Geoenvironmental Engineering (Environmental Geotechnology): Landfills, Slurry Ponds & Contaminated Sites

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Lecture - 13
Liners for Landfills - Part 4

So good day to all of you: we have been discovering and talking about liners for the last 3 lectures. I think and today let us wind up the discussion on liners for landfills, let us wrap it up in a nice comprehensive nyana.

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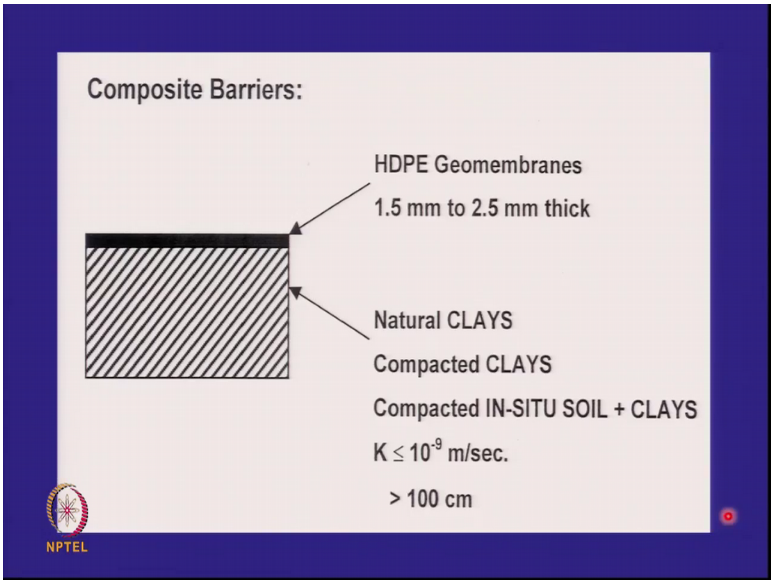

A brief recap, we have been discussing about this concept of a composite barrier which has a geomembrane at the top in intimate contact with a low permeability clay.

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A thin element and a thick element, and we started discussion on the thick element the compacted clays and the amended soils last time. And we said typically at a site we will have 4 options use the insitu clay if it is available excavate and recompacted.

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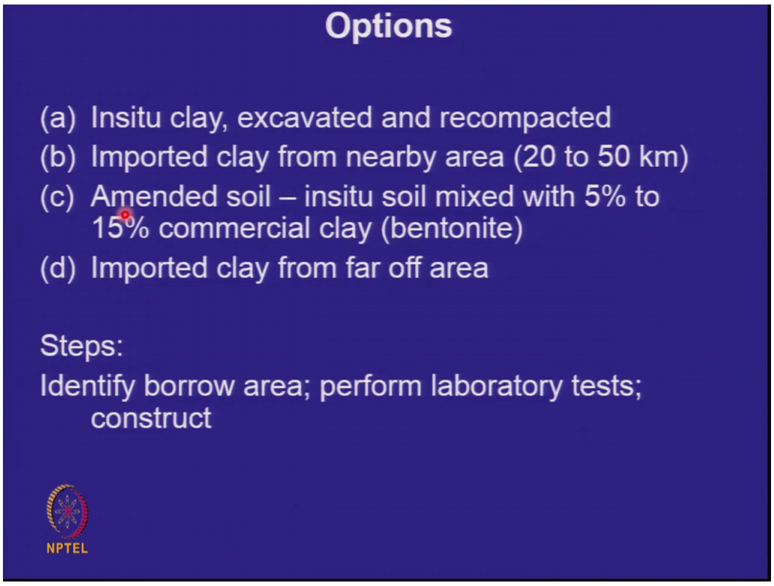

If clay is not available we will have to imported from a nearby area, if that is not the case we can amend the local soil by adding 5 to 15 percent commercial bentonite to it and the permeability will typically fall below the required level or you may have to import a clay from a far off area.

So, the steps typically add to identify a borrow area from where the clay is going to come. Suppose you have a borrow area, but the clay is still not having permeability less than 10 to the power of minus 7 centimeters per second because it is clay silt.then you can bring it from the borrow area and still do the amended soil; that means, you still add the commercial bentonite to it. And then you will get the permeability. So, you have to perform laboratory tests and then you have to construct.

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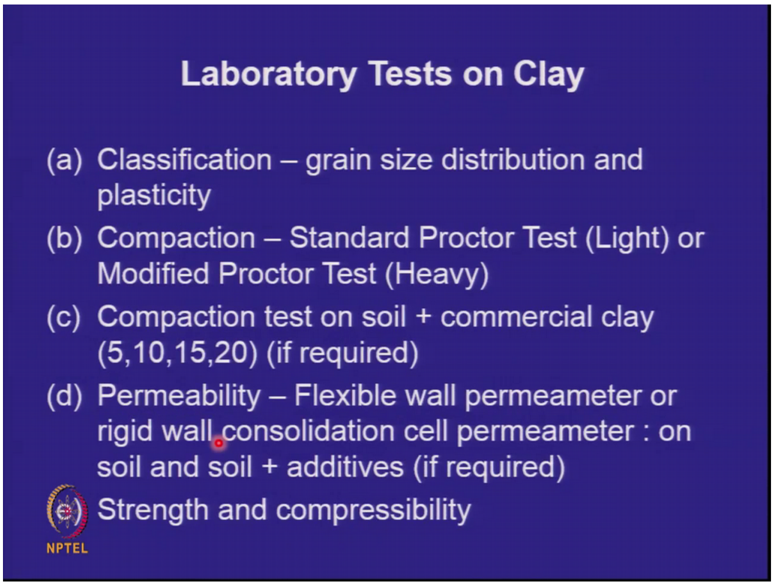

So, the laboratory tests which we talked about a classification of the soil grain size distribution and plasticity compaction the standard proctor tests we have done in the lab and the modified proctor test. And the compaction test on soil plus commercial clay, now the difference is in soil plus commercial clay every time you add the clay the compaction curve changes why because the grain size distribution is changes. So, the omc will change and the mdd will change.

So, we have to perform for all the range of additions. In fact, we should start from 0 original soil 5 10 15 20 percent. And then we have to find the permeability and this is the critical parameter and you understand that when we talk about permeability of less than 10 to the power of minus 7 centimeters per second or 10 to the power of minus 9 meters per second. We are talking about the saturated permeability and not the permeability of the unsaturated soil.

So, critical to doing the permeability test properly is the fact that we must be able to saturate the sample. And we must be able to prove that it is saturated. If I think I have saturated the sample, but it still has got air in it is going to give you a lower permeability and you are going to feel very happy that you have got a soil which meets the permeability requirement. So, we look at this a little more carefully and after that we can do strengthen compressibility.

Now, here a word is used flexible wall of permeameter which we have not used. In the undergraduate class and a rigid wall consolidation cell permeameter most of us have done the consolidation test and we can get the permeability from the consolidation test either indirectly by computing cv coefficient of consolidation or directly by permeating the water.

So, we are going to look at these 2 a little more closely, but first let us examine whether with your current knowledge, how would you perform a test on a low permeability material and how would you ensure that it is saturated. So, which tests have you performed in the undergraduate days or at least theoretically you know about them the falling head method.

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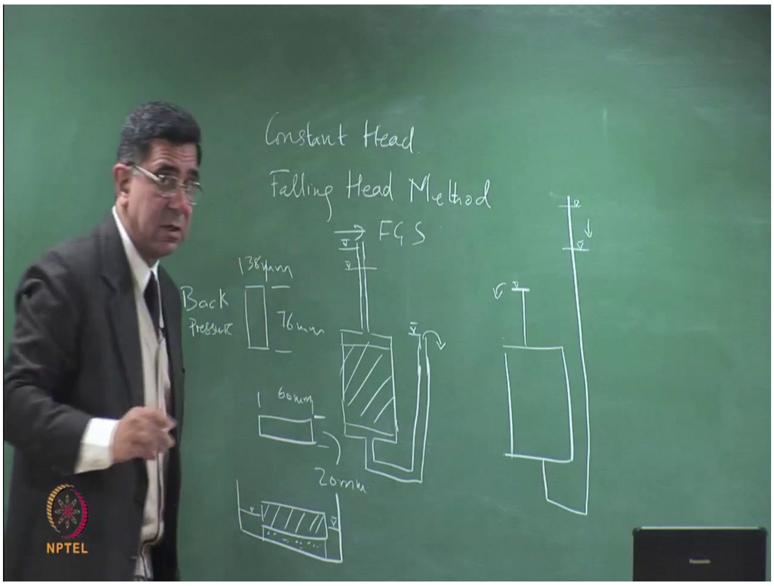

Student: Constant head.

Constant head method; so which method do you use in clays or in fine grained soils.

Student: Falling head method.

So, we use the falling head method constant head method is not used, but falling head is used. So, this is used for fine grained soils do you remember, how you did this test how did you prepare? The sample the sample must represent the field condition right we are finding the permeability of a compacted clay liner. So, it is going to be compacted it is going to come from a borrow area we are going to compact it in layers. So, we have to do the same compaction in the laboratory and having done the compaction then we have to perform the permeability test.

So, which compaction test will you will you do in the laboratory or did you do in the laboratory when you do your undergraduate test and how did you do the permeability test. Anybody has done the permeability test in their undergraduate life the falling head permeability test. It is an essential requirement to get your bachelors degree that you should know how to do a permeability test in the lab. Conceptually you know how following a test is done. So, how is the sample prepared?

How do you prepare as compacted sample, I can take the soil I can take the omc or the water content at which I am going to make it in the field and I can compacted in a compaction test? So, I can compact in a proctor mode. Now, I have a proctor mode full of soil. And how do I do the falling at permeability test? A falling at permeability test conceptually looks like this is the sample, you create a difference of head and see the rate at which the water falls right.

So, anybody recalls this how does this happen there is a you may have an arrangement where there is a thin tube at the top. And you may allow this to overflow. So, this head is constant this head may fall with time. And as it falls you have a formula from which you can get permeability. Do you remember this well this is one way of doing it the other way and the better way of doing it is to push the water bottom up push the water bottom up; that means, keep this higher and this lower.

So, the other alternative is if I am having, the reason is whenever you are trying to extract air from a sample is better to push the water bottom upwards because air take being lighter then water will come out at the top. You put water at the top and try and push air downwards it resists being moved downwards. So, this is another arrangement, but the main question is how do you ensure that this is saturated, how would you ensure that your proctor compaction sample is saturated any thoughts.

Student: (Refer Time: 08:38) we are addings water (Refer Time: 08:43).

But if you have clay and if you add water to it in how much time will the water come out from the sample. How much time will it take to travel how many centimeters is this 10 centimeters or there abouts. So, water travels in clay at 10 to the power of minus 7 centimeters per second which I have often said is of some feet per year. So, water comes out very slowly does not take out does not become saturated. If you through sand, you can say I will flush the sand I will put the water from below and the air will come out and because sand has got high permeability water will come out in a few seconds or few minutes.

So, clay is difficult to difficult to saturate. And the only 2 ways of doing it, and one is how did you saturate your sample in the tri axial apparatus, when you did the tri axial test you have all done a tri axial test.

Student: Yes.

You have done a cu bar consolidated undrained tri axial test with pore water pressure measurement. So, did you have to ensure that there was no in trap air in trapped in the sample.

Student: Yes.

Now, how did you ensure that there was no air? I know, but if it is not equal then what you do what I said was in in a tri axial cell you apply a cell pressure increase the cell pressure and the pore pressure should increase by an equal amount, but if it does not then how do you saturate the sample.

Student: Force saturation means back pressure.

So, the word is we do back pressuring of a sample we force the air to get dissolved in water by putting extra pressure in the sample. So, in a tri axial test, you are using back pressure, to saturate the sample and you use a parameter called the.

Student: B factor.

B factor and how much should be a b factor ideally.

Student: 1 9 5.

Ideally it should be one because then that means delta change in cell pressure is equal to change in pore water pressure, but the acceptable level has to be point more than 0.95. In fact, do not think 0.95 means 95 percent saturated. So, you have to have a b factor very close to unity. So, we can saturate a tri axial sample, but we cannot saturate a large sample in the proctor mode. In a consolidation test we also saturate a sample. The size of the tri axial sample is.

Student: 38 millimeters.

38 millimeters and 76 and does the shape of a consolidation sample is it similar to that of a tri axial sample you remember consolidation ring what is the size the contro consolidation ring.

Student: 60.

So, we the consolidation ring is like this. 20 or 25 mm about one inch thick how do you saturate a sample in the consolidation test?

Student: (Refer Time: 12:13).

Anybody you would like typically; we say soak the sample. And soaking the sample might saturated, but that is a misnomer once you immerse a sample in water you the water is at the top also and at the bottom also the air inside cannot come out. Unless it is being forced under some gradient to come out air will not come out.

So, soaking a sample does make the degree of saturation go up because water is in contact with the lower surface and with the upper surface and some of the suction if there is negative pore water pressure will draw in the water, but does not necessarily saturated 200 percent to get a b factor of one for saturating a sample which is in a consolidation ring you have to have contact with water only on one side and leave it open on the other side. So, that the air can come out and in clay you remember there is a capillary fringe in clay if you have a groundwater. Then a capillary fringe is formed above the ground water do you remember the magnitude of this capillary fringe, how high can this capillary fringe be few millimeters, few centimeters, few tens of centimeters, few hundreds of centimetres.

Student: 10 meter.

10 meter is huge, but a few meters. So, you can have capillary fringe a few meters; that means, clay tends to suck in the water because it has got if it is partially saturated it has got a suction in the suction draws up the water and due to surface tension the water rises by capillary action.

So, just if I take this sample and put it in a bowl of water; there is a porous stone at the bottom this is the clay sample it is in a consolidation ring. And I feel this I do not submerge it I do not soak it in underwater, what will happen? Water will be pulled up and air will be pushed out from the top and our experience shows in the laboratory that this is going to saturate the sample, but you have to keep on checking the water content and keep on checking the degree of saturation.

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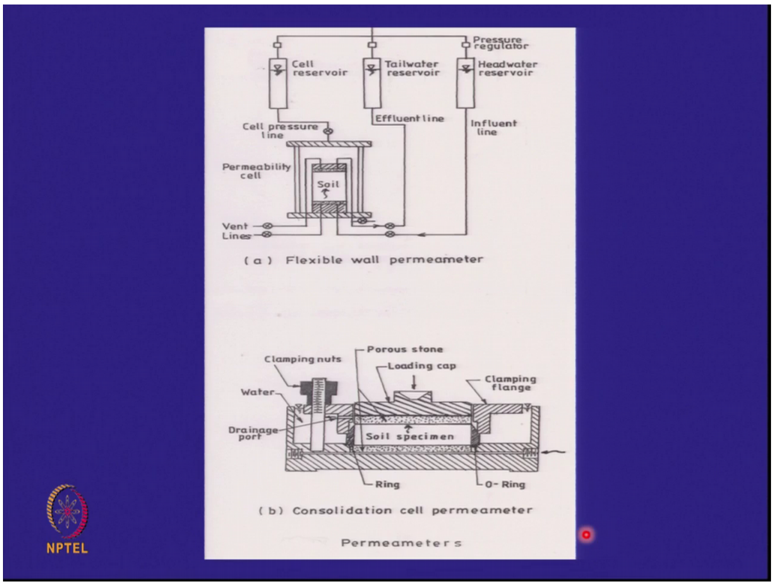

So, let us look at what are the ways we test this in the laboratory. So, I use what is called a flexible wall permeameter. A flexible wall permeameter is the permeability test which is done in the tri axial apparatus. The tri axial cell the same soil sample stage one is identical you saturated by back pressure as in a consolidated undrained test with pore water pressure measurement, but now instead of sharing the sample by putting a load on it. I caused a head difference between the 2 sides of the sample.

And water will flow from in the bottom upwards. And as the water comes out from the top please remember you had a loading cap on the top and the loading cap did not have a hole in it through which water could come out, but in this case you use a loading cap with through which water can come out.

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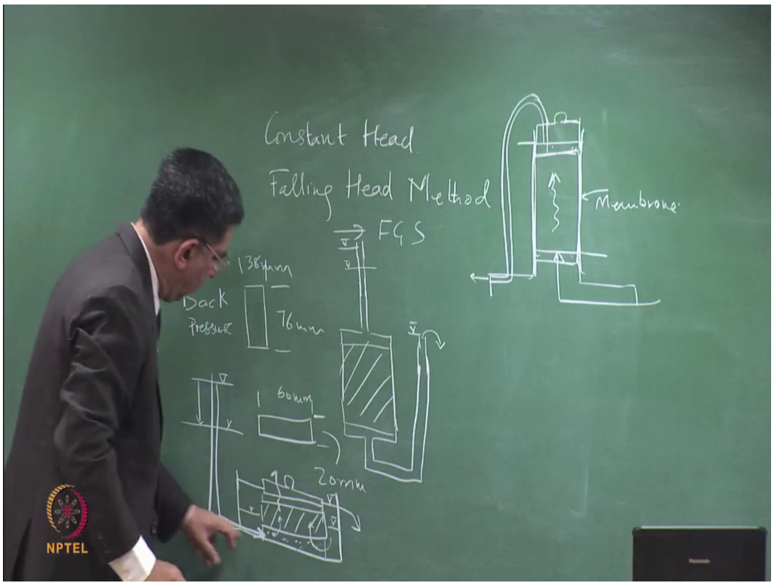

So, if I was to make a diagram of the tri axial sample in you have your porous stone here you have the porous stone here you have the loading cap here and there is a hole in the loading cap. And this is attached to the pedestal of the tri axial cell you recall that and this hole can also have a pipe which is attached to the base pedestal. And this can come out from one of the 4 walls at the bottom.

So, I do everything identical to the tri axial test except that I caused a head difference and I make water to flow through a sample of b factor equal to one. And measure the volume change with time, measure the volume change with time. So, there is a differential in head at this point and at this point. And that difference in head is applied by the cell pressure application and the pore water pressure application system. So, I can create a small head and measure the amount of water coming out and this is called a flexible wall permeameter.

So, the concept is identical you can read up more about this, but why is it called flexible wall because it has a rubber membrane around it is not a rigid wall like a consolidation ring. So, you have a membrane around it, and that is the flexible wall. The membrane prevents sidewall leakage. The other test is the consolidation test in which if you look at this diagram, we can flow the water from the bottom of the sample through the sample and out of it right. So, I can attach a burette here, I can attach a burette here and create a head. So, if I go back to my diagram here I can cause attached water to flow under a head and I can, I have a porous stone and I have a loading cap if you recall, then I can get the water to come out.

But this will be done like a falling head test. So, the water level will be increase increased by us to this level. And this will allow overflow and my head will fall with time and the flow will occur bottom upwards. So, you can use a direct measurement in a consolidation cell, but this is a rigid wall permeameter rigid wall because the ring is rigid and this is a flexible wall permeameter. So, the testing which is done in the laboratory is in a flexible wall permeameter and a rigid wall permeameter. And the size of the sample has nothing to do with the proctor compaction mode saturation is the most important aspect.

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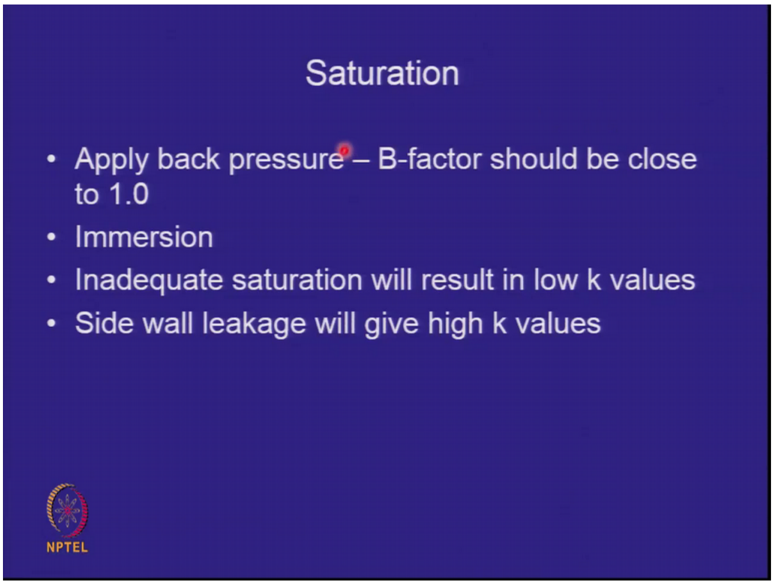

So, remember apply back pressure in the flexible wall permeameter b factor should be close to one consolidation sample is by immersion not by soaking. Immersion means you will have water at the lower surface, but no water at the other side. So, it is partial immersion of the sample partial immersion of the sample. Inadequate saturation will give you low k values and those results will be erroneous. Sidewall leakage will give high k values.

Now, just imagine that I put some cement concrete in the consolidation ring. And I do a permeability test after the rich cement concrete has set. I get some water is coming out one of the problems with a rigid wall permeameter is there can be leakage between the smooth wall of the ring and the soil or the impermeable material.

So, we have to be very careful that sidewall leakage does not occur. And how do we ensure that we have to apply a normal stress on the sample. So, that the soil pushes against the walls of the ring. And we must not forget to apply the; what do you apply on the inside of a consolidation ring silicon grease that is we will prevent the water from passing along the side wall. So, side wall leakage is an important aspect. And I have to change this immersion to partial immersion. So, let me try.

So, once you have done this what do we see?

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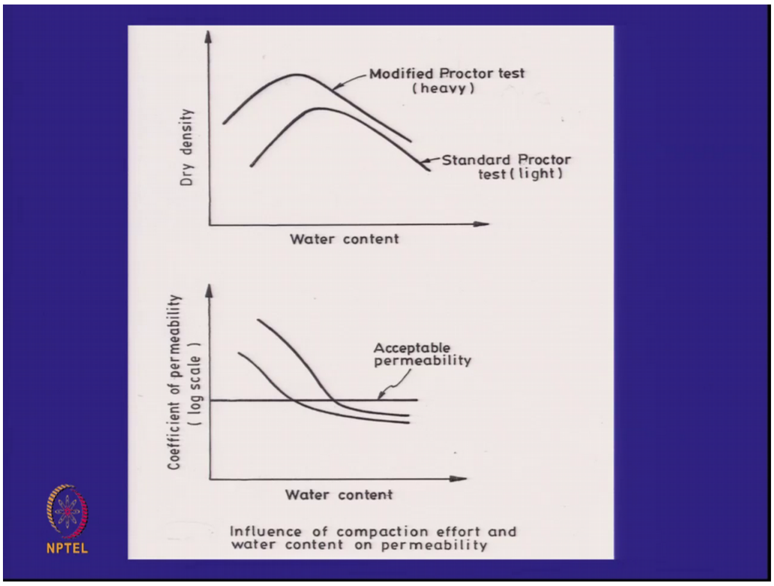

I will have to do these permeability tests at different points along the proctor curve to see how the permeability varies with the water content. So, this is the standard proctor test this is the modified proctor test. So, I may take 5 samples 1 2 3 4 5. And when I have these 5 samples then I can get the permeability values and this will show you that the permeability really decreases with water content. This curve has lower permeability than this. So, this corresponds to the modified proctor test this is for the standard proctor test. If this is 10 to the power of minus 7 I know that I should compact weight of this point to get that permeability.

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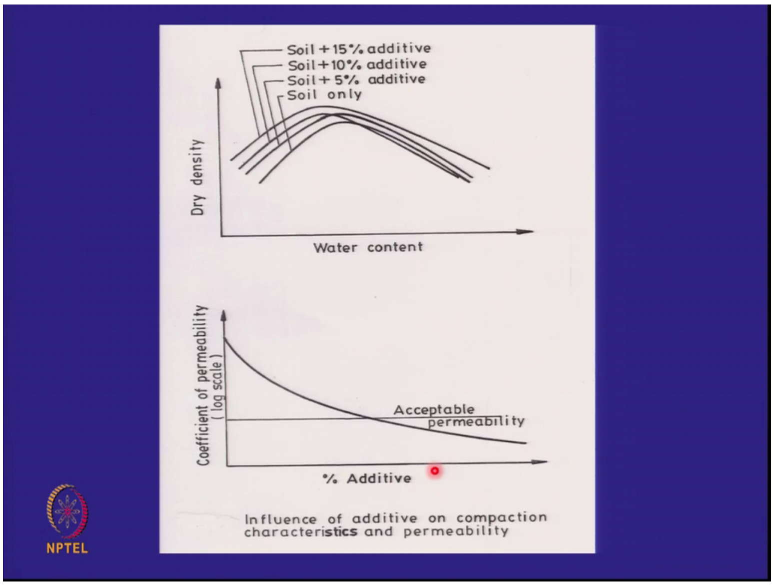

When I am using an additive when I am using an additive my compaction curve will change with the amount of additive. So, I cannot predict and how it will change, but I can get these different curves. And then for each curve at a given prescribed water content weight of the optimum I can find the permeabilities.

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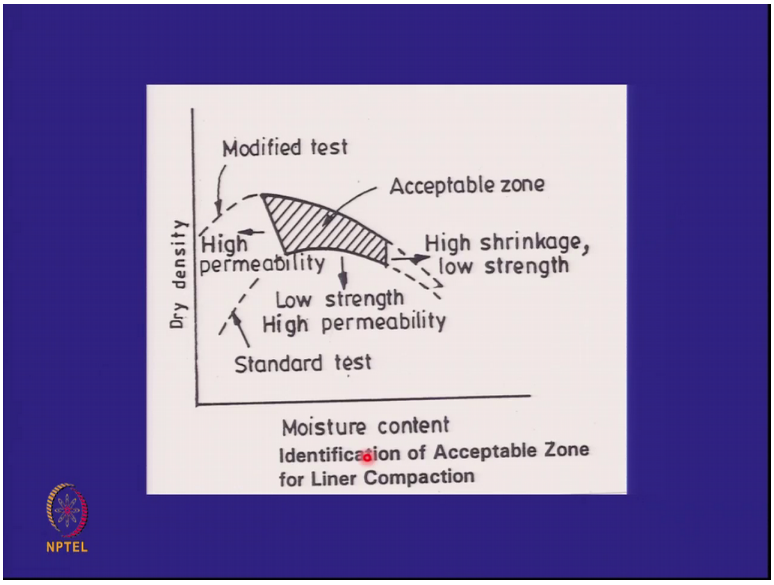

And I can get a plot of coefficient of permeability with the percentage additive that I have added. And again this will give me how much is the additive required for getting the permeability.

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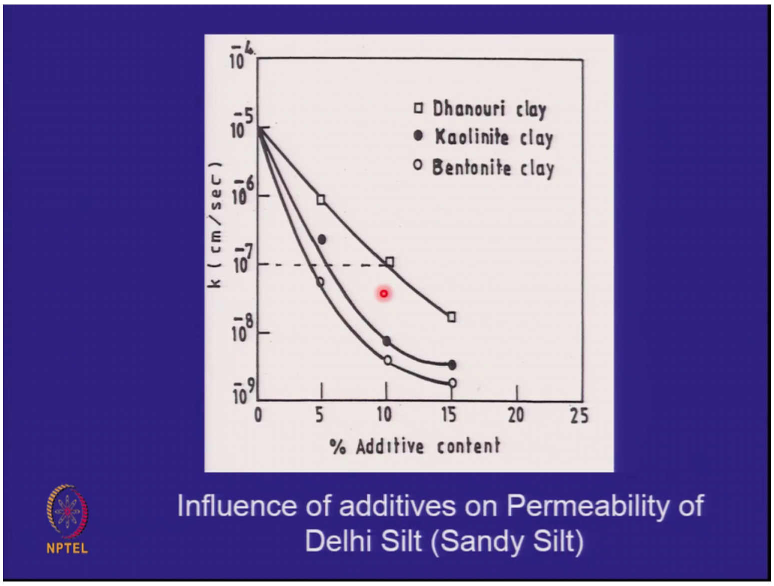

And this we have already discussed earlier we should preferably be on the wet side of the optimum. And here it shows that in Delhi silt which was sandy silt we added 3 types of additives bentonite kaolinite and a local clay which comes from near rodki it is called the dhanouri clay.

So, the round symbols show how the permeability decreased with bentonite the dark symbols show how it decreases with kaolinite and this shows how it decreased with dhanouri clay.

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So, if you are going to add bentonite 5 percent is sufficient for the purpose of getting low permeability, but it must be mixed very well and you will need higher percentages of the other material depending on it is plasticity.

So, in this way I can find out the additive content. Then I have to construct the clay barrier we have done the lab studies. So, we identify the borrow area. Suppose I am only using the compacted clay barrier then I adjust the water content in the borrow area, suppose the soil is totally dry I can do some sprinkling there. So, that it is close to the optimum moisture content we excavate it. And transport it at the landfill site we level the landfill base, we unload and spread the clay we are going to do 4 layers of 25 centimeters thick we do some spraying of water and mixing this is final adjustment for an example let us say that the optimum moisture content is about 28 percent right for clay you want to compact it weight of optimum one percent; so 29 percent.

In the field at the bottom area the soil has got 4 percent moisture it is dry. So, you will bring the 4 percent moisture to 20 25 percent in the field by sprinkling or irrigating that soil. When you reach your site then you will make the final adjustment from 25 to 29 because you then you apply a little bit of water, if you bring it to the site and start adding a lot of water or water may form is slush with the soil and it may create a problem.

So, only final adjustment is done on the site we will do compaction using sheepsfoot roller and then place. The next layer and after the 4 layers are over we will do final smoothing with steel drum roller and then as soon as the final smoothing is done we have to place the geomembrane on the compacted clay liner. So, that the liner clay does not become dry and desiccate and you do not get shrinkage cracks.

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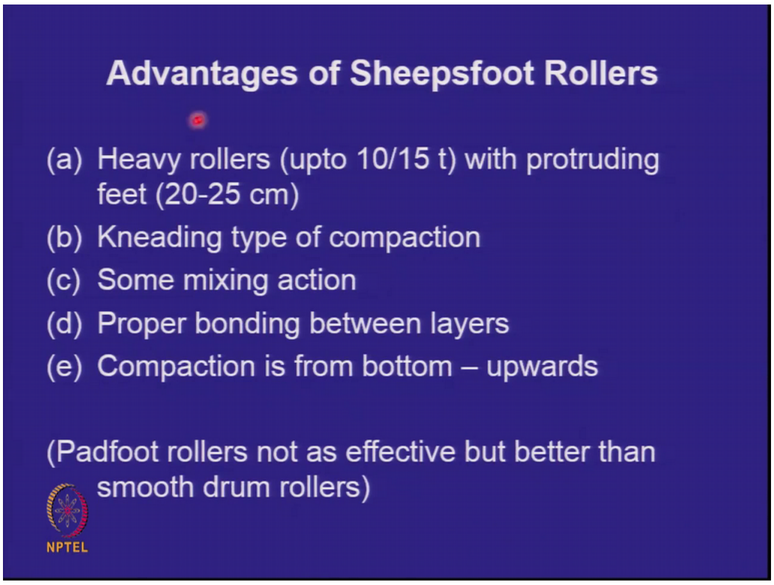

And further we should cover the geomembrane without delay with a protector. So, that no damage takes place to it.

So, advantage of using sheepsfoot roller you can use heavy rollers with protruding feet you get kneading type of compaction which breaks down clods the kneading action has some mixing action also. So, water gets mixed properly it take a clay sample 25 centimeters thick you put some water on top. And you run a smooth steel drum roller on it the water will not even penetrate properly into the soil you will have to use some disc harrows you can try that, but here while the sheepsfoot roller is moving it is making pock marks and the clods are breaking and the water is mixing properly, it allows you to have proper bonding between the layers and compaction is from bottom upwards.

You can also use padfoot rollers which are smaller protruding feet then sheepsfoot rollers and, but they are not as effective than the sheepsfoot roller, but they are better than smooth steel drum rollers.

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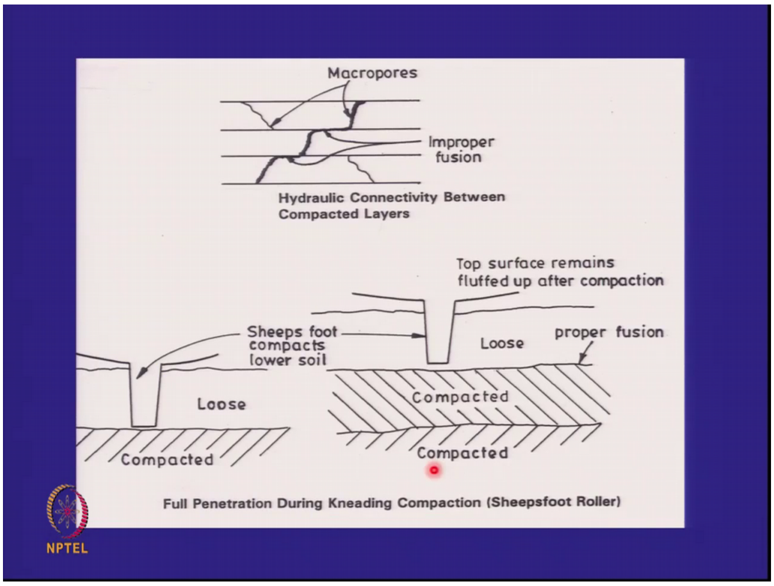

So, please do remember that you are going to have 3 or 4 layers, they should be properly fused if they are not fused properly then you will have these horizontal zones of high permeability. The sheepsfoot roller actually compacts bottom upwards when the soil is loose you will find the whole sheepsfoot sinks into the soil. As you do the number of passes the sheepsfoot begins to walk out it begins to rise because the lower portion is properly compacted. This is quite opposite to what happens in a smooth steel drum roller when you move the roller the top one gets compacted first and then low lower layers do not become that dense.

So, this is the way you have to use the rollers in the.

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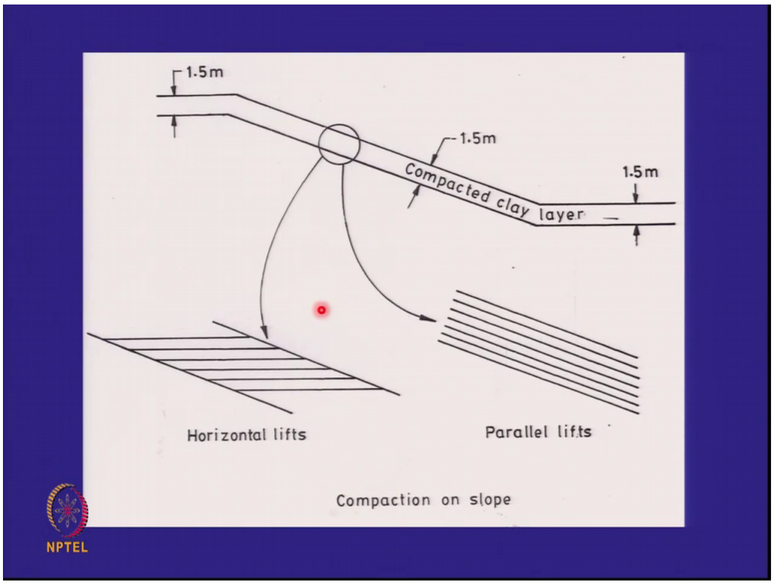

In the field for compacted clay liners the critical thing is how do you compact the clay along the slope both options are available both options are available, but mostly this is a better way to do it. Because it is very difficult to move the rollers typically your side slope will be 3 is to one or 4 is to one to be able to move a roller along that a dozer can move with a good drive, but a roller is difficult to move along a slope. So, you are you will be compacting in horizontal layers. And remember if your bonding is not proper then you are creating zones of high permeability in the horizontal direction.

So, it is critical that your fusion is good and that sort of sheepsfoot roll roller does. So, the thickness of this clay is one meter. So, the question asked is how can I compact a one meter thick player I my roller is 2 and a half meters wide right. Well do remember first you have to use smaller rollers, but this is one meter thick if you look at a 3 to 1 slope this will become 2 or 3 or 3.5 meters wide in a horizontal chains the thickness when we talk about is normal to the slope. So, this is when you cut it horizontally will have a much wider thickness and it is possible to do this compaction.

If you are constructing with amended soil liner now this is a little different process and you should know it. You will excavate and polarize the local soil.

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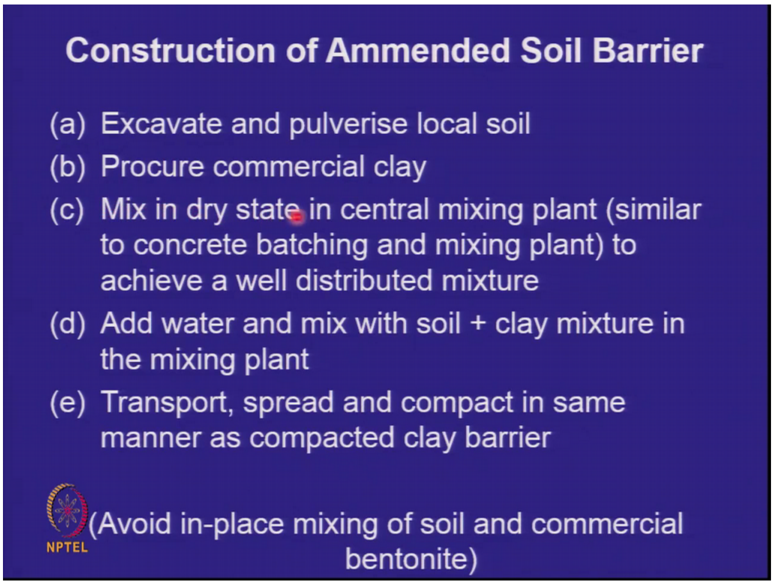

the very important thing is polarize it then you will get your commercial clay in cement bags as I said you can get bentonite in cement bags. You have to mix in a dry state in a central mixing plant. So, excavate your soil it may be local soil or may be coming from 5 kilometres crush it and pulverize it. So, that it becomes like powder fine powder because you need intimate mixing just remember, you are going to add 5 to 10 percent bentonite if there are clods.

If it is not dry it is sticky then that 5 percent bentonite will get concentrated in one area it would not mix, but if it is finely ground and it is like powder and you have the bentonite powder then like cement will mix with soil and it is dry pulverized state that is the way it will mix. So, mix in dry state in a central mixing plant this is like a standard batching and mixing plant of a say concrete production unit add the water after the dry mixing is complete. So, that there is well spread out bentonite in the entire matrix add the water and mix in the plant then you transport and spread and compact in the same manner.

It says here a wild in place mixing of soil and commercial bentonite. I had shown you a slide program where they were doing in place mixing they were working very hard at it, but the issue is how many clods of the breaking and how much effective would that be,

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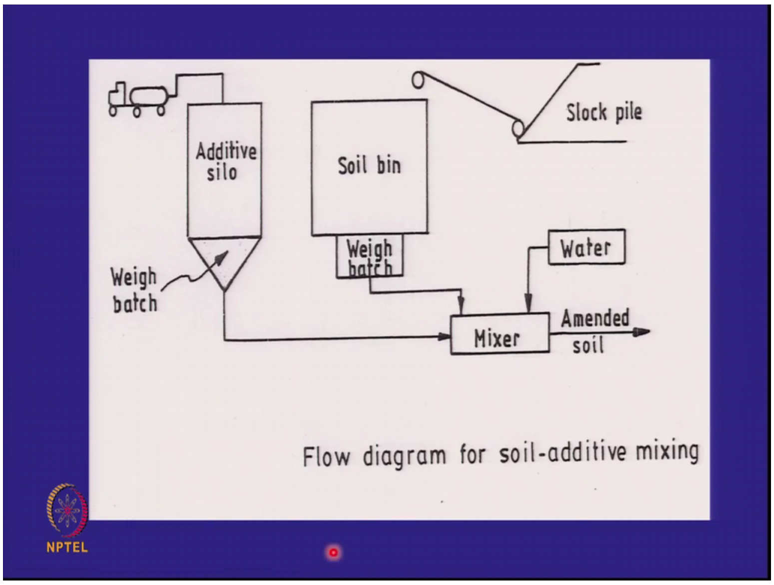

So, if you are going to do in place mixing please use more bentonite I would say then instead of 5 to 10 percent you are going to be operating in 15 percent plus range because you will not have that much homogenized mixing of in place mixing, I do not normally agree with in place mixing of soil, but it is cheaper people tend to use a tractor and Klaus and Harold's to do that.

So, this is the set up if you see. You can store your bentonite in a silo. You can also have a soil bin this is your slock pile of the soil which has come from the borrow area it goes into a soil bin, where you might be crushing it further or pulverizing it further you do weigh batching you weigh batch you have a mixer. First you mix the additive and the soil in dry then you adds the water and then you have the amended soil put it in a truck.

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Quality Control (Compacted Clay)

Test on	Test Type	Frequency
Borrow material	Grain Size Distribution	One set per 1000 cu.m
	Atterbergs Limits	One set per 1000 cu.m
	Water Content	One set per 1000 cu.m
	Compaction (light & heavy)	One set per 5000 cu.m
	Laboratory Permeability (as compacted-then-saturated)	One set per 5000 cu.m
Compacted Soil	Insitu Density	Five tests per 500 sqm. of each compacted lift/layer
	Insitu Water Content	Five tests per 500 sqm. of each compacted lift/layer
	Laboratory Permeability on Undisturbed Sample	One set of tests for 2000 cu.m

And send it for compaction, and you have a and rigorous testing program what kind of quality control tests must you do. So, typically you will see that you have to do grain size distribution atterbergs limit is water content compaction laboratory permeability tests, insitu density compaction control instead of water content and laboratory permeability on undisturbed samples.

How often do you use it 1000 to 5000 cubic meter one set of tests it is not one test? Please understand if you are going to find the permeability of a soil one set of tests may mean 3 tests why you are not. So, sure you are getting a little bit of variability. So, one set of tests per thousand cubic meters for 5000 cubic meters. And of course, for compacted soil it is per square meter 500 square meters of the compacted layer.

So, this kind of a quality control program will be prescribed, this is for just compacted clay without additive.

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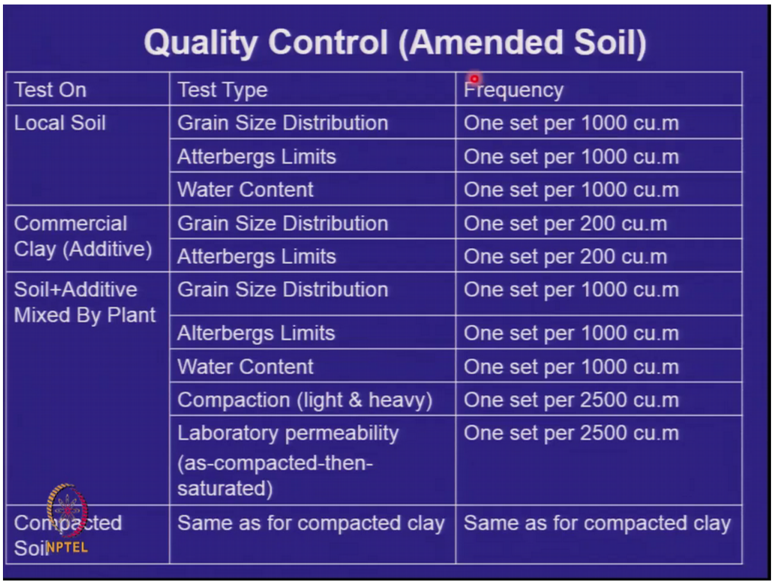

Quality Control (Amended Soil)

Test On	Test Type	Frequency
Local Soil	Grain Size Distribution	One set per 1000 cu.m
	Atterbergs Limits	One set per 1000 cu.m
	Water Content	One set per 1000 cu.m
Commercial Clay (Additive)	Grain Size Distribution	One set per 200 cu.m
	Atterbergs Limits	One set per 200 cu.m
Soil+Additive Mixed By Plant	Grain Size Distribution	One set per 1000 cu.m
	Alterbergs Limits	One set per 1000 cu.m
	Water Content	One set per 1000 cu.m
	Compaction (light & heavy)	One set per 2500 cu.m
	Laboratory permeability (as-compacted-then-saturated)	One set per 2500 cu.m
Compacted Soil	Same as for compacted clay	Same as for compacted clay

If you have an additive that is if you have an amended soil, then you have to do a lot of testing at the plant you have the original soil you have the additive tests. So, first do the original soil test additive then do the mixture testing of the mixture and then of the compacted soil.

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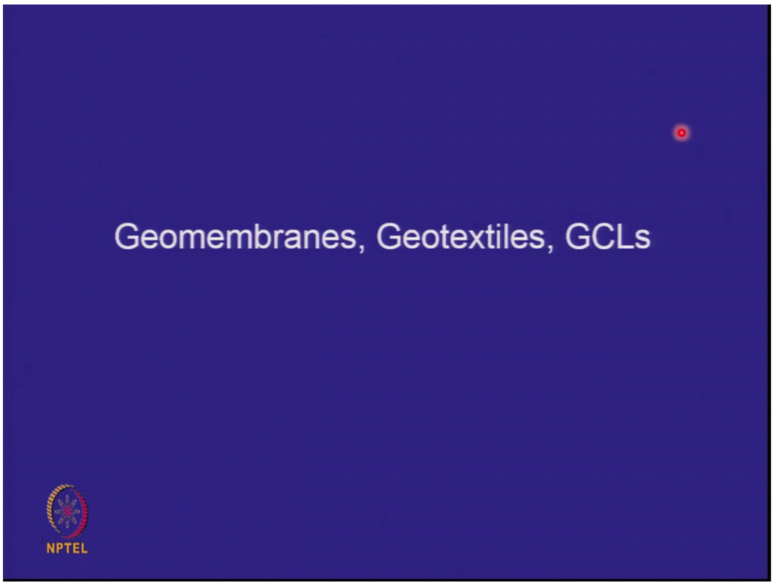

So, here also it is 1000, 1000 1000 2500 that kind of a sampling program. So, with this we have looked at the thick element now how to construct the thick element not easy, requires quite a precise field construction and strict quality control. And therefore, one is always looking at an alternative to this very intensive field construction activity.

Now, we look at the thin elements and we look at a geomembranes and a new set of barrier material called gcls geosynthetic clay liners, I will come to that, but our next discussion is on the thin element at the top. Geotextiles you will do in your course on geosynthetics I have only said 2 things a protector or a filter typically nonwoven geotextile more than 400 grams per square meter, but why is it nonwoven and not woven why it is 400 and not 200 or 600 this will come to you from your course on geosynthetics

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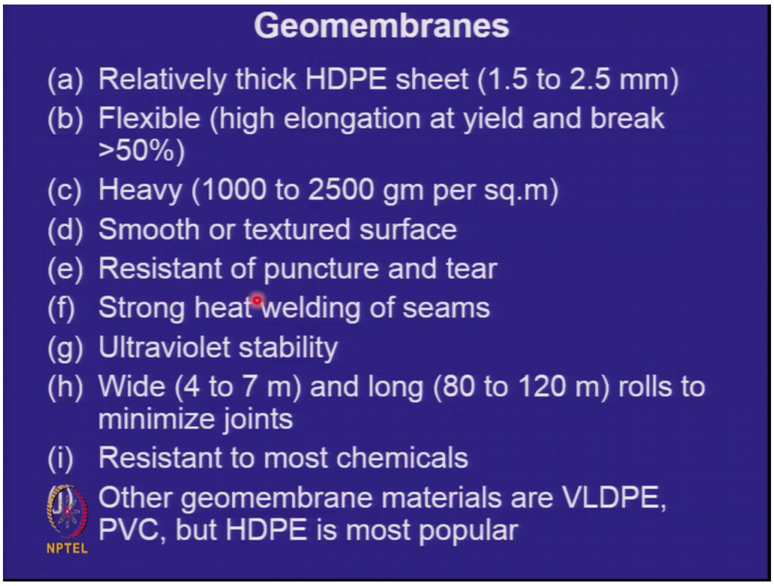

So, just to recall geomembranes are relatively thick polymer sheets. Typically, in a landfill you will find them to be 1.5 to 2.5 mm thick for very high landfills, there will be 2.5 mm thick they are flexible, when I say flexible how much will they elongate before they break. So, if you do a tensile strength test on an hdpe geomembrane before it yields or breaks it will have 50 percent elongation.

Just compare it with soil, if I was stiffed clay what is the failure strain at failure or strain at yield strain at break, and if I have soft clay, or if I have loose sand. And if I have dense sand and so in dense sand if you do a tri axial test where will the failure come at what strain.

Student: 12 14.

Pardon.

Student: sir 12 to 15.

12 to 15 percent is for loose sand and for dense sand.

Student: Low.

It is low you remember in dense and the stress strain curve will look like this you can have this behaviour or you can have this behaviour.

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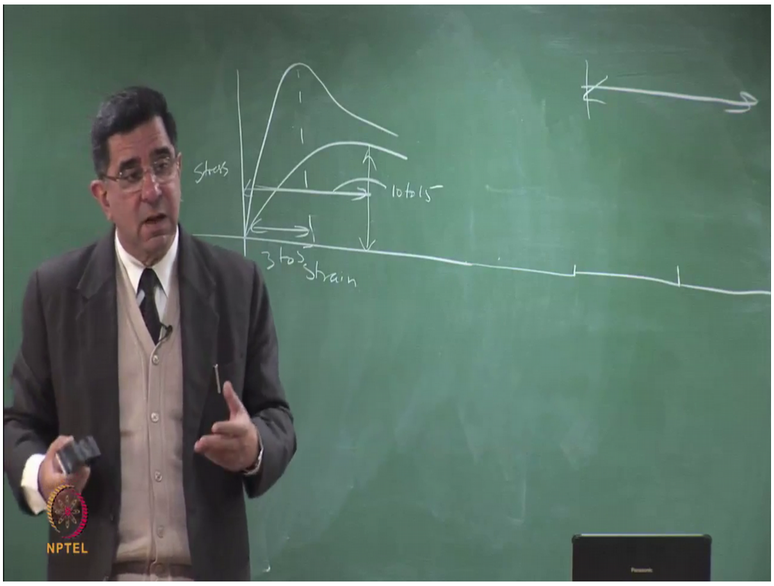

So, this is stress, this is strain and we said that in soils in dense sand or stiff clays this may be 3 to 5 and this may be 10 to 15. So, where is the failure strain for an hdpe geomembrane if this is 15? This is 30 this is 45, this is 60 and this is 75. So, the range that we are talking of hdpe will have failure in that range it can be also a 100 percent 50, 200 percent is the elongation before a geomembrane fails. So, it is a flexible material even if the base settles a little bit it is not going to rupture or fail in tension it is going to have that flexibility. And if you want even more flexibility then there are other materials which are like VLDPE, LLDPE low density polyethylene which instead of failing at 50 200 percent would fail at 200 to 300 percent, but they will not be that strong. So, it is going to be a playoff between flexibility and strength.

So, maybe which has more settlement cover or liner? A liner has more settlement because the stresses are higher, but a cover has more settlement because there is biodegradation. So, municipal solid waste landfills where the biodegradable content is higher, their cover settlements can be very large, but if you have inorganic waste which does not settle due to biodegradation then maybe the liner settles more, but if you are going to have very large settlements then you will use ldpe polymer.

So, they are relatively thick they are flexible they have significant strength they are heavy. We talked about 400 gsm for a geotextile, but here we are talking of 1000 to 2500. So, a lot of polymer they can be smooth or textured. I showed this to you last time and they will have resistant to puncture and tear you can they can have strong welding of seems almost the same strength as the parent material. When you weld something you are always bothered you are used thermal welding or you added something is it as strong as the parent material.

So, in hdpe welding you will see what is the quality control criteria they have ultraviolet stability most of the time they look black. Because ultraviolet stability comes in polymers when you use carbon black carbon black gives you UV stability. So, many of the overhead water tanks and many of the polymeric materials which look black are on account of UVd stability.

They can come in wide rolls 7 meters. Now they are talking of even 10 to 12 meter wide rolls. So, 10 to 12 meter wide is 30 feet. That is the width of your drawing room perhaps. So, you can get very wide rolls and the rolls can be as long as 100 meters. That is the football field. So, this can be rolled and they will come in a truck to minimize the joints the wider the longer the left the joints they are resistant to most chemicals.

Other than hdpe there are vldpe lldpe pvc pet, but most popular is hdpe for liner.

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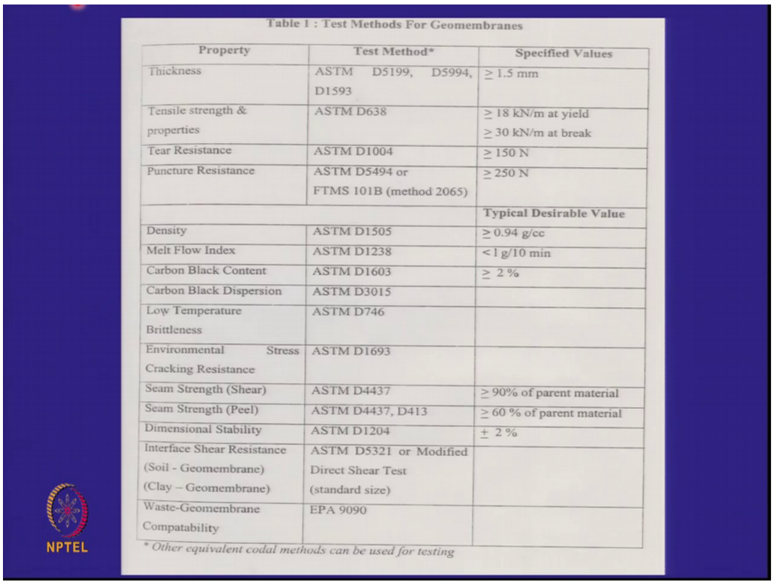

Table 1 : Test Methods For Geomembranes

Property	Test Method*	Specified Values
Thickness	ASTM D5199, D5994, D1593	≥ 1.5 mm
Tensile strength & properties	ASTM D638	≥ 18 kN/m at yield ≥ 30 kN/m at break
Tear Resistance	ASTM D1004	≥ 150 N
Puncture Resistance	ASTM D5494 or FTMS 101B (method 2065)	≥ 250 N
		Typical Desirable Value
Density	ASTM D1505	≥ 0.94 g/cc
Melt Flow Index	ASTM D1238	< 1 g/10 min
Carbon Black Content	ASTM D1603	≥ 2 %
Carbon Black Dispersion	ASTM D3015	
Low Temperature Brittleness	ASTM D746	
Environmental Stress Cracking Resistance	ASTM D1693	
Seam Strength (Shear)	ASTM D4437	≥ 90% of parent material
Seam Strength (Peel)	ASTM D4437, D413	≥ 60 % of parent material
Dimensional Stability	ASTM D1204	± 2 %
Interface Shear Resistance (Soil - Geomembrane) (Clay – Geomembrane)	ASTM D5321 or Modified Direct Shear Test (standard size)	
Waste-Geomembrane Compatability	EPA 9090	

* *Other equivalent codal methods can be used for testing*

And if I look at this table I will not go into details, but just like we test soil grain size distribution density, specific gravity, plasticity, water content, strength, compressibility, permeability. There are a series of tests which have to be formed on geomembranes. Thickness tensile, strength, tear resistance, puncture resistance, density, melt, flow index, carbon content, brittleness, environmental stress, cracking, seam strength, dimensional stability, interface shear waste to geomembrane compatibility. Some of these are routine some of these are special tests.

But just to get an idea a 1.5 mm thick geomembrane will have 18 kilo newton per meter as it is tensile strength. And it will have some tear resistance and some puncture resistance and this is the requirement from the point of view that it should not be damaged during installation.

The tear resistance and puncture resistance has very little to do with design it is these are durability tests it. Will normally have a density of the order of 0.94 grams per cc carbon content must be more than 2 percent. And seam strength must be greater than ninety percent of the original material this is a requirement seam strength in shear and seam strength in peel which is totally different should be 60 percent of the parent material and we will have a look at this later.

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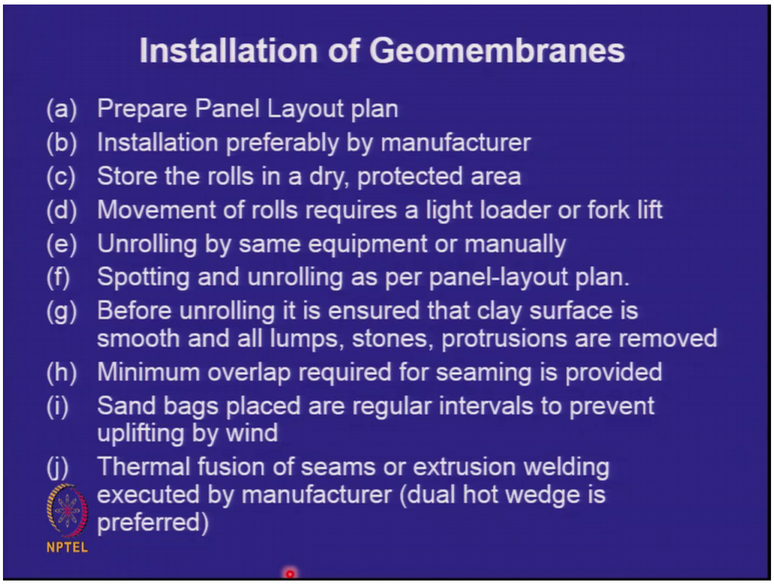

So, there is a full gamut of tests which the geomembrane must meet. What you have to do before you lay a geomembrane is to prepare basically if this is the base of the geomembrane of the phase in which you are going to put the cell.

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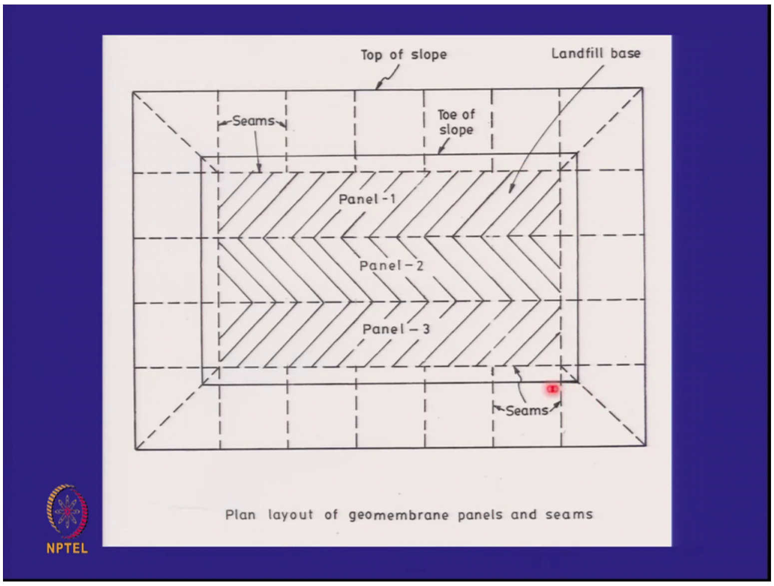

Suppose this is an below ground landfill this is the base and this is at ground level. So, it means the ground is sloping like this and like this. You have to prepare a panel layout map how are you going to unroll your geomembrane where are the welds going to be. So, it shows that one roll will be like that one roll will be like that, and depending on the lengths and widths you will have these joints which will be welded together along the slope.

So, prepare a panel layout plan. Installation should preferably by be by the manufacturer or his installer; because how are they going to join it how are they going to seal it is a specialized job. Store the rolls in a dry protected area, movement of roller rolls requires a light loader or a forklift underling should be done at the site spotting and unrolling should be as per the panel layout plan before unrolling. It should be a no ensure that the clear surface is smooth and all lamps stones protrusions roots should be removed, if there any which are coming with the bottom material. Minimum overlap required for seaming is to be provided when 2 of them have to be joined they do not join like this they have an overlap.

Wind tends to blow this geomembranes and displace them. So, you will find a lot of sandbags are required to prevent up lifting by wind in India, a lot of old tires are put you will find in some photographs and then thermal fusion of seams many types of welds are there we prefer the dual hot wedge.

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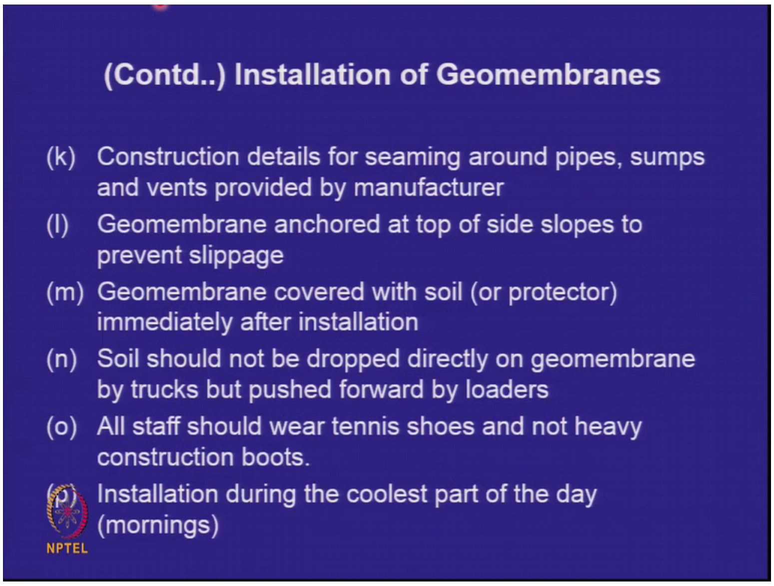

Very important is there will be some pipes which will be passing through the geomembrane. And that how do you weld the geomembrane to the pipe those construction details have to be given by the manufacturer and have to be with strict quality control they have to be ensured. Geomembranes are anchored at the top of side slopes if you put a geomembrane on a side slope it tends to slip down. So, there will be an anchorage in a trench at the top geomembrane should be covered with the soil or the protector immediately after installation. Soil should not be dropped directly onto the geomembrane, but pushed forward in India we do this manually, but in developed world they use light crawler mounted loaders and they push this forward.

All staff should wear tennis shoes and not heavy construction boots installation should be done during the coolest part of the day when the geomembrane has not expanded otherwise there is a thermal expansion coefficient of the geomembrane and they can become longer during the day time.

So, I only showed you the plan layout of a geomembrane panels and where the seams will be made.

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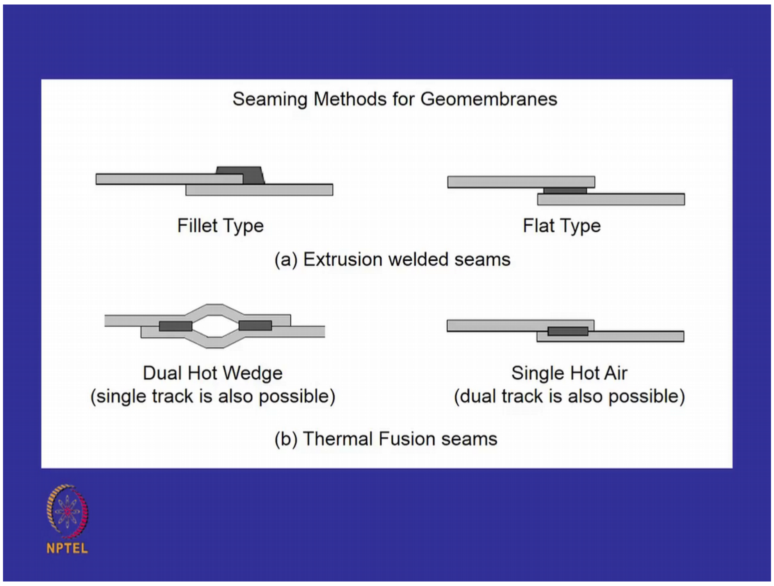

And these are some of the type of wells these are extrusion wells you are putting extra material on the overlap or in between and these are thermal fusion wells. So, the weld which is done in most geomembranes is this one, it is called a dual hot wedge weld you weld it in such a manner that there is an air gap at the centre and basically just heat it and weld it.

Now, when you have a air graph at the centre. Please remember suppose you have a hundred meter roll and the 2 geomembranes are going overlapping and the weld is being created like that. So, you are creating a tunnel. So, the good thing about the tunnel is you can check whether it is leak proof or not if this weld and this weld is good if I put air pressure in it. If I put air pressure in it is going to the air pressure will not be dropped like in a cycle tube. So, that is the test one test for a full length of the roll along the dual hot wedge weld you apply air pressure keep it for a few minutes if the air pressure is sustained it means there is no leakage.

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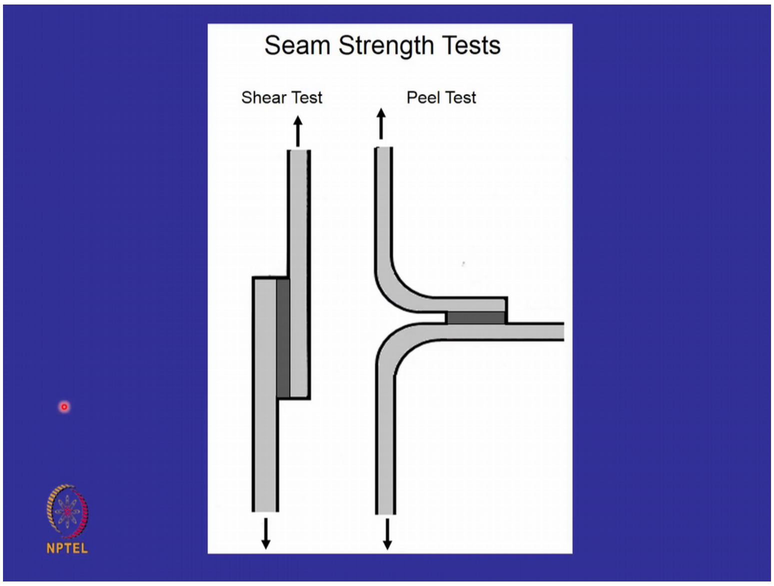

2 types of tests are done for seam strength, if this is the welded portion. If this is the welded portion we are doing the sheared shear strength test pulling the 2 membranes in this direction. So, there is shear along this face. This must be having the same value as ninety percent of the parent material. So, the shear strength in this test should be ninety percent. This is the peel test you try and peel apart the joint. And this is most of the stress situation mostly is like this, but here also you should have 60, 60 percent of the strength of the parent material.

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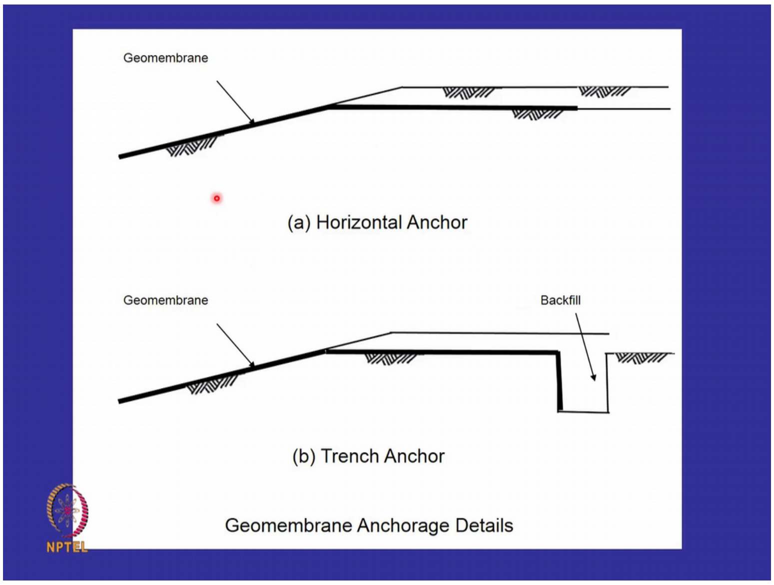

So, these are the 2 seam strength tests which are done in the field and as I told you the geomembrane has to be anchored at the top. Otherwise it has a tendency to slip down if this will not slip down when you put soil on top that will have a tendency to make the slip down. So, either the geomembrane will go into a trench or if there is sufficient horizontal distance available it will be run out horizontally. So, these are the 2 ways in which you can hold the geomembrane in position.

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Just like there is quality control in soils there is quality control in geomembranes, but before I discuss this is there anything that you would like to talk about regarding geomembranes.

Student: Sir regarding.

Yeah.

Student: (Refer Time: 47:58).

Yes.

Student: There is the probability of (Refer Time: 48:03).

There is the probability of.

Student: Puncture and tearing of elongated (Refer Time: 48:09).

So, the question being asked is if you are doing the welding dual hot weld wedge welding and the 2 roles are going like this. And I am welding like that and I apply air pressure and I find that the air pressure is not sustaining itself. So, how do you find a leak how do you find a leak in when your cycle tyre is punctured?

Student: We put it in water and bubble.

You put it in water and bubbles will come out bubble right. Well here you cannot put the 2 geomembrane in water, but you can take a soap solution. And you can put it the soap solution along the joint and you can apply the pressure and wherever there is a leak that soap solution will form bubbles. And sealing it is no problem because you heat it and it is sealed the polymer how is the weld made it is just too hot points which are running across they seal the thing together. So, once you have got the leak you can do a patch weld you can put an extra patch and you can heat it and just like a puncture this will be sealed the only thing is locating it for which typically a soap solution is used any other question which is coming to your mind.

So, we have quality control in geomembranes as well. You must have a proper contractor who supplying the geomembranes has been doing projects for 3 years. You will do the tests on the rolls as received before they are installed. And then you will do the tests on the field installation some of them will be destructive testing and some of them will be non destructive testing.

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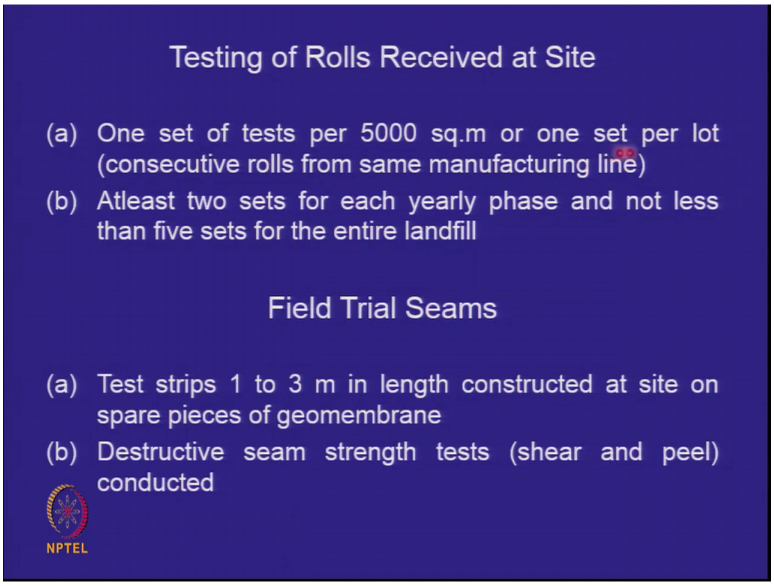

So, typically one set of tests per 5000 square meter is what you do the testing. And one set per lot. I mean if doing geomembranes are coming to you in different lots then you do one set per lot it is less which may be less than 5000 square meter, but at least 2 sets for each yearly phase and not less than 5 sets for the entire landfill field trial. Seams test strips of one to 3 meter in length you will construct these seams or these joints on some leftover pieces spare pieces of geomembrane, you will construct this and then you will do the shear and peel tests.

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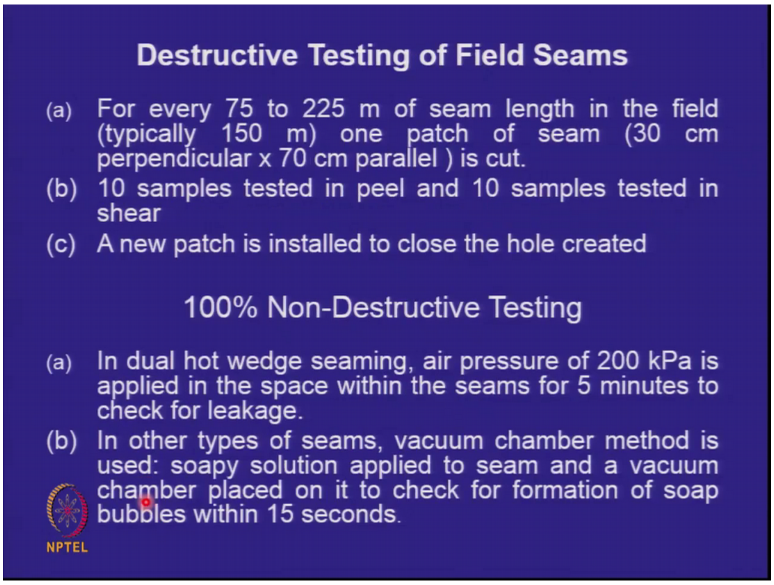

You will also did do destructive testing of field seams actually, when you have installed the seam you will cut out portions and you will do field testing. And you will new patch is installed to close the hole which is created and there is certain number of tests which are prescribed as I said 100 percent non destructive testing every joint in the dual hot well seeming air pressure of 200 kpa is applied within the seam for 5 minutes to check for leakage the pressure much sustained for 5 minutes and a soapy solution can be applied to the seam with a vacuum chamber sometimes to see whether there is any leakage at a particular point within 15 seconds.

So, there is a destructive testing procedure and a non destructive testing procedure for the geomembranes.

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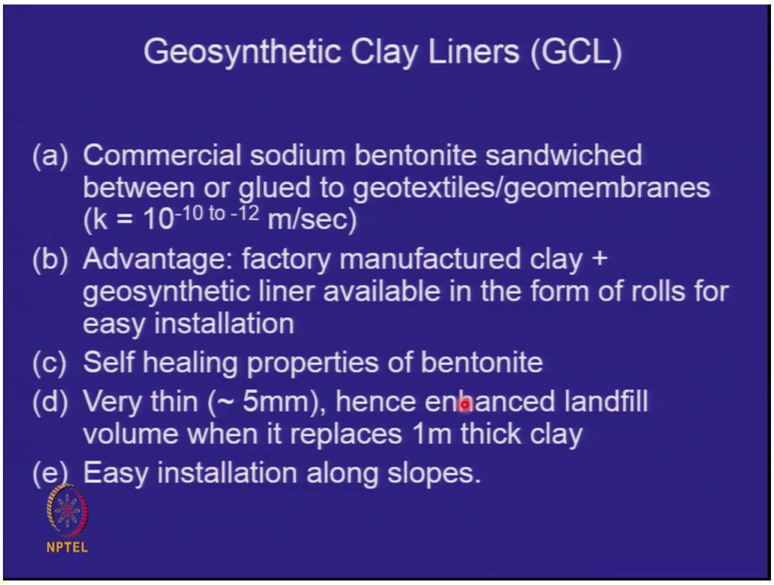

The last material that I had like to talk to you is about geosynthetic clay liners. Now why is it that geomembranes which are almost impervious are not good, as standalone material because they can have tears and punctures. What if they were self healing (Refer Time: 52:26) you had a tear and a puncture, but as soon as water they had access to water they would swell and self heal themselves.

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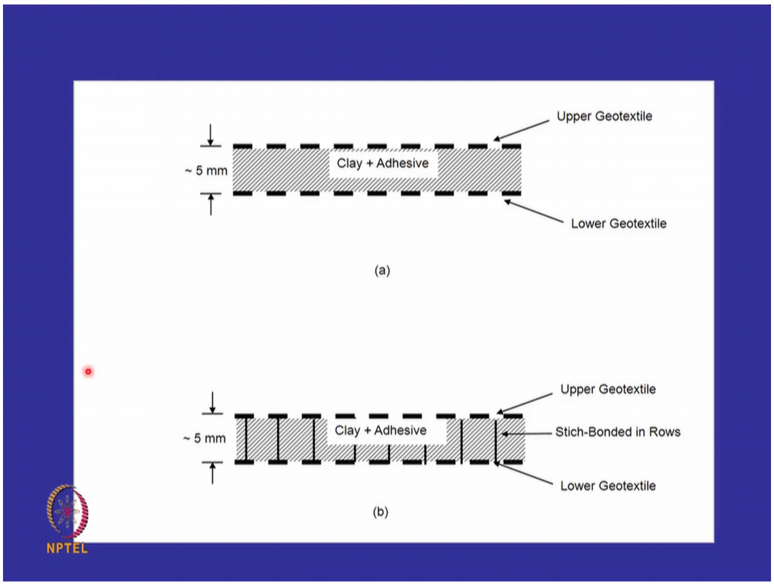

So, a new generation of materials called geosynthetic clay liners has now been developed which are thin factory made, but are self healing. So, before I look at that you have 2 geotextiles, and if you place clay between them you get a gcl. And how much clay only 5 millimetre clay, 5 millimetre less than one centimetre thick clay that sounds great the only question is how do you put the clay between this how do you ensure that the clay does not move from one side to the other and how do you ensure that it has the permeability of a one meter thick clay.

So, if I one meter thick clay and my permeability is 10 to the power of minus 7 centimeters per second right. And if I need a 10 millimetre thick clay what should be the permeability, of that clay 10 millimetre clay is one hundredth of the one meter thick clay therefore, the permeability of a 10 millimetre thick clay should be 10 to the power of minus 9 centimeters per second. And we do have a clay which has permeability of 10 to the power of minus 9 which is sodium bentonite this is commercially available clay. So, the concept is to put clay inside to geotextiles and give you a roll and what is. So, great about a geomembrane it comes in the form of a roll, I can just roll it out I do not have to get a compactor I do not have to mix I do not have to pulverize I do not have to do; so many things.

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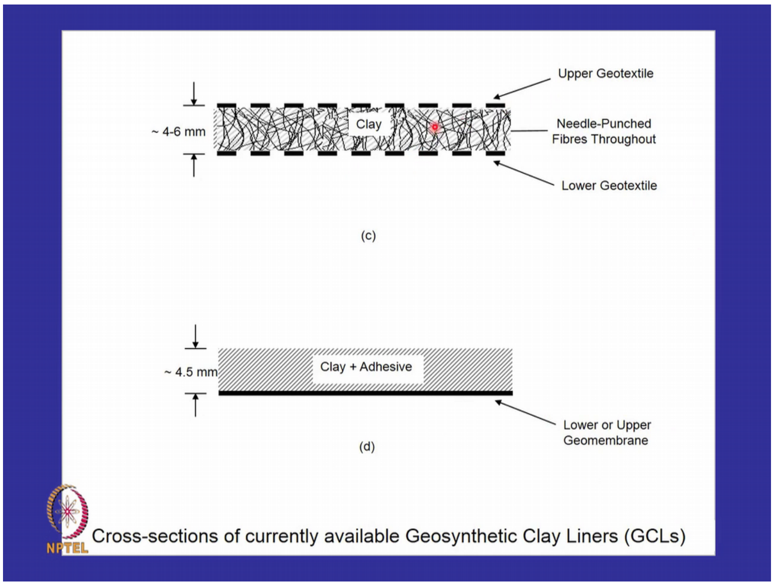

So, the geosynthetic clay liner can look like this to geotextiles with play and adhesive maybe the adhesive will change the permeability that is something which you may like to do research in sometimes they will do clay plus adhesive plus some stitching stitch across the 2 faces or you can have a needle punched; that means, you can have a lot of fibres which are punched in it which gives it some holding capacity for the clay and you can have a geomembrane plus clay.

So, these are the various kinds of gcls I like to show you a sample. So, that you just get the idea.

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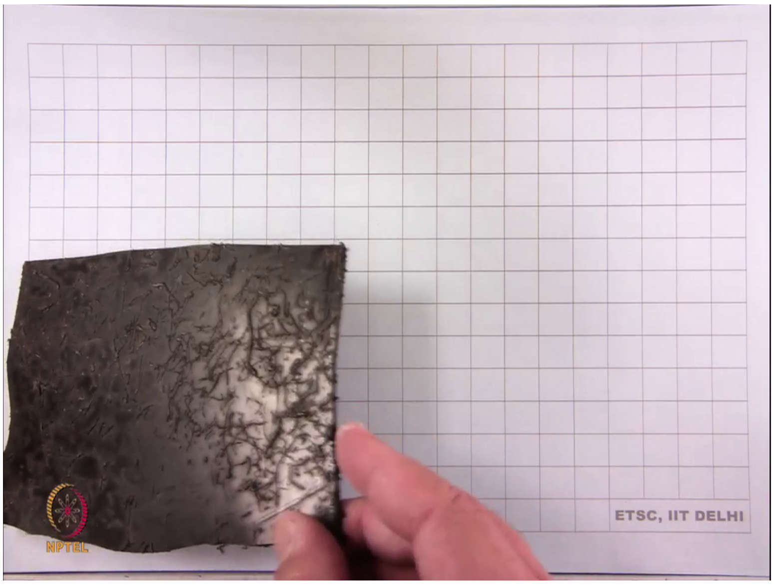

We did the geomembrane last time and then we will have said it can be smooth or textured will you remember this, and I showed you it had it had a shining surface and I the shining surface reflects like a mirror and then we talked about a textured geomembrane.

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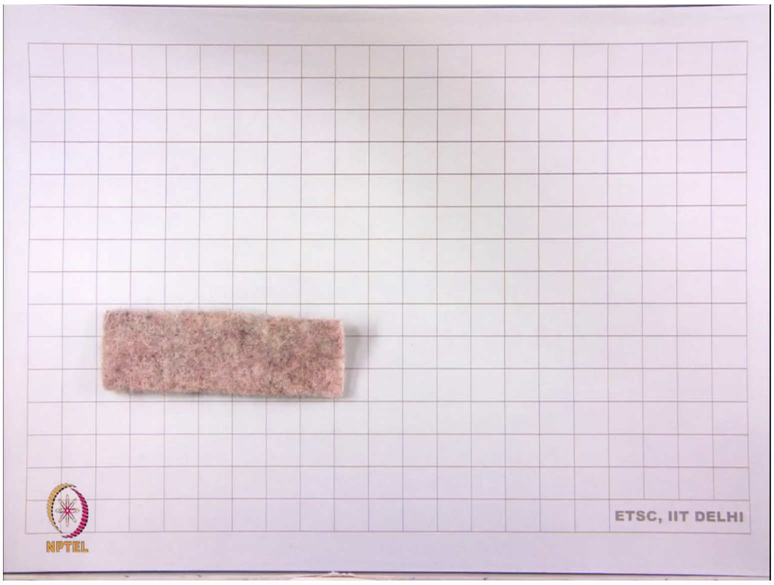

And also this also had a roughness and then I talked to you about a geotextile a blanketing material. Well this is yet another geotextile probably more like 400 gsm.

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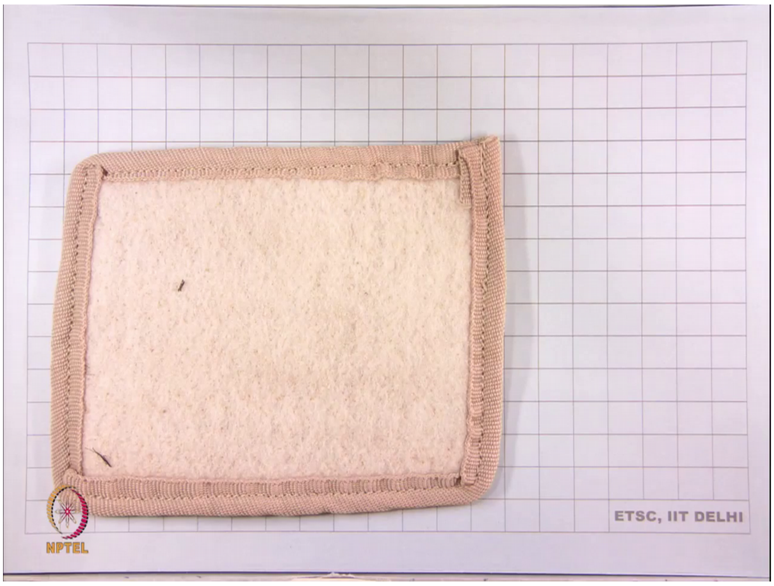

And now I had like to show you a gcl this looks like the nonwoven geotextile on the top, I flip it around this is a non woven or a woven geotextile at the bottom or a hybrid between the 2 if I look at this this is stitched together, but between the 2 is bentonite powder right.

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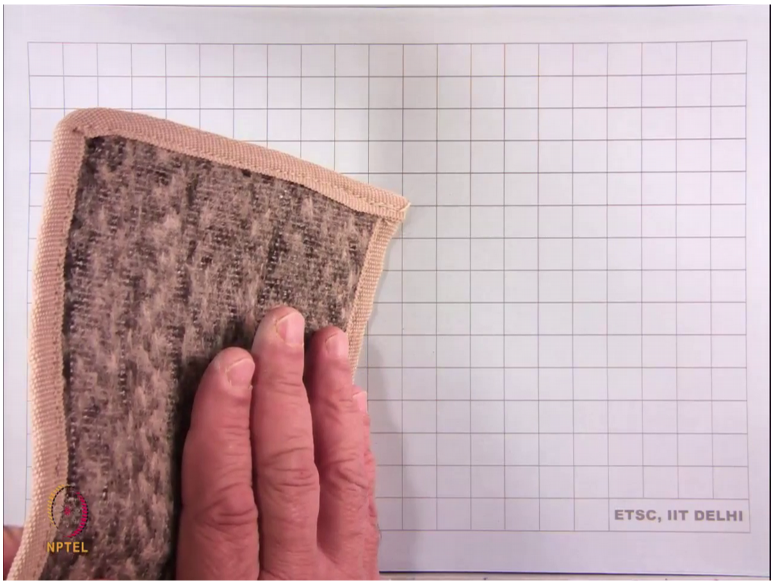

And it is about 5 millimeters thick this is one type of material this is another one nonwoven geotextile a geomembrane slow geomembrane.

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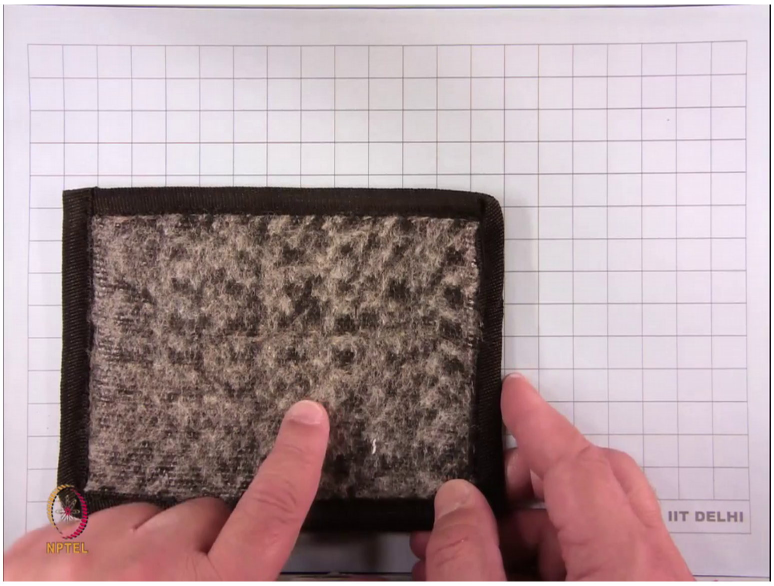

And between them bentonite you are always bothered that if I put it up like this you will the you will the bentonite come to one side because it is a powder.

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So, it is either stuck or it is needle punched or there is some stitching across which holds the material in position.

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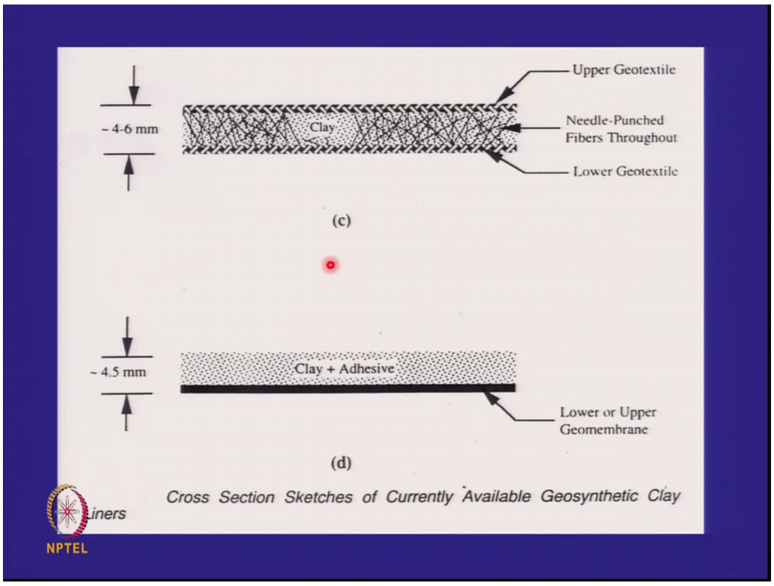

So, these are new materials which come in rolls and which can be rolled out. So, commercial sodium bentonite sandwiched between or glue to geotextiles or geomembranes with k 10 to the power of minus 9 to 10 to the power of minus 12 meters per second 10 to the power of minus 10 to 10 to the power of minus 12 meters per second advantages they are factory made clay plus geosynthetic liners available in the form of rolls for easy installation. They have self healing properties the manufacturers say that if you put a pin through them. Or a needle through them and when you remove the needle and when you saturate this is the bentonite will swell and self healing.

They are very thin and hence if you use them to replace the clay, if you use them to replace the clay you will get one meter more of space to put the waste in it. And they are easy to install. So, they are now being proposed that one should use them in place of compacted clay liners the European practice has not you allowed a thick. Clay mem layer to be replaced by a thin gcl in the American practice, one of the 2 double layers in American practice there are you remember double composite liners.

So, in what if you have a double composite liner one of the 2 can be replaced by the gcl, but one thick clay must remain in position because it might be able to heal a pinprick or a needle prick or a screwdriver, but will it be able to heal a tenant a large hole 3 inches by 3 inches we talked about small hole being 10 millimeters by 10 millimeters and a large hole being 100 millimeters by 100 millimeters. 100 millimeters is 4 inches by. So, if it has a chair the bentonite is not going to expand and heal itself. So, they cannot repair major tires in it.

So, geosynthetic clay liners the experience shows they work well when hydrated properly.

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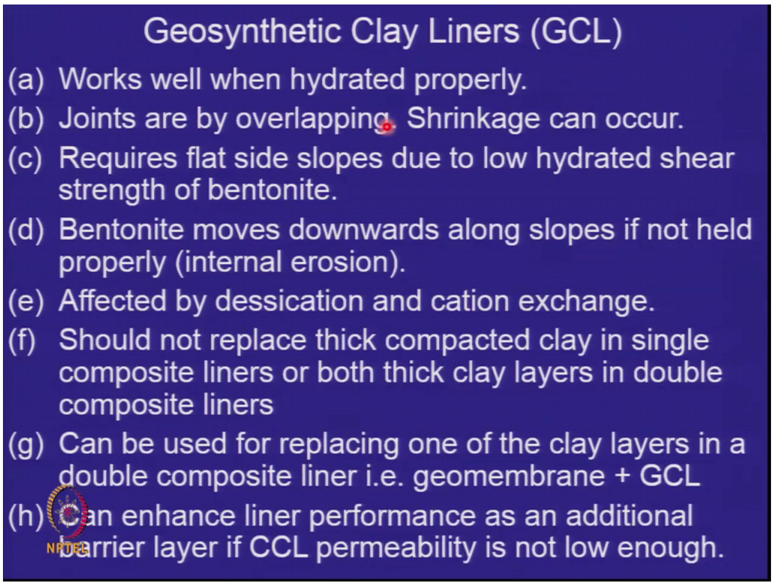

That means, they must have been given adequate moisture to swell otherwise air will pass through them and water will pass through them. Joints are by overlapping they are no longer welded, they are by overlapping shrinkage can occur if they are allowed to dry out. Because of the because of the bentonite what is happening because of the bentonite the when it hydrates, it is strength is very low it is like a clay powder.

So, when you put it on the sides it can have a failure. So, requires flat side slopes due to low hydrated shear strength of bentonite. Also it is observed now from field results that bentonite tends to move downwards there is internal erosion if the gluing and stitching is not proper. And definitely it is affected by cation exchange, because if the sodium bentonite if calcium chloride solution will go in permeability will increase by an order of 10 to a 100.

So, gcl should not replace thick compacted clays in a single composite liner or both the thick clay layers in double composite liners. They can be used for replacing one of the clay layers in a double composite liner; however, if you want to use this as an additional layer you are not getting very good soil. So, you want to have a soil with 10 to the power of minus 6 centimeters per second. And instead of mixing 10 percent bentonite in it you say no I would like to enhance it by using the gcl; so can enhance liner performance as an additional barrier layer if ccl permeability is not low enough.

So, this is a area of intense research nowadays they have been around for 5 years, now and there are definitely some good examples of their performance, but the debate about whether all thickly elements can be replaced by thin gcl is still going on.

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So, with this we just see some photographs of the liners; just remember you can see why damage occurs what kinds of shoes are being used.

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And this is that air pressure test which is being conducted, this is another site where nonwoven protector over the geomembrane, but typically you should be able to see the seams can you see the seams all across.

This is where I told you why what is the role of these tires.

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Just to prevent the flying away of the geo geomembrane and this is; what is happening closure this is the waste being covered with daily cover.

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And that is your geomembrane and I could not get a better shot than this for you to see I told you always that they are inclined. So, that the water comes to the one drain this is just after a rain fall and you can see all the water has come here and this is where the leachate will be pumped out from.

The other thing that you have to notice in all these figures is you will see some wrinkles right. And that is because the geomembranes expand during the day.

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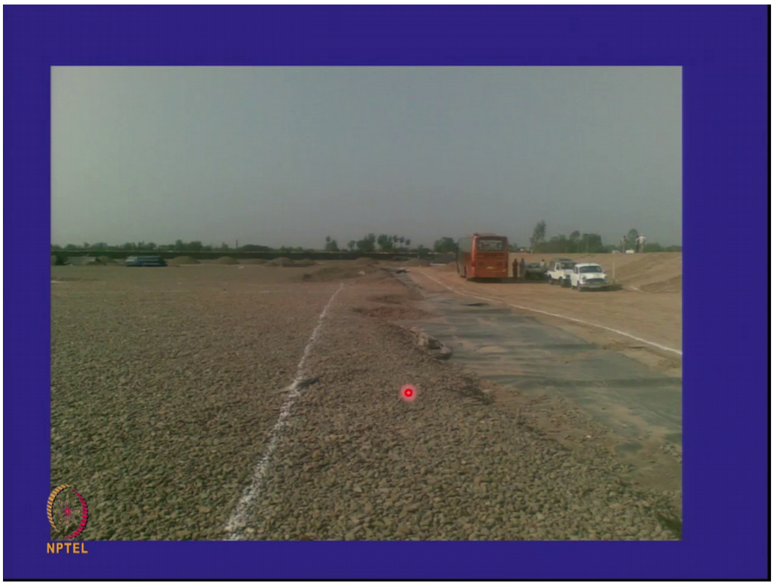

And contract during the evening. So, wrinkles are essential part of what we have seen, but you do not place them well that is a separate issue for example, here you can see the geomembrane is not properly covered. So, it will get damaged and that is another site.

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So, with this we come to a end our discussion on landfill line liners, we are now better exposed to what is a composite liner what are geomembranes how are they join and how do liner systems work in landfills the design components. So, far we have only looked at minimum specifications, what is the thickness of the clay what is the thickness of the geomembrane and individual component design will do as we go along. Any questions you have then.

Thank you.