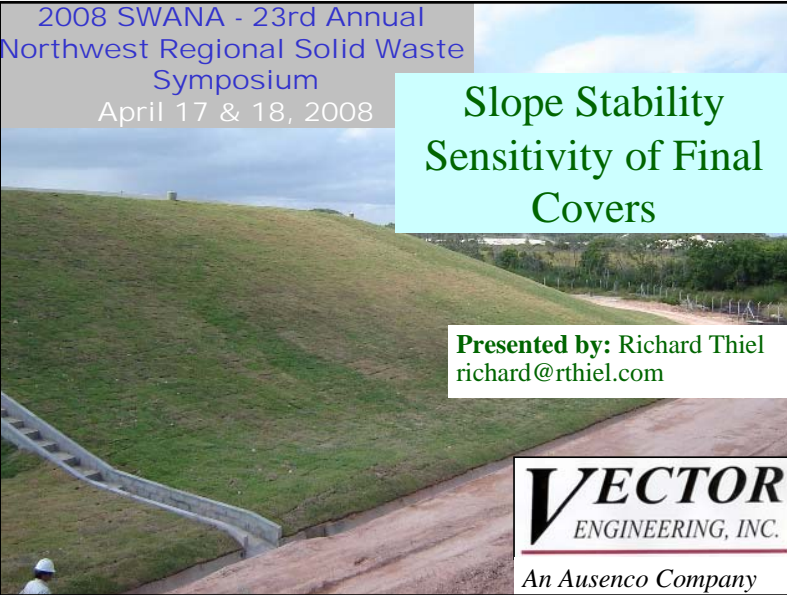


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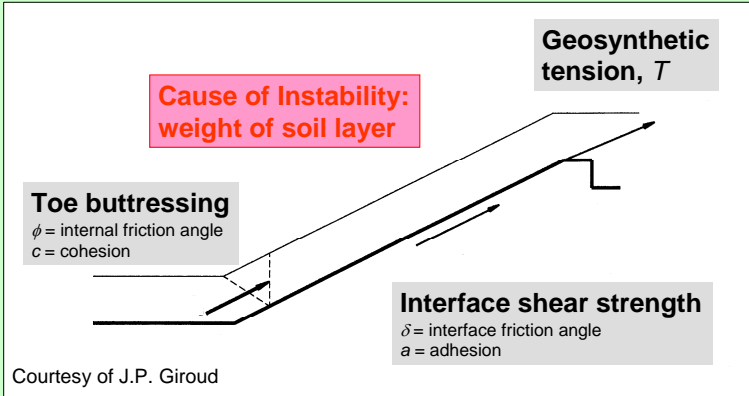
Slope Stability Sensitivity of Final Covers

Presented by: Richard Thiel
richard@rthiel.com



VECTOR
ENGINEERING, INC.
An Ausenco Company

SLOPE STABILITY MECHANISMS



Cause of Instability:
weight of soil layer

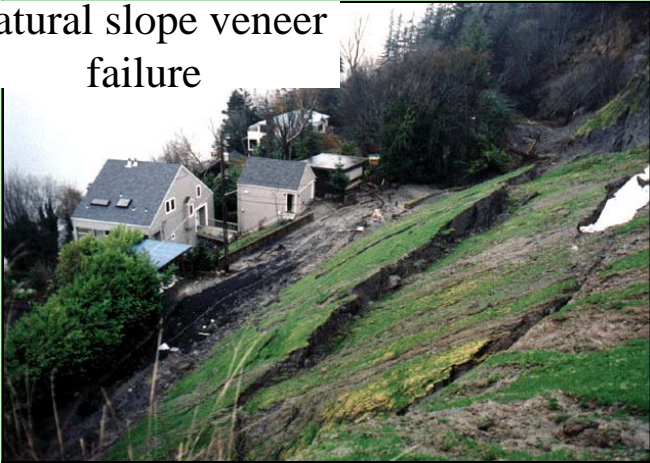
Geosynthetic tension, T

Toe buttressing
 ϕ = internal friction angle
 c = cohesion

Interface shear strength
 δ = interface friction angle
 a = adhesion


Courtesy of J.P. Giroud

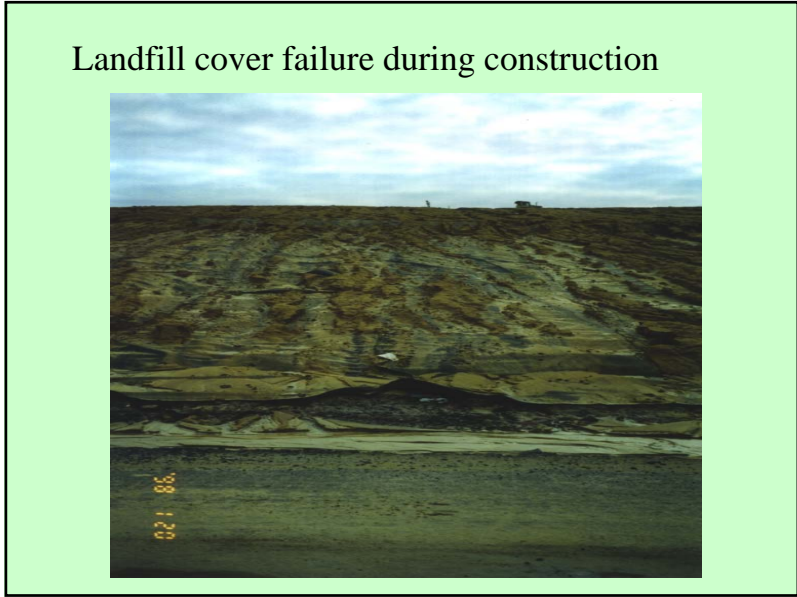
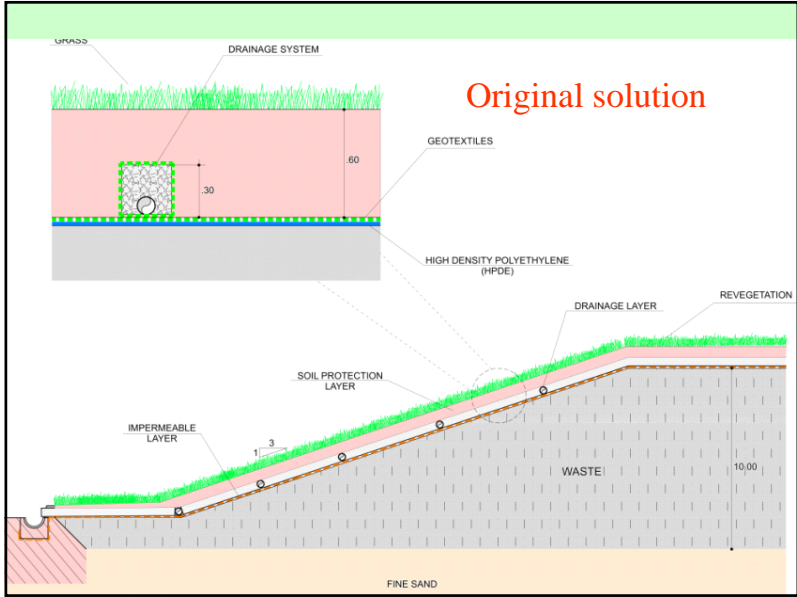
Natural slope veneer failure



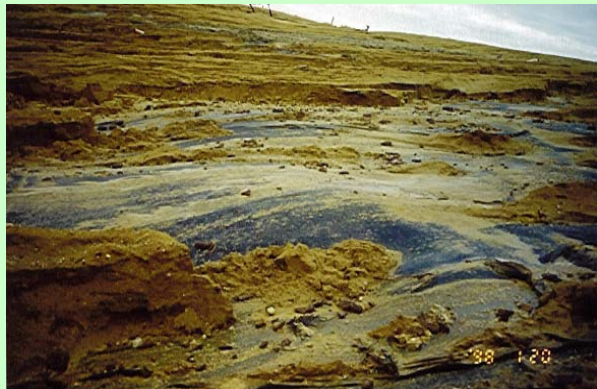
Infinite slope failure in Seattle, WA, USA. Sheets of soil slide off the hillside.

Landfill Cover Slope Failure





Landfill Cover Veneer Failure on Slope



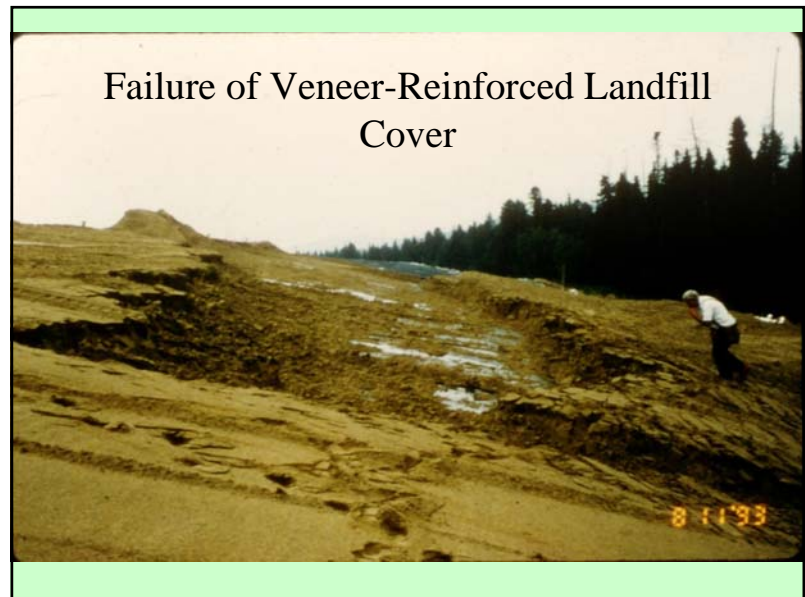
Landfill Cover Geocomposite Failure in California



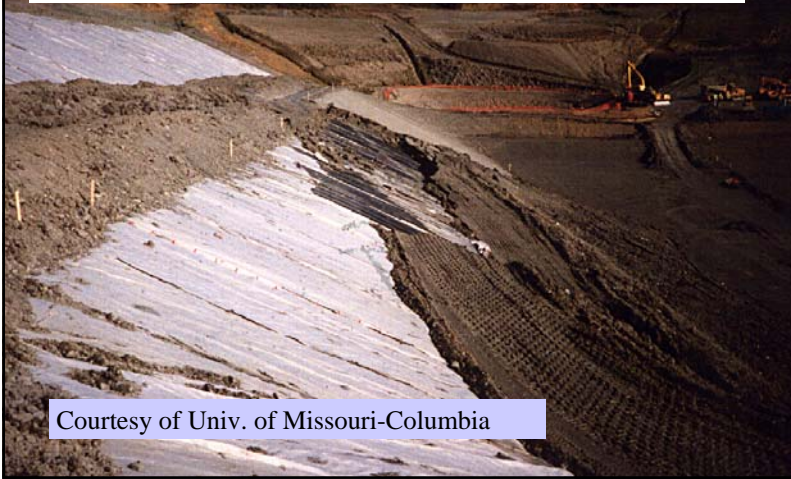
Internal failure of geocomposite underdrain while placing clay liner (UK landfill)



Failure of Veneer-Reinforced Landfill Cover



Veneer Failure GT/GM During Bottom Liner Construction



Courtesy of Univ. of Missouri-Columbia

Veneer Slides at Geomembrane-GCL Interface – Cincinnati Study

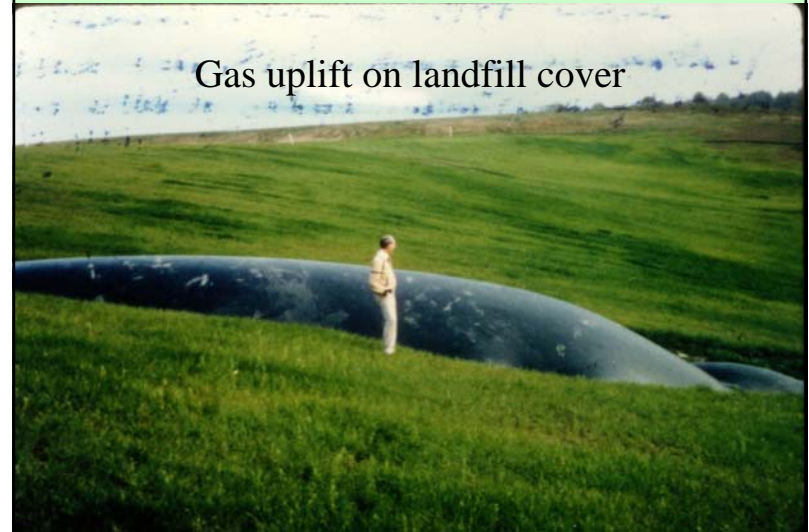


Woven GT facing up

Recent Landfill Cover Failure – Composite System



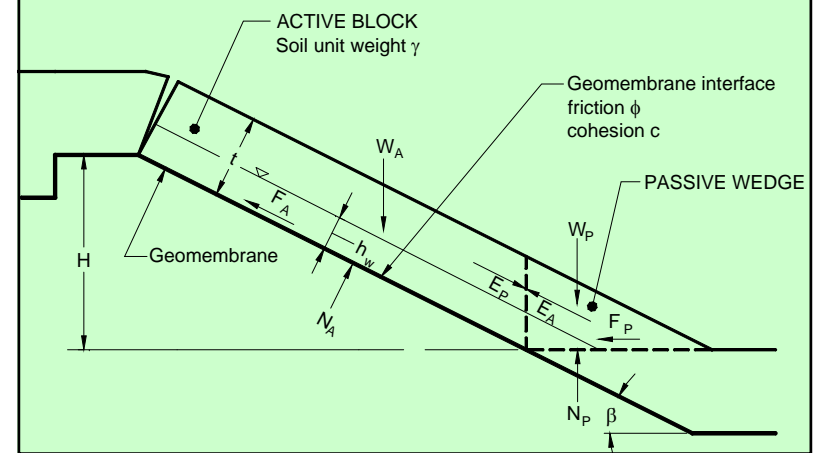
Gas uplift on landfill cover



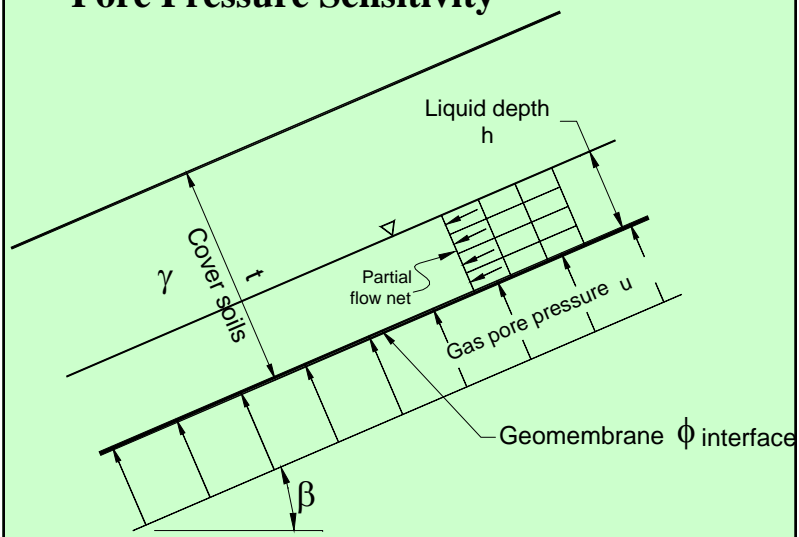
Landfill Cover Slide Due to Gas Pressures



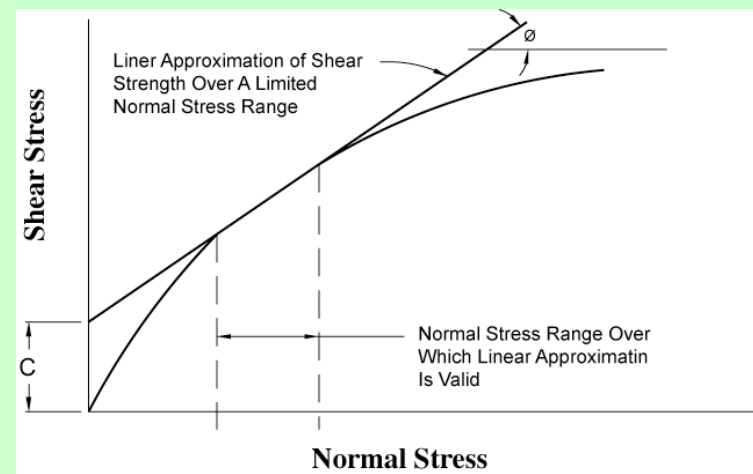
Geotechnical Sensitivities of Veneer Cover Systems



Pore Pressure Sensitivity



Shear Strength Sensitivity



Factor of Safety and *Reliability*

- Duncan, 2000, ASCE J. of Geotec. and Geoenv Engr.
- In addition to standard FS, Duncan's paper provides the tools to evaluate the *reliability*, or its inverse, *the probability of failure*, by estimating the variability of key parameters such as shear strength and pore pressures (or anything else you wish)

Example problem

- 1(V):3(H) slope; steepest conceivable 1:2.5; flattest conceivable 1:3.5
- Critical interface friction angle of 27°; highest conceivable value (HCV) 33°; lowest conceivable value (LCV) 21°
- Specified cover thickness 0.5 m; HCV= 0.55 m; LCV= 0.47 m
- Gas pore pressure likely value 1 kPa; HCV= 4 kPa; LCV= 0 kPa

Spreadsheet calculation of reliability for the design example (*yes – I know you cannot read it, but it's in the paper*)

CONDITION	F _{MLV}	Slope angle β			Friction angle φ			Cover thickness t			Liquid depth h			σ _v	V _f	lognormal reliability index β _u	Reliability	Probability of failure Pf
		FS-σ	FS+σ	ΔF ₁	FS-σ	FS+σ	ΔF ₂	FS-σ	FS+σ	ΔF ₃	FS-σ	FS+σ	ΔF ₄					
Sliding above geomembrane using Eqn. 2	1.527	1.443	1.626	0.183	1.394	1.660	0.266	1.527	1.527	-	1.397	1.532	0.135	0.175	0.115	3.6491	99.99%	0.013%
Sliding below geomembrane using Eqn. 4	1.352	1.277	1.441	0.164	1.235	1.470	0.235	1.347	1.357	0.010	1.232	1.473	0.241	0.187	0.139	2.1186	98.29%	1.706%

Pf Scenarios
10.000% Upper end of what is considered acceptable for pit mine slope stability, where occasional failures are tolerated.
5.000% Mid range of what is considered acceptable for pit mine slope stability, where occasional failures are tolerated.
1.000% Considered acceptable for building foundation settlement, or for fixed ocean drill rigs.
0.100% Considered in the mid range for fixed ocean drill rigs.
0.010% Considered in the upper range acceptable for dams.
0.001% Considered in the lower range acceptable for dams.
 - After Whitman, *Evaluating Calculated Risk in Geotechnical Engineering*, ASCE 1984

Results of FS calculations and Duncan's reliability approach

- The *most likely* FS above the geomembrane is FS=1.53, which is good. The *probability of failure* (P_f) for this condition is 1:7700, which is excellent.
- The *most likely* FS below the geomembrane is FS=1.35, which is not too bad. The *probability of failure* (P_f) for this condition is 1:58 (1.7%), which is poor, and could be unacceptable.

Conclusions

- Veneer cover systems are very sensitive to small changes in strengths and pressures
- Calculating a simple FS may hide the true risks of a project. Even so, good, basic, correct FS analyses are the foundation of an evaluation
- Simple reliability analyses performed *in conjunction with* a good standard FS calculations provides a more complete basis for making decisions than an FS-only approach

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Questions?

Thank You!
Gracias!

Slope Stability Sensitivities of Final Covers

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