Geosynthetics Engineering: In Theory and Practices
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Lecture -14
Geosynthetics Properties and Test Method

Welcome to lecture 14, my name is Professor J. N. Mandal, Department of Civil Engineering, Indian Institute of Technology, Bombay, Mumbai, India. The name of the course Geosynthetics Engineering in Theory and Practice, this is module number 3 lecture number 14, Geosynthetics Properties and Test Methods.

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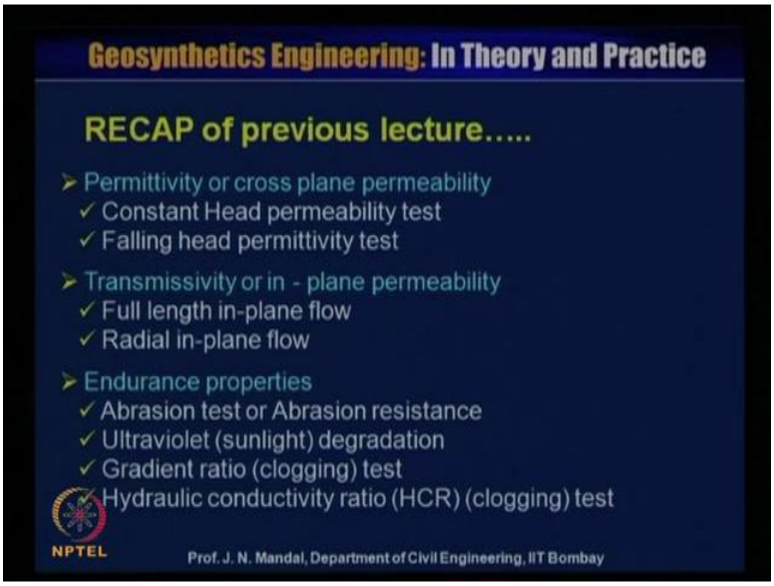

I now so the recap of the previous lecture, what we have covered that is, permittivity of cross plane permeability that is under constant head permeability test and falling head permittivity test the, transmissivity or in plane permeability, that is under full length in plane flow and radial in plane flow. And next endurance property, that is abrasion test or abrasion resistance, ultraviolet or sunlight degradation, gradient ratio or clogging test, hydraulic conductivity ratio HCR or clogging test.

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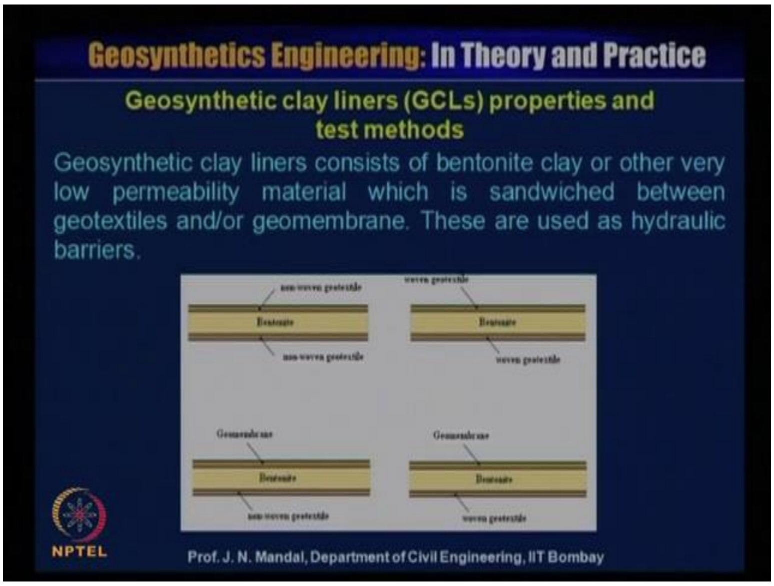

Now, we will discuss the geosynthetics clay liner that is, GCL properties and test method. Geosynthetics clay liner consists of bentonite clay or other very low permeability material, which is sandwiched between geotextile and or geomembrane, these are used as a hydraulic barrier. So, this material may be, this bentonite and sandwiched between the non-woven geotextile, non-woven geotextile, bentonite it may be bottom is woven geotextile and top is woven geotextile.

Or this is a bentonite, it is bottom non-woven geotextile and top is geomembrane or this is bentonite, this bottom is woven geotextile and top is geomembrane. So, you can see that, one of the sample like this you can see that, here in the woven geotextile material and sandwiched by this also non-woven geotextile material and the bentonite is inside between this non-woven and woven geotextile material. So, this is the kind of the geosynthetics clay liner material and this is alternative to geomembrane material.

And when this bentonite is come and contact with the water so it will act as a barrier so we will show that, some of the test of this geosynthetics clay liner material. So, before that going through the test procedure, we would like to focus what should be the properties of the bentonite.

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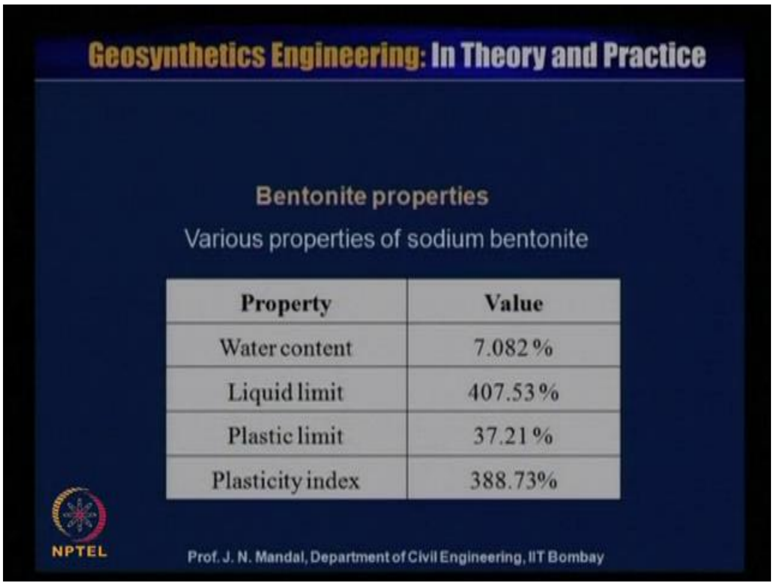

This is various properties of the sodium bentonite, it contain water content 7.082 percentage, liquid limit 407.53 percentage, plastic limit 37.21 percentage, plasticity index 388.73 percentage. So, there are also sodium bentonite, calcium bentonite so they are also to be equally careful, what kind of bentonite you should require for the preparation of the geosynthetics clay liner.

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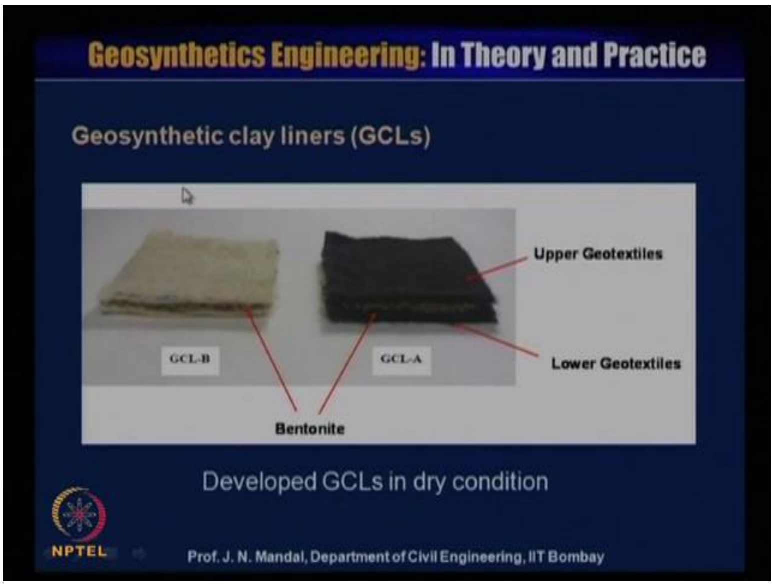

So here, we have developed two kind of the geosynthetics clay liner, one geosynthetic clay liner A, another geosynthetic clay liner B and you can see, this is the geosynthetic bentonite in the middle and this is the lower geotextile this is a upper geotextile. Similarly, for this GCL B so two different types of the material, one is GCL A, one is GCL B.

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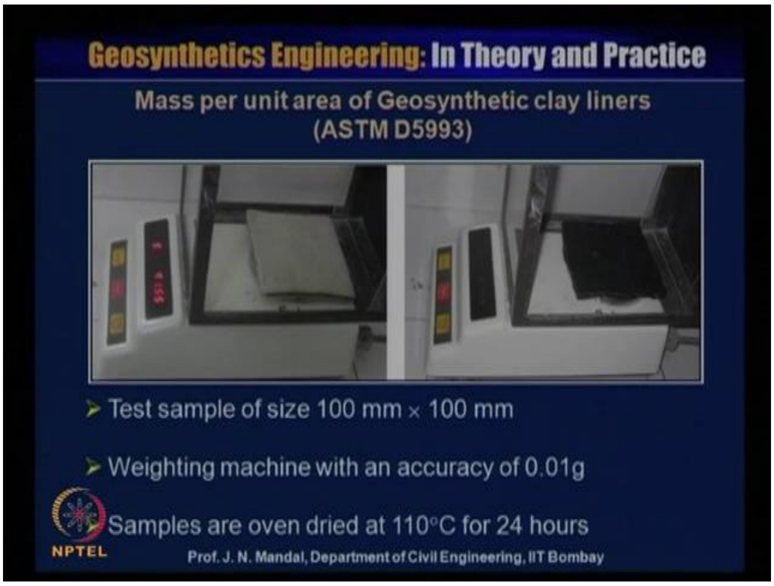

So, initially, we have to calculate what would be the mass per unit area of geosynthetics clay liner as per ASTM D5993. So, this is very simple way to determine that, mass per unit area of geosynthetics clay liner you can see, this is the sample, this is the white colour and this is the black colour, this is the test sample of size 100 millimetre by 100 millimetre. And you are putting in a weight machine with an accuracy of 0.01 g and sample are oven dried at 110 degree centigrade for 24 hour.

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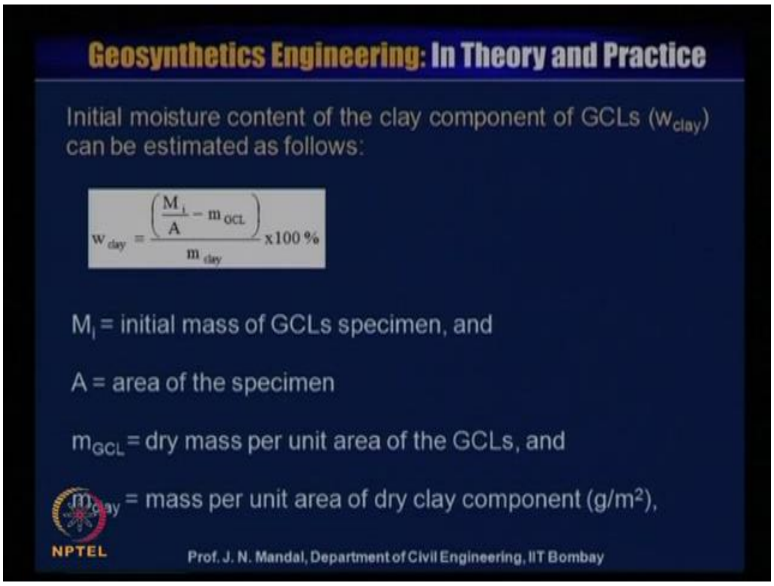

Then initial moisture content of the clay component of geosynthetics clay liner or W clay can be estimated as follow. That is, W of clay is equal to M i by A minus m GCL by m clay into 100 percentage where, M i is initial mass of the geosynthetics clay liner specimen and A is area of the specimen, m GCL is the dry mass unit area of GCL and m clay mass per unit area dry clay component that is, gram per meter square. So, from this you can calculate that, what should be the initial moisture content of the clay component in a GCL.

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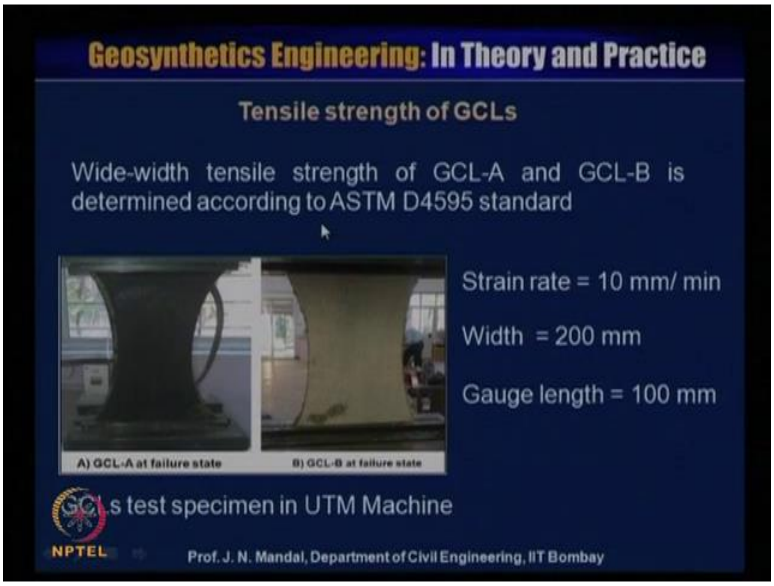

So, this is a kind of the I say that, geosynthetic clay liner and this geosynthetics clay liner is performed for the tensile strength, so what will be the tensile strength of this material. So, this is wide width tensile strength have performed for the sample GCL A and GCL B as per ASTM D4595. So, you can see here that, strain rate is 10 millimetre per minute and the width of the sample is 200 millimetre and this gauge length is about 100 millimetre.

So, this is geosynthetic clay liner test specimen have performed in a universal testing machine you can see for the sample here, what will be the type of the failure that is, the formation of depth. And similarly, for the geosynthetic clay liner B sample also failure, you can see very typical neck type of the failure as observed for both the sample GCL A and GCL B.

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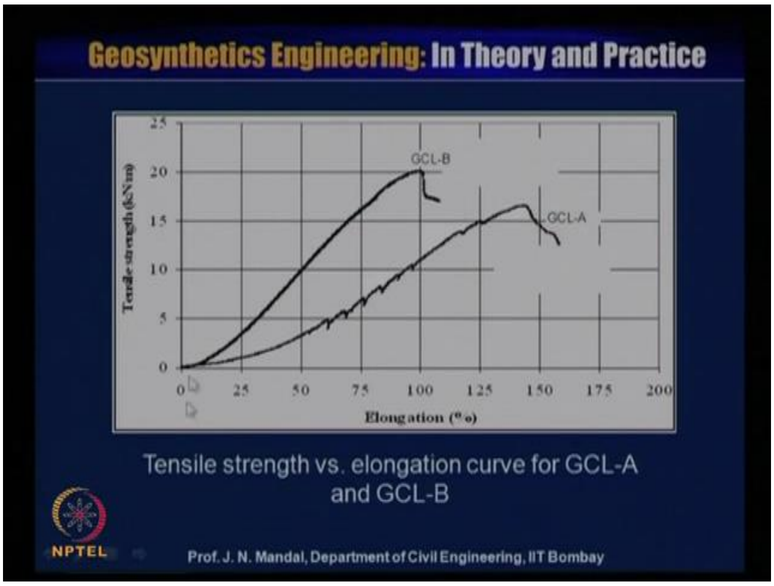

We can see here, the tensile strength versus elongation curve for the GCL A and GCL B, we can see it is increasing and then is reached to the top and then it is the decreasing. You can see elongation, elongation is more 100 percent and near about let us say, 130, 40 percentage elongation and the tensile strength is very, very less. So, elongation is more so this is like a geomembrane material.

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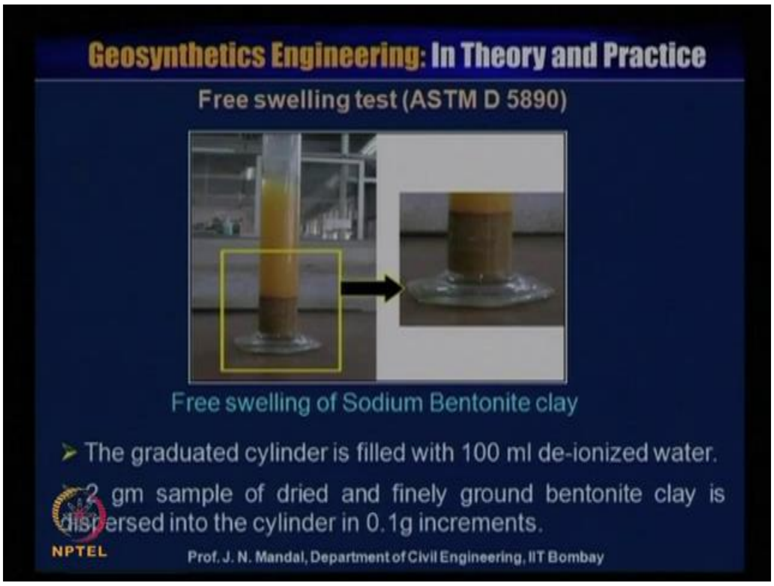

So, whenever test for this bentonite is that free swelling test ASTM D5890 so these are the tests are very important when you design for the land ((Refer Time: 08:48)) or the canal or the dam, whatever you use this geosynthetics clay as a liner or as a barrier. So, this is free swelling of sodium bentonite clay, so this is the graduated cylinder is filled with 100 millimetre deionized water and then 2 gram of the sample of dried. And finally, ground bentonite clay is dispersed into the cylinder in 0.1 g increment.

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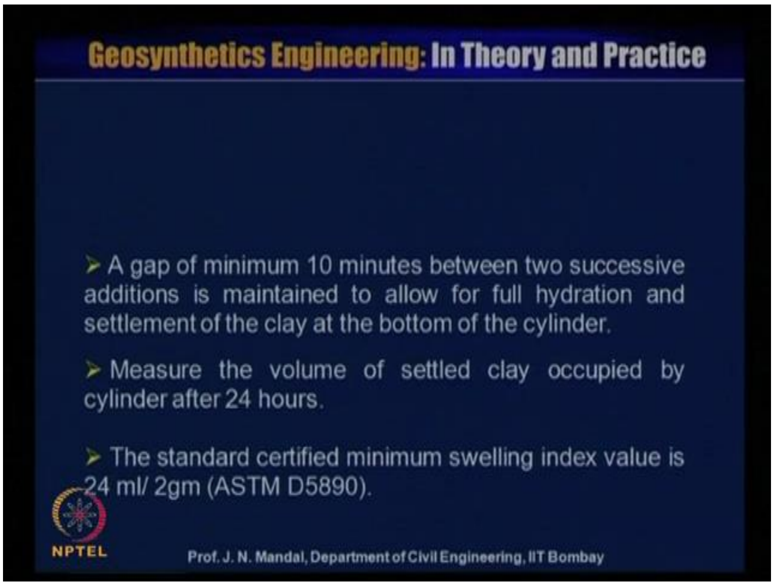

Then, a gap of minimum 10 minutes between the two successive addition is maintained to allow for full hydration and settlement of the clay at the bottom of the cylinder. Then measure the volume of the settled clay occupied by the cylinder after 24 hour. The standard certified minimum swelling index value is 24 ml per 2 gm as per ASTM D5890.

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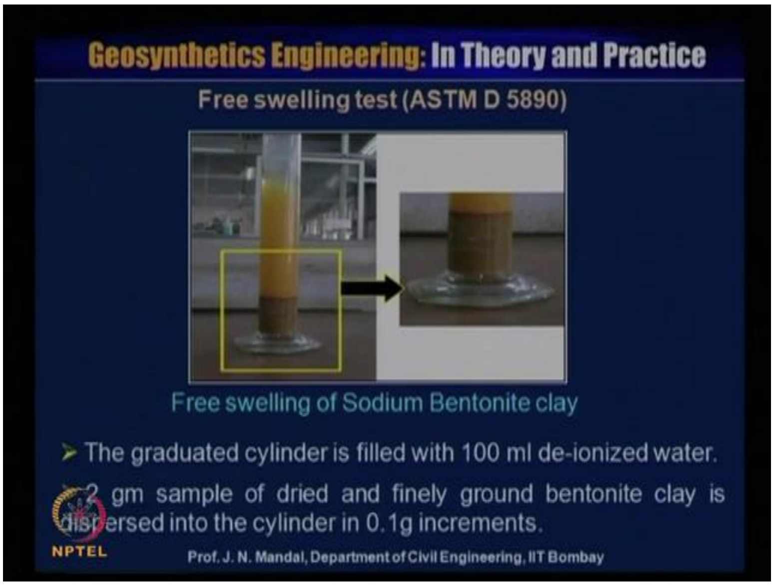

You can see that, after the 24 hour, you can see here after the 24 hour, you can measure that what this is extension here so you can measure that it will be the 24.

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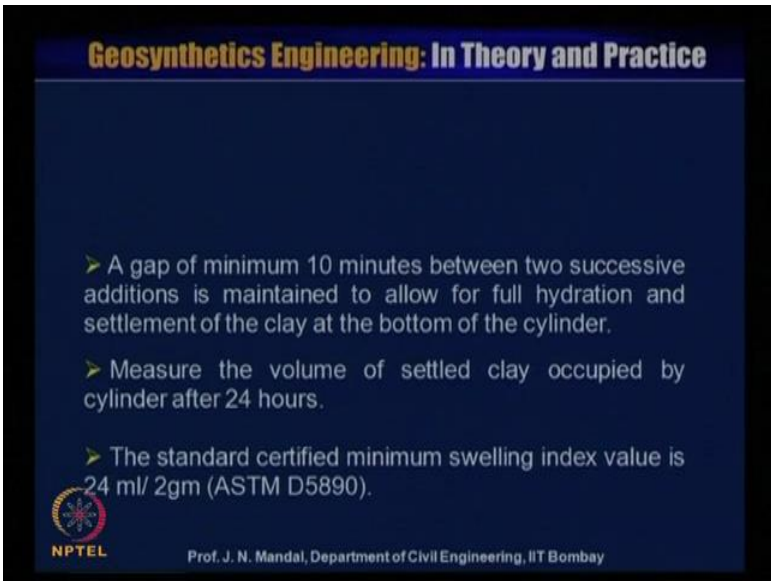

So, that it should satisfy the minimum swelling in this criteria, if it satisfy then it is ok if it is not satisfied, you have to be careful to think that, what alternative bentonite system is to be added or what is the repetition of the test are also needed. But that is the minimum swelling index value needed also ((Refer Time: 10:42)), etcetera they also recommended that, a minimum swelling index of 24 millimetre per 2 gram of bentonite.

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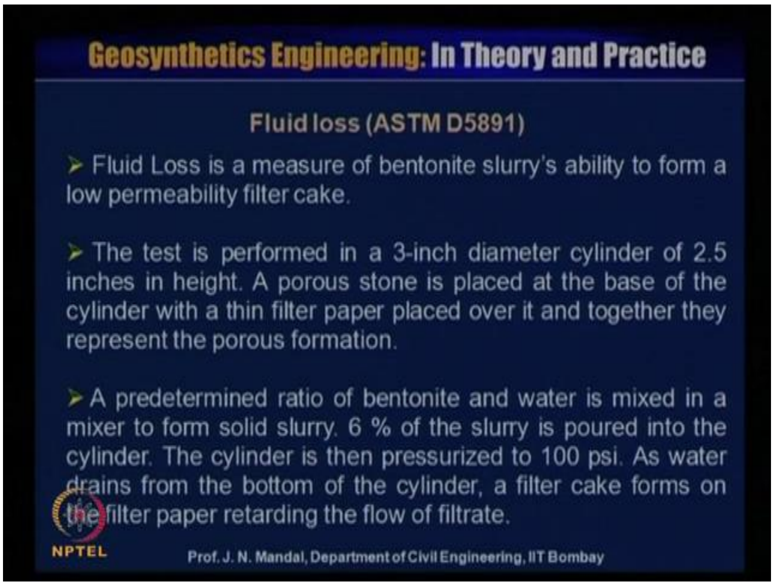

Next, fluid loss test as per ASTM D5891, fluid loss is a measure of bentonite slurry's ability to form a low permeability filter cake. The test is performed in a 3 inch diameter cylinder of 2.5 inches in height, a porous stone is placed at the base of the cylinder with a thin filter paper placed over it and together they represent the porous formation. A predetermined ratio of bentonite and water is mixed in a mixer to form solid slurry, 6 percent of the slurry is poured into the cylinder.

The cylinder is then pressurized to 100 psi as the water drain from the bottom of the cylinder, a filter cake form on the filter paper retarding the flow of filtrate. The filtrate is allowed to flow for the first 7.5 minutes of the test.

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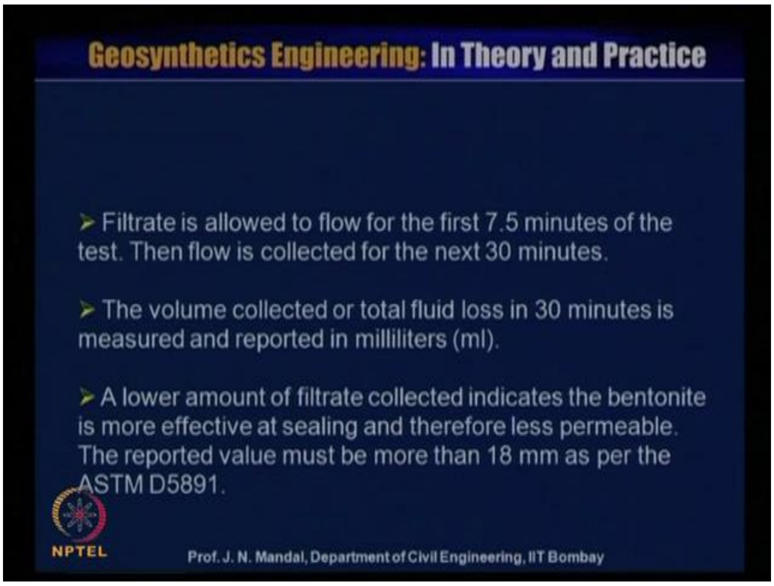

And then flow is collected for the next 30 minutes, the volume collected or the total fluid loss in 30 minutes is measured and reported in millilitre or ml. A lower amount of filter collected indicate the bentonite is more effective at sealing and therefore, less permeable. The reported value must be more than 18 millimetre as per the ASTM D5891.

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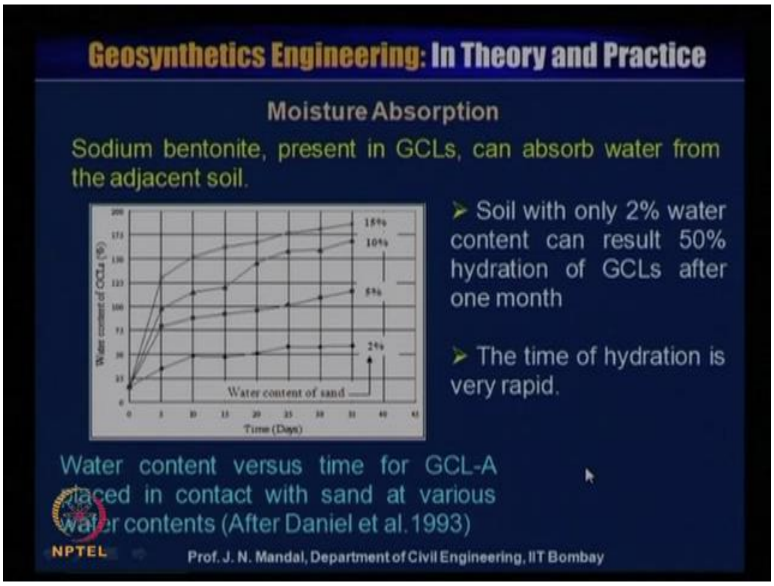

Now, some test also had performed for moisture absorptions tests now, sodium bentonite present in the geosynthetic clay liner can absorb water from the adjacent soil. Here, you can see that, water content versus the time for a geosynthetics clay liner A placed in contact with the sand at various water content. So, soil with 2 percent water content can result that, 50 percentage of hydration of the GCL after 1 month.

These you can see that, this is the percentage of the soil with water, different percentage of the soil with water content. So, in this curve, you can see that, after this 1 month you can see here that, after about a month that is, it reached about the 50 percentage, here 50 percentage hydration of GCL, the time of hydration is very rapid.

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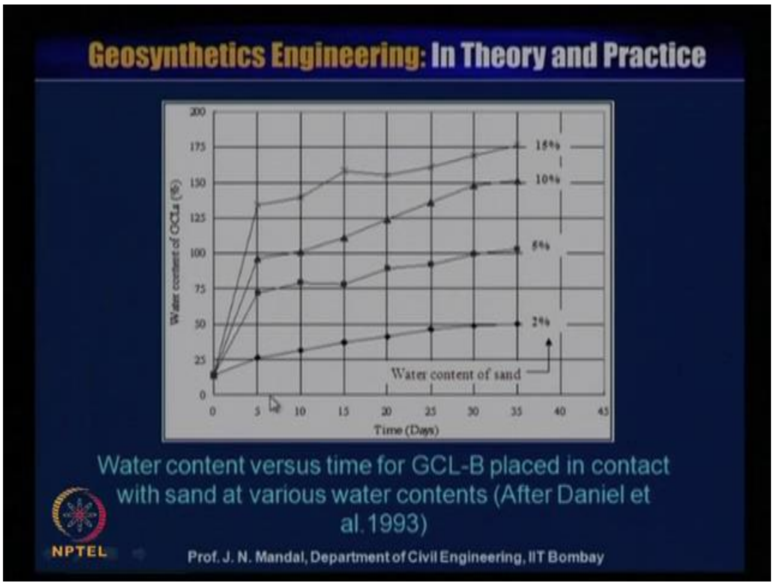

Similarly, you can see the water content versus time for the sample GCL B, which is placed in contact with sand at various water content, this is after Daniel et al. So, this is the various water content 2 percent, 5 percent, 10 percent, 18 percent. Here also, you can see after 30 days, almost it is constant so it is reached the value about the 50 percent, water content 50 percent.

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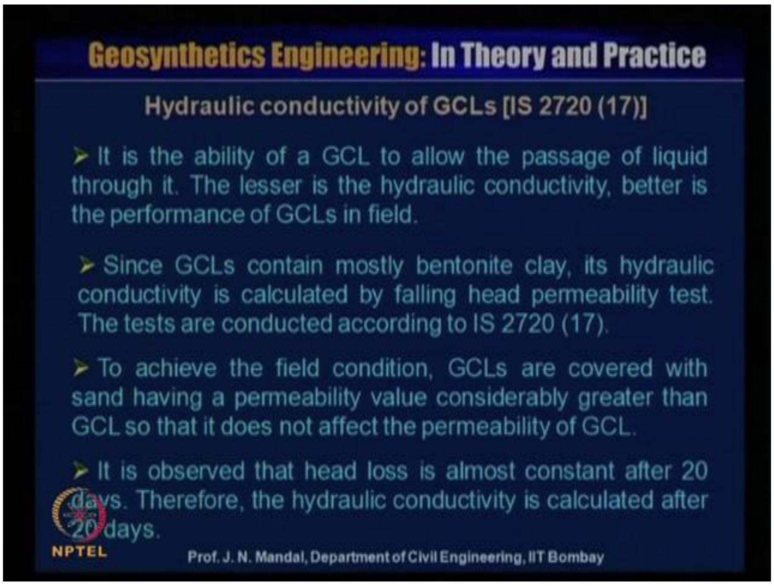

Now, hydraulic conductivity of GCL as per IS 2720 (17), it is the ability of a geosynthetics clay liner to allow the passage of liquid through it. The lesser is the hydraulic conductivity, better is the performance of GCL in field. Since GCL contain mostly bentonite clay, if hydraulic conductivity is calculated by falling head permeability test, these test are conducted according to IS 2720. To achieve the field condition, GCL are covered with the sand having a permeability value considerably greater than the GCL.

So that, it does not affect the permeability of the GCL it is observed that, head loss is almost constant after 20 days therefore, the hydraulic conductivity is calculated after 20 days.

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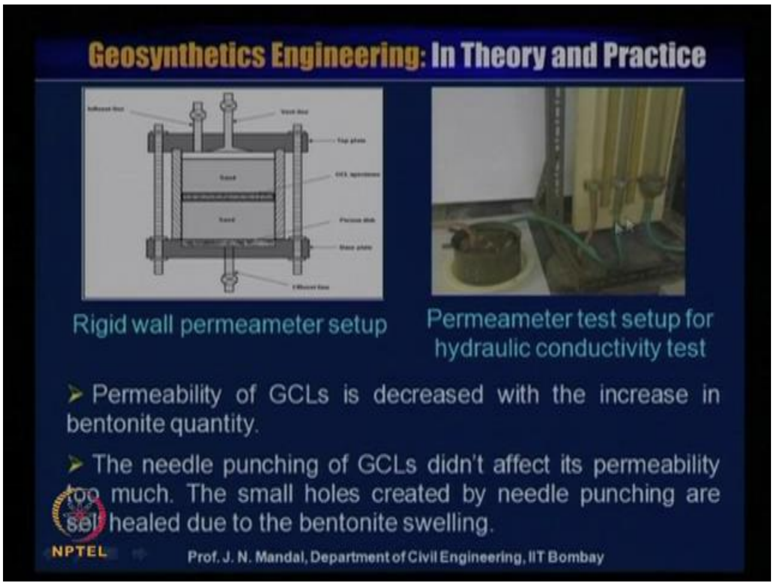

So here, the rigid wall permeameter setup here, the permeameter test setup for hydraulic conductivity test. So, permeability of the geosynthetics clay liner is decreased with the increase in the bentonite quantity, the needle punching of GCL did not affect it is permeability too much. This small holes created by the needle punching are self-healed due to the bentonite swelling.

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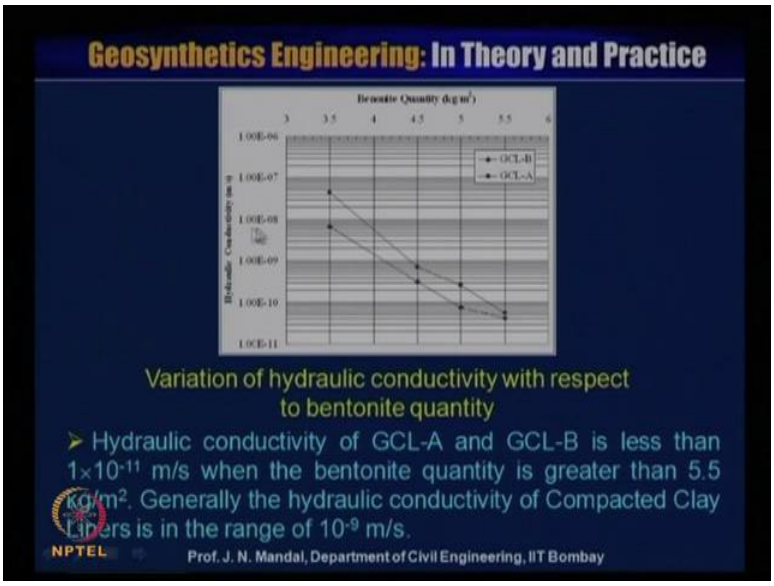

So, this figure it is shown, the variation of hydraulic conductivity with respect to the bentonite quantity. This is the bentonite quantity that is, kg per meter square and this is the hydraulic conductivity and that is metre per second. So, this is for the GCL sample A and also GCL sample B so you can observe from this figure that, hydraulic conductivity of the GCL A and the GCL B is less than 1 into 10 to the power minus 11 here, you can see, 1 into 10 to the power minus 11 meter per second.

When the bentonite quality is greater than 5.5 kg per centimetre square generally, the hydraulic conductivity of compacted clay liner is in the range of 10 to the power minus 9 meter per second. So, what we wanted to conclude here that, when you use this compacted clay liner you know that, what is hydraulic conductivity of the compacted clay liner, and that value may be 10 to the power minus 9 metre per second.

But, alternative to the compacted clay liner, if we use the geosynthetics clay liner whose, coefficient of permeability or the hydraulic conductivity is about 1 into 10 to the power minus 11 metre per second. And also at the same time, we should know that, what quantity of the bentonite is required. So, it has been observed sometimes, if this bentonite quantity is greater than 5.5 kg per metre square so you will obtain the better hydraulic conductivity of the geosynthetics clay liner.

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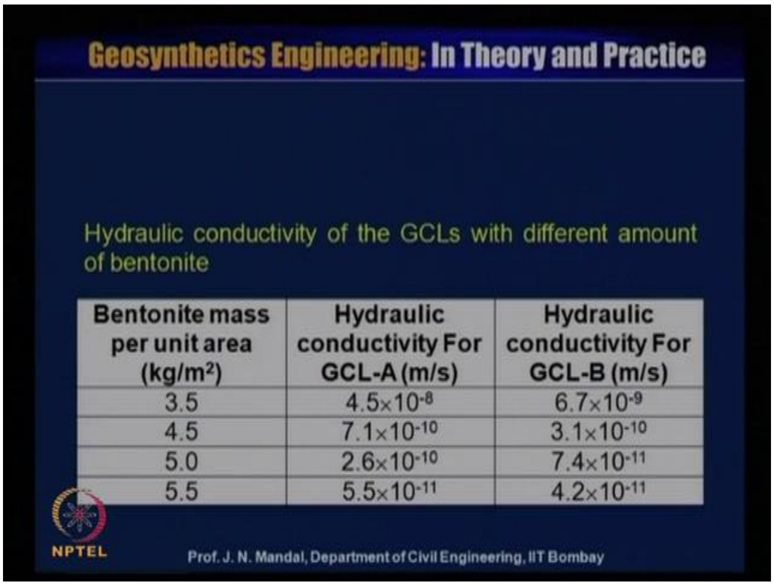

Bentonite mass per unit area (kg/m²)	Hydraulic conductivity For GCL-A (m/s)	Hydraulic conductivity For GCL-B (m/s)
3.5	4.5×10^{-8}	6.7×10^{-9}
4.5	7.1×10^{-10}	3.1×10^{-10}
5.0	2.6×10^{-10}	7.4×10^{-11}
5.5	5.5×10^{-11}	4.2×10^{-11}

So here, showing in the table that, hydraulic conductivity of GCL with different amount of bentonite. So, bentonite mass per unit area you can see, kg per metre square that is, you have been given 3.5, 4.5, 5, 5.5 and thus, hydraulic conductivity for GCL A that is metre per second when the mass is 3.5 kg, this hydraulic conductivity 4.5 into 10 to the power minus 8 and hydraulic conductivity for GCL B that is metre per second, 6.7 into 10 to the power minus 9, when the bentonite mass per unit area 4.5 kg per metre square, the hydraulic conductivity for GCL A is 7.1 into 10 to the power minus 10 metre per second and for the GCL B 3.1 into 10 to the power minus 10. When the bentonite mass per unit area 5 then hydraulic conductivity for GCL A 2.56 10 to the power minus 10 meter per second and the hydraulic conductivity for GCL B 7.4 into 10 to the power minus 11. Then when the bentonite mass per unit area 5.5 then hydraulic conductivity is 5.5 into 10 to the power minus 11 and for the GCL B 4.2 into 10 to the power minus 11.

You can see that, how you are having better result with increasing the mass of the bentonite or bentonite mass per unit area. So, you can fabricate it or develop a geosynthetics clay liner where, you require the bentonite and this bentonite sodium bentonite is abundantly available in India. So, it can be manufactured at this GCL, which will be the more convenient to produce this kind of the product and it is alternative to the geomembrane material.

Production of geomembrane material may be the costly but at the both the woven and non-woven geotextile materials also are available and the bentonite is abundantly available. So, this kind of the product would be very useful for different project in India like this landfill project or wherever in any project where, you require for the proper kind of the barrier or to control the slippage.

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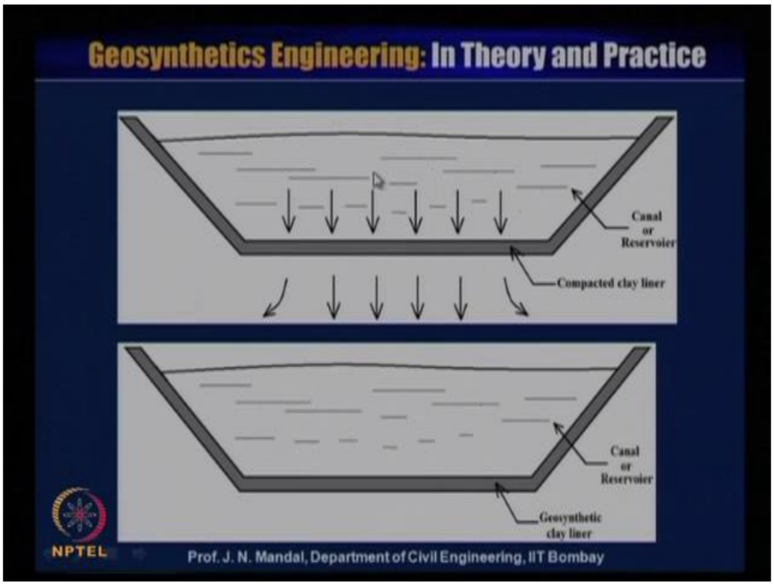

In this slide, I am showing that one canal or the reservoir and this is the compacted clay liner and alternative to the compacted clay liner now, we place in this canal one geosynthetics clay liner, this is geosynthetics clay liner. So, you can see that, how the water can flow in case of the compacted clay liner, you can also observe how the water can flow through the geosynthetic clay liner. I said, when this water will come and contact with the geosynthetic clay liner and it is swell and it will act as a barrier.

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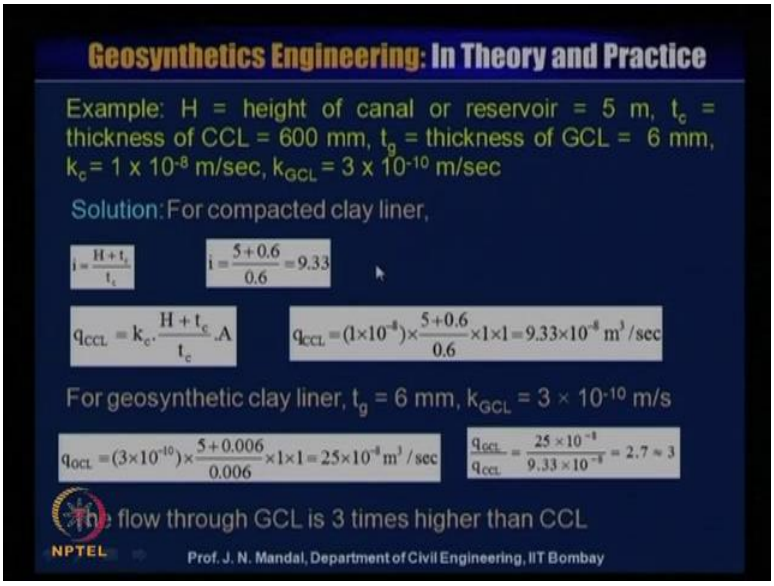

So, I am giving one example so here, you can see height of the canal or reservoir is 5 meter and thickness of the compacted clay liner is 600 millimetre. So, you can see that, this is 600 millimetre, height is 5 metre and this is 600 millimetre. Whereas, in case of the GCL or geosynthetic clay liner, the t g is 6 millimetre so you can see, this t g will be the 6 millimetre. And coefficient of permeability of clay liner 1 into 10 to the power minus 8 metre per second and hydraulic conductivity of geosynthetic clay liner is 3 into 10 to the power minus 10 metre per second.

Now, in this example that, this solution is here for compacted clay liner, so hydraulic gradient i is equal to H plus t c divided by t c, and whereas that thickness of the compacted clay liner is 600 millimetre. So, this is H is the height of the canal that is, 5 metre so this is to be converted into metre so that is why, t c will be the 0.6 and this height is equal to the 5. So, i is equal to 5 plus 0.6 divided by t c is 0.6 so this hydraulic gradient i will be 9.33.

Now, quantity of q of CCL quantity of flow of water through the compacted clay liner that you know from the Darcy's equation that, q CCL is equal to K c into H plus t c divided by t c into A. So, K c is given is 1 into 10 to the power minus 8 metre per second into H plus t c, H is the 5, t is 0.6 divided by t c is 0.6 into A, 1 is to 1. So, you will have this q CCL is 9.33 into 10 to the power minus 8 metre cube per second, this is the quantity of water flow through the compacted clay liner.

Now, alternative to the compacted clay liner, if you can add up the geosynthetic clay liner, which thickness t g is given 6 millimetre, t g is equal to 6 millimetre and the hydraulic conductivity of the geosynthetic clay liner is 3 into 10 to the power minus 10 metre per second. So, here the q GCL will be equal to 3 into 10 to the power minus 10 that is here, k GCL 3 into 10 to the power minus 10 into H plus t c that mean 5, 5 is the reservoir height plus thickness, thickness you can see less of GCL that is, 6 millimetre.

So, this is 0.006 millimetre divided by t c that mean, 0.006 into 1 into 1 so this will give you the 25 into 10 to the power minus 8 metre cube per second. Now, if you take the ratio of q CCL, by ratio of q GCL by q CCL, you can have this q GCL is 2.5 10 to the power minus 8 divided by q CCL is 9.33 into 10 to the power minus 8. So, this is 2 point say approximately is 3 so flow through geosynthetic clay liner is 3 times higher than the compacted clay liner. Next, the x ray diffraction test, x ray diffraction is a versatile non-destructive technique.

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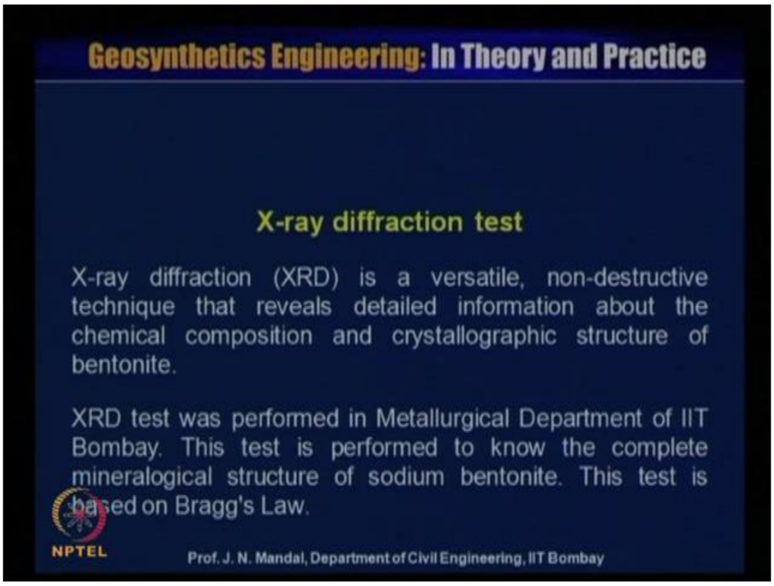

That reveal detail information about the chemical composition and crystallographic structure of bentonite. So, XRD test was performed in metallurgy department of IIT, Bombay this test is performed to know the complete mineralogical structure of sodium bentonite, this test is based on Bragg's law.

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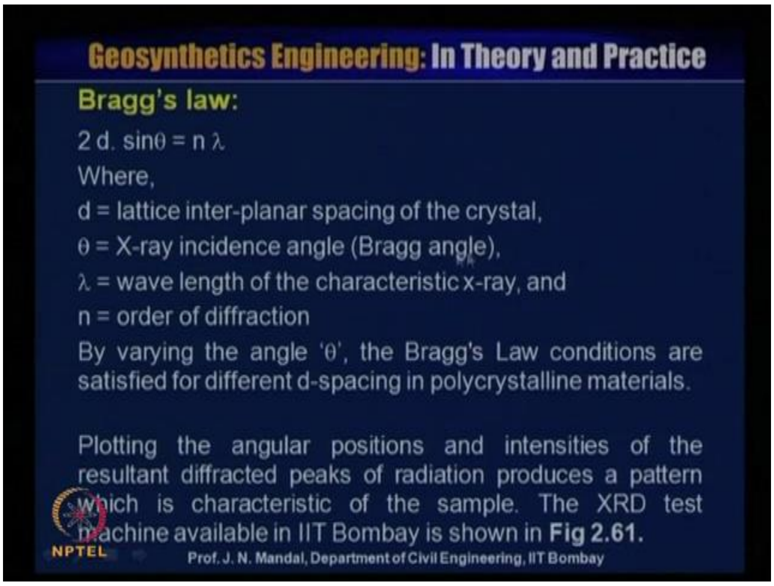

So, what is Bragg's law is 2 d sin theta is equal to n lambda where, d is lattice inner planar spacing of the crystal, theta is equal to x ray incidence angle is Bragg's angle and lambda is wavelength of the characteristics x ray and n order of diffraction. By varying the angle theta, the Bragg's law conditions are satisfied for different d spacing in polycrystalline material.

Plotting the angular position and intensities of the resultant diffracted peaks of radiation produces a pattern, which is characteristic of the sample. The XRD test machine is available in IIT, Bombay.

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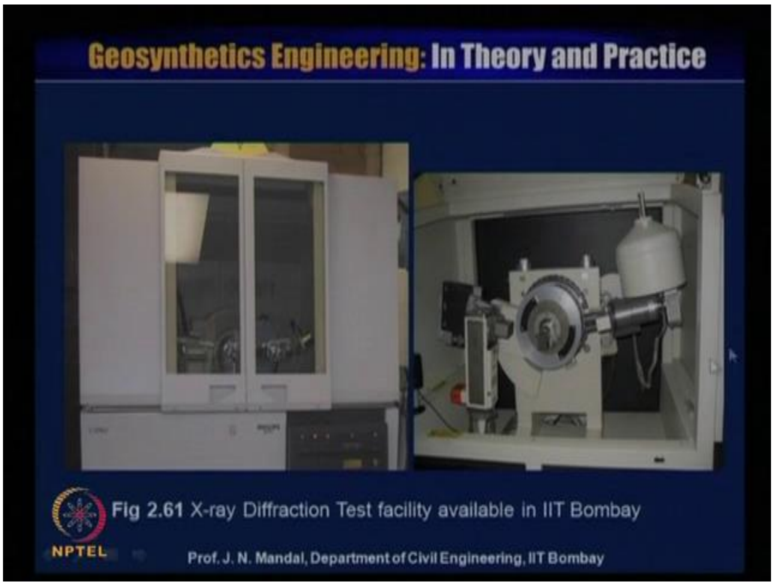

You can see this is the x ray diffraction test facility.

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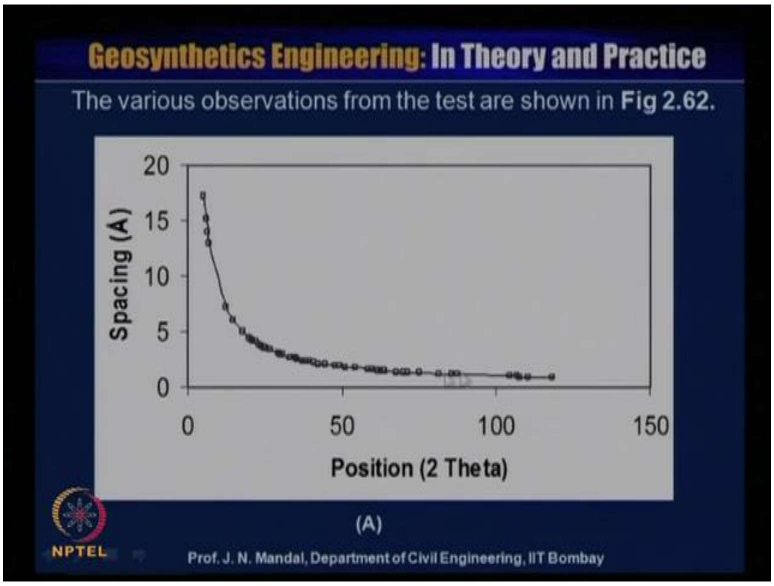

And this is the variation observation from the test, this is between the spacing and this is position 2 theta, how this spacing is decreasing and position 2 theta is also increasing.

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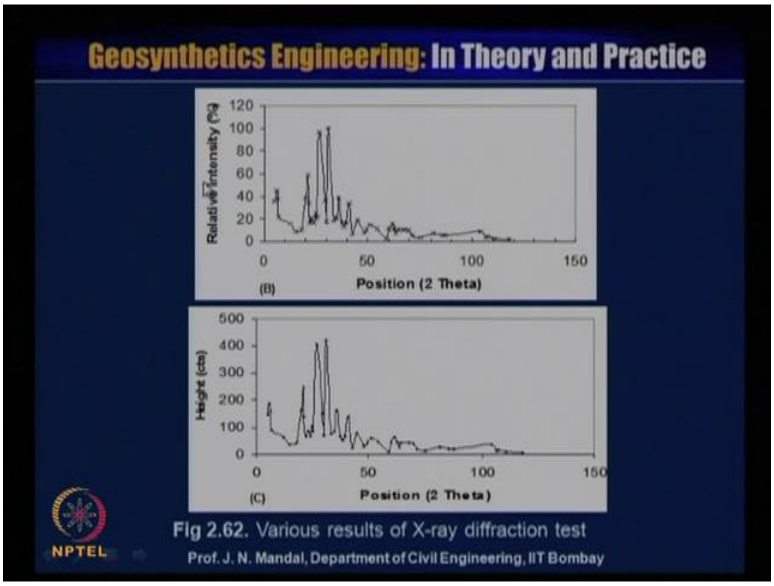

So, this figure shows the various result of x ray diffraction test between the relative intensity, that is in percentage to the positioning of 2 theta and this figure shows that, what will be the height and this with the position of 2 theta.

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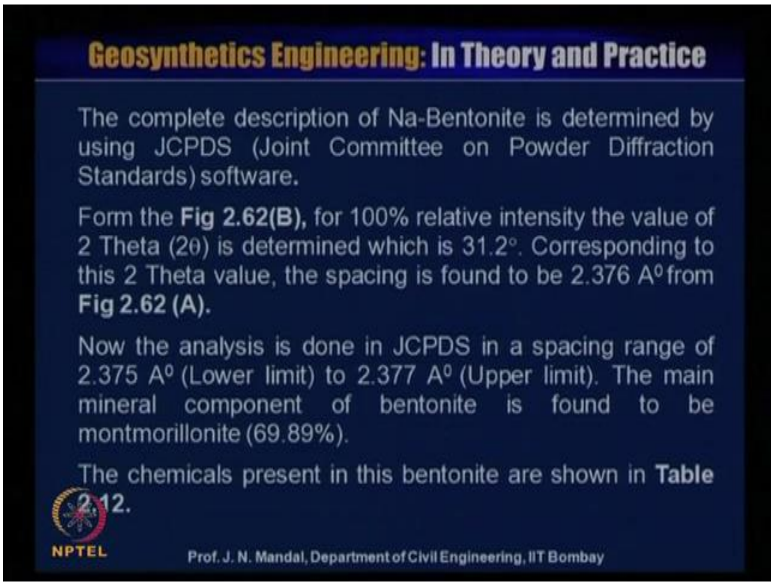

So, from this, the complete description of sodium bentonite is determined by using JCPDS, what called Joint Committee on Powder Diffraction Standards software. From this from this figure from this figure this is suppose B and also the C. So, for 100 percent relative intensity, the value of 2 theta is determined which is 31.2 degree.

Corresponding to this 2 theta value, the spacing is found to be 2.376 Angstrom from the figure so you can also determine from this figure.

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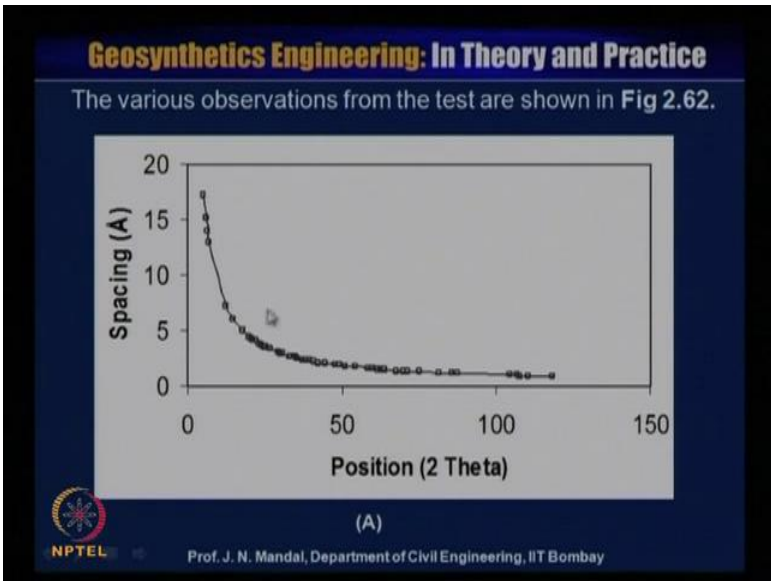

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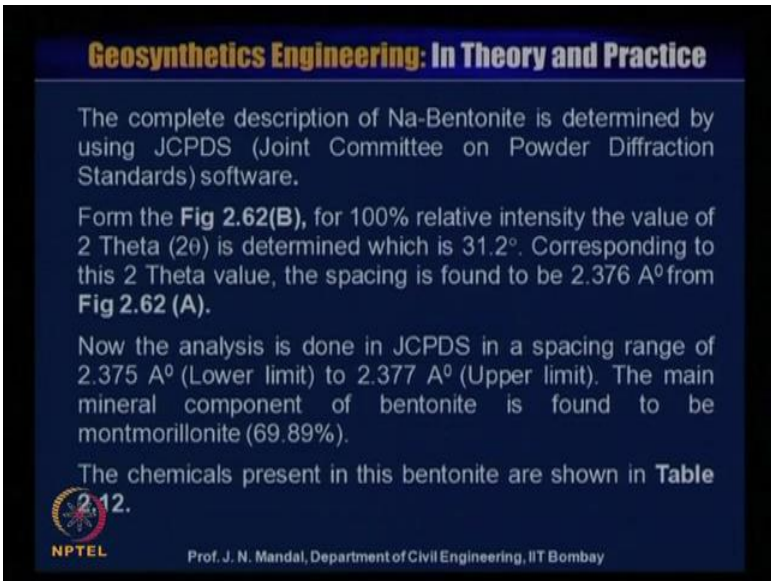

And now, the analysis is done in JCPDS in a spacing range of 2.375 Angstroms that is lower limit to 2.377 Angstrom for the upper limit. The main mineral component of bentonite is found to be montmorillonite that is about 69.89 percentage, the chemical present in this bentonite are shown.

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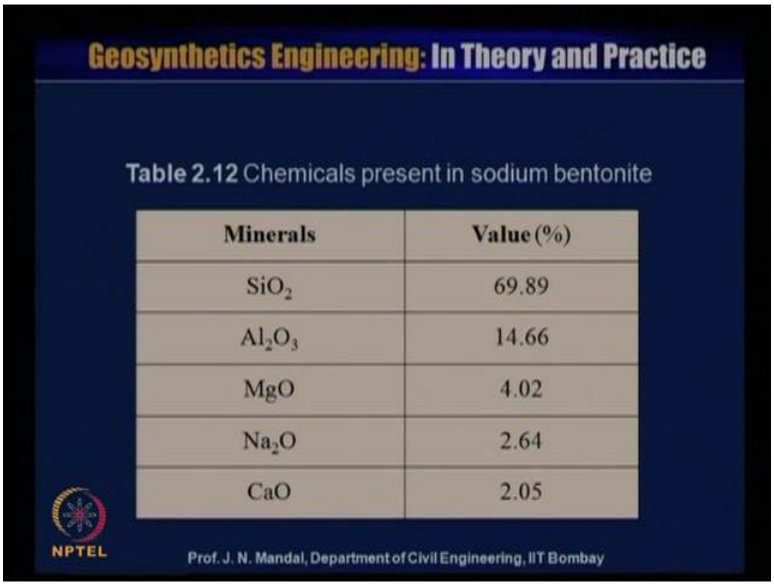

You can see that, what will be the percentage of chemical present in the sodium bentonite, this mineral is silicon di oxide is about 69.89 percent, aluminium oxide is 14.66 percentage, magnesium oxide is 4.02 percentage, sodium oxide is 2.64 percentage, calcium oxide is 2.05 percentage.

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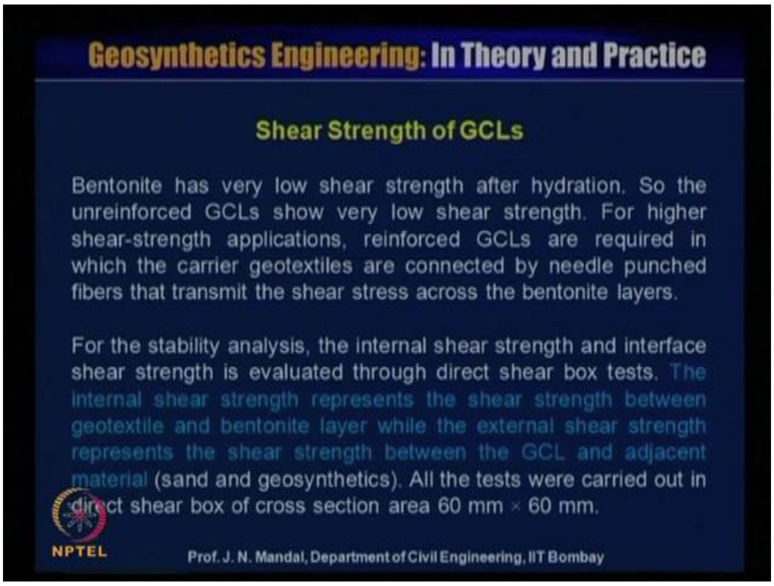

Shear strength of the geosynthetics clay liner, bentonite has very low shear strength after hydration so the unreinforced geosynthetic clay liner show very low shear strength. For higher shear strength application, reinforced geosynthetic clay liners are required, in which the carrier geotextile are connected by the needle punched fibre, that transmit the shear stresses across the bentonite layer. For the stability analysis, the internal shear strength and the interface shear strength is evaluated through direct shear box test.

The internal shear strength represent the shear strength between the geotextile and the bentonite layer, while the external shear strength represent the shear strength between the GCL and adjacent material that is, sand and geosynthetics. All the test was carried out in a direct shear box of cross section area 60 millimetre by 60 millimetre.

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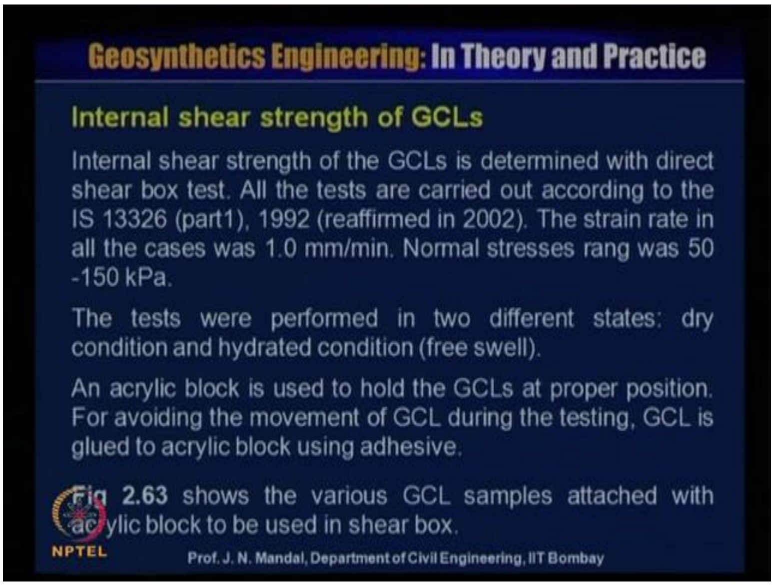

Now, internal shear strength of the GCL is determined with direct shear box test, all the test are carried out according to the IS 13326 part 1 1992 reaffiliated in 2002. The strain rate in all cases was 1 millimetre per minute, normal stresses range from 50 to 150 kilo Pascal. The test was performed in two different state, dry condition and hydrated condition, that is free swell.

An acrylic block is used to hold the GCL's at proper position for avoiding the moment of the GCL during the testing, GCL is glued to the acrylic block using adhesive.

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This you can see that figure, this is the geosynthetics clay liner sample, it is attached with the acrylic block and this is the direct shear test machine.

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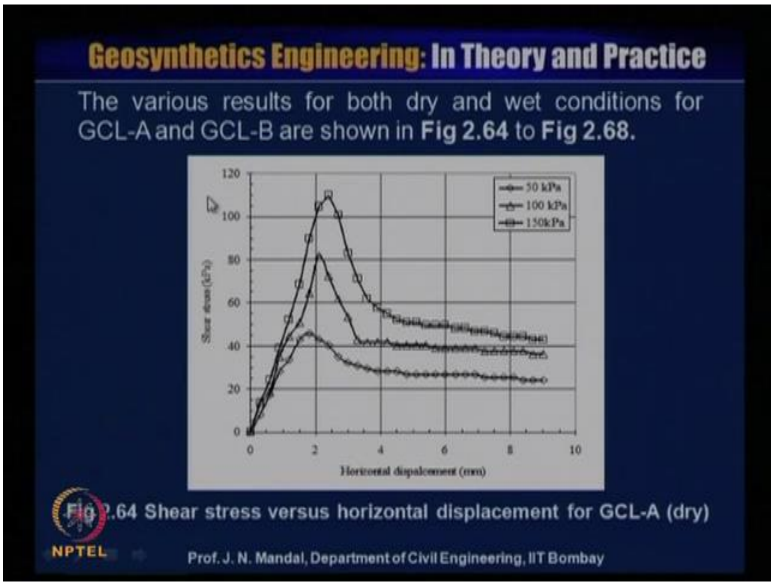

So, you have performed the shear stress versus this horizontal displacement, the various result for both the dry and the wet condition for the geosynthetic clay liner A. And geosynthetic clay liner B has been performed under the pressure of 50 kilo Pascal, 100 kilo Pascal and 150 kilo Pascal. You can see here, how the shear stress is increasing with the increasing of the hydraulic displacement.

But, you can see that, when hydraulic displacement is about 2 millimetre and you can see, you can have almost the maximum stress value. And then it is gradually decreasing and almost later on, it is as a constant.

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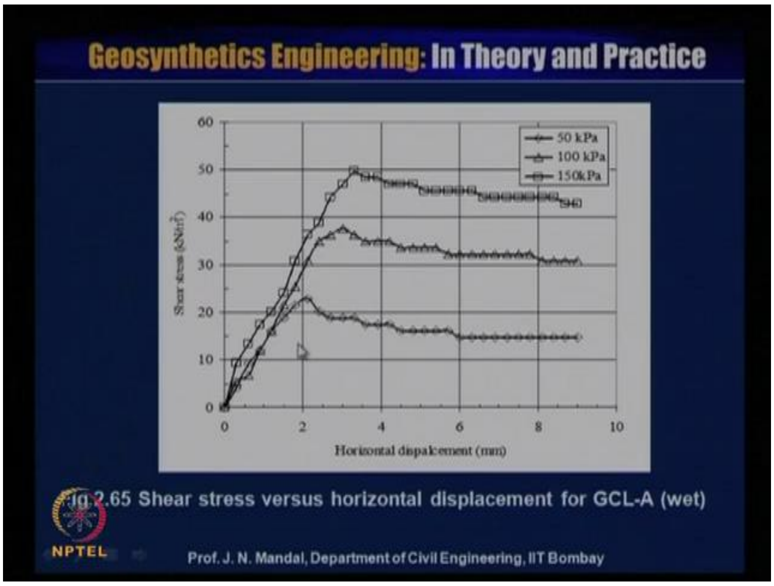

So, similarly for the geosynthetics clay liner A in wet condition, this is the shear stress versus the horizontal displacement. You can see here also, similar nature of the curve you can obtain under the different pressure 50, 100 and 150 kilo Pascal.

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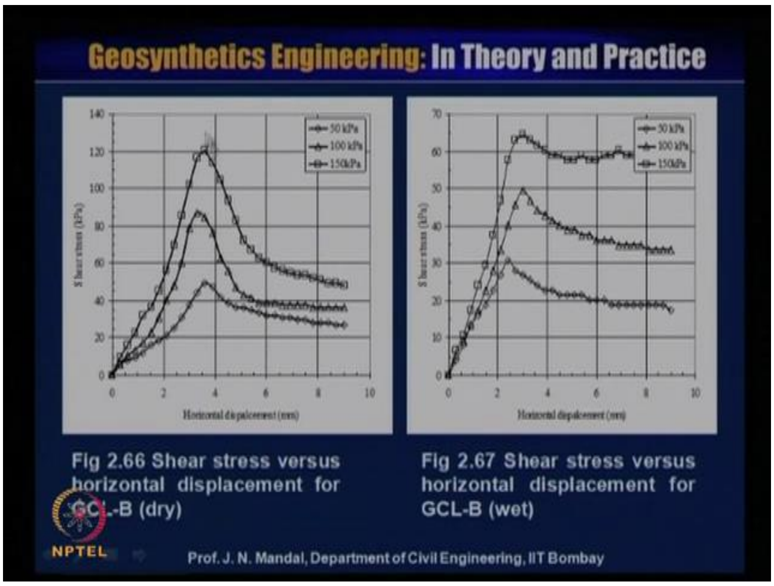

This figure shows the shear stress versus the horizontal displacement for the GCL B in dry condition. You can see that, how the shear stress value is increasing, it goes up to 120 and then it is decreasing and then almost like a constant. All the curve under the various pressure, nature is the same and the horizontal displacement is relatively less whereas, this shear stress is more. But this is the figure for the geosynthetic clay liner B sample in wet condition and this is the relationship between the horizontal displacement and the shear stress under different pressure.

You can see that, the shear stress is increasing and then it is decreasing almost like a constant. But from here, it can be some conclude that, when the GCL is in the dry condition, the shear stress value is higher. And when the GCL is in the wet condition, shear stress value is relatively low and but almost the horizontal displacement is the same, whether it is a wet or it is a dry condition.

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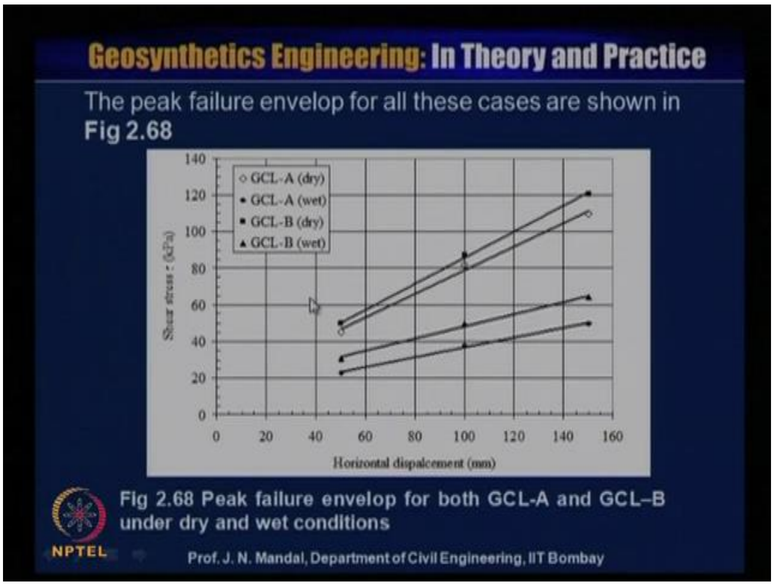

So, this is a kind of the behaviour of the geosynthetics clay liner now, this figure shows the peak failure envelope for the geosynthetic clay liner A and this B, both mean the dry and as well as the wet condition. So, this peak failure envelope, all these cases are shown here, this is the relationship between the shear stress versus the horizontal displacement. You can see that, shear stress is increasing with the increase of the horizontal displacement whether it is a dry or wet, that failure envelope is almost the same in nature.

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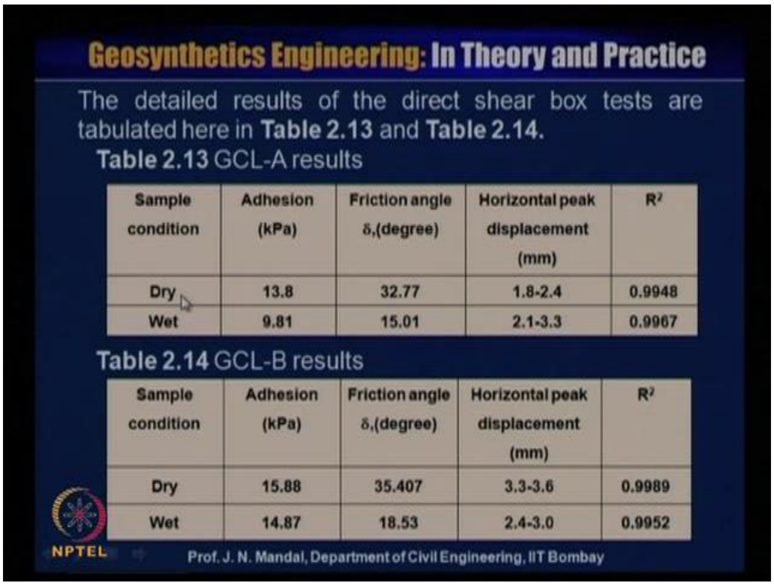

So here, detailed result of the direct shear box test are tabulated in this figure, you can see sample condition, whether it is a dry or the wet or the adhesion value is 13.8, this weight is 9.81, friction angle delta is 32.77. And for wet condition 15.01, horizontal displacement in dry condition 1.8 to 2.4 millimetre and wet condition 2.1 to 3.3 millimetre and this is r square is 0.9948 and 0.9967. You can see that, when it is the dry condition, this adhesion and the friction angle is more compared to, when it is the wet condition.

And horizontal displacement is not so much significant different, whether the sample is in dry condition as well as the wet condition. Now, this is for the geosynthetic clay liner B, you can see whether it is a dry condition and wet condition, this adhesion factor 15.88 kilo Pascal for dry, this is 14.87 kilo Pascal for wet, this is 35.407 this is friction angle for dry and wet is 18.53. Then horizontal displacement for dry 3.3 to 3.6 and this is wet is 2.4 to 3.3.

So, in all cases, whether geosynthetic clay liner in the dry condition or the wet condition, most of the cases the adhesion value is higher with respect to the wet condition. Both the adhesion and the friction angle is higher but the horizontal peak displacement not so significance difference.

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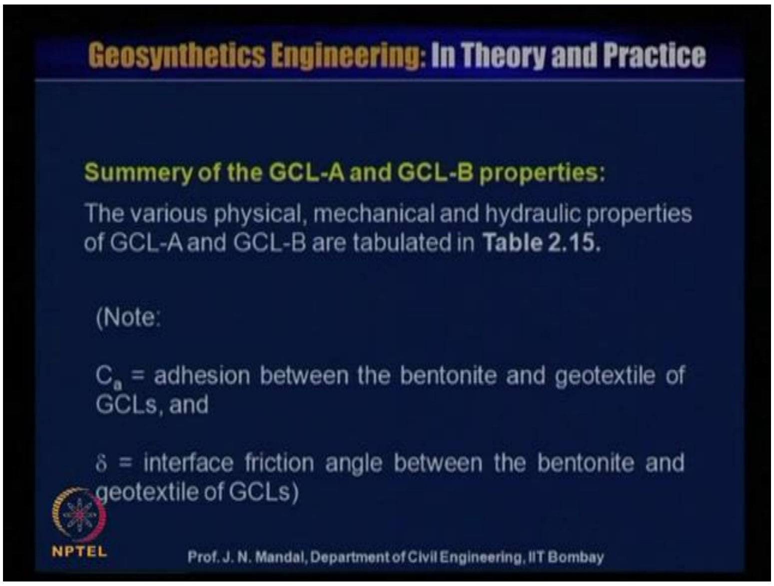

So, what summary of the GCL A and GCL B property can we conclude, the various physical, mechanical and the hydraulic property of GCL A and GCL B are shown. And where C a is the adhesion between the bentonite and the geotextile of GCL and delta is the interface friction angle between the bentonite and the geosynthetics clay liner.

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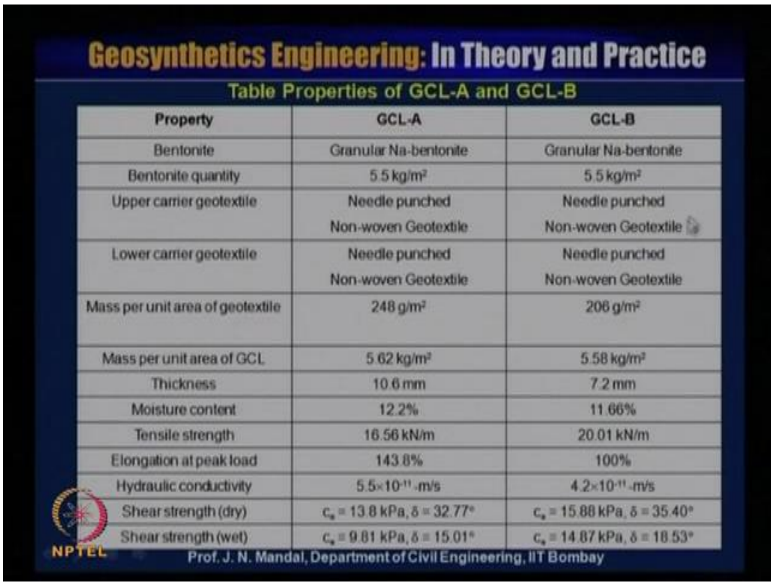

Property	GCL-A	GCL-B
Bentonite	Granular Na-bentonite	Granular Na-bentonite
Bentonite quantity	5.5 kg/m²	5.5 kg/m²
Upper carrier geotextile	Needle punched Non-woven Geotextile	Needle punched Non-woven Geotextile
Lower carrier geotextile	Needle punched Non-woven Geotextile	Needle punched Non-woven Geotextile
Mass per unit area of geotextile	248 g/m²	206 g/m²
Mass per unit area of GCL	5.62 kg/m²	5.58 kg/m²
Thickness	10.6 mm	7.2 mm
Moisture content	12.2%	11.66%
Tensile strength	16.56 kN/m	20.01 kN/m
Elongation at peak load	143.8%	100%
Hydraulic conductivity	5.5×10^{-11} m/s	4.2×10^{-11} m/s
Shear strength (dry)	c_a = 13.8 kPa, δ = 32.77°	c_a = 15.88 kPa, δ = 35.40°
Shear strength (wet)	c_a = 9.81 kPa, δ = 15.01°	c_a = 14.87 kPa, δ = 18.53°

You can see here test properties of GCL A and GCL B, this is the bentonite, sodium bentonite, this is the what kind of bentonite quantity you have taken, this is 5.5 kg per meter square, this is also 5.5 k g per meter square. This is upper carrier geotextile that is, needle punched non-woven geotextile material, this is also needle punched non-woven geotextile material, this is lower carrier geotextile needle punched non-woven geotextile material, needle punched non-woven geotextile material. But mass per unit area for GCL A is 248 gram per meter square and GCL B is 206 gram per meter square.

Mass per unit area GCL geosynthetic clay liner is 5.62 kg per meter square and for GCL B is 5.58 kg per meter square, thickness is 10.6 millimetre, this is for GCL B 7.2 millimetre, moisture content 12.2 percentage and for GCL B 11.66 percentage. Tensile strength of GCL is 16.56 kilo Newton per meter and for GCL B 20.01 kilo Newton per meter. Elongation as peak load is 143.8 percentage and for the GCL B is 100 percentage. Hydraulic conductivity 5.5 into 10 to the power minus 11 meter per second for GCL A and 4.2 into 10 to the power minus 11 meter per second for GCL B.

Shear strength value is dry C a is 13.8 kilo Pascal, delta is 32.77 degree and the shear strength this in the wet condition C a is 9.8 kilo Pascal and delta is 15.01. And for GCL B, the C a is 15.88 kilo Pascal, delta is 35.40 degree and C a is 14.87 kilo Pascal and delta is 18.53, this is all the information is given by confirming this tests.

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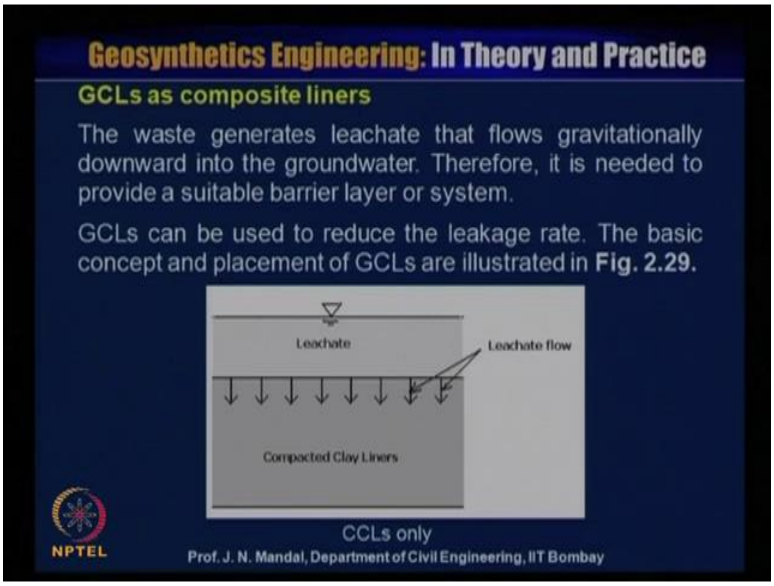

The geosynthetics clay liner as a composite liner, the waste generates a leachate that flow gravitationally downward into the groundwater. Therefore, it is needed to provide a suitable barrier layer or the system. GCL can be used to reduce the leakage rate, the basic concept and the placement of the GCL are shown in this figure. You can see, if this is the leachate formation is there in the landfill, there is a formation of the leachate. So, leachate can flow, if we provide with a compacted clay liner that is the traditional method and you can see, how the leachate can flow even then it is a compacted clay liner.

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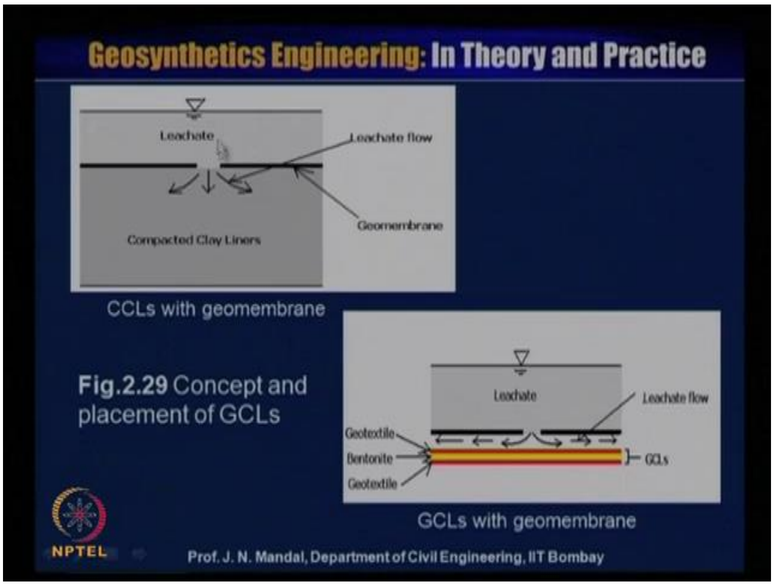

Now, in case of the compacted clay liner you can see, if there is a hole let us say, it is a geomembrane material and leachate you can pass through this also and can flow so how the leachate flow here. So, this is the geosynthetic clay liner or it is may be the geomembrane but what should be the concept and the placement of the GCL, what will be the concept and the placement of the geosynthetics clay liner. So, this is we are providing here, the geosynthetics clay liner and you can see here, is the bentonite and this geotextile on the top and the bottom, it is like a sandwich.

But, when the leachate pass through this ((Refer Time: 42:54)), you can see the direction of the flow, leachate flow this direction. Whereas, when the leachate pass in clay liner is vertically downward but here, you can see, it passes like this, like a transmissivity like this, it flow like this.

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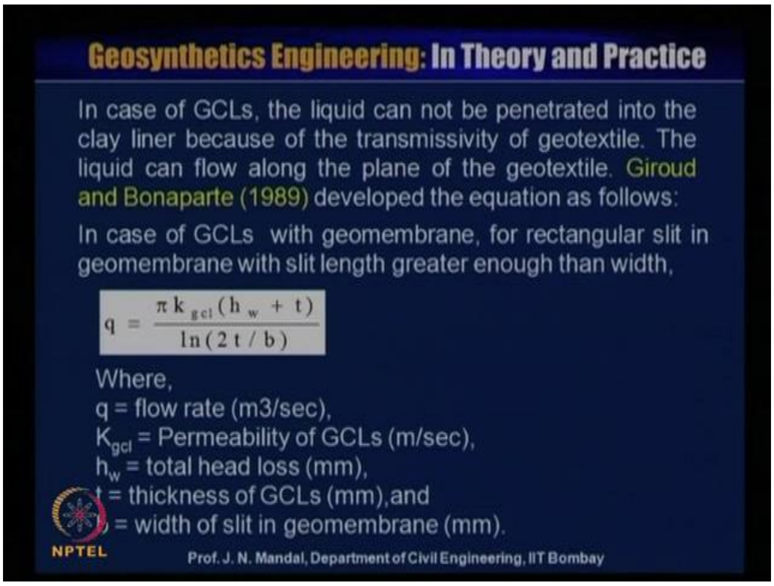

So, in case of the geosynthetic clay liner, liquid cannot be penetrated into the clay liner, because of the transmissivity of the geotextile. The liquid can flow along the plane of the geotextile, Giroud and Bonaparte 1989 developed the equation, as flow in case of GCL with geomembrane for rectangular slit. In a geomembrane with slit length greater enough than width then he gave this equation q is equal to pi k gcl that is, permeability of the GCL meter per second, this is h W that is total head loss in millilitre and this is t is the thickness of the GCL in millimetre and this divided by ln 2 t divided by b where, b is the width of the slit in the geomembrane in millimetre.

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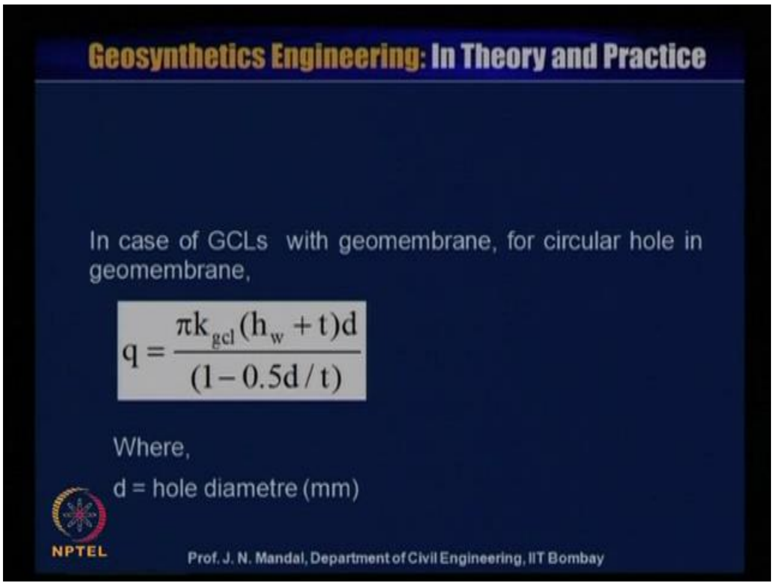

And in case of GCL with geomembrane, for circular hole in the geomembrane, if it is a circular hole so then q will be equal to pi into k gct then h W plus t into d divided by 1 minus 0.5 d by t where, d is the hole diameter so this is a circular hole. But in this case, this is the width of the slit, d and if it is a circular then this is the difference between the circular and width of the hole of the geomembrane.

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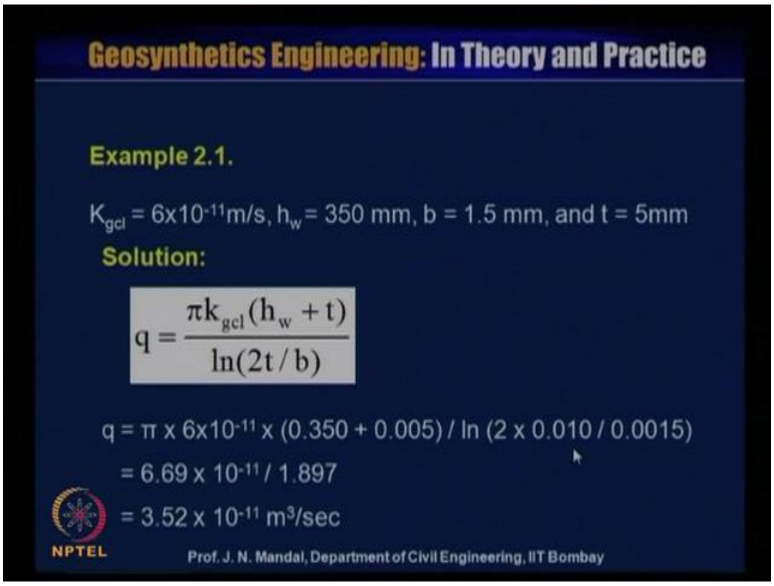

Now, I am giving one typical example where, k of gcl is equal to 6 into 10 to the power minus 11 meter per second, h W is 350 millimetre, b is 1.5 millimetre and t is 5 millimetre. Now, this is the equation q you know now, if you substitute this value then q will be equal to pi into this is k gcl is 6 into 10 to the power minus 11 into h W, h W is 0.350 in meter and then this is the t, t is 5 meter that mean, plus 005, this divided by ln into 2 into t, 2 into that is the t, that is 0.010.

This divided by, this is the 2 of t that mean, 2 into 5 that mean, 10 that is 0.010 this divided by b, b is equal to this 1.5 millimetre or 0.0015. So, if you calculate you can have this, you can have 3.52 into 10 to the power minus 11 meter cube per second.

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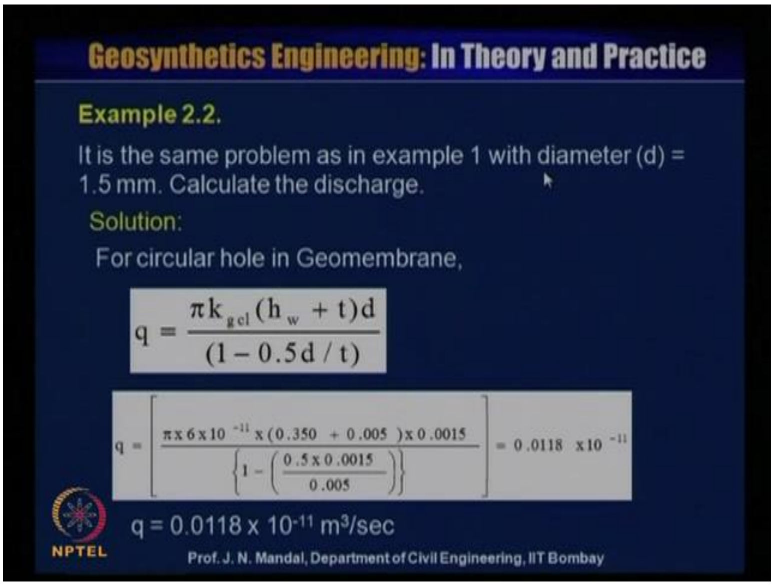

Now, in example 2, in the same problem as in the example 1 we discussed, where the diameter d is 1.5 millimetre then you calculate the distance. So, it is a circular hole in the geomembrane then equation is changing, this is the equation. So, in the same formula, if you calculate what is q, this everything is same, only that it is the d value will change so d will be the 1.5 millimetre. So, you substitute this value that is, 0.0015 and also this will be the 0.0015, other remain constant.

So, if you substitute this value, you can see that key value will be equal to 0.0118 into 10 to the power minus 11 meter cube per second. It depend upon, what will be the type of the hole pattern, whether it is a circular like the hole or it is a width wide that hole. Then accordingly you can calculate, what should be the quantity of flow of leachate can pass through the GCL with geomembrane, etcetera.

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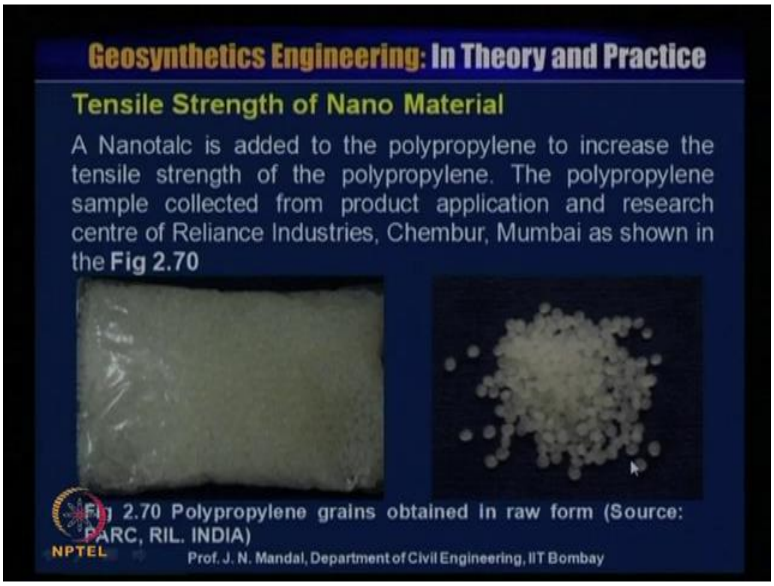

Now, this is some tensile strength of nano material, a nanotaic is added to the polypropylene to increase the tensile strength of polypropylene. The polypropylene sample collected from the product application and research centre of reliance industry, Chembur, Mumbai. This you can see, this is the sample is been collected, this is the polypropylene grain and this is obtained in raw form and this is the source for PARC, RIL, India you can see, this is the bits.

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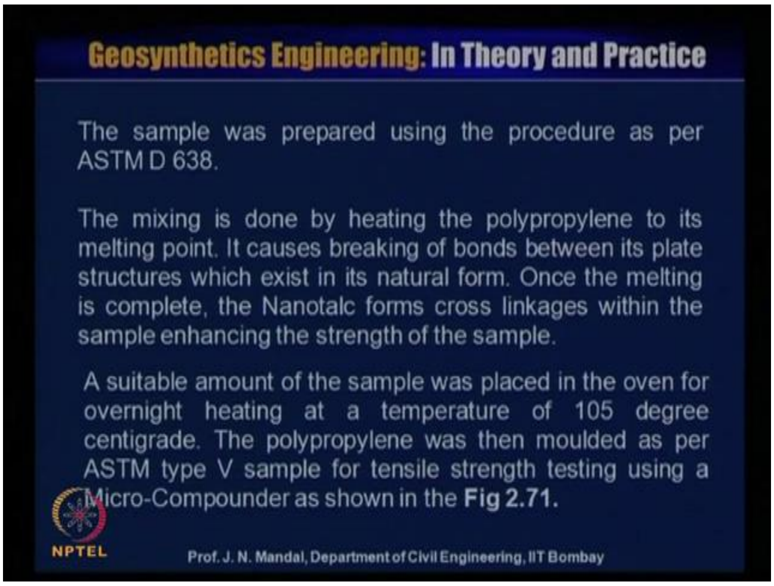

So, this sample was prepared using the procedure as per ASTM D638, the mixing is done by heating the polypropylene to it is melting point, it causes breaking of bond between it is plate structure, which exist in natural form. Once the melting is complete, the nanotalc form cross the linkage within the sample enhancing the strength of the sample. A suitable amount of the sample was placed in the oven for overnight, heating at a temperature of 105 degree Centigrade. The polypropylene was then moulded as per the ASTM type V sample for tensile strength testing using a microcomputer, that as shown in this figure.

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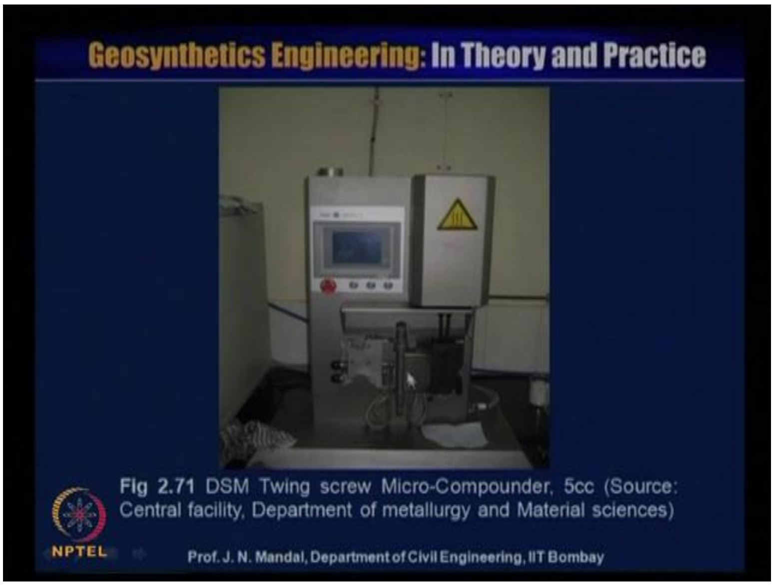

So, this is the DSM Twing screw micro compounder, this is the source from the central facility of the department of metallurgy and material science.

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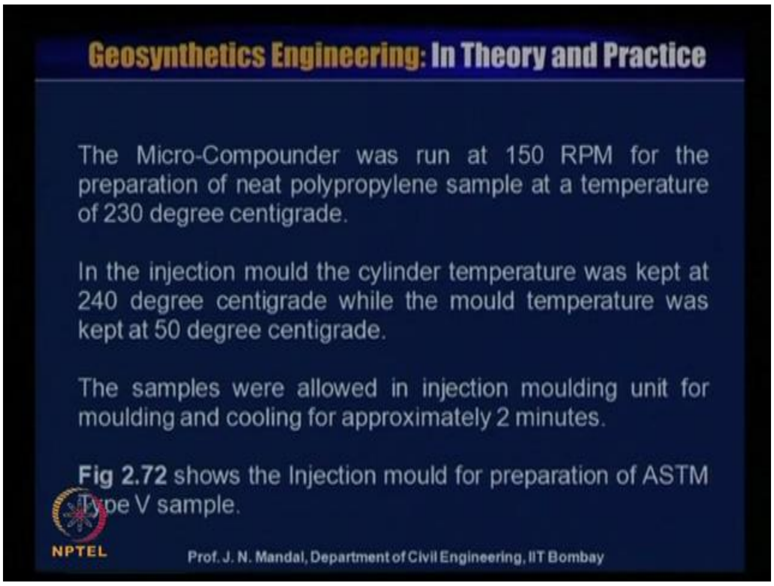

These microcomputer was run at 150 rpm for the preparation of neat polypropylene sample at a temperature of 230 degree Centigrade. In the injection mould, cylindrical temperature was kept at 240 degree Centigrade, while the mould temperature was kept at 50 degree Centigrade. The samples were allowed in injection moulding unit for moulding and cooling for approximately 2 minutes.

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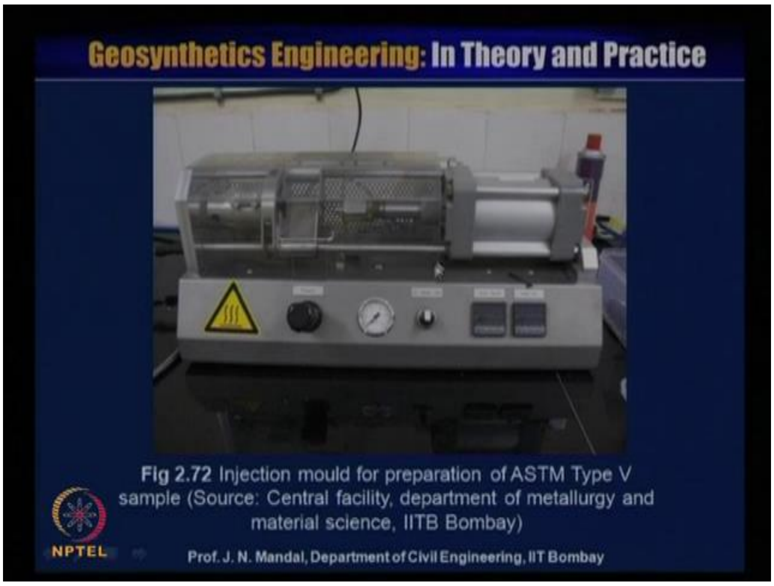

So, this you can see, this is the injection mould for the preparation of ASTM type V sample and this is also central facility for department of metallurgy and material science IIT, Bombay.

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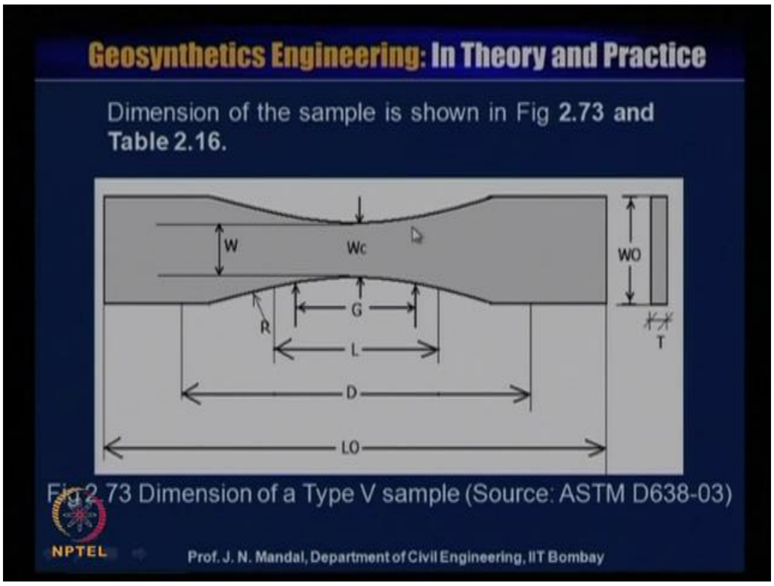

And from this, we can prepare this kind of the sample and you can perform the test, this is the dimension of the sample as various ASTM D638 so you know all these dimension or this sample.

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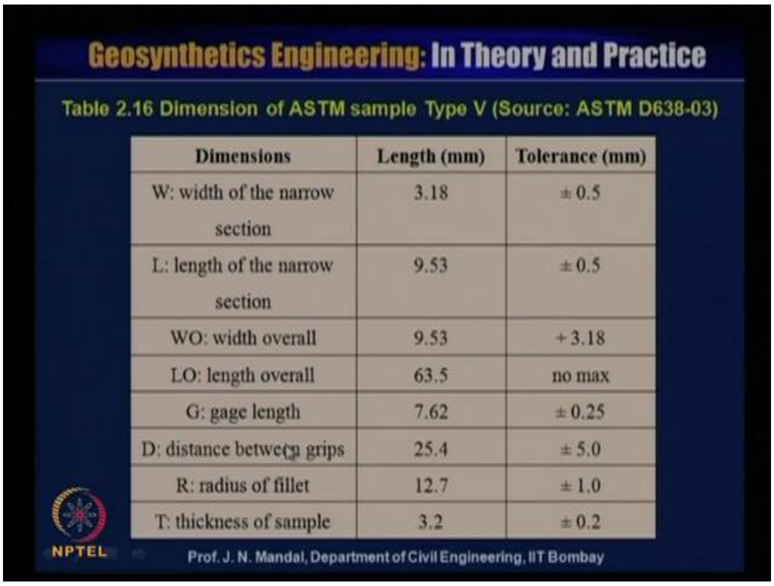

Dimensions	Length (mm)	Tolerance (mm)
W: width of the narrow section	3.18	± 0.5
L: length of the narrow section	9.53	± 0.5
WO: width overall	9.53	+ 3.18
LO: length overall	63.5	no max
G: gage length	7.62	± 0.25
D: distance between grips	25.4	± 5.0
R: radius of fillet	12.7	± 1.0
T: thickness of sample	3.2	± 0.2

And then this also sample has been performed and you can see that, this is the W means here, which length is equal to 3.18. And then some tolerance say plus minus 5 millimetre, length is 9.53, this is length 9.53 plus minus 0.5 and the width overall is 9.53 that is W of O, this is about 9.53 millimetre. And LO is the length overall is 63.5, length overall is 63.5 and then the G is the gage length is 7.62 and the D is the distance between the grip 25.4 millimetre that is, D is equal to distance 24.5 millimetre.

And R is the radius of fillet 12.7, this is R 12.7 and the T is the thickness of the sample, note T is the thickness of the sample here, that is about 3.2 millimetre and some tolerance is there.

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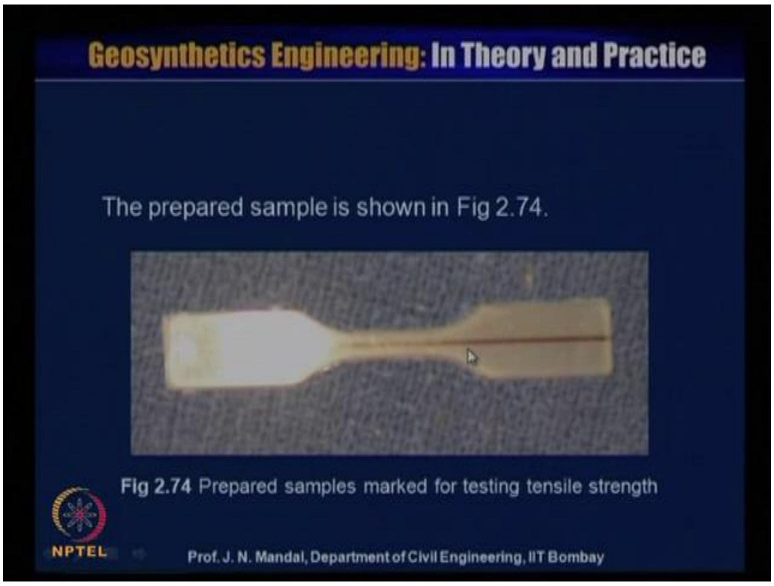

So, this is the sample and this prepares the sample is shown in this figure so this is the prepared sample for marked for testing for the tensile strength.

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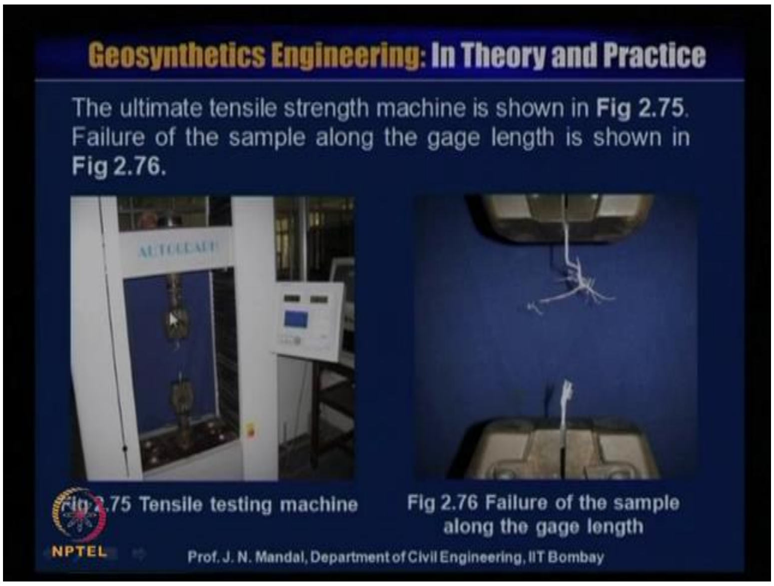

So, this is the universal testing machine and this test has been conducted and you can see that, how the failure of the sample along the gauge length. The ultimate tensile strength machine is shown, the failure of sample also along the gage length is shown.

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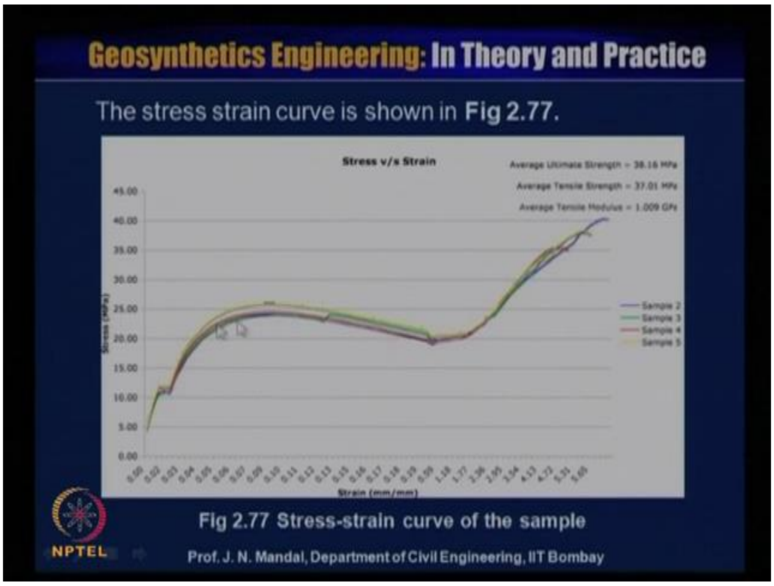

So, this is the figure so the stress strain curve of the sample you can see that, how the stress is increasing with the strain. And then it is increasing then almost constant and then decreasing then again also it is increasing.

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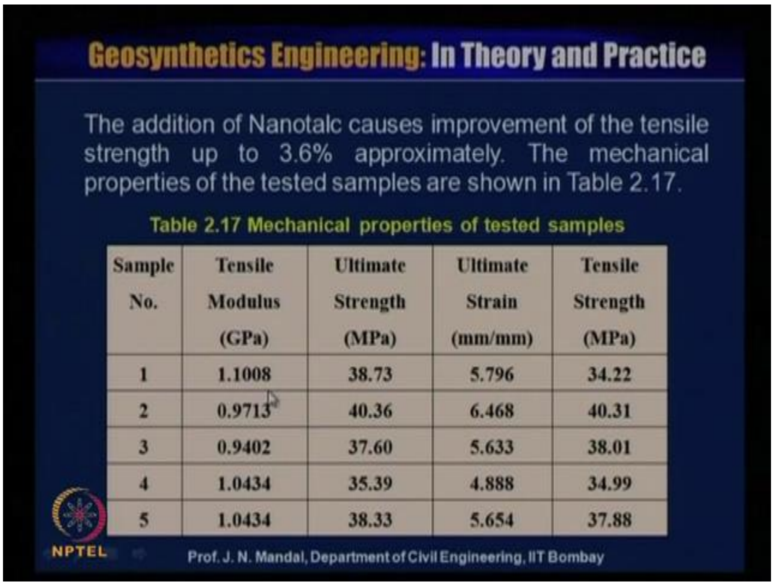

Sample No.	Tensile Modulus (GPa)	Ultimate Strength (MPa)	Ultimate Strain (mm/mm)	Tensile Strength (MPa)
1	1.1008	38.73	5.796	34.22
2	0.9713	40.36	6.468	40.31
3	0.9402	37.60	5.633	38.01
4	1.0434	35.39	4.888	34.99
5	1.0434	38.33	5.654	37.88

So, this is the additional of nanotaic cause the improvement in the tensile strain upto 3.6 percent approximately. The mechanical property of the testing is given for the different sample 1 to 5, and tensile modulus, ultimate strain and ultimate strength and tensile strength also has been determined. You can see that, this is the tensile modulus 1.1008, ultimate strength is 38.73 mPa and the ultimate strain is 5.796 millimetre per minute and tensile strength is 34.22 mega Pascal. So, like this, for the other sample also it has been given in the table.

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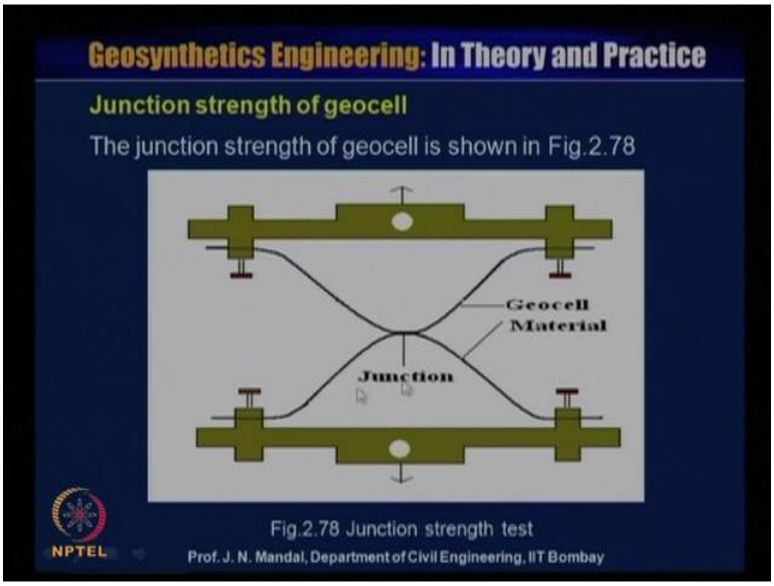

So, this is the one junction strength of the geocell material, which we have also discussed earlier so how to connect the geocell material.

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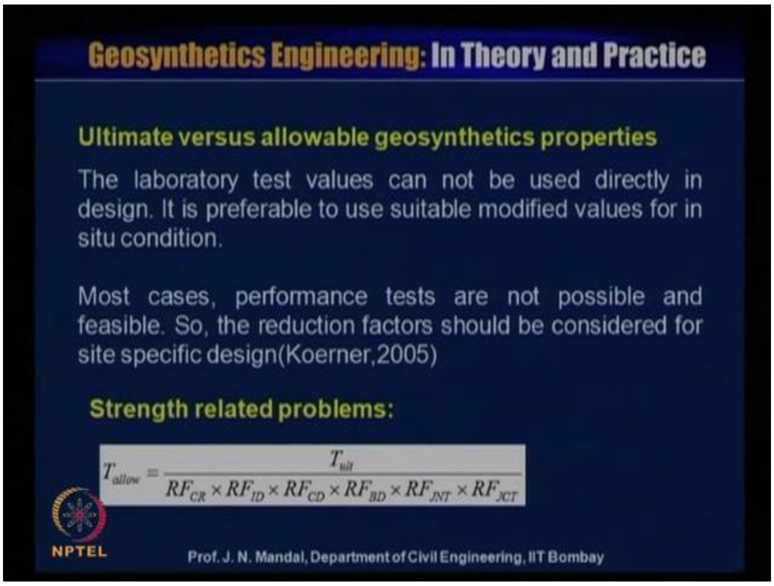

Now, ultimate values the allowable geosynthetics property, the laboratory test values cannot be used directly in the design. It is preferable to use the suitable modified value for in situ condition, most cases performance test are not possible and feasible. So, the reduction factor should be considered for site specific design as Koerner mentioned in 2005. And so far, whatever we have performed the test, that is the strength related problem and also, the flow related problem. So, I will just show very few slides with the strength related problem, how you can calculate the T allowable value.

So, T allowable value will be equal to T ultimate value divided by all this reduction factor, this is reduction factor R F C R, R F I D, R F C D, R F B D, R F J N T, R F J C T. So, this factor you have to be considered for the design so where, the T is ultimate tensile strength.

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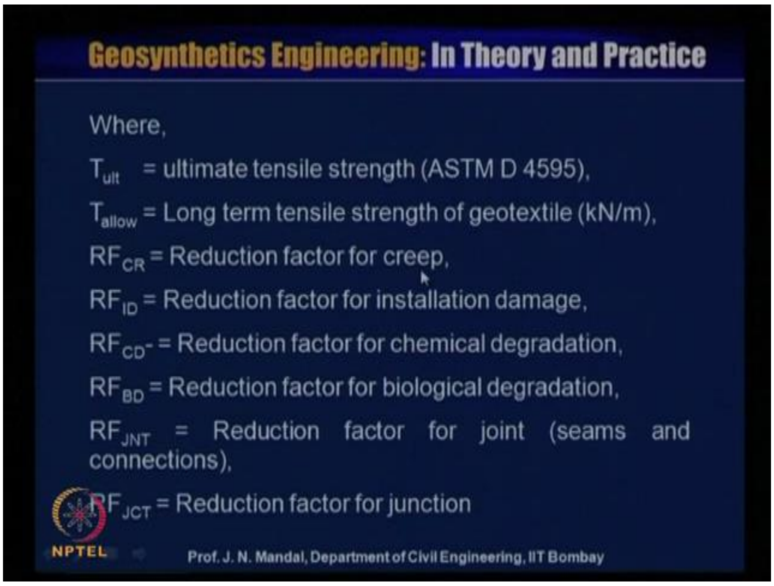

Then, T allowable tensile strength R F C R reduction factor for the creep, this is reduction factor for the creep. Then R F I D reduction factor for installation damage then R F C D is the reduction factor for chemical degradation and then R F B D reduction for the biological degradation and this is R F J N T reduction factor for the joint and R F J C D reduction factor also for... So, this factor is to be taken into consideration, for the different types of the application this reduction factor is different. So, you have to calculate for the design, what will be the allowable tensile strength of the geosynthetics material.

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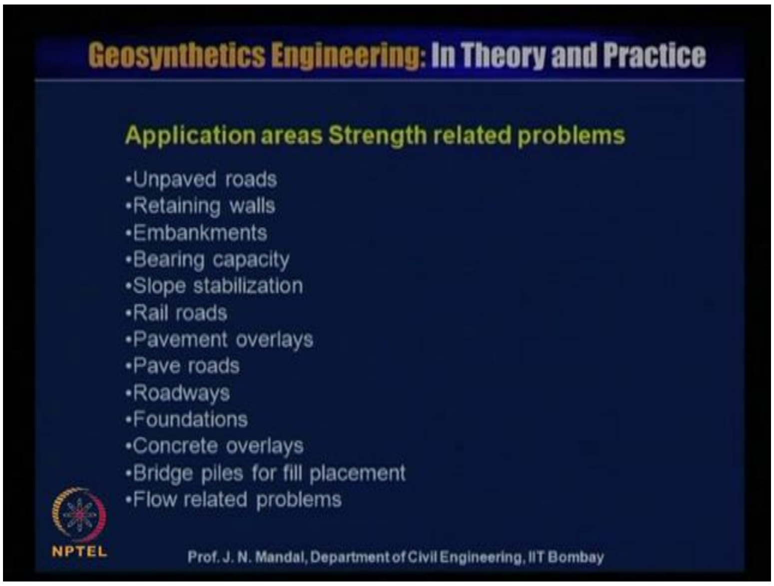

So, you know from the test, what will be the ultimate tensile strength value, if you know that and different types of application different reaction factor so you have to consider that reduction factor. And then you have to determine what will be the allowable tensile strength of the geosynthetic material. And this kind of the strength related problem you can apply for the unpaved road, retaining wall, embankment, bearing capacity, slope stabilization, railroad, pavement overlay, pavement road, roadway, foundation, concrete overlay, bridge piles for fill placement and flow related problems.

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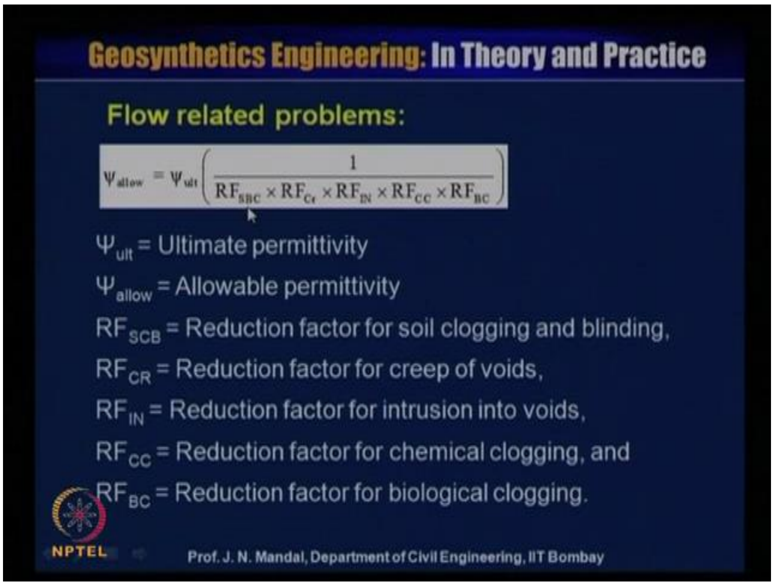

The other is the flow related problem, hydraulic related problem where, psi allowable is equal to psi ultimate by 1 by this is R F S B C that is reduction factor for the soil clogging and blinding. And this is R F C R that is reduction factor for creep of the void, this is R F I N this is reduction factor for intrusion into the void, this is R F C C that is reduction factor for chemical clogging and this is R F B C that is reduction factor for biological clogging. So, all these factor is given by the Koerner for the different application.

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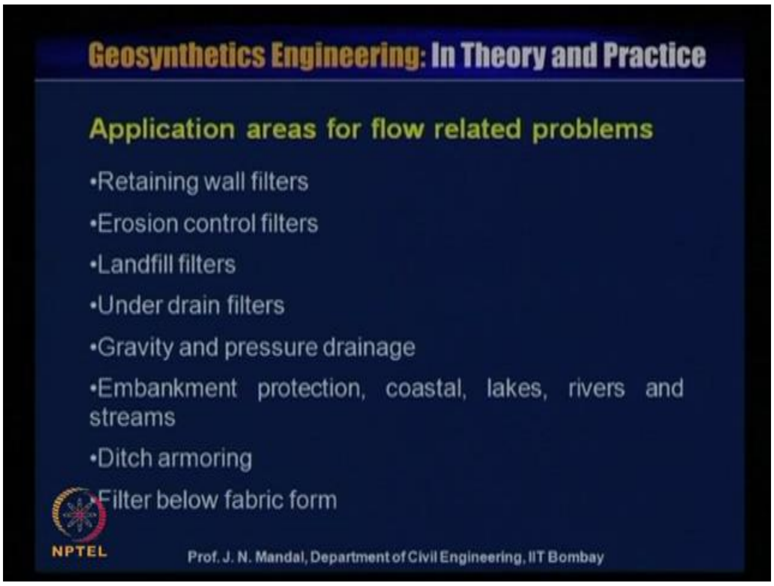

And here, the application area for flow related problem is retaining wall filter because this is all hydraulic related problem, flow related problem. Erosion control filter, landfill filter, under drain filter, gravity and pressure drainage, embankment protection, coastal, lake, river and stream, ditch anchoring and filter below fabric form.

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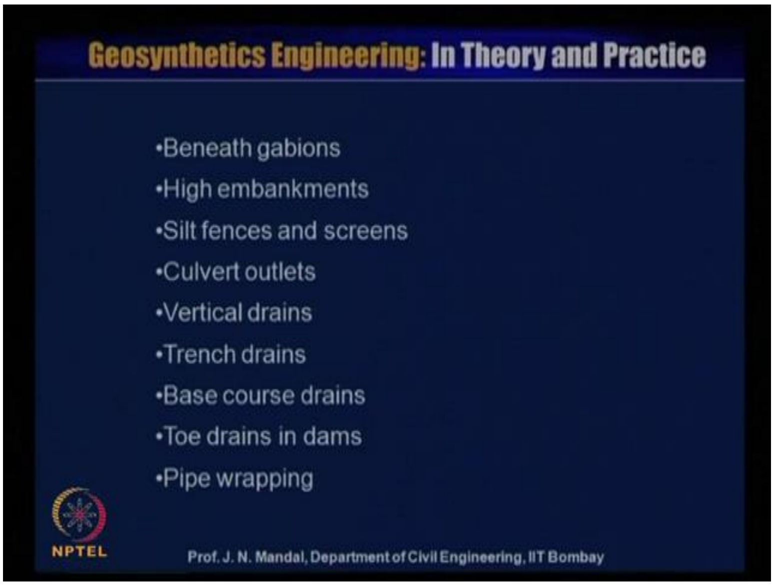

Also, beneath the gabion, high embankment, silt fences and screen culvert outlet, vertical drain, trench drain, base course drain, toe drain in dam and pipe wrapping. With this, I ended up this lecture today, please let us hear from you any question. Thanks.