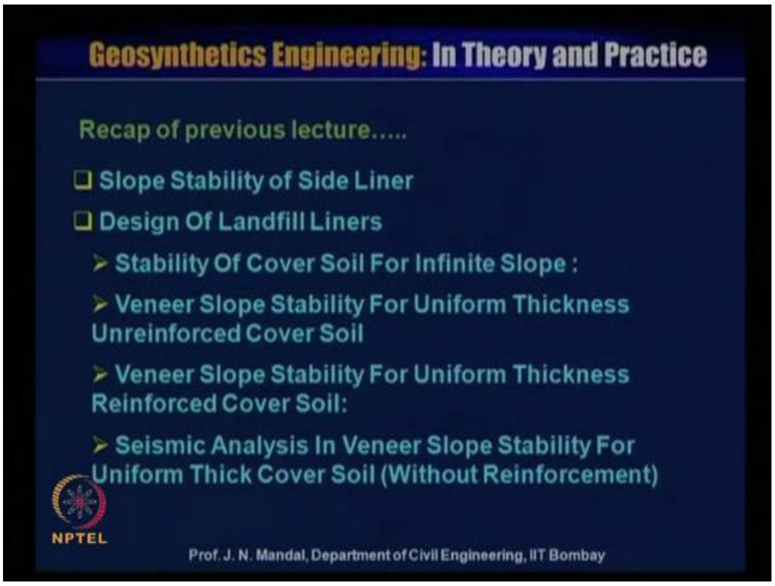
Geosynthetics Engineering: In Theory and Practice
Prof. J. N. Mandal
Department of Civil Engineering
Indian Institute of Technology, Bombay

Lecture - 55
Design of Geosynthetics for Landfills

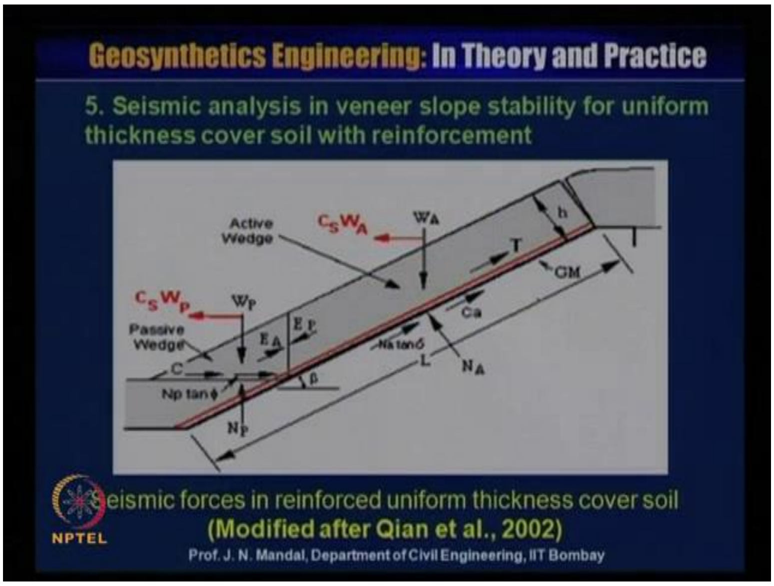
Dear student warm welcome to NPTEL phase two program video course on geosynthetics engineering in theory and practice. My name is Professor J.N. Mandal, Department of Civil Engineering, Indian Institute of Technology, Bombay, Mumbai, India; this module 12 lecture number 55 design of geosynthetics for landfill.

(Refer Slide Time: 00:52)



Now, I will address the recap of the previous lecture that is slope stability of side liner, design of landfill liner; that is stability of cover soil for infinite slope and veneer slope stability for uniform thickness unreinforced cover soil. The veneer slope stability for uniform thickness reinforced cover soil. Also we covered seismic analysis in veneer slope stability for uniform thick cover soil without reinforcement.

(Refer Slide Time: 01:40)

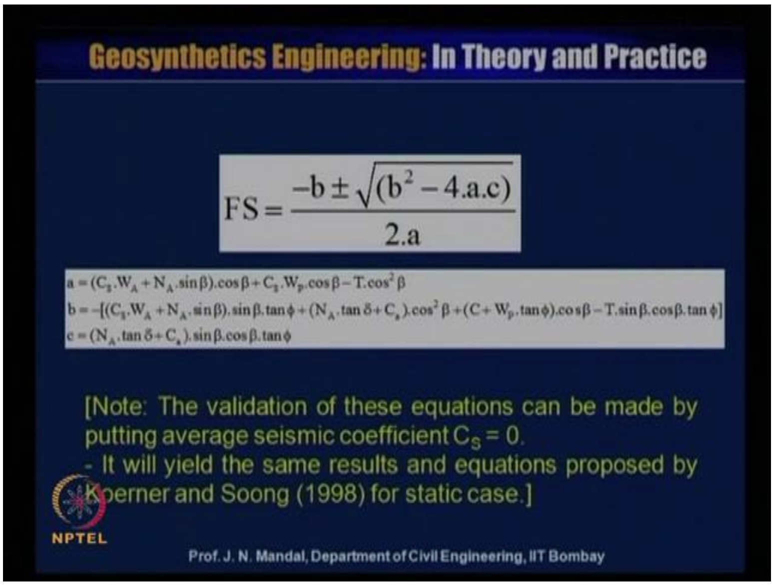


Now, I will focus 5 that is seismic analysis in veneer slope stability for uniform thickness cover soil with reinforcement. So, this is the seismic force in the reinforced uniform thickness cover soil this is modified after Qian et al 2002. Here the seismic force have been taken into consideration for the design that is that C of s which you call the seismic coefficient. You know W a is the weight of the active zone this is W p weight of the passive zone also in the weight of the passive zone. This is C s into W of p where C s is equal to the seismic coefficient.

In this passive wedge it has a weight W p and also the cohesion which is acting along this direction. This is the N p vertical component which is N p into tan of phi. That is phi is equal shearing resistance of the cover soil and slope angle is equal to the beta. Here the L is equal to length of the slope, this is the geomembrane and this is the reinforcement red color that is T is tensile strength of the reinforcement h is equal to thickness of the cover soil.

N a is the vertical component in the active zone W h is the weight of the wedge in the active zone. N a tan of delta that is delta is shearing resistance between the soil and the reinforcement. You know that this is the E of a that is inter wedge forces which is acting on the active wedge from the passive wedge and E of p also inter wedge forces which is acting on passive wedge from the active wedge. So, here you have considered the seismic force says E reinforced uniform thick cover soil.

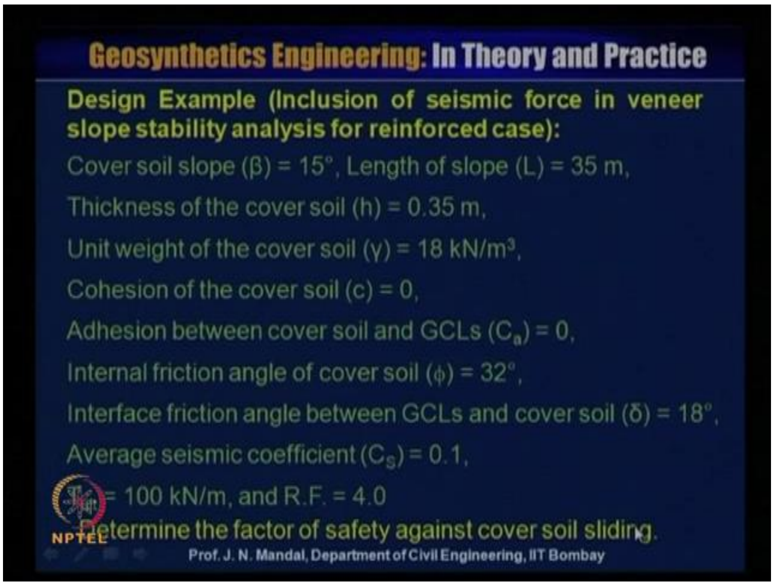
(Refer Slide Time: 03:59)



Now, we find the factor of safety is equal to minus b plus minus root over b square minus 4 a c by 2 a where a is equal to C of s into W a plus N a into sine beta into cos beta plus C s W p cos beta minus T cos square beta, b is equal to minus C s into W a plus N a sine beta into sine beta into tan phi plus N a tan delta plus C of a into cos square beta plus C plus W p tan phi into cos beta minus T sine beta cos beta and tan phi. C is equal to N a tan delta plus C of a sine beta cos beta and tan phi, where that C s I say that seismic coefficient here.

So, here it is to be noted that validation of this equation can be made by putting the average seismic coefficient that C s value is equal to 0. So, you can check it will yield the same result and the equation proposed by the Koerner and Soong 1998 for the static case. So, this way you can validate that whether your program is in order or whether your program is ok or not. So, we find that when we considering that seismic coefficient value is 0 and it is matching with the result obtained from the Koerner and Soong 1998 for the static case, so we able to say that this can valid this program.

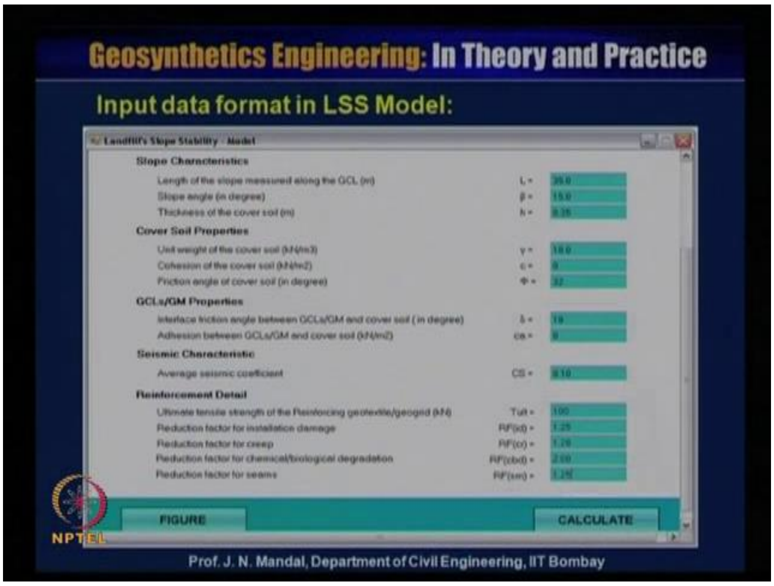
(Refer Slide Time: 05:53)



Now, this is one design example inclusion of the seismic force in veneer slope stability analysis for reinforced case. Cover soil slope beta is 15 degree length of the slope l is 30 5 meter thickness of cover soil h is equal to 0.35. Meter unit weight of cover soil gamma is equal to 18 kilo Newton per meter cube, cohesion of 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 32 degree interface.

Friction angle between the geosynthetics clay liner and cover soil delta is equal to 18 degree, average seismic coefficient c s is equal to 0 .1. Now, T ultimate tensile strength of the reinforcement 100 kilo Newton per meter and cumulative reduction factor is equal to 4.0. So, you have to determine the factor of safety against the cover soil sliding. So, here is the input data formation in the landfill slope stability model or LSS model, this is slope.

(Refer Slide Time: 07:07)

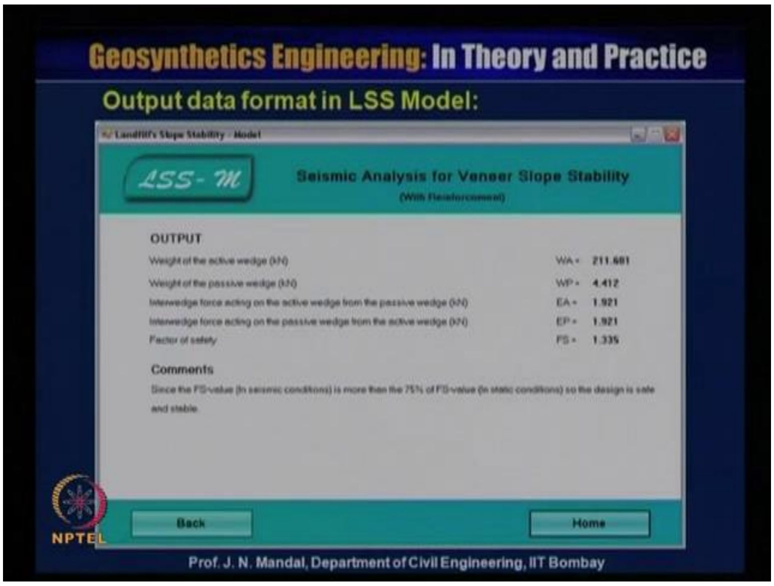


Characteristics, that is length of the slope measured along the geosynthetics clay liner that is L is equal to 35 meter. Slope angle beta is equal to 15 degree and thickness of the cover soil h is equal to 0.35 meter. And cover soil property unit weight of the cover soil that is gamma is equal to 18 kilo Newton per meter cube and cohesion of the cover soil c is equal to 0. Friction angle of the cover soil phi is equal to 32 degree.

Geosynthetics clay liner or geomembrane properties that is that interface friction between the geosynthetics clay liner or geomembrane and covered soil that is delta is equal to 18 degree. Adhesion between the geosynthetics clay liner or geomembrane and covered soil that is C a is equal to 0. Now, the seismic characteristics the average seismic coefficient that C s is equal to 0.10. Now, reinforcement detail that is ultimate tensile strength of the reinforcement geotextile or geogrid T ultimate is equal to 100 kilo Newton.

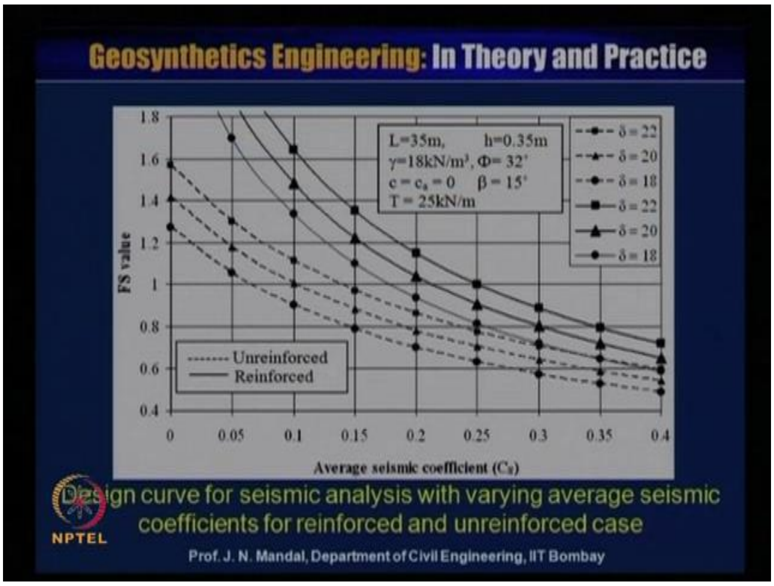
Then the reduction factor for the installation damage that is RFID is equal to 1.25 reduction factor for creep that is RFCR is equal to 1.28. And reduction factor for chemical or the biological degradation that is RFCBD is equal 2.0 and reduction factor for seam that is RFSM is equal to 1.25. So, you have to put this value into this program and then you can obtain the output.

(Refer Slide Time: 09:29)



That is weight of the active wedge W a is equal to 211.681 kilonewton, weight of the passive wedge W of p is equal to 4.412 kilo Newton. Inter wedge force acting on the active wedge from the passive wedge that is E a is equal to 1.921 kilo Newton and inter wedge force acting on the passive wedge from the active wedge that is E of p is equal to 1.921 kilo Newton. So, factor of safety you will be obtained 1.335. So, what is the comment since the factor of safety value in the seismic condition is more than 75 percentage of the factor of safety value in static condition. So, design is safe and stable.

(Refer Slide Time: 10:32)



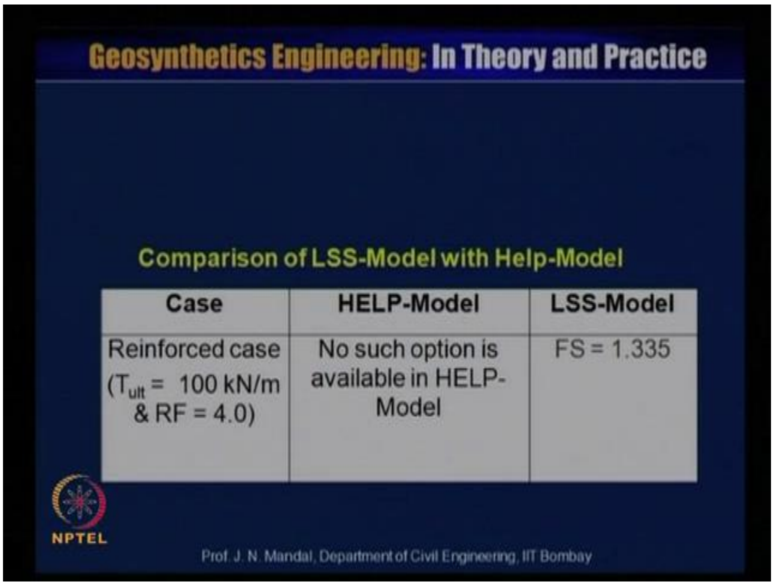
Now, this is one design curve for the seismic analysis with varying the average seismic coefficient for reinforced and unreinforced case. So, here this is the factor of safety value versus the average seismic coefficient. So, you can go average seismic coefficient 0.1,0.15,0.2,0.25,0.3,0.35 and 0.4 for the different values of delta. Delta value may be 18 degree. So, it may be 18 degree it may be 20, 22. Also here it has been shown for both cases unreinforced cases and reinforced cases. The dotted line shows for the unreinforced cases and the firm line shows for the reinforced cases.

So, that is why this firm line delta is shown from the for the reinforced case same interface friction angle between cover soil and the reinforcement. This dotted also the same friction angle between soil and the reinforcement that is 18, 20 and 22 this is the dotted line for unreinforced case. The problem is length of the slope 3.5 meter and thickness of the cover soil 0.35 meter and unite weight of cover soil gamma is 18 kilo Newton per meter cube. Angle of internal friction of the soil phi is equal to 32 degree. And C a is equal to 0 and slope angle beta is 15 degree. Tensile strength of the reinforcement is 25 kilo Newton per meter.

So, you can obtain this correlation between the factor of safety value and the average seismic coefficient for the unreinforced and the reinforced case. So, you can select this any that seismic coefficient value at that zone so it is a zone 1 2 3 4. So, you will be knowing what will be the seismic coefficient C s. Then you know that what will be the delta value either it is 18, 20 or 22 and then you can calculate for what will be the factor of safety for unreinforced case. As well as you can also determine what will be the factor of safety for the reinforced case if this value is does not satisfy.

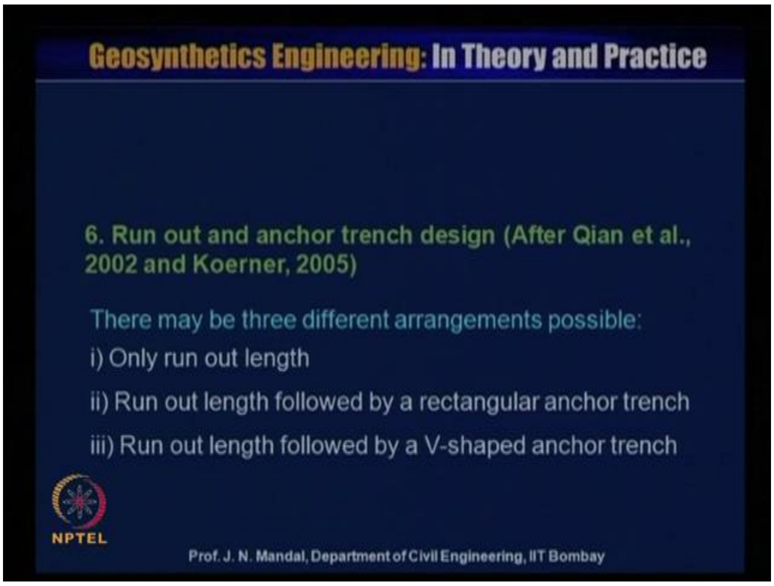
So, then you can incorporated the reinforcement and you can achieve the higher factor of safety value. You can see that all the firm line is on the higher than this one here, but when the seismic coefficient value is increasing then factor of safety value also is decreasing. So, in that case also you may require very high strength of the reinforcement or the geogrid. Then this value will be on the upper side also it depend upon what will be the friction value between the soil and the reinforcement value. If the friction angle value is on the higher side then also factor of safety value will be on the higher side. So, it also depend upon that what will be the geometric configuration of the geogrid material. So, this design chart also can help you to determine the factor of safety for both unreinforced and the reinforced case with seismic.

(Refer Slide Time: 14:24)



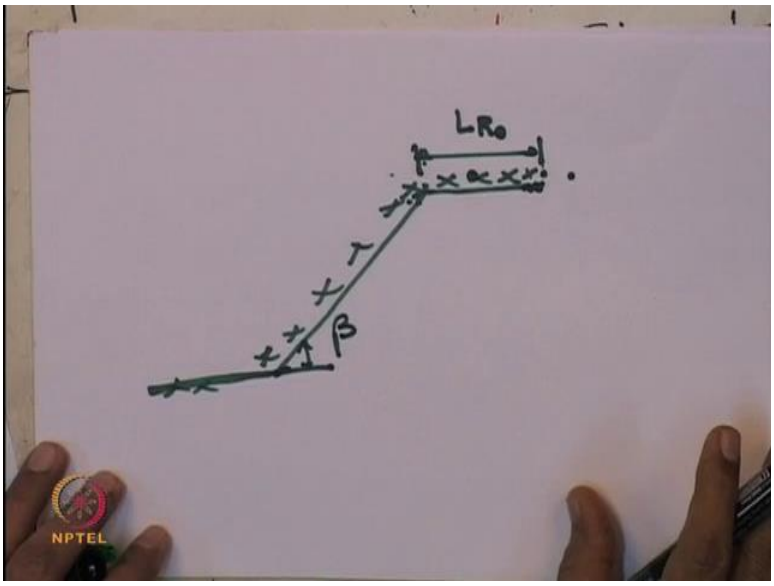
Now, this is the comparison of LSS model with the Help model. That case that reinforced case the tensile strength of the reinforcement T ultimate is 100 kilo Newton per meter and cumulative reduction factor RF is equal to 4.0. In case of the help model no such option is available in the help model, but length in slope stability or LSS model which can provide the factor of safety is equal to 1.335.

(Refer Slide Time: 14:59)



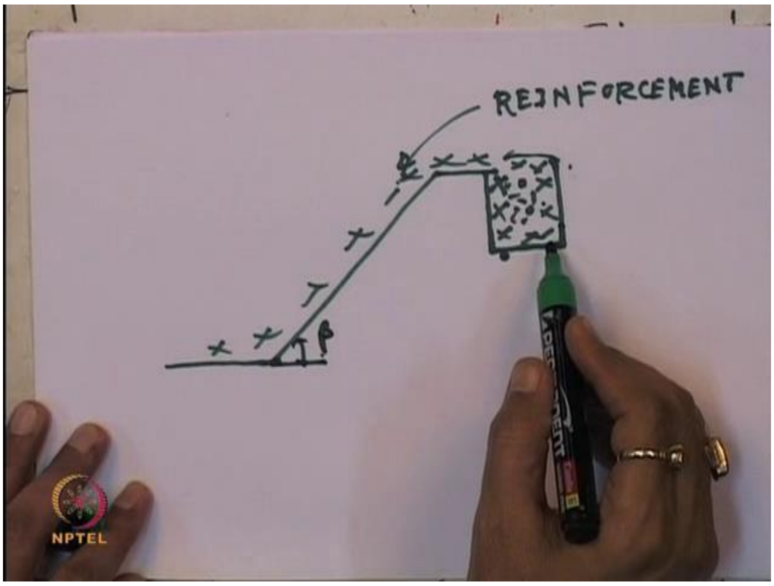
So, this way that LSS model is very helpful and can calculate the factor of safety. Next 6, run out for anchor trench design after Qian et al 2002 and Koerner 2005. There may be the 3 different arrangement possible, it is sometimes required to anchor the reinforcement to make a stable slope. So, 1 only run out length and 2 run out length followed by rectangular anchorage trench and 3 run out length followed by v shaped anchorage trench, so this 3 type of the anchored. So, what I am trying to say that this run out length for example, that it is a slope.

(Refer Slide Time: 16:01)



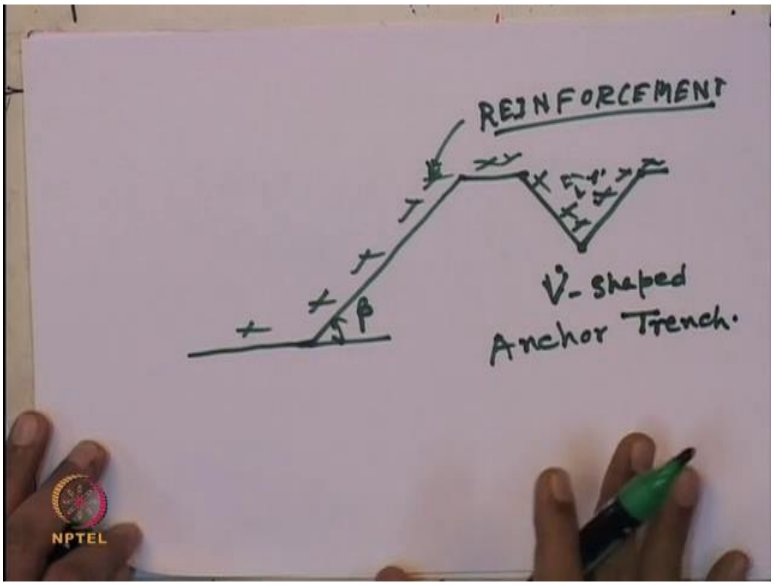
So, you are placing the some reinforcement. So, you can place the reinforcement like this at a particular length. So, this what you call the run out length here it is the run out length. So, this is one system you can this will act as a anchor. So, you have to calculate what will be the length of the anchorage or you can say it is a L r 0. So, if this you can say that this is the length of the anchorage length which is called the L r 0. So, this weight also you have to design and to find out that what will be the anchorage length to make a stable slope. Let say this slope is equal to the beta. So, this is the first case what you call the run out length. Also sometimes, you require that run out length followed by rectangular anchor strength.

(Refer Slide Time: 17:15)



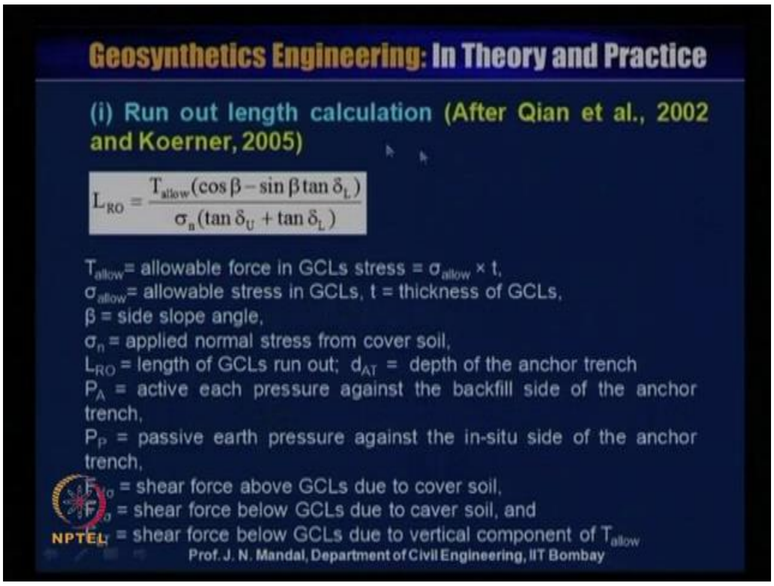
So, suppose if this is the slope. So, you are placing this reinforcement like this and then you can make a trench here. So, you require and you can fill up some aggregate like this you can cover it. So, this is the act as a this is the reinforcement. This is what you call the run out length from the rectangular anchor trench this is the rectangular anchor trench. Let us say this angle is equal to beta. So, you have to calculate what it should be length and this also this is run out length of the anchor. The other case is that run out length followed by a v shape anchor trench.

(Refer Slide Time: 18:27)



So, for example that if this is the slope and this is the reinforcement then you can make a v shape like this. So, this angle is beta and this is the reinforcement. So, this is the v shape anchor trench it is called v shape anchor trench. So, you have the idea about the 3 that different arrangement it is possible. One may be that run out what you call length another is may be the rectangular another is may be the v shape anchor trench. So, run out length calculation how to calculate the run out length.

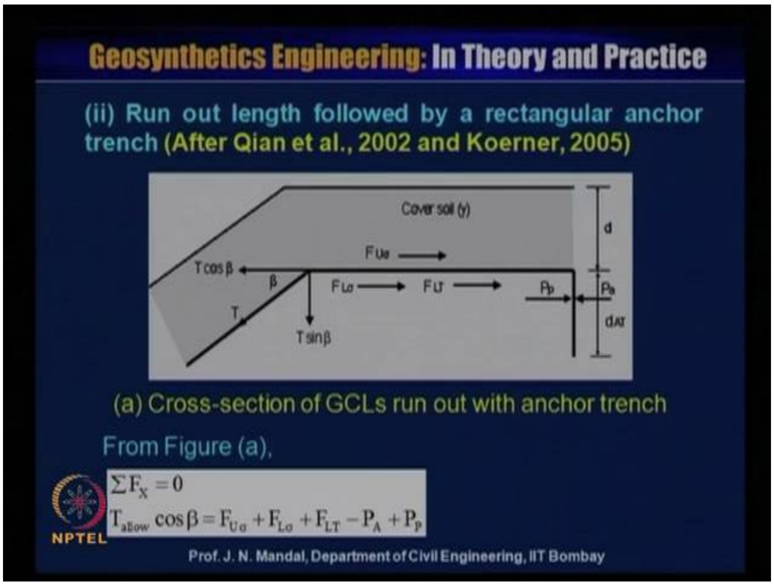
(Refer Slide Time: 19:31)



So, run out length calculation after Qian e t a l 2002 and Koerner 2005. This is L r 0 will be equal to T allowable into cos beta minus sine beta into tan delta L divided by sigma n tan delta u plus tan delta L. So, where the T allowable is allowable force in the geosynthetics clay liner stress that is sigma allowable into T. So, sigma allowable is allowable stress in the geosynthetics clay liner or geomembrane and T is the thickness of geosynthetics clay liner or geomembrane. Beta is equal to side slope angle sigma n is applied normal stress from the cover soil.

L r 0 the length of the geosynthetics clay liner that is run out length and d a t is the depth of the anchor trench up to what depth of the anchor trench. P a is the active each pressure against the backfill side of the anchor trench. P p is the passive earth pressure against the in situ side of the anchor trench. F u sigma is the shear force above the geosynthetics clay liner due to cover soil and F h sigma is the shear force below the geosynthetics clay liner due to cover soil. F l t shear force below the geosynthetics clay liner due to vertical component of t of allowable.

(Refer Slide Time: 21:23)



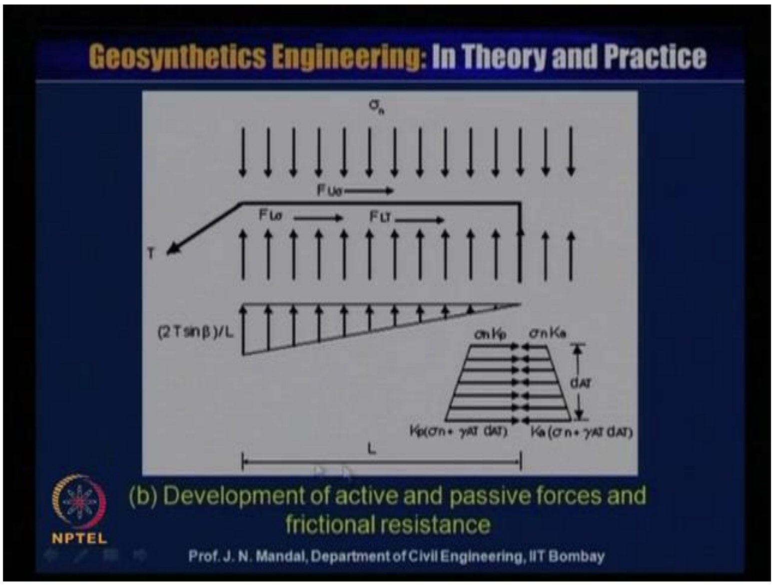
So, this is the actually 2 the run out length followed by the rectangular anchor trench and this is the cross section of the geosynthetics clay liner run out length with anchor trench. Here you can see this is the cover soil this is the d and this is the reinforcement and this angle is equal to the beta. So, this tensile force of the reinforcement is 2 component this is horizontally T of cos beta and this vertically T of sine beta. This cover soil has a thickness let us say this cover soil thickness is equal to the d and this cover soil has also the unit weight that is in gamma.

So, this is run out length followed by a anchor trench after Qian et al 2002 and Koerner 2005. Here that this is the F of u sigma that means the shear force above the geosynthetics clay liner due to cover soil this is shear force above the geomembrane. So, let us say this is the geomembrane above geomembrane what is the shear force are acting whereas, F l sigma is the lower what will be the shear force acting this is lower the shear force below the geosynthetics clay liner due to the cover soil. So, this is shear force soil is acting below the geomembrane liner. And this is the F of l t and that is the shear force below the geosynthetics clay liner due to the vertical component of the T allowable.

So, this vertical component there is also development of the shear stresses and that is F of l t. So, that is why this is the upper this is the lower and this F l t due to the vertical component of the reinforcement. There is also the P a and P p because reinforcement also is here. So, this is the P a that means this P a which we call the active earth pressure against the backfill side of the anchor trench here. This is the p p that means this P p is the passive earth pressure against the in situ side of the anchor trench here against the anchor trench. So, from this figure if you take that summation of F x is equal to 0 .

So, you can write that T allowable into cos beta will be equal to F of u sigma that shear stress which is acting on the top above the geomembrane plus F l sigma that was the shear stress acting below the geomembrane plus F l t. That is due to the vertical component of the reinforcement F l t minus this is the P a what is called active pressure which is acting in this direction and minus this is the P p in this direction. So, minus P p is an what will be the passive pressure is acting in this direction. And this is the d a t that means this d a t that is the depth of the anchor trench. So, you have to calculate what will be the depth of the anchor trench. So, when your summation of F x is equal to 0 you are having this equation.

(Refer Slide Time: 25:22)

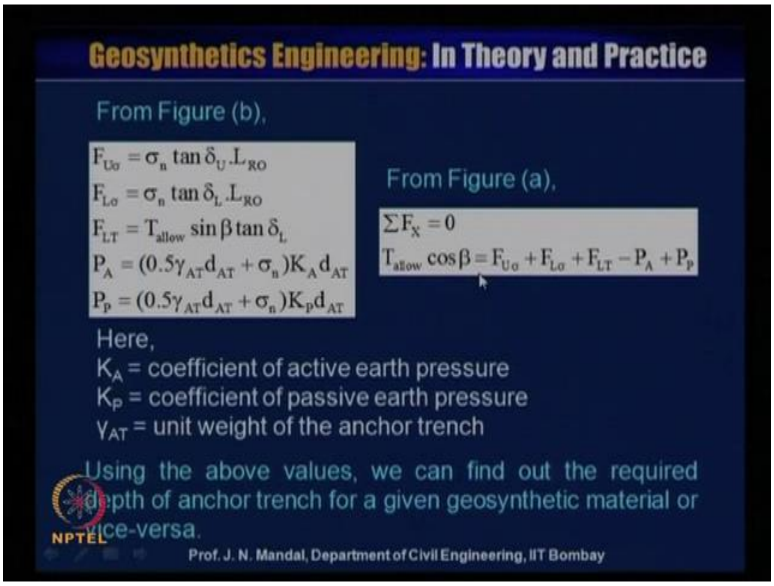


Now, you can see here the development of active and the passive force and the frictional resistance. Now, you know this is the T tensile force allowable tensile force of the reinforcement. This is for the sigma n this is sigma of n. So, this sigma n is acting vertically downward you know what is that F of u sigma upon this F l sigma that is on the lower.

This is F l t and here you can see there is a this is the this d a t I say the depth of the anchor trench and there is a what you call the active pressure which is acting here. That will be the sigma n k this will be k a plus sigma n gamma of a t and then d a t. Gamma of a t that means unit weight of the anchor trench soil and d a t is the what will be the height of the trench that is d of t or depth of the trench.

Similarly, for the passive this is sigma n into k p which is passive is acting on this direction. So, this will be k p into sigma n into gamma a p into d a t. This is the length this is the length this is the l from here to here this is the l. So, this is the vertical forces which is acting 2 t sine beta divided by l. So, this is the development of the active and the passive force and the frictional resistances.

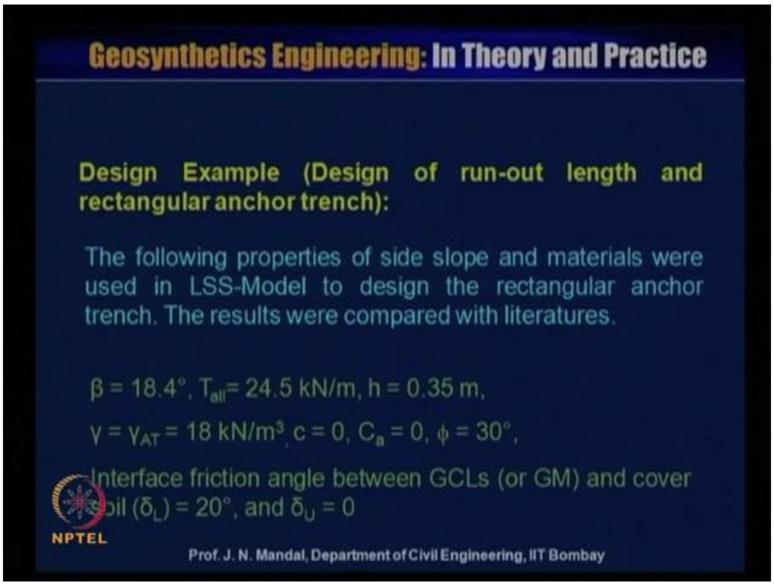
(Refer Slide Time: 27:20)



So, from this figure you will obtain F u sigma is equal to sigma n into tan delta u this is from figure b from this figure you can have sigma n tan delta u into L r 0. F of l sigma will be sigma n tan delta into L r 0 in the lower and similarly, F l t will be equal to T allowable into sine beta into tan delta l. So, from this you can calculate what will be the P of a p ,you know half into gamma a t into d a t plus sigma n into k a into d a t, where k a is coefficient of active earth pressure and d a t is the what will be the depth of the anchor trench and then p p will be equal to half into gamma a t d a t plus sigma n into k p into d a t, where k p is coefficient of passive earth pressure and gamma a t you know what will be the unit weight of the anchor trench. Similarly, from figure a which I showed you earlier here that we are having this equation.

So, we are having this equation that is T allowable cos beta is equal to F u sigma plus F l sigma plus F l t minus P a plus P p. So, using this above value we can find out the required depth of the anchor trench for a given geosynthetics material or the vice versa. So, we are interested to find out what will be the depth of the anchor that means d a t.

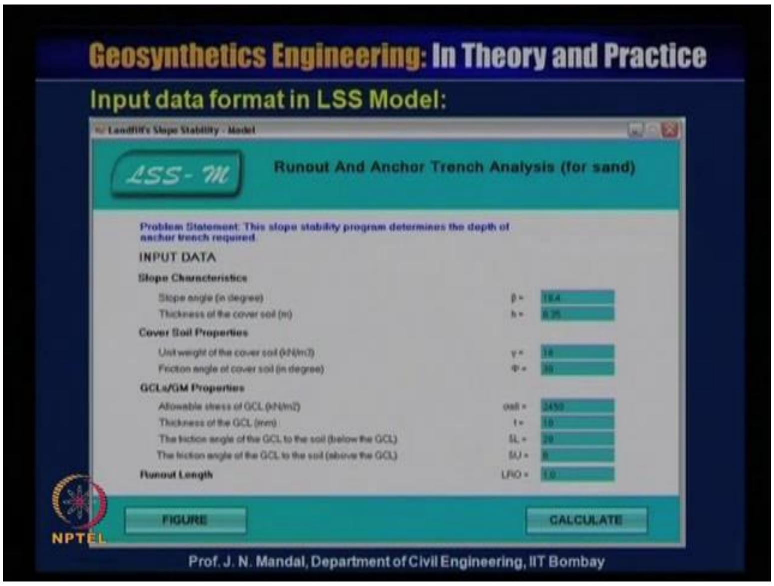
(Refer Slide Time: 29:25)



So, here one design example design of run out length and rectangular anchor trench. Now, the following properties of side slope and the material were used in the landfill slope stability model to design the rectangular anchor trench the result was compared with the literature. So, slope angle beta is given 18.4 degree allowable tensile strength of the reinforcement is 24.5 kilo Newton per meter h thickness of the cover soil is 0.35 gamma or gamma a t that is unit weight of the trench soil is equal to 18 kilo Newton per meter cube.

C is equal to 0, C a is equal to 0 angle of shearing resistance of soil is 30 degree interface friction angle between the geosynthetic clay liner or geomembrane. And cover soil delta l is equal to 20 degree and delta u is equal to 0 because there is a delta l. Delta u 1 is the lower friction angle another is the upper interface friction angle. So, you have considered here that upper interface friction angle delta u is equal to 0.

(Refer Slide Time: 30:49)

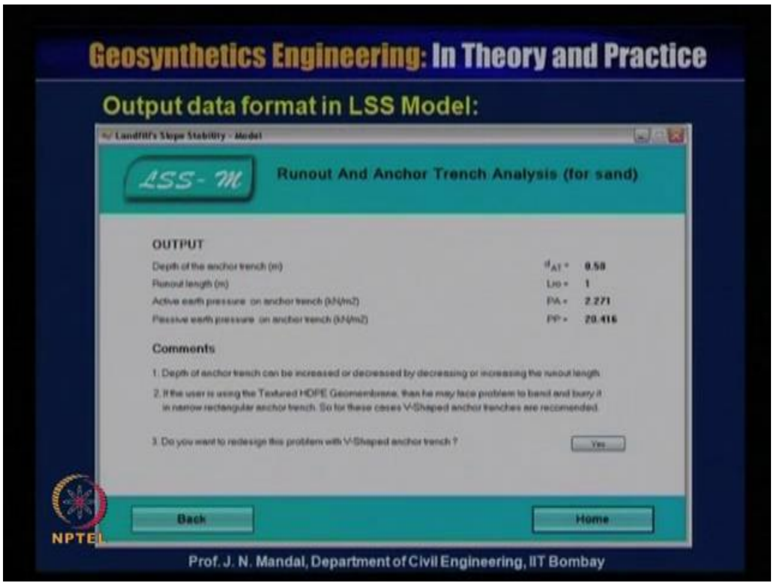


Now, we have to find out run out and the anchor trench this analysis has been done for sand and this problem statement the slope stability program determine the depth of the anchor trench required. So, input data you have the slope characteristic that is slope angle beta is equal to 18.4 degree then thickness of the cover soil that is h is equal to 0.35 meter. Now, cover soil properties, that is unit weight of the cover soil gamma is 18 kilo Newton per meter cube. The friction angle of the cover soil is phi is equal to 30 degree.

Next geosynthetics clay liner or geomembrane property that is the allowable stress of geosynthetics clay liner that is sigma allowable is equal to 24.50 kilo Newton per meter square. Thickness of the g c l or geosynthetics clay liner that is t is equal to 10 millimeter and friction angle of the g c l or soil below the geosynthetics clay liner and that is this delta of l is equal to 20 degree.

Friction angle of the g c l to the soil above the g c l or geosynthetics clay liner that delta L j is equal to the 0. The trench angle of the g c l to the soil above the g c l that is L of r 0 is equal to the 1 that is L r 0 is equal to the 1 that is run out length is equal to the 1. So, the friction angle of g c l to the soil above the g c l that is delta L j is equal to 0, the run out length that L r 0 is equal to 1.0.

(Refer Slide Time: 32:57)

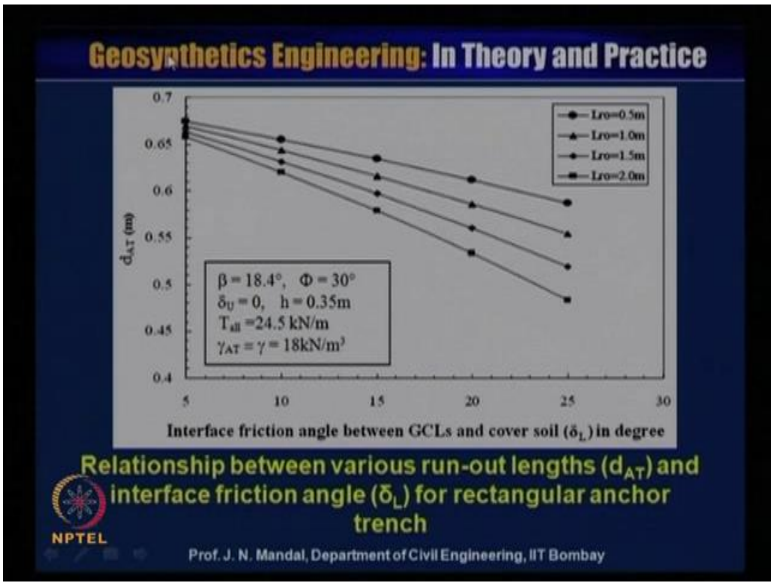


Now, what will be the output of this that is depth of the anchor trench that is d a t will be equal to 0.58 meter and run out length in meter that is L r 0 is equal 1 meter. Anchor active earth pressure on the anchor trench that is P a is equal to 2.271 kilo Newton per meter square. Passive earth pressure on anchor trench P p is equal to 20.416 kilo Newton per meter square. So, the comment the 1 the depth of the anchor trench can be increased or the decreased by decreasing or increasing the run out length.

So, you can decrease or increase the run out length and accordingly also you can calculate what will be the depth of the anchor trench that is d a t or 2. If the user is using the any textile material like high density polyethylene geomembrane then he may face the problem to bend and the burry it in a narrow rectangular act anchor trench. So, this case v shape anchor trench are recommended. Sometimes you know that if the some geomembrane material it is very something difficult to bend it in a 90 degree angle.

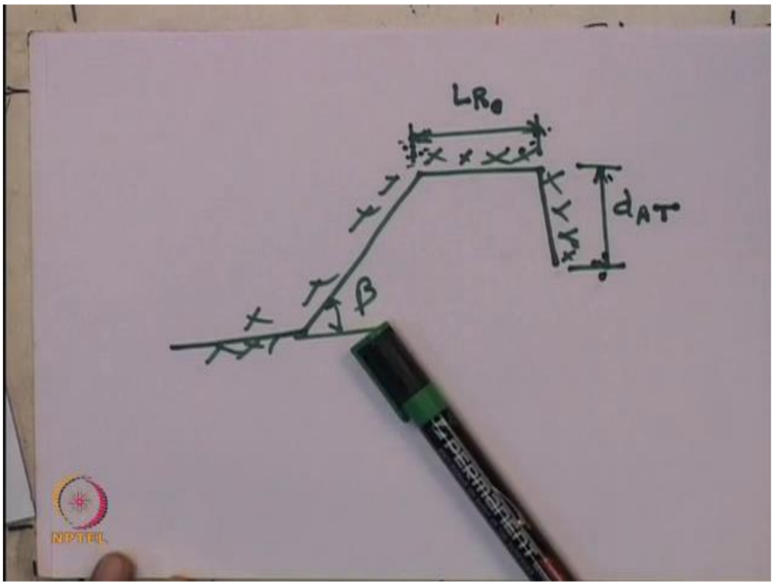
So, but you can make a v shape. So, that will this recommended that if we can provide with the v shape greater than the rectangular in shape because it is very difficult to bend the geomembrane. Also there is a possibility for the damage of the geomembrane material and 3 do you want to redesign this problem with v shape anchor trench if. So, then you can design and that option is there. So, with the v shape you can also design and then you will be knowing what should be the parameter.

(Refer Slide Time: 35:29)



Now here the relationship between the various run out length that is d a t and the interface friction angle delta l for rectangular anchor trench. So, this is the interface friction angle between the geosynthetic clay liner or geomembrane and the cover soil that is delta l in degree. It may be 5, 10, 15. 20 25 and 30 that delta value, his is d a t that is run out length and this is anchorage length what you call d a t that is depth of the anchorage trench. This is depth of the anchorage trench and this is L r 0 is the run out length. So, L r 0 may be 0.5 may be 1 meter 1.5 meter and the 2 meter. What I want to mean that between the depth of the anchor.

(Refer Slide Time: 36:35)

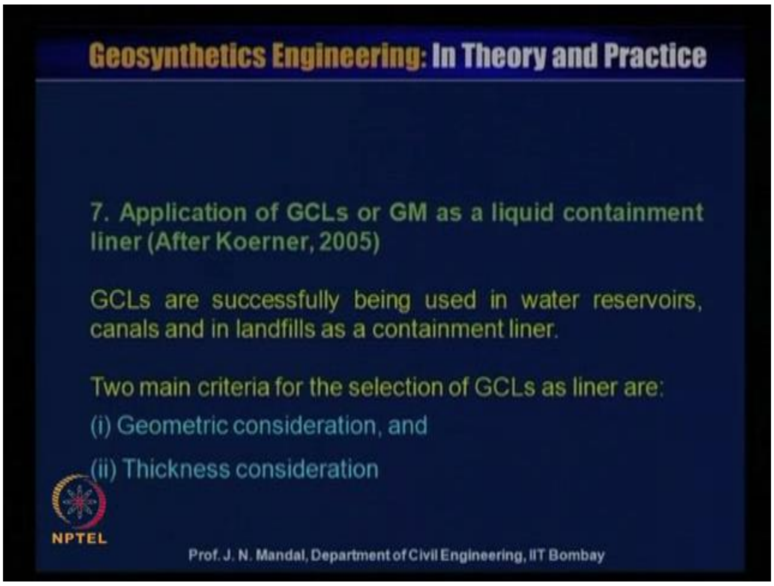


So, for example, that this is the slope if this is the reinforcement this is the slope angle is beta. This to this is L r 0 that means length of the g c l run out this is run out length L r 0. Whereas, this is the d a t this is d a t that is depth of the anchor trench. So, depth of the anchor trench. So, you can check this L r 0 value it may be 0.5 meter depending upon the space available in this zone. This is may be 0.5 meter or 1 meter or 1.5 meter and 2 meter and equally you can obtain the d a t value.

So, from this chart so for the various what you call run out length. So, you know the what do you mean by run out length you know the 0.5 ,1, 1.5 and 2 depending upon the availability of the place you can select what will be the run out length value. So, you can obtain the different curve for different L r 0 or the run out length value. So, this the problem when beta is equal to 18.4 degree phi is equal to 30 degree delta u is equal to 0 thickness of the cover soil.3 5 meter. Allowable tensile strength of the reinforcement is 20 4.5 kilo Newton per meter and gamma of a t of gamma is equal to 18 kilo Newton per meter cube.

So, knowing the interface friction angle between the geosynthetic clay liner or geomembrane. The cover soil then you can select that what will be the run out length whether 0.5 or whether you want to take 1 meter 1.5 or 2 meter and then correspondingly you can be knowing what will be the d a t, d a t means what should be the depth of the anchor trench that is whether it is 0.6 meter or 0.5 meter or 0.55 meter. So, accordingly from this design chart for this specific problem, you can calculate that what should be the run out length. What should be depth of the anchor trench anchor?

(Refer Slide Time: 39:35)

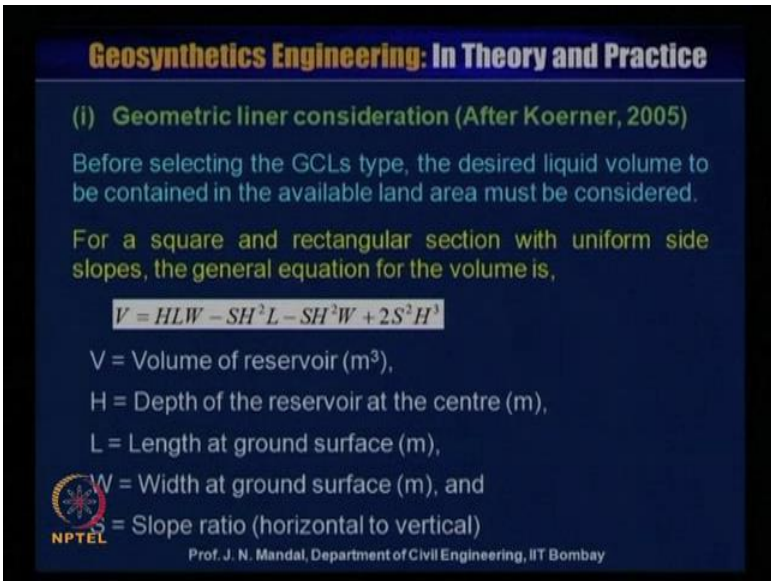


Now, 7 application of geosynthetic clay liner or geomembrane as a liquid containment liner after Koerner 2005. Now, geosynthetic clay liners are successfully being used in water reservoir canal and in the landfill as a containment liner. So, two main criteria of the selection of the geosynthetic clay liner or geomembrane in a liner are used. That is geometric consideration and thickness consideration. So, you should know that what should be the geometry, whether it is a reservoir whether it is a landfill.

For example, in a landfill case then you should know that what volume of the material have to be dumped in that locality. So, you should know what will be the area what will be the volume of the landfill. Similarly, for a water reservoir or the canal for water reservoir you should know what will be the volume of water wanted to procure or in a canal that when the water is flow. Also you know this all cases that when a water reservoir you can use the geomembrane material as a barrier which is a impermeable material or geosynthetic clay liner also has a barrier.

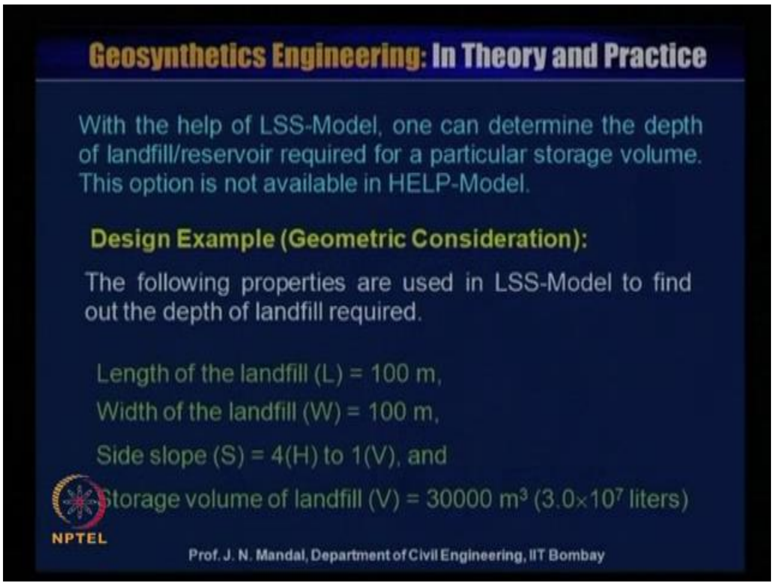
In geomembrane you know that you know how to detect that if there is any leakage. I have shown you that when the power is supplied to the inducer and then if there is a leakage and then some computer data record can give you the idea the location of the hole of the geomembrane. So, you can also indentify that whether there is any defect or in the geomembrane or not, but here just two main criteria for the selection of the geomembrane geosynthetic clay as a liner or one is geometric consideration, another important the thickness. Now, you can have the various thickness of the geomembrane it may be 0.75 millimeter, it may be 1 millimeter, it may be 1.25 millimeter, it may be 1.5 millimeter or 2 millimeter or 2.5 millimeter. So, which one you should select. So, this is important that what thickness of the geomembrane is required for a particular job.

(Refer Slide Time: 42:19)



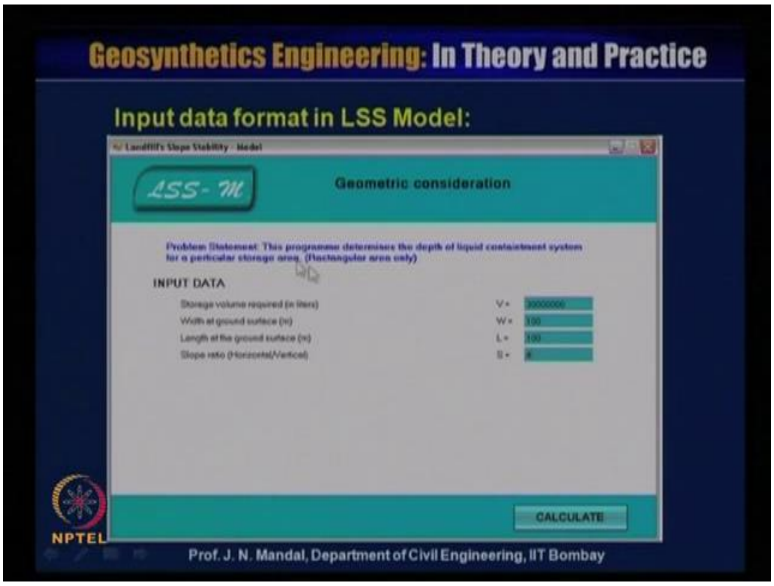
So, here we will discuss the geometric liner consideration after Koerner 2005. Before selecting the geosynthetics clay liner type the desired liquid volume to be contained in the available land area must be considered, for a square and the rectangular section with uniform side slope. The general equation for this volume is that V is equal to H L W minus S H square l minus S H square W plus 2 S square into H to the power cube. Where V is volume of the reservoir in meter cube, H is the depth of the reservoir at the centre in meter. L is the length at the ground surface in meter. W is the width of the ground surface in meter and S is the slope ratio that is horizontal to vertical.

(Refer Slide Time: 43:35)



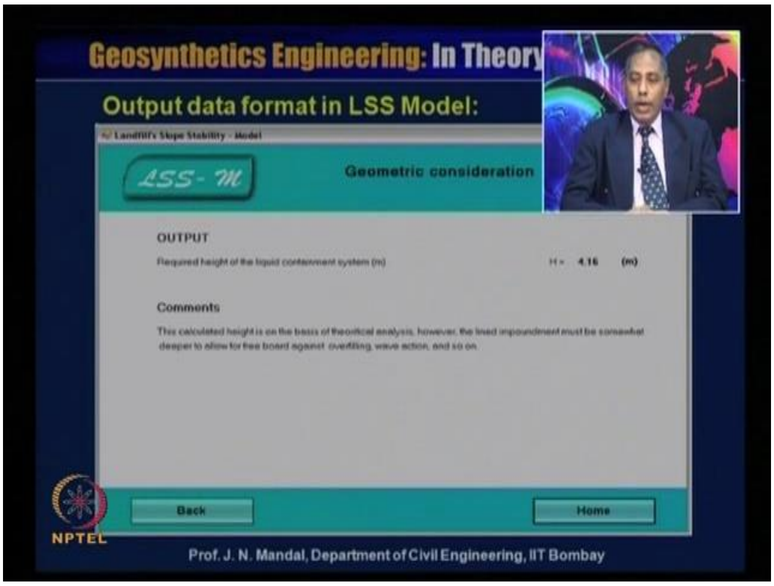
So, you know this equation with the help of the landfill slope stability model. One can determine the depth of the landfill or the reservoir required for a particular storage volume this option is not available in the Help model. So, here you are giving one design example in terms of geometric consideration. So, this design is very simple the following properties are used in the landfill slope stability model or LSS model. To find out the depth of the landfill required. So, length of the landfill L is equal to 100 meter and width of the landfill W is equal to 100 meter. Side slope S is 4 horizontal to 1 vertical. Storage volume of the landfill V is equal to 30000 meter cube that means 3 into 10 to the power 7 liters. So, this kind of the volume of the landfill is required.

(Refer Slide Time: 44:45)



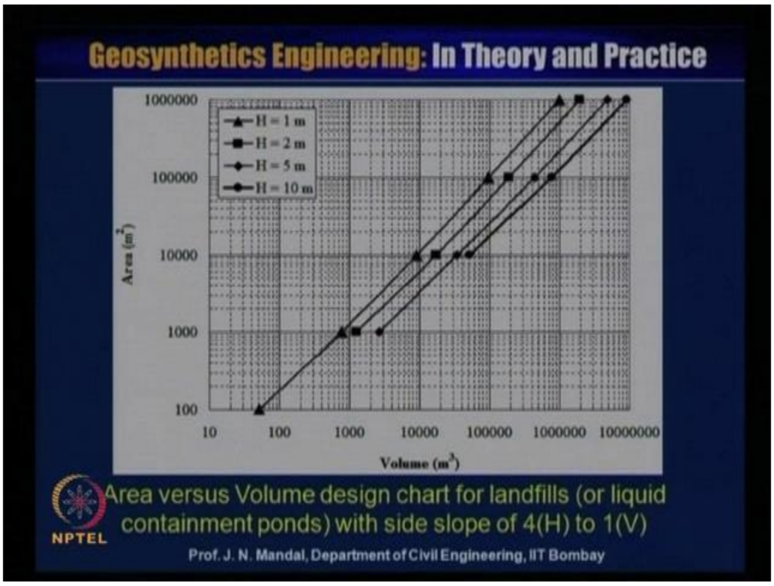
Now, geometric consideration here the problem statement the program is determine, the depth of the liquid containment system for a particular storage area that is rectangular area only. So, you have to be input data the storage volume required that is V in liter that will be the 3 into I say that here 3 into 10 to the power 7 this liter. Width of the ground surface that is W is equal to 100 meter length of the ground surface. L is equal to the 100 meter and slope that is horizontal to vertical that is S is equal to 4. You should put this input data and then you can calculate.

(Refer Slide Time: 45:48)



You can calculate and then you can obtain the output. That is required height of the liquid containment system that is h will be equal to 4.16 meter. So, here is comment that this calculated height is on the basic of the theoretical analysis. However the line impoundment must be somewhat deeper to allow for the 3 board against the overfilling or the wave action and so on. So, from this you can have some idea that what should be the height of the containment system of the landfill or the reservoir because you know that what volume is required.

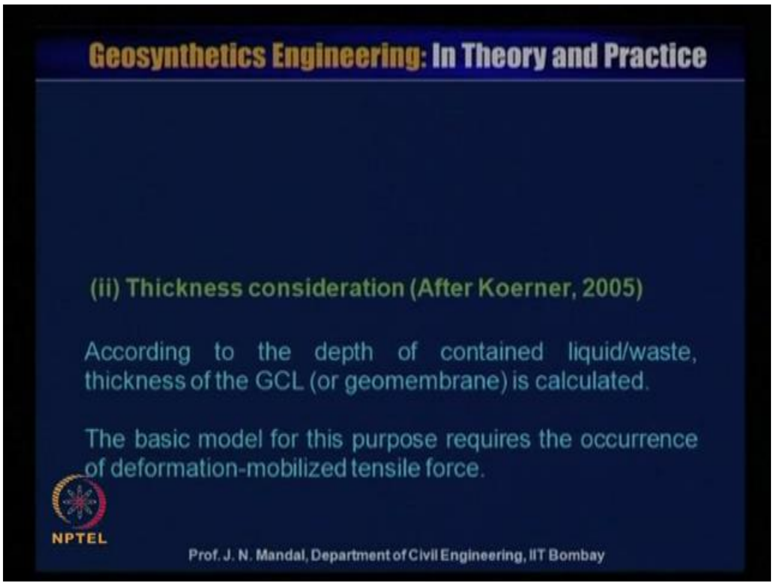
(Refer Slide Time: 46:52)



So, here this area versus the volume design chart for the landfill or liquid containment pond with the side slope of 4 horizontal to 1 vertical is shown. So, this is the volume in meter cube and this is the area in meter square. This is the H value the h value may be 1 meter H value is 2 meter, H value is 5 meter or H value may be 10 meter. So, suppose you should know what should be the height of the reservoir or the landfill. So, you know that what should be the volume you require. So, if you know the this quantity of the waste material are to be dumped for so many years or you wanted to construct a reservoir. So, you know the what should be volume of water you wanted to store using the geomembrane material. Then you can think about the what should be the height, whether height you require 10 meter 5 meter 2 meter or 1 meter.

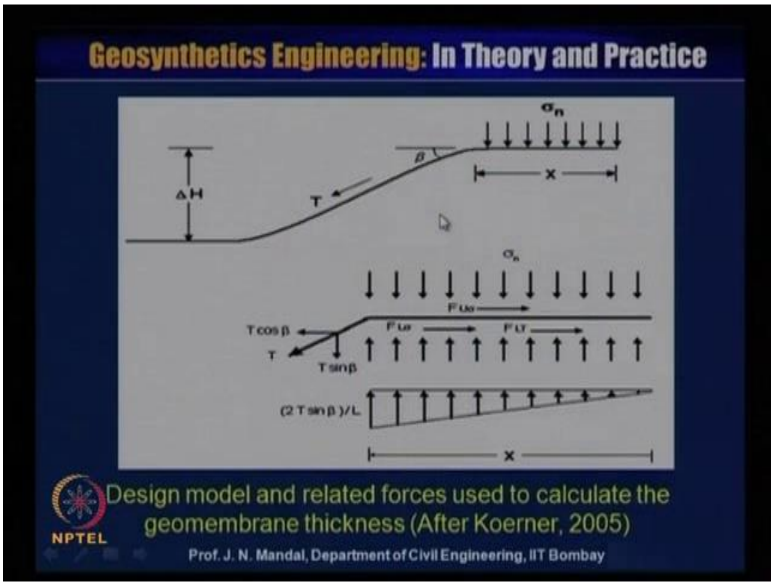
Then you can you will be knowing that what area in meter square whether you required 10 thousand meter square, 20 thousand, 1lakh meter square. So, that area depend upon the availability of the area. So, you can change the height of the reservoir. So, from this design chart you can calculate what will be the height of the reservoir.

(Refer Slide Time: 48:49)



Now, second consideration thickness consideration the after Koerner 2005. According to the depth of the contained liquid waste thickness of the geosynthetic clay liner, or geomembrane is calculated the basic model for this purpose require the occurrence of deformation mobilized tensile force.

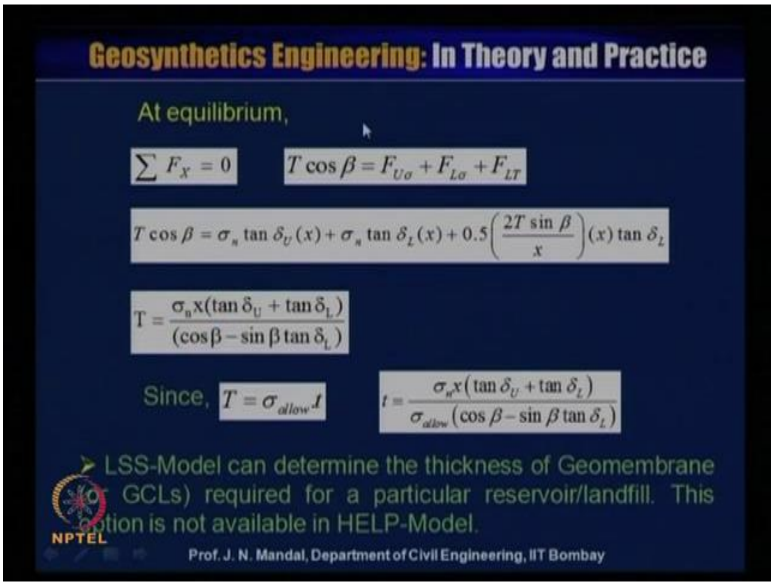
(Refer Slide Time: 49:16)



Now, here design model and related forces used to calculate the geomembrane thickness. This is very important that where geomembrane thickness it should be the after Koerner 2005. So, this is the geomembrane this is you are placing along the slope which is you are making at an angle of beta and this is the tensile force of the reinforcement this height is equal to delta of h. This is the distance x where the shear force mobilized that where distance you should keep and this is the normal forces are acting here.

So, this is the sigma of n and this T is allowable tensile strength of the reinforcement which is making at angle beta. So, this will be t of cos beta in the horizontal direction and this will be T of sine beta. You know what is that F u sigma which is in the upper shear stress is acting and then this is the lower F l sigma. This is F l sigma T due to the vertical component T of sine beta and this distance is the x. So, this is 2 sine beta divided by L.

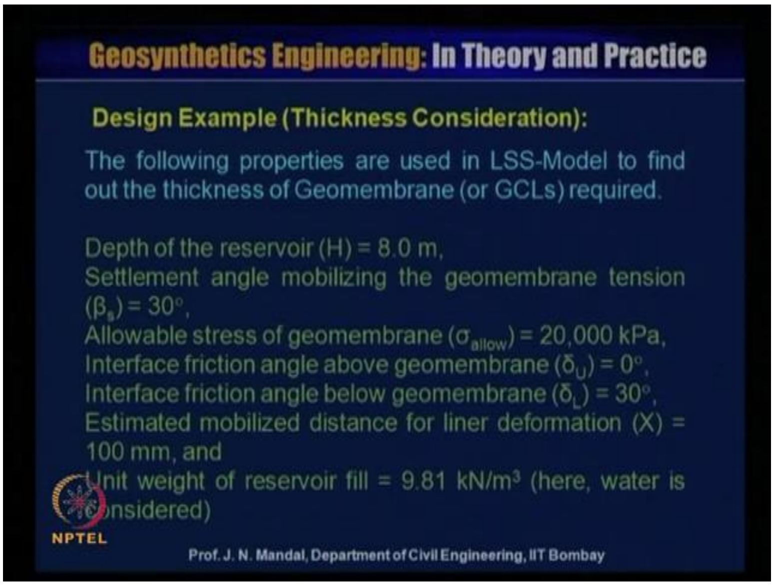
(Refer Slide Time: 50:26)



So, with this you have to make the equilibrium. At equilibrium summation of F x is equal to 0. So, we can write T cos beta from this here that is T cos beta is equal to this plus this plus this. So, you can write T cos beta F u sigma plus F l sigma plus F l t. So, also you can write T cos beta will be equal to that means this T this is T of cos beta will be equal to sigma n in tan delta u into x. This in the upper you know this is sigma n and this is tan delta u in the upper zone into this is x this distance is x. So, sigma n tan delta u into x plus sigma n tan delta l this is the lower into x plus 0.5 2 T sine beta by x into x into tan of delta L for this. So, you can calculate what is T?

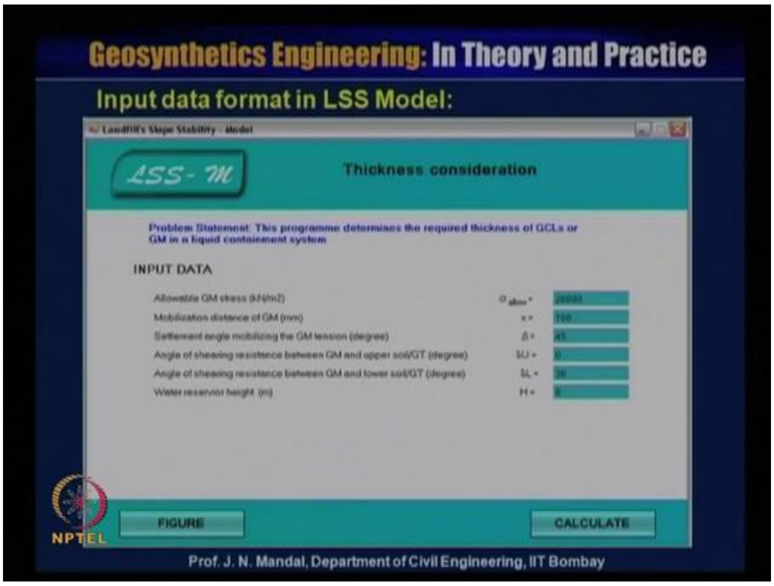
So, you can obtain T is equal to sigma n into tan of delta u plus tan of delta L divided by cos beta minus sine beta into tan delta L. Since you know the T is equal to sigma allowable into T where T is the thickness of the geomembrane. So, ultimately you will obtain this T that is this T is equal to sigma n into x tan delta u plus tan delta L divided by sigma allowable into cos beta minus sine beta into tan delta L. So, now in the landfill slope stability model or LSS mode can determine the thickness of geomembrane or geosynthetic clay liner required for a particular reservoir or landfill. This option is not available in the Help model.

(Refer Slide Time: 52:25)



So, here is a one design example that thickness consideration the following properties are used in the LSS model to find out the thickness of geomembrane or geosynthetic clay liner required the depth of the reservoir K is equal to 8 meter. Settlement angle of mobilizing of the geomembrane tension that is beta s is equal to 30 degree. Allowable stress of geomembrane sigma allowable is equal to 20,000 kilo pascal. Interface friction angle above the geomembrane delta u is equal to 0 degree. Interface friction angle below the geomembrane delta l is equal to 30 degree. Estimated mobilized distance for the liner deformation x is equal to 100 millimeter and the unit weight of reservoir fill is equal to 9.81 kilo Newton per meter cube, here water is considered.

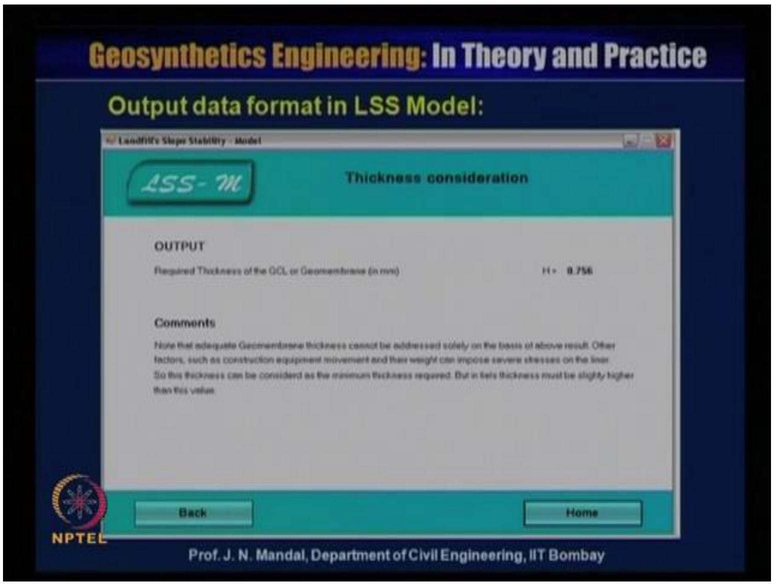
(Refer Slide Time: 53:21)



So, this is the input data format in the LSS model that is problem statement. This program is determined the required thickness of the geosynthetic clay liner or geomembrane in a liquid containment system. Input data that is allowable geomembrane stress is equal to sigma allowable is 20000 that is kilo Newton per meter square this is geomembrane. So, is stress expressed in kilo Newton per meter square and mobilization distance of the geomembrane x is equal to 100 millimeter.

Settlement angle mobilized for geomembrane tension that is beta is equal to 45 degree. Angle of shearing resistance between geomembrane and the upper soil or geotextile that is delta of l if it is 0 and of shear resistance between the geomembrane and lower soil g t degree delta l is equal to 30 degree. So, water reservoir height H is equal to 8 meter.

(Refer Slide Time: 54:31)

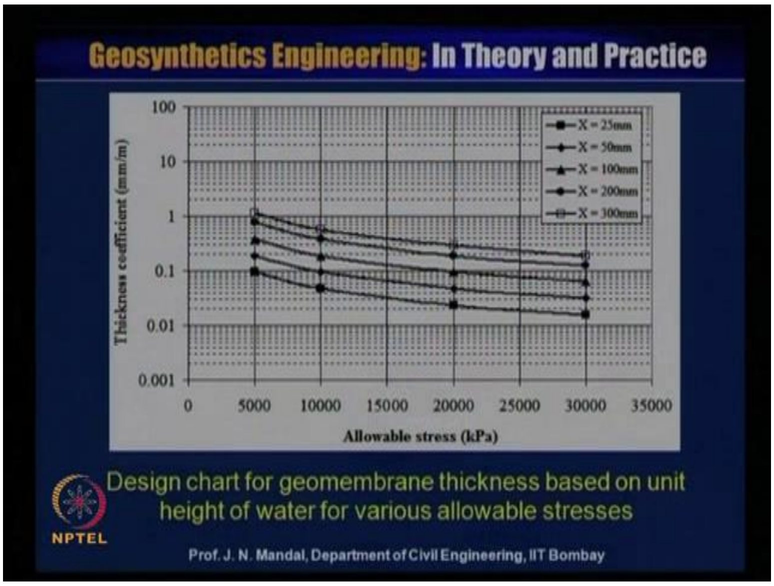


So, if you calculate you can obtain the thickness consideration. So, output of this required thickness of the geosynthetics clay liner or geomembrane H will be equal to 8.756 that millimeter. So, here is the comment note that the adequate geomembrane thickness cannot be addressed solely on the basic of the above result, either these factors such as construction equipment movement and their weight can impose severe stresses on the liner.

So, this thickness can be considered as the minimum thickness required, but the thickness must be slightly on the higher than this value where specified. Suppose this here this thickness of consideration H is 0.756 millimeter because we have to check up that also the manufacturer production sometimes it is 1 meter 1.5 meter and 2 meter. So, accordingly you can select the thickness of the geomembrane material.

Apart from that you know because when you are constructing that land fill or the reservoir and you have to compact the cover soil. So, there is a possibility for the damage of the geomembrane material. So, it is always the preferable that you could provide with the higher thickness of the geomembrane material. If suppose you are having here the thickness of the geomembrane is 0.756 meter though it is 0.75 millimeter thickness is available. But it is preferable to consider that 1 millimeter thickness of the geomembrane, or depending upon the situation you can also design and you can have also something higher value also.

(Refer Slide Time: 56:48)



So, this is the that design chart for geomembrane thickness based on the unit height of water for various allowable stress. So, this is the x axis is the allowable stresses and this is the thickness coefficient millimeter per meter. This is the x that it may be 25 millimeter or may be 50 millimeter or 100 millimeter or 200 millimeter or 300 millimeter. So, this is the what thickness for this allowable stress. So, you can see here this x value means this is the this is the x this also may vary.

So, that is why this x value this is the different values of x that is why you are having the different curve based on the value of the x. So, if it is a minimum this x value is here if it is a higher value maximum suppose x value is equal to 300 millimeter. So, depending on this that what will be the allowable stress of the geomembrane, then you knowing the value also the selecting the value of x. So, thickness coefficient also can be determined from this chart. With this I finish my lecture today. Let us open a question from your end.

Thanks for listening.