Geosynthetics Engineering: In Theory and Practices
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Lecture - 56
Design of Geosynthetics for Landfills

Dear student warm welcome to NPTEL phase two program video course on geosynthetics engineering in theory and practice. My name is Professor. J. N. Mandal department of civil engineering, Indian Institute of Technology, Bombay, Mumbai, India, lecture number 56, module 12 design of geosynthetics for landfill. I will now focus the recap of the previous lecture.

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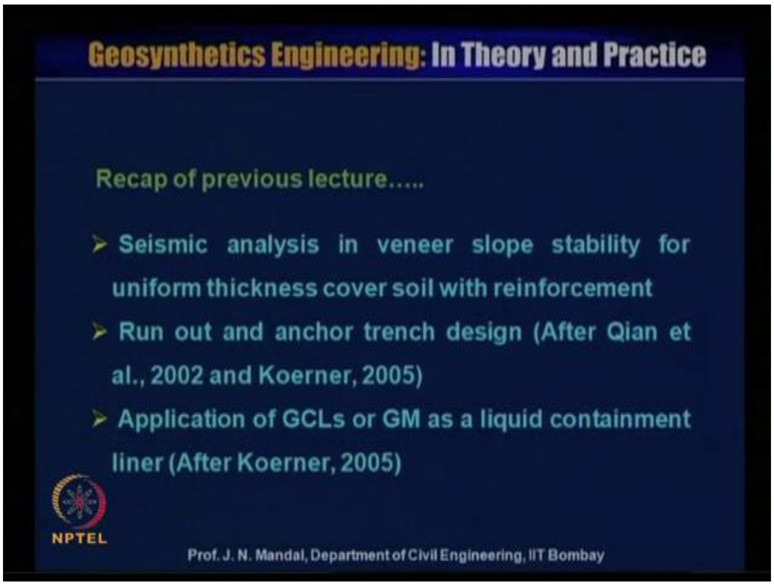

The seismic analysis in veneer slope stability uniform thickness, cover soil with reinforcement run out and anchor trench design after Qian et al 2002 and Koerner 2005. Application of geosynthetics clay liners or geomembrane as a liquid containment liner named after Koerner, 2005.

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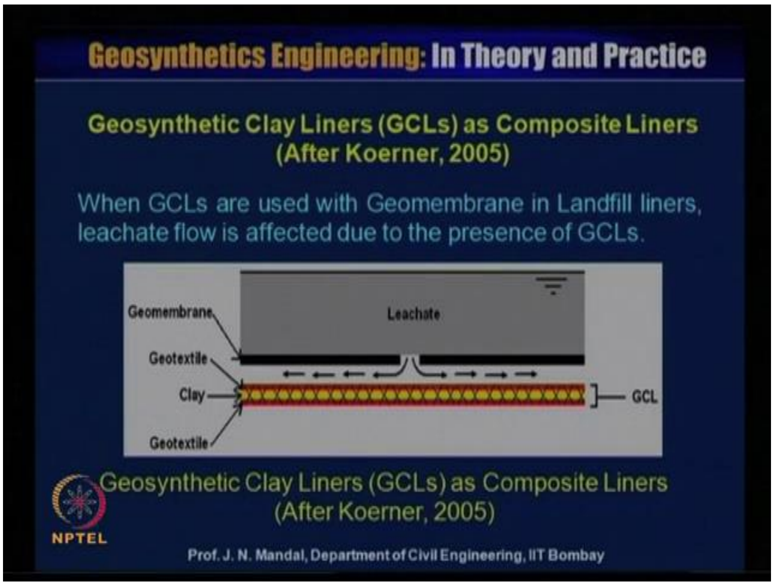

Now, I will address the geosynthetics clay liner GCL as a composite liner after Koerner 2005, when the geosynthetic clay liner is used with the geomembrane in landfill liner. Leachate flow is affected due to the presence of the geosynthetics clay liner, so what will happen? Sometimes, it has been observed that if there is no geomembrane or the geosynthetics clay liner, then leachate can percolate through the ground surface and polluted the ground.

Also this leachates flow is vertically downwards at any depth and poses a great pollution problem. So, here we are providing a kind of the geosynthetics clay liner which is made of the bentonite and the geotextile at the top and the bottom. A geomembrane in which the leachate can pass through this geomembrane, suppose if there is any hole into the geomembrane then and below that geosynthetic clay liner. You can see here that leachate propagated, almost in the horizontal direction rather than going down vertical direction.

So, this is one of the major advantages for the use of the geosynthetic clay liner or the geomembrane as a liner. So, that is why this geosynthetic clay liner has a composite liner, so it is more useful and it will not pollute the ground surface, because leachate flow direction is absolutely different from usual. In the traditional method, the flow rate or the leakage rate is calculated from the formula given by the Giroud.

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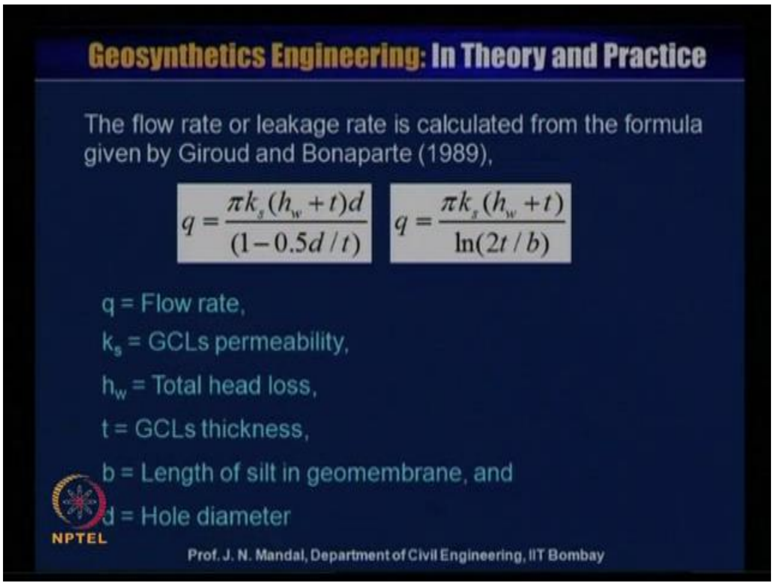

Bonaparte 1989, q is equal to pi k s h w plus t into d divided by 1 minus 0.5 d by t or q is equal to pi into k s h w plus t divided by l n 2 t divided by b. Here, q is equal to flow rate k s is geosynthetics clay liner permeability h w is the total head loss and t is equal to geosynthetics clay liner thickness and b is the length of slit in the geomembrane and d is the hole diameter.

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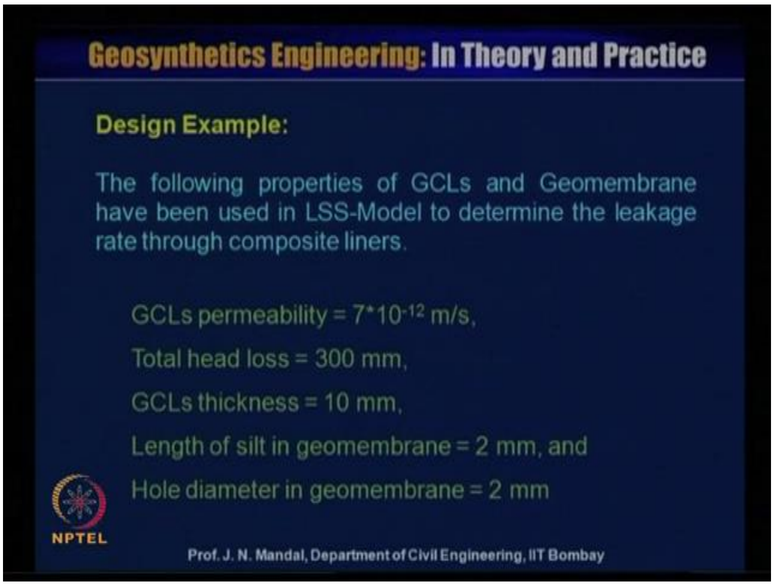

So, I am giving the design example, the following properties of the geosynthetics clay liner, and the geomembrane have been used in the landfill slope stability model or LSS model to determine the leakage rate through the composite liner. Here, geosynthetics clay liner permeability is 7 into 10 to the power minus 12 meter per second, total head loss is equal to 300 millimeter. Geosynthetics clay liner thickness is equal to 10 millimeter length of the slit in the geomembrane is equal to 2 millimeter, and hole diameter in the geomembrane is equal to 2 millimeter.

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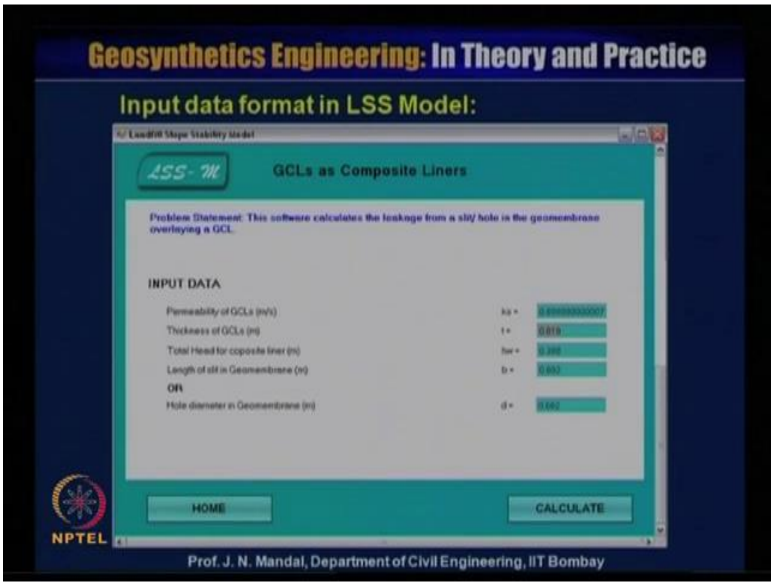

Now, we have put this input data formulation it over LSS model and this problem statement that this software calculate, what will be the leachate from any slit or hole in the geomembrane, and overlying by geosynthetics clay liner. Here, input data is permeability of the geosynthetics clay liner is equal to 7 into, note this data we have put 7 into 10 to the power minus 12 meter per second.

Thickness of GCL is equal to 0.010, that is in meter and total head for the composite liner is equal to h w is equal to 0.300 meter and length of the geomembrane that is equal the about 0.002. Now, you can have the hole diameter of the geomembrane that is small d is equal to 0.002 meter.

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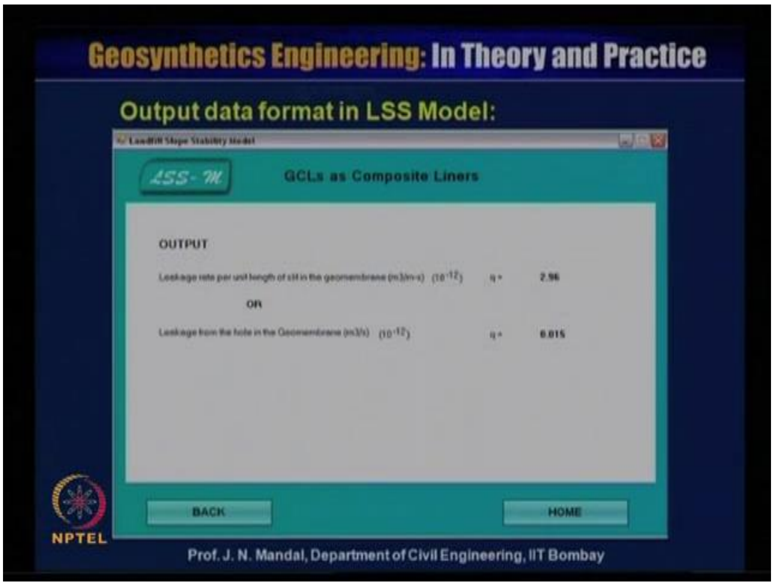

So, if you put this input data into this LSS program and then you can calculate, so you can obtain the output of this result, that is leakage rate per unit length of silt in the geomembrane, that is 2 q is equal to 2.96 meter cube per meter second. The leakage from the hole in the geomembrane that is q is equal to 0.015 into 10 to the power minus 12 meter cube per second. So, there is a possibility for the leakage may occur due to the length of the shield or this may occur if there is any hole.

I have also shown you that how you can detect the leakage of any geomembrane when the geomembrane is placed below the water, so I have mentioned that how you can detect the hole. So, here in this problem we observe that what should be the leakage unit, length of slit in the geomembrane or leakage flow if it is a slit or if there is a hole.

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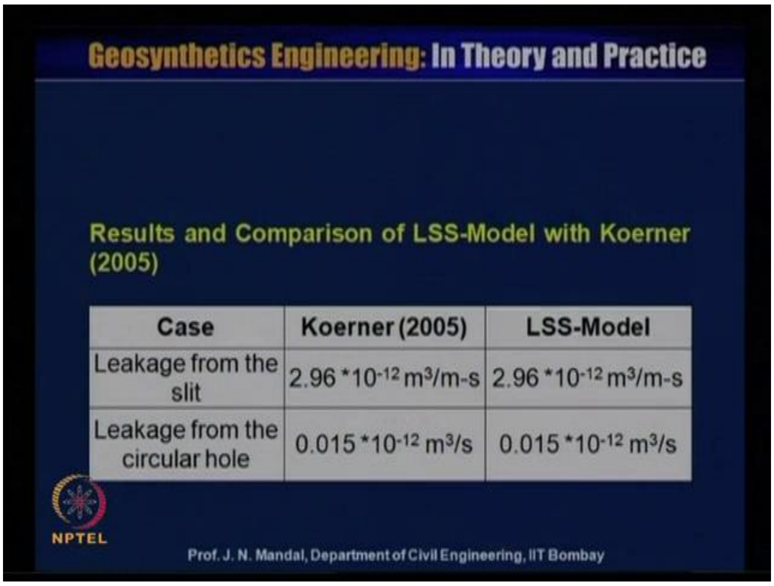

Now, this result had compared with the LSS model with the Koerner, 2005 model case when the leakage from the silt, the koerner 2005 given 2.96 into 10 to the power minus 12 meter cube per meter second. From the landfill slope stability model, this value is 2.96 into 10 to the power minus 12 meter cube per second leakage from the circular hole. Koerner has given 0.015 into 10 to the power minus 12 meter cube per sec and LSS model.

Give 0.015 into 10 to the power minus 12 meter cube per second, so it is matching 100 percentage in both the cases, either the leakage from the slit or leakage from the circular hole. So, this model is very appropriate for the determination of the leakage. Now, I will show our landfill slope stability model when you will design any landfill, then you require the proper kind of the design. So, when you will design this landfill, then you must go to all this point.

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So, you must go near, about may be 29, this is the landfill slope stability model and this is a developed by J K Soni.

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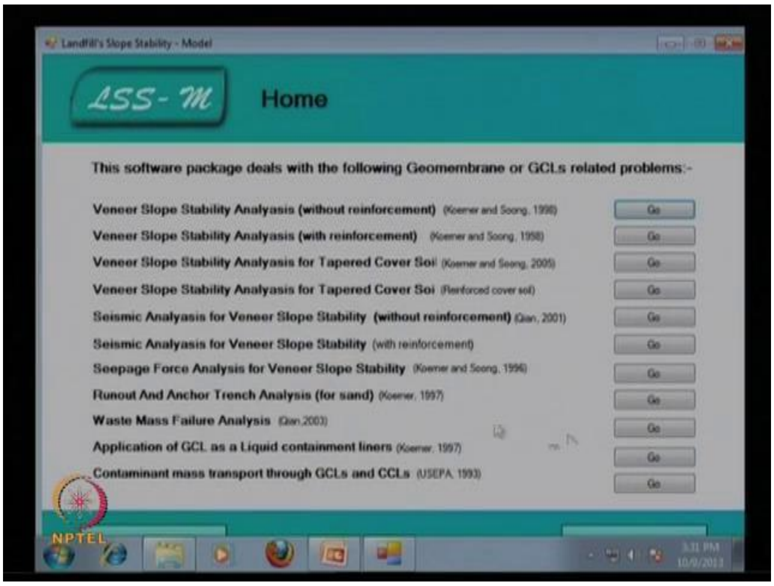

This is the software package deal with the following geomembrane or geosynthetic clay liner related material, so you have to go through all this cases. So, it may be veneer slope stability analysis without reinforcement, this is by Koerner and Soong 1998 and I will just show you one by one. Already, I have also shown you that how you can calculate the factor of safety against the veneer slope stability analysis. Here, I wanted to focus in this model how you can use this software.

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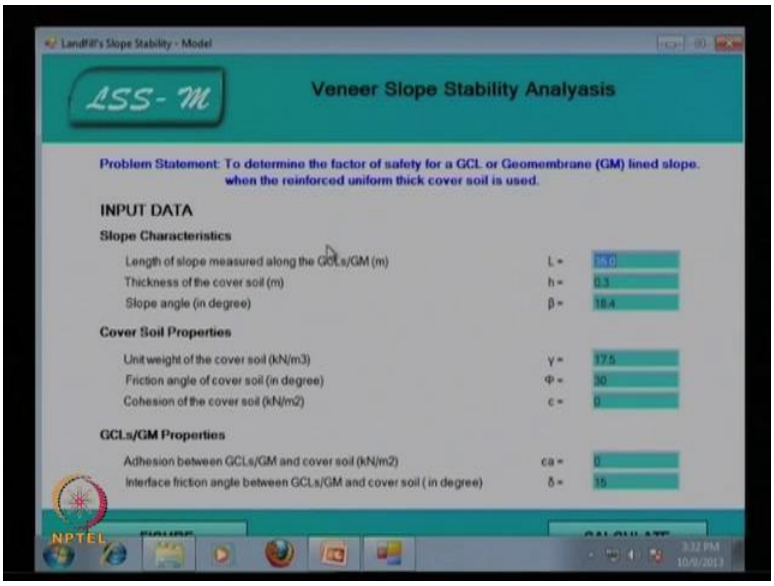

So, this is the problem statement to determine the factor of safety for the geosynthetic clay liner or geomembrane line slope when the reinforced uniform thick cover soil is used. So, this is the input data that is for the slope characteristic that means you should know what will be the length of the slope. You should know what will be the height of the thickness, you should know the slope angle and also you should know cover soil property whose unit weight of the cover soil. Also, friction angle of the cover soil phi and the cohesion of the cover soil that is gamma is 17.5 phi is equal to 30 degree.

Apart from that, you require the GCL or geomembrane property, that is the adhesive between geosynthetic clay liner and the cover soil c i is equal to 0 or interface friction angle between the geosynthetic clay liner geomembrane cover soil that is 15 degree. So, you have to substitute in this model, these are the input data.

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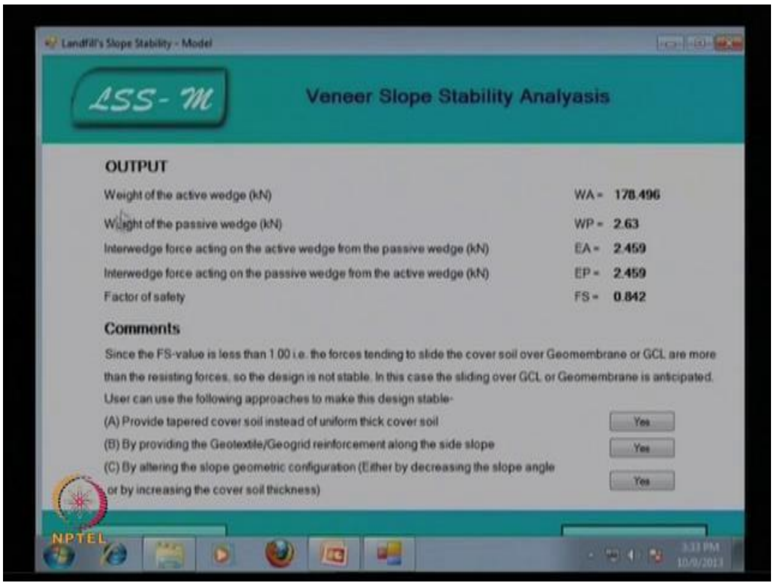

Then, you can calculate and can determine what should be the weight of the active wedge that is 178.496 kilo Newton weight of passive wedge W P 2.63 kilo Newton. Also that interwedge force, acting on the active wedge from the passive wedge E A is 2.459 and interwedge for active wedge on the passive wedge from the active wedge is E P is 2.459 and you find here that factor of safety value is equal to 0.842. So, we have already just solved this problem, I have shown you that earlier in my course presentation, but here I am just showing how to make use of this software, now because this factor of safety is less than 1.

Then, you have to adopt some three system, so you can provide the tapered cover soil instead of uniform thick cover soil A,B. You have to provide the geotextile or the geogrid reinforcement along the side slope and see by alternating the slope geometric configuration. Either by decreasing the slope angle or by increasing the cover soil thickness, then you can make the slope stable. Let us say in case of A, if you provide the tapered cover soil instead of the uniform thickness.

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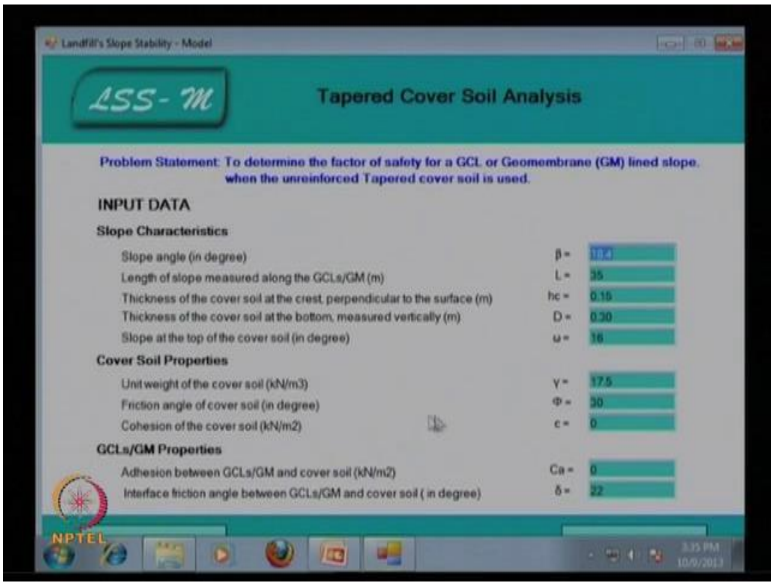

So, if you go for tapered cover soil that means this will be like this.

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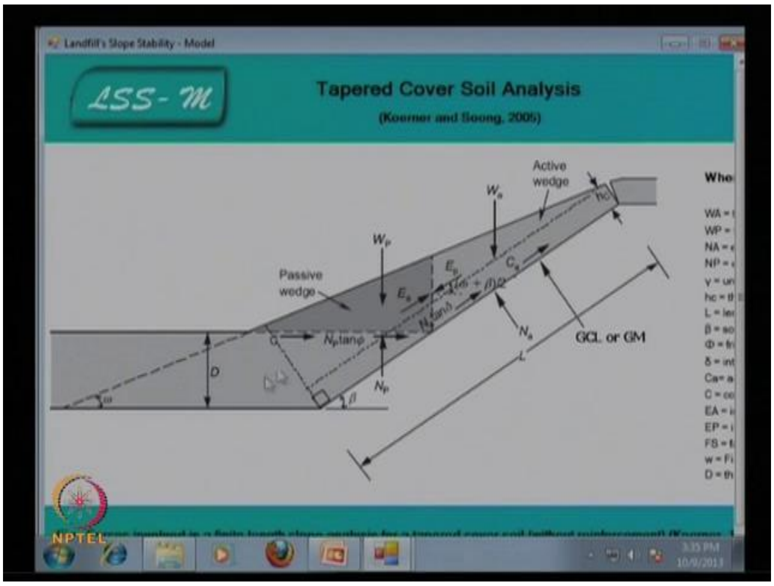

Tapered cover soil, initially it was the uniform; now this is a tapered cover soil has been used. So, if you if you provide with the tapered soil and if you substitute the value of this slope angle, and that what will be the length what will be the thickness of the cover soil. The thickness of the cover soil at the bottom, measured vertically that is D is equal to 0.30 meter and slopes where the top of the cover soil is 16 degree and cover soil property.

The unit weight of the cover soil is 17.5 kilo Newton per meter cube, friction angle of cover soil is phi 30 degree and cohesion of the cover soil is C is 0 and geosynthetics clay liner or geomembrane property. The adhesion between the geosynthetics clay liner geomembrane and the cover soil that is C A is equal to zero. Interface friction angle between the geosynthetic clay liner and geomembrane and cover soil is about delta is equal to 22 degree.

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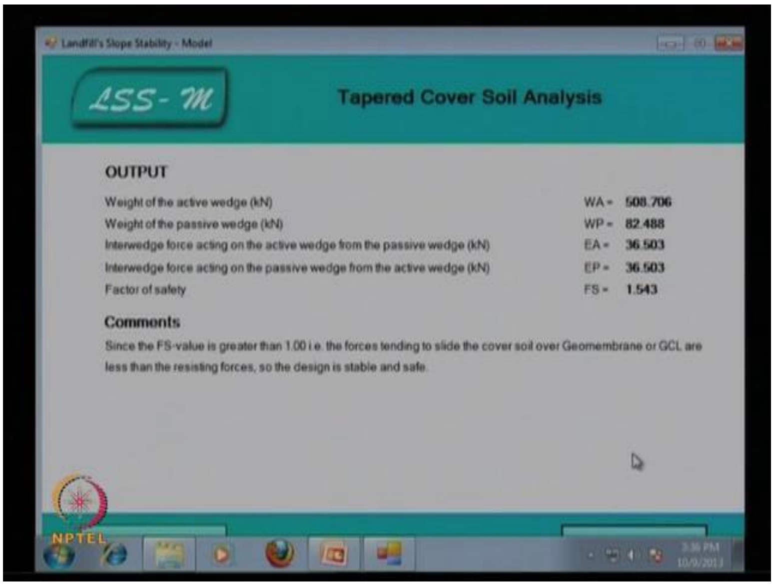

So if you substitute or input this data case A, so this is the output weight of the active wedge W A is equal to 508.706 kilo Newton, weight of the passive wedge W P is equal to 82.488 kilo Newton. Interwedge force acting on the active wedge from the passive wedge that is E A is equal to 36.503 kilonewton, interwedge force acting on the passive wedge from the active wedge that is E p is equal to 36.503.

You see here, that factor of safety value is 1.543, since if the factor of safety value is greater than one, that is the force tending to slide the cover soil over the geomembrane in geosynthetics clay liner are less than the resisting forces. So, design is stable and the safe. Now, if I go for this for this second case, here I am also the showing that initially this is the uniform, it was there in the beginning. Now, if I go for the B's where you want to introdue the layer of the reinforcement material.

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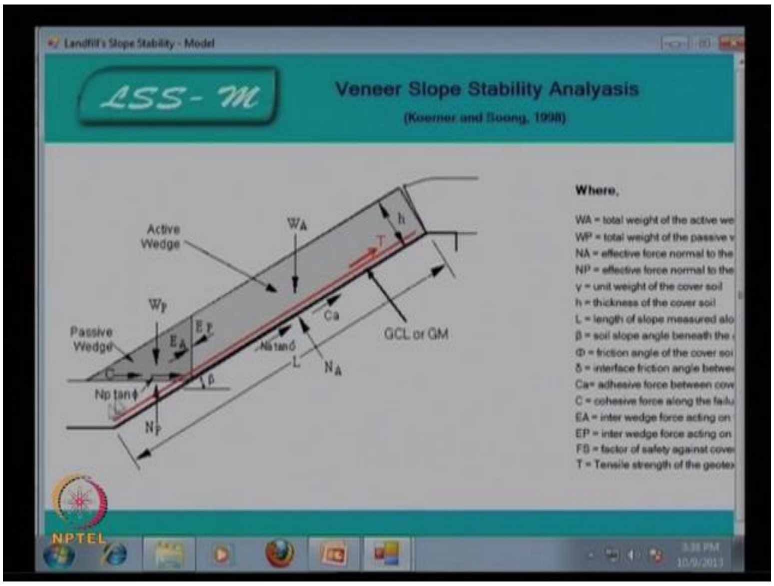

So, if you want to introdue the layer of reinforcement material, this here the red color which will give you the layer of the reinforcement along the slope, we are adding the second case that is B case that what we are using this reinforcement. Now, we are substituting this value input data, the soil characteristics that is the length of the slope, the L is equal to 35 meter. The thickness of the cover soil is 0.3 meter and slope angle beta is 18.4 degree and cover soil property, unit weight of the cover soil 70, gamma 17.5 and angle of friction of the cover soil is phi is equal to 30 degree. Cohesion value is equal to zero and geosynthetics clay and geomembrane properties C a is 0, delta is is about 15 degree.

Now, we are adding this reinforcement, either the ultimate tensile strength of the reinforcement getextile or geogrid is 300 kilonewton and we are considering that reduction factor for the installation damage RFI, d is 1.25 reduction factor for the creep. Here RFCR is equal to 1.28 and reduction factor for chemical and biological degradation RCBD is equal to 2.0. So, reduction factor for the seam because it is required some joining the geotextile or the geogrid material, so RFSM is 1.25.

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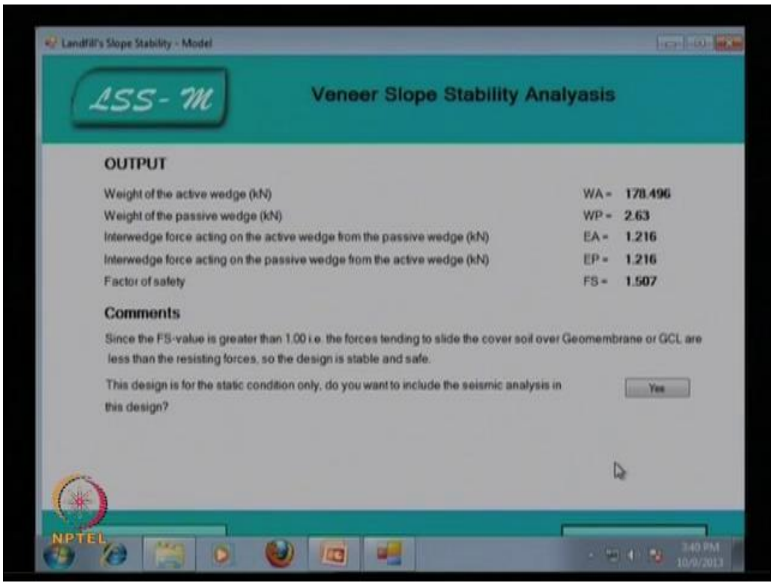

So, for the introduction of the reinforcement for slope stability, now we calculate and we find that output is weight of the active wedge W i is equal to 178.496 kilo Newton weight of the passive wedge w p is equal to 2.63 kilonewton. Interwedge force acting on the active wedge from the passive wedge EA is 1.216 kilo Newton, interwedge force acting on the passive wedge from the active wedge that is E P is 1.216 kilo Newton and the factor of safety value is F s is equal to 1.507.

So, comments since this factor of safety value is greater than 1, the force tending slide the cover soil over the geomembrane and geosynthetic clay liner are less than the resisting force. So, the design is stable and safe, so design also is for the static condition only, but if you want to include the seismic analysis in this design, you can so if you add the seismic, seismic also into this. So, if you want to, you are calculating this now if you wanted to include the seismic also.

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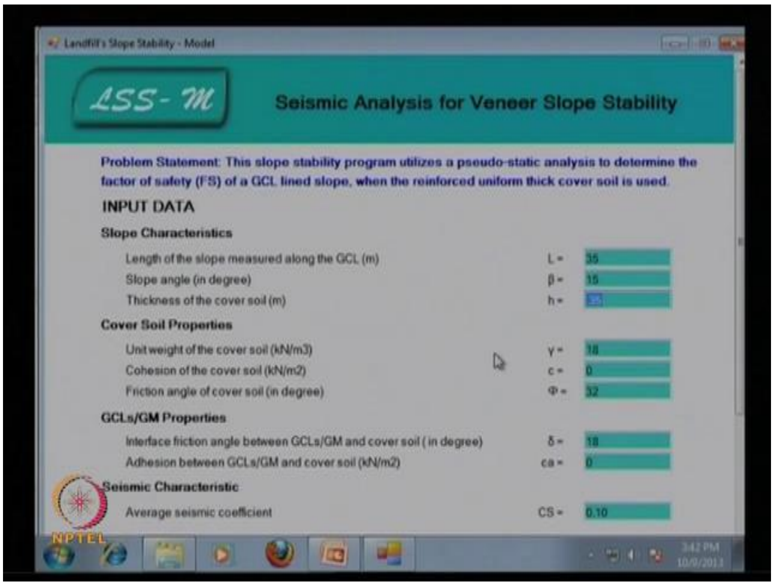

Then, this problem statement that seismic analysis for veneer slope stability that problem statement the slope stability program utilize the pseudo static analysis to determine the factor of safety F s of a geosynthetics clay liner slope, when the reinforcement uniform thick cover soil is used. Here, input data, the soil characteristics that is length of the slope L is equal to 35 meter, then slope angle beta is equal to 15 degree and thickness of the cover soil h is equal to 0.35 meter. Cover soil property, that is gamma is 18 degree and C is equal to 0, phi is equal to 32 degree and geosynthetic clay and geomembrane property, that is delta is equal to 18 degree and C a is equal to 0.

Apart from that, you have to add that seismic characteristic here, so average seismic coefficient we have include C S is equal to 0.30 and reinforcement detail. So, reinforcement detail, ultimate tensile strength of the reinforcement geotextile or geogrid t ultimate equal to 100 kilonewton. So, reaction factor for the installation damage 1.25, reduction factor for the creep 1.28, reduction factor for chemical and biological degradation that is 2.0 and reduction factor for the seam 1.26.

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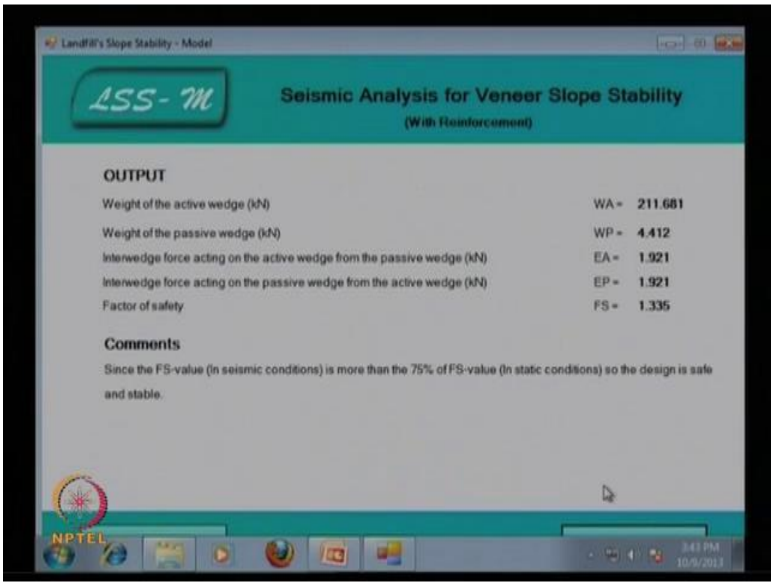

So, if you consider even then seismic force and then you can also calculate what should be the factor of safety. So, here output weight of the active wedge W a is equal to 211.681 kilo Newton. Weight of passive wedge W p is equal to 4.412 and the interface wedge acting on the active wedge from the passive wedge that is EA is equal to 1.921. Then, interwedge force acting on the passive wedge from the active wedge that is E P is equal to 1.921. So, factor of safety 1.335, so comments since the factor of safety value in the seismic condition more than the 75 percentage of factor of safety value in static condition. So, the design is safe and the stable, so we consider the seismic forces and also find that how you can calculate this this factor of safety due to the seismic force.

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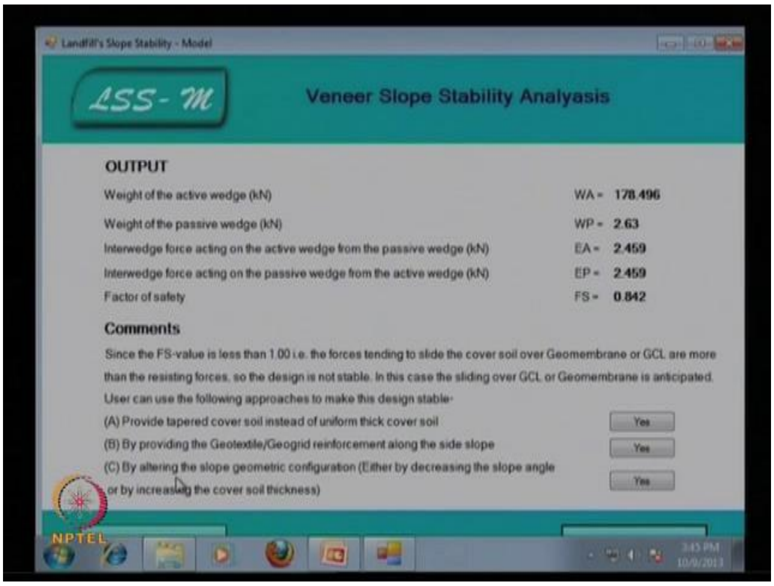

Now, in the C that by altering the slope geometry and the configuration either by decreasing of slope angle or by increasing the slope angle, that also you can you can change this.

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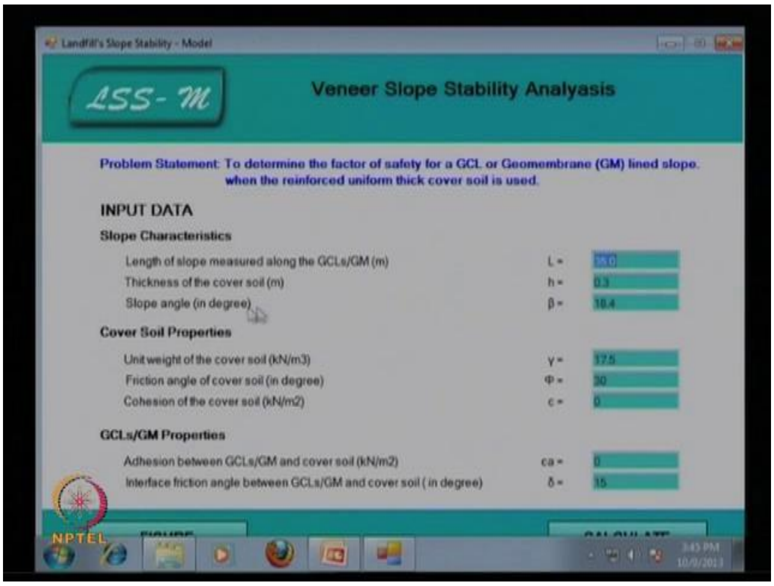

So, we are keeping almost this slope characteristics value A that is the length of the slope, the height of the thickness of the cover soil. This friction angle, also this is the soil cover property, that is gamma phi and C and the that is gamma is 17.5 phi is 30 degree, C is 0. The geotextile geomembrane property, that is adhesion value 0 and the interface friction between GCL and geomembrane soil is 35.

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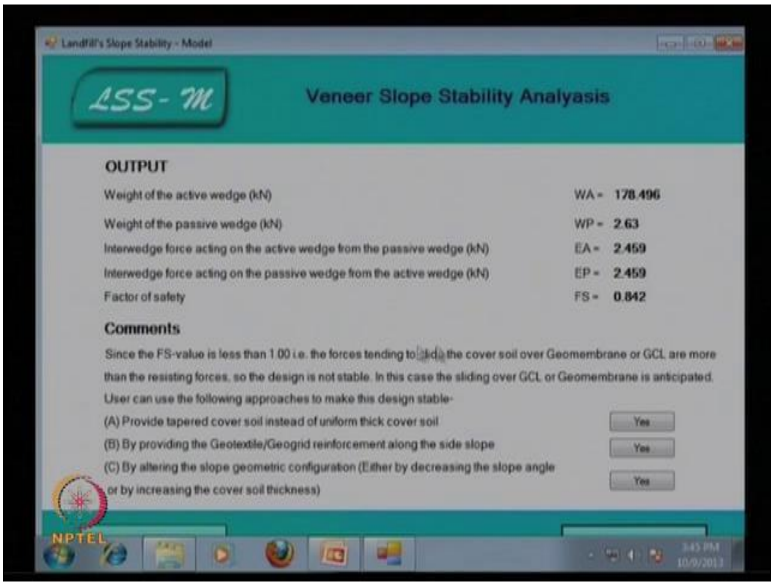

So, you can calculate and then you can have the output of this and you find here the factor of safety value is less than 0.642. So, next the veneer slope stability analysis with reinforcement.

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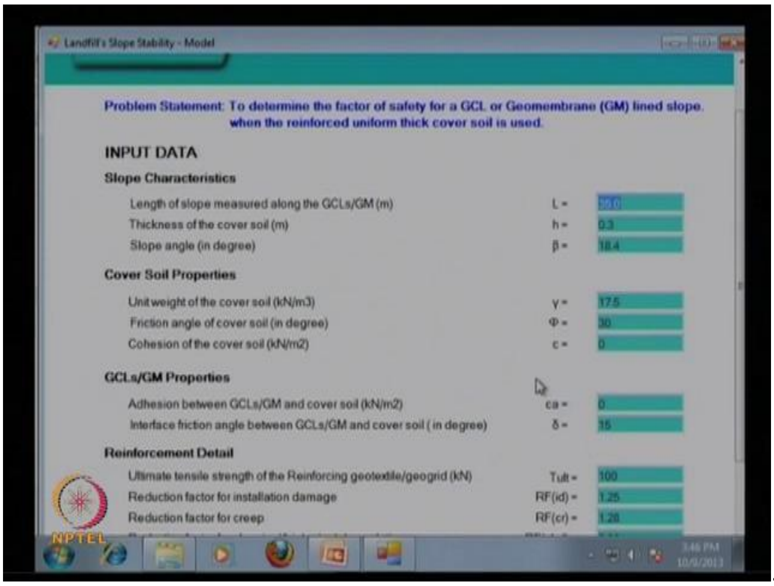

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So, this problem statement to determine the factor of safety GCL or geomembrane liner slope when the reinforcement gives uniform cover soil. So, this is the slope characteristic, you know what will be the length of the slope is given 35 meter and the thickness of the cover soil 0.3 meter. Slope angle beta 38.4 and cover soil property is given that is gamma is 17.5, phi is 30 degree and this cohesion value is equal to 0, and geotextile geomembrane property C a is equal to 0, delta is equal to 15s.

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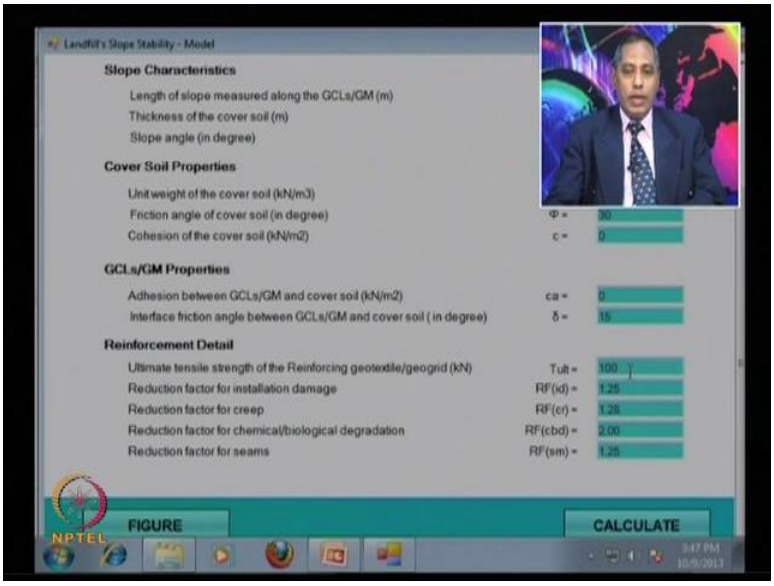

Here, the reinforcement detail is given which that 100 ultimate tensile strength, these are all the reduction factor and then you can calculate.

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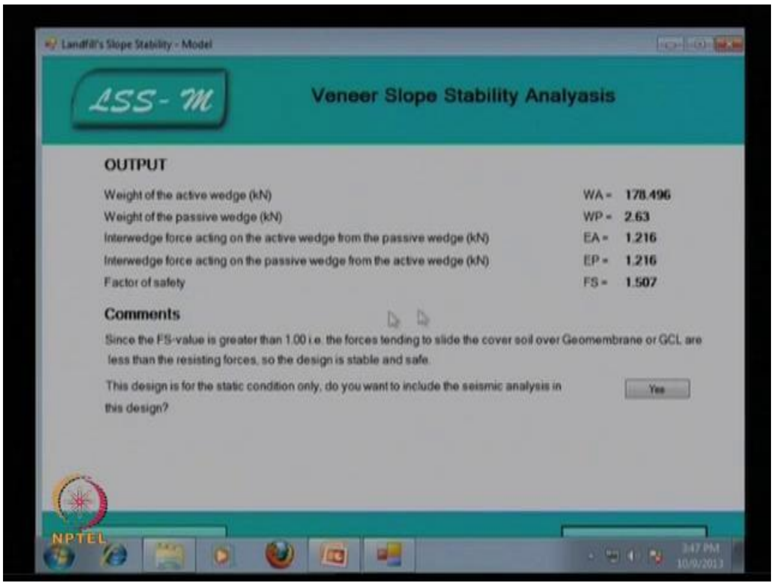

You can determine what will be the factor of safety, this factor of safety is come 1.507. So, since this factor of safety is greater than 1, then force tending the slide that cover soil over the geomembrane or geosynthetic clay liner are lesser than the resisting force. So, design is stable and safe.

Now, design is static condition only, but you can also calculate for the seismic condition, also if you want to calcualte the seismic condition, you have to add the average seismic coefficient value C S is equal to 0.10, others remain as it is. So, you can calculate and you can obtain this value 1.335 and you find that this value is about 75 percent of the static value. Then it is now veneer slope stablity analysis of tapered cover soil, this is by Koerner and Soong 2005.

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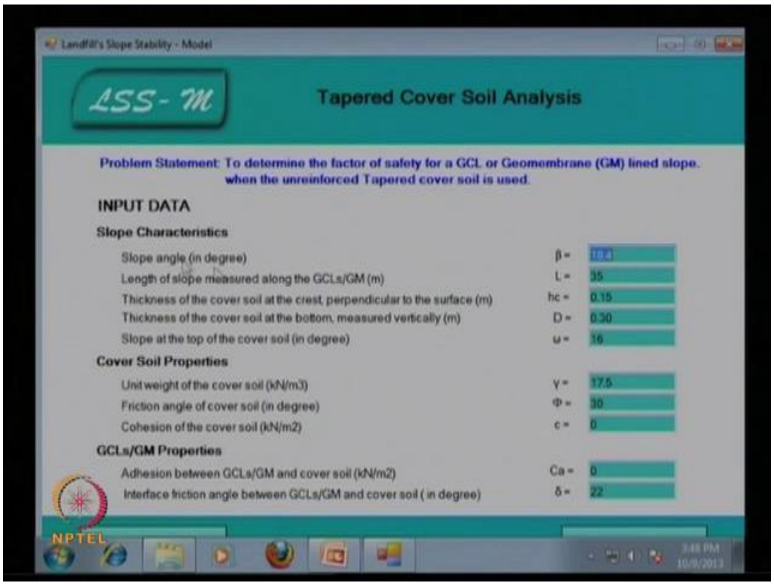

When the tapered cover soil, this you have to provide this, it is like this, this is design like this.

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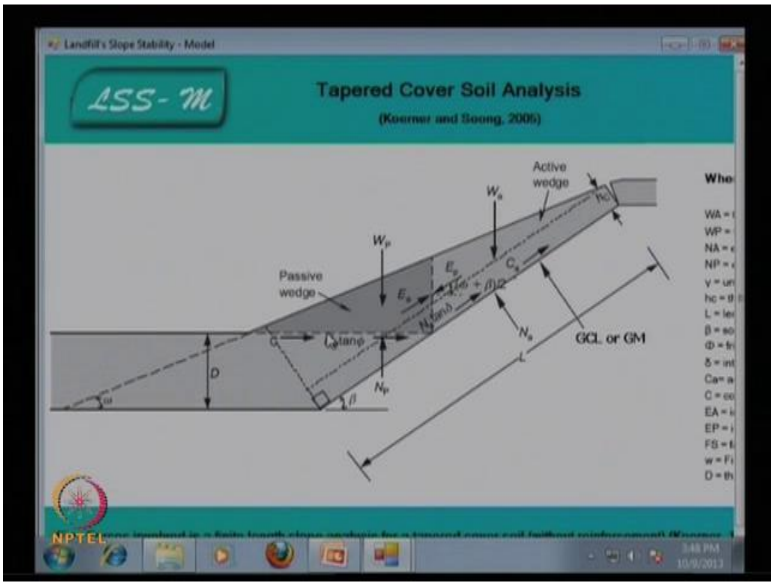

Copper tapered cover soil, like tapered cover soil analysis and you have to input data slope characteristic. Here, slope angle beta is is equal to 18.4 degree, length of the slope measure from along the geosynthetic clay liner L is equal to 35 meter and the thickness of the cover soil at the crest perpendicular to the surface s is equal to 0.15 meter. Thickness of the cover soil at the bottom measure vertically, that is d is equal to 0.30

meter and the slope at the top of the cover soil that is this small of w is equal to 16 degree.

Now, cover soil property unit weight of cover soil gamma 17.5 kilo Newton per meter cube, friction angle of the cover soil phi is equal to 30 degree and cohesion of cover soil c is equal to 0. The geosynthetic clay liner and geomembrane property, that is adhesion between geosynthetic clay liner geomembrane and the cover soil that is C a is equal to 0. Interface friction angle between the geosynthetic clay liner or geomembrane and the cover soil that is delta is equal to 32 degree.

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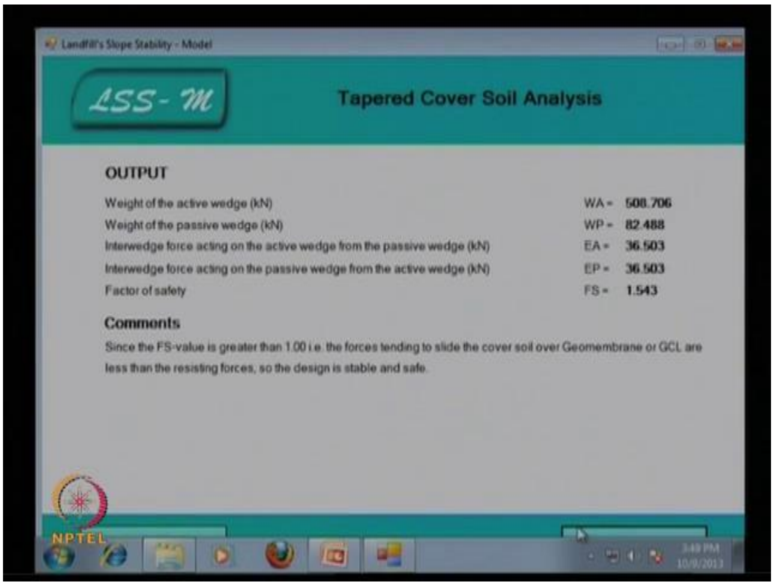

Now, this is for the tapered cover soil, so this is the output of the tapered cover soil analysis the output is weight of the active wedge W A is equal to 508.706 kilo Newton, weight of the passive wedge W P is equal to 82.488. Then interwedge force acting on the active wedge from the passive wedge E A 36.503 kilo Newton. Interwedge force acting on the passive wedge from the active wedge that is E P is equal to 36.503 kilo Newton.

So, you are will obtain the factor of safety F s is equal to 1.543, so here comments since the factor of safety value is greater than 1. So, the force tending to slide the cover soil over the geomembrane or geosynthetic clay liner are less than the resisting force, so design is the stable and the safe. Now, next is veneer slope stability analysis for the tapered cover soil and here the reinforcement cover soil has been used.

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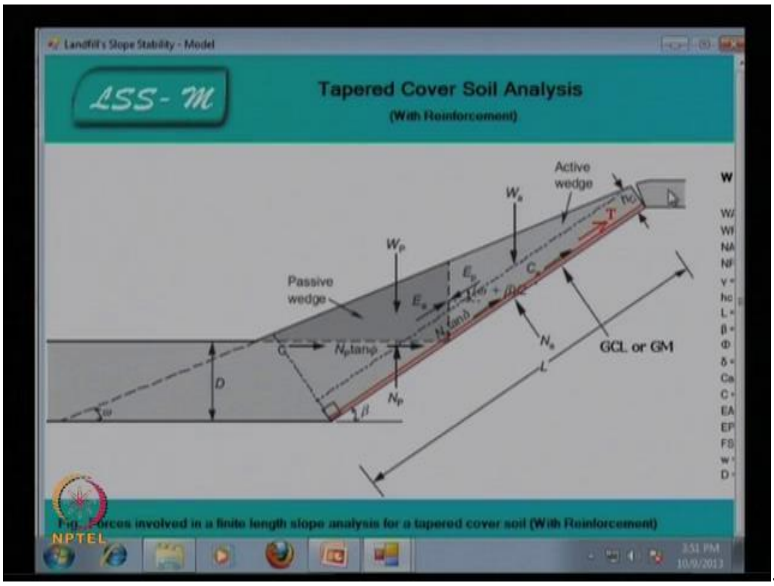

So, in case of the reinforcement and this is the figure you can see here in a tapered cover soil analysis with the reinforcement. The red one is the reinforcement, this is D is this one.

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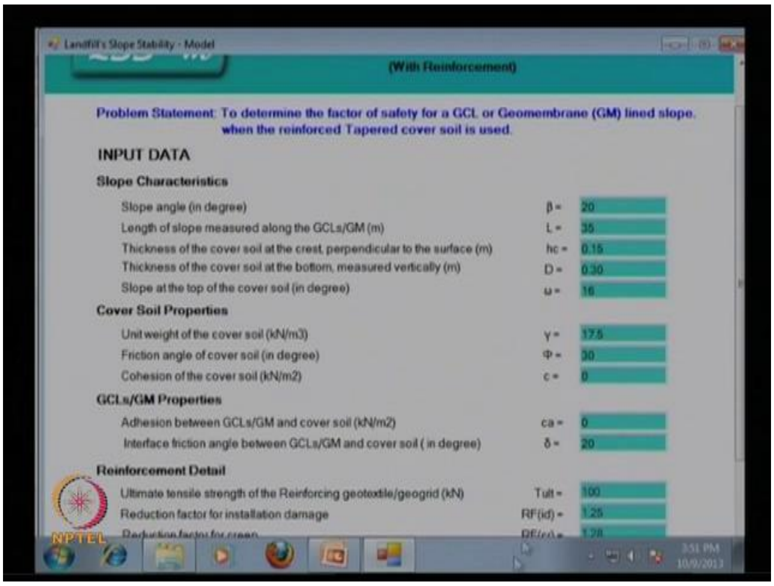

So, then you have to include what will be the slope characteristic, that is beta is equal to 20 degree. Then L the length of the slope is 35 meter and thickness of the cover soil h c 0.15 and thickness of the cover soil at the bottom measured vertically D is equal to 0.30 and slope at the top of the cover soil that is small, w is equal to 16 degree. Cover soil property gamma 17.5, phi is 30 degree and C is equal to 0, geosynthetics and the geomembrane property C a is equal to 0, delta is equal to 20 degree.

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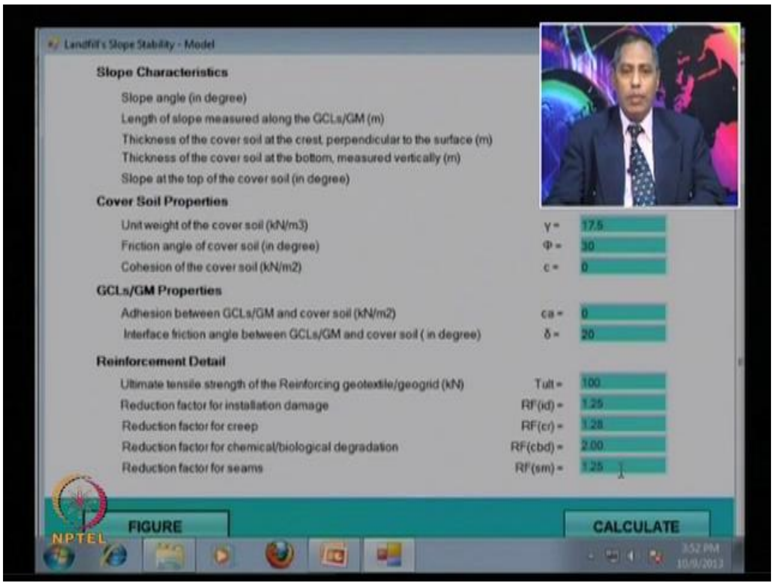

This is the reinforcement in detail is given ultimate tensile strength of the reinforcement geotextile T ultimate is 100 kilo Newton. These are all the reduction factor for the installation damage reduction factor, for creep reduction, for chemical and biological degradation and reduction factor for seam.

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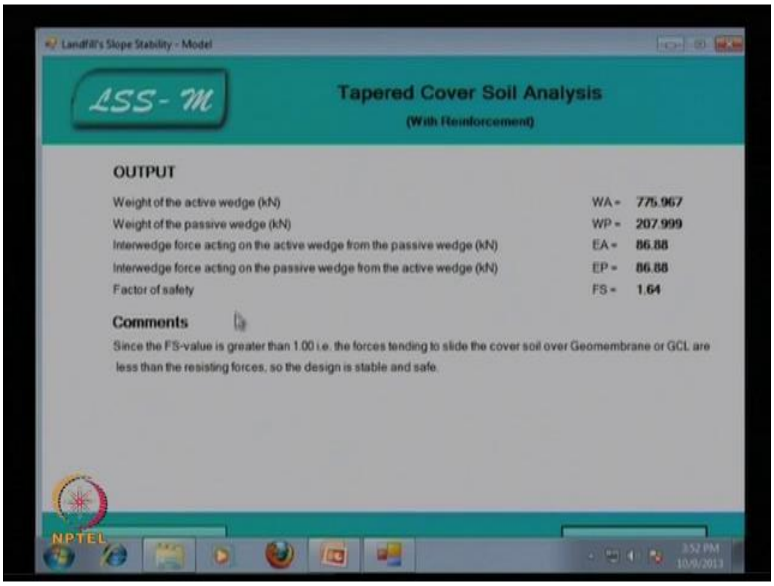

Then, you calculate, you can have the output the weight of the active wedge W a is 775.967 for passive W p, 207.999 and the E A is 66.88 kilo Newton and E P is 66.88 kilo Newton and factor of safety 1.64. So, you find the factor of safety value is greater than 1, so it is the safe and stable structure. So, we will discuss seismic analysis for veneer slope stability analysis without reinforcement, that is Qian 2001.

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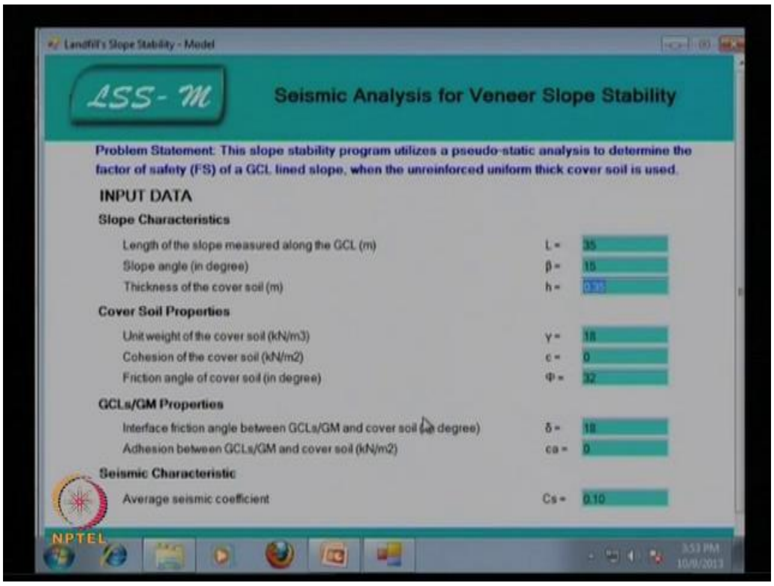

So, this is seismic analysis of veneer slope stability analysis, here the slope charateristic the length L 35, beta 15 degree, h is 0.35 meter. Cover soil property gamma is 18 degree, C is equal to 0, phi is equal to 32 and GCL geomembrane property delta is equal to 18 C a is equal to 0 and here the seismic characteristic the average seismic coefficient C a is 0.10.

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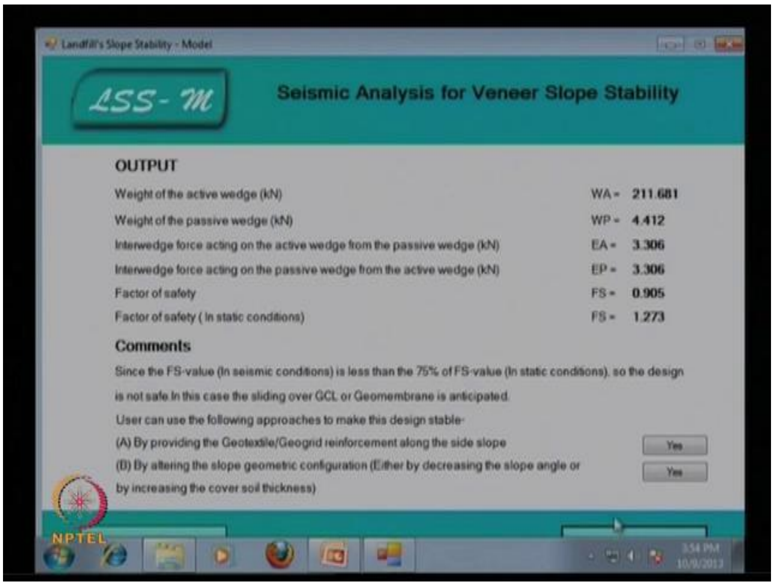

So, you can calculate, so you will obtain the factor of safety value here two cases, one that factor of safety is 0.905 for factor of safety in static condition is 1.273. So, comments since the factor of safety value in seismic condition is less than 75 percent of factor of safety of static condition. So, the design is not safe in the case of sliding over the geosynthetic clay liner or the geomembrane is anticipated. So, you can use the following approach to make this design stable by providing the geotextile or geogrid reinforcement at the side slope and by altering the slope geometry or configuration either by decreasing the slope angle or increasing the cover soil.

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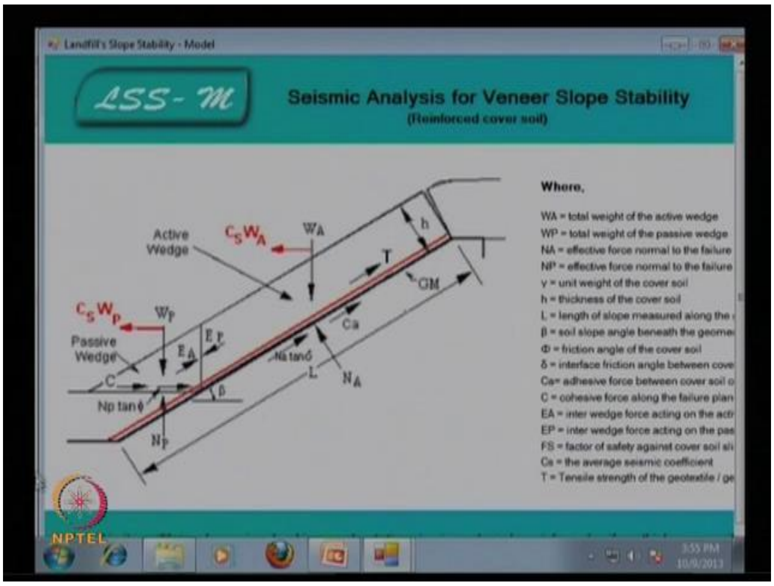

So, if you can add the add the reinforcement here, the seismic analysis for veneer slope cell with the reinforcement. So, this red color is shown that reinforcement and here due to the seismic that is C S into W P in the passive wedge that is seismic coefficient C S. here, the seismic coefficient C S, this is in the active zone, this is C S into W a. Now, if you consider this seismic effect for the veneer slope stability analysis, then you can calculate and you can determine that what will be the factor of safety. This is coming 1.335, so it is stable because it is greater than 1. Now, seepage force analysis veneer slope stability, this Koerner and Soong 1996.

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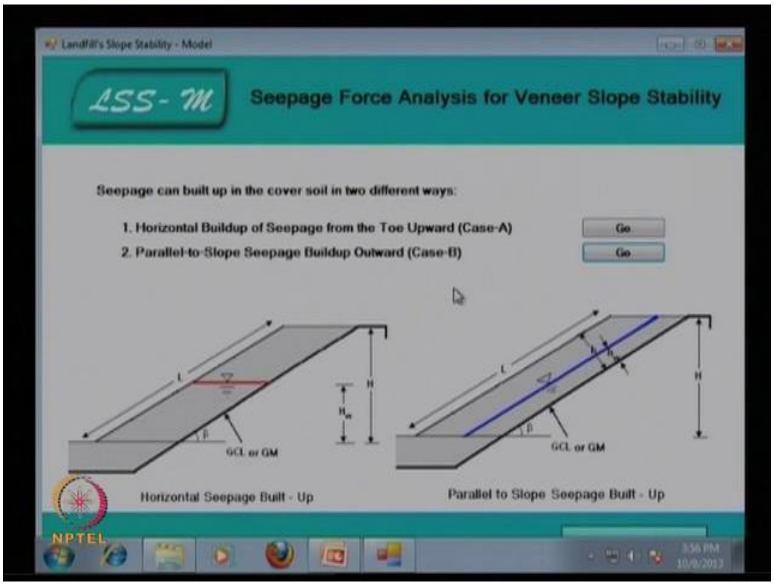

So, if there is a seepage, so seepage force analysis for veneer slope stability seepage can build up in the cover soil in two different way, one horizontal buildup seepage like this from the toe and upward. This is the case and to the parallel to the slope, this one, this is parallel to the slope seepage buildup outward. This is case of B, this is the geomembrane or geosynthetic clay liner and will show that how can we determine if the horizontal seepage buidup. You also can determine the seepage forces analysis by veneer slope stability when the parallel slope.

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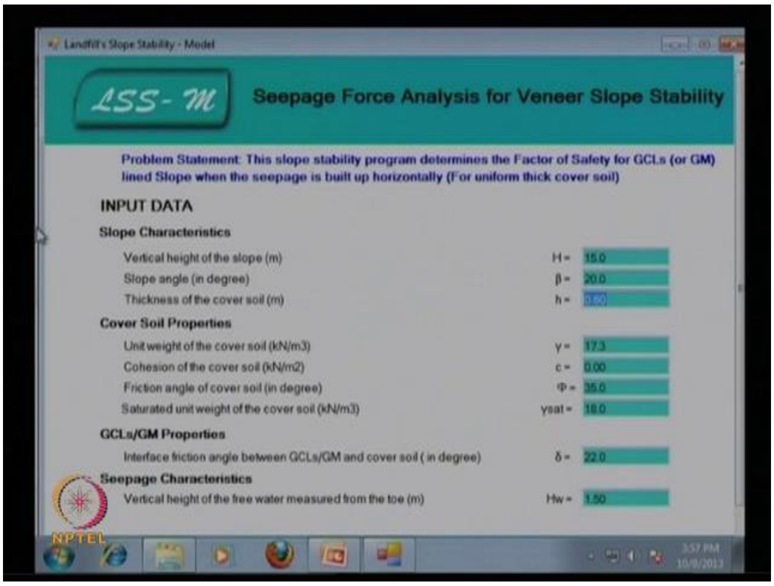

So, if it is a horizontal buidup, you go and this is the problem statement, this slope stability program determination of factor of safety for geosynthetic clay or geomembrane line slope when the seepage is build horizontally for uniform thick cover soil. Here, you have to put the input data, that is slope characteristics, that is the vertical height of the slope is H is equal to 15 meter and the slope angle beta is 20 degree. The thickness of the cover soil H is equal to 0.60 meter cover soil property that is unit weight of the cover soil 17.3 kilo Newton per meter cube.

Cohesion value is equal to 0 and phi value equal to 35 degree and also that is the saturated unit weight of the cover soil because we are considering the seepage. So, this gamma saturated is 18 kilo Newton per meter cube geosynthetic clay or geomembrane property. The value of delta is equal to 22 and the seepage characteristic, this is the vertical height of the free water measured from the toe that is h w is equal to 1.5 meter.

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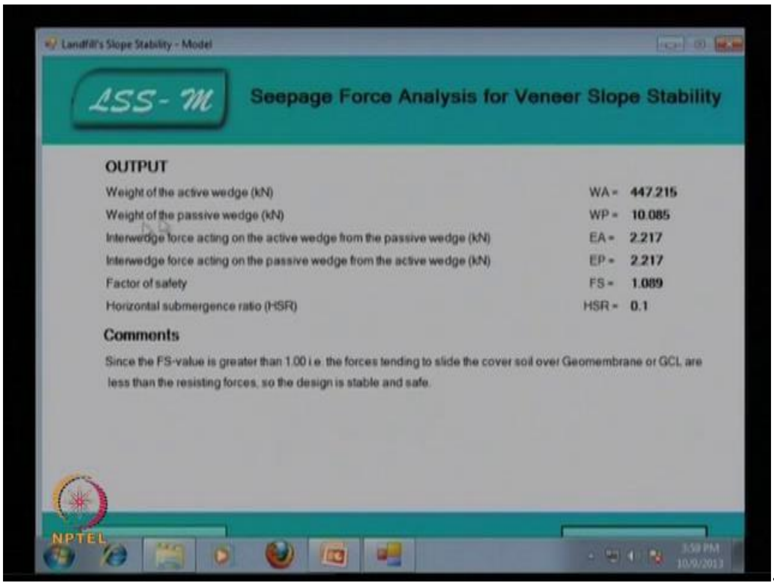

So, if you now calculate, you can obtain the output for the seepage force analysis for veneer slope stability. This is W a is 447.215 W p 10.085, E A is 222.217 kilonewton E P is 2.217 kilo Newton and factor of safety value 1.089 and the horizontal submergency ratio HSR is equal to 0.1. So, comment since the factor of safety value is greater than 1, the force tending to slide the cover soil over the geomembrane or geosynthetic clay liner are less than the resisting force. So, design is stable, I will show you the horizontal buildup is the parallel to the slope seepage buidup, so like this parallel to the slope if it is happen.

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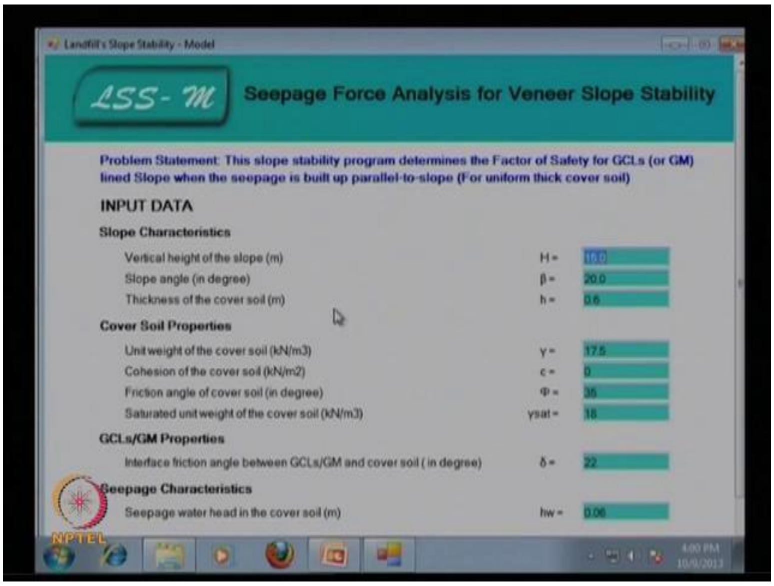

Then, how you can make use of this program, this is the problem statement the slope stability program determine the factor of safety of geosynthetic clay liner slope, when the seepage buidup parallel to the slope for uniform thickness. Here, input data that slope charateristics that is veneer height of the slope H is equal to 15 meter beta angle, 20 degree and h is equal to thickness of the cover soil is 0.6 meter. Cover soil property that is gamma 17.5 kilonewton per meter cube c is equal to 0, phi is equal to 35 degree, gamma saturated 18 kilonewton per meter cube and geosynthetic. Geomembrane property delta is equal to 22 degree and seepage characteristic, that is seepage water head in the cover soil that is H W is 0.06.

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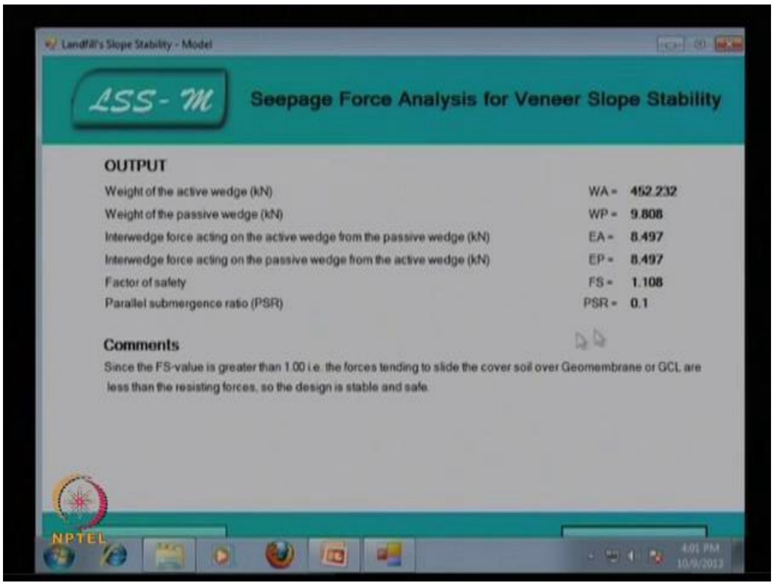

So, you can calculate and can determine what will be the factor of safety this factor of safety value is 1.108 and parallel to the submergence ratio, which is called PSR is 0.1. So, here we find the factor of safety value is greater than 1, so it is safe. So, now the runout and the anchor trench analysis of sand Koerner 1997, that is runout.

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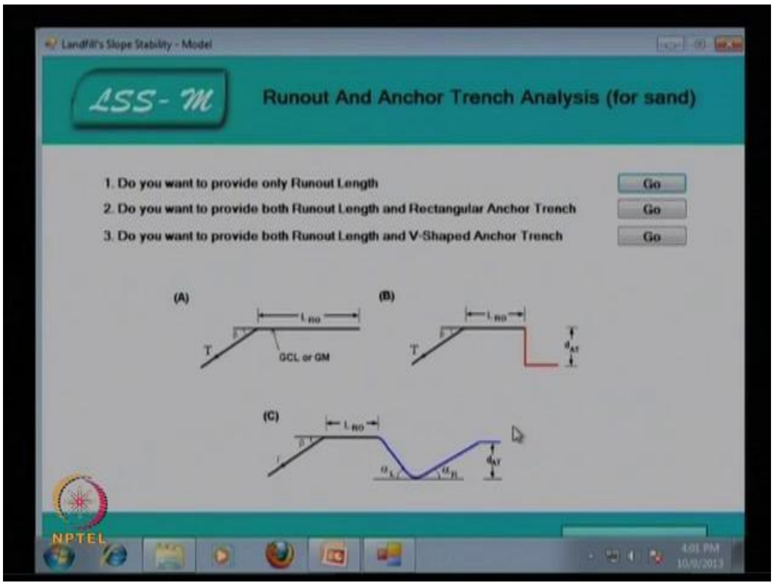

Anchor trench, I have shown you that in my earlier presentation, that do you want to provide only runout length. You want to provide both runout length and the rectangular anchor trench or number three do you want to provide both runout length and the v shaped anchor trench. So, this is runout length L at 0 you know this is the runout length L r 0 and this is the anchorage trench, that is D a t rectangular shape or it may be the v shape type, so suppose do you want to go for the runout length you go.

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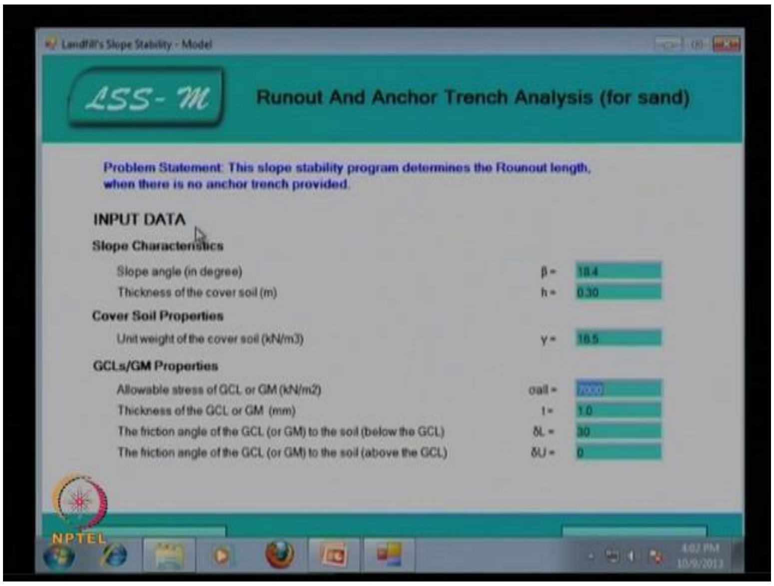

Then, this is the runout problem statement, the slope stability program determine the runout length when there is no anchor trench provided. So, input data soil characteristics slope angle beta 18.4 degree and thickness of the cover soil H is equal to 0.30 meter. Cover soil property unit weight of cover soil gamma that is 16.5 kilonewton per meter cube and GCL and geomembrane property.

The allowable stress of GCL or geomembrane that is sigma allowable is equal to 7,000 kilo Newton per meter square, thickness of the GCL or geomembrane that is t that is 1.0 millimeter. The friction angle of GCL or geomembrane to the soil below the GCL, that is delta L is equal to 30 and the friction angle of the GCL or geomembrane to the soil above the geocell that is delta U is equal to 0 degree.

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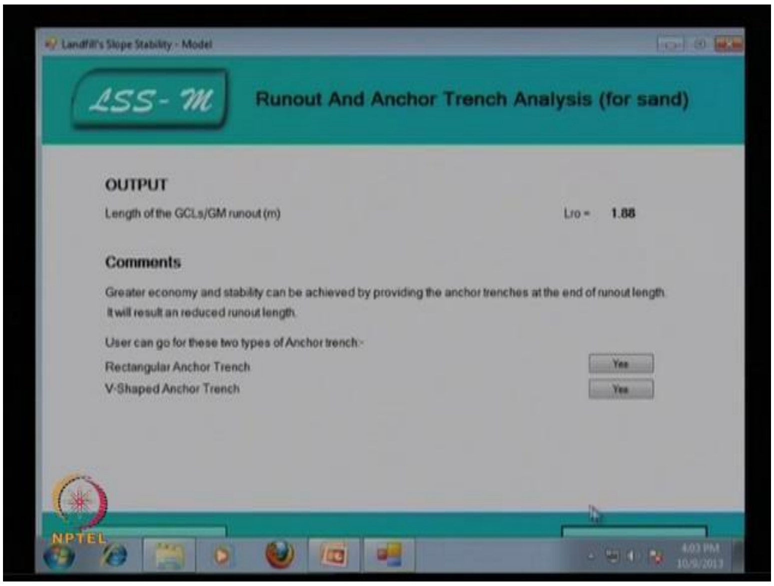

Now, you can calculate and you can find that what will be the length of the GCL or that is L is 0, that is 1.888. So, comment if it is a greater economy and stability achieved by providing the anchor trench at the end of the runout length. It will result to reduce the runout length, so user can go of these two types of the anchor trench either the rectangular anchor trench or v shaped anchor trench.

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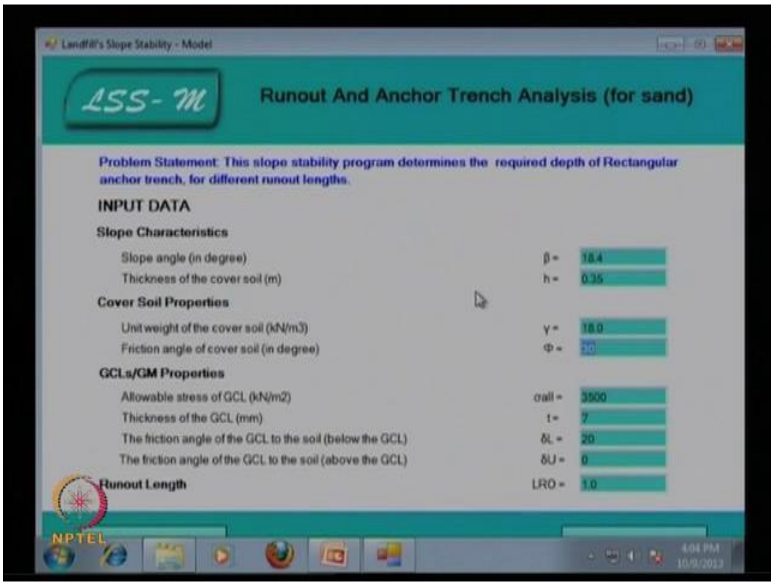

So, if you go, this is the problem statement, the slope stability program determination required depth of the rectangular trench anchor for different runout length. Now, if you go for the runout length, then here the input data for slope characteristics beta is 18.4, h is equal to 0.35, cover soil property gamma is equal to 18, phi is equal to 30. The allowable stress for the geosynthetics clay liner sigma allowable is 3,500 kilo Newton per meter square. Thickness of the GCL is, t is equal to 7 millimeter because this is a GCL and the friction angle of the GCL to the soil below the GCL, that is delta L is equal to 20 degree. The friction angle of the GCL to the soil above the GCL that is is equal to 0 and then runout length, let us say L r 0 is equal to the 1.0.

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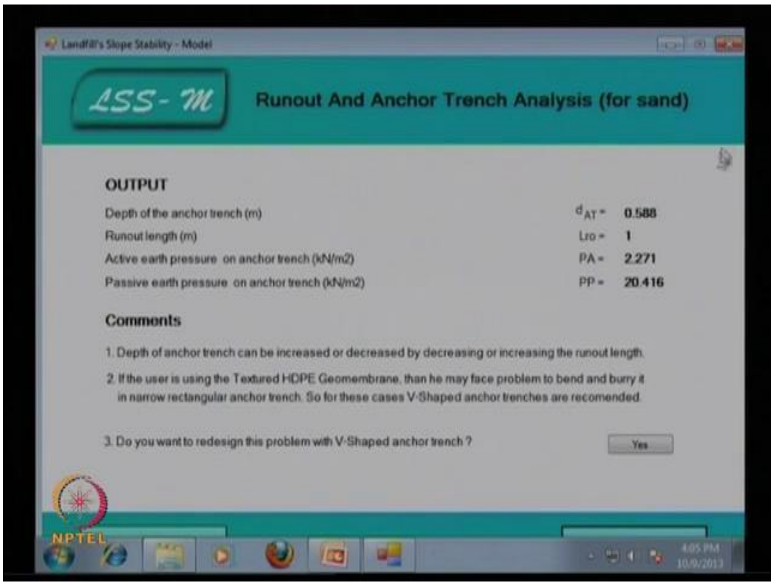

So, then you can obtain the output data what will be the design of the anchor trench, that is D a t which we are interested, that means D a t is equal to 0.588 and runout length L t 0 is equal to 1 meter. So, you can calculate P a and also the P p, so comment depth of the anchor trench can be increased or decreased by decreasing or increasing the runout length too.

If the user is using the any geotextile or high density polyethylene geomembrane, then he may face the problem to bend and burry, it is the narrow rectangular anchor trench, so for this case that v shape anchor trench are recommended. So, do you want to design this problem with the v shape anchor trench? If you say yes then you can.

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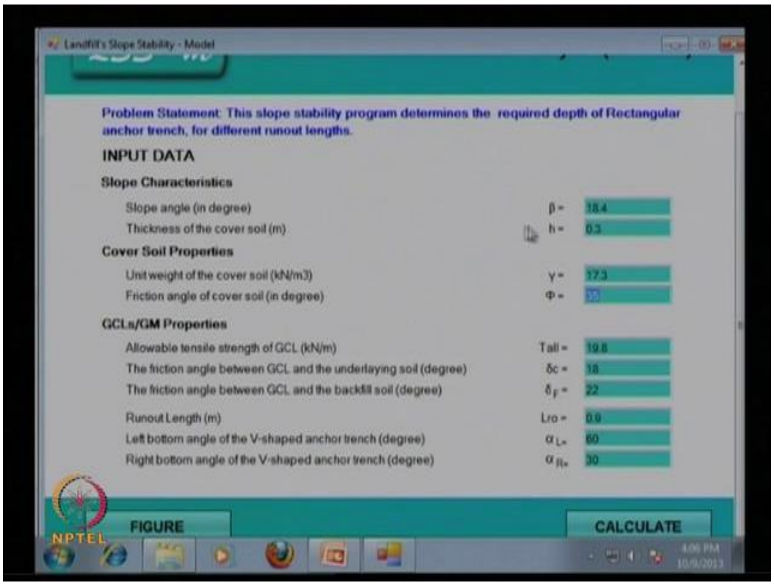

So, we can use this is a problem statement, the slope stability program determine the required depth of the rectangular anchor trench for the different. So, here slope charateristics beta is 18.4 and the thickness is 0.3, this is the cover soil property that gamma is is equal to 17.3, phi is equal to 35. This is geosynthetics and geomembrane property t allowable is equal to 19.8 kilo Newton per meter and the friction angle between GCL and the underlying soil delta C is equal to the 18.

This is the friction angle between GCL and the backfill soil, that is delta f is equal to 22 degree and runout length L r 0 is equal to 0.9. The left bottom angle of the v shaped anchor trench, that is alpha of L is equal to 60 degree and this right bottom of the v shape anchor trench that is alpha of R is equal to 30 degree.

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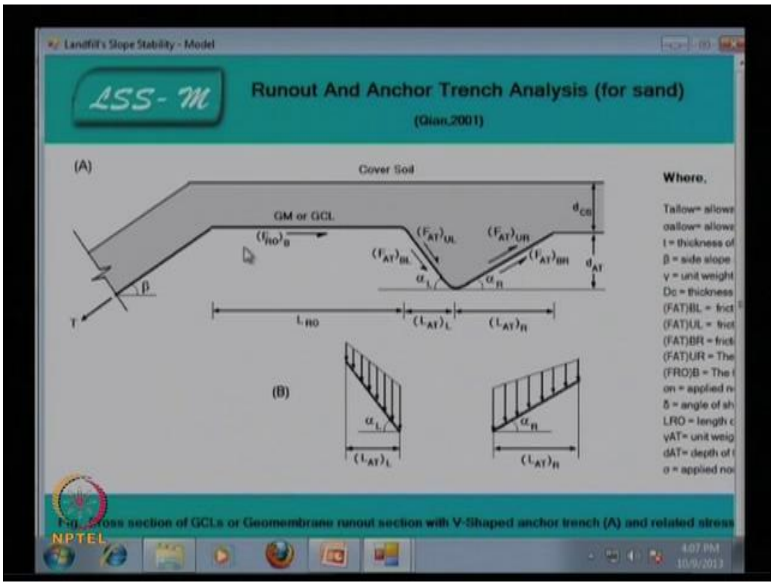

You can have like this this is a v shape, this is a v shape like this k, so for this v shape you can also calculate.

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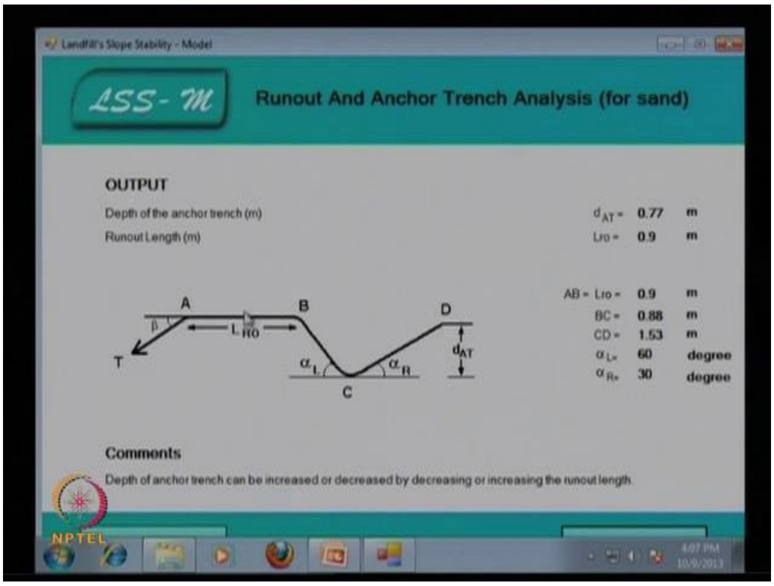

This is the output that is depth of the anchor trench and you can have D is 0.77, L r 0 is 0.9 meter. So, depth of the anchor trench can be increased or decreased by decreasing or increasing the runout length. Here, A of B, which is runout length L r 0 is equal to 0.90 meter and B C can calculate 0.88 meter and c d this is 1.53 meter and alpha of L is equal to 60 degree and this alpha of R is equal to 30 degree.

Runout length and anchor trench analysis for sand, the output depth of the anchor trench that is D is equal to 0.77 meter and runout length L r 0 is equal to 0.9 meter. So, in case of v shape, you know that this is the A of b, that is L r 0 runout length, that is L r 0 is 0.9 meter. You can calculate B c also, 0.83 meter, this is the C D is equal to 1.53 meter and also D at this depth is 0.77 meter. Also, the alpha of L is 60 degree and alpha of R is equal to 30 degree.

So, depth of the anchor trench can be also increased or decreased or by decreasing increasing the runout length. So, instead of the rectangular shape, it is sometimes very difficult to make it 90 degree in the geomembrane. So, in that case, you can go ahead with the v shape, because you can bend it at 60 degree or the 30 degree and also it is much more convenient to use this.

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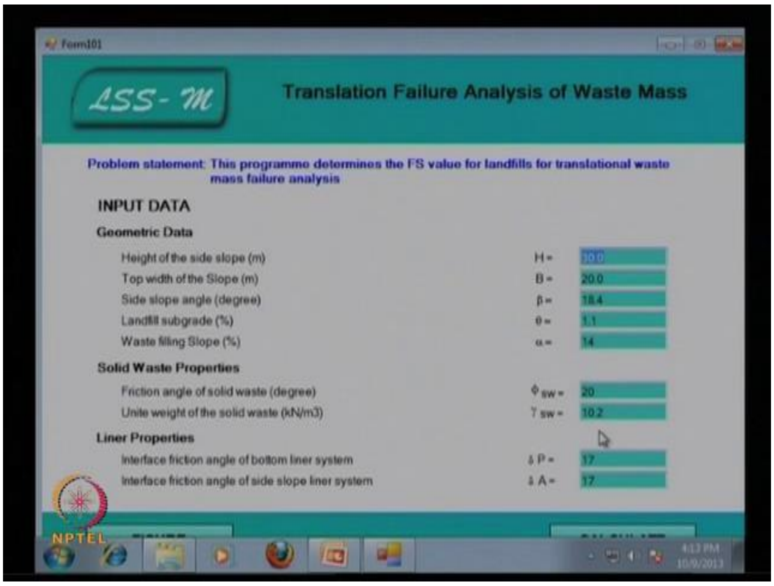

So, next waste mass failure analysis Qian 2003 in the landfill, you can see that after this, after the waste material in dumping and landfill. Then you find that there is a failure of the waste mass itself and also that there is a translation failure of the waste mass.

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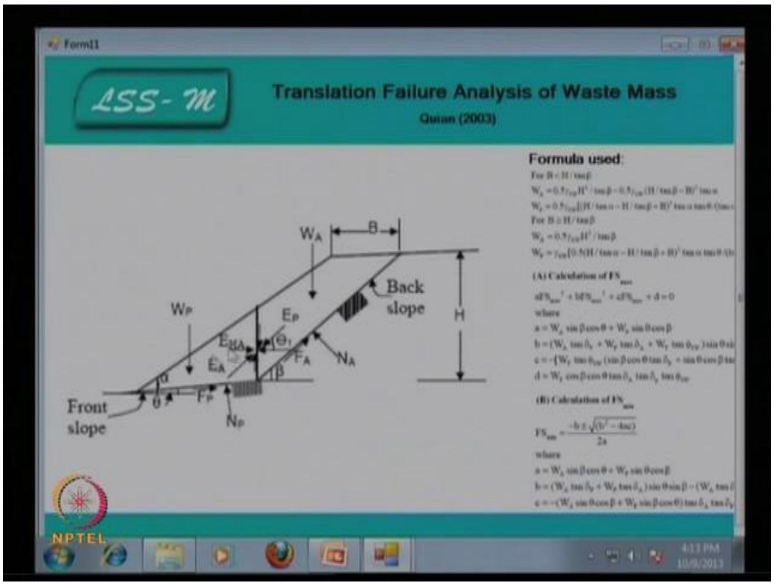

This is the waste mass, how it fail, so if the waste mass fail it is also necessary to properly design this. So, in this program also this problem statement this programme determine the factor of safety value for the landfill for translation waste mass failure analysis. The input data that is geometric data that has height of the slide slope H is equal to 30 meter and top width of the slope b is equal to 20 meter.

The slope angle beta is equal to 18.4 degree landfill subgrade percenatge is 1.1 and waste fill slope alpha percentage is 14 and solid waste properties that is friction angle of the solid waste that is phi S w is equal to 20 degree. The unit weight of the solid waste gamma s w is 10.2 kilo Newton per meter. Liner property that is the interface friction angle of the bottom liner system that delta P is equal to 17 and also interface friction angle of the slope liner system, delta A is equal to the 17 degree.

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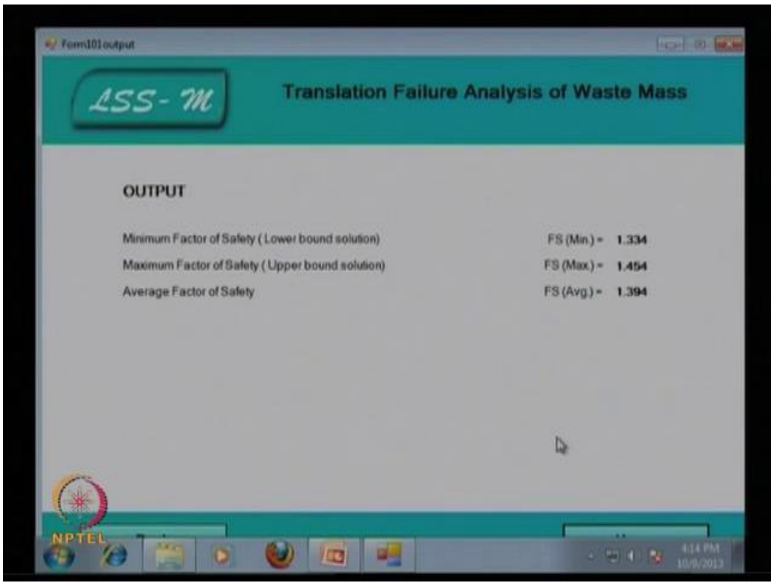

Now, if you calculate this, so you can have the output that is minimum factor of safety lower bottom solution F s minimum 1.334. The maximum factor of safety of the upper bottom solution F s maximum is 1.454 and average factor of safety that is F s average 1.394, so it is safety and the safe then it is ok. So, application of the GSL as a liquid containment liner.

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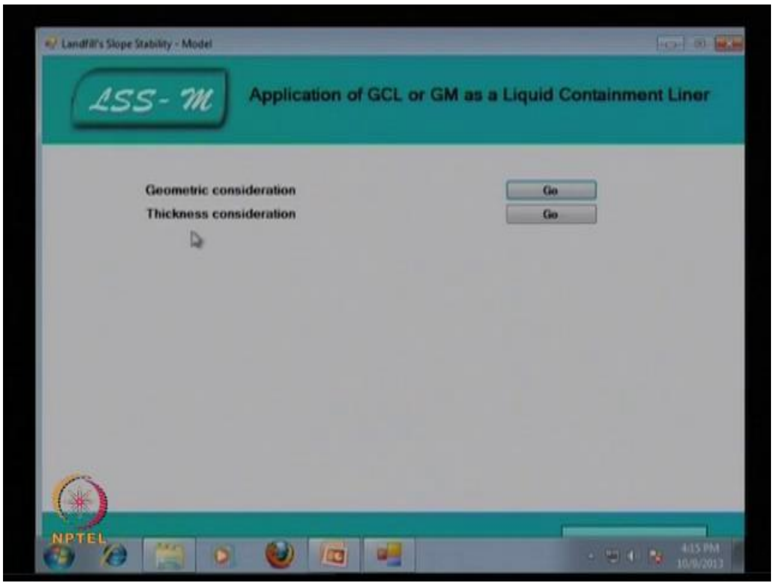

So, here the geometric consideration and thickness consideration is important, I also mentioned this geometric and thickness consideration.

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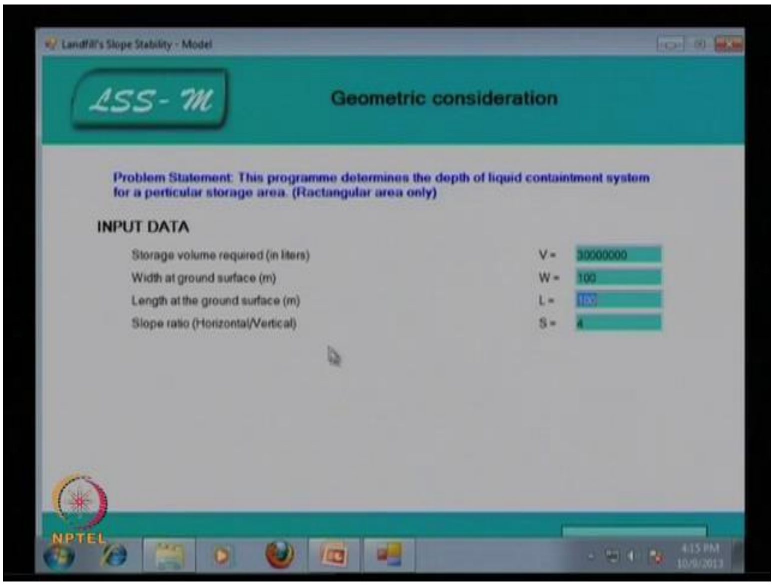

This is the input data what will be the storage volume required, let us say this is the v and this is in liter and you know the what will be the width of the ground surface that 100 meter length. So, the ground surface is 100 meter and the slope ratio that is horizontal to vertical s is equal to 4.

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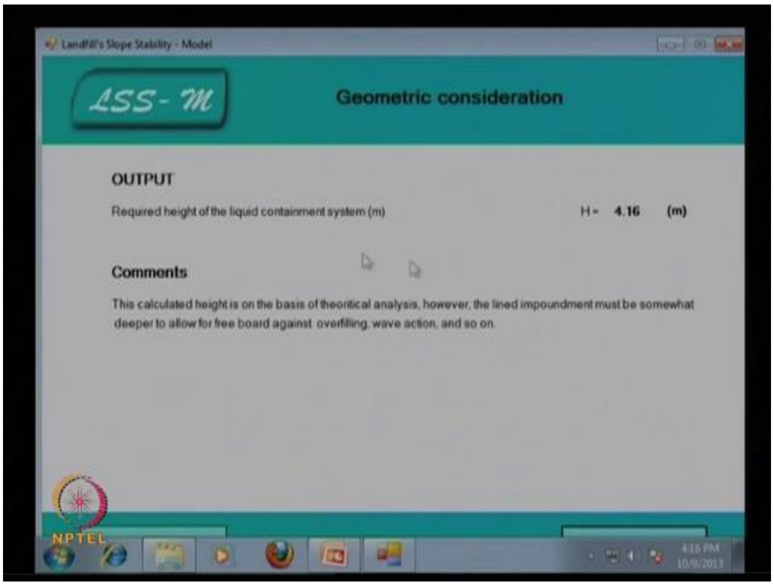

So, you can calculate and can determine that what will be the required height of the liquid containment system, that is H is equal to 4.16. So, you can calcualte the height on the basic of the theoritical analysis, however the liner impoundment must be somewhat deeper to allow the free board against the overfilling wave action and so on.

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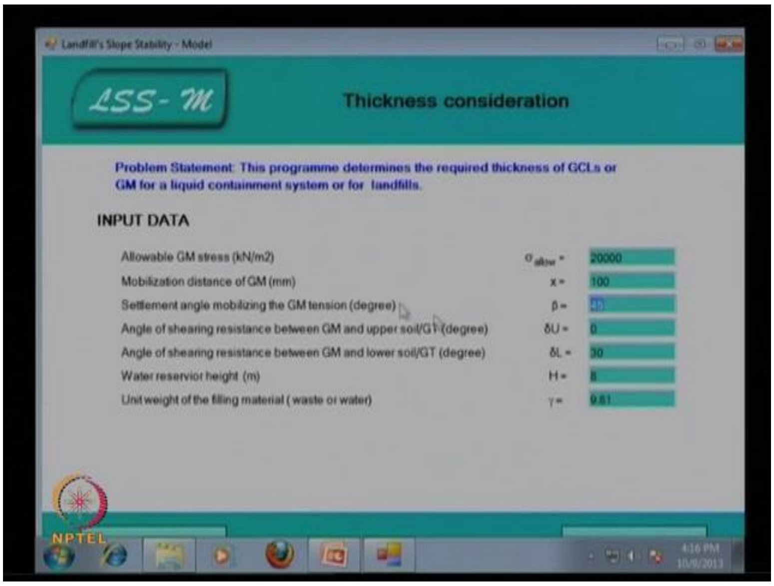

If you go thickness consideration, so thickness consideration this is the problem statement, the program determine the required thickness of GCL or geomembrane liquid containment system for the landfill. The input data allowable that geomembrane that stress, that is sigma allowable is equal to 20,000, that kilo Newton per meter square. This is mobilization distance of the geomembrane, x is equal to 100 millimeter, then strip the the that is the settlement angle mobilize the geomembrane tension in degree beta is equal to 45.

The angle of shearing resistance between the geomembrane and the upper soil or the geotextile delta u is equal to 0 angle of shearing resistance between geomembrane and the lower soil or the geotextile in degree delta is equal to 30 degree. Water reservior height H is equal to 8 meter and the unit weight of the filling material that is waste or the water that is gamma is equal to 9.81. Now, if you substitute this, this, this and whatever I am showing you, that what will be the figure like that.

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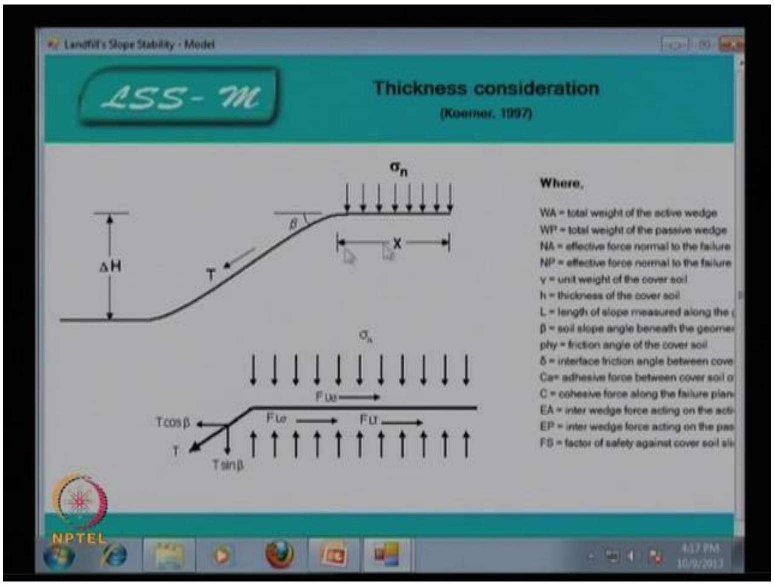

This is the x, this I have already also the explained the how we can calculate this calculate the thickness.

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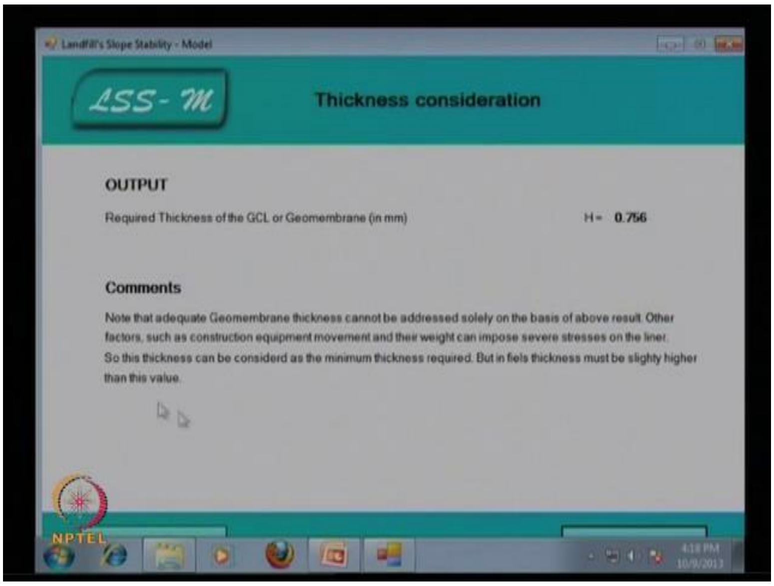

So, with this programme then ultimately you can have the required thickness of the geomembrane or geosynthetic, that is h is equal to 0.766 millimeter. Sometimes, though it is on the it is 0.776, it is preferable always you put in the higher thickness. Then you can give the 1 meter or you can 1.5 or 2 meter. So, because it is sometimes necessary that when you dump this any waste material and it is compacted, there is a possibility for the damage of the geomembrane. So, it is preferable that you can give a little bit higher thickness. So, then contamination transport of GCL then this is a contaminant transport through the geosynthetic clay liner or end compacted clay liner, this is steady adverse mass flux.

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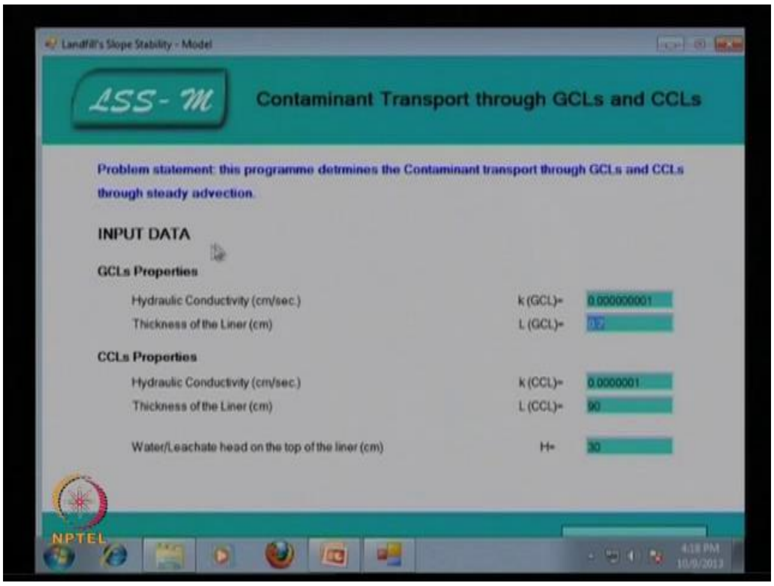

So, their problem statement this programme determine that contamination transport to GCL and geosynthetic clay liner through the steady advection the input data geotextile property. Hydraulic conductivity k of GCL is 0.0000001, then thickness of the liner is given L GCL is 0.7 centimeter. GCL property hydraulic conductivity is given k of GCL is this value and thickness of the liner that is L CCL is equal to 90 and water and leachate head on the top of the liner h is equal to the 30 degree.

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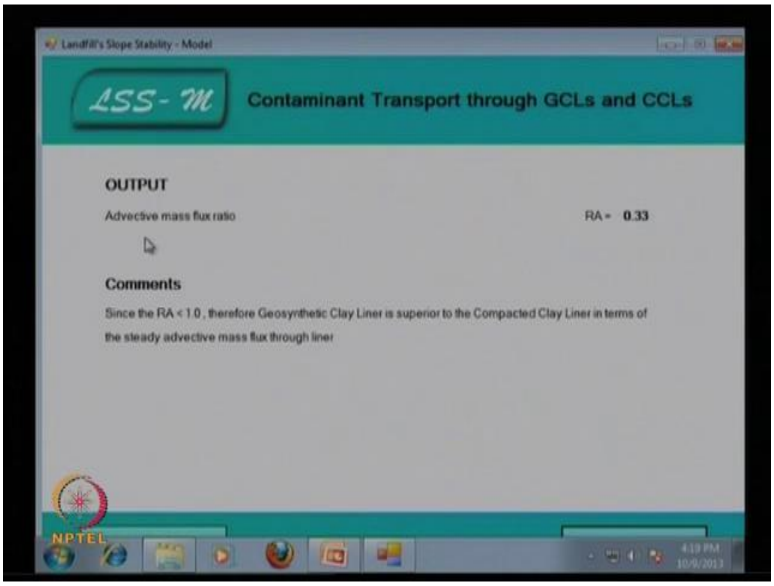

So, you can calculate what will be the advective mass flux ratio, that is R a is equal to 0.33. Since the R a value is less than 1, therefore geosynthetic clay liner is superior to the compacted clay liner in terms of the steady advective mass flux through the liner and if it is a steady diffusive mass flux.

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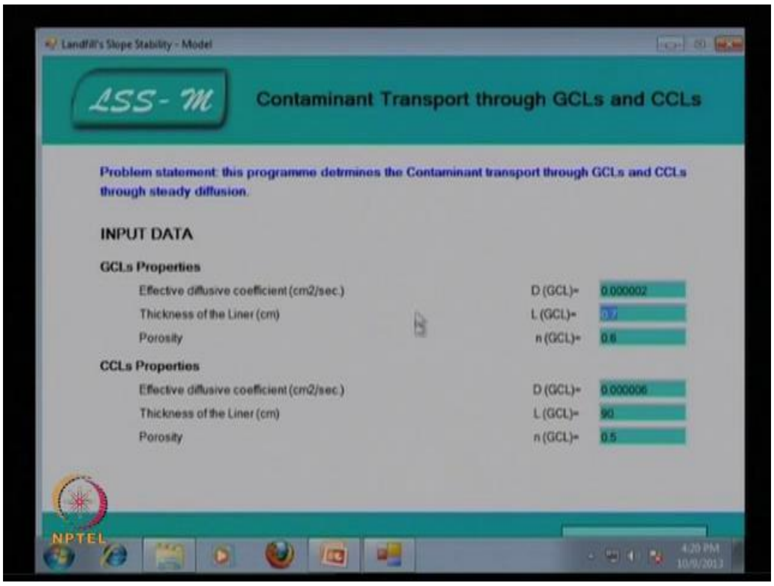

If it is a steady diffusive mass flux, this is the problem statement, the programme determine the contamination transport through GCL and the CCL through the steady diffusion. So, input data GCL property effective diffusive coefficient, that is d for the geosynthetic clay liner is this centimeter per second. Thickness of the liner that is L GCL is equal to 0.7 centimeter and the porosity that for GCL is 0.6. The CCL compacted clay liner property effective diffusive coefficient, that is d centimeter per second is this value. Thickness of the liner that is L GCL is equal to 90 centimeter and porosity that is GCL is equal to 0.5.

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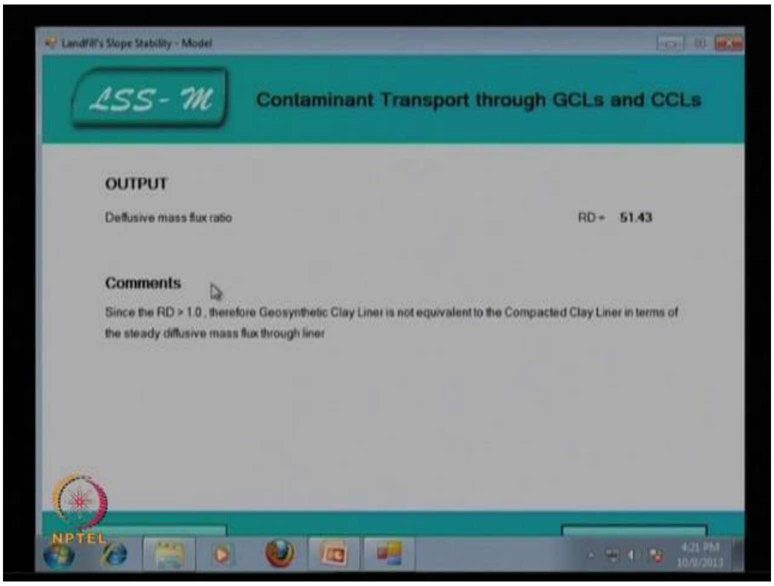

So, if you substitute this input data, you can have a output data that is the diffusive mass flux ratio R d is 510.43. Since the R d value is greater than 1, therefore geosynthetic clay liner is not equivalent to the compacted clay liner in terms of the steady diffusive mass flux through the liner. Now, this software also deals with the following landfill design for the related problem that cover soil slope stability landfill gas pressure, if there is a development of the gas pressure.

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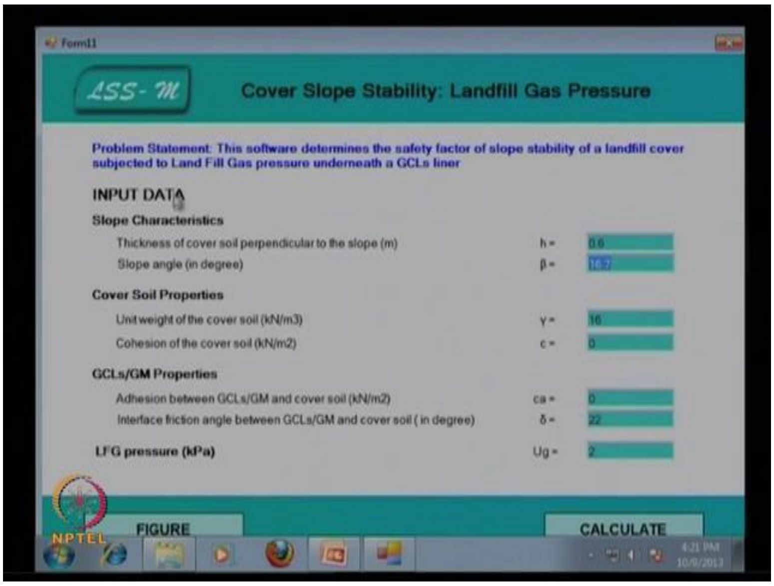

So, this problem statement, the software also determine the safety factor of the slope stability of the landfill cover subjected to the landfill if the gas pressure undermine the geosynthetic clay liner. The slope characteristic is thickness of the slope of the pipe, perpendicular to the slope that is in h meter is 0.6 meter and beta angle is equal to 16.7 degree. And cover soil property unit weight of soil gamma is equal to 16 and C value is equal to 0 and geosynthetic clay liner property, that is C s is equal to 0, delta is equal to 22 degree and L f g pressure that is kilo Pascal that is U g is equal to 2 kilo Pascal.

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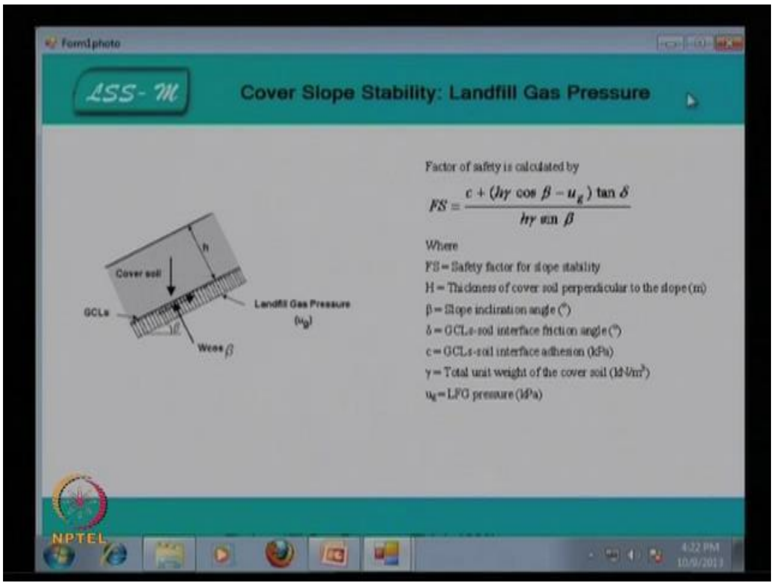

So, if there is a development of cover soil stability, where there is a development of gas if gas there is a leachate and gas pressure developed here. So, you have to calculate that what will be the factor of safety, so you can calculate and you find the factor of safety value 1.05. Now, for the lateral drainage system for unit gradient ratio for lateral drainage system for unit gradient ratio.

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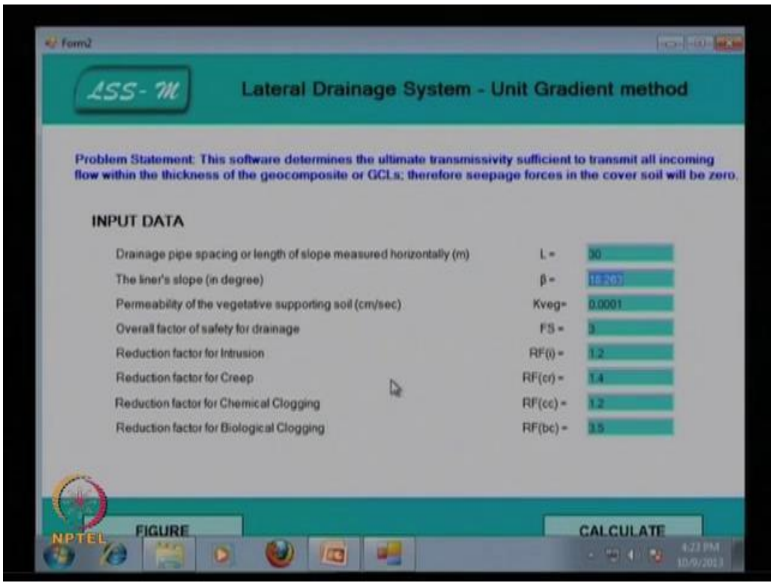

So, this is the geocomposite or geosynthetic clay liner this is a gradient i.

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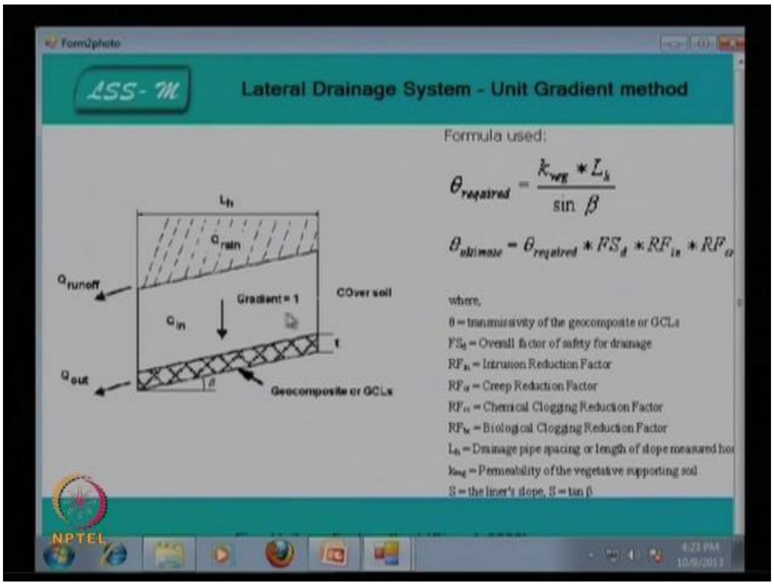

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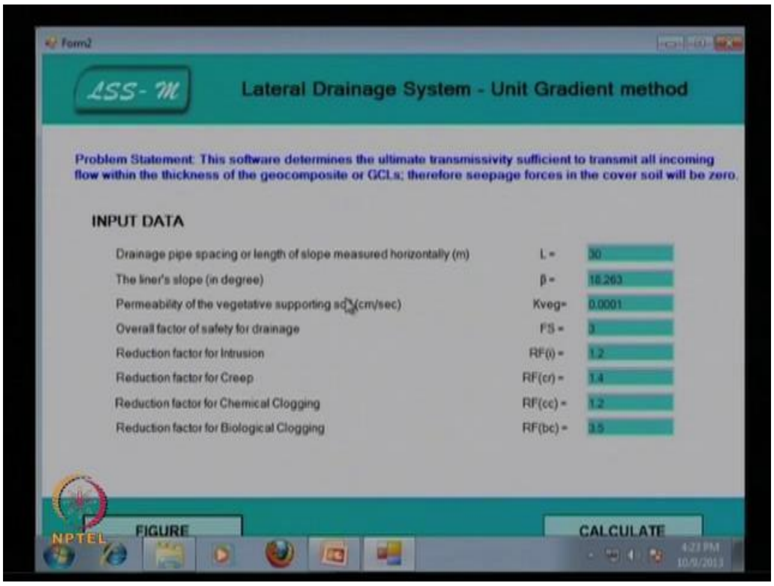

Here, that input data is the drainage or spacing length of the slope measured horizontally, that is L is equal to 30 meter. The liner slope that is beta is equal to 18.263 degree permeability of the vegetative supporting that k veg is 0.0001 centimeter per second. Overall factor of safety to the drainage, F s is equal to 3 and these are the reduction factor, reduction factor for the intrusion reduction factor for the creep reduction for the clogging and reduction for the biological clogging, so you are doing 1.2, 1.4, 1.2 and 1.5.

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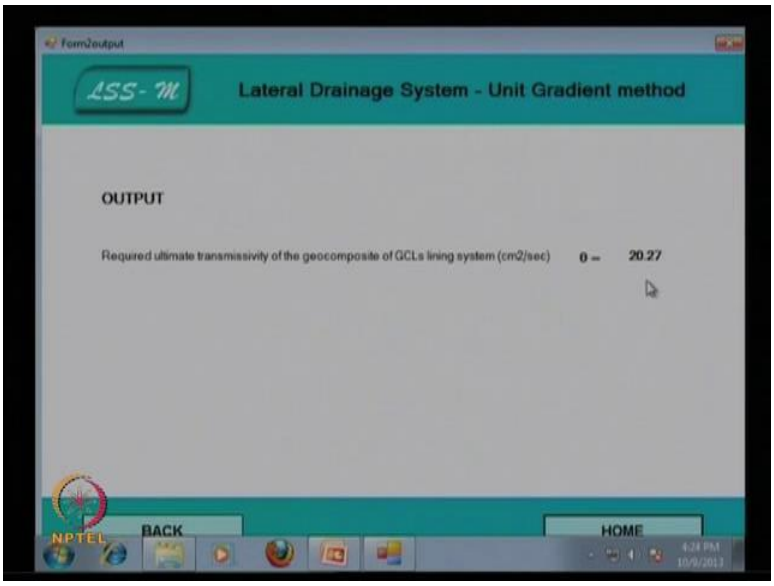

Then, you calculate and find that the required ultimate transmissivity of the geomembrane, geosynthetic clay liner lining system is theta is equal to 20.27 centimeter per second.

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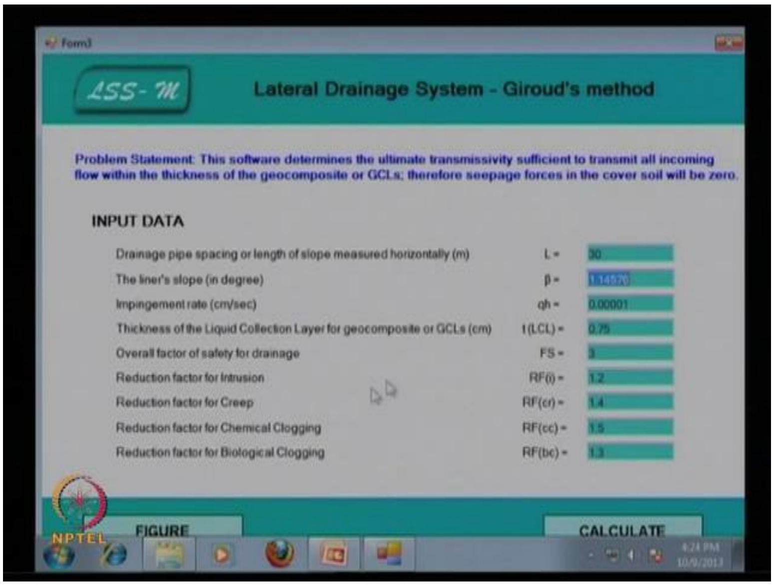

So, next lateral drainage system in the giroud method, so giroud method also this is the lateral drainage system for the Giroud's method. This is the equation has been used into this programme and this is the drainage pipe that spacing length of the measurement horizontally L is equal to 30 meter. The liner slope angle beta is equal to 1.345 that is degree and this is the impingnated rate that q h centimeter per second is 0.000001.

The thickness of the liquid collective layer on the geocomposite GCL, that is 0.75, that is centimeter and the overall factor of safety for drainage that is F s is equal to 3. These are the reduction factor for the intrusion creep and the chemical clogging and biological clogging, so you have taken 1.2, 1.4, 1.5 and 1.3.

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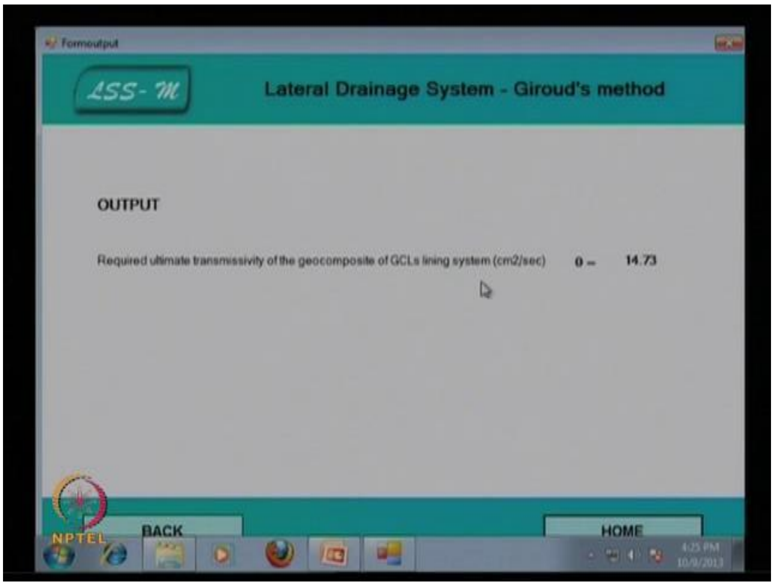

Then, you calculate and find the required ultimate transmittivity of geomembrane or the GCL lining system that is theta, 14.73 centimeter per second. So, then design of the landfill for access ramp, that is access ramp one and there is a access ramp like this.

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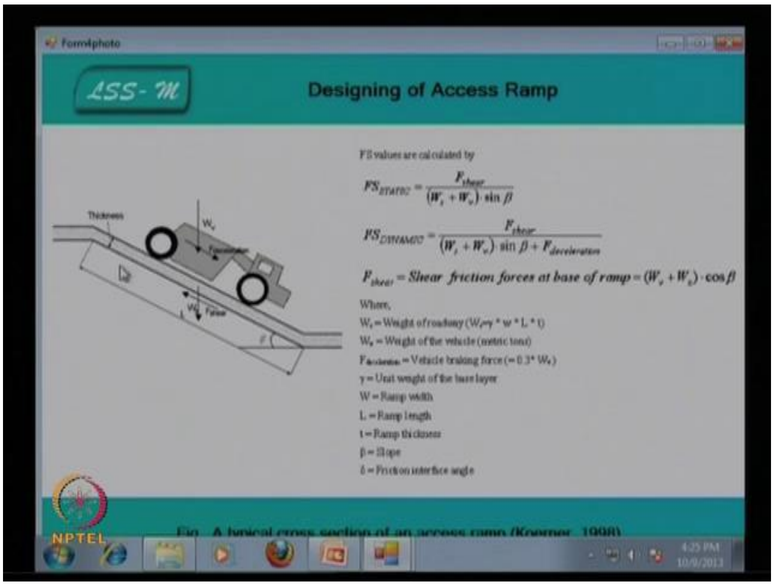

When the vehicle should move in which direction, from top to the bottom or bottom to the top, so these are the equation has been used for this.

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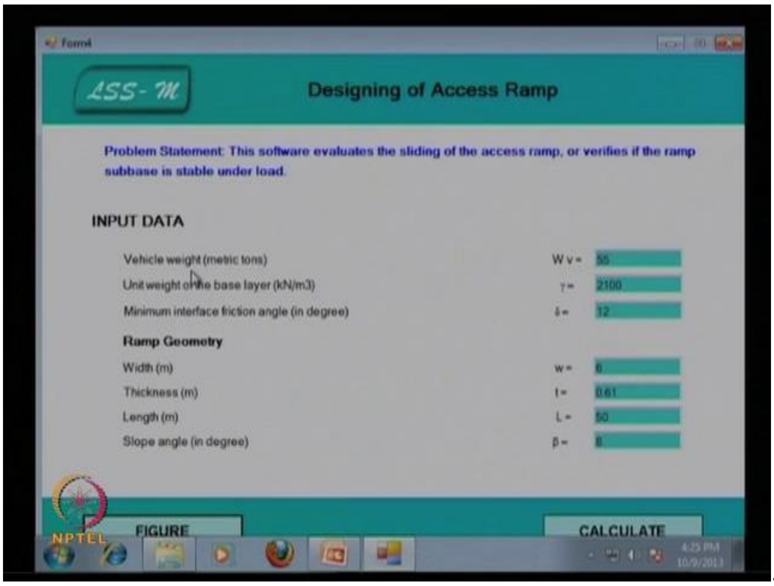

This is the vehicle weight that is W v is equal to, that is 55 metric ton and unit weight of the base layer gamma 2100 kilo Newton per meter cube and minimum interface friction angle delta is equal to 12 degree. The ramp geometry is width is equal to w, is equal to 6 meter thickness, t is equal to 0.61 meter and the length is equal to L 50 meter and slope angle degree is beta is 8.

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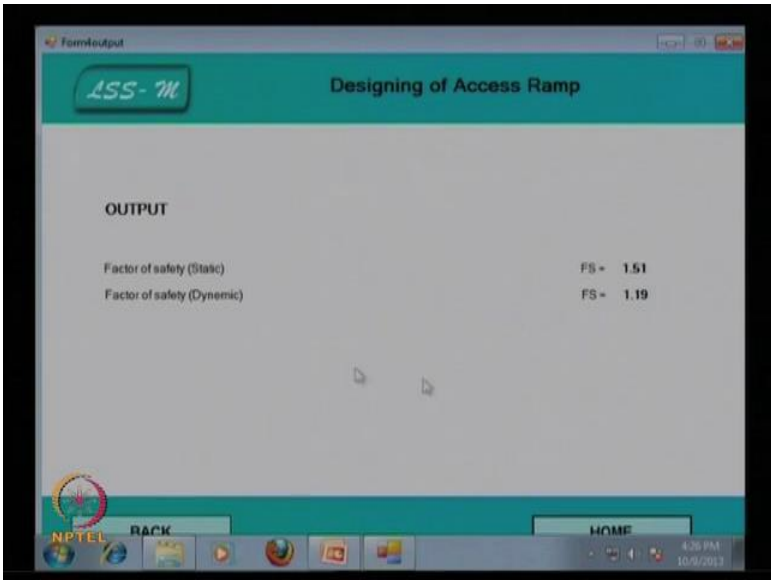

So, if you can calculate this, then you can determine factor of safety in the static condition 1.51, factor of safety in dynamic condition 1.19. So, this is the design for the landfill access, one design for the landfill access too.

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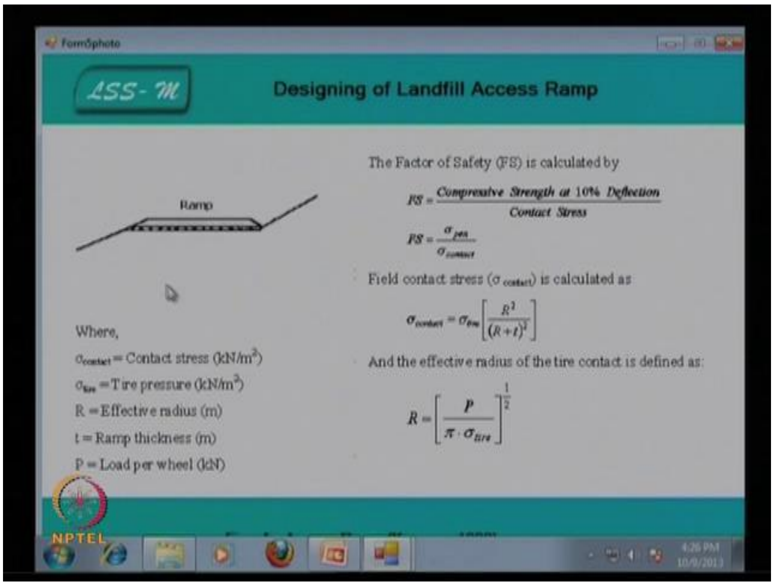

So, it may ramp like this, so these are the equation has been used.

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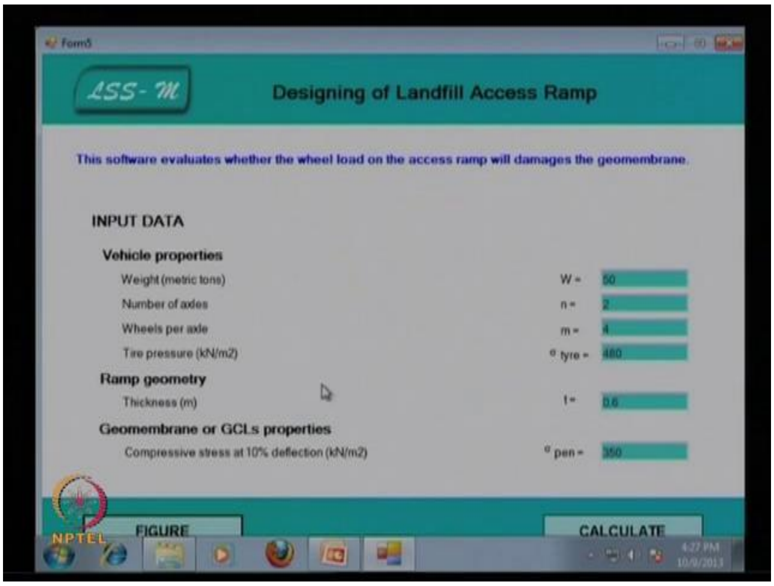

The input data vehicle property, that weight w is 50 metric tons, the number of axis is 2 and that is wheel per axle m is equal to the 4 and this is the this is the tire pressure. The sigma tire pressure is equal to 480 kilo Newton per meter square. Then ramp geometry that is thickness is equal to 0.6 meter and geomembrane and GCL property sigma of geomembrane is 350 kilo Newton per meter cube.

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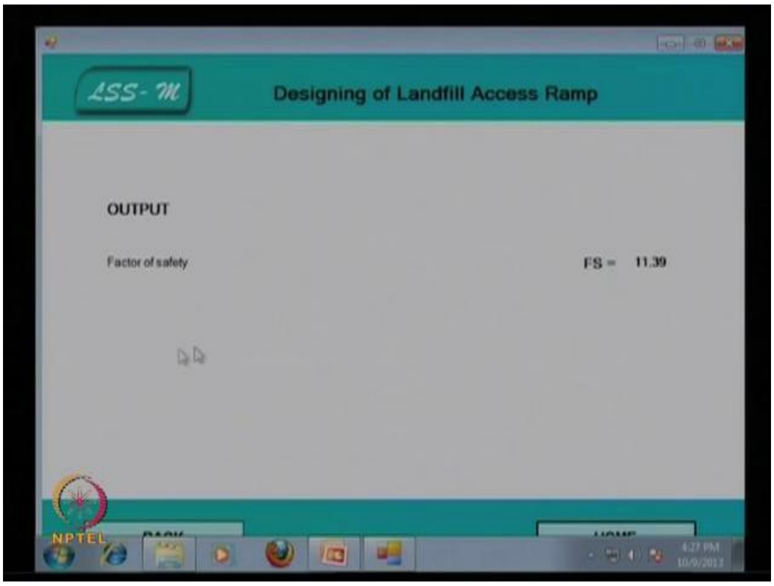

So, if you can calculate what will be the factor of safety, this is 11.39, so it is the same. So, leakage rate through the composite liner, so leakage rate through the composite liner.

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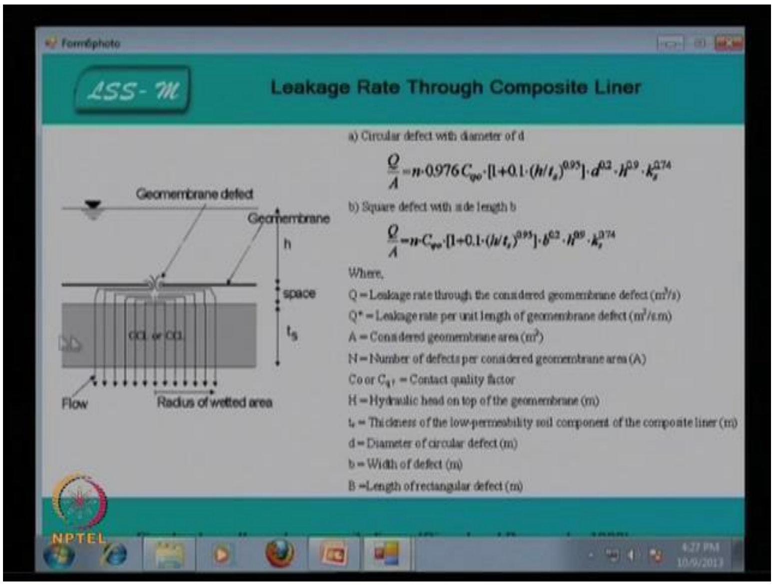

So, there is a leakage, this is the geomambrane material and then how you can see that how leakage is occurred. So, leakage rate through the geocomposite liner, so you have used this equation.

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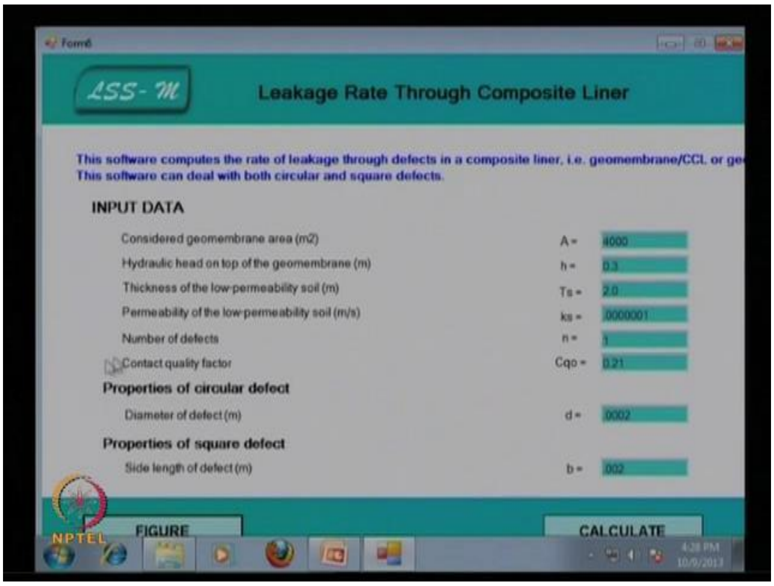

Then, we put that considered of the geomembrane area that is A is equal to 4000 meter square, hydraulic heat on the top of the geomambrane h is equal to 0.3 meter, thickness of the low permeability soil that is T s is 2 meter. The permeability of the lower permiability soil K s is equal to this value meter per second, number of the defect. Let us say, is equal to 1 and the contact quality factor that is C q o is 0.21 and properties of the cicular defect, that is diameter of the defect D is equal to 0.002 meter. Properties of the square defect is that means side length defect, that is b is equal to 0.002 meter.

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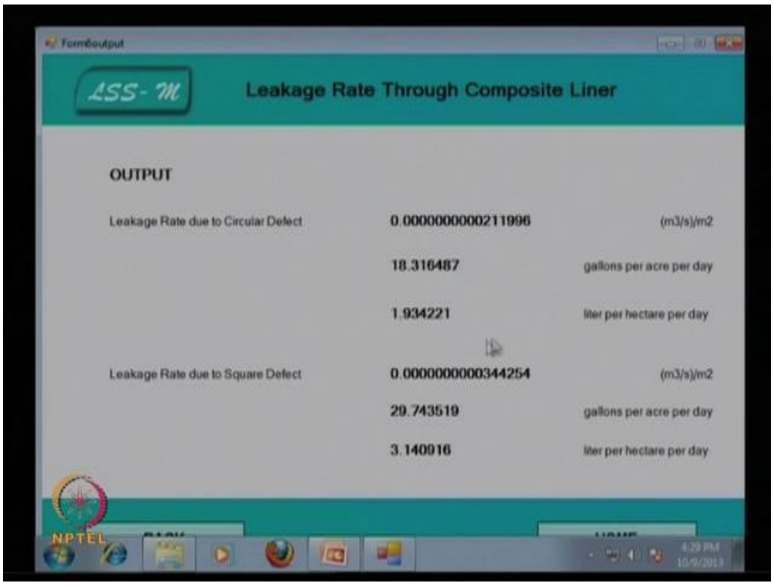

So, if you can calculate, so you can have the output what will be the leakage rate due to the circular. So, you can obtain this value this gallon per or this litre per per day 1.934 litre per day. Leakage due to the square defect then 3.10494 litre per hectare per day. So, next is drainage designing with the access ramp, so drainage design with the access ramp.

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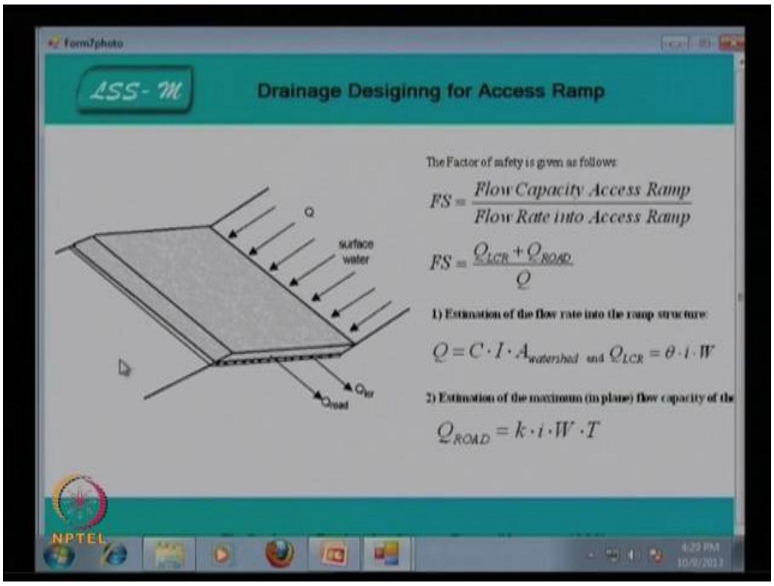

So, this is the drainage design for the access ramp this is the equation has been used and this is the input data.

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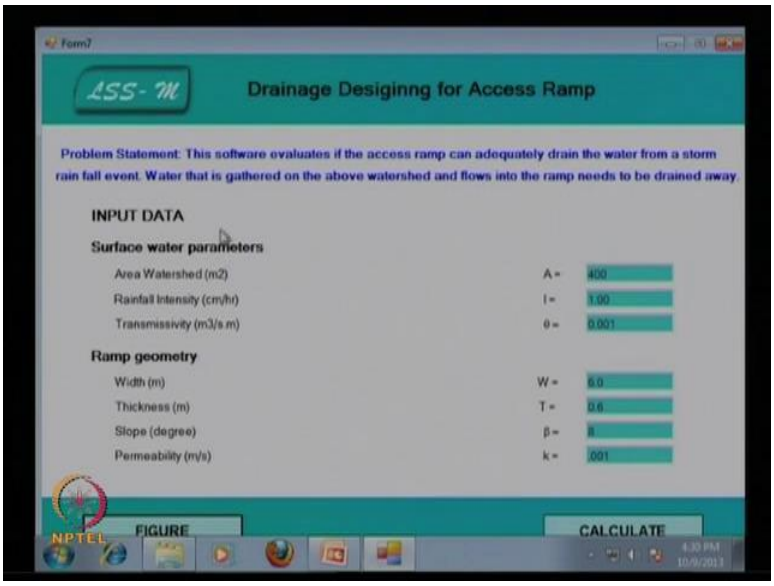

Surface water parameter area of the water A is 400 meter square rainfall intensity is 1.0 centimter per year. The transmittivity theta is 0.001 meter per cube per. This is ramp property that is width is equal to 6.0 meter, thickness is equal to 0.6 meter, slope is equal to 8 and the permeability k is equal to 0.001 meter per second.

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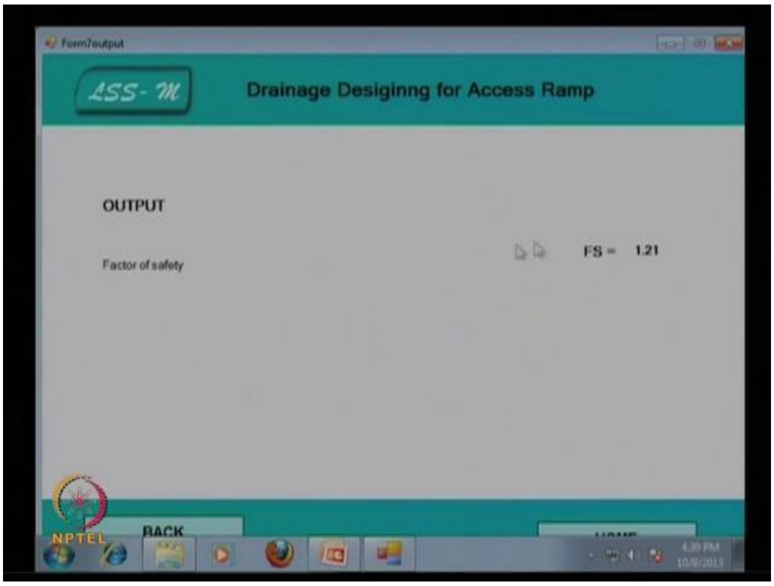

This is the output data F s is equal to 1.21, so it is safe. Now, this geometric puncture protection, so geometric puncture protection.

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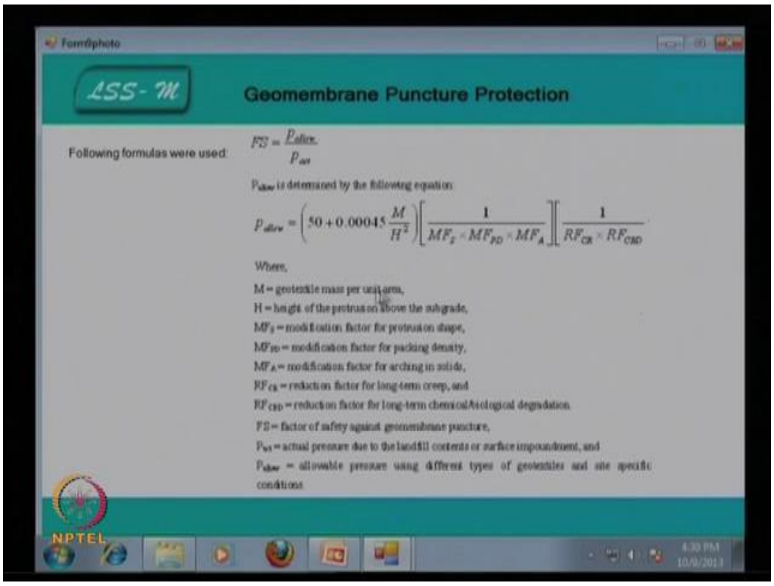

So, if there is a puncture geometric puncture protection, so this is equation has been used.

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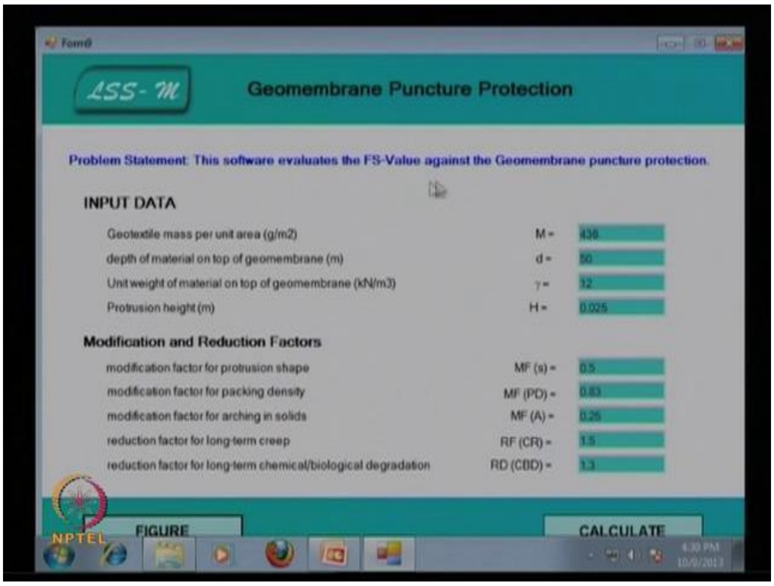

This is the input data geotextile mass per unit area is 430 gram per meter square, depth of the material on the top of the geomembrane d is equal to 50 meter. The unit weight of the mass on the top of the gamma is 12 kilo Newton per meter cube and protrusion length this H is equal to 0.025 meter. This is the modified reduction factor this is M f is 0.5 M F P D, that is modification factor for the packing density is 0.83, modification factor for arching solidified M a a is 0.05. This is modification factor for long term creep RFC r is 1.5 and this is the redution factor for chemical and biological clogging, that is 1.3.

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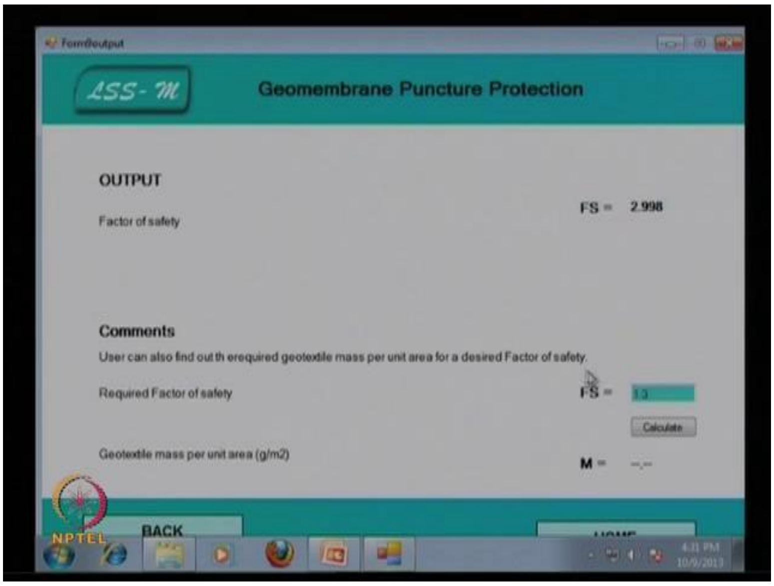

So, if you can calculate you can have the output data factor of safety 2.998, so comment that we can also find out what will be the required geotextile mass per unit area desired for the factor of safety. Required factor of safety F s is equal to 1.3 and you can also you can also calculate, you can determine that mass per unit area is 455.988 gram per meter square, so you can determine what will be the mass per unit area. Now, then design of the lateral drainage layer of the two composite slope.

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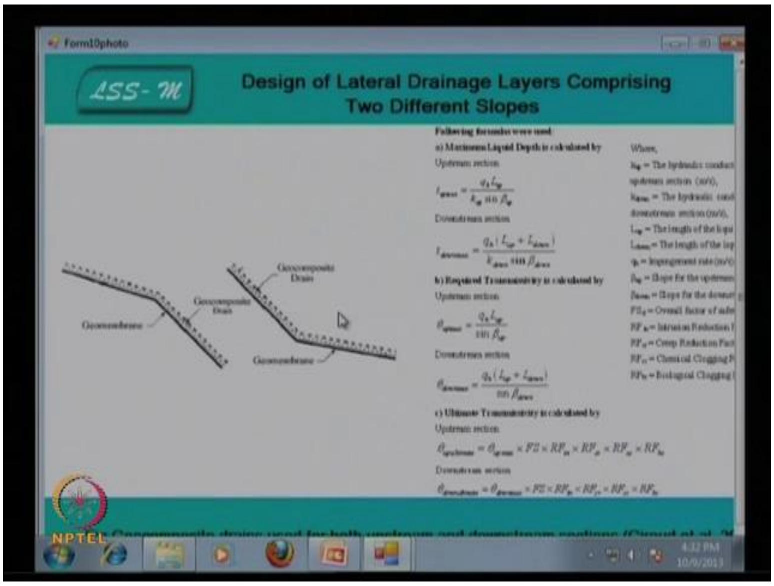

So, this is the two composite slope, this equation has been this equation has been used.

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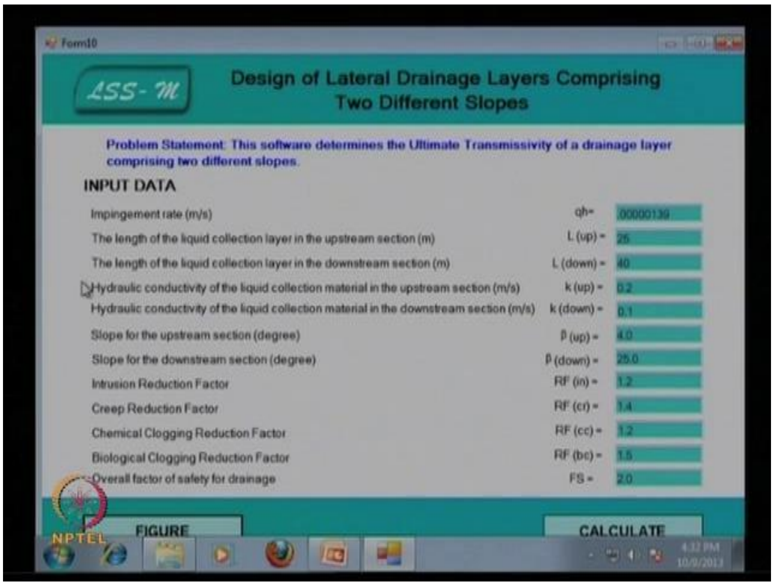

This input data is given impingement that rate, that value and L is equal to 26, this L down is 40, k is equal to 0.2, k down is 0.1, beta is equal to 4.0 and beta down is equal to 2.4, this is all the redution factor you calculate.

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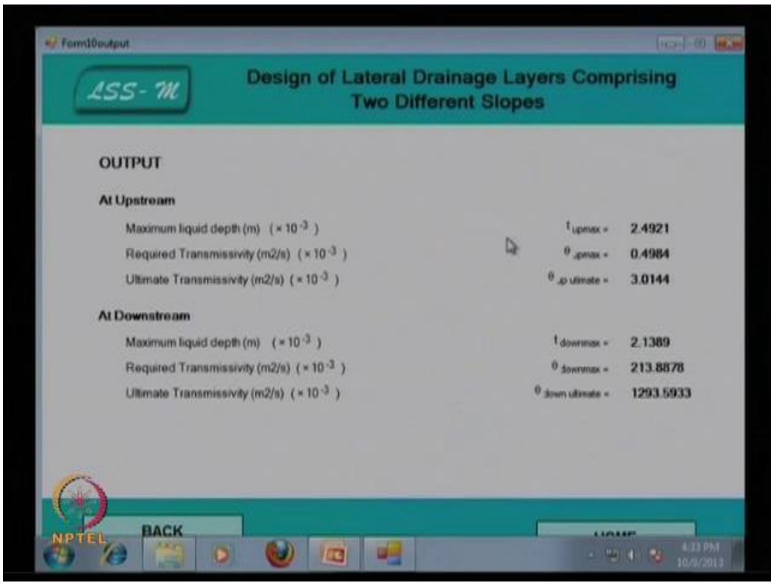

You can have what is at upstream, what is at the downstream, so you can obtain this value ultimately. You will have that what will be the required transmittivity value and what will be the ultimate transmittivity value in the upstream. Also in the downstream, you can calculate what will be the maximum liquid depth what should be the required transmittivity and what will be the ultimate transmitivity. So, this also you can calculate from this software, also the design of drainage layer for the two different slope this I mention transmittivity equivalency of geosynthetic drain and the soil liner.

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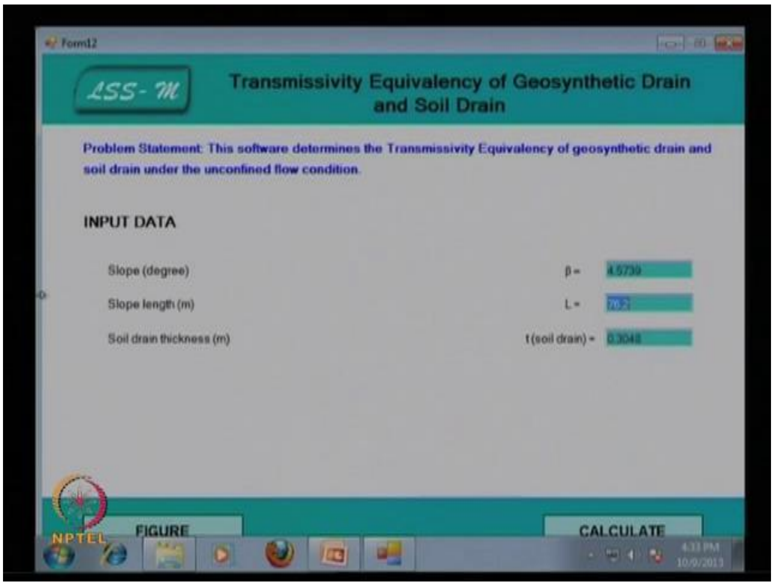

So, this is the transmittivity equivalency of geosynthetics drainage soil, this slope angle beta is 4.75. This slope length this L 20.2 and the soil drain thickness, so this is the equation has been used.

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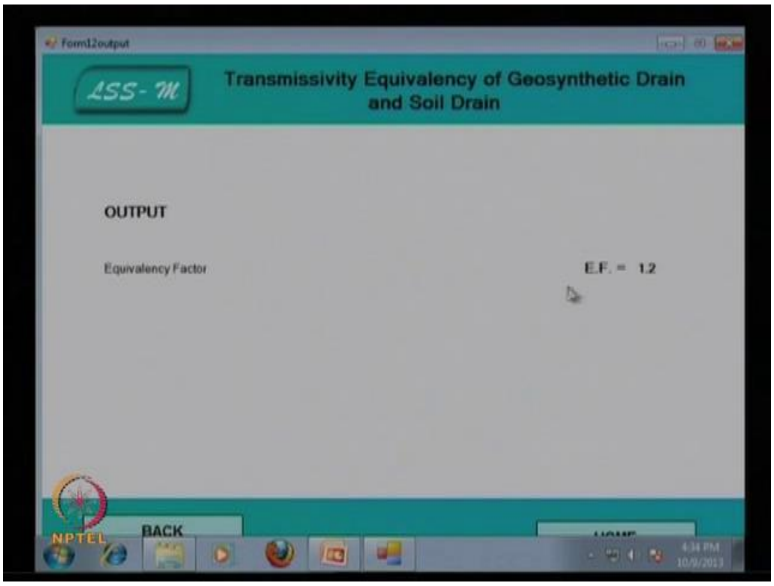

Then, you calculate the equivalency factor is 1.2 and then the landfill gas pressure relief layer. It is also require, so you can provide with the gas presure relieve layer.

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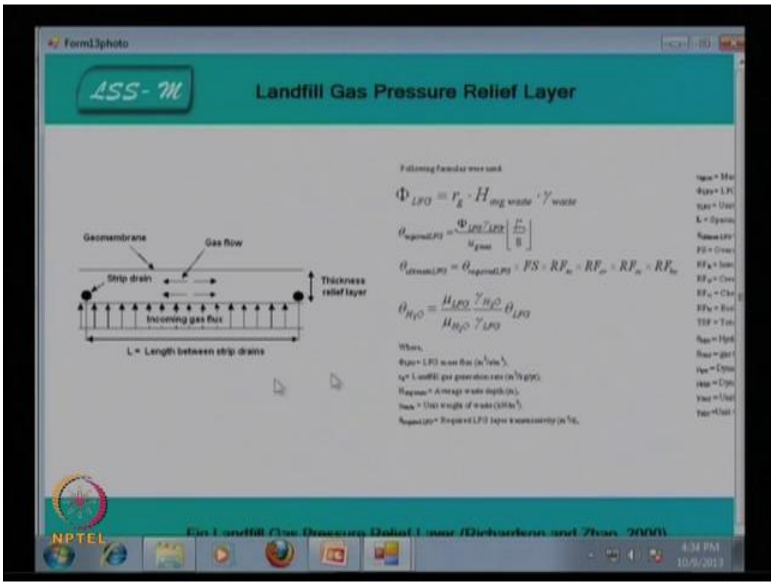

So, here is the liquid landfill gas pressure relieve layer, so this is the equation has been used.

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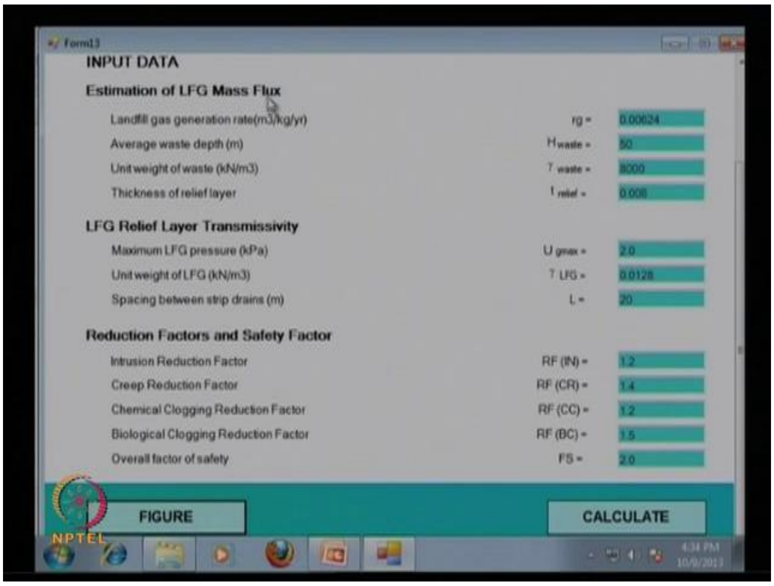

This is the estimated LFG mass flux, this is landfill gas generation that is 0.00024, that is the unit meter cube per k g per year. Average waste, that is h waste is equal to 50 meter, unit weight of the waste gamma is equal to 8 thousand that is kilonewton per meter cube.

Thickness of the relief weight T relief is 0.008 and the LFG relief layer, transmittivity value that is the maxmium LFG pressure U is upper 2 kilo Pascal unit weight of LG that is gamma U l g is 0.012 kilo Newton per meter cube. Spacing between the steep drain that is L is equal to 20 meter and these are all the reduction factor for intrusion for the creep for the chemical clogging. The reduction is biological clogging and overall factor of safety that is 1.2, 1.4, 1.2, 1.5 and then 2.0.

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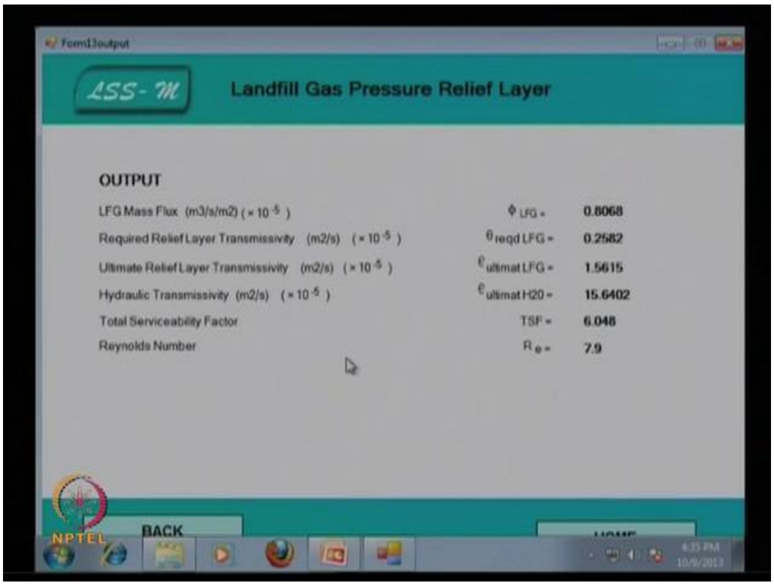

So, the landfill output gas pressure relief, you can have that mass flux phi U g is 0.8068, this is the theta required L f g is 0.82582 and this is the epsilon ultimate L f g is 1.5615 and epsilon ultimate is equal to 15.640. This is the total serviceability factor T s f is 6.068 and the reynold number is equal to 7.9 geocomposite gas pressure relief layer.

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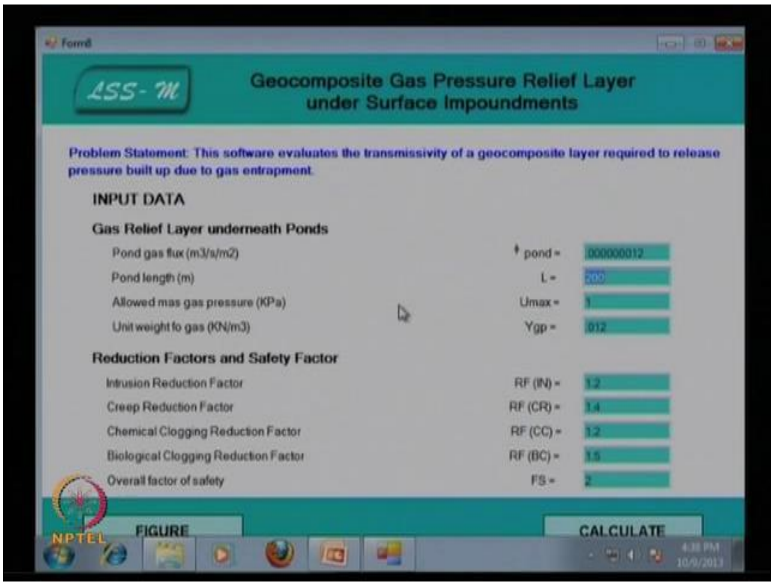

So, this is the problem statement that software evaluate the transmittivity of geocomposite layer required to release the pressure built up due to gas.

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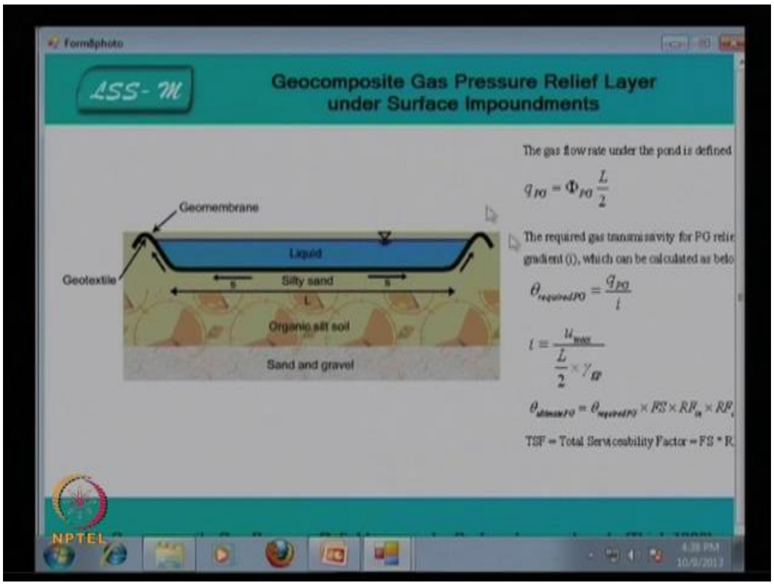

Now, here that this is the geocomposite gas pressure relief layer under the surface impoundment and this is the equation has been used in this program.

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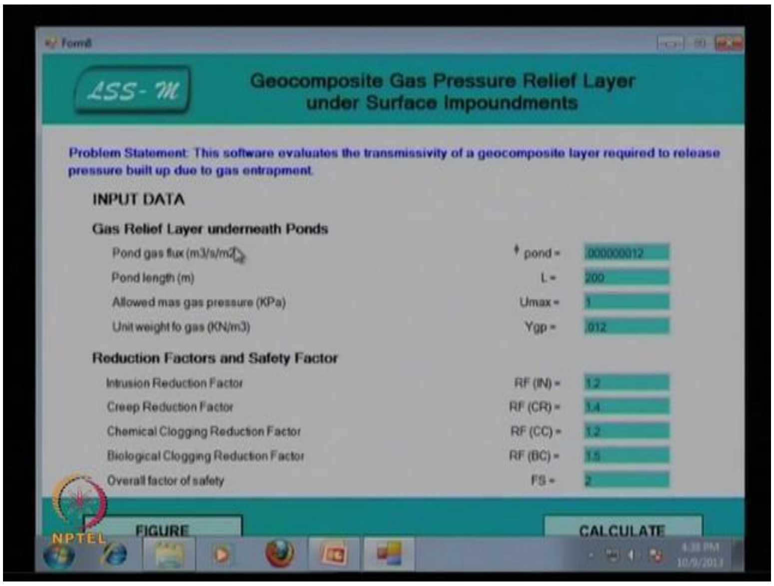

Now, input data gas relief layer underneath pond that is pond gas flux that is phi pond is equal to this meter cube per second per meter square and point length L is 200 meter, allowable mass gas pressure, U maximum is equal to 3. Unit weight of gas gamma g is 0.12 kilo Newton per meter. And this is the reduction factor for the intrusion reduction factor, then creep reduction factor, chemical clogging reduction factor, this is biological clogging reduction factor and this is overall factor of safety. So, this is 1.2, 1.4,1.2,1.5 and then 2.

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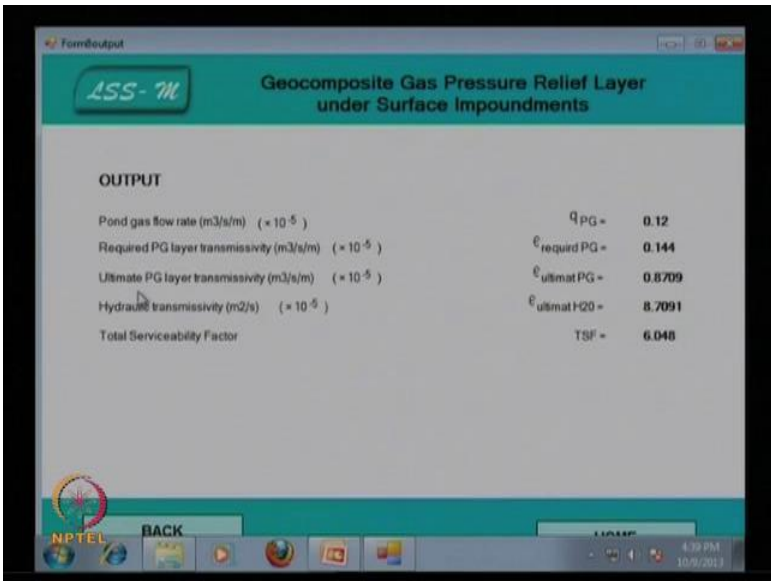

So, we can calculate and you can have the output, that is pond gas flow rate that will be that Q p g is 0.12 10 to the power minus 5 meter cube per second per meter. Required P G layer transmittivity, that is theta required PG is 0.144 10 to the power minus 5 meter cube per second per meter. Then ultimate P G layer transmittivity meter cube per second meter into 10 to the power minus 5 is 0.8709.

The hydraulic transmittivity into 10 to the power minus 5, this meter square per second, that is theta is 8.7091 and total serviceability factor T s f is equal to 6.048. So, you can go all this detail about the program and can design the thoroughly. So, you require the proper kind of the design of the landfill using this software. With this, I finish my lecture today, let us hear from you, any question.

Thanks for listening.