Geosynthetics Engineering: In Theory and Practices
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Lecture - 54
Design of Geosynthetics for Landfills

Dear student, warm welcome to NPTEL phase 2 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. This is module 12 and lecture number 54, design of geosynthetics for landfill.

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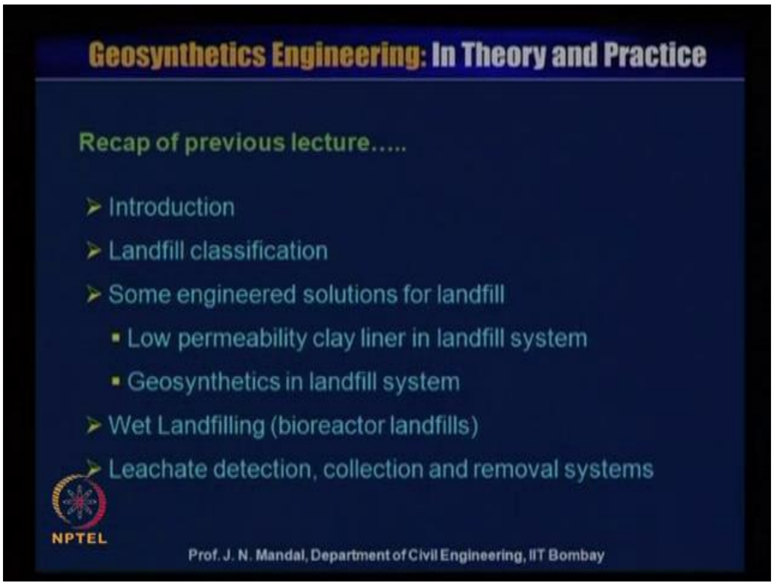

I will now show you the recap of the previous lecture which we have covered, that is introduction, landfill classification, some engineered solution for landfill, low permeability clay liner in a landfill system, geosynthetics in landfill system, wet land filling bioreactor landfill, leachate detection, collection and removal system.

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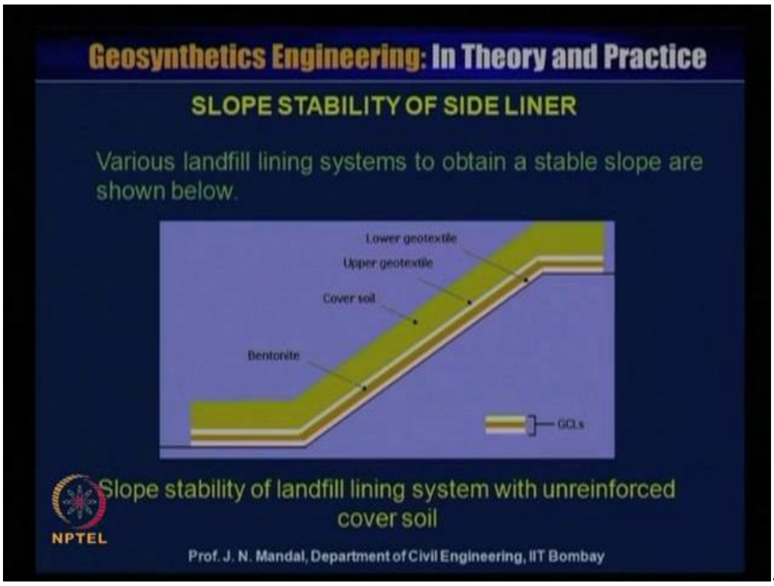

Now, I will address the slope stability of side liner. You know that design of the stability of the soil mass beneath the liner system of any solid waste landfill has been carried out. You can see here the slope and this is the geosynthetics clay liner or you can give the geomembrane, which consist of a lower geotextile and this bentonite and then upper geotextile and then you are providing with the cover soil alternative to this geosynthetics clay liner. We can also provide with geomembrane material this various landfill lining system to obtain a stable slope.

So, we want to achieve a stable slope. So, this is a slope stability of landfill lining system with unreinforced cover soil and you also require number of the layer of the reinforcement that what you call the multiline side slope cover soil slope stability. This situation of the liner also means, that there is a provision of providing the leachate collection along this slope where you may require any geocomposite material or the geonet material.

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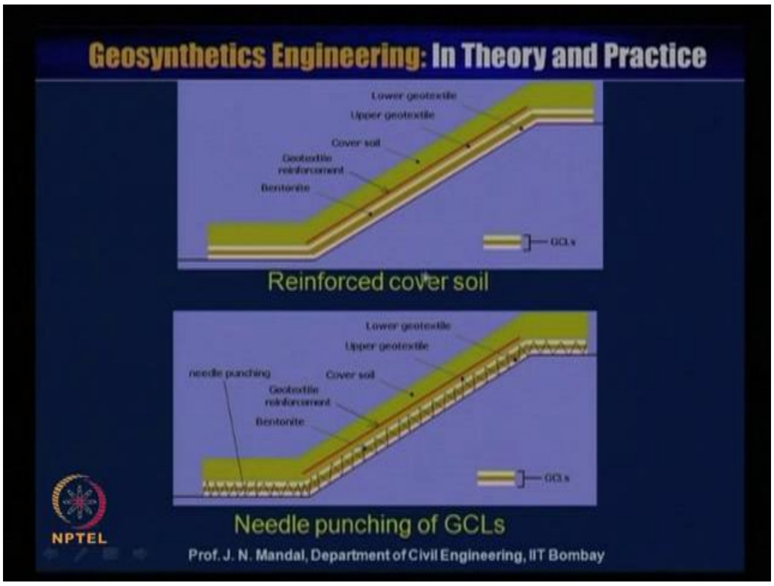

So, here also shown the reinforced cover soil apart from the geomembrane or geosynthetics clay liner. You can provide with the reinforcement to make a proper slope. You can make any steeper slope or the angle as you like it. So, you can provide sometimes the geosynthetic clay liner also the geomembrane also the geonet. This is all combination of the geosynthetics material.

So, what will happen that if we provide the multilayer of the geosynthetics reinforcement and there is a possibility to induce the shear stresses through this system so this is the challenging each of the interface layer and that are in this cross section. Now, if all the interface shear strength are greater than the slope angle. This slope angle stability is achieved and deformation involved will be the small.

On the other hand if the interface shear stresses are lower than the slope angle then it is required that wide width tensile stresses are induced with the overlying geosynthetics material. There may cause of the failure of the geosynthetics or for the pullout failure also along the anchor trench or the tensile reinforcement. So, here different layer of the geosynthetics clay liner or geomembrane or GCL which is made of the needle punches of GCL also has been provided.

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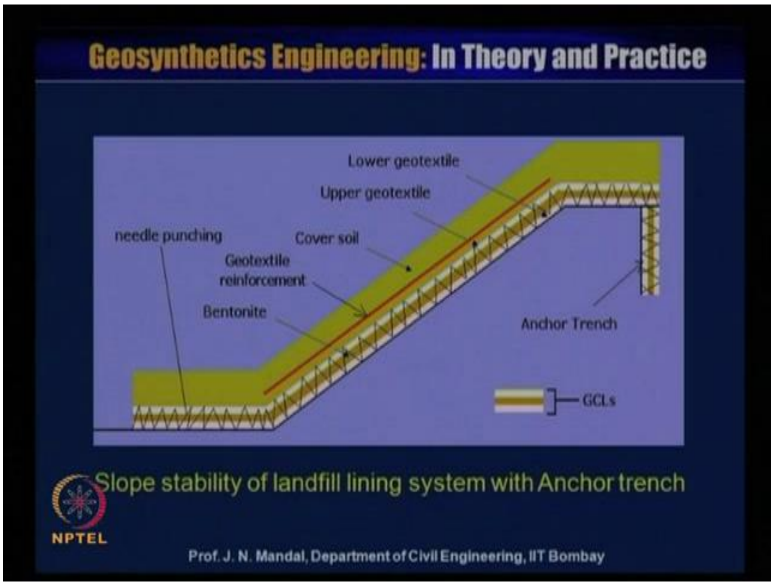

Now, sometimes also you require for slope stability of the landfill liner system, you require some anchor so there are different types of the anchor. It may be you can step forward, you can put some anchoring digging and can put the anchor trench, where you can place this geogrid or geosynthetic clay liner like this or you can make a rectangular shape or you can make a v shape anchor to make the soil much more stable. So, if sometimes it is also require that anchoring system to make the slope more stable.

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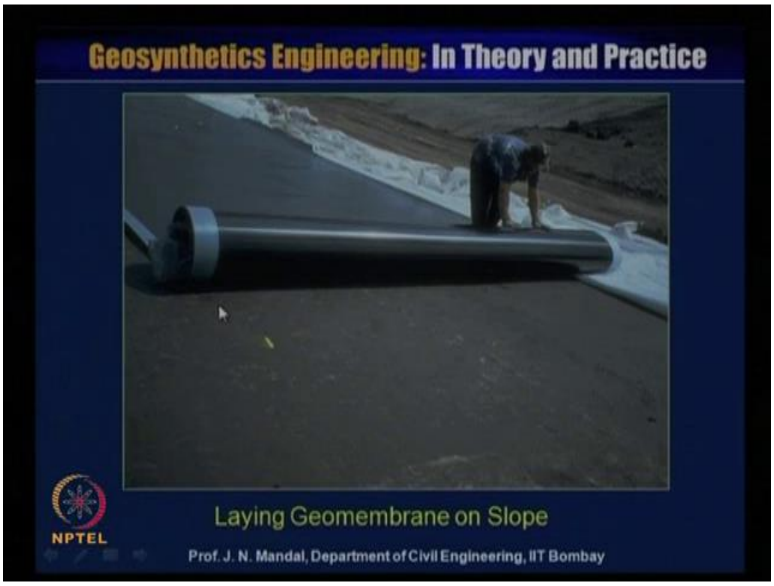

So, this is one side source that lining of the geomembrane on the slope. This is the geomembrane that black colour and how you have to line that it is in the form of the roll and then you can spread along the slope.

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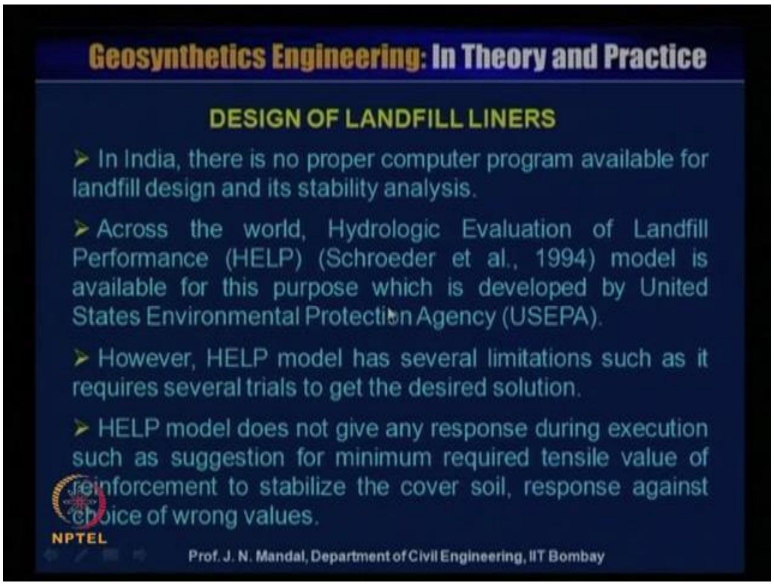

We are more interested here the design of the landfill liner. How can we design the most of the cases? We provide with something that thickness of the geomembrane or geosynthetics clay liner and they are introduced into the landfill in many project but one has to be very careful there are many, many issue which are need to be addressed for the design of the landfill liner.

In India there is no proper computer program available for landfill design and its stability analysis. Across the world, Hydrologic Evaluation of the Landfill Performance which is HELP that is Schroeder et al., 1994 model is available for this purpose which is developed by United State Environmental Protection Agency or USEPA. However, HELP model has several limitation, such as it requires several trial to get the desired solution. HELP model does not give any response during execution such as suggestion for minimum required tensile value of reinforcement to stabilize the cover soil response against the choice of wrong values.

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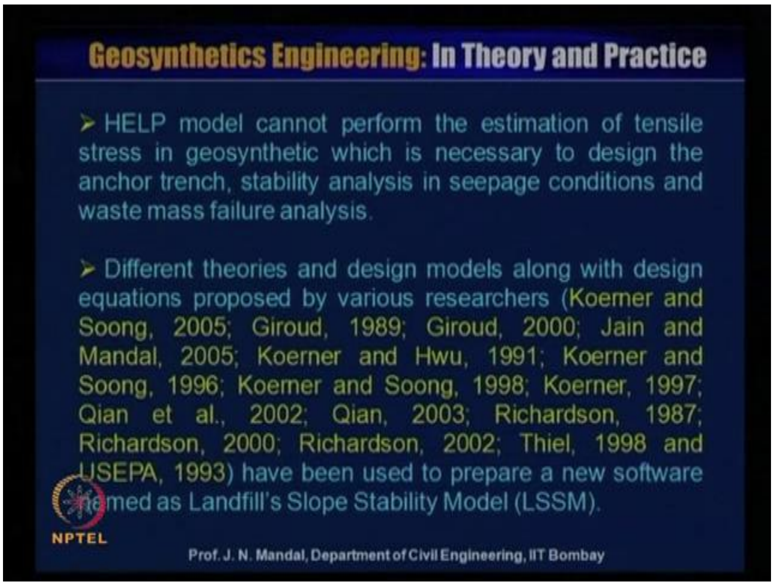

HELP model cannot perform the estimation of tensile stress in geosynthetics, which is necessary to design the anchor trench stability analysis in seepage condition and waste mass failure analysis. Sometime also in the landfill it has been observed the waste mass itself is failure.

So, this is require how to design that. So, based on that we have developed a program which we will show you how we can design all those issues. So, different theories and design model along with the design equation proposed by the various researcher Koerner and Soong 2005, Giroud 1989, Giroud 2000, Jain and Mandal 2005, Koerner and Hwu 1991, Koerner and Soong 1996, Koerner and Soong 1998, Koerner 1997, Qian et al 2002, Qian 2003, Richardson 1987, Richardson 2000, Richardson 2002 and Thiel 1998 and USEPA 1993 have been used to prepare a new software named as landfill slope stability model which we call the LSS model, IIT Bombay.

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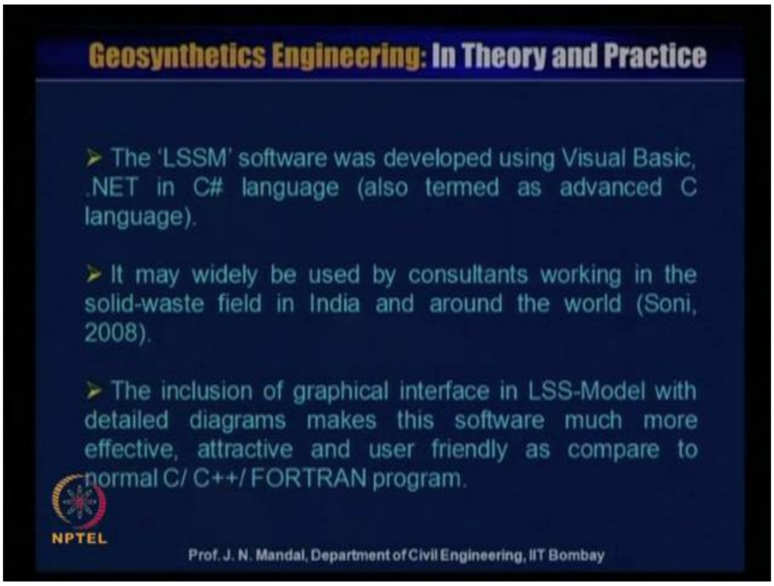

So, this LSSM software was developed using visual basic net in c sharp language also termed as advance c language. It may widely be used by consultant working in the solid waste field in India and around the world, Soni 2008. The inclusion of graphical interface in LSS model with detailed diagram makes this software much more effective attractive and user friendly as compared to normal c or c plus plus or fortran program.

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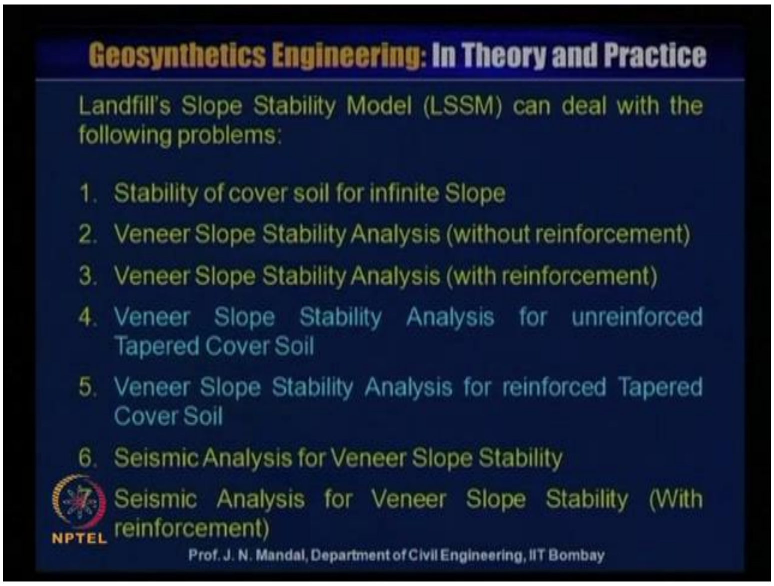

The landfill slope stability model LSSM can deal with the following problem. So, I am showing some of the problem. Here I can show you more problem in our program that is landfill slope stability model. 1 stability of cover soil for infinite slope. 2. veneer slope stability analysis without reinforcement. 3. veneer slope stability analysis with reinforcement. 4. veneer slope stability analysis for unreinforced tapered covered soil. 5. veneer slope stability analysis for reinforced tapered covered soil. 6. seismic analysis for veneer slope stability. 7 seismic analysis for veneer slope stability with reinforcement eight seepage force analysis for veneer slope stability.

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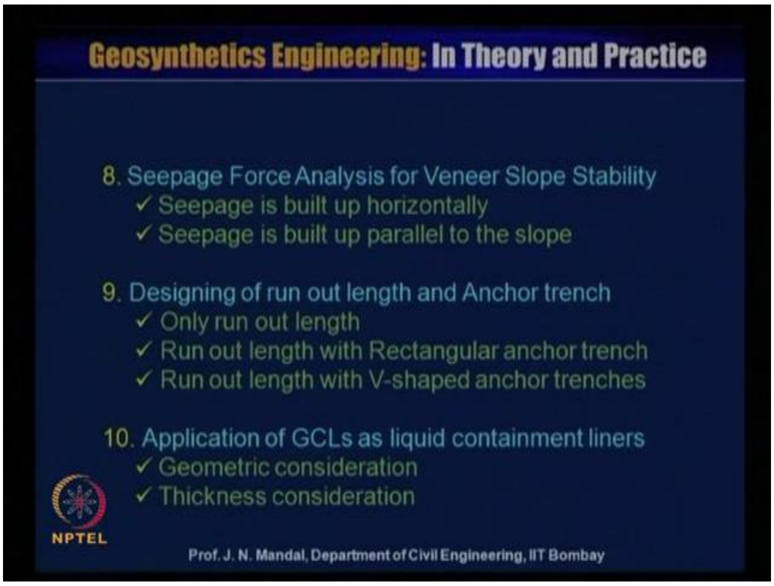

That is seepage is build up horizontally or seepage is build up parallel to the slope nine designing of run out length and anchorage trench. Only run out length, run out length with the rectangular anchor trench or run out length with the v shaped anchor trenches. 10 application of geosynthetics clay liner or geomembrane liquid containment liner that is geometric consideration and thickness consideration, so I will show you that some of the when that stability of cover soil for infinite slope.

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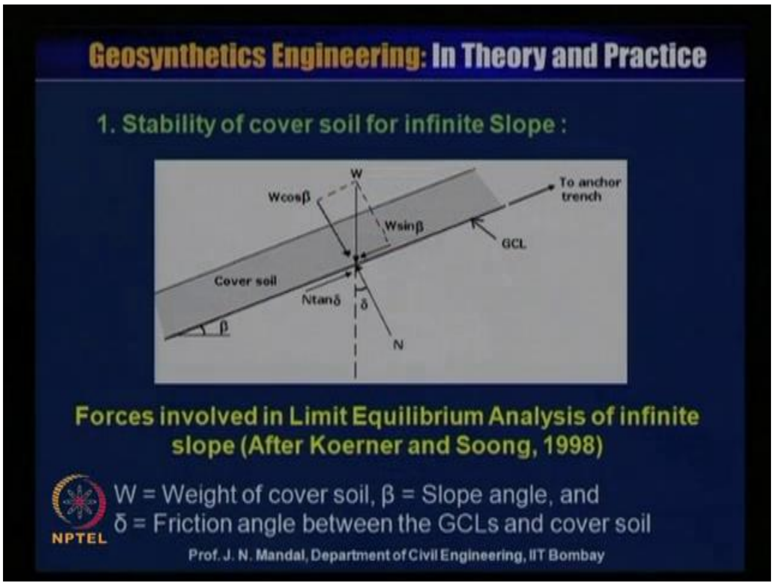

Here you can see that what are the forces involved in limit equilibrium analysis of infinite slope, This is after Koerner and Soong 1998. Here this w the weight of the cover soil and beta is the slope angle and this is the delta is the friction angle between the geosynthetics clay liner and the cover soil. So, this cover soil has a thickness and also this is the geosynthetic clay liner or geomembrane.

This is like a anchor trench and this w as a to component horizontal component will be sine beta and vertical component is w cos beta and n is the normal which is acting along this slope on GCL. And so this force resisting force would be N into tan of delta N into tan of delta, where delta is equal to friction angle between the geosynthetics clay liner and the cover soil.

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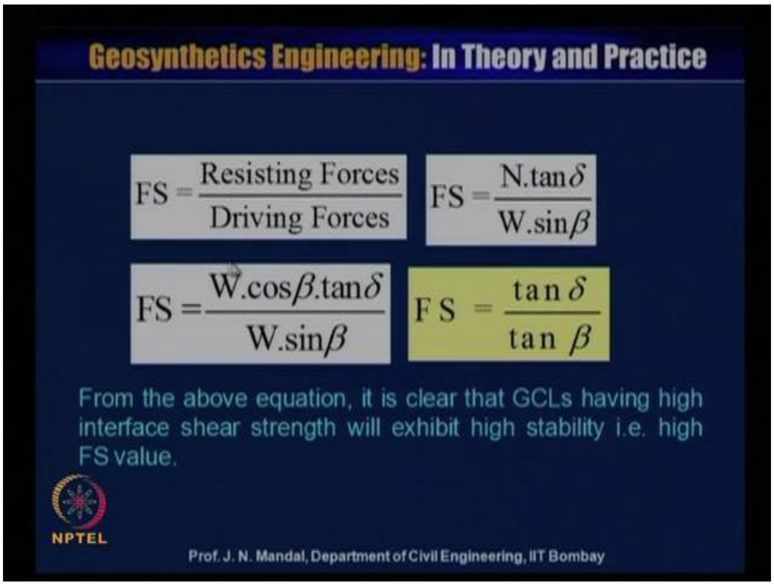

So, we can calculate the what will be the factor of safety. Factor of safety will be the resisting forces divided by driving forces, That means the resisting forces is N tan delta. So, this is the resisting force acting along this slope. So, this is N tan delta. So, that is why this is N tan delta divided by driving force. Driving force is this, that is W of sin beta. This is driving force, this is acting is downwards along the slope so we can write that factor of safety is equal to N tan delta divided by W sin beta.

Now, again what is N? So, N is this W of cos beta. This N is W of cos beta. So, you can write N is equal to W cos beta. So, W cos beta into tan delta divided by W sin beta. So, ultimately you will obtain factor of safety FS will be equal to tan delta divided by tan of beta. From the above equation it is clear that geosynthetic clay liner or the geomembrane having high interface shear strength will exhibit high stability that is high factor of safety value. Now, I will give one example design example of stability of cover soil for infinite slope.

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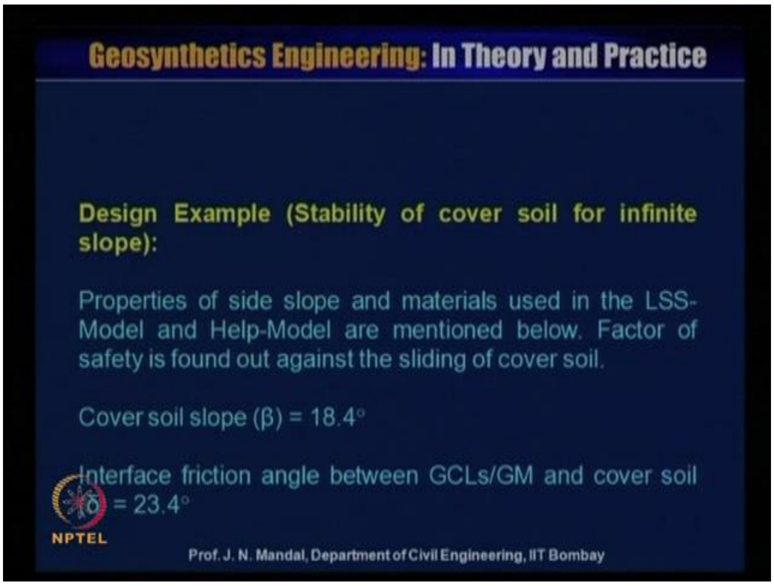

Now, property of the side slope and the material used in the LSS model that is landfill slope stability model and the help model are mentioned below. Factor of safety is found out against the sliding of cover soil and cover soil slope angle beta is equal to 18.4 degree. Interface friction angle between the geosynthetic clay liner or geomembrane and cover soil that is delta is equal to 23.4 degree.

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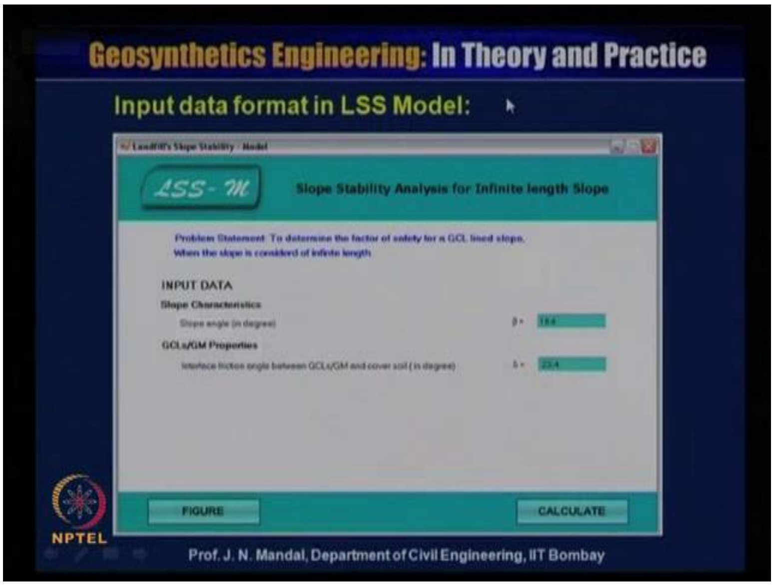

So, this is the input data of the format in the landfill slope stability model and this is slope stability analysis for infinite length slope. Now, this problem statement to determine the factor of safety for a geosynthetics clay liner or geomembrane line slope within the slope is considered in infinite length. Now, you have to put the properties. What should be the input data?

So, input data will be the what will be the slope characteristics, that means what will be the slope angle in degree. Here slope angle beta in degree will be equal to 18.4. So, then what will be the geosynthetics clay liner or the geomembrane property that means what should be the interface frictional angle between the geosynthetics clay liner or geomembrane and the cover soil and that is delta is equal to 23.4 degree.

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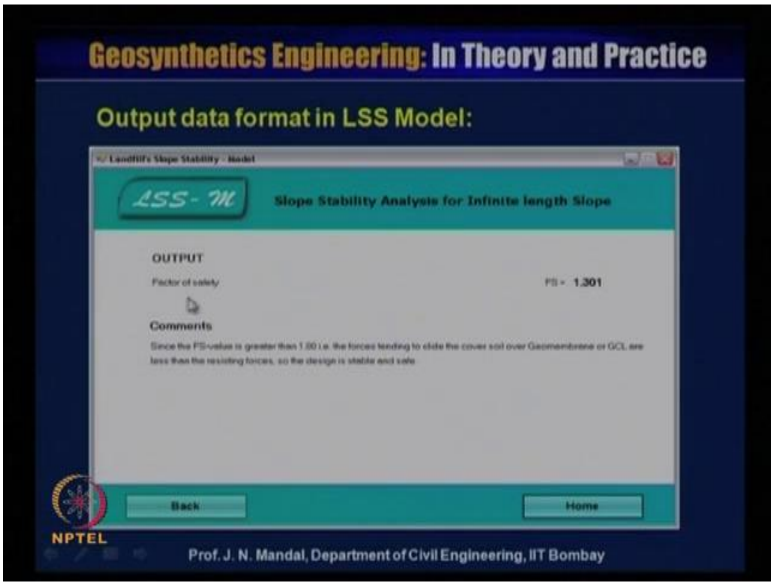

Now, you have to input this data into this model and then you calculate and then you can have the what will be the output, you can see the factor of safety is equal to FS 1.301. So, you can make a comment that since the factor of safety value is greater than 1.00 that is the force tending to slide the cover soil then over the geomembrane or geosynthetics clay liner are less than the resisting forces.

So, the design is stable and safe. So, we see that if this model you can just put the properties of the soil and the properties of the geosynthetics clay liner or geomembrane material. And then you can determine that what will be the factor of safety, so that way you can find out the slope stability analysis.

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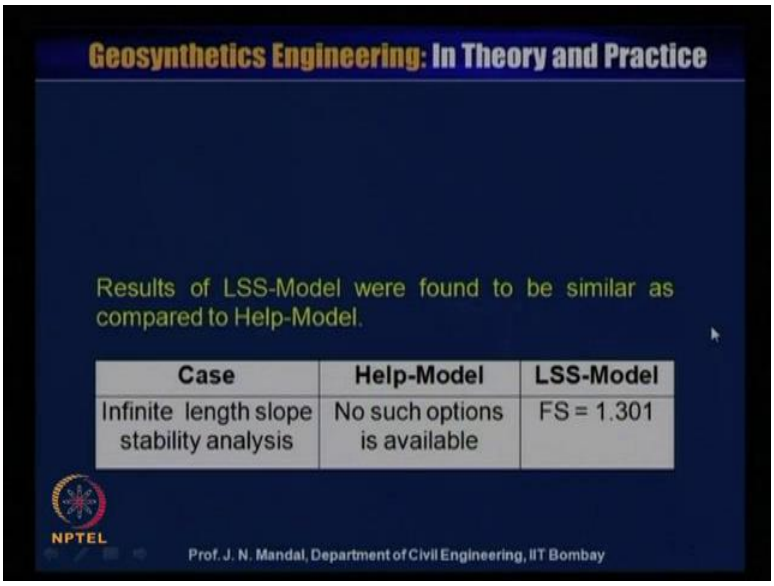

Here result for LSS model was found to be similar as compared to the HELP model. So, case with the infinite length slope stability analysis help model, no such option is available more or less that landfill slope stability model, which give factor of safety is equal to 1.301. So, it is a safe.

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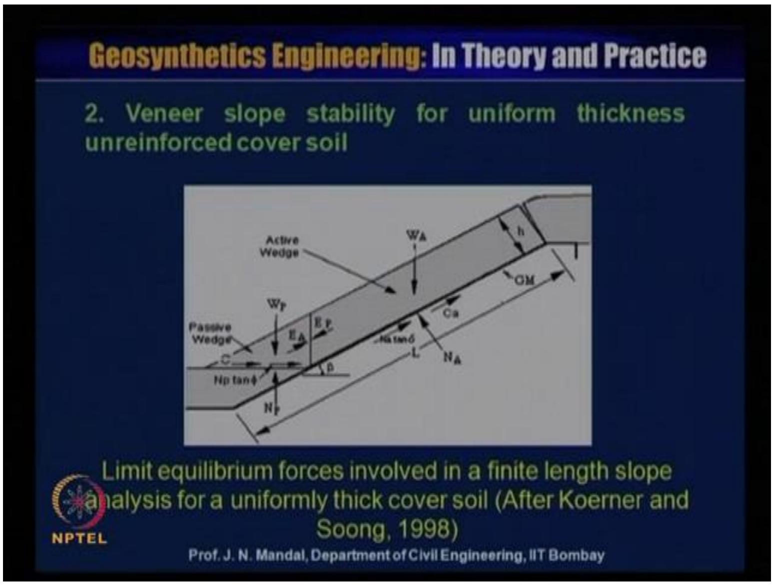

Next, 2 the veneer slope stability for uniform thickness unreinforced cover soil. So, there is no reinforcement and this is the slope and this is limit equilibrium forces involved in a finite length slope analysis for a uniformly thick cover soil, this after Koerner and Soong

1998. This is the thickness h is equal to thickness of the cover soil and this is the length of the slope of cover soil that is l and this is the active zone. So, this is the cover soil which thickness is 8 and W h is the active wedge which is active in the active zone.

Whereas, here when the cover soil is slide down in this direction so there will be a passive wedge. So, W P is also the passive wedge which is active in this passive zone and there is the shearing resistance between this soil and which is the value of the phi shearing resistance of the soil is phi. So, there will be a N P which is acting vertically towards the passive wedge.

So, this shearing resistance will acting in this direction and that is what we call the N C tan of phi and there is a C, the cohesion value. Also, this is the C value cohesion in the passive wedge side and there is also a normal force that is the N A, which is acting along the slope and there is a shearing resistance between the cover soil and this sub grade soil and that you can say that delta.

So, this is delta is acting along this direction that is N of A into tan delta and there is also adhesion and that adhesion is the C of a and this is the geomembrane material. So, there will be the internal friction between the cover soil and the geomembrane and that is designated at delta and C a is the adhesion and apart from that there is a E of a that is inter wedge force acting on the active wedge from passive wedge. And similarly, this is the E of P which is inter wedge forces which is acting on passive wedge from the active wedge and that is in kilo Newton. So, these are the limit equilibrium forces are acting in finite length slope of uniformly thick cover soil.

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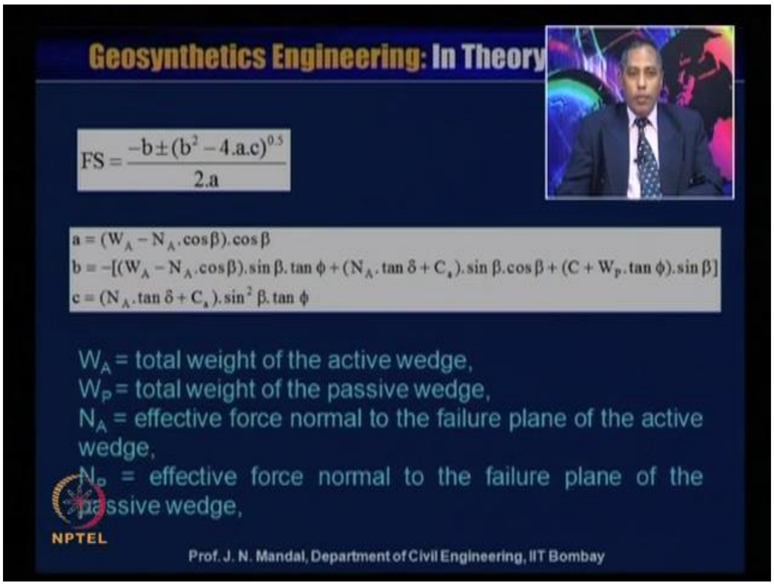

So, from this you can calculate what will be the factor of safety with this equation minus b plus minus b square minus four a c whole to the power 0.5 divided by two a, where a is equal to W A minus N A cos beta into cos beta. Hence b is equal to minus W A minus N A cos beta into sin beta into tan phi plus N A tan delta plus C a into sin beta into cos beta plus C plus W P tan phi into sin beta. And c is equal to N A tan delta plus C a into sin square beta into tan phi.

Where W A I told the total weight of the active wedge, here total weight of the active wedge. And W P total weight of the passive wedge, this W P total weight of the passive wedge and N A the effective force normal to the failure plane of the active wedge. This is the active wedge, N A normal force and also the N P is the effective force normal to the failure plane of the passive wedge, here N P.

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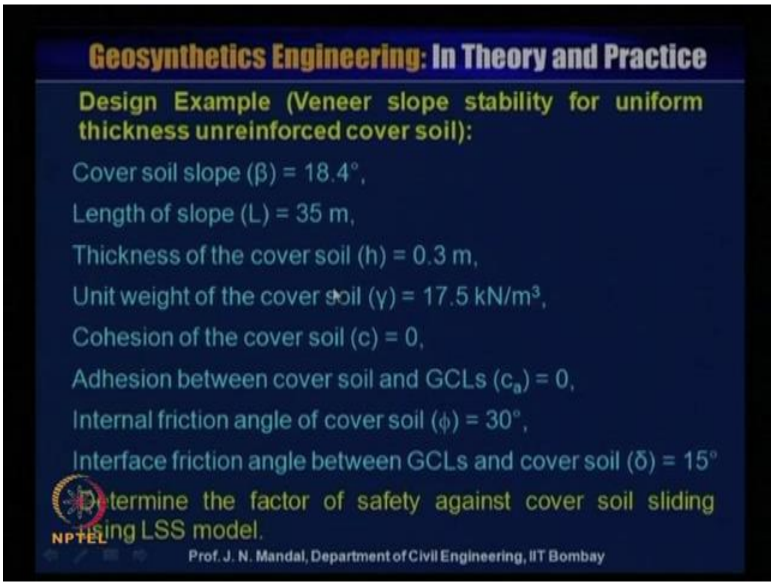

So, we will be knowing that all this value that is a, b and c and then you can calculate that what will be the factor of safety. Here I am giving one design example for veneer slope stability for uniform thickness unreinforced cover soil. Now, in the problem it is given cover soil slope beta is equal to 18.4 degree and length of the slope l is 35 meter, thickness of the cover soil that is h is equal to 0.3 meter, unit weight of cover soil gamma is 17.5 kilo Newton per meter cube and cohesion of the cover soil c is equal to 0.

Adhesion between the cover soil and the geosynthetics clay liner that is C a is equal to 0. Internal friction angle of cover soil phi is equal to 30 degree. So, interface friction angle between the geosynthetics clay liner and cover soil delta is equal to 15 degree. Now, determine the factor of safety against cover soil sliding using the landfill slope stability model.

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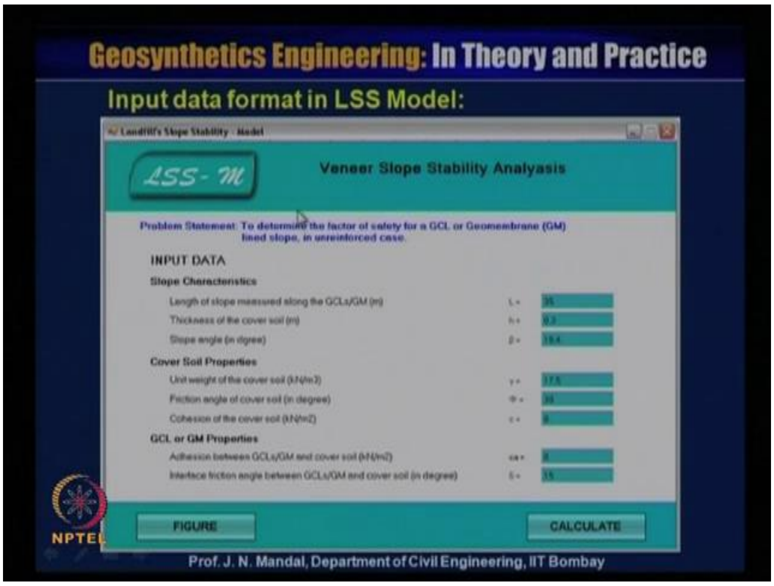

So, here is the input data format in the LSS model. This is veneer slope stability analysis. The problem statement that determine the factor of safety to a geosynthetic clay liner or the geomembrane line slope in unreinforced case. So, input data you have to put that what will be the slope characteristic, that means what will be the length of the slope measure along the geosynthetic clay liner or geomembrane, that is l is equal to 35 meter and thickness of the cover soil small h is equal to 0.3 meter and slope angle that is beta is equal to 18.4.

Now, cover soil have its own property. So, cover soil property is given unit weight of cover soil that is gamma is 17.5 kilo Newton per meter cube. Friction angle of cover soil delta phi is equal to 30 degree and cohesion of the cover soil that is c is equal to the 0, apart from this you have to provide with the properties of the geosynthetic clay liner and the geomembrane property.

So, adhesion between the geosynthetic clay liner and the geomembrane and the cover soil and that is C of a is equal to the 0 and interface friction angle between the geosynthetics clay liner or geomembrane and the cover soil is 15 degree. So, these are the input data are required for the veneer slope stability analysis. You have to provide with the what will be the characteristics of the slope what will be the characteristics of the cover soil and as well as what will be the characteristics of the geomembrane or geosynthetic clay liner and now you can calculate.

So, you can obtain the output that is weight of the active wedge W A is 178.496 kilo Newton and weight of the passive wedge that is W P is equal to 2.63 kilo Newton and inter wedge forces acting on the active wedge from the passive wedge that is of a is equal to 2.459 kilo Newton. And similarly, that inter wedge force acting on the passive wedge from the active wedge that is E of P is equal to 2.459 kilo Newton.

So, you calculate what will be the factor of safety then factor of safety FS is equal to 0.842. Now, what will be your comment since the factor of safety value here is less than 1. So, the forces tending to the slide the cover soil over geomembrane or the geosynthetic clay liner are more than the resisting forces so the design is not stable. In this case the sliding over the geosynthetic clay liner or the geomembrane is anticipated so user can use the following approach to make the design stable.

So, there is a three option, one option is they provide the tapered cover soil instead of the uniform thick cover soil. If yes you want to go for the tapered soil then you can also calculate and also you can find out what will be the factor of safety. I will show you in my program later on and b by providing the geotextile or the geogrid reinforcement along the slide slope because if we can provide with the geogrid reinforcement.

So, there will be the development of the shearing resistance between the cover soil and the geogrid material and that will improve also the stability factor then c by the slope geometric configuration you can alter the geometric configuration that is effect by decreasing the slope angle or by increasing the cover soil thickness and you can check that whether it satisfy the factor of safety or not. So, this way you can solve the problem.

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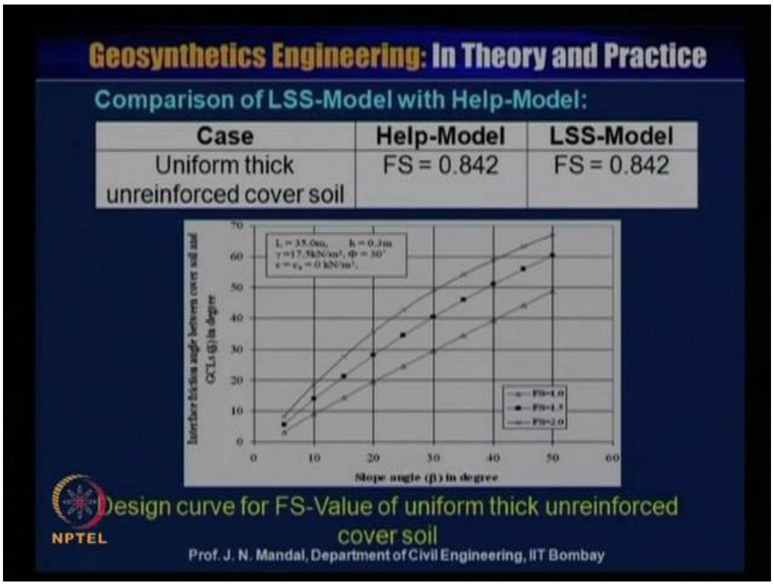

So, here some comparison of landfill slope stability model with the help model case uniform thick unreinforced cover soil that is with the help model factor of safety is equal to 0.842 and the landfill slope stability model factor of safety is 0.842. So, you can see that LSS model is satisfying with the help model that means it satisfy that criteria that means LSS model is now this is the design curve for the FS vale of uniform thick unreinforced cover soil.

So, this is the factor of safety value 1 factor of safety 1.5 and the 2 and this x axis is the slope angle. Beta in degree and this y axis is the interface friction angle between the cover soil and the geosynthetic clay liner delta in degree and this is the problem when l is equal to 35 meter, h is thickness of the cover soil is 0.3 meter and gamma unit weight of cover soil is 17.5 kilo Newton per meter cube, phi is equal to 30 degree and C a is equal to 0 kilo Newton per meter. So, you can obtain the curve like this for the different factor of safety.

So, if you know what will be the slope angle and what you require the factor of safety whether 1.51 or 2 then accordingly also you can, you will be knowing what will be the friction angle. That means, what friction angle you require or if you know that what will be the friction angle and also the slope angle then you can calculate what should be the factor of safety. So, if the factor of safety is reasonable so then accordingly you can select that what will be the slope angle and what will be the corresponding friction angle between the between the cover soil and the geosynthetics material. Three various slope stability for uniform thickness reinforced cover soil.

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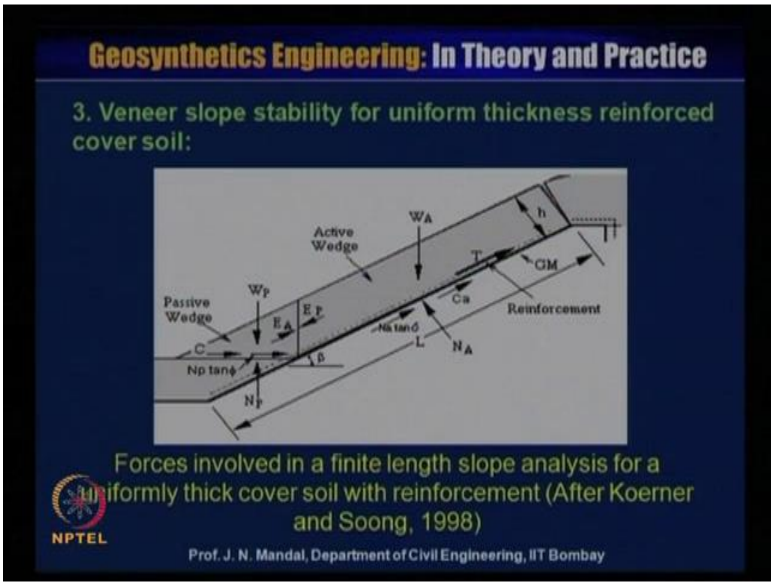

Now, in this slope the reinforcement is added. So, if this is the reinforcement here this dot is the reinforcement is here so this is the forces involved in a finite length slope analysis for a uniform thick cover soil with reinforcement. This is after Koerner and Soong 1998. So, again you know that this is W A weight of the wedge in the active zone and this is weight of the wedge in the passive zone and here the slope angle is beta and here is the development of the friction between the reinforcement and the cover soil and that is the delta and N A you know.

So, this will be N A into tan delta and this is the length of the slope that is l and this is the edge is the thickness of the cover soil and this is the geomembrane and this is the reinforcement which tensile strength value is, let us say is equal to T and there is also that what will be the inter wedge forces is acting that is E A.

And also E of P that is inter wedge, E A is inter wedge forces acting on the active wedge from the passive wedge. And this E P is the inter wedge on passive wedge from the active wedge and N A you know normal force in the active wedge and this N P normal force in the passive wedge. So, these are the forces are involved in a finite slope analysis for uniform thickness with the reinforcement. Here we add the reinforcement.

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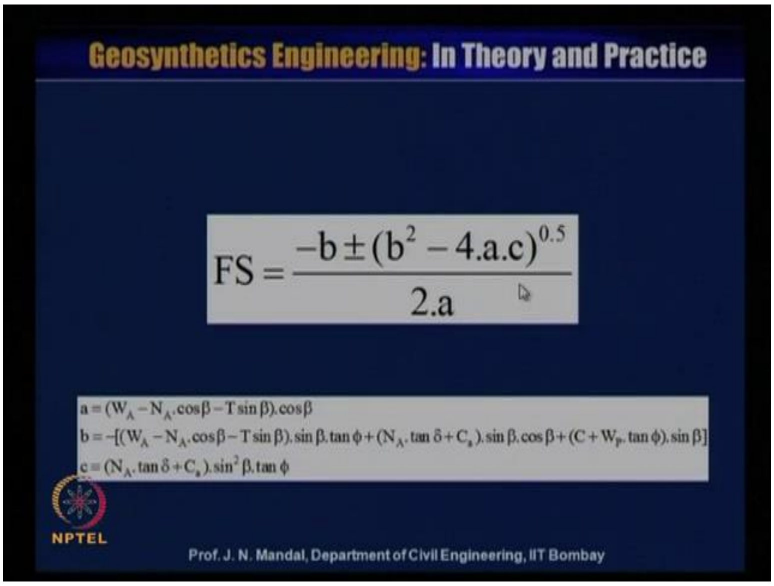

Now, this factor of safety again will be equal to minus b plus minus root over b square minus four a c by 2 a, where a is equal to W A minus N A into cos beta minus T into sin beta into cos beta, b is equal to minus W A minus N A into cos beta minus T sin beta sin beta tan phi plus N A into tan delta plus C a into sin beta into cos beta plus C plus W P tan phi into sin beta. And c is equal to N A into tan delta plus C a into sin square beta into tan phi. So, if you know this all these value w a n a or beta that means you know all the a b c so you can calculate that what will be the factor of safety.

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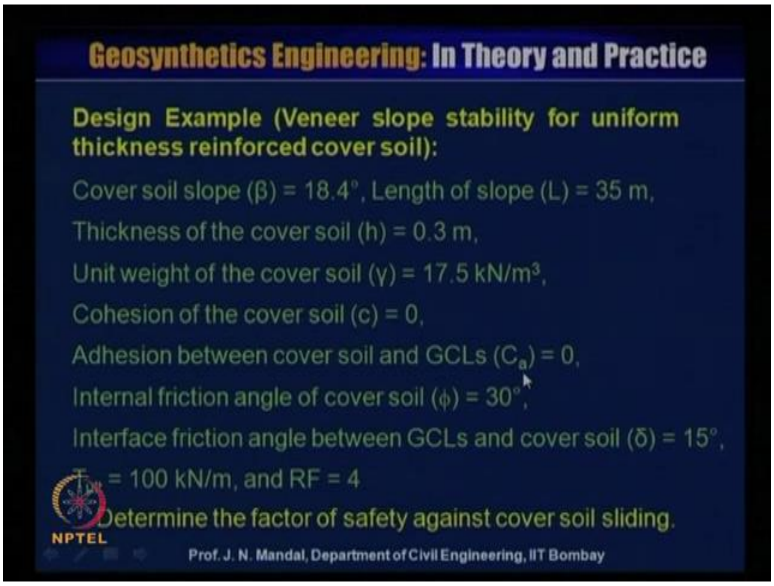

So, now I am giving one design example of veneer slope stability for uniform thickness reinforced cover soil. Let us say cover soil slope beta is 18.4 degree, length of the slope L is equal to 35 meter, thickness of the cover soil h is 0.3 meter, unit weight of cover soil gamma is equal to 17.5 kilo Newton per meter cube, cohesion of the cover soil c is equal to 0, adhesion between cover soil.

And the geosynthetic clay liner C a is equal to 0, internal friction angle of cover soil phi is equal to 30 degree, interface friction angle between the geosynthetic clay liner and cover soil delta is equal to 15 degree and tensile strength of the reinforcement T ultimate is equal to 100 kilo Newton per meter and cumulative reduction factor RF is equal to 4. So, you have to determine what would be the factor of safety against the cover soil sliding.

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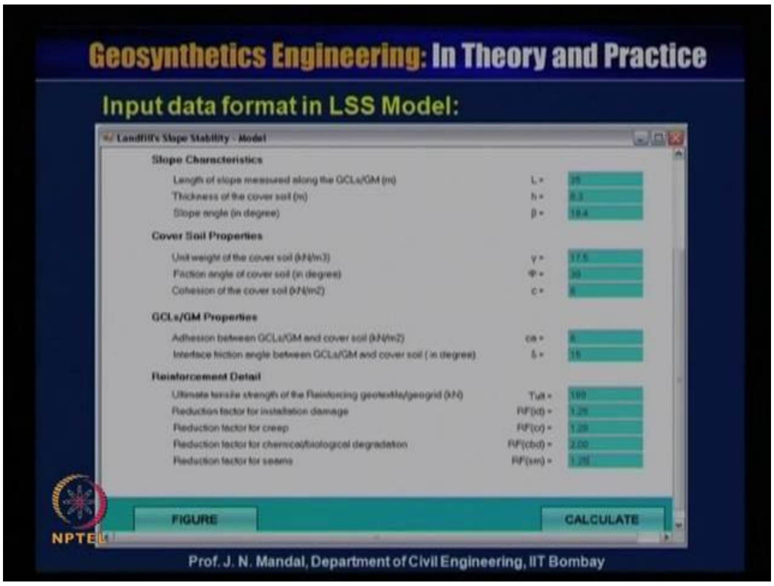

So, here is the input data format in the landfill slope stability model. So, you did what will be the slope characteristics that means what will be the length of the slope measure along the GCL or the geomembrane, that is L is equal to 35 meter and then the what will be the thickness of the cover soil, that is h is equal to 0.3 meter and slope angle is equal to 18.4. Now, what will be the cover soil property that is unit weight of the cover soil that is gamma will be equal to 17.5 kilo Newton per meter cube and friction angle of cover soil phi is equal to 30 degree and cohesion of the cover soil is 0.

Now, what will be the geosynthetic clay liner or geomembrane property that means adhesion between the geosynthetics clay liner and the geomembrane. And the cover soil that is C of a is equal to 0 and interface friction between the geosynthetic clay liner geomembrane cover soil that is delta is equal to 15 degree. Now, because we have added the reinforcement here to make the much more stable slope so here we given the reinforcement detail that is ultimate tensile strength of the reinforcement geotextile or the geogrid and that is T ultimate is equal to 100 kilo Newton. Reduction factor for installation damage that is 1.26, then reduction factor for creep that is R of FCR is 1.29 and reduction factor for installation damage a RFID is 1.25and reduction factor for chemical and biological degradation that is RFCVD is equal to 2.0 and the reduction factor for seam.

So, it will require something sometimes to join the geotextile material and that RFSM is equal to 1.25. So, you have to put all these input data that is what is slope characteristics, what will be the properties of the cover soil, what will be the interface between the soil and the geomembrane material and also what will be the properties of the reinforcement.

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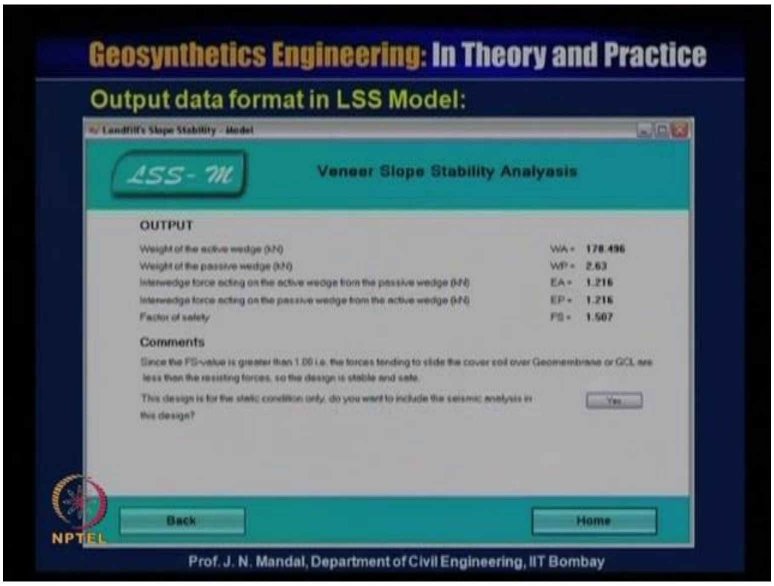

Then you will have the output that means weight of the active wedge W A is 178.496, weight of the passive wedge W P is equal to 2.63 and the inter wedge forces acting on the active wedge from the passive wedge is E A is 1.216 kilo Newton or inter wedge forces acting on the passive wedge from the active wedge that is E P is 1.216 kilo Newton.

So, you know that W A, W P, E A, E P you can calculate the what will be the factor of safety. So, factor of safety is 1.507. So, comment since the factor of safety value is greater than 1 that is the force tending to slide the cover soil over the geomembrane or geosynthetics clay liner are less than the resisting forces. So, design is stable and safe. Now, this design is for static condition only but do you want to include the seismic analysis in this design? Yes you can and also you can calculate what will be the factor of safety due to the seismic design. I will show you later.

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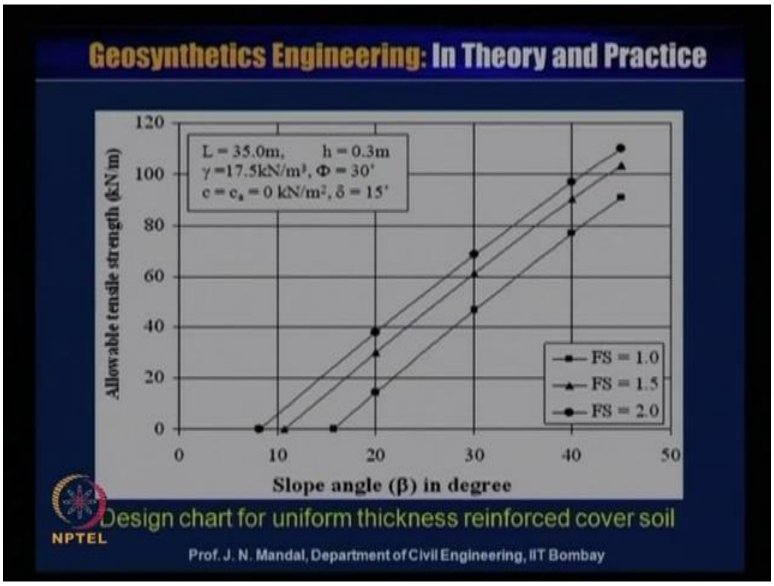

Now, this is the design chart for uniform thickness reinforced cover soil. So, this is the slope angle beta in degree. Different slop angle and the corresponding what will be the allowable tensile strength. Now, here this is the curve for the different factor of safety value is 1.0 1.5 and 2.0 and problem is that length of the cover soil is 35 meter and thickness of the cover soil h is equal to 0.3 meter and unit weight of cover soil 17.5 kilo Newton per meter cube and angle of friction phi is equal to 30 degree and c c a is equal to the 0 kilo Newton per meter square and delta is equal to 15 degree.

So, knowing that what should be the slope angle and the required factor of safety so you can calculate what will be the allowable tensile strength of the geosynthetics material or knowing the geosynthetics material and the slope angle also you can calculate what will be the factor of safety from this design chart and this design chart for uniform thickness reinforced cover soil.

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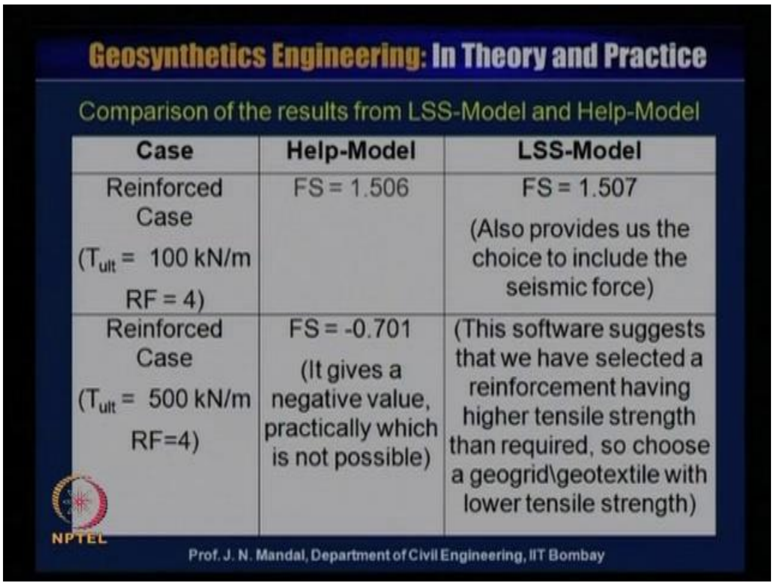

Now, here shows the comparison result from the landfill slope stability model and the help model case when the reinforced case when the ultimate tensile strength of the geogrid is 100 kilo Newton per meter and cumulative reduction factor 4. Then the help model you are having that factor of safety is equal to 1.506 in case of landfill slope stability model factor of safety FS is 1.507 also provide us the choice to include the seismic force. Here you can choose, you can go for the seismic force also.

So, in case of the reinforced case that help model and the LSS model is matching very well when the reinforced case that T ultimate 500 kilo Newton per meter that means reduction factor is equal to 4. Then in case of the help model the factor of safety giving minus 0.701, that means it is a negative value that means it gives a negative value in practically which is not possible. But in case of LSS model this software suggest that we have selected a reinforcement having higher tensile strength than required. So, choose a geogrid or geotextile with lower tensile strength. So, there is a option so you can select the proper kind of the reinforcement which the LSS model will give the response but HELP model does not give the response.

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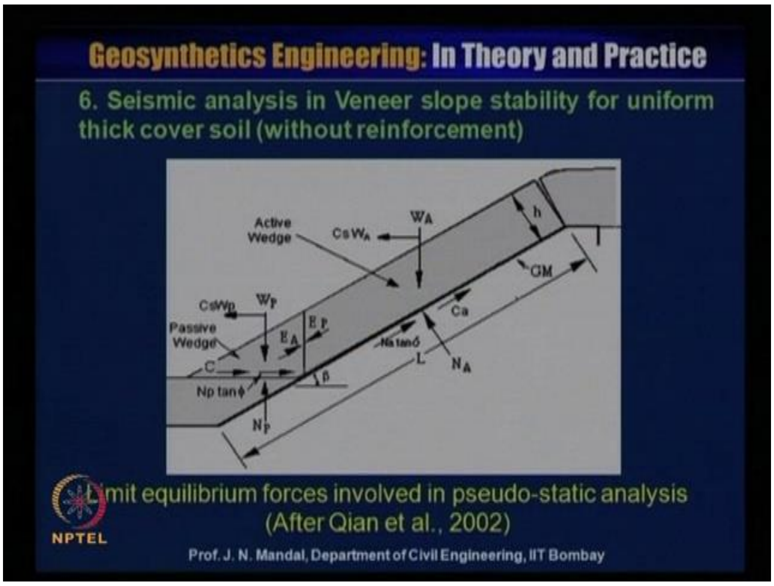

Now, 6 the seismic analysis in veneer slope stability for uniform thick cover soil without reinforcement. So, we are considering here limit equilibrium force involved in a pseudo-static analysis after Qian et al 2002. So, here you can see this is the slope whose angle is equal to the beta and this is the active wedge. Here you know what is W A weight in the active wedge this is the passive wedge this is W of P and this is the geomembrane and this is the thickness of the cover soil and this is the length of the slope is L. Here that we have consider that seismic that means this C of s, the C s is the seismic coefficient.

So, here it is W A due to seismic coefficient so you have to take into account that C s into W A in the active wedge. Similarly, in the passive wedge this is the W P weight in the passive zone and this is the C s into W P where C s is the seismic coefficient, so C s into W P. So, this seismic force in the active wedge and passive wedge are to be taken into consideration for the in pseudo-static analysis.

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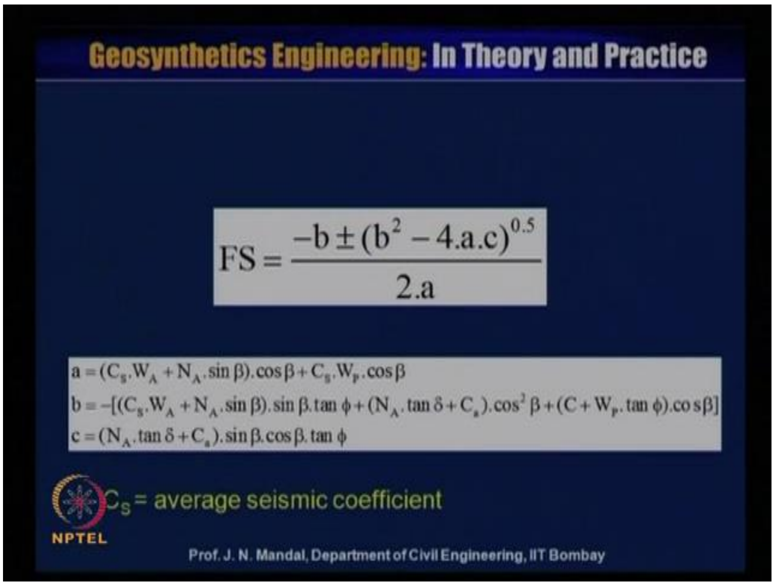

Now, again that factor of safety is equal to minus b plus minus root b square minus four a c by 2 a, where a is equal to C s into W A plus N A into sin beta into cos beta plus C s into W P into cos beta. Then b is equal to minus C s into W A plus N A into sin beta into sin beta into tan phi plus N A into tan delta plus C a into cos square beta plus C plus W P tan phi into cos beta. And c is equal to N A tan delta plus C a into sin beta into cos beta into tan phi. Here that C of s is the average seismic coefficient so why it has been added.

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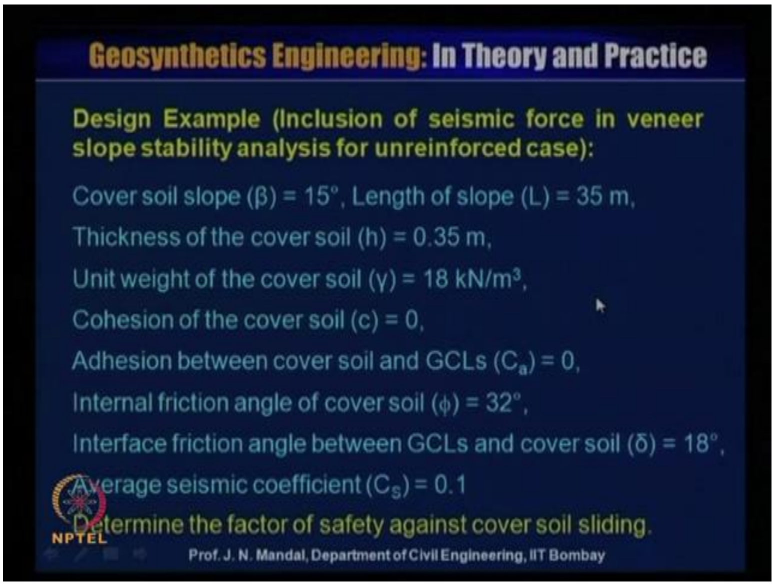

So, this is one design example inclusion of the seismic forces in a veneer slope stability analysis for unreinforced case cover soil slope. Beta is equal to 15 degree, length of the slope L is equal to 30 meter and thickness of the cover soil h is equal to 0.35 meter, unit weight of cover soil gamma is 18 kilo Newton per meter cube, cohesion of the cover soil c is equal to 0, adhesion between cover soil.

And the geosynthetic clay liner or geomembrane C a is equal to the 0, interface friction angle of cover soil phi is equal to 32 degree and interface friction angle between geosynthetic clay liner or geomembrane and cover soil delta is equal to 18 degree, average seismic coefficient C s is 0.1. You have to determine the factor of safety against the cover soil sliding.

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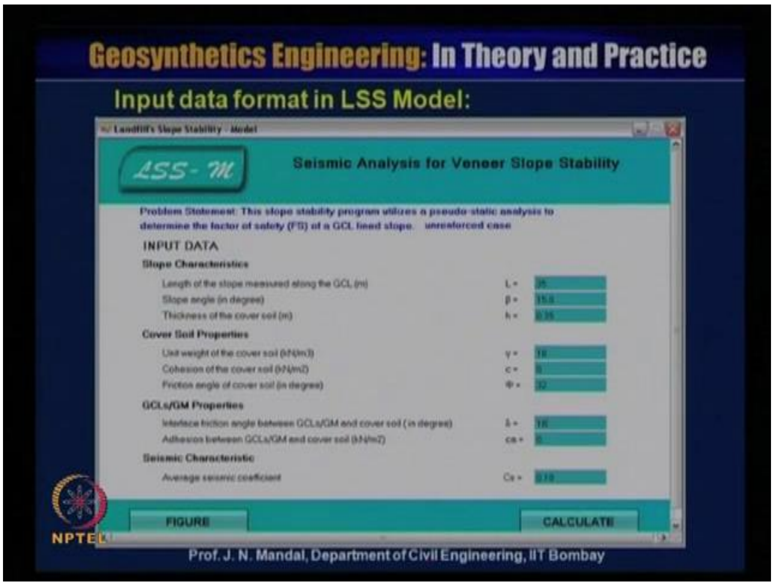

So, here it is the seismic analysis for veneer slope stability. This problem statement this slope stability program utilized in a pseudo-static analysis to determine the factor of safety of a geosynthetic clay liner slope and this is a unreinforced case. So, input data the slope characteristics that is the length of the slope measure along the geosynthetic clay liner L is equal to 35 meter. And the slope angle beta is equal to 15 degree and then the thickness of the cover soil that is h is equal to 0.35 meter.

And cover soil properties is the unit weight of cover soil that is gamma is 18 kilo Newton per meter cube and cohesion of the cover soil that is c is equal to 0 and friction angle of the cover soil that is phi is equal to 32 degree. And then geosynthetic clay liner or geomembrane property that is interface friction angle between the geosynthetics clay liner or geomembrane.

And the cover soil in degree that is delta is equal to 18 and then the adhesion between the geosynthetic clay liner and the geomembrane cover soil is C a is equal to 0. Here we have considering the seismic analysis for veneer slope stability therefore, the seismic characteristics also you have to take into account. So, average seismic coefficient that is C s is equal to 1.10.

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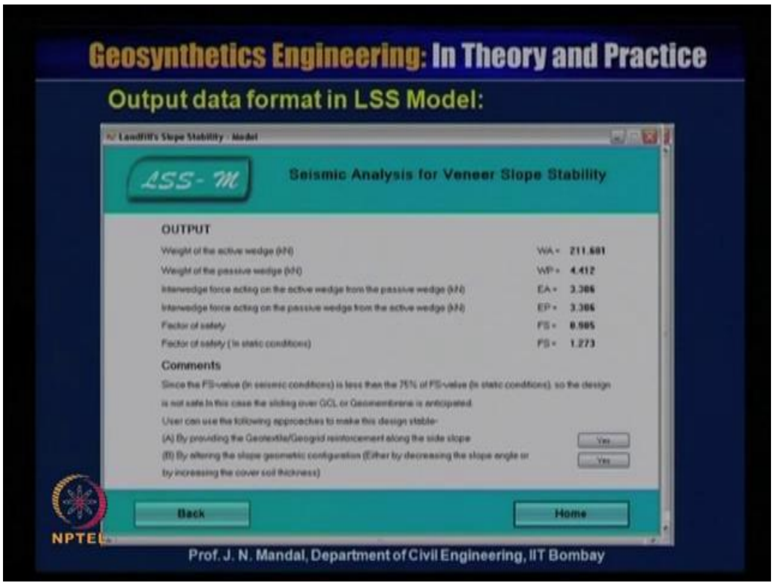

Now, we can calculate and you can obtain the output data that is weight of the active wedge W is a is equal to 211.661, weight of the passive wedge W P is equal 4.412 and that inter wedge forces that is acting on the active wedge from the passive wedge in kilo Newton E A is 3.306 kilo Newton. Inter wedge forces acting on the passive wedge from the active wedge that is E of P is equal to 3.306 kilo Newton. This factor of safety FS is equal to 0.005 0.905 and factor of safety in the static condition that is FS will be equal to 1.273.

So, what is the comment that since the factor of safety value in the seismic condition less than that of 75 percentage of the factor of safety value of the static condition. So, design is not the safe in this case the sliding over geosynthetic clay liner or geomembrane is anticipated. So, user can use the following approach to make the design stable a by providing the geotextile or geogrid reinforcement along the side slope or b the alternating the slope geometric configuration either by decreasing the slope angle or by increasing the cover soils thickness. So, these are the two options so you can go the both the option and can check whether it is stable or not.

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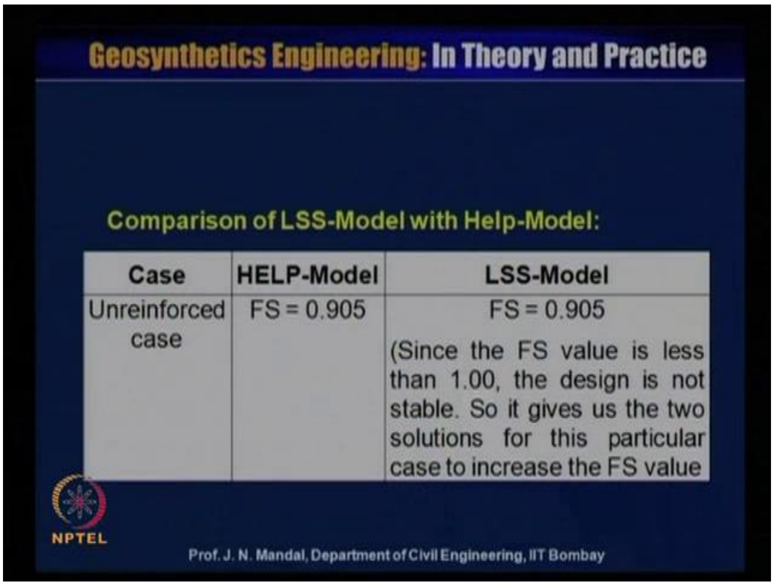

Now, this is the comparison of the landfill slope stability model with the help model case. When it is a unreinforced case help model factor of safety 0.905 and LSS model FS is equal to 0.905. Since, this factor of safety value is less than 1 so design is not stable, so it gives us the two solution for the particular case to increase the factor of safety value. So, we can avoid with these two options, you can you can make the slope either in the stable or the berm or the anchor or you can provide with the geogrid or geotextile reinforcement to make it as a stable, when the factor of safety will be the greater than 1. So, with this I finish my lecture today. Let us hear from you any question.

Thank you for listening.