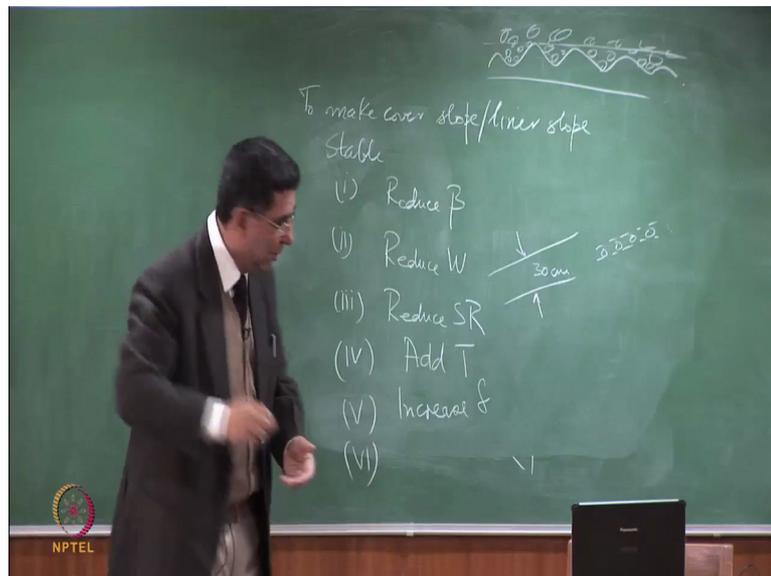


Geoenvironmental Engineering (Environmental Geotechnology): Landfills, Slurry Ponds & Contaminated Sites
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Lecture - 20
Stability of Slopes - Part 3

Welcome to the last lecture on stability of slopes, today we will see a few case studies and we will also look at the design of anchor trench for getting adequate capacity to hold reinforcement at the top of a slope. So, if a slope is coming out to be unstable what is it that we can do to make it stable? So, we are using a very gentle slope of 3 is to one last time I showed you that even with the gentle slope of 3 is to one you can have a little bit of problem. So, what I will can we do how do a make a slope stable. So, I can simplest is I can make the slope flatter, right.

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So, to make cover slope or liner slope reduce beta you use the slope intonation. So, we are now coming into that 3 is to 5, 3 is to 1 to 5 is to 1 that is the preliminary slope that I gave you. Many landfills will have 4 is to 1.

What else can we do? Reduce W. So, just as an example if I want to reduce W what can I do; I have the W of the topsoil and I have the W of the drainage layer can I reduce the W of the topsoil by reducing the thickness all depends on what you want to grow on the top

right. We said it depends on the root penetration zones so, if you are going to grow shrubs or little higher than just grass then definitely you need 45 centimeters there if not 60 centimeters. So, you need 1 and a half feet of soil. Can I reduce the drainage layer? Yes. How can I reduce the thickness of the drainage layer?

Student: (Refer Time: 02:45).

Right, we can use a geocomposite and let us say that if I have a 30 centimeter drainage layer I can instead put on geo composite instead of that this will make a lot of difference to W significant just if you were to calculate in terms of the weight per square meter right. So, the gamma of the soil can be 2 tons per cubic meter and this is 0.3 meters.

So, it will become 0.6 tons per square meter; instead if I was to use a geocomposite what would it be? Way much lighter what is the grams per square meter of the geotextile I told you that you should adopt a geotextile of 400 GSM; 2 geotextiles 400 plus 400; 800 GSM, add the weight of the geonet to it another 800. So, 1500 grams per squares meter that is 1.5 kilograms per square meter and what was the kilograms of 30 centimeter of sand per square meter; it will be 100.

Student: (Refer Time: 04:24).

100s of kilograms, so, you can definitely reduce W by reducing thickness the question is can the geocomposite handle your water sand can definitely handle a water or sand gravel, but will the geocomposite handle it if it does not what will happen submergence ratio will go up if submergence ratio goes up factor of safety goes down. So, yes you should reduce W what else you do reduce submergence ratio its possible what else can you do add t ; that means, add a reinforcing element.

So, all this can help you improve the factor of safety of course, without any doubt try and increase δ . So, in the case of sand when I use a textured geomembrane what is δ 25 to 5 right to increase δ 25 to 5 can I make my δ more than 5 I will make my your membrane really rough we will δ become more than 5, no, it seems if it is smooth it is less than ϕ , if it is adequately rough it is equal to ϕ , if it is more than rough will it become more than ϕ .

Student: (Refer Time: 06:17).

No because.

Student: (Refer Time: 06:18).

Because.

Student: (Refer Time: 06:22).

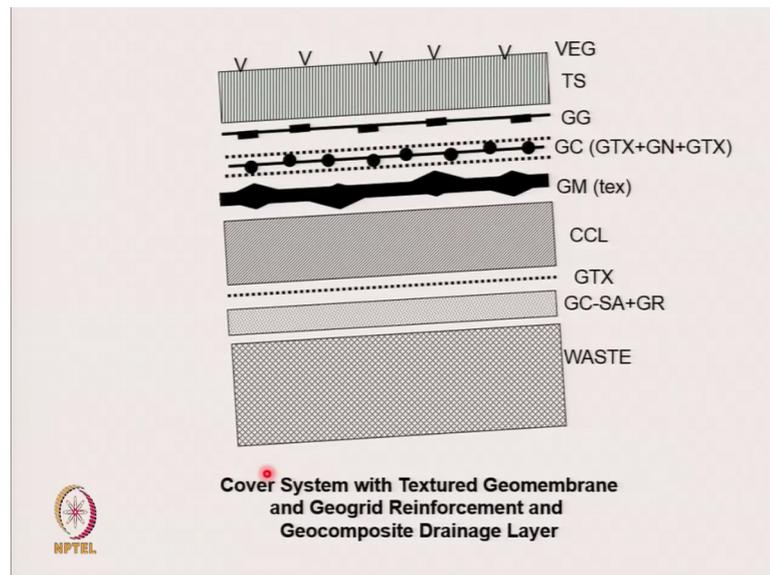
Because phi is the limiting value no matter how rough I make my geomembrane bigger than the sand particles right that looks very rough no these are my sand particles, but what will happen when I make it very rough the failure surface in pass through soil and the limiting value will be when a surface will not pass through this it will pass through the soil and therefore, the limiting value will be phi you cannot make anything rougher than the phi of the soil the roughness can be larger, but the limiting value is phi.

So, I should increase that problem is not its sand you are able to get delta equal to phi with rough problem is the interface between the geomembrane and the clay and then clay the long term phi dashes anyways depending on the plasticity of the clay c dash is 0 and phi dash is definitely less than 25 it is not going to; so, you can a best take your delta to 15 to 20 it would be too difficult somebody says sir I will put some sand in between the clay and the geomembrane how is that for increasing deltas that is a jolly good idea when you move the geomembrane on the clay it is giving low delta. So, I will put some sand.

Student: (Refer Time: 07:47).

There will be no intimate contact and therefore, you will get 0 out of 100 in an exam and in and you all get a lot of leakage in the field and you all be fired; fired means if you are in America you will be thrown out if you are a designer it will be showcased everywhere how not to design a composite barrier because the intimate contact is very very important and you will be de credited; that means, you got a you had a professional engineer certification. So, you all said no cross. So, exactly this do not put any sand between the geomembrane and the clay let us look at a couple of case histories realize problem.

(Refer Slide Time: 08:32)



So, what do you see here student: here the waste slope was not becoming stable. So, what they did whatever I have written on the board they did not reduce the topsoil thickness, but they replaced the sand with the geocomposite geotextile geonet geotextile and they made the geomembrane rough, but now it is not about delta between sand and the geotextile it is between the sand and the geomembrane it is delta between the;

Student: (Refer Time: 09:07).

Geomembrane and geocomposite and the lower surface of the geocomposite is a;

Student: (Refer Time: 09:15).

Geotextile, so, this delta is geotextile to geomembrane agreed that becomes up comes into play and they have also put a geogrid.

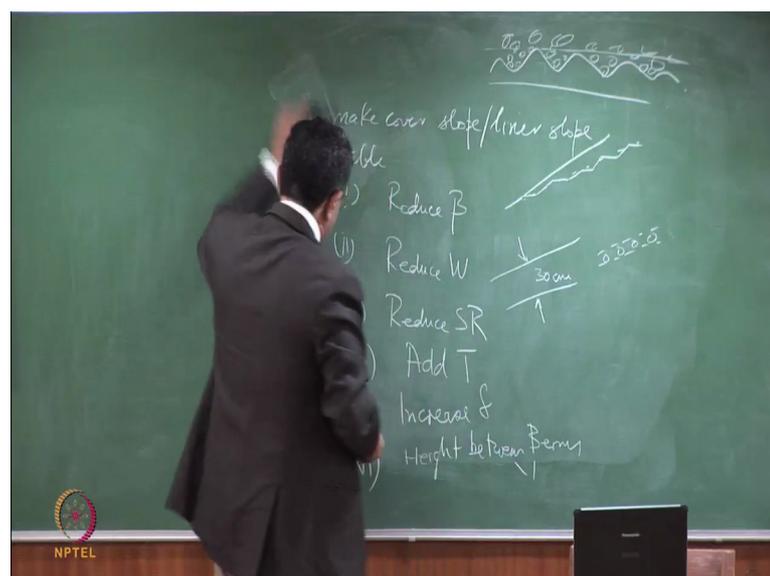
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Table 7: Results of Stability Analysis at Interface of GM (textured) – Geotextile (NW, NP) ($\delta=17^\circ$) with Geogrid Reinforcement after replacing Drainage Layer by Geocomposite Drain (5mm)

Slope (H:V)	Height between Berm (m)	FOS With Reinforcement							
		Long Term Tensile strength T = 30 kN/m				Long Term Tensile strength T = 40 kN/m			
		Dry	Seepage	E.Q	E.Q + Seepage	Dry	Seepage	E.Q	E.Q + Seepage
2 : 1	5.00	2.24	1.63	1.23	1.01	19.64	6.53	2.51	1.98
	7.50	1.19	0.93	0.81	0.68	1.73	1.31	1.05	0.87
	10.00	0.96	0.77	0.69	0.58	1.19	0.93	0.81	0.68
2.5 : 1	5.00	2.80	2.04	1.40	1.17	24.47	8.15	2.61	2.13
	7.50	1.48	1.17	0.96	0.81	2.16	1.63	1.21	1.02
	10.00	1.20	0.96	0.83	0.70	1.48	1.17	0.96	0.81
3 : 1	5.00	3.36	2.45	1.55	1.31	29.55	9.80	2.68	2.25
	7.50	1.78	1.40	1.09	0.93	2.59	1.96	1.36	1.15
	10.00	1.44	1.15	0.95	0.81	1.78	1.40	1.09	0.93
3.5:1	5.00	3.92	2.86	1.67	1.43	34.56	11.45	2.73	2.34
	7.50	2.08	1.63	1.20	1.03	3.02	2.29	1.48	1.27
	10.00	1.68	1.34	1.05	0.91	2.08	1.63	1.20	1.03
4:1	5.00	4.47	3.26	1.77	1.54	39.11	13.03	2.76	2.41
	7.50	2.37	1.86	1.30	1.13	3.45	2.61	1.58	1.37
4:1	10.00	1.92	1.54	1.15	1.00	2.37	1.86	1.30	1.13

So, the idea was to how steep can we get this W is down delta is up T is up looks like the one of the best cover systems that we can get here are the results how many cases dry seepage earthquake; earthquake plus seepage you remember are acceptable factors of safety 1.5 1.3 1.1 and 1 by 05 or something like that. So, these are the 3 cases and remember I am only showing you one table I am showing your table oh; we forgot here a very important thing, what did we forget I talked about.

(Refer Slide Time: 10:08)



Student: (Refer Time: 10:15).

Height between berms the height of the slope, so, the lower it is the better do you remember that when I give too many berms what am I doing I am actually flattening the slope if I did not give a berm the slope would be here if I give too many berms the slope is ending here. So, I am in de facto I am flattening the slope that does not keep my objective giving too many berms because then I might well make a gentler slope. So, what have I done I have put a T lobal of 30 and a T lobal of 40; this is normally not possible with geomembrane this implies that I am using a geogrid is there a problem you cannot see I hope the camera can catch it.

Now, let us look at the results I started with a very ambitious slope well let us look at the gentlest slope I started with the gentle slope of 4 is to one everything is stable height between berms 57.510 beautiful factors of safety unimaginably high factors of safety and I go to a slope of 2 is to one I am trying to get a slope which are normally can get in soils can you make a embankment of 2 is to one to horizontal to one vertical is a slope which you can make an embankment or no definitely.

So, let us see whether we can make this there is a geotextile a geogrid of 30 kilo Newton per meter and 42 is to 1 and I find 5 meters is too small. So, the client was more interested in having a berm height between berms of 7.5 I am going to look at the solution my drive was 1.19 why the cause that delta was seventeen because the it was between geomembrane textured and geotextile it is not between geomembrane and sand delta was seventeen and 2 is to 1; 1.19 below 1 below 1 below 1. So, fail of gas slope even if you take T to 40.

Nothing exciting happens 1.19 goes to 1.73 good 0.93 goes to 1.31 good because we wanted 1.3; 0.81 goes to 1.05, but there say if there is rain and earthquake it falls below 2 and that is not acceptable. So, 2 did not work. So, we try to 0.5 let us make the slope flatter does it work with 30 kilo Newton per meter 1.48 almost 1.5, but seepage is still below 1.3 right and earthquake it does not work and earthquake the seepage does not work, but if I take 40 kilo Newton per meter 2.16 is more than 1.5; 1.63 is more than 1.3 1.2; 1 is more than 1.1 and 1.02 is more than one this is the rarest of the rare this is not likely to occur some codes may not even ask you to do it, but I you are doing this.

So, Bombay and Bombay you know with monsoon comes does it come how do we know because every year we see flooding in Bombay and lot of water. So, we just said will try

this. So, with 40 kilo Newton per meter now the only thing is can you hold 40 kilo Newton per meter at the top how many how 40 kilo Newtons just to convert it into tons how many tons is this.

Student: (Refer Time: 14:33) 4.

4 ton.

Student: 4.

It is like a truck full of 4 tons of waves and every meter has to hold that. So, it will a soil or one meter width hold a truck from falling down we will have to find that out. So, while theoretically if you give it a tension you have to see whether the anchor trench will hold or not I can give you a product which will give you 40 kilo Newton per meter I can give you a design which works, but the design will only work if the 40 kilo Newton per meter can be held where at the top are at every berm?

Student: (Refer Time: 15:20).

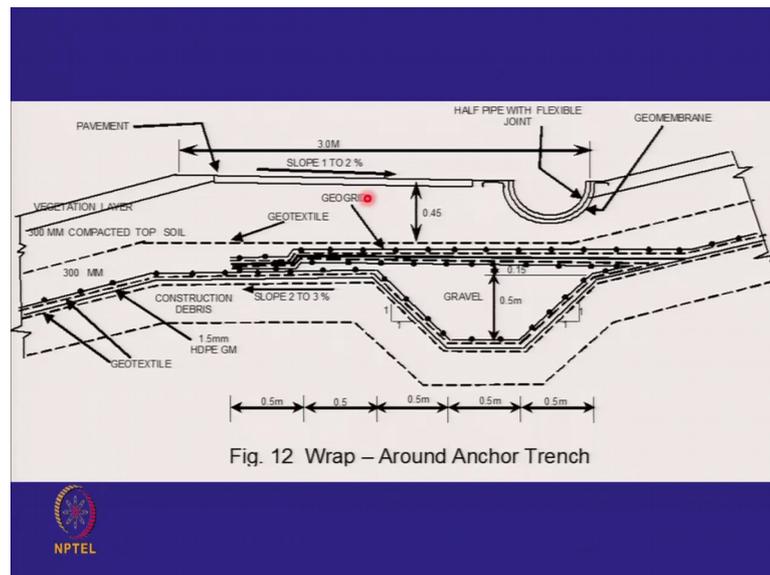
Because the solution is for 7.5 meters if you are going to say at the top suppose there are 4 berms of 7.5 take 30 meters multiply this by 4 and then you have to do 4 times because every segment has the unbalanced tension the (Refer Time: 15:38) So, this has to be done at every berm and how much width do you have in a berm.

Student: (Refer Time: 15:44).

1.5 meters, so, well complicate it, but anyways theoretically there is an answer we were hoping that with 30 kilo Newton per meter this would become stable 7.5 dry was find seepage was find earthquake was find, but this was still 0.93. So, what it told us was that even with all this if I want to use a T equal to 30 kilo Newton per meter I have to use a slope of 3.5 is to 1 with everything we have done my do the leaves 4 is to 1 and be happy.

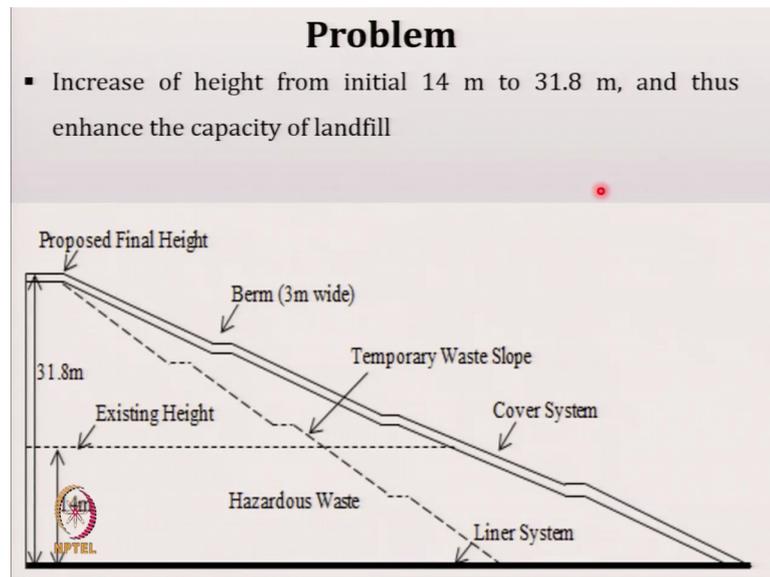
I am saying up putting 30 kilo Newton per meter reducing it to the geocomposite nothing great happened because 4 is to one the delta would be very low, but beta would be much lower. So, let me now go back and see we have 2 there are 1 2 and 3 geo geosynthetics which are coming in rolls right and all of them have to be anchored at the top.

(Refer Slide Time: 17:03)



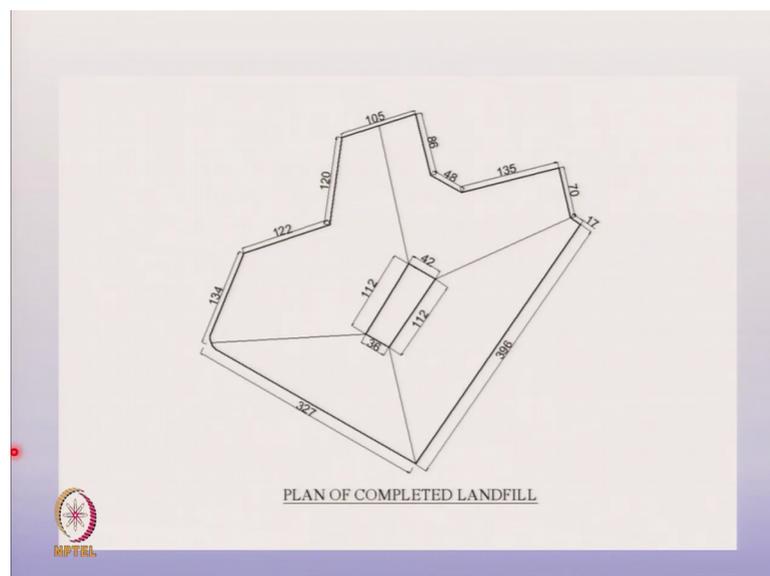
So, what happens when I look at the construction drawing I had a berm it just goes crazy it is not so easy to construct the anchor trench input 1 2 3 4 putting the (Refer Time: 17:16) inside it and then you have to wrap it around because you are not getting enough capacity. So, so the geomembrane and the geotextile and the geocomposite and the geogrid everything has to be it comes up the slope it has to be put in a trench has to be wrapped around and you have to make a berm at the top and you do not have a drain and. So, this is complicated if I was to make it 4 is to 1 maybe 4.54125 is to 1, I may not need any Anchorages. So, this whole thing is sometimes the solution are complicated let me take another example view. So, far we have been discussing about interfaces.

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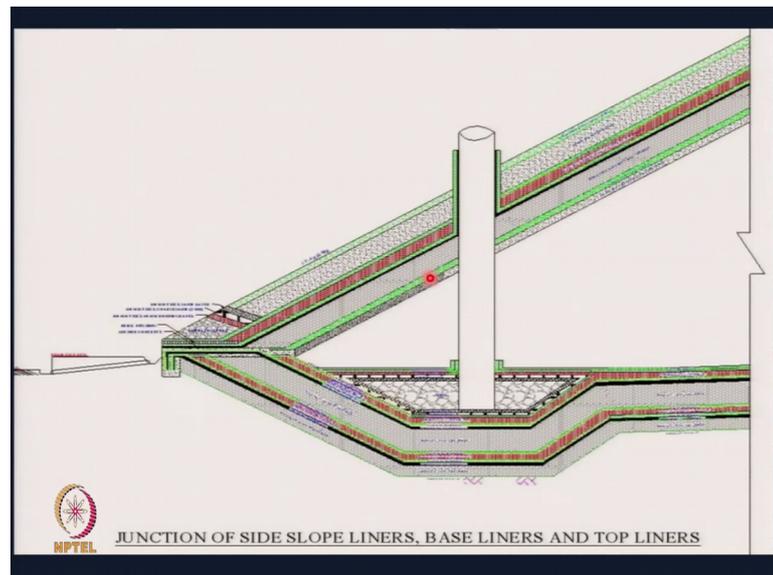
Let me now focus on another aspect I said excavated slope I have to analyze waste slope I have to analyze and I have to analyze the interfaces I have done the interfaces this is a landfill which is under construction in west in India and it was originally designed for a height of 40 meters and the outer slope is 4 is to one very very gently the owner said I want to make this landfill to 31 or 32 meters high I want to store more waste. So, this was the original landfill this is the 31 meter high landfill he asked us to check the stability of this not the interfaces we had checked, right.

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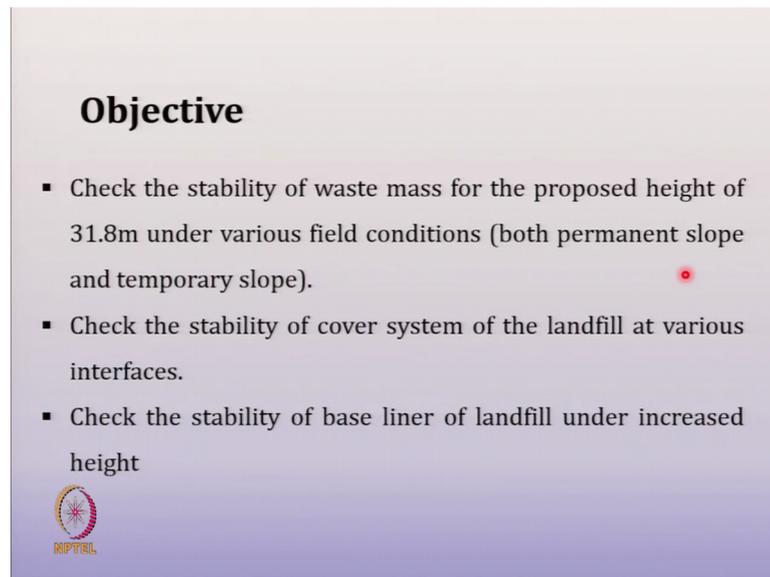
This is what the landfill looked like in plan and this is the top of the landfill and the base this profile and this is the little flat ground at the top it is like a conical mount going up and do see that this is about 300 meters and if you are coming 4 is to 1; 30 meters 120 meters will go here 4 is to 1.

(Refer Slide Time: 19:41)



Another 100-200 meters will go there all that will be left at the top is 40-50 meters it was an above ground landfill not below above ground that is the Leachate collection well these are the multiple double composite layer that is the cover system you can see the geomembrance and everything we are not discussing this stability we are discussing this stability; stability of the mass objective check the stability of the waste mass.

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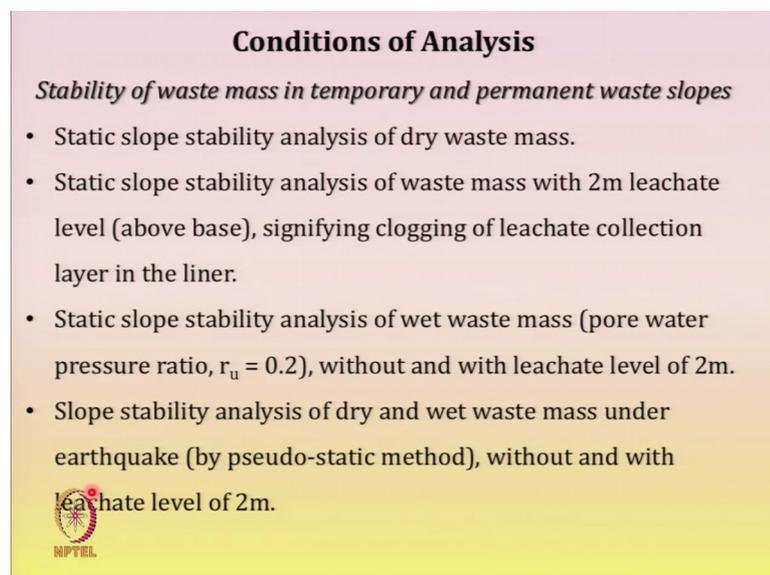
Objective

- Check the stability of waste mass for the proposed height of 31.8m under various field conditions (both permanent slope and temporary slope).
- Check the stability of cover system of the landfill at various interfaces.
- Check the stability of base liner of landfill under increased height



For the proposed height of 32 meters check the stability of the cover system at various interfaces which we will not discuss check the stability along the base liner you know base liner in conditions of analysis.

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Conditions of Analysis

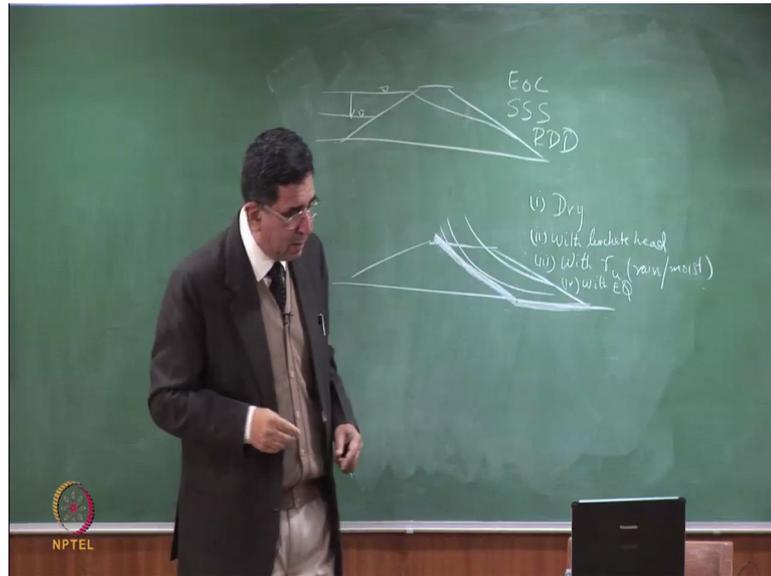
Stability of waste mass in temporary and permanent waste slopes

- Static slope stability analysis of dry waste mass.
- Static slope stability analysis of waste mass with 2m leachate level (above base), signifying clogging of leachate collection layer in the liner.
- Static slope stability analysis of wet waste mass (pore water pressure ratio, $r_u = 0.2$), without and with leachate level of 2m.
- Slope stability analysis of dry and wet waste mass under earthquake (by pseudo-static method), without and with leachate level of 2m.



When you want to do the waste mass what conditions would you adopt for an embankment of or a damp.

(Refer Slide Time: 20:42)



What are the conditions of analysis you normally do 3 conditions for a dam you do 2 conditions for an embankment for a dam what are the 3 conditions of analysis.

Student: End of construction.

End of construction.

Student: Steady state seepage.

Steady state seepage and.

Student: Rapid (Refer Time: 21:07).

And rapid draw down end of construction means the embankment after compaction as it has come up steady safely seepage means the reservoir has become full and there is a flattened line which is developed and rapid draw down means this falls rapidly to a lower level that is what we do for an embankment what do we do for a landfill we are talking of failure to the waste mass well a few similar conditions the first is the dry test first in the dry test second is with Leachate head.

See unlike an embankment which does not have a liner at the bottom if any rain comes through it will go down right here we have made a liner and we have got a Leachate collection system. So, there should normally be no Leachate maximum head should be 30 centimeters corresponding to the thickness of the Leachate collection layer, but what

do we have here we have a liner suppose the Leachate collection system is clogged suppose it becomes clogged then the Leachate will rise inside the landfill. So, when we are saying we have to do with Leachate head it means Leachate to some level when you do a road embankment you also do an analysis with rain and rain is simulated by a pore pressure parameter RU.

Student: (Refer Time: 22:49).

So.

Student: (Refer Time: 22:50).

You can also have.

Student: (Refer Time: 22:51).

That means it is simulating rain or moisture not fully saturated, but you are wet waste therefore, you are having pore potential development as the layers come on top of the other then of course, with earthquake.

So, these are some of the cases which one can analyze for the failure through the mass I am talking of these failures and one more failure that I am talking about is I told you because we have a base liner which may have a geomembrane that may be an interface which is very weak in all the landfills that we have designed we have kept the base line or smooth because you said there is no slope fine, but we did not realize that you can have failure like this. So, our delta is very slope for the base line delta is high for the side slope liner and see what happened in this case study. So, we did stability of waste mass in temporary and permanent waste slopes permanent waste slopes of 4 is to 1 not a problem the temporary waste slope is when the soil when the waste is being filled up they tend to have steeper slopes.

So, they are steeper than 4 is to one. So, we are looking at 3 is to one we did statics to slope stability of dry mass static slope stability analysis of waste mass with 2 meter Leachate level signifying clogging of Leachate collection layer we did static slope stability of wet mass pore pressure ratio of 0.2 RU 2 cases without and with Leachate level. That means, with clogging and without clogging, and finally slope stability analysis of dry and wet waste mass under earthquake by the pseudo static method.

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Material Properties considered for Analyses			
Material	Unit Weight (kN/m ³)	Cohesion (kPa)	Angle of Shear (°)
Materials used in stability analyses of waste mass			
Waste	16	3	25
Clay Liner	20	2	23
Subgrade Soil (Clay)	14 (Unsat.)	85	0
	18 (Sat.)	0	24
Materials used in stability analyses of cover system and liner system			
Drainage Sand	19 (γ _{dry})	0	30
	20 (γ _{sat})		
Drainage Sand- Geotextile		0	24
Geotextile- Textured GM		0	26
Textured GM-Clay Liner		0	24
Smooth GM-Clay Liner interface		0	10

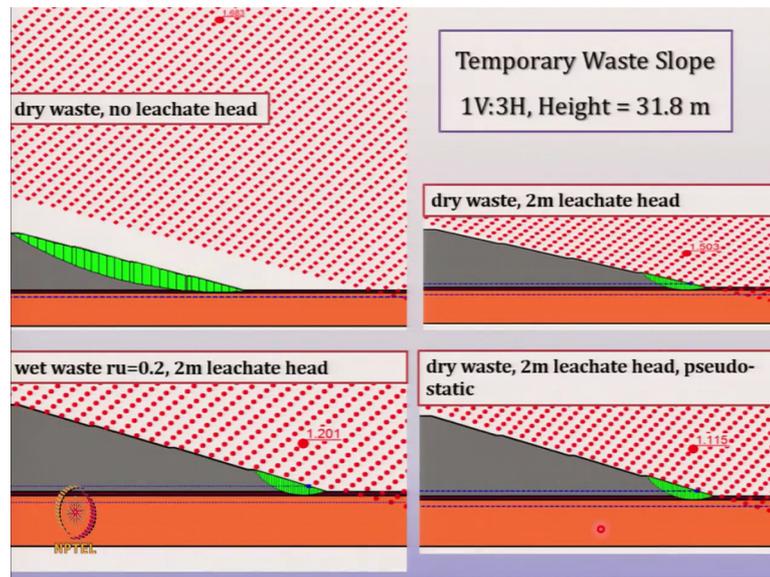
So, these are the conditions which we analyzed and these are the properties that we used unit weight cohesion angle of shear and these were the interface values that we used modern thing for you to notice that at the base also we have a liner and smooth geomembrane clay liner interface tendencies.

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Stability Analyses	
Minimum Acceptable Factor of Safety (FoS)	
Permanent Waste Slope	
• Dry and Wet Waste	1.5
• Temporary Clogging (Short Term)	1.3
• Rain/Seepage (Short Term)	1.3
• Earthquake (Pseudo-static) (Very Short Term)	1.1
• Rain/Seepage/Clogging + Earthquake (Very Rare)	1.05
Temporary Waste Slope	
• Dry and Wet Waste	1.3
• Temporary Clogging (Short Term)	1.2
• Rain/Seepage (Short Term)	1.2
• Earthquake (Pseudo-static) (Very Short Term)	1.1
• Rain/Seepage/Clogging + Earthquake (Very Rare)	1.05

Textured geomembrane clay liners on the slopes 24 degrees that is not what we were really analyzing here and we use the same factor of safety which we have discussed in our earlier class.

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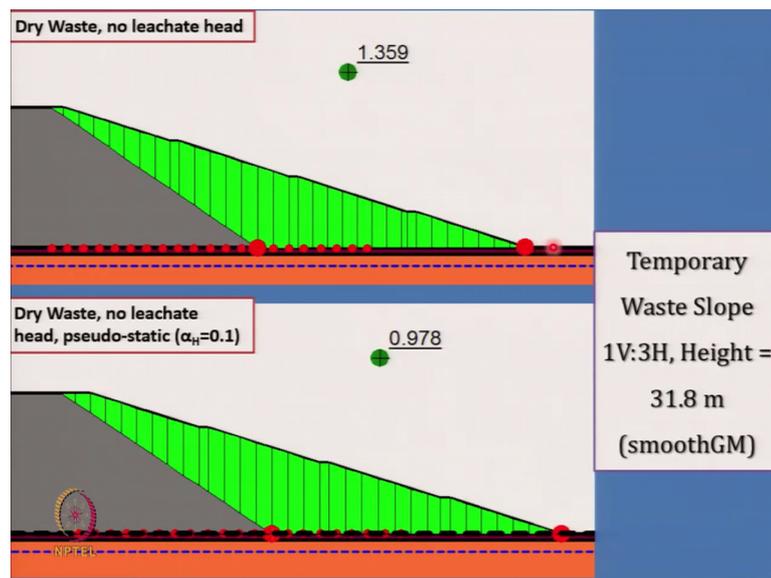
And here are my results this temporary waste slope it is assumed that before the cover is put the temporary slope has reached the top this 31 meters high dry waste no Leachate head factor of safety is 1.683; I do not know you cannot read it here, but itself 2 meter Leachate head 1.503 all very stable wet waste RU is equal to 0.22 meter Leachate head 1.201 and dry waste 2 meter Leachate head pseudo static with earthquake 1.115. So, just look at the shapes of the failure surface when the Leachate head comes then the failure surface tends to pass through the Leachate then there is no Leachate head it is a general large failure surface.

(Refer Slide Time: 26:59)

Results of Stability Analyses		
Temporary Waste Slope 1V:3H, Height = 31.8 m		
Condition	FoS	Acceptable FoS
Static analysis		
Dry waste, no leachate head	1.683	1.3
Dry waste, 2m leachate head	1.503	1.2
r_u Analysis		
Wet waste $r_u = 0.2$, no leachate head	1.335	1.3
Wet waste $r_u = 0.2$, 2m leachate head	1.201	1.2
Seismic (Pseudo-static) Analysis		
No leachate head, pseudo-static $\alpha_H = 0.1$	1.235	1.1
2m leachate head, pseudo-static $\alpha_H = 0.1$	1.115	1.05

But here the Leachate head this blue line show the Leachate head and therefore, its passing through this and if I look at the final critical factor of safety this is a temporary slope. So, the acceptable factor of safety is 1.3 here we got 1.683; 1.5 more than 1.2 and like this we got the factor of safety with RU find with RU and Leachate head find and so on and so included pseudo static where this was better than the acceptable factor of safety.

(Refer Slide Time: 27:38)



So, the temporary slope with circular failure surface was fine no issues we just said let us now put the delta 10 degrees here and now convert the problem into a 2 wedge problem right and this is smooth geomembrane 3 is to 1 dry waste no Leachate head 1.359.

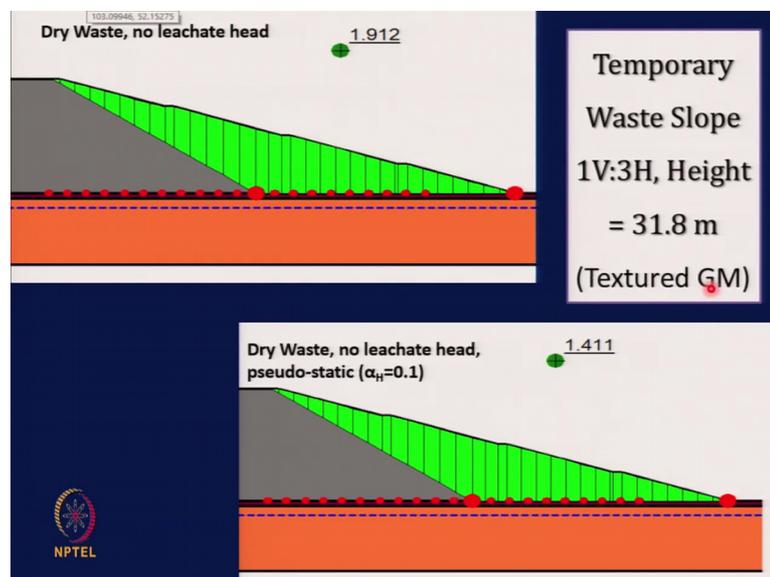
Since it is temporary slope 1.3 is acceptable, but dry waste is no Leachate head pseudo static method falls to less than 1. So, that is the problem that because we had a 10 degrees here the slope is not stable if the waste is full and an earthquake comes then it can just slip off the this human brain and all these red marks came out of the 2 wedge analysis.

(Refer Slide Time: 28:19)

Results of Stability Analyses		
Interface Sliding Stability of Base Liner System, Temp. Waste Slope 1V:3H, Height = 31.8 m, Smooth Geomembrane		
Condition	FoS	Acceptable FoS
Static analysis		
Dry waste, no leachate head	1.359	1.3
Dry waste, 2m leachate head	1.300	1.2
r_u Analysis		
Wet waste $r_u = 0.2$, no leachate head	1.059	1.3
Wet waste $r_u = 0.2$, 2m leachate head	1.037	1.2
Seismic (Pseudo-static) Analysis		
No leachate head, pseudo-static $\alpha_H = 0.1$, $T_{GM} = 12\text{kN/m}$	0.978	1.1
2m leachate head, pseudo-static $\alpha_H = 0.1$, $T_{GM} = 12\text{kN/m}$	0.915	1.05
* Basal interface shear angle = 10°		

So, while the circle of slip surface was all clear the interface was pulling it towards itself because it is the softer interface we just checked what if we had used textured what we are using at the side.

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The moment you use textured factor of safety 1.9; 1.411 everything becomes stable.

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Results of Stability Analyses		
Interface Sliding Stability of Base Liner System, Temp. Waste Slope 1V:3H, Textured Geomembrane		
Condition	FoS	Acceptable FoS
Static analysis		
Dry waste, no leachate head	1.912	1.3
Dry waste, 2m leachate head	1.819	1.2
r_u Analysis		
Wet waste $r_u = 0.2$, no leachate head	1.660	1.3
Wet waste $r_u = 0.2$, 2m leachate head	1.483	1.2
Seismic (Pseudo-static) Analysis		
No leachate head, pseudo-static $\alpha_{H1} = 0.1$, $T_{GM}=12\text{kN/m}$	1.411	1.1
2m leachate head, pseudo-static $\alpha_{H1} = 0.1$, $T_{GM}=12\text{kN/m}$	1.265	1.05
* Textured Geomembrane, Basal interface shear angle = 24°		

In fact, given becomes stable for 1 is to 2.5 is to 1. So, luckily you know this is a landfill which is going like that forward and we are in a second year of construction at the moment we still have another 15 years to come. So, we have replaced all the geomembranes for the future the base will also be textured because textured base gives you.

Student: Good values.

Good values now I thought that one of you will ask me this question that how did you use 24 degrees for textured with clay because I have given you the table it is typically 10 to 15 degrees well this stability analysis was done by an overseas consultant. So, they have given us this value. So, we told the owner that we think it should be about eighteen degrees, but if your consultant is underwriting this is fine when you make the geomembrane very rough it will become a clay to clay failure right what is the phi dash of clay less than 25 degrees 22, 23, 24. So, the thought in this design is that it is a clay to clay failure in a textured geomembrane. So, this has to be actually determined from the lab test it is very very critical.

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Conclusions

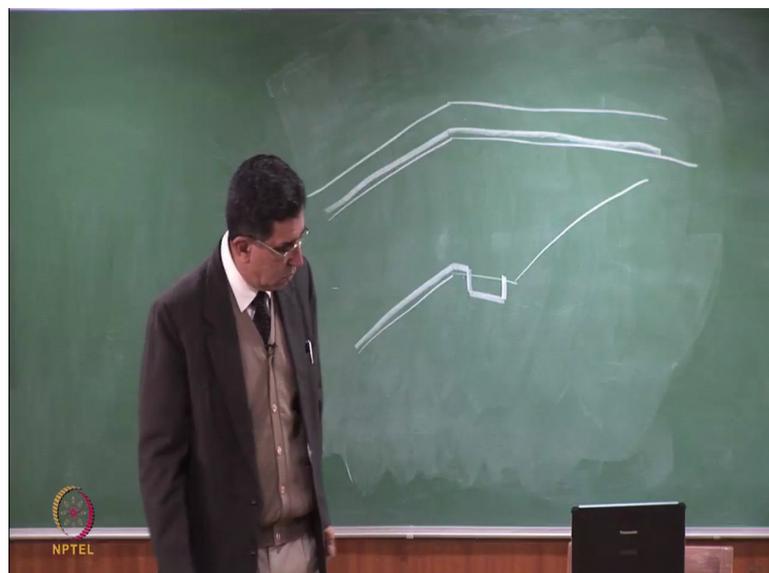
- It is normal practice to provide textured geomembranes along slopes of covers and liners of landfills.
- Along the base of landfills, a smooth geomembrane is usually provided as the base is horizontal.
- The present study shows that when height of an above-ground landfill becomes large, failure by two-wedge mechanism along the base can occur if smooth geomembranes are used; hence steep temporary waste slopes are not stable.
- It is desirable to have textured geomembrane along the base to enhance stability of steep temporary slopes of the waste having large height.



So, the conclusion is that even if circle of slowly stability analysis gives you fine please go to the weakest interface it is just like going in the zone damp you have to do a 2 wedge method along the core similarly here also please do a 2 wedge.

Method along the base and now let us come to the final think about anchorage how do we anchor the geomembrane at the top or at the berm both your geomembrane and a reinforcing geogrid if you are using the T you have to anchor them to the top right and the simple thing is if you know if you have a lot of horizontal.

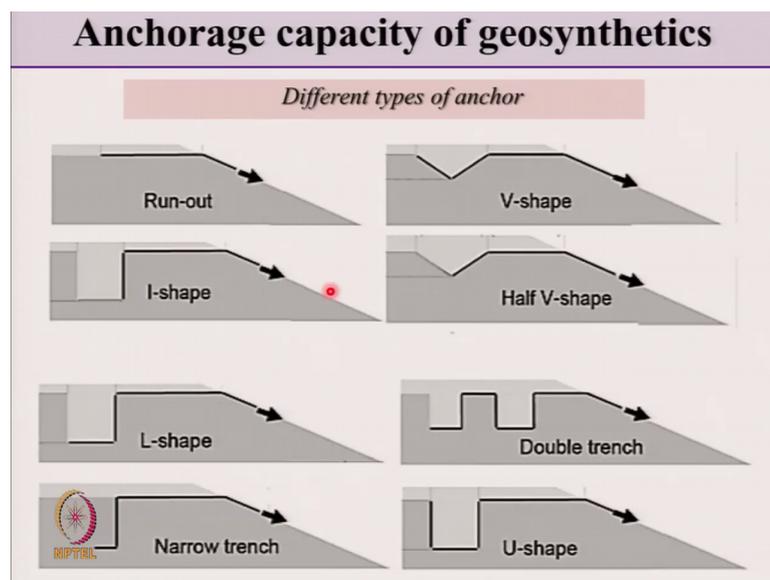
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Lengths available to you right here is your geomembrane coming up you take it horizontal there is cover soil at top to take it here and you keep on taking it till you get the capacity after all what is this capacity $q \tan \delta$, right. So, this is called horizontal anchorage at the top of a landfill you may take a geomembrane very far horizontally a few meters to hold the soil to hold the geomembrane even if the soil wants to slip then the T will be generated.

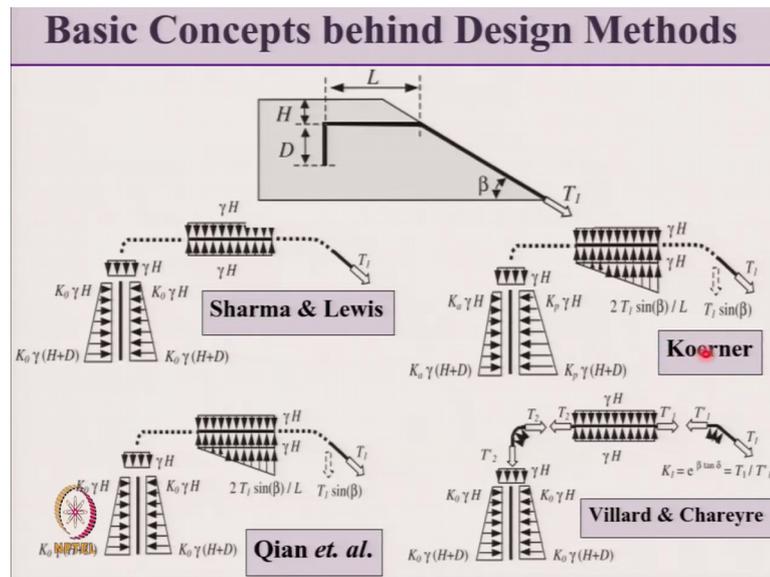
However, this long length may not be available to you [FL] if you are in a berm what will you do you have this problem this is your berm your geomembrane is coming what do you do you want 5 meters you do not have 5 meters. So, then the tendency is to put this in a trench digger trench here that is called an anchor trench. So, anchorage can be by just run out or anchorage can be through a trench.

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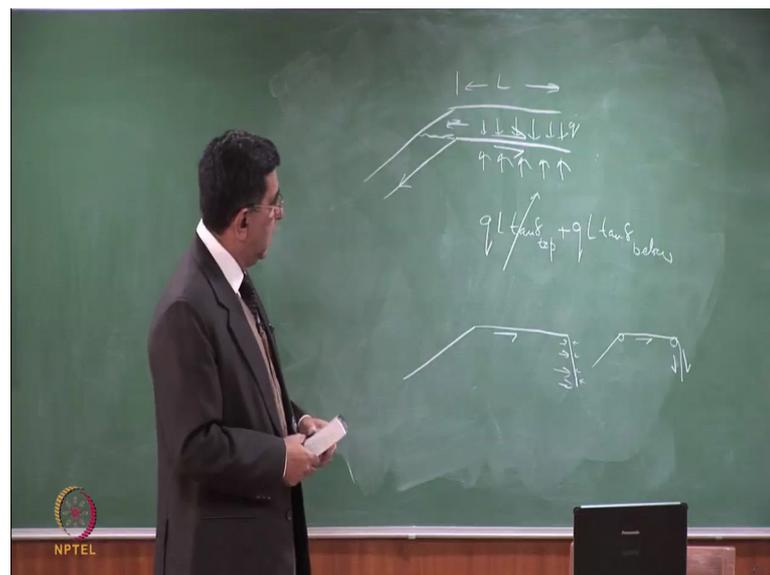
And there are some configurations of trenches run out just going down l narrow trench sometimes we may not be able to excavate vertically then V shape half v double trench u shape. So, these are the kind of anchorages which you can try it us not very simple to bend these thick geo geomembrance do you remember that that they are not like a thin things which can be you know like cloth that they can be bend, but they do bend and you can to the anchorage.

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Now, next therefore, the question is what about the capacity. So, there are many theories the Sharma and Lewis there is a Koerner theory and the Qian's theory and Villard and Chareyre Oscar theory you can take one of them and design them the simplest is Sharma and Lewis, but let me see what how you would like to solve this problem if I have this is simple as I said there is normal stress here and therefore, there is a reaction of the ground and therefore, there is a resistance agree.

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So, actually it should be if this is q this is l and this is q then $q l \tan \delta$ top plus $q l \tan \delta$ below because as you will pull this there will be friction at the top and friction at the bottom, but you know when your cover goes up it is possible that when you pull the geomembrane the cover will also come up because not very thick it is not held in restrained in position you have like this. So, maybe this will move out along with the geomembrane you put some soil on a geomembrane and try and pull it the top soil can come with it. So, therefore, one tends to neglect this though then you should take this shear strength into account though you should then take this shear strength into account.

But that is not taken into account in design as a conservative design the more important question is if you have a geomembrane like this. Then what is the additional resistance which comes quite clearly there will be a resistance here which is equal to this, how will this how will this give you or any resistance.

Well there are 2 theory there are 4 theories one of the theories is that it is this cluster if it behaves like a rigid wall what will happen p_p minus p_a agreed this $q l \tan \delta$ below plus p_p minus p_a this is assuming that the whole thing is rigid, but if you have assumed that there are frictionless pulley is here just assume that there are frictionless pulley is then what is it this and again somebody may not be able to see it if there are frictionless pulley is then the mechanism is different you are pulling its you will get friction here the topsoil is moving out with it this is a frictionless pulley here this will want to come up.

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Geomembrane Stability: Adequate Anchorage

q	=	normal stress from cover soil
T	=	force in geomembrane
δ	=	angle of shearing resistance between geomembrane and bottom soil
δ_i	=	angle of shearing resistance between geomembrane and trench backfill soil
P_A	=	active earth pressure on backfill side of anchor trench
P_0	=	at-rest earth pressure on insitu side of anchor trench
β	=	slope angle
t	=	membrane thickness
L	=	horizontal length of geomembrane
d	=	depth of anchor trench

(a) Horizontal: $T \cos \beta - T \sin \beta \tan \delta = q L \tan \delta$

(b) Horizontal + Trench: $T \cos \beta - T \sin \beta \tan \delta = q L \tan \delta + P_P - P_A$

So, it will be the $T \tan \delta$ then the friction on both sides of the 2 membrane these are 2 different theories one Back Koerner and one by Sharma and Lewis and if I was to try and summarize it here this is the Koerner's theory. Please understand what does Koerner do I just want your attention the formula are very simple this is T Koerner brakes up T into T $\cos \beta$ and T $\sin \beta$ this is the horizontal pull T $\cos \beta$. And he will do the stability by taking equilibrium of horizontal forces T $\cos \beta$ will be equal to $q l \tan \delta$, but there is also a T $\sin \beta$ that adds to the reaction its gives you a triangular reaction here.

So, it becomes T $\sin \beta \tan \delta$ is an additional because this T $\sin \beta$ is bringing this down. So, please see T $\cos \beta$ is equal to $q \tan \delta$ that is the resistance along this first plus T $\sin \beta \tan \delta$ because this is pushing down T $\sin \beta$ it is T $\sin \beta$ assume this T $\sin \beta$ is acting here additionally.

The T $\sin \beta \tan \delta$ that is equation and when there is a trench T $\cos \beta$ minus T $\sin \beta$; this equation is the same plus p_p minus T a passive pressure will develop here and active pressure will develop here this is Koerner's approach and you have this on moodle. So, you can look at it more carefully.

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Geomembrane Stability: Adequate Anchorage

(a) Horizontal:
 $T = qL \tan \delta$ (soil below)

(b) Horizontal + Trench:
 $T = qL \tan \delta$ (below) + $P_h \tan \delta$ (trench) + $P_h \tan \delta$ (right)

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But if you have any questions I can answer them, but unless you do model tests it will not be define what a Sharma and Lewis do Sharma and Lewis say there is a frictionless pulley here and there are 2 frictionless pulley is here. So, they do not resolve T this is T it

is like a rope then the frictionless pulley. So, here the T is horizontal. So, T is equal to $q l \tan \delta$ topsoil is moving.

And there is another pulley. So, that T is here also. So, T is equal to $q l \tan \delta$ plus p horizontal $\tan \delta$ on the trench side and p horizontal $\tan \delta$ on the right side now the p horizontal can be active passive or at rest mostly in the case of Sharma and Lewis p horizontal is taken as at rest k naught condition it is taken as not because this is dug up and this is backfilled once you backfill it you get the k naught condition for the purpose of analysis. So, these 2 approaches give you very different results, but this is the way you check whether you can give the anchorage capacity that you need or not.

So, your T must be available from here and you can put a factor of safety on it if you want to be very very sure let me go back here it is T becomes $T \cos \beta$ $T \cos \beta$ is equal to $q l \tan \delta$ plus $T \sin \beta \tan \delta$ because $T \sin \beta$ is the download component and here it becomes $T \cos \beta$ is equal to $q l \tan \delta$ plus $T \sin \beta$ plus pp that is the total pressure minus the active earth pressure here it is T is equal to $q l \tan \delta$ and T equal to $q l \tan \delta$ plus th plus T this is the more conservative approach it will give you larger lengths than Koerner's approach this is the most conservative approach. So, with this we end our discussion on slope stability and in a sense philosophically if we are not relying on T then it is a passive system right there is no tension in the elements.

So, if you use 4.5 is to 1 or 4 is to one you may not have an issue of requirement of, but you want to go to 2.5 is to 1. So, the 40 kilo Newton per meter I showed you can use permits of 7 or 6 meters, but you will need to hold these in position and design of anchor trenches is a current area of research not anchored anything anchor weights anchors run our clients wrap it around the pipe all kinds of work going on in this area.

Thank you and we will continue in the next class.