Ground Improvement
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Lecture No. # 35

Design of Embankments on Soft Soil Using Geocells

Use of Geosynthetics for Filtration and Drainage

In this lecture on design of embankments on soft soil using Geosynthetics, we would be seeing the use of Geocells.

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The Geocells are three-dimensional form of Geosynthetic materials with interconnected cells filled with soil; it can be stone or even it can be a marginal material like a fly ash. The important advantages of the Geocell layers at the base of the embankment are; it acts as immediate working platform for the construction. Say, for example, if you want to have working platform, the soil is very soft. So, one can spread this Geocell material and then start filling up soils, actually you can put a Geotextile at the bottom put a Geocell and fill up all those things, all of those things and put a roller then use it as a platform.

Then, it acts as a stiff rigid base to the foundation promoting uniform settlements. Then, it minimizes the construction time, prevents the bearing capacity failure and minimizes settlements.

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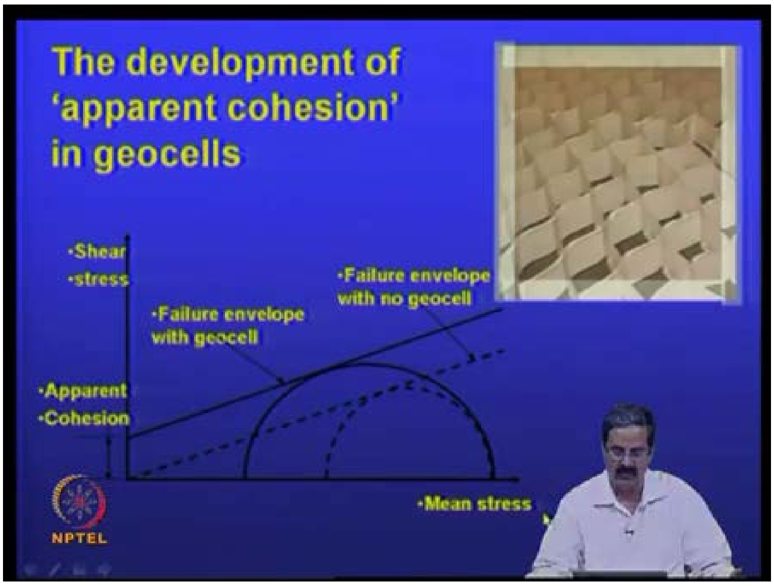

These are all some advantages, in fact, it comes in this form like you have a… It can be a cellular matrix, you can just expand, and then you have in this gaps, lot of soil could be compacted, and what it does is like in the cells, you compact the sample, and then the when it expands, there is a radial strain is or radial stresses are introduced in this system and then they provide a confining pressure. In fact, a similar to a triaxial cell, you have a sort of a confining pressure. There, actually we apply the confining pressure, we can design these members to see that there is some rigidity or the stiffness that gets that they provide to the expanding soil mass and keep them in the confinement condition.

So, because of this confinement, what we have is some cohesion gets developed, because there is a confining pressure. In fact, if you look at, say for example, Mohr Circle envelope like, if this is a… you know you take a soil first. For example, sand - it has a zero cohesion, and then this is the failure envelope, and you just put this in the confinement within the Geocell, and then if you just apply load, it behaves as if it has a higher confinement pressure, which is something like this, and it will take even higher strength, as well like, you know shear stress that it can take care of are higher, because of the confining pressure.

Like now, earlier it was this line. Now, this is the second line that you have, this is what happens is it under the action of the Geocell, the apparent cohesion, you know, actually the soil is essentially sand. You know it is like this, the Mohr Circle line is like this in a failure line. And once you have a cohesion introduced into this membrane material, then you have an apparent cohesion that gets introduced. So, this is an extra cohesion that you have because of this Geocell. So, this is extra cohesion also it is called the confining pressure, you know. So, like, so that is an advantages here. So, the advantage of the Geocell is that they add a sort of a confining pressure.

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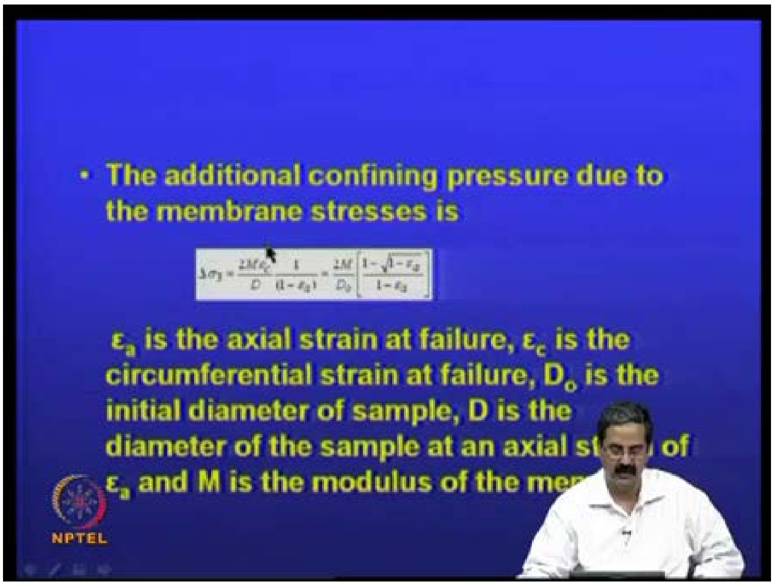

So, how do you get this confining pressure? There is some expression that is available literature, like see the delta sigma 3 is something that you have to have, and this is an expression, which is given in a literature by researchers, who are trying to understand the membrane correction required for a triaxial cell. You know, when you apply some load on the triaxial sample, even you know it is possible that there may be a higher shear strength, because of the membrane that you have put, is not it?

So, you have to correct that membrane. Do that membrane correction for the cell pressure. So, in that connection they have come out with this expression and that has been quite useful to calculate what should be extra confining pressure, because of this Geocell Composition? So, that is given in terms of the axial strain of the material, then the circumferential strain as well and D 0 is initial diameter of the sample, D is a diameter of the sample at an axial strain, say for example, if it gets expanded to some other strain level, what is that and m is the modulus of the membrane. What is a modulus? So, tension modulus of the membrane. Once you have all of this information, it is possible for us to calculate the extra confining pressure. It is an advantage here.

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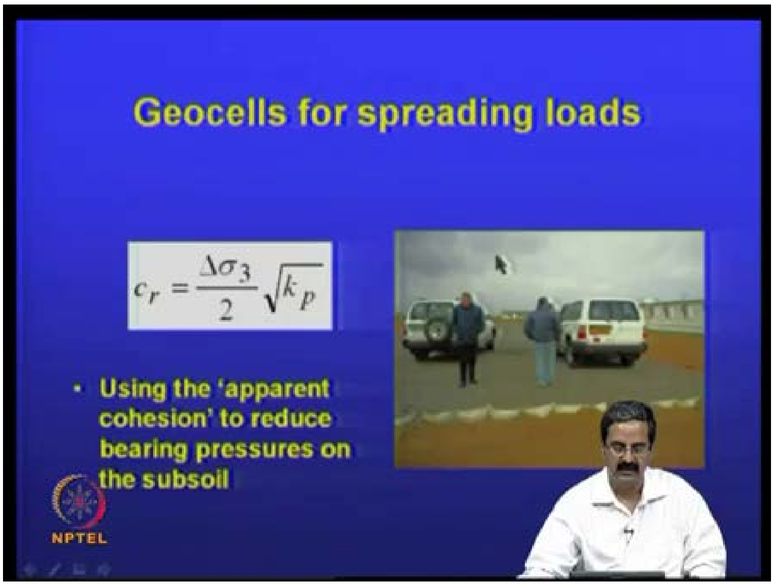

So, once you know the extra confining pressure, you know like it, what is that it is doing, it is really putting a sort of a passive resistance. It is not allowing or it is not active; it is a passive resistance. So, you have to use this formula k p. So, 1 plus sin phi by 1, 1 minus sin phi. So, you are able to get this cohesion also. So, using this apparent cohesion, one can do like, you know, that is what like one can use in slope stability calculation or bearing capacity calculations to calculate. Otherwise, you know the material was actually a sandy material. Now, because of the cohesion, you got higher bearing capacity, that is an advantage here. So, you can see a small example with all the Geocells and all that you can see this parking and all that. So, this is an advantage here.

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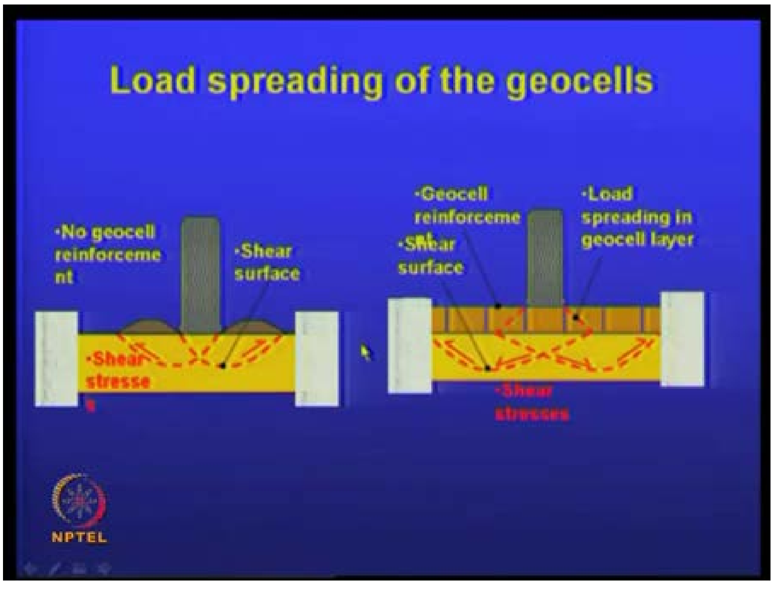

What it is… What it is some experimental evidences have shown that, say for example, of course, the theory is quite simple, and this because of this confinement, you know, the failure planes are not allowed to develop. You know, in this case, there are failure surfaces like this; here they are all just restricted to this area under the form like this. You know, it is an advantage here and some experiments that people have conducted.

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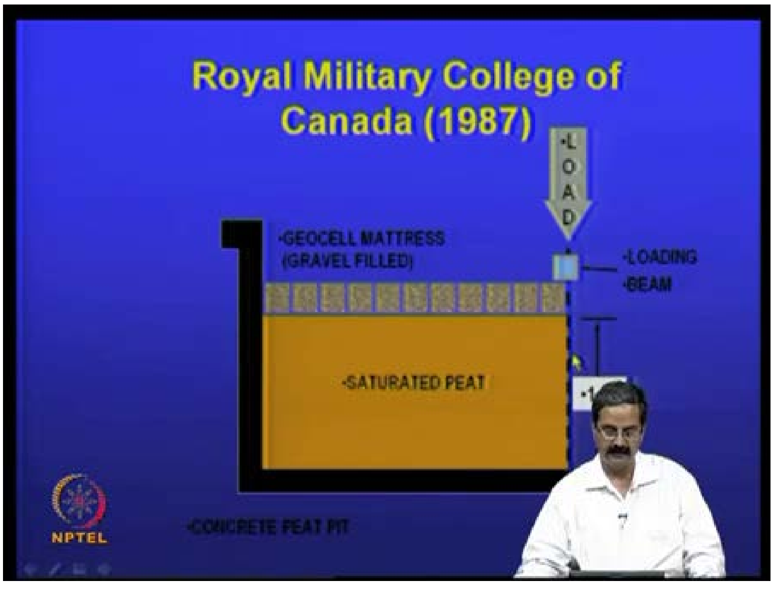

In fact, in interest of science also, lot of experiments have been conducted on Geocells and this is an example, one of the earliest examples, actually given by professor in

Canada, and this is a saturated peat; it is an organic soil, and then they filled up to 1 meter level, and then you the load is applied; it is a Geocell matrix matrix with a gravel filled in is there, and once it is loaded, you can see the difference.

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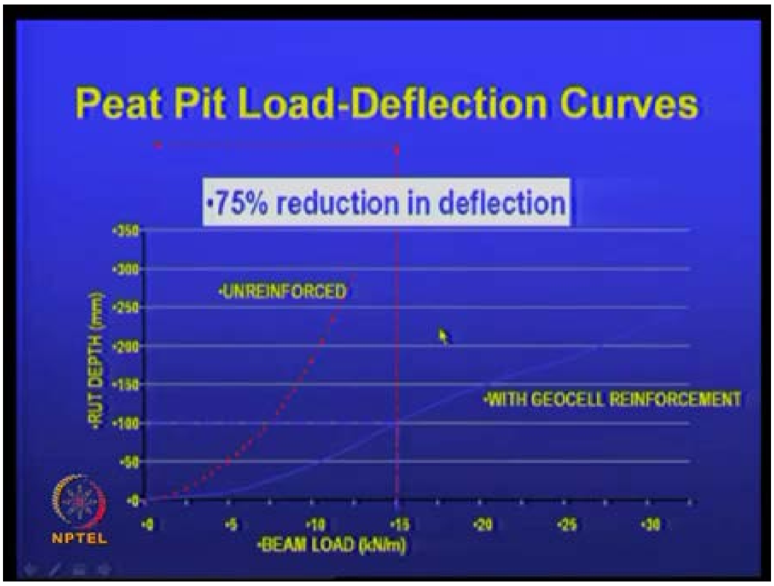

Like in the case of an unreinforced soil, this is that load versus a displacement of the depth, but whereas, in the case of the reinforcement material with a Geocell, you can see that there is a very big difference, like what is the settlement or the permanent deformation is may be, for example, if you just extend up to it 15 kilo Newton per meter, it could just go up to is about 350, whereas you know the RUT DEPTH, whereas in the other case it could be just 100.

So, there is a good settlement reduction, and even if you want to take any at any given rut depth or whatever that you know the bearing pressure improvement is quite significant, say for example, at 100 mm rut depth, in fact, it is very useful in payments rut depth is only very important characteristics with 100 mm. You just see, it is about 15 here, whereas it is about 7.5 here. You can see that it is a good difference in terms of the load carrying capacity and reduction settlements. at any At any load level, there is a good difference in bearing pressure and even settlement reductions are also possible.

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So, with this, we have… You know like, I would like to show you some case studies on use of this Geosynthetic materials; there are many actually some I have collected from Indian Geosynthentics in International or Geosynthetic society and the chapter of the Indian Geotechnical. We have an Indian chapter also for the same society. And the three case studies that we see in Hong Kong particularly, and other places you will see how they are look like.

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In this you know the embankment soil; the embankment was supposed to be constructed on a swamps and fishponds. Actually, in Soft soil clay foundations, 10 meters deep and the strength of the soil is very low like 3 k 3 kP a is required a low number and they used you know Geotextile here, like we know already about Geotextiles.

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We use the Geotextile here and we have seen how the Geotextiles reduce a preload right and it also avoids the replacement of soft soils.

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So, they have used a Geosynthetic Band drains to increase the rate of consolidation and they were measuring Geotextiles strains, Settlements, Pore pressure and Lateral displacement. One should do this in an instrumentation project, involving particularly when you are trying to have a ground improvement technique, it is always advantages to measure the actual quantities that may be of very importance to us in terms of calculations theories, because we apply some theories, but then if you are able measure the strains and settlements, pore pressures, displacement, it is going to be excellent.

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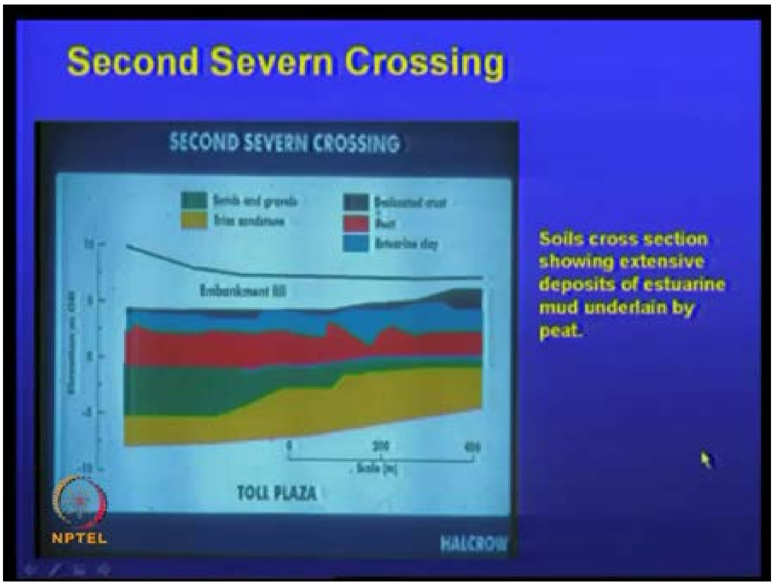

So, that is another… So they are able to see for the platform. They they did like that the other one was the another crossing, where there is an extensive deposits of a mud material here, like you know, you have some other sand stones here sands and gravels and embankment fill is there you have lots of desiccated crusts here.

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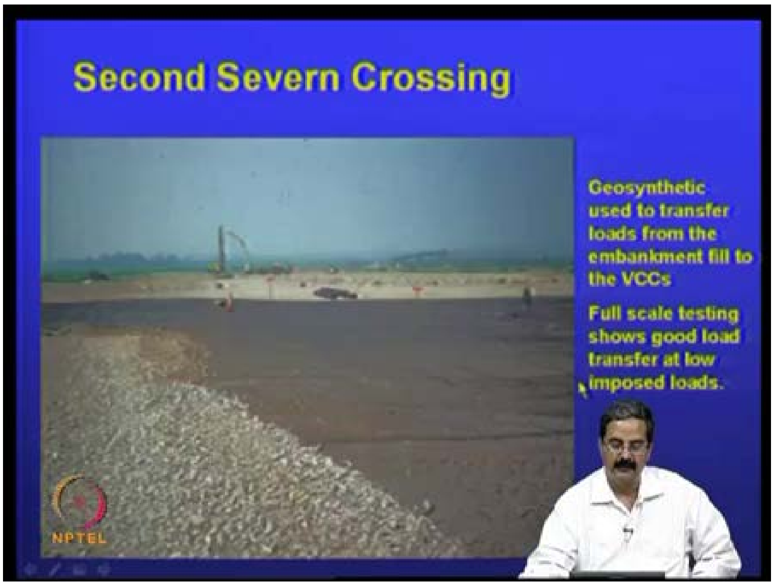

They would like to use; they use the sort of a stone columns and for that you know actually to transfer the load, exactly what they did was that, you need to have a… See we have seen how to design stone columns but if you are able to place a sort of a Geogrid at the top like this. It can help in load transfer, you know, in fact load from the embankment to the payment to the actually the stone columns could be less.

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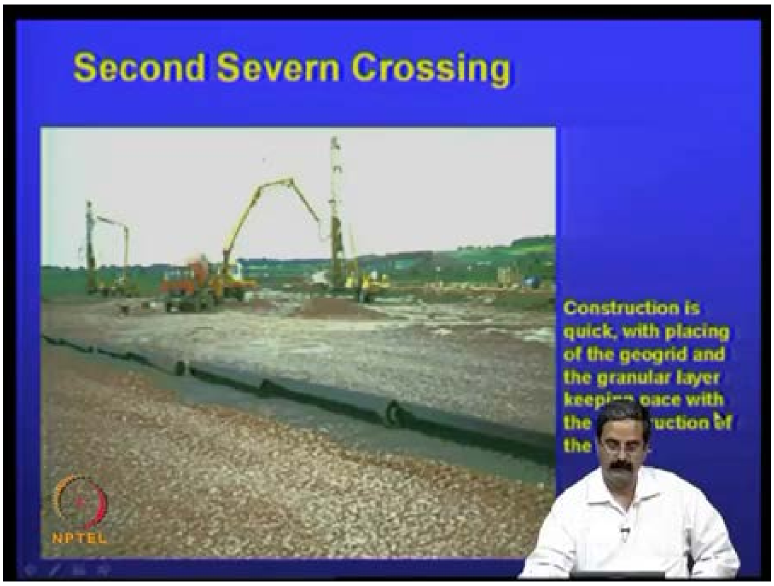

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So, the construction is also quite fast in this case and this is the way that you know in all these materials is looks like stone columns and then there is another one that we have the there is an access road and then it is about embankment height is about 10 meters. The embankment is founded on soft soil of 6 meters thick and the shear strength is 10 to 25 k P a quite a low number and to increase to what they did was that.

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The solution was to install band drains to increase the rate of consolidation, with a Geocell mattress here, as a foundation to the embankment. This is another one that say that what that doing here.

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You can see that is how they placed a Geocell here. Like they just it comes like this; it is a this is the Geocell. The Geocell consists of transverse grids with a triangular honeycomb structure formed by interlacing other sheets of uniaxial geogrid into the mesh.

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How it is? This is how it looks like? So, filling is being done. Filling takes place from one edge, once the area is filled, delivery trucks can run on the surface of the geocell, once it is completed, one can go ahead and walk on it. work… Lateral extensions in the geocell were less than 1 percent and mattress acted as a stiff foundation. It is a very good system here.

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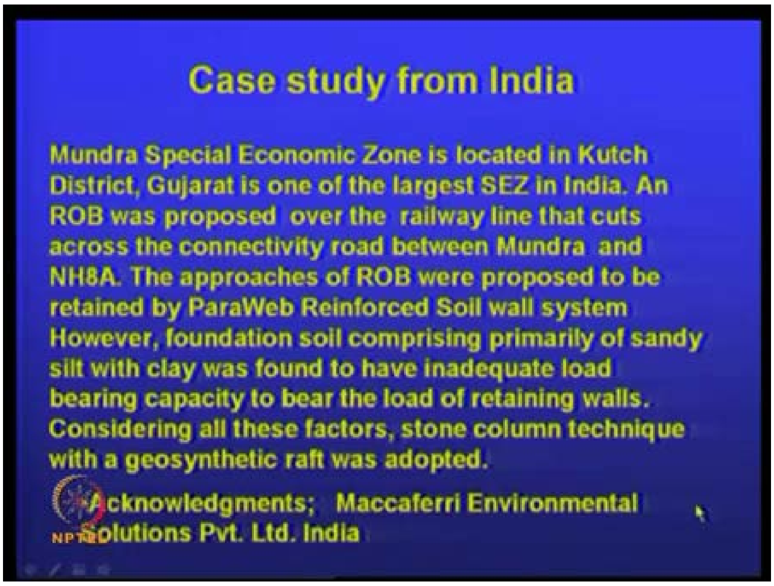

There is another case study that I would like to just highlight from India, of course we have many case studies that in India also, and for example: this is in Gujarat, where they are trying to have a special economic zone and the soil was very soft there in Kandla port trust, and there was ROB means road over bridge were supposed to be constructed and so the soil was suppose to be having poor bearing capacity.

So, what they did was they use a stone column technique along with a geosynthetic raft. You have a stone columns and then a geosynthetic raft came at the top, actually I was in touch with Maccaferrri International Environmental solution company in Bombay.

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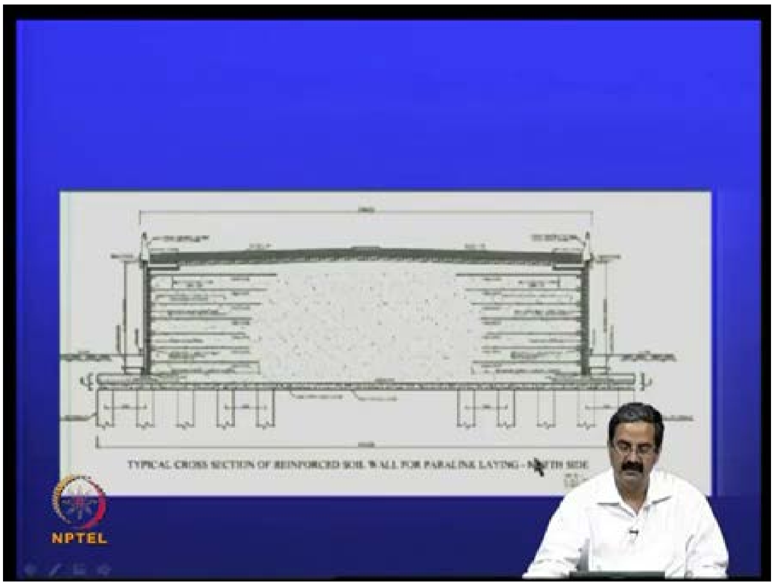

They are able to give me this case study because I thought; I should discuss this with you. In fact, this is in (( )) wall structure that they have made and this is all the this is that what we are talking about the Geocell, I mean this Geosynthetic foundation material here and loading platform actually.

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This is another one and the way that they are doing this you can see that that they doing the stone column work. They are spreading that Geosynthetic product.

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This is the completed view of this structure. Actually, even there are some cases where you know there are some air, the voids also are formed in the ground, I was just mentioning about one case, where you know the possibility of voids formation in certain deposits are there and if you do not want the loads to be transfer to that, because it is very difficult to fill up the void.

You know the thing is, we do not know, where the void starts; where it ends. And one conventional way of filling up the voids is to use lot of cement grout and cement grout, yes, it can be done, but at the same time, if you want to really see that, there are no loads or stresses that reach that, say for example: Void you can put a Geocell mattress at the top and see that all the load is only taken care of by the Geocell mattress. The materials know… Whatever foundation bed, we can call it loading platform also. So, you can see that, it it could be much more economical than trying to try to fill up hole, that we do not know, where it starts and where it ends.

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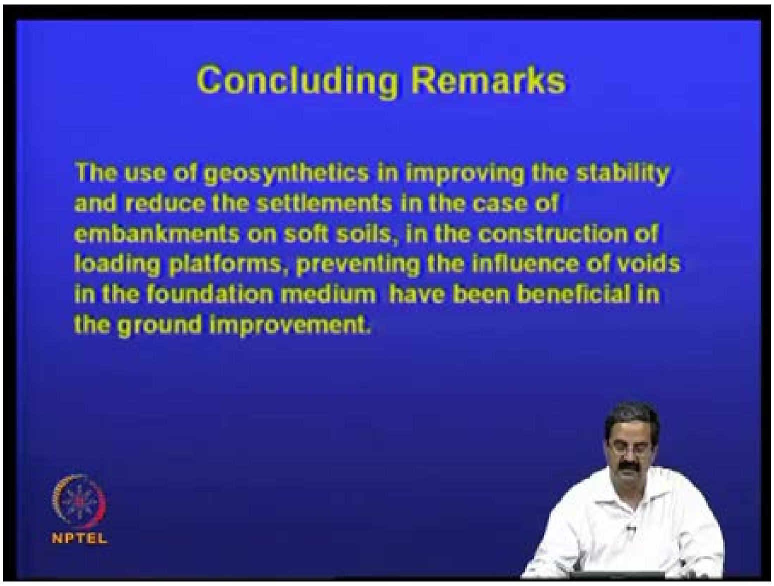

So, they have been lot of case studies on the use of Geosynthetics in India, and you know the science is quite simple, that I also explain to you that particularly, when you are trying to handle the embankment and soft soils, you have to calculate how much is the shear the there…We had discussed about internal stability and external stability and also like, one can do that and in the construction of loading platforms also, you can use the geocell foundations and the influence of voids in the foundation medium also could be avoided. You know, in the sense, if there is some problem like that one can do that. So, this technique has been quite useful because in many places in soft soils, there is no technique available and this is only technique and people have perfected in many places in Abroad and in India also.

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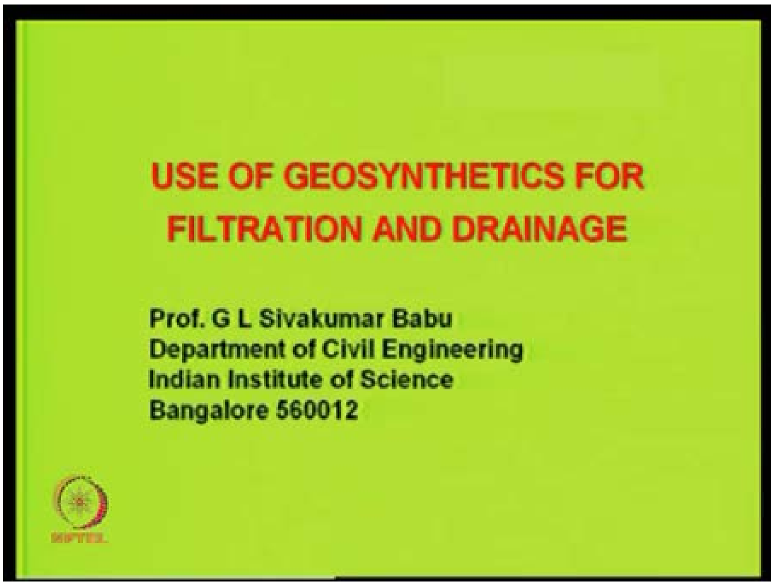

Now, I will take up the next lecture which is on Filters.This Geosynthetics as we have been discussing about reinforcement function and now there are actually, the Geosynthetics are much more helpful in other applications as well. We know that the functions of the Geosynthetics are the reinforcement, separation, filtration and drainage. So, when you have all of these or even moisture barrier as well. So, you can use them in many other applications, particularly in the case of filtration drainage, which is so crucial in many water related projects, because we have a this problem with water, that when they there is water, you have high pore pressure mobilization then drainage, if it is not there then it is an issue.

So, or and then the other one is that two soils like a poor soil and you would like to isolate the poor soil from a good soil. So, you have to separate them and you also need to allow only water in some places not the soil. So, you have to call, what you call filtration. So, we have in all these applications, the use of Geosynthetics is phenomenal and we can use these materials in a very significant way and people have been using it.

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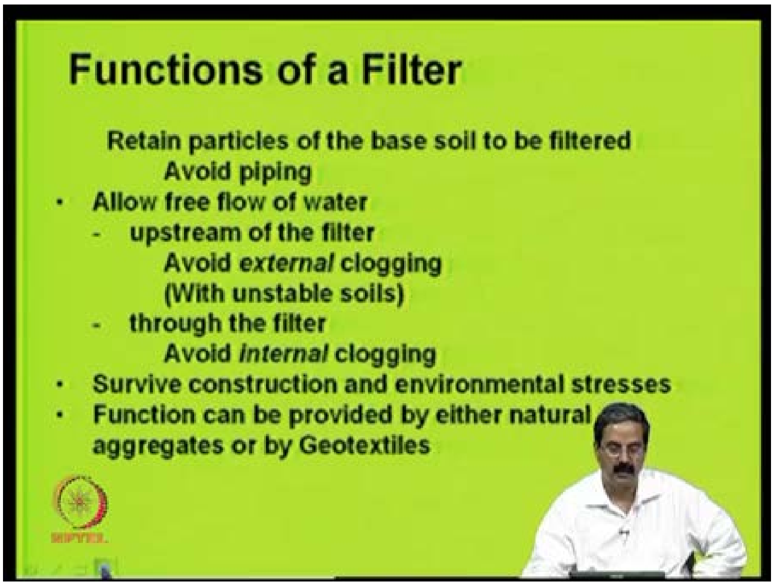

So, Why? When do you need filtration? (No audio from 17:04 to 17:09)We need filtration, when you want to just allow the water to go through a particular system, say for example: The water behind a retaining wall, you would like to water, you would like to see that the water comes out of the deep holes properly and see that there are no pressures on the retaining wall because of the water. So, you would like to have a clean filter, so that water only comes out, but not the soil. So, that is the and then we should retain the base soil, say for example: Whatever is the soil, backfill soil is there; it will start removing it then it is a problem. So, you do not want to soil to be lost, you only want water to come out. So, that is one thing.

Then, you would like to avoid piping, you know, in some cases you know, when we when the certain conditions, the you know when water comes from the bottom, there is a possibility of piping or liquefaction, we call it static liquefaction and when the effective stress comes down to zero, the possibility of piping may come or even there is a dislodgement of particles and all that. So, you would like to avoid piping then you would like to allow the free flow of water.

Say for example: You would like to avoid the on the avoid external clogging, say sometimes clogging also need to be prevented, because clogging is a serious issue and even internal clogging is also possible. Say for example: What happens you have a some soil, base soil what you call and then at the top we have a filter. So, water goes from here then what happens is that the filter should be able to only allow the water. And then you should also not lead to that filter should not get clogged.

The clogging is two reasons: We have one is external clogging, be at the periphery and the internal clogging also, because of many other means like biological and other means and both should not happen. And the thing is that the if the filter does not work for properly for a you know, even for a short term, then it is a serious problem. So, you must be able to design the filtration such a way that they take care of the environmental stresses like you know wetting and drying.

You know the even the water flow is cyclical, you know the water comes up and goes and when you have this sort of situations, the water flow is are cyclical and the filter should work properly, otherwise, you will have lot of serious issues and this function can be provided by natural aggregates like you can just use sand alone or a filter paper or anything like or or even say for example: Fly ash and all that and Geotextiles are also useful.

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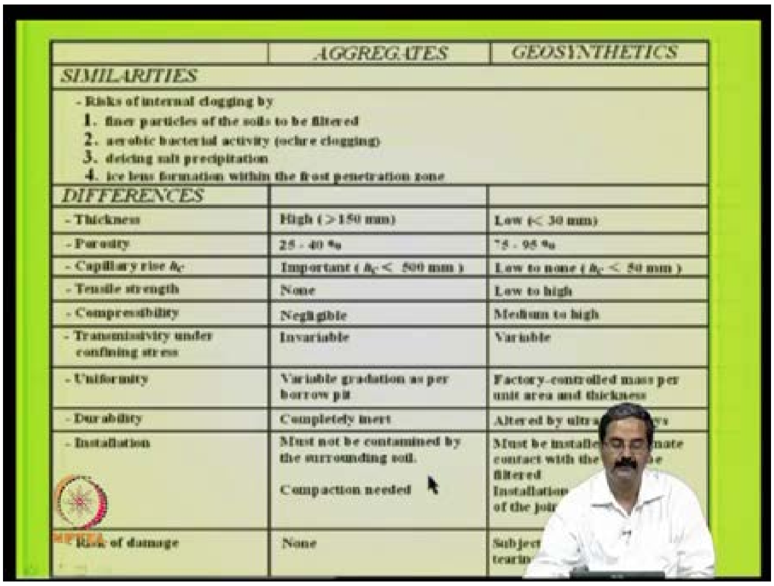

So, we will see, what is the difference between aggregates Geosynthetics, like I just first mentioning about the clogging. I think I must just mention about it. The internal clogging is because of the fine particles of the soils to be filtered bacterial activities then, some you know sometimes in some places abroad, they you know when you want to remove this ice from there, the air fill payments they do, they use deicing salts. So, they lead to some difficulties in filtration than ice lens formation and other things. So, anyhow most importantly we need to avoid this and we should understand, "what is the difference between conventional filters which we use like sand and all that, and what is a Geosynthetic filters".

First thing is the thickness. Thickness can be as you know normally you have to provide some thickness like 100 mm to 150 mm, where you need to get a actually gradient you should get. But you do not need to have that much thickness here, thickness is quite less, it can be just 3 centimeters, You know 30 mm which is quite simple; whereas, this is the 15 centimeters, this much and it is at least 5 times less than this this materials are you know poracity of this materials will be about 25 to 40 percent; whereas, the porosity in this case is much higher. You know, you just you are able to make the channels properly. You do not allow the water to go, so porosity can be higher actually.

Then, the capillary rise is another important property. In some materials, you know the capillary rise is nothing, but because of the capillary forces the water column; water will rise; because of this rise of water water column is known as capillary rise and this can be 500 mm and in a clay soil or you know some in some materials, it is not very good like you know, the capillary rise is going to be higher, it wets the surface which may not be necessary. It creates pockets of weak localized weak pockets. Then here, the capillary rise is less. Then you know aggregates, the compressibility is less whereas, a compressibility is little more in the case of Geotextile because Geotextile is actually a compressible material. Then transmissivity under confining stress: Yes, it is it does not depend so much on the pressure, but it varies as a function of pressure. Then, what about uniformity.

Uniformity of the the aggregate materials actually it is not easy to really got a good gradation and control on the gradation because you try to use whatever material you get from the borrow pit materials. Then you try to check, if it can satisfy as a filter; the second thing is that the factory, the Geosynthetic materials of the factory controlled materials and the thickness and area and they are all mass per unit area. You know the another property, they are all constant or you know they have some fix numbers whereas, this is somewhat different. Then durability; Yes, aggregates are excellent and of course, Geosynthetic materials, they have some influence of ultraviolet rays, that is one problem.

Installation must not be contaminated by surrounding soil and compaction is required; whereas, installation is easy because it is quite convenient to put a Geotextile and also that the you can even if the soil is contaminated there is no problem actually..

Like, the soil can be in touch with the contaminated soil can be in touch with the filter. Risk of damage of course, aggregates there are no problem at all whereas, in Geosynthetics, it is subjected to puncture and tearing. So, one should be careful.

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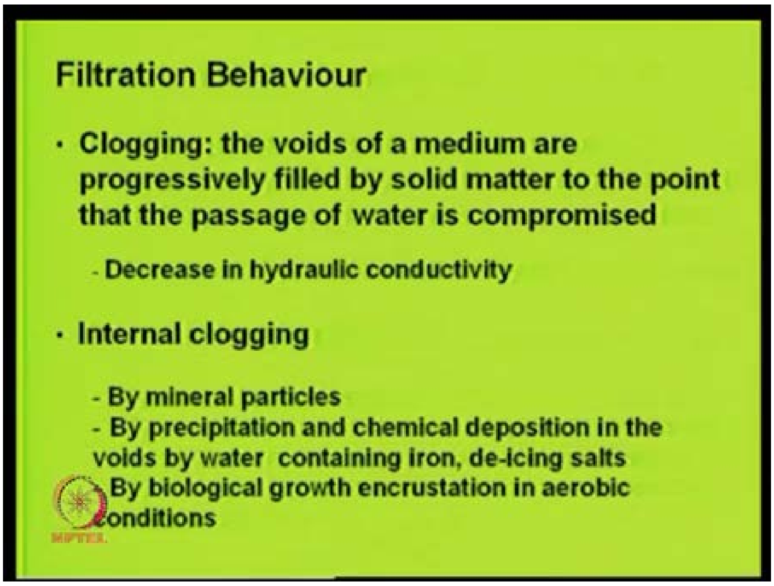

So, what is this clogging? Clogging is something very important, we should understand particularly in the case of filters, that the voids or getting filled up by the solid matter. You know, to the point that there is passage of the water is compromised. So, there is a decrease in hydraulic conductivity. Then, internal clogging is also possible by mineral particles by precipitation and chemical deposition in the voids by water containing iron, de-icing salts, biological growth, encrustation in aerobic conditions.

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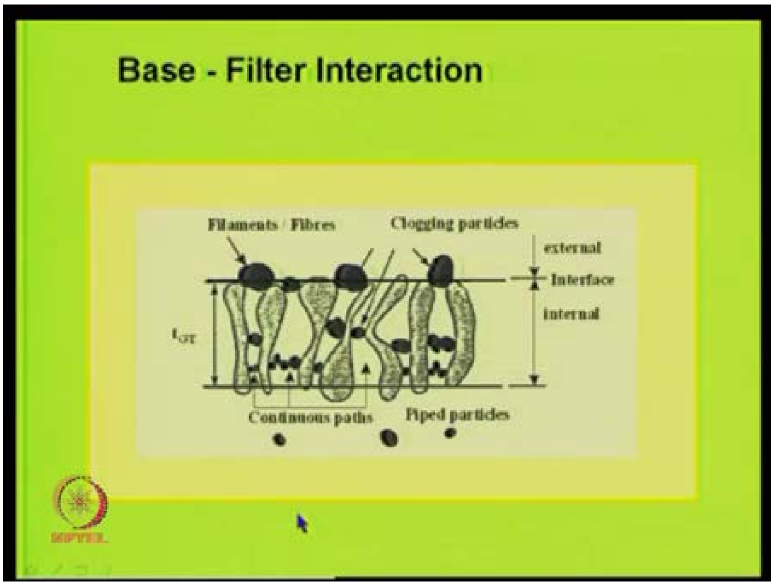

This is in a way depicts the filter base - filter interaction. See, external clogging, this is a this is a Geotextile material. This is ATGT is a thickness of the Geotextile and if there is some deposition here, the Geotextiles can lead to clogging. That is its external and internally also, it is can possible that it can clog you know like this. With some biological depositions and all that clogging of particles are also possible here. So, this things one should understand even this is actually also possible in you know the natural aggregates, but one thing one should remember is that, the paths are continuous. you know in the case of Geotextile, it the it is much more porous compare to the natural aggregates.

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Where do use them? you know applications are too many, You know you know whatever whenever there is a water flow and if you want make it properly flowing, we should use drainage, having the good drainage functions are important. So, beneath pavement bases and base courses, retaining walls and bridge abutments, drain and well pipes, slope stabilization, earth dams and levees many like erosion control like it. It protects the runoff collection, slope protection along stream banks, scour protection around structures, construction facilities across and adjacent to water bodies, culverts drop, inlets artificial stream, channels, etcetera.

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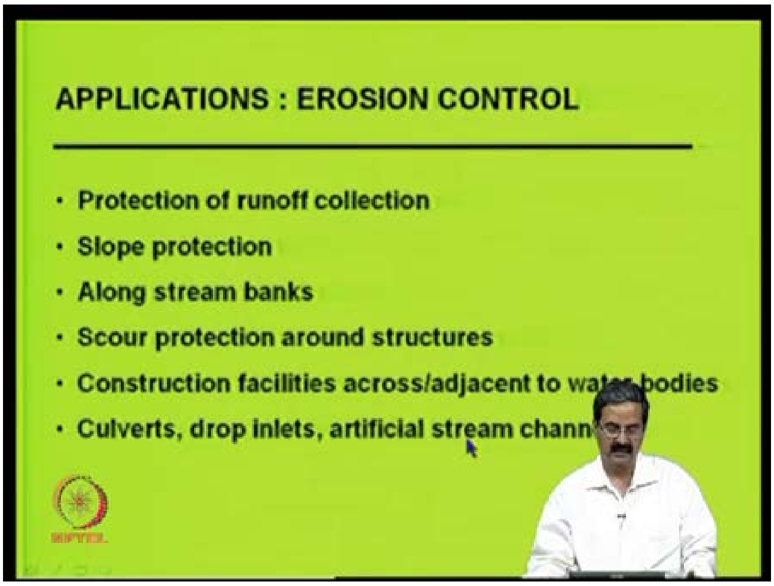

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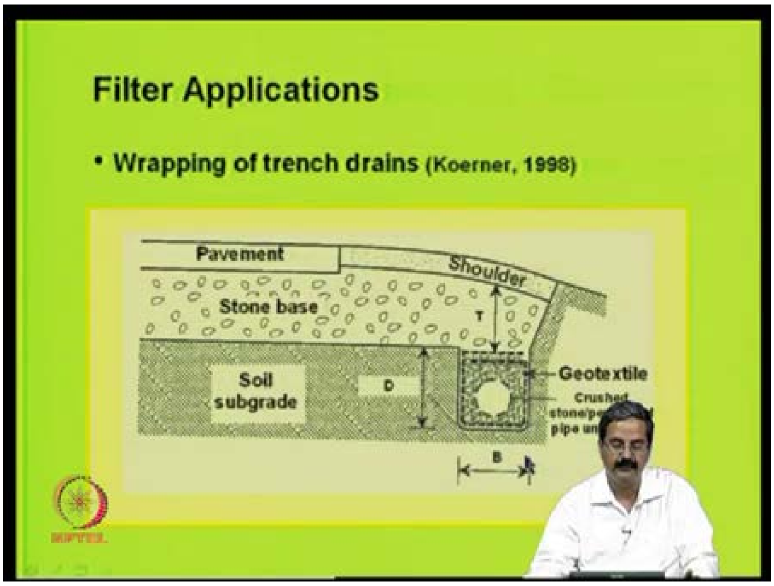

So, this is a typical example like you have a pavement pavement shoulder, then soil subgrade and the Geotextile is put like this you know . You can early, even this is a pipe here. So, this is how it is done and in the case of a the you know retaining wall, this is a way it is done at the early you had some 30 centimeters or 50 centimeters gravel here.

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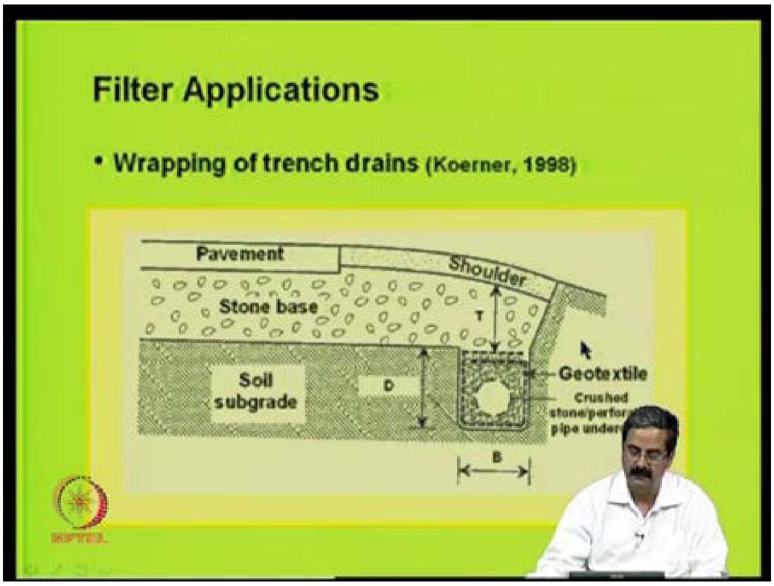

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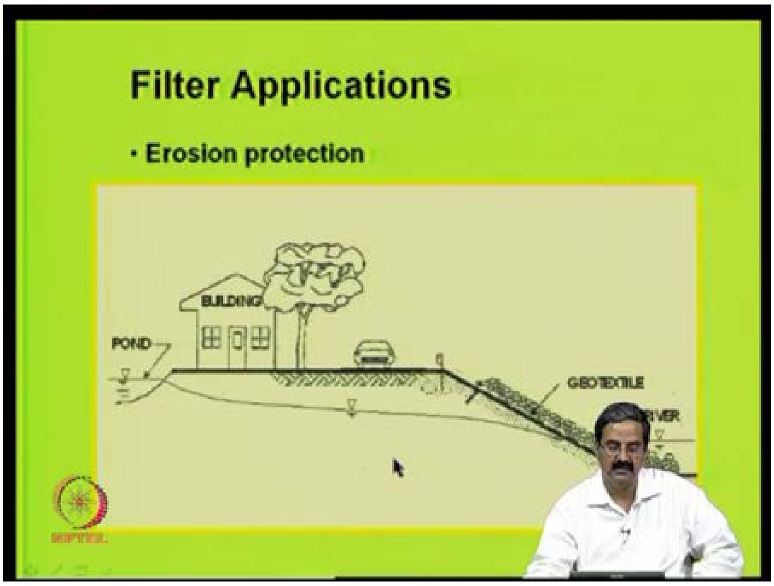

Gravel and then start compacting it, that is how we do it. So, then you have a simply you know you have a Geotextile here then it have a drainage here. That is it. Then erosion protection like, see you have a Geotextile here, what happens? We do stone pitching in the you know in. We are use this pitching up stones keeping like this, but still you do not. They do not lost because the possibly, they know what happens is that this pressure and water, the phreatic line comes here and then it reaches here the possibility is that what happens because there is always you know soil and aggregate mixing up. There is always a a pockets of low settlements and other things and then they finally, it leads to lot of you know disfigurement of the whole area but if you have a Geotextile like this, then it is only the water, that is allowed and the soil that is there as a working as a slope stands there.

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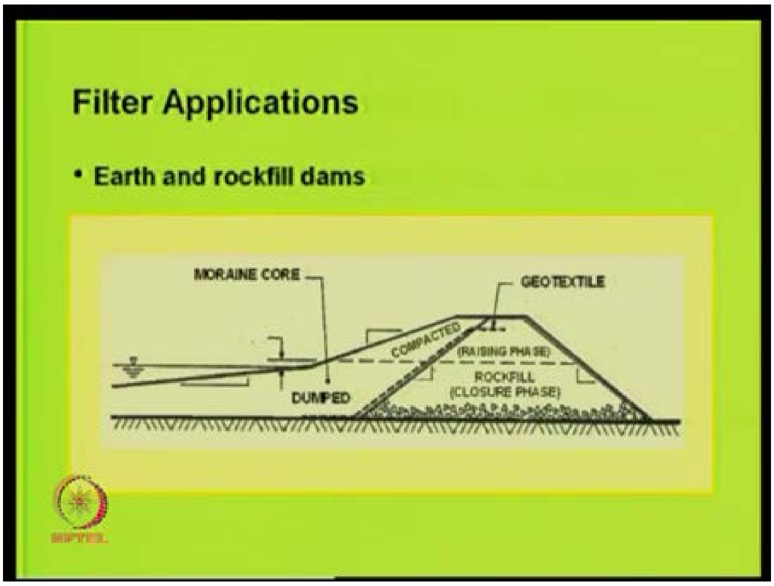

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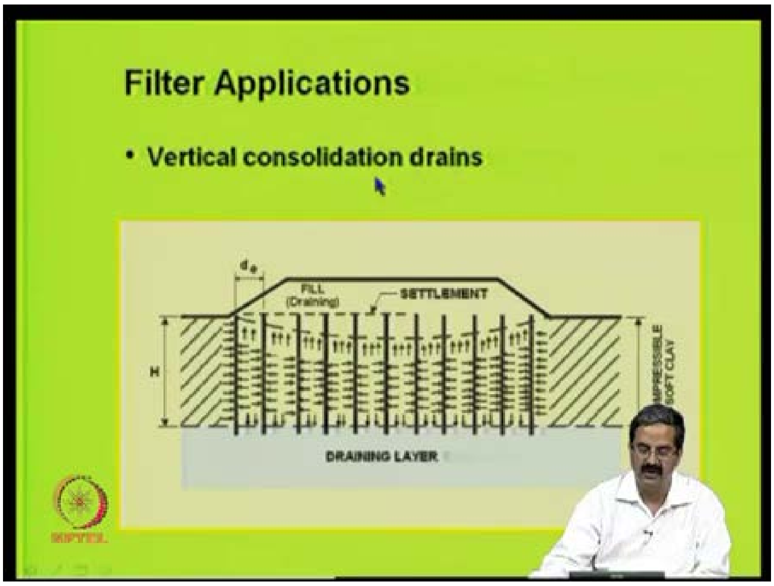

So, that is one important point and so in the case of dams like you one can put a Geotextile here, one can put a Geotextile here and consolidation, vertical consolidation drains, we have already seen that you have a a prefabricated vertical drains in which the central portion is You know the it has a drainage channels, it they then the cover you know, it is called a cover cover access the filter because it only allows the water and then the water released reaches at that the top and bottom and it gets pumped out.

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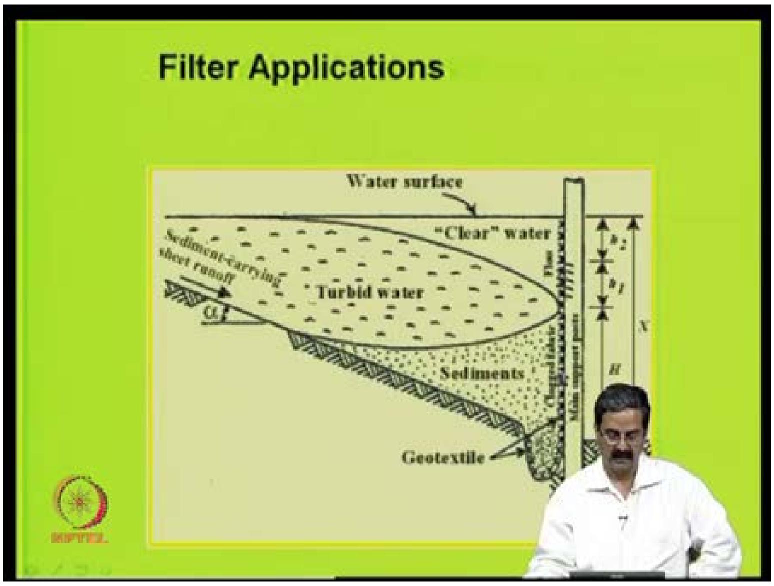

Then, there is another one that in some places, What you call You know the one can have you know sediments sediment tanks, you know if you have a material like this, it is easy to clean them also and then the possibility is that sediments get deposited like this and then one can effectively this also acts in this cases.

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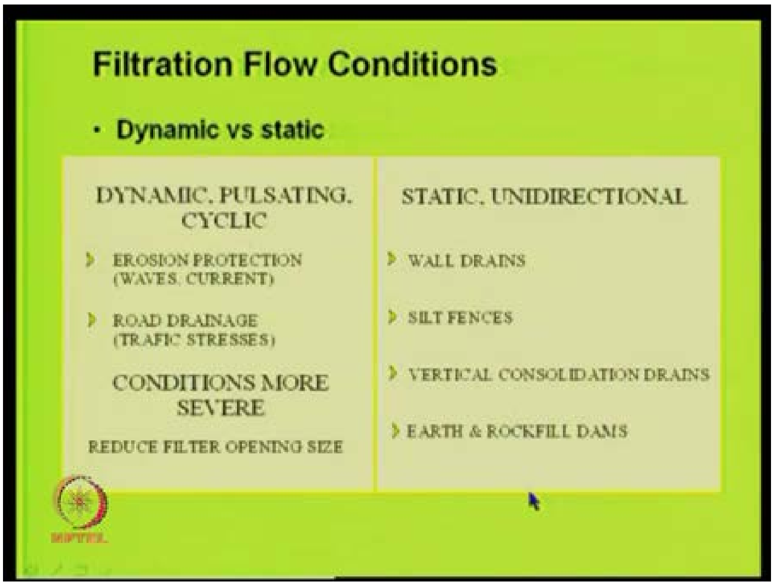

So, there are many applications here in the for a particularly filtration drainages. There are so many application that you know, one can think of and actually the maximum use is in this area because as I said wherever there is a water problem, water plus soil related problem, it is better to isolate them and problem is reduced. There is another important point that we should understand. There are two types of flows: One is the static and the other one is dynamic. What is a dynamic flow? the dynamic flow is nothing, but it is cyclic pulsating like you know in the case of or high forces, whatever it can be and in some cases, this is static and unidirectional.

So, where is it in dynamic and pulsating. Actually in erosion protection systems where the water comes and continuously imping on the you know sure protection systems, you know it is a dynamic. Road drainage you know it is a combination of traffic. You know the thing is the moment, there is a load on the traffic, the water goes out and if water goes there is always that cyclical response. That is there at the fundamental level and the conditions are suppose to be more severe here. You know, like why it is the distinct is important is that, we should understand. You know, the what is a force acting You know how do you handle the filter design?

Then static and unidirectional: In the case of wall drains; in the case of silt fences; in the case of vertical consolidation drains and earth dams and code these are all no problem at all they are all unidirectional.

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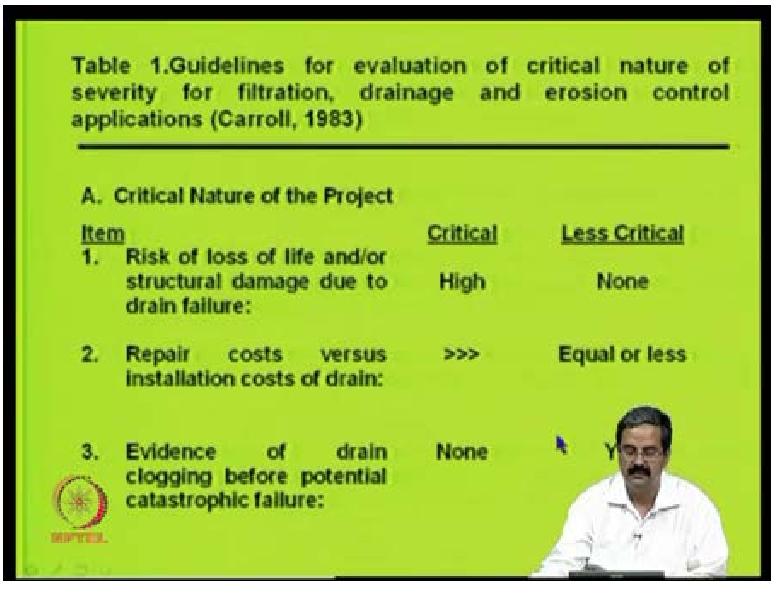

and one should also understand the nature of critical nature of the this problems. Particularly, one should design the systems in because unless you understand the criticality of the you know the projects, say for example: irrigation projects, if you do not understand the criticality of the projects then it is very serious. and so there is a need to understand to what extent it is important. Say for example: here critical nature of the project. Risk of life and structural damage due to drain failure: say for example: the drainage is not good and then there is a pore pressure development and all that things are there. Then the requirement are going to be very high, you know criticality is very important.

Repair cost versus the installation cost of the drains: So, one should be able to understand what is the difference? How much the repair could cost? and how much is the cost of reinstallation? are some of these things. One should able to understand. So, that could be if there it is not much, it is equal or less then less critical. Then evidence of the drain clogging before potential catastrophic failure: you know. See, in some, if you have information about the possibility of drain clogging, then this much more easy to handle and it is much less critical. Otherwise, if it happens after the damage and all it is going to be serious.

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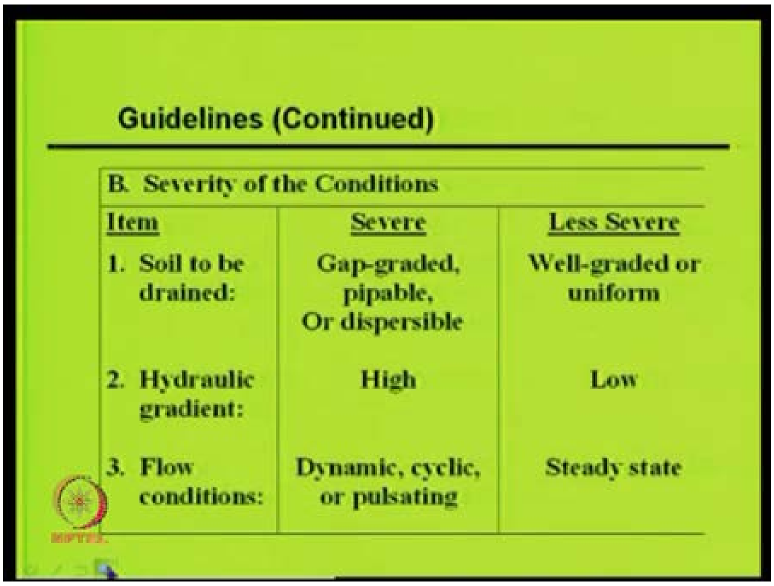

Then, what are the other issues that we have: One is that the, if the type of soil is it also has a function of the type the type of soil. If the soil is gap graded or pipable, you know pipable means that it can easily come out or dispersible that, if the material when if it is well graded, then the problems with filtration are less like you know because what happens the pores are all the the distribution of particles is so well So well presented in that particular, the material that there is no problem of pore pressure mobilization and all that. but if it is a gap graded material, the problem is that, water gets accumulated and there is a pressure and then there is a possibility of damage. So, soil to be drained. So, this is a severe condition. This is less severe and then hydraulic gradient, if it is going to be high you know, it is going be definitely the condition is severe, but if the hydraulic gradient is low then there is no problem.

Flow conditions, Yes, if it is dynamic and cyclic, one should understand that properly and then steady state is another issue, that like, it is not serious. Like it, you just smoothly flowing, then there is no problem, but in some other case where this lot of erosion and then there are lot of waves and all that, if the possibility of damage is going to be high you have to understand that it is going to be severe.

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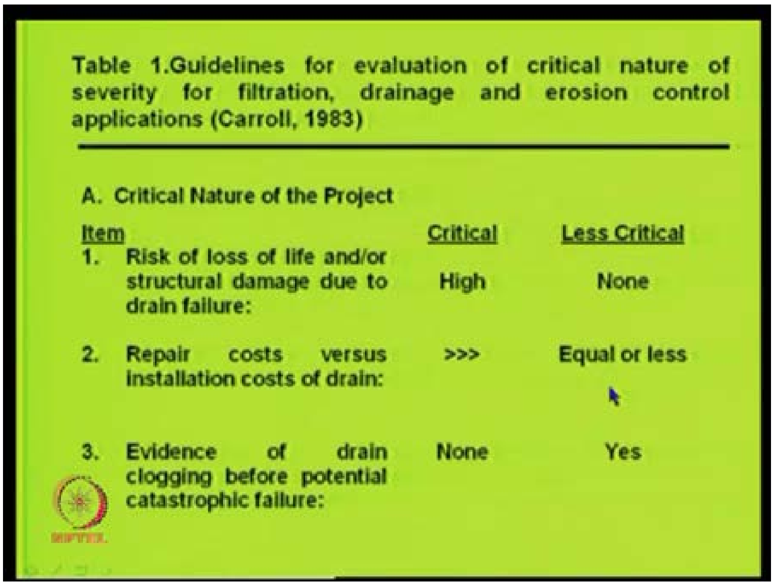
Table 1.Guidelines for evaluation of critical nature of severity for filtration, drainage and erosion control applications (Carroll, 1983)

A. Critical Nature of the Project

Item	Critical	Less Critical
1. Risk of loss of life and/or structural damage due to drain failure:	High	None
2. Repair costs versus installation costs of drain:	>>>	Equal or less
3. Evidence of drain clogging before potential catastrophic failure:	None	Yes

So, the objective here is that why why why are you discussing this is that essentially the previous case is also we should be able to understand, the critical nature of the project to what extent they are going to be very important you know. You assign that, Yes, it is a critical or less critical depending on the nature of the project as well as type of soil, Severity of the conditions.

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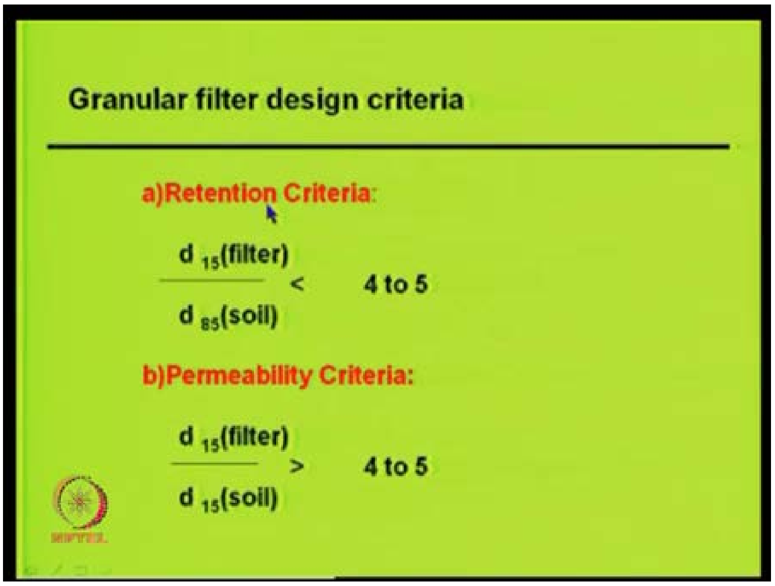

You may remember that with all this problems associated with the importance of the design, that we have. The design criteria is very empirical. What we do is that if you want to retain the soil, say for example: you do not allow the soil to go out, we have from the grain size distributions, you take a d 15 of the soil from the filter d 85 the grain size distributions both of them you have and then if you say d 15 by d 85 of the soil, if you find the ratio is to be less than 4 to 5 soil is retained. That is a criteria that given by then permeability criteria d 15 of the filter should be much higher than the d 15 of the soil like at least 4 to 5 times. So, that is what we said these are the two filter criteria that we say that. We expect that it is going to be satisfactory. It is not really not easy to say why? Because, just if you follow some of this criteria like that; however, we sure about time dependency and you know how do I expect the filters to work for five 5 years where is a check here, there is no check . But then people have been living with this and then you know of course, there are lot of theoretical work, but this have been you know more or less practiced to maximum extent.

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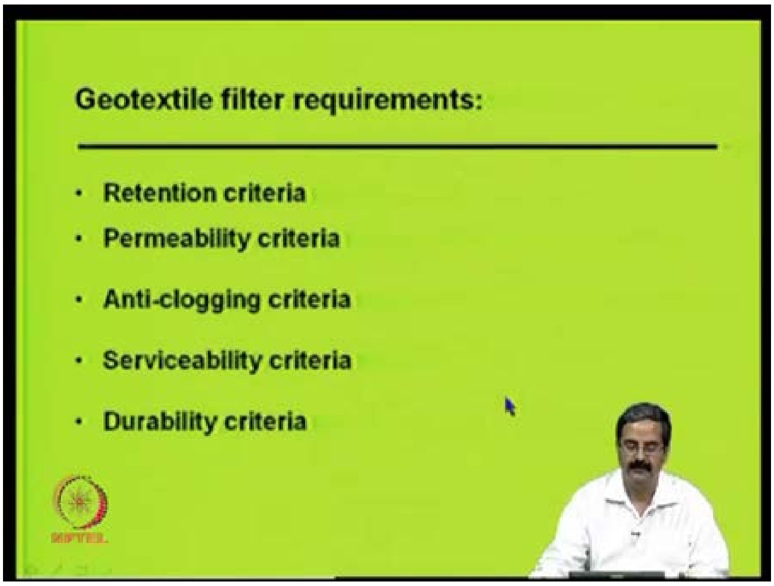

So now, we know that Geotextile performs better for the simple reason, that it can create you know. It cleanly removes the water and thickness is less. We saw the differences between a Geotextile filter and regular filter like a aggregate filter, the differences is good and if you you know if you are putting the Geotextile, you should also design it properly. One is a retention criteria and permeability criteria and anti clogging. So, people have thought about the thing is criteria of just soil retention permeability may not be sufficient, we should have some more information because when you are putting a Geotextile, it should work properly. That was a question.

So, the people looked at if I am putting Geotextile it should not get clogged. So, anti clogging criteria was put then, there is a serviceability criteria like you know. It should be able to work for some time you know. If it does not work, there is no use and then durability criteria is also specified.

So, this is another the criteria that they have introduced because whatever you do should be durable like you know if it lost for 6 months, if you do a design, filter design and you do not know how it works or if it only loss. See the only problem is that, if the filter fails you will immediately see the result like you know water logging in the area or some of these things.

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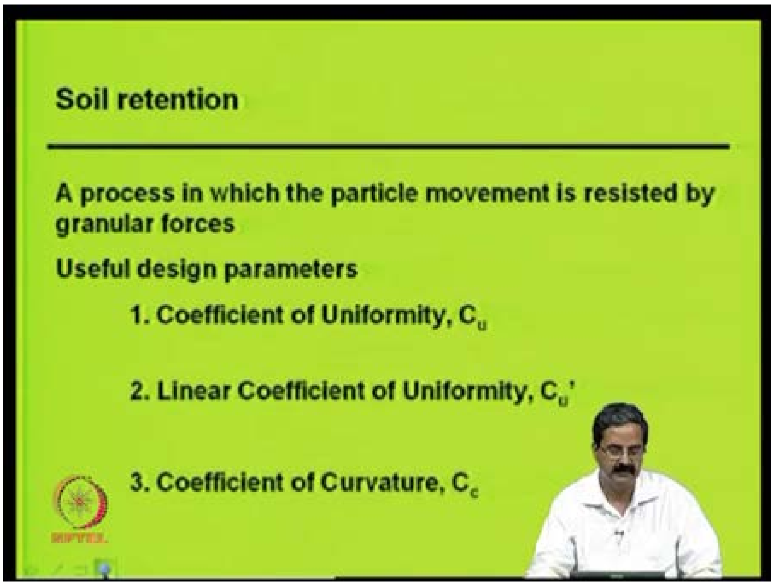

So, how do you get some more information from this is something that you know. In fact, there was one professor Giroud, who did extensive work on filter criteria, there is lot of very interesting work and he came out with a simple design procedure that we will discuss and what are the design parameters? He looked at you know the thing is the grain size distribution is one thing. So, coefficient of uniformity is one thing, which is we normally use. Then he also defined a term called coefficient of linear coefficient of uniformity, then coefficient of curvature.

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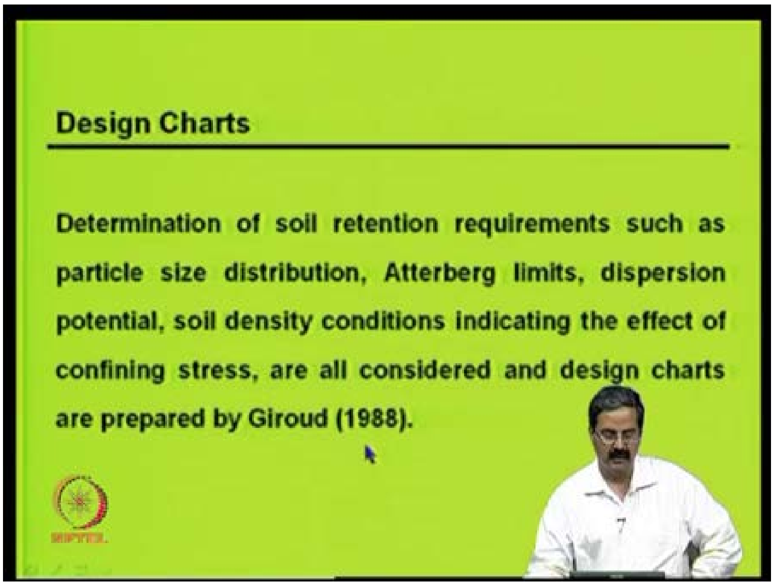

These are all some terms that that are useful and he prepared, say he realize that apart from the particle size distribution, he can also have some idea about Atterberg limits dispersion potential because dispersion potential is another important thing and the density of the soil is also important. you know some loose soils, they have a tendency for you know they become very loose. They are very loose and the water may waste, if there is a water availability, soil and water both come out. So, density is very important. So, density all these things are all very important and he prepared some designed chart which is very interesting.

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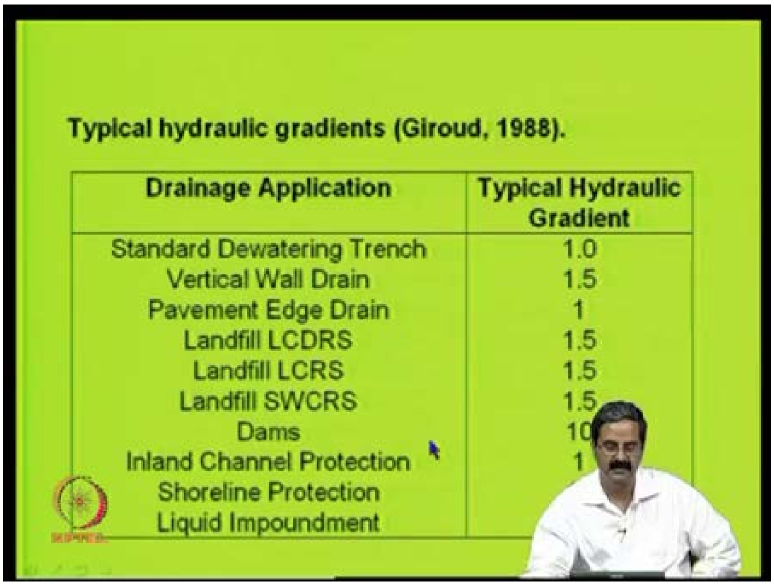

And he also identified the hydraulic gradients because the hydraulic gradient in each problem application is different and one should use gradients properly. Otherwise, the you know, you cannot assume the same type of hydraulic gradient everywhere you know the behavior. Say for example: in the case of a dam, it could be different in the case of a small trench it could be different. So, he identified typical hydraulic gradients, say for example: standard dewatering trench, It is about 1; vertical wall drain about 1.5; pavement drain, it is one and landfills it is about 1.5 dam stand inland. So, liquid impoundment stand. If he is able to identify, say for example: if you just identify the filter to be every effective, you say that the filter has to be working there. Then, what is a pressure that is acting on it? and what is the hydraulic head it is coming on that? you should be able to understand.

Like one can do all of these things from flow nets, we are familiar with flow net construction and one can simply know the steady state conditions of the water flow and if you know the structure, whether, it is a pavement edge and other dam and you will be able to know where is that piping piping chances of piping are there? what are the chances of hydraulic gradient being low or high? One can calculate and then come out with some understanding, otherwise it is very difficult to just based on the soil retention criteria and permeability criteria alone, it could be very difficult.

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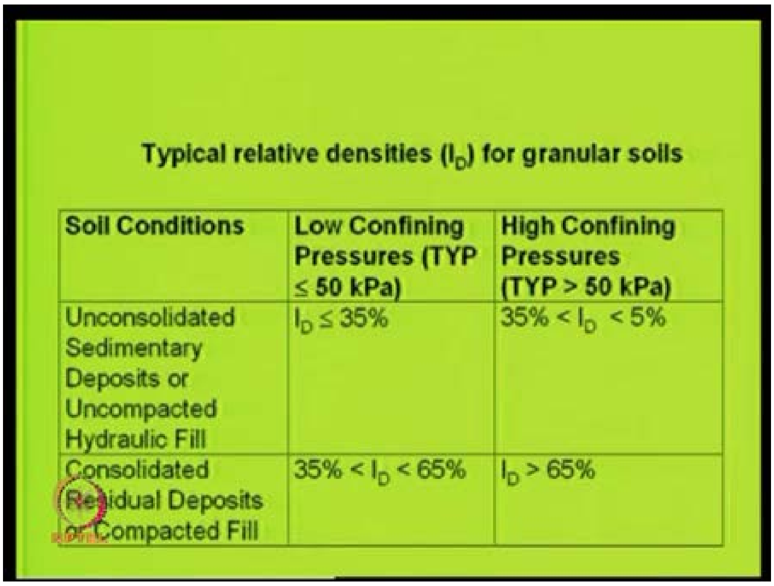
Typical relative densities (I_D) for granular soils

Soil Conditions	Low Confining Pressures (TYP ≤ 50 kPa)	High Confining Pressures (TYP > 50 kPa)
Unconsolidated Sedimentary Deposits or Uncompacted Hydraulic Fill	$I_D \leq 35\%$	$35\% < I_D < 5\%$
Consolidated Residual Deposits or Compacted Fill	$35\% < I_D < 65\%$	$I_D > 65\%$

So, the other important thing that he made was that soil conditions, if it is a loose soil like you know unconsolidated material or a uncompacted material, the relative density is about you know the confining pressure is about 50 k p a, the load is not much. So, the related density is in the less than 35 percent and if it is high confining pressure is the relative density in the range of 35 to you know 50 actually. So, it is then consolidated residual deposits 35 to 65 and relative density is high.

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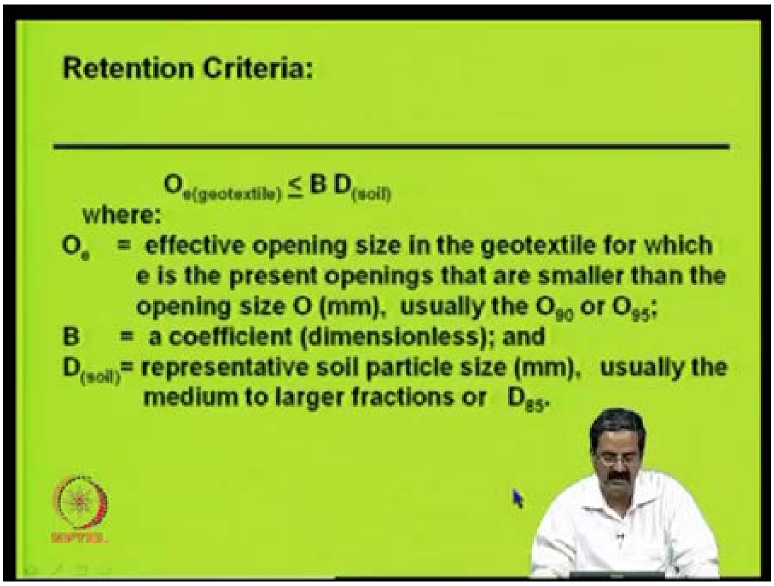

So, some of these numbers as given and so he has been able to identify the pressure or the hydraulic gradients, the type of soil influence, the type of pressure influence and all that and he proposed a a retention criteria you know using Geotextile.

What is that retention means, the what the material should only allow the water to go out and soil should stay back there. So, the apparent opening size of the Geotextile should be less because it should be less. Otherwise, the particle will come out. So, it is some ratio of the soil D, D size of the soil there is some factor B here. So, the effective opening size in Geotextile for which, e is a openings that are smaller than the this the O 90. We call it.

We call it O 90 sometimes and less than or equal to B and you know it could be some number , you know it can be one also like B is a coefficient; normally what we say is that like D. D soil is a representative soil particle size usually the medium to larger of fractions you know like you know you take larger size particles, in fact, we also defined in the regular criteria and the it should not allow the soil to the soil to go out. So, they it should be, so small and you also compare with a bigger size here.

So, some ratio it should be 3 or 4 or whatever, we said. So, the same this apparent opening size how do you get it?

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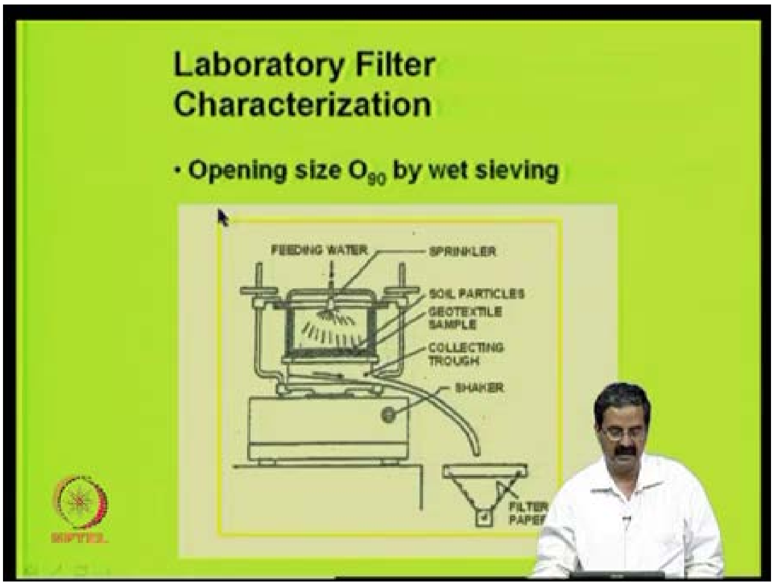

There is a test here. By there is a it is called O 90 size and apparent opening size actually, we discussed earlier in the hydraulic properties of Geotextiles, it is just obtained by a simple test in which you know the you can have a series of glass beats, say for example: point the glass beats can be of different standard sizes and you it can be you know you place that soil particles Geotextile sample, you can see there are two samples here: There is a water flow feeding water flow soils particles. Then Geotextile sample and collecting trough.

So, the like you have that soil particles, you say 0.1 size all you make a some material. The some material here, only with uniform size actually 0.1 and then you have a Geotextile allow the water to go out and water cleanly goes out in some cases, where 90 percent of that of the whole water comes out that size corresponds to D O 90 size apparent opening size.

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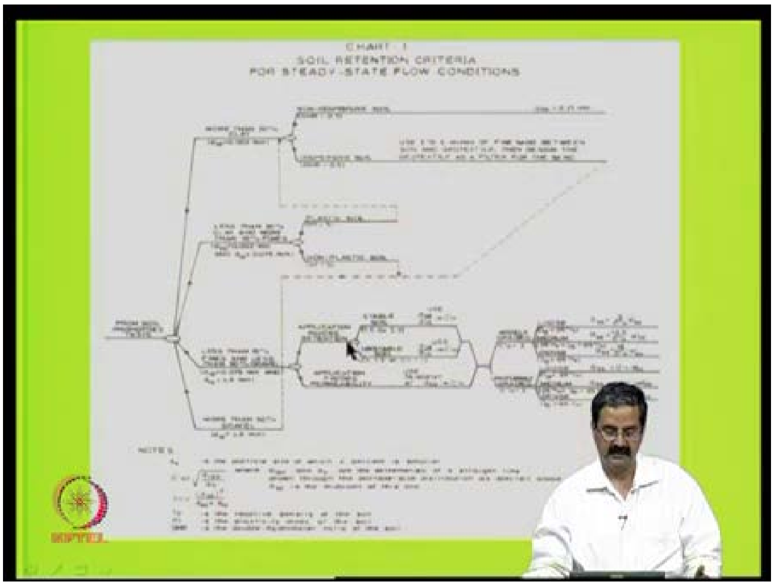

One can the characterize the Geotextile based on the apparent opening size . So,once you have that, there is you know there is a test that we should do and there is a chart that is given by you know the professor Groud, there is a simple explanation here of course, it is not very clear, but at the same time I should I suggest you to see the textbooks that are available on this topic.

But because it is very difficult to it is a big chart and it is very easy to, I mean it is comprehensive chart, this chart needs say for example: there is a tank band; you do not want water to see that the tank band, the tank band should be stable and you should not be you know the soil tank band should not get you know erosion type of failure and all is that our question. What do you do is that, now you want to do filter stone pitching or a filter pitching for it and you want to come out with a simple design for filter. That is our objective.

So, what is the procedure? You take soil samples from the area; then find out its clay size. You know percent clay more than 20 percent less than there you have a clay. What is a clay content? Once you know the clay content you can use at appropriately. Say for example: in this chart what I want to say is that, if the clay content is more than the like more than 20 percent, the possibility is that you should check. If the clay is a dispersive type of clay you know clay, there are some clays that I saw that the movement you put in water it just starts coming out.

So, for example: if you are trying to put a nice you know you want a nice water body there and then you want a nice slope and the the water should be nice and the slope also should be nice, but there there is what you want you know, you do not want the slope to be collapsing out of erosion. So, you want to really check, if this clay that you have, say for example: the movement the soil testing results show that it is more than 20 percent clay, you have to see whether it is dispersive soil or non dispersive soil.

So, there is a test for it which is called you know we have a some prevision there, what is called double hydrometer test? is there and based on that test you get some result and whether, if it is less than or equal to 0.5, then it says that you have to provide an apparent opening size of 9 less than 0.21 mm like point Geotextile, the size will be do fine that it gives a size of 0.21 here and if it is somewhat dispersive then, you say he says that you have put a cushion of 3 to 6 inches of fine sand between the soil and Geotextile.

You know if the material is so dispersive and if you add as a tendency, you need to put a cushion and then put a Geotextile. Otherwise, even Geotextile may not be affective. Then if the clay is if the material is less than 20 percent clay and more than10 percent fines, so there is some more criteria here is a soil plastic means, if the not non plastic. If it is plastic and like P I more than 5 there is again it goes back here and if the plastic, it is not plastic then again it comes back here, like we come to this chart and if the sand material whatever you know, it has less than 10 percent fines and you know this is then it it goes to this material and if it is more than 10 percent you know more than 90 percent gravel. you know sometimes it is just a gravel in deposit in-situ. Then he he suggest to provide you know like case like this. So, put some sort of if it is fully gravel, then the you have to some sort of sand cushion and the Geotextile you cannot just so that is what he says. So, and then if it is a some many of the materials fall into this category because it will be less than 10 percent fines and less than 90 percent gravel and we should also see that we should understand that, the there is a difference in terms of application application. Do you want water to flow like application should favor permeability or you want soil to you you have to choose. You know the thing is there are two things here: One is that the flow of water soil retention is something. So, from the point of soil retention you need to small pores.

But in terms of the permeability criteria you want big pores. You understand the same. They both are contradictory requirement. It is very. So, the thing is that, it is a very like.

Based on grain size distribution only you want to get everything again, so it is very tricky contradictory requirements and what we do is that in some cases, we should decide you want application just retention alone or more retention or more permeability. So, in some cases, where you you want more retention, there is a system that we have where if it is a stable soil based on c c, and c u and all that. One can get and then if the c u dash, we have widely graded material and you can find out it is. Say for example: if the application pavement retention one then it is a stable soil, then you have system like this c u dash also, you can find out and if you know the relative density of the material, also then you can find out the O 90 actually the whole exercise here is to calculate O 90 size of the material. what is this is actually a retention criteria; soil retention criteria for steady state conditions.

There are two types of conditions: One is the steady state condition; the other one is a dynamic condition. In both the cases, we should be possible for us, to find out what is the steady state condition? what is the dynamic condition?.

So, in the steady state conditions where is a single flow, you this chart from soil suspension criteria, it gives the apparent opening size. You can see here O 95 should be less than 0.21 .

So, the other thing that I was just mentioning, coefficient of uniformity linear one. It is square root of D 100 by D 0. There is another term and then c c, we know the definition D 30 whole square by D 16 to D 10. All these terms are important in using the fix in soil suspension criteria. Because you want a very thin pore, thin size to see that the water I mean soil is retained not the water.

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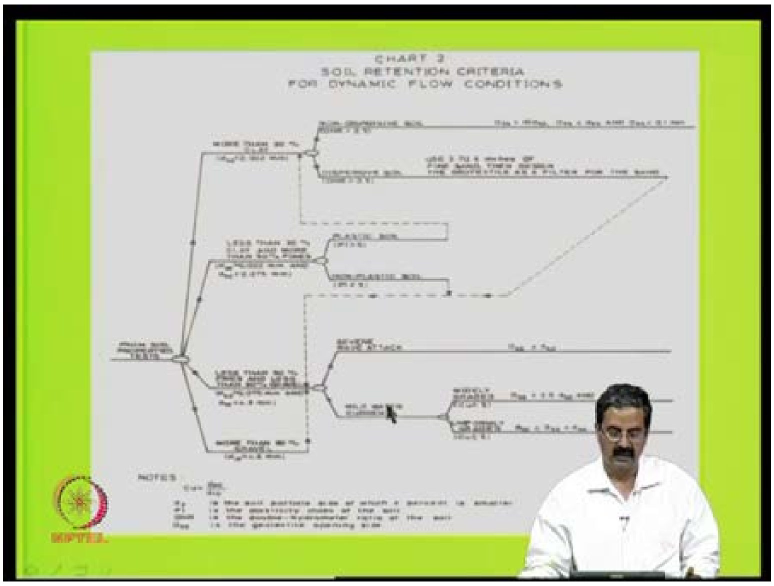

So, this is for the dynamic conditions: You can see that, it takes care of you have a soil testing results and then you have some gradation characteristics. It will what Is is it severe wave attack? or Is it a mild wave attack? and then is it a plastic soil? Is it a non plastic soil? Is it a dispersive soil? All that criteria is actually addressed in this. And once we have this, then one can choose the proper size of the Geotextile

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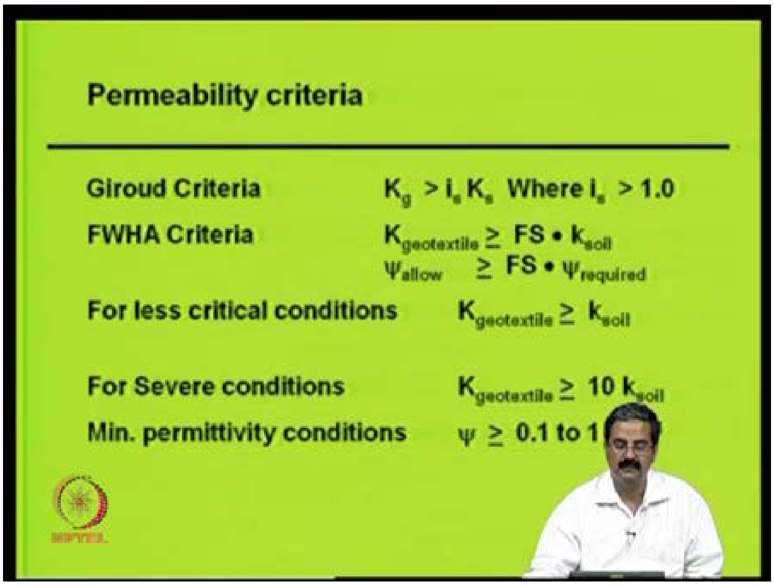

Once you know the the size of the Geotextile of course, from suspension criteria you also should see, what about permeability criteria? The objective here is that, the permeability of the Geotextile should be more than the permeability of the soil. The water it should be able to allow the water to go out and then the that is a function of the hydraulic gradient I S so if it is more than 1.

Then, even federal highway code you know like of course, in India, we do not have as rigorous course on these lines, but normally, we follow federal highway as well. So, here again K, Geotextile should be more than or equal to I mean like a factor of safety 3 or 4 or whatever of the soil and then we also have what is called permittivity as I just mentioned, the permittivity is another number like as I said thickness is an important parameter in Geotextile. So, K by T thickness K, K is nothing centimeter per second divided by centimeter.

So, you will get, we call that particular thing as permittivity which is we denote by ‘psi’ you know because if you want to compare different types of Geotextiles of different thicknesses, How do you compare? I must only have some dimensional way of non dimensional way of doing it, which is in terms of this you know because that is important,

whereas, in other cases like stones we do not have that type of criteria. So, this permittivity criteria is another important and permittivity allowable should be more than required, that is one thing and for less critical conditions, the K Geotextile is more than or equal to K soil is fine, but for severe condition, the factor of safety should be good and minimum permittivity conditions as I just mentioned, it is a centimeter second by centimeter thickness so it comes in the units of second minus and it can be 0.1 to 1.

So, these are all the some minimum criteria, that they have given and if you just see any of the manufacturing product literature of the Geotextiles, they will all have this information.

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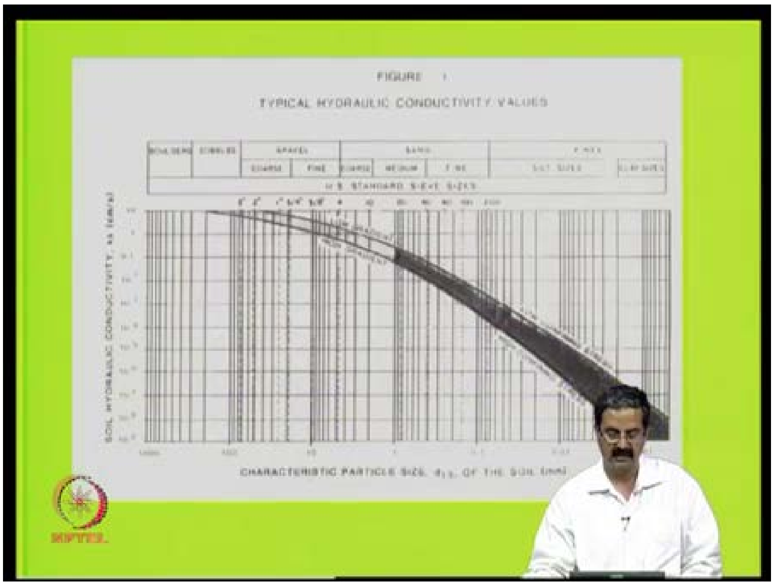

Actually, this is another important relationship. This is called typical hydraulic conductivity values. In fact, we know if you know the D 10 of the particles. You know how to get K value; So, that sort of relationship is given by you know this is instead of D 10 this is D 15 size and if you know the D 15 size of a particular material, you can find out its permeability and if you know the confining pressure also, in the code in the Giroud method, they have given this. Say for example: if you know the D 10 of the soil and then it is subject to high confining pressure, the permeability is some number here and if it is subjected to low confining pressure, it is little higher.

So, like that one can calculate because it is very difficult to do permeability test all the time. In the field and all that. So, these are just in the absence of any test. One can do that.

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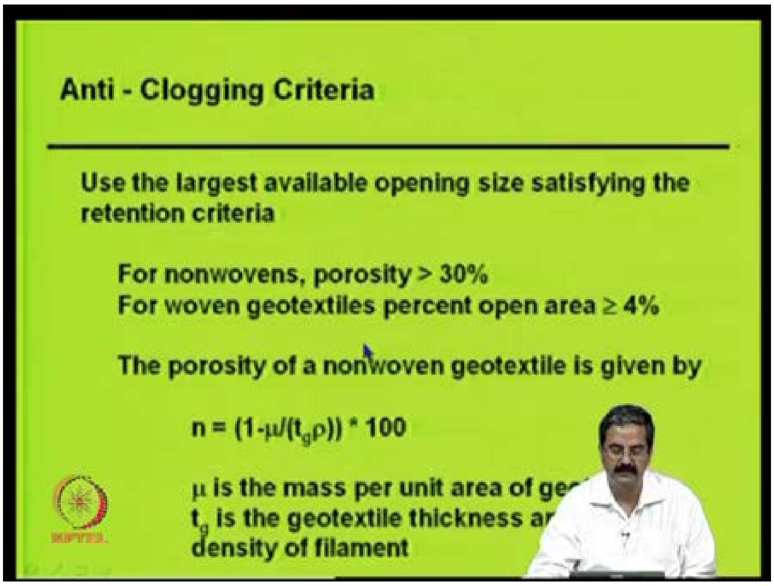

So, anti-clogging criteria is something that is another important thing, say, we do not want the material to be clogging. In fact, in some cases, we will we can repair, but in landfills you know in the landfills if the things gets clogged, What happens? Leachate gets generated; Leachate gets accumulated actually. There is no way to remove the Leachate.

So, what people will have is that, in landfills they have an automatic flashing systems. If you go to a landfill, they will have an automatic flashing systems, in which you know the movement you know that yeah the hydraulic add has increased, you know they will have monitoring also. How much of Leachate is there in this particular locality? One can monitor actually, they will put all the pipes instrumentation is heavily done in landfills and once there is a particular problem in a particular area, then it gets showed up as gas and Leachate generation both gas and Leachate generation if they are very high, then we know that there is a problem.

So, you have to understand, that you know Leachate particularly, you know there could be some problem because it brings lot of load on everything. So, it they number 1 it increases a chance of contamination of groundwater, it increases the load on the Leachate collection pipes everything. So, the movement you have that. So, people will have this automatic flashing systems, so anti clogging should clogging should not occur.

Soanti clogging criteria is important particularly in landfills, there will be lot of biosystems you know biota. So, they have a possibility of creating this clogging.

So, how do you do that avoid clogging? Best is to increase the size of the pores; So, if it is a nonwoven material like you know you discussed about two materials: One is nonwoven and woven. The for nonwoven, we see that the porosity of the Geotextile should be not, it should be at least 30 percent; The second thing is, if it is a woven the percent opening size should be more than 4 percent and the porosity of the non Geotextile is given by you know ‘n’ into this you know 1 minus mu into thickness of that you know mass per unit area into thickness and everything is coming here. So, once you have this that is fine.

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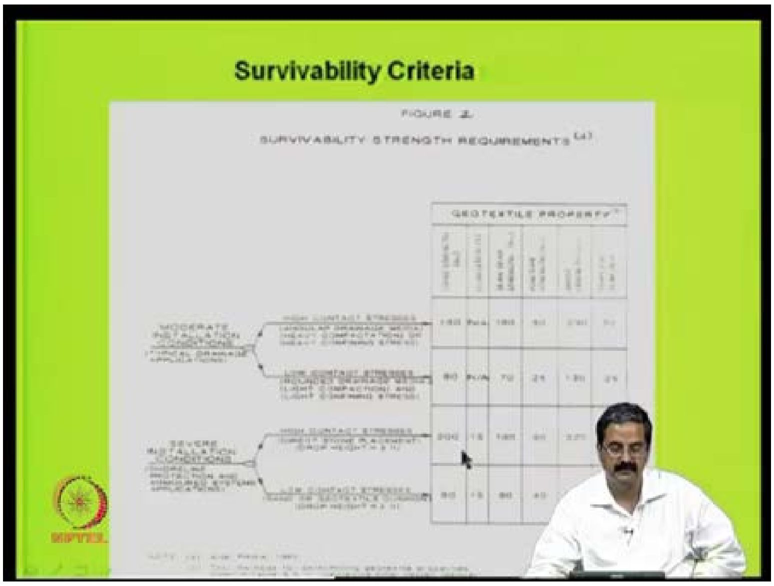

Then there is some more, you know you are putting at Geo textile. We should also see that, it should stand installation conditions. The Geotextile should not get punctured and all that quite easily.

So, we have what is called installation conditions which needs some minimum strength, you know we discussed about grab strength. There are so many parameters that we should have like, so all that was presented in terms of you know say depending on the contact stresses, like is it moderate or severe or all that. So, it gives say for example, grab strength of 9 pounds is and elongation 15 percent; then stream strength 80 percent;

puncture strength 40 lb, you know they are all in pounds actually. This is A 80. So, 90 80 40 these are all in pound. They are all says test you should get all these numbers are given. So, normally the Geosynthetic companies really see that these specifications are met.

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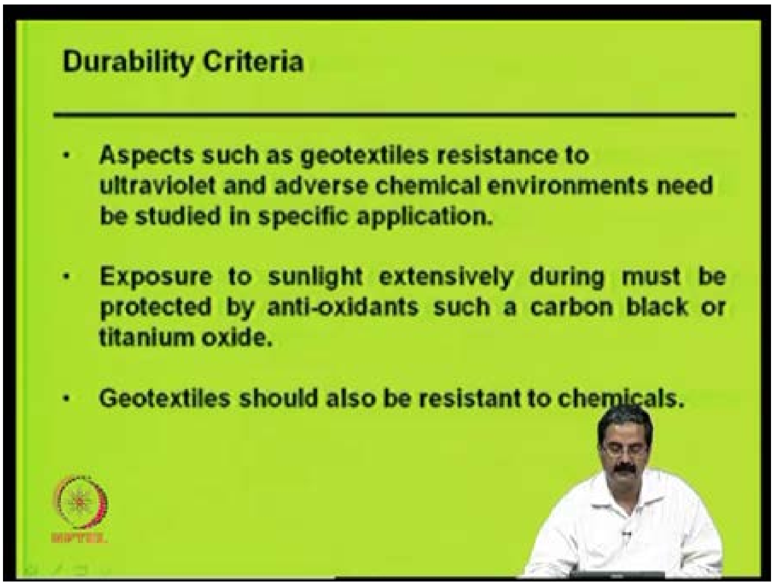

The other one is that, you should just see that, the durability criteria you know you are trying to use Geotextiles and they should not have wrinkles and all these problems ultraviolet resistance and all and chemical resistance also should be able to see that.

So, exposure to sunlight extensively, during it should be prevented and they have anti oxidants in that material and all that and they should also be resistant to chemicals.

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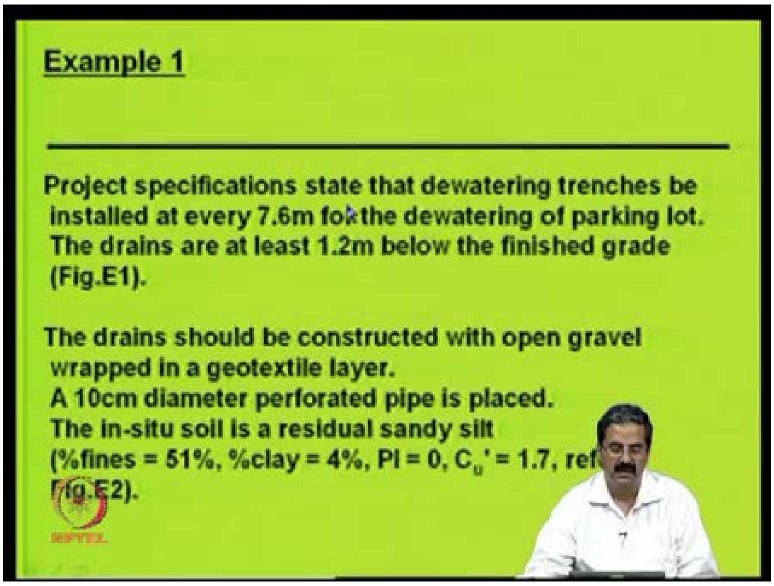

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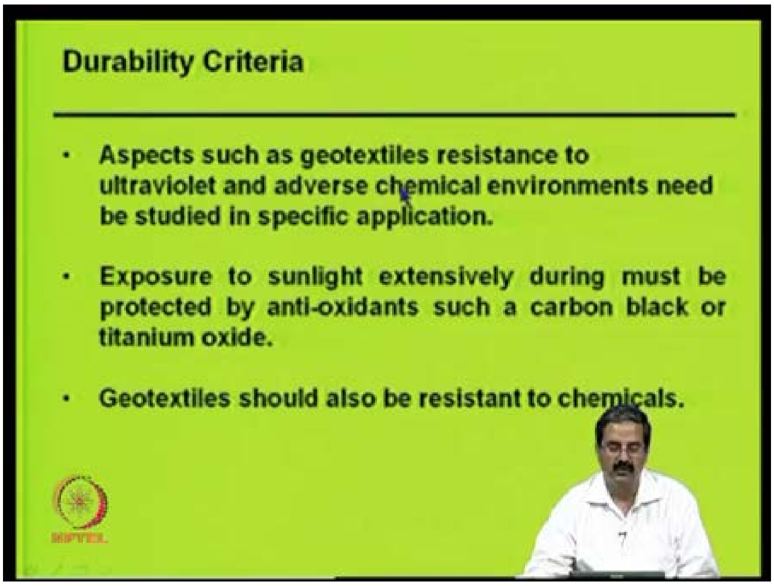

So, what I want, I would to like to say is that this five criteria are important ; One is a soil suspension criteria; permeability criteria; anti clogging criteria; then survivability criteria and durability criteria.

Once all these criteria are satisfied, then you know apart from then, it is fine. In a Conventional Geotextile, what you are doing you have only two criteria that we are doing: One is just soil suspension criteria; the other one is permeability criteria; Using the D 60 D 10 sizes, that is all there is no other design method, but Giroud, you know has they have he has looked into more detail and looked it all these factors and then come out with a design method, which is quite reasonably well established.

With this I will conclude and we will see some more examples on this filter design. Thank you.