In such cases, wherever we have sufficient cohesive strength, the pore openings of the geotextile could be larger because for very small pore openings.

Our permeability could be very small and in variably, some soil will always come, lose and they get deposited inside the geotextile and in the service life of let us say some 5 to 10 years the geotextile might get clogged. It is always preferable to going for larger opening sizes to prevent the loss of efficiency because of the clogging.

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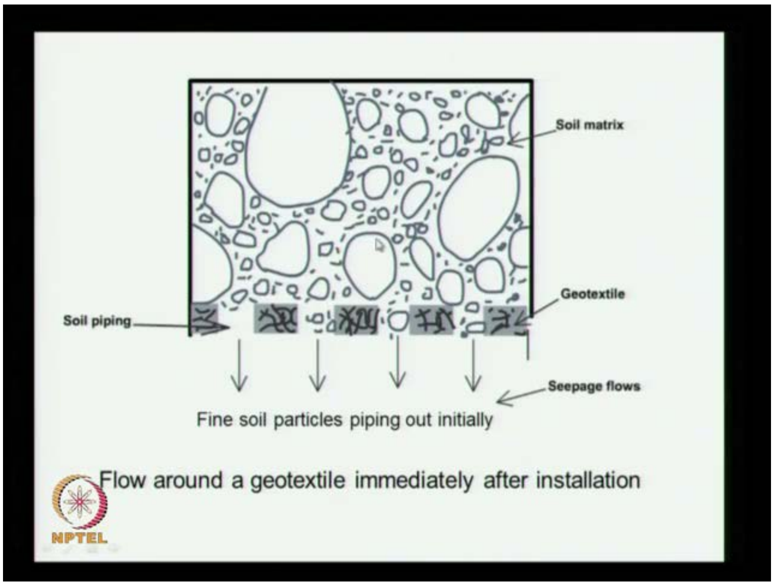

This is what happens immediately after the installation of a geotextile, in once the flow starts taking place. Initially, there could be some loss of fine soil particles and till the soil particles rearrange themselves to bridge over the gaps. So, this is a schematic illustration, there could be some initial loss of fine soil particles. But, that is fine because that is a natural process and that loss of fines happens until we form this bridge between the, between the openings.

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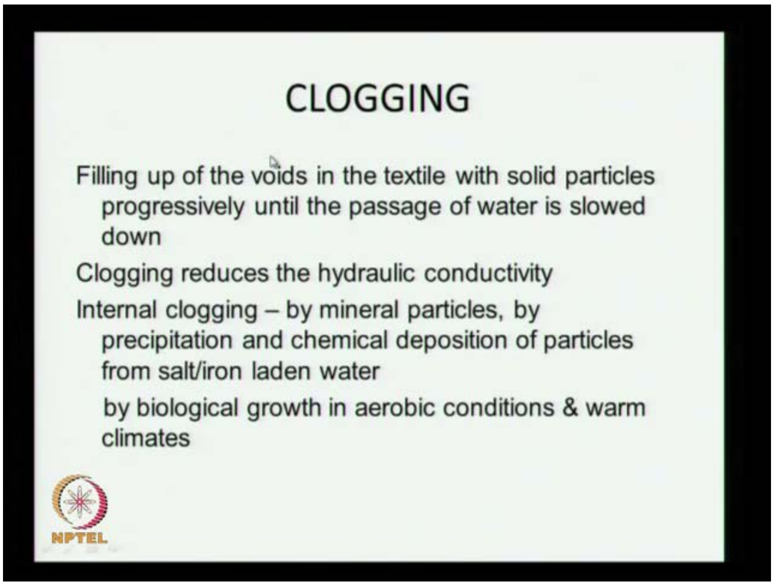

Well, the clogging is one of the very important phenomenons that we need to address and there is no easy solution. There are lots of conflicting requirements, conflicting suggestions, conflicting guidelines depending on how the tests are perform. Depending on the gradient at which these tests were performed, people have noticed different type of requirements and just to highlight the clogging is very simple phenomenon filling up of the voids in the textile. In the natural filter with solid particles progressively, until the passage of water is slowed down is called as the clogging and obviously, the clogging reduces the hydraulic conductivity. The internal clogging of the filter could happen either because of the mineral particle deposition or the precipitation on the chemical deposition of the particles from the salt or iron laid and water and or because of the biological growth. In the aerobic conditions and warm climate, we require warm climate for the microbiological activity to take place.

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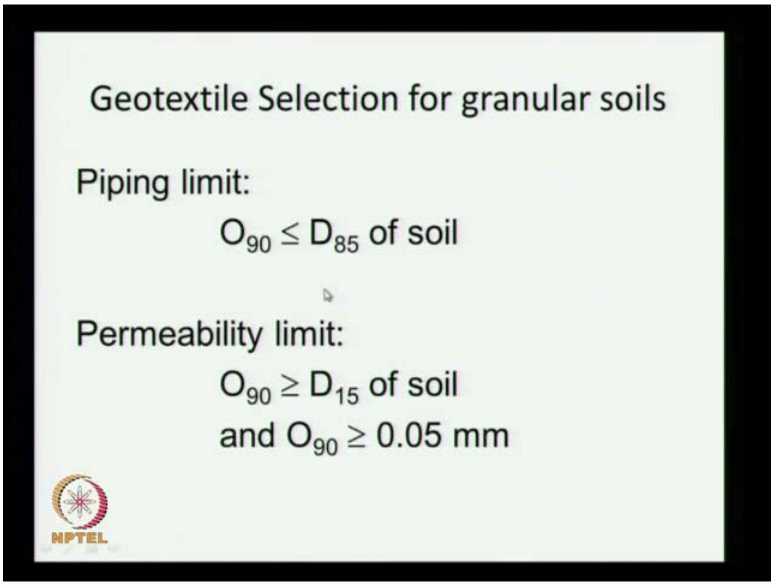

I will just give you some brief, some empirical guidelines and by no means these guidelines are complete by themselves, and many times you see that they are contradicting each other. One suggestion on a appropriate geotextile, to prevent pumping is O 90 should be less than or equal to D 85 of the soil, that is the O 90 is the opening size corresponding to 10 percent finer of the geotextile.

It should be less than D 85 of the soil, and then the permeable to limit is O 90 should be at least greater than D 15 of the soil. If D 15 is less than 50 microns, O 90 should be greater than 5 microns, sorry 50 microns that is 0.05 millimeters.

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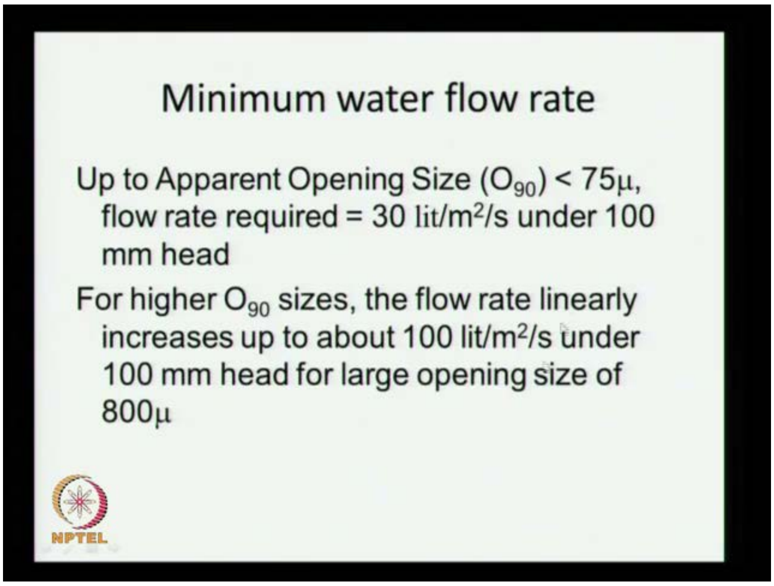

Together, with the pore opening size, we also require some minimum water flow rate and the water flow rate ensures that there is adequate permeability because initial water flow rate may be very high. But, during the service life, once the soil particles start clogging the geotextile, the water flow rate may reduce considerably. This water flow rate required is related to the particle sizes and when the opening size of the geotextile is less than 75 microns we require a flow rate of at least 30 liters per square meter per second.

Under 100 millimeter, head of water and for higher opening sizes the flow rates linearly increase some about 100 liters per meter square per second and 100 millimeter, head for very large opening size of 800 microns, that is 0.8 millimeters. This is actually, it is an approximate guideline and usually as the opening size increases, we should have higher flow rate. This requirement simply says the same thing, at a very small opening size we require about 30 liters per square meter per second, that is a very low flow rate, when we go to very large size openings that we use, when base soil particles itself are very large we should expect a larger flow through the soil and that means that we should have a higher flow capacity even through the geotextiles.

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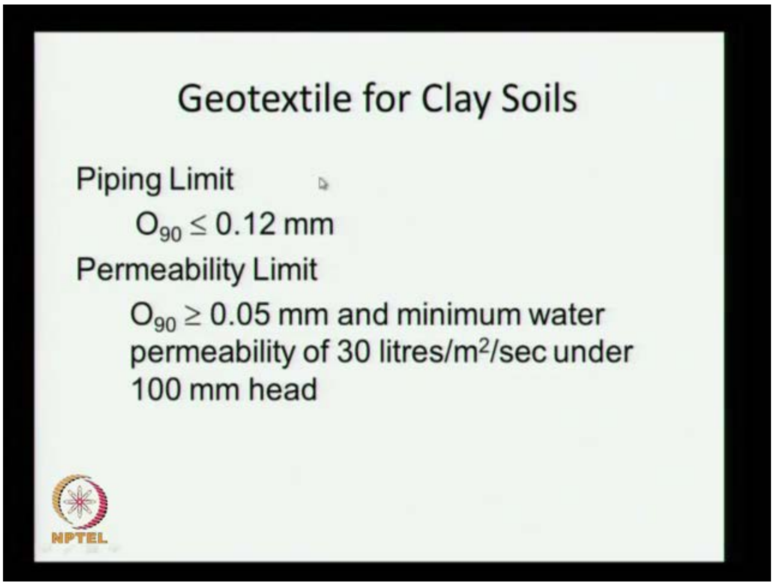

For the clay soils, the specification is very hazy. It is not a straight forward and the O90 for piping limit is less than 0.12 millimeters or 120 microns and for the permeability O90 should be greater than 0.05 millimeters or 50 microns. Then the flow of water should be at least 30 liters per meter square per second, under 100 millimeters head of flow.

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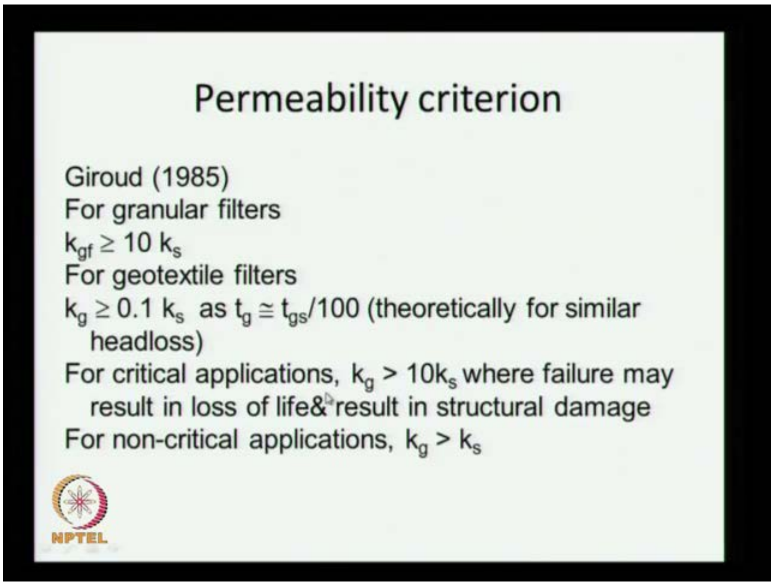

Giroud in 1985, he has come out with lot of summary of the published test data that has shown, that for the granular filters, that is for the conventional filters. The permeability of the granular filters should be at least ten times the permeability of the native soil and he showed that because the geotextile filters are very very thin. He showed that, the geotextile permeability if it is more than about one-tenth of ks, it is sufficient mainly because the thickness of the geotextile is about one-hundredth of the thickness of the granular filter. This is assuming that, there is a similar head loss in the flow through either the natural filter or through the geotextile, but then this is only a theoretical proposition.

But, then if we have a fabric, that has such a low permeability, initially it could lead to a disaster because the openings are so fine that it is easy to clock those particles with a clock those openings, with fine soil particles. For critical applications, the US army core of engineers they suggest that the permeability of the geotextile should be at least ten times the permeability of the soil. The critical application is where any failure of the filter could result in loss of life or result in structural damages. Say for example, we have a filter below a hydro liquid dam or very large dam, any failure the filter could mean the damage to the dam structure and if the dam collapses you can imagine the consequences.

In such cases, the geotextile should be highly permeable and it should have permeability as high as ten times the permeability of the soil. For the non critical applications, the kg can be just simply greater than ks that are sufficient. Non critical application is may be like a canal bank or some other small structure where the consequences of the filter not functioning may not be too severe.

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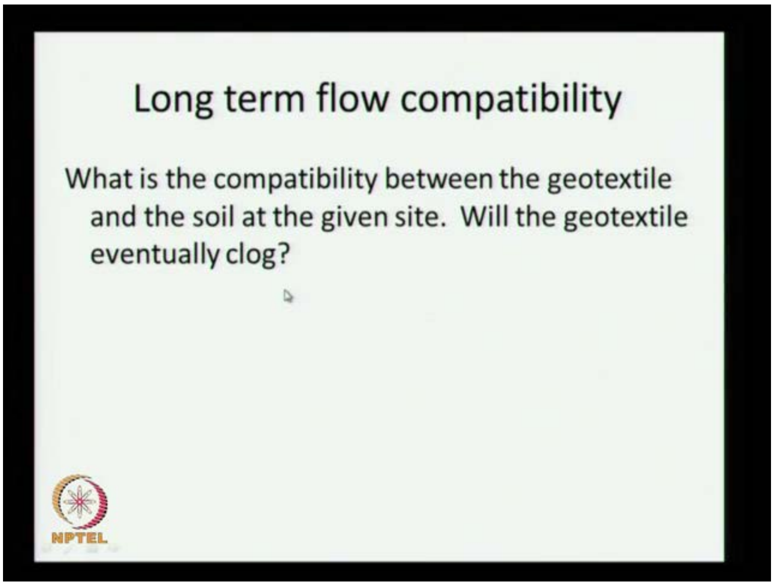

So, how do we ensure that a given textile is compatible with a given soil, because if you look through all these the different requirements, it is it is quite confusing because one code says something and whereas some other code says entirely different things. None of these codes, they are straight forward when it comes to problematic soils that is one we have gap graded soils, there is no single requirement or there is no single code that definitely says do this and the filter will work fine. It is very difficult because there are instances where the filters have performed fantastic, whereas in some other case they have just simply failed because for several unknown factors. So, in order to ensure that this is a good compatibility between given fabric and the soil we perform what is known as a long term flow test.

We allow the water to flow through this soil and the geotextile or very long period of time says up to about two weeks or one month. See, whether the given geotextile gets clogged because of either the flow of the particles or because of the clogging, either because of the fine soil particles coming through the soil or some biological activity and these are some of requirements.

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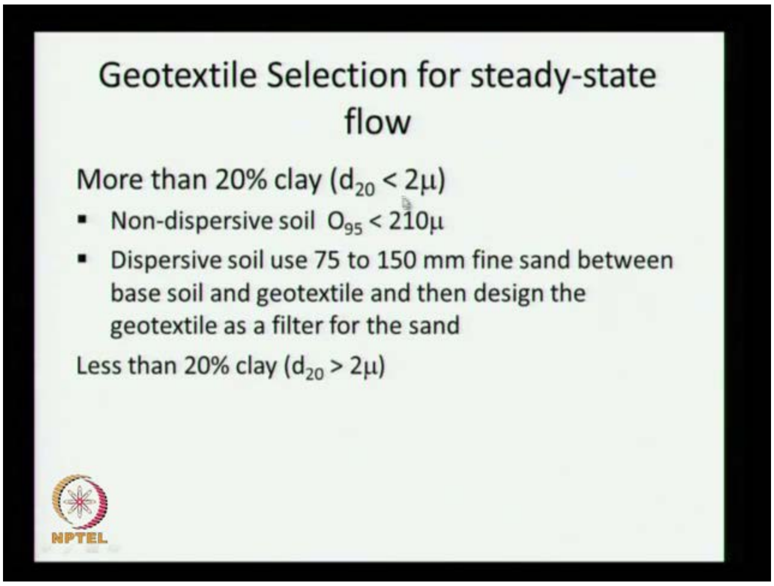

Say for steady state flow, that is when there is unidirectional flow under constant head, this is how we can select geotextile. Say if your base soil has more than 20 percent clay soil that is the D 20 less than 2 microns and when we have a non-dispersive soil that is the plasticity is slightly high so that the soil particles do not get and detached from each other. For that case, the O 95 could be less than 290 microns and when we have the dispersive soils, it is not easy to provide a filter.

There in such cases, it is recommended that we can provide about 75 to 150 millimeter thick fine sand between the base soil and the geotextile. The geotextile opening is designed as a filter for the fine sand, because the fine sand we know how it performs, but a clay soil that is tend to disperse is very difficult to predict and in such cases, we can provide a fine sand layer.

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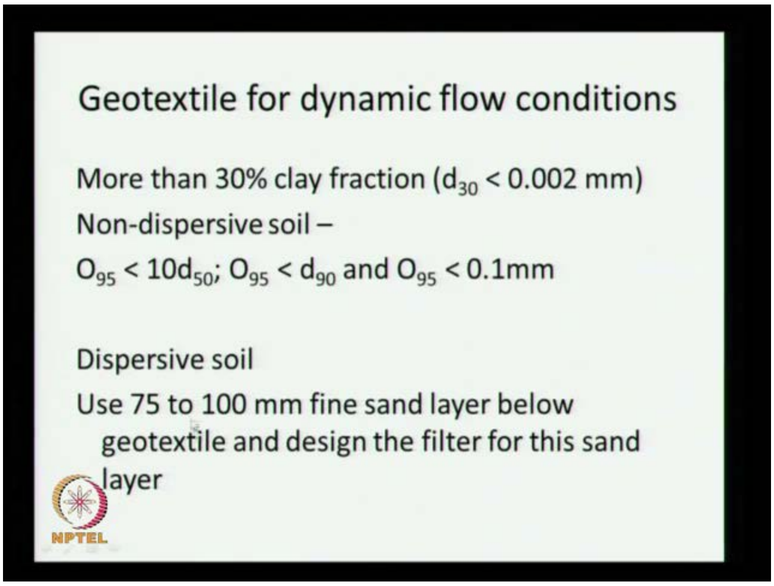

The same requirement for dynamic flow conditions, that is the dynamic flow could happen either because of very high a gradients or there could be a reversal of flow. Under certain situations, the O 90 in this case should be less than ten times the D 50 of the soil and O 95 should be less than D 90 and O 95 should also be less than 0.1 millimeters. It is actually all them may not be simultaneously satisfied because there are too many requirements and in the case of a dispersive soils. Once again, we are going for a thin fine sand layer and design the geotextile opening for that particular fine sand.

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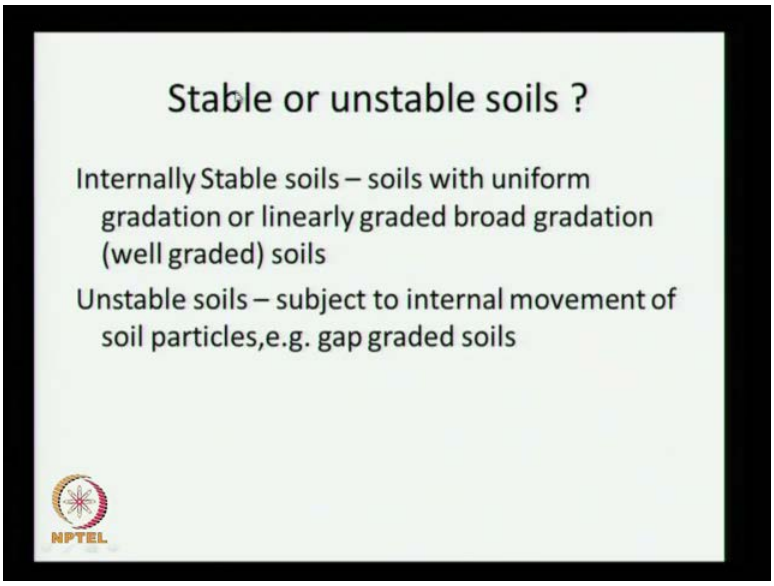

Well, how do we define whether a given soil is stable or unstable, because most of the codes they have the terms stable or unstable. See, the internal stable soils are those with uniform gradation or linearly graded soil like a well graded soil and whose performance is very well fine. Unstable soils, these are the soils that are subject to internal soil moments and mostly the gap graded soils, sometimes when you have instead of a continues curve we have different gaps in the grain size distribution, that means that some particle sizes are absent in that particular soil. These are called as gap graded soils and they are very tricky to stabilize, because the fine soil particles might flow through and occupy the wides between larger size particles and that type of soils they are defined as unstable soils.

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The Dutch guidelines for the filters are very simple, O 90 less than d 90 for less than geotextiles and O 90 less than two times the d 90 for nonwoven geotextiles is actually woven geotextile its has openings of more or less uniform size. Whereas, nonwoven geotextiles, their openings are mix of different sizes because of their manufacturing process and because of that there is a higher tolerance that is given for nonwovens. That is O 90 less than two times the d 90 we can go in for larger pore openings in the case of nonwoven.

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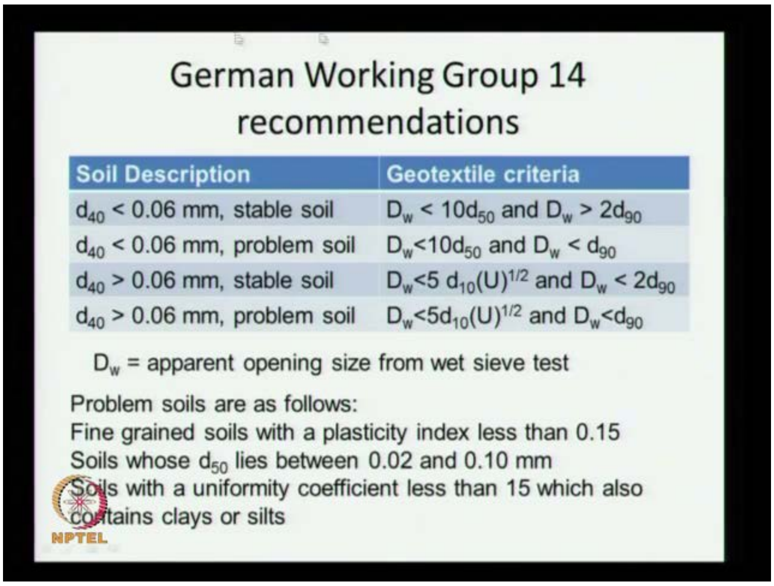

The German recommendations when your d 40 is less than 60 microns and if it is a stable soil D w that is a apparent opening size, that is obtained from wet sewing. So, the normal apparent opening size is as per the ASTM standards by the glass beats methods or the sewing method. The particle sizes that we get, the wet sewing could be different from those that are obtained from dry sewing methods and the German code is dependent on the wet sewing method. The D w should be less than ten times of d50 and D w should be greater than two times of d 90 and when the same d 40 is less than 60 microns.

But, we have a problematic soil, the D w should be less than ten times d 50 and D w should be less than d 90 and when d 40 is greater than 60 microns, for stable soil we have this. For problematic soil, this is the recommendation that we have, and the German code defines the problematic soils as those soils. The fine grain soils with plasticity index less than 15 percent and the soils whose d50 lies between 0.02 and point 1 millimeter that is the average particle size between 2 microns and sorry 20 microns and 100 microns. The soils with a uniformity coefficient less than 15 and which also contain the clays and silks these are all called as problematic soils.

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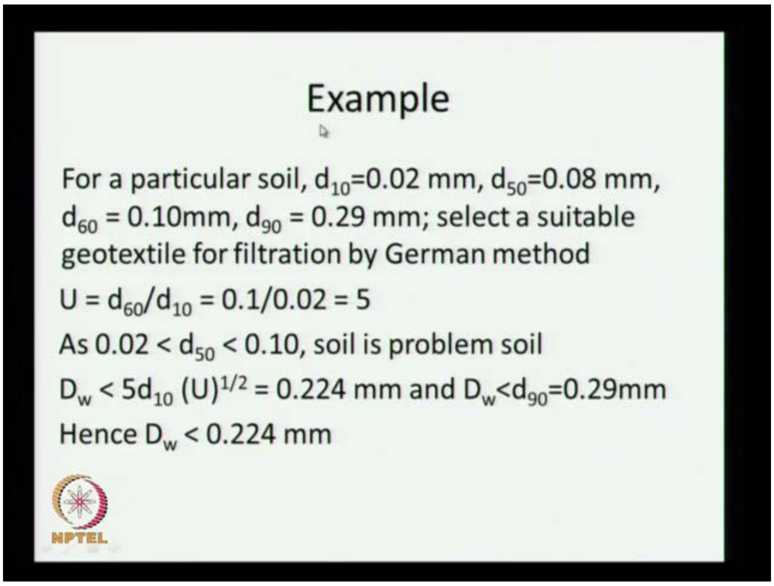

Well, let us look at a simple example. Let us say that base soil has these properties d10 of 0.02 millimeters, d 50 of 0.08 millimeters, d 60 is 0.1 millimeters, d 90 is 0.29 millimeters and select a suitable geotextile for filtration. By the German method, the uniformity coefficient U is d 60 by d 10 that is 5 and the soil d 10, d 50 is between 0.02

and 0,1 it is a problematic soil. Here, the D w should be less than five times the d10 times square root of uniformity coefficient that comes out as 0.224 millimeters and D w should be also less than 0.9 that is 0.29 millimeters and whichever one is more critical. So, the D w, that is the apparent opening size on the wet sew method should be less than 225 microns that is 0.224 millimeters.

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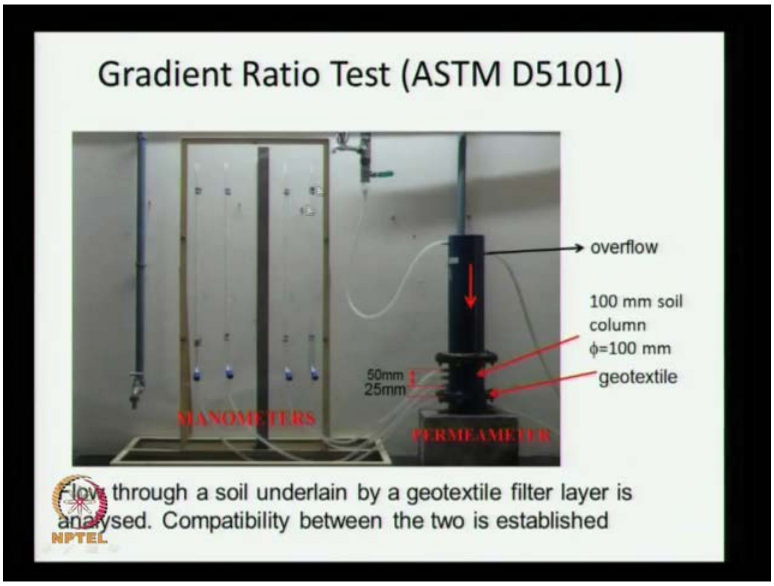

The long term compatibility is best defined through this gradient ratio test that we have seen earlier, this is as per the ASTM D5101. We have a glass or plastic jar of 100 millimeter diameter and in which we can have, we can place a 100 millimeter soil column. Below the soil, we have a geotextile and the water flows through and comes out and at different locations, we measure the head of water through a number of manometers. There is one head measured just below the geotextile, one head measured at 20 millimeters above the geotextile and then there are two more heads measured at 25 and 50 millimeter, head the height this from the bottom most manometer. This is actually schematic, it is shown here we measure.

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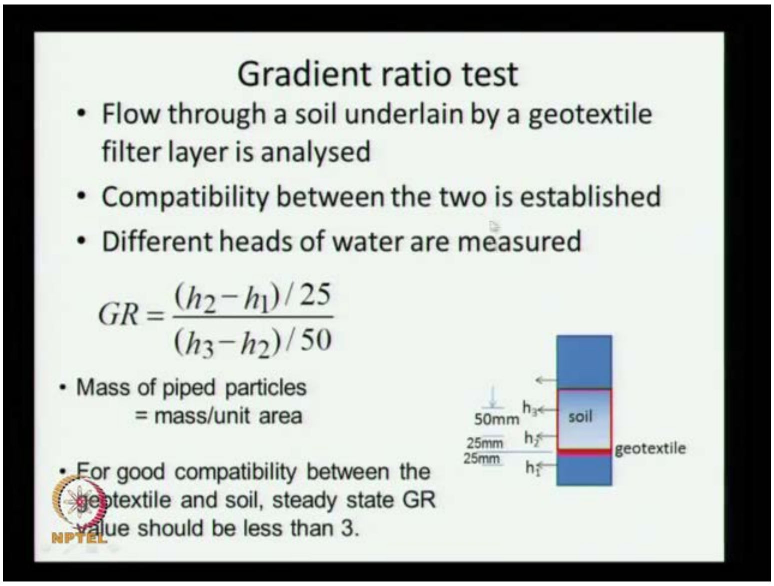

So, the head h 1, h 2 and h 3 and the distance between h 2 and h 3 is 50 millimeter. Whereas, the h 2 to geotextile is 25 millimeters and the gradient ratio is defined as h 2 minus h1 divided by 25 divided by h 3 minus h 2 by 50. Basically, the gradient ratio compares the gradient of flow between the geotextile and through the soil. For a good compatibility, that the given geotextile does not get clogged because of the flow of fine soil particles, this gradient ratio should be less than 3, is actually if there is clogging h3 and h 2. They become almost equal, that case the denominator reduces and the gradient ratio increases.

When there is a good flow of water, there will be substantial difference between h 3 and h 2 and because of that, the gradient ratio could be lower. We also measure the mass of the piped particles that is the particles that come through the geotextile, we take a measurement and then there is a codal requirement on how much mass that we can allow through to be piped out.

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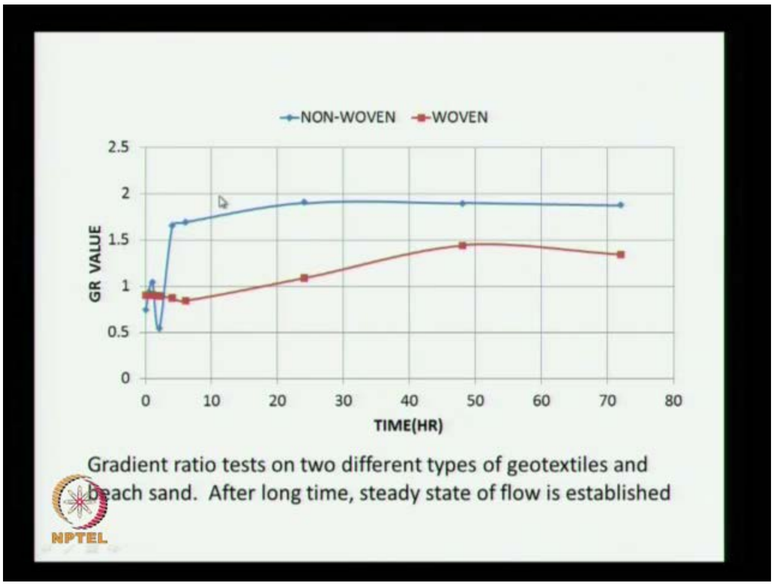

A typical result of the gradient ratio test is shown here. This is for a non woven geotextile, this is for a woven geotextile, and these were performed on beach sand and within about 10 hours, 10 to 15 hours the steady state conditions have been achieved.

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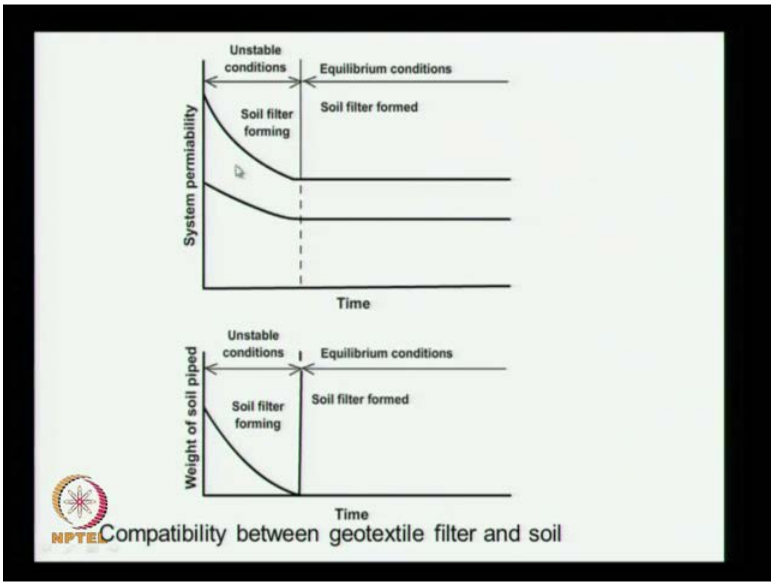

The typical result from a long term permeability test may look something like this. Initially, the system permeability could be very high and after sometime the permeability goes on decreasing. That is, during the process of filter formation and during the process of the equilibrium state being achieved, the permeability goes on reducing. After the equilibrium is obtained, that is when the soil filter is formed the permeability remains more or less constant.

If you look at the other plot, that is the weight of the soil particles piped out, initially we will have some particles piping out and after sometime after the equilibrium is established we will not see any soil particles coming out. That means that this given geotextile is compatible with the given soil and this minimum permeability that we have after the equilibrium is obtained, should be high enough to satisfy our requirements of the flow rate that we estimate in the field.

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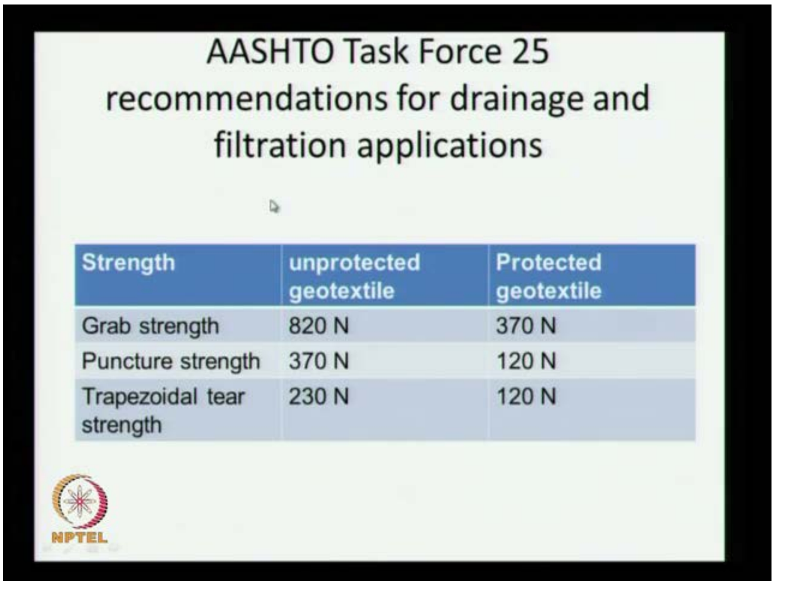

There are different standards on what should be the strength of this filter fabric and the AASHTO task force 25 is given these recommendations. Grab strength for an unprotected geotextile should be at least 820 Newtons, whereas a protected geotextile should be at least 370 Newtons. A protected geotextile is a geotextile that is provided below a concrete slab or something, whereas an unprotected geotextile could be a geotextile like say below a railway ballest.

The geotextile is not protected because ballest itself is very large size and it has a very large sharp corners and at any time a geotextile can just simply get punched. In that case, we provide a higher strength in geotextile and then the puncture strength also is higher for an unprotected geotextile of the order of 370 Newtons as compared to only 120

Newtons for a protected geotextile. Then the trapezoidal tear strength 230 Newtons and 120 Newtons, these are just generic guidelines and the European code.

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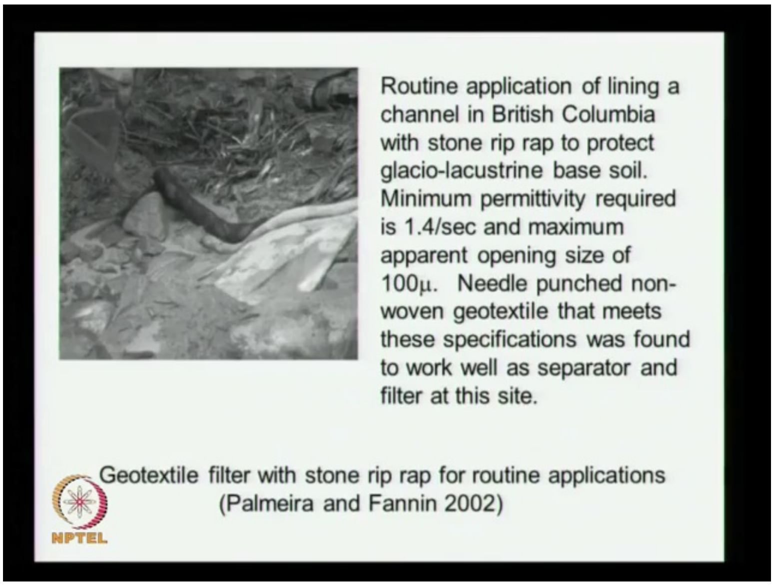

They also give certain other requirements and this particular picture is from the paper published by Palmeira and Fannin. Here, they aligned channel in for an irrigation canal and British Columbia with a fabric and that is provided below a rip rap, stone rip rap. This first to protect a Glacio lacustrine base soil, a glacial soil lacustrine is something similar to our sandy clay and the minimum permittivity that is required for the geotextile was 1.4 per second, maximum apparent opening size of 100 microns. They used a needle punched non woven geotextile that meets these specifications and it was found to work well as both separator and filter is actually at this location. They provided this fabric not only to act as a filter, but also as separator and the field observations of the 2 years they have shown that this particular fabric is working satisfactorily.

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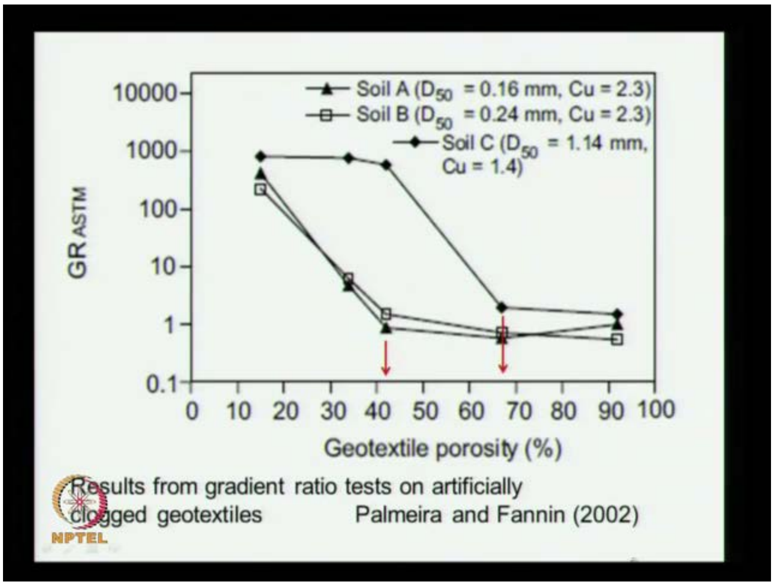

Palmeira and Fannin, in the same paper they published an excellent test data on the geotextile porosity and then the gradient ratio. What they have done is, they have taken a given geotextile and purposely they have created some clogging by spraying it with some wax or paraffin. Then they have done experiments with three different types of soils, the soil A, B and C and the D 50 is different for different soils and the C u is also different.

We see that for the soil, the core soil, the soil C the critical porosity where the gradient ratio, gradient ratios starts increasing is about 65 percent. That means that if you are protecting the soil C with a D 50 of 1.14 which is relatively cores grained as compared to the other soils, you require minimum porosity of 65 percent. Below that, the gradient ratio increases drastically and when we are protecting relatively fine soils that is D 50 having a 0.16 and 0.24, the critical porosity is about 40 percent and this result shows that the importance of the porosity on the particle size and then the clogging.

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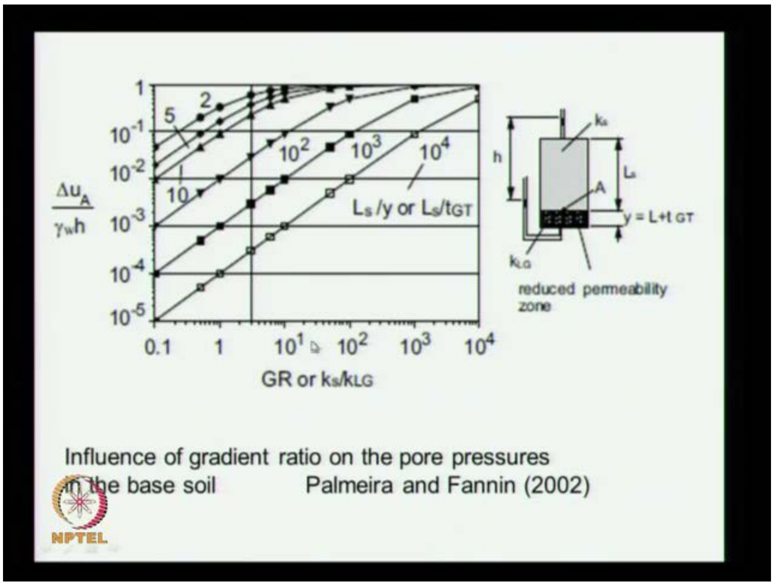

They have also shown the affect of the gradient ratio on the pore pressures that are built up. They have measured the pore pressures in this long term permiameter, a different gradient ratios, they have measured the pore pressures and published this data. The gradient ratio of 3 is given is well accepted and below that value we do not have much of clogging and if there is no clogging, the pore pressures will be within the limits. Above this gradient ratio, our pore pressures could shoot up and this is what they have quantified.

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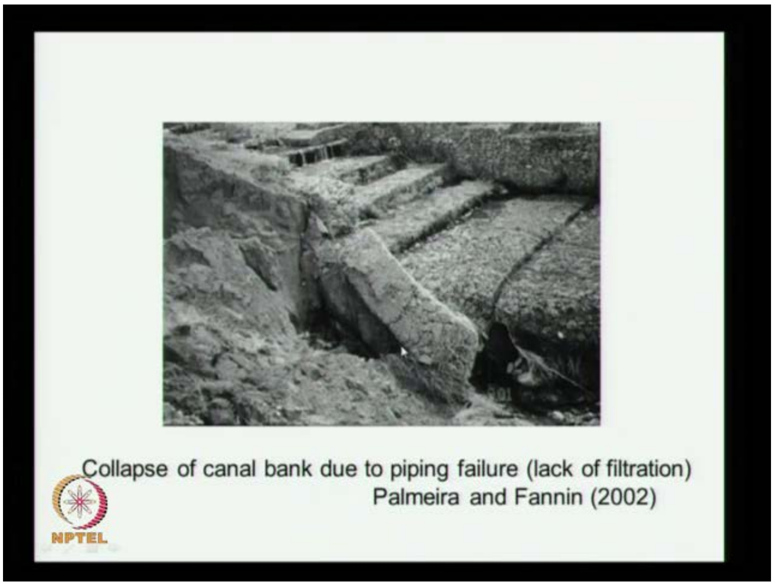

Some other applications, they have seen the canal bank failing because of lack of filter. There was no filter fabric provided and the canal bank has just simply slid down because the fine soil particles have got piped out is actually.

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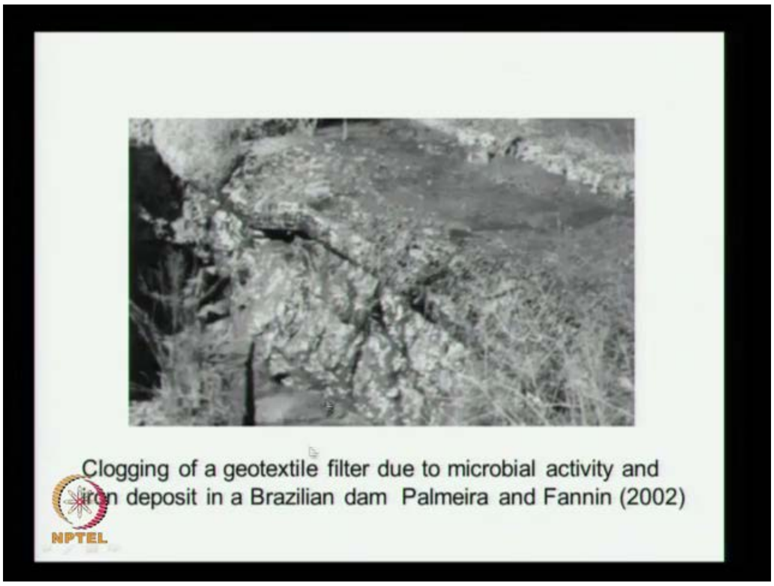

Here, you see large wide that happen because all the fine soil particles have reached out or they have piped out. Here this particular picture is of a geotextile that was clogged because of some severe microbial activity in Brazilian dam, where the temperatures are high and the microbial activity happens whenever there is a high temperature.

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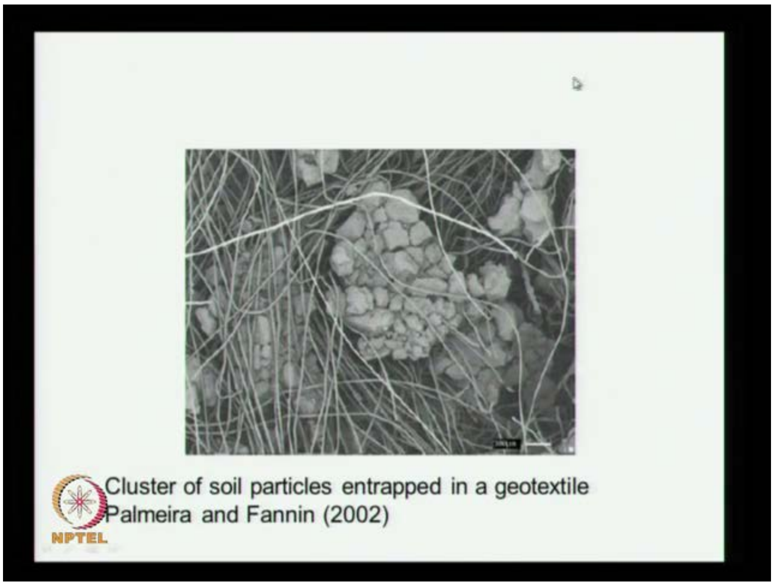

This is one picture of a cluster of soil particles that are entrapped within a non woven geotextile is actually it is a scanning electron microscope picture is not just a direct photograph.

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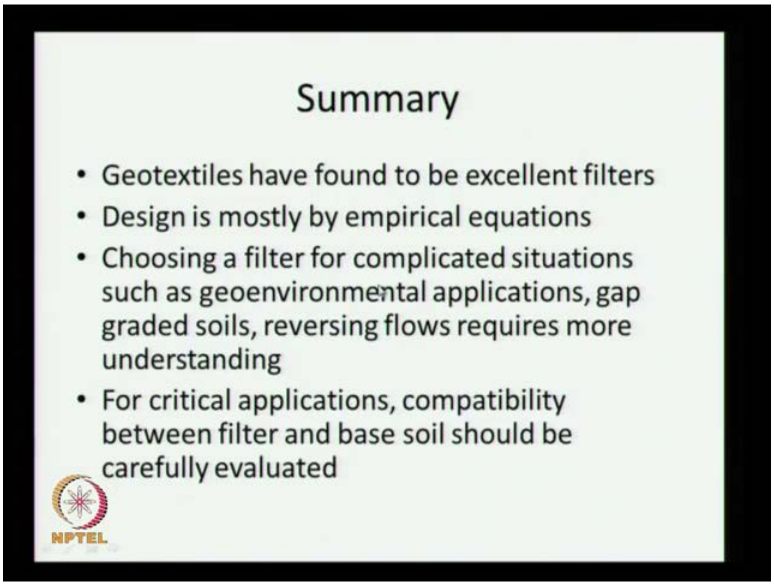

So, just summarize the geotextiles have been found to be excellent filters and also excellent separators and the design is mostly by empirical equations. Choosing a filter for a normal situation is not very difficult because there are sufficient experiences that show how the geotextiles function. But, in some critical applications and wherever there is problematic soil that is highly gap graded, we need to look at the laboratory tests. See, normally people may not do the laboratory tests, but it is recommended that whenever we have a critical application or whenever we are dealing with gap graded soils are with reversing flow, it is better to do the laboratory test.

Subject the geotextile to flow through the soil for sufficient long time to make sure that there is a good compatibility between the given soil and given the geotextile. Also in geo environmental applications, we could have the clogging because of the chemicals that are generated and the compatible to it between the geotextile. That type of soils is best analyzed by conducting laboratory tests.

Thank you very much.