FINAL COVER SYSTEM STABILITY ANALYSIS – VENEER MODE

GEOSYNTEC CONSULTANTS

COMPUTATION COVER SHEET

Client: TVA **Project:** KIF Gypsum Disposal Facility **Project/Proposal #:** GR3731 **Task #:** 06

TITLE OF COMPUTATIONS FINAL COVER SYSTEM STABILITY ANALYSIS - VENEER MODE

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FINAL COVER SYSTEM STABILITY ANALYSIS VENEER MODE

PURPOSE

The purpose of the analyses described in this calculation package is to evaluate static and seismic stability of the final cover system in a veneer failure mode for the proposed Kingston Fossil Plant Gypsum disposal facility (hereinafter referred to as KIF Gypsum disposal facility) located at Peninsula site.

METHOD OF ANALYSIS

Slope stability of a landfill final cover system can be analyzed assuming infinite slope conditions or finite slope conditions. The infinite slope method considers a slope of infinite length whereby driving and resisting forces occur only along or parallel to an interface (i.e., slip plane). The finite slope method considers a slope of finite length and additionally takes into account soil strength above a slip plane, primarily as a toe-buttressing effect. Due to the buttressing effect provided by graded-in benches of the final cover system, the finite slope method is used for analysis of the final cover system for the KIF Gypsum disposal facility (Figure 1).

The finite slope stability factor of safety equation, as formulated by Giroud, et. al. [1995], is:

$$FS = \left[\frac{\gamma_t(t-t_w)+\gamma_b t_w}{\gamma_t(t-t_w)+\gamma_{sat} t_w}\right]\frac{\tan\delta}{\tan\beta} + \frac{a/\sin\beta}{\gamma_t(t-t_w)+\gamma_{sat}t_w}$$

$$+\left[\frac{\gamma_t(t-t^*_w)+\gamma_b t^*_w}{\gamma_t(t-t_w)+\gamma_{sat}t_w}\right]\left[\frac{\tan\phi/(2\sin\beta\cos^2\beta)}{1-\tan\beta\tan\phi}\right]\frac{t}{h}$$

$$+\left[\frac{1}{\gamma_t(t-t_w)+\gamma_{sat}t_w}\right]\left[\frac{1/(\sin\beta\cos\beta)}{1-\tan\beta\tan\phi}\right]\frac{ct}{h} \qquad (1)$$

where: FS = factor of safety;
- δ = interface friction angle;
- a = apparent interface adhesion;
- ϕ = soil internal friction angle;
- c = apparent soil cohesion;
- γ_t = moist soil unit weight;
- γ_b = buoyant soil unit weight;
- γ_{sat} = saturated soil unit weight;
- t = depth of cover soil above critical interface;
- t_w = water depth above critical interface;

t_w^* = water depth at slope toe;
β = slope inclination; and
h = vertical height of slope.

It should be noted that while the above equation is specifically for an interface above a geomembrane, or similar layers, it can also be applied to interfaces below the geomembrane by changing the coefficient of the first term, (i.e., the coefficient of $\tan\delta / \tan\beta$) to 1.0. The slope geometry, which is used to derive the above equation, is shown in Figure 2. The above Equations used to calculate the FS above and below a geomembrane are coded in a spreadsheet presented herein as Tables 1 and 2, for peak and residual final cover shear strength parameters, respectively.

The water depth (t_w) in the drainage layer above the geomembrane was calculated using the HELP model [Schroeder, 1994] as presented in the calculation package titled "*Alternative Final Cover System Demonstration*". Based on this analysis, the average head in the drainage layer was estimated to be 0.021 in.

The final cover system static stability analyses were performed by solving the finite slope stability equation, presented above, for various combinations of peak and residual internal/interface shear strength parameters (i.e., "δ" and "a" for above and below a geomembrane) based on the target factors of safety.

Seismic Stability:

A pseudo-static slope stability analysis is performed for the final cover system. The pseudo-static factor of safety is estimated by performing an infinite slope analysis using Equation 2 [Matasović, 1991]:

$$FS = \frac{c/(\gamma z \cos^2\beta) + \tan\phi\,[1 - \gamma_w (z - d_w)/(\gamma z)] - k_s \tan\beta \tan\phi}{k_s + \tan\beta} \qquad (2)$$

where: FS = factor of safety;
k_s = peak average horizontal acceleration as a fraction of gravity;
γ = unit weight of slope material(s) in pcf;
γ_w = unit weight of water in pcf;
c = cohesion in psf;
β = slope angle in degrees;
ϕ = angle of internal friction on the assumed failure surface in degrees;
z = depth to the assumed failure surface in ft; and
d_w = depth to the water table (assumed parallel to the slope) in ft.

The peak average horizontal acceleration (k_s) is estimated using the mean horizontal acceleration (MHA) at the site and a chart (Figure 3) developed by Idriss [1990], as presented by Kavazanjian and Matasović [1995].

A calculated factor of safety greater than 1.0 suggests that no permanent seismic deformation is expected. A factor of safety less than 1.0, however, suggests permanent deformation can occur. The amount of seismic displacement can be computed based on k_s and the yield acceleration, K_y. The yield acceleration is the horizontal acceleration which results in a pseudo-static factor of safety of 1.0. The yield acceleration may be calculated using Equation 3 [Matasović, 1991]:

$$K_y = \frac{c/(\gamma \bullet z \bullet \cos^2\beta) + \tan\phi\,[1-\gamma_w(z-d_w)/(\gamma \bullet z)] - \tan\beta}{1 + \tan\beta\tan\phi} \qquad (3)$$

The seismic displacement, corresponding to the computed K_y/k_s ratio, is estimated using the results presented by Hynes and Franklin [1984] and the "modified mean + one standard deviation curve" developed by GeoSyntec as presented in Figure 4. The "modified mean + one standard deviation curve" considers data associated with only large earthquakes and therefore is more conservative to use. This procedure is consistent with those given in the USEPA guidance document [USEPA; 1995].

The seismic stability analysis, described above, was performed assuming the final cover interfaces have the minimum shear strength values required to achieve a static factor of safety of 1.5 (i.e., peak shear strength parameters), as presented in Table 3.

PERFORMANCE CRITERIA

For the static stability analysis, the target FS for peak and residual internal/interface shear strength is 1.5 and 1.2, respectively. Based on the recommendations of Seed and Bonaparte [1992] and Anderson and Kavazanjian [1995], the performance criterion for seismic analysis is permanent deformation. The permanent deformation is considered acceptable if it is less than 6 to 12 in.

GEOMETRY AND MATERIAL PROPERTIES

The KIF Gypsum disposal facility will be constructed on outer slopes of the facility that has an inclination of 3 horizontal to 1 vertical with graded-in benches that are spaced vertically every 30 ft. The graded-in benches are expected to provide a buttressing effect. Therefore, analysis is performed considering the height of the final cover to be 30 ft.

Details of the proposed final cover system are shown in Figure 1. For the purpose of this analysis, the vegetative soil was conservatively assumed to have a unit weight of 120 pcf and shear strength parameters of $\phi = 30^{o}$ and c = 0 psf.

DESIGN PEAK GROUND ACCELERATION

The MHA at the site was assumed to be the maximum expected horizontal acceleration, depicted on a seismic hazard map, with a 90% or greater probability that the acceleration will not be exceeded in 250 years. Therefore, the MHA was estimated to be 0.25g based on the 2002 United States Geological Survey (USGS) Seismic Hazard Map. Based on this value, the corresponding peak horizontal acceleration (k_s) at the top of the KIF Gypsum disposal facility was estimated using the chart developed by Idriss [1990] presented in Figure 3. According to Figure 3, k_s is estimated as 0.32g .

RESULTS AND CONCLUSIONS

Results of the final cover system static stability analyses are presented in Figures 5 and 6. These figures represent various combinations of peak and residual internal/interface shear strength parameters (i.e., δ and a) required for a target static FS of 1.5 and 1.2, respectively. It is noted that the minimum requirements for internal/interface shear strength parameters are typical of many commercially available products. Prior to construction, the peak and residual interface/internal strength properties of the soil and geosynthetic materials selected for use shall be measured by performing site-specific testing to verify that they exceed the envelopes shown in Figures 5 and 6.

Calculated pseudo-static factor of safety for the final cover system using peak internal/interface shear strength parameters was less than one, indicating permanent deformation can occur when subjected to the design earthquake event. However, the maximum calculated seismic deformation (illustrated in Figure 4) was 3.2 in., which is considered acceptable (i.e., less than 6 to 12 in.).

REFERENCES

Anderson, D. G. and Kavazanjian, E. Jr., "Performance of Landfills under Seismic Loading," *Proceedings of the 3rd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, St. Louis, Missouri, Vol. 3, 1995.

Giroud, J. P., Bachus, R. C., and Bonaparte, R., "Influence of Water Flow on the Stability of Geosynthetic-Soil Layered Systems on Slopes," *Geosynthetics International*, Vol. 2, No. 6, 1995, pp. 1149-1180.

Hynes, M. E., and Franklin, A. G., "Rationalizing the Seismic Coefficient Method," *Miscellaneous Paper GL - 84 - 13,* U.S. Army Engineer Waterways Experiment Station, Vickburg, MS, 1984, pp. 34.

Idriss, I. M., "Response of Soft Soil Sites During Earthquakes," *Seed Memorial Symposium Proceedings,* Vol. 2, BiTech Publications, Berkeley, CA, 1990.

Kavazanjian, E., Jr., and Matasović, N., "Seismic Analysis of Solid Waste Landfills," *Geoenvironment 2000*, Geotechnical Special Publication No. 46, D.E. Daniel and Y.B. Acar (eds.), ASCE, New York, NY, Vol. 2, pp. 1066-1080, 1995.

Matasović, N., "Selection of Method for Seismic Slope Stability Analysis," *Proceedings of the 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, Vol. 2, St. Louis, 1991, pp. 1057-62.

Seed, R. B., and Bonaparte, R., "Seismic Analysis and Design of Lined Waste Fills: Current Practice," Proceedings, Stability and Performance of Slopes and Embankments-II, Vol. 2, *ASCE Geotechnical Special Publication No. 31*, Berkeley, California, 1992, pp. 1521-1545.

Schroeder, P. R., N. M., Lloyd, C. M. and Zappi, P. A. *"The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3,"* EPA/600/R-94/168a, September 1994, U. S. Environmental Protection Agency Office of Research and Development, Washington, D.C, 1994.

USEPA, *"RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities"*, Office of Research and Development, EPA/600/R-95/051, April 1995.

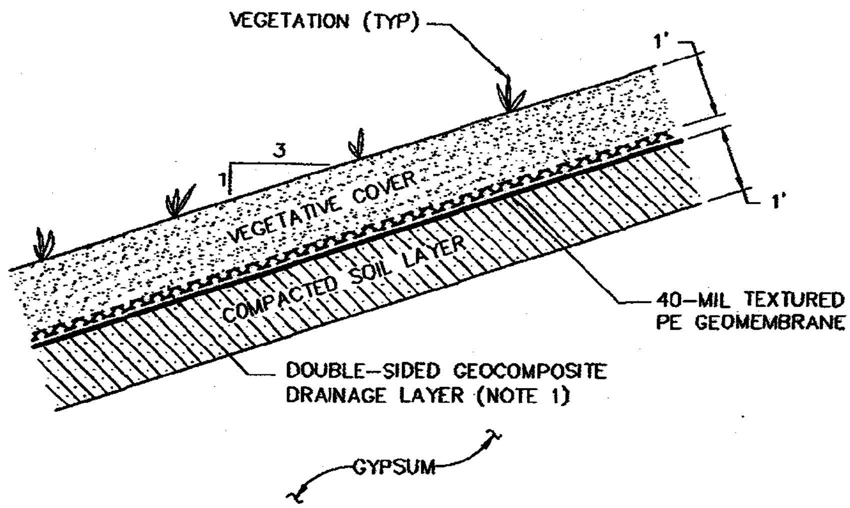

Figure 1. Final Cover System

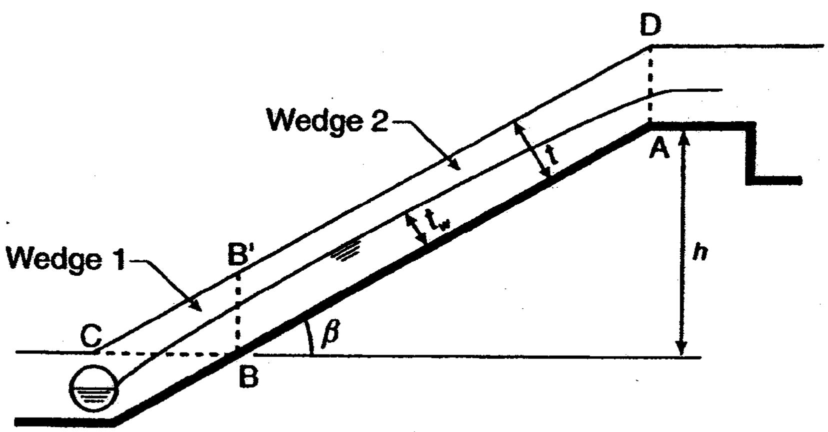

Figure 2. Slope Geometry Used to Derive Finite Slope Stability Equation

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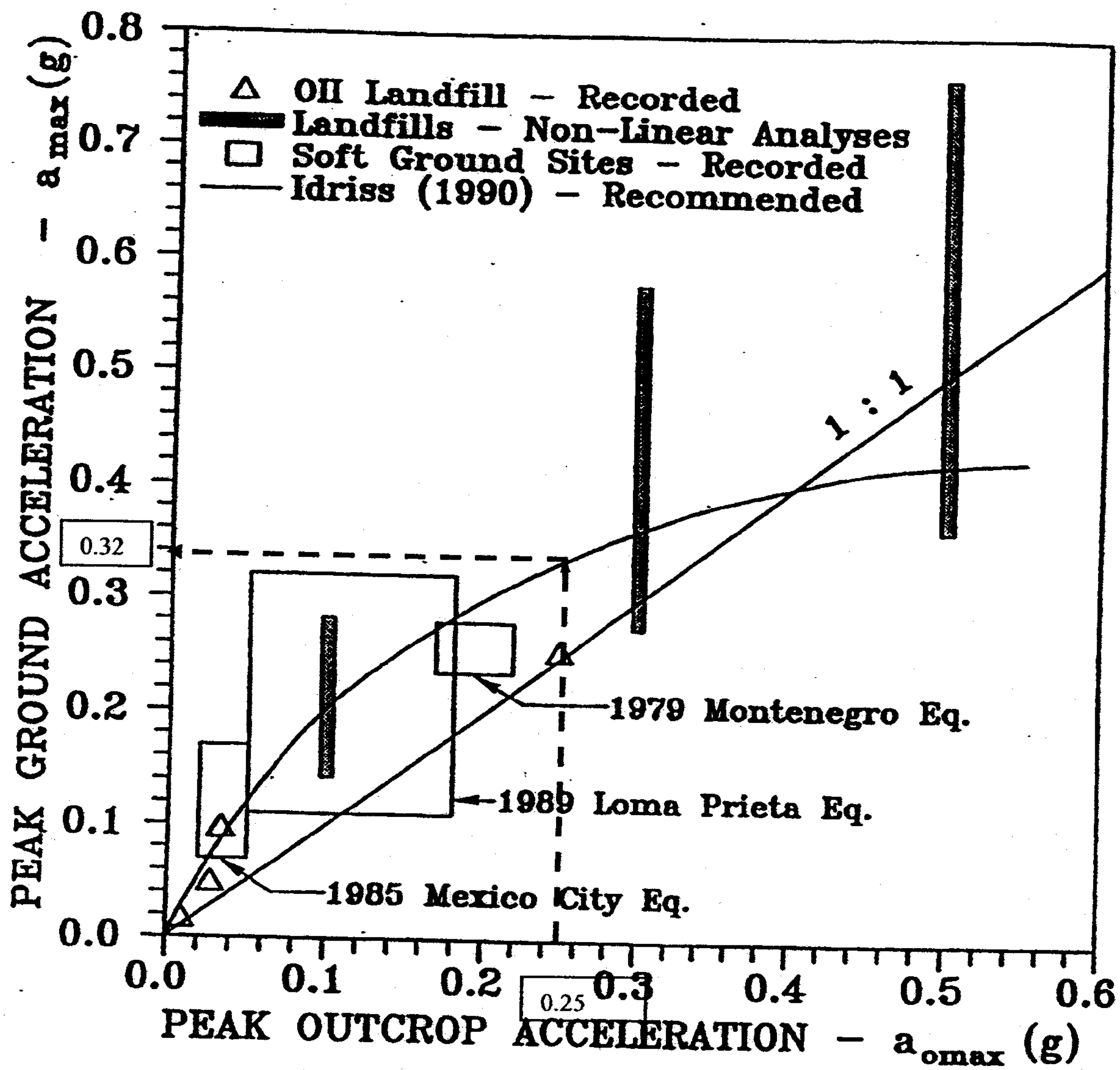

Figure 3. **Observed Variations of Peak Horizontal Accelerations on Soft Soil and MSW Sites in Comparison to Rock Sites (Kavazanjian and Matasović, 1994).**

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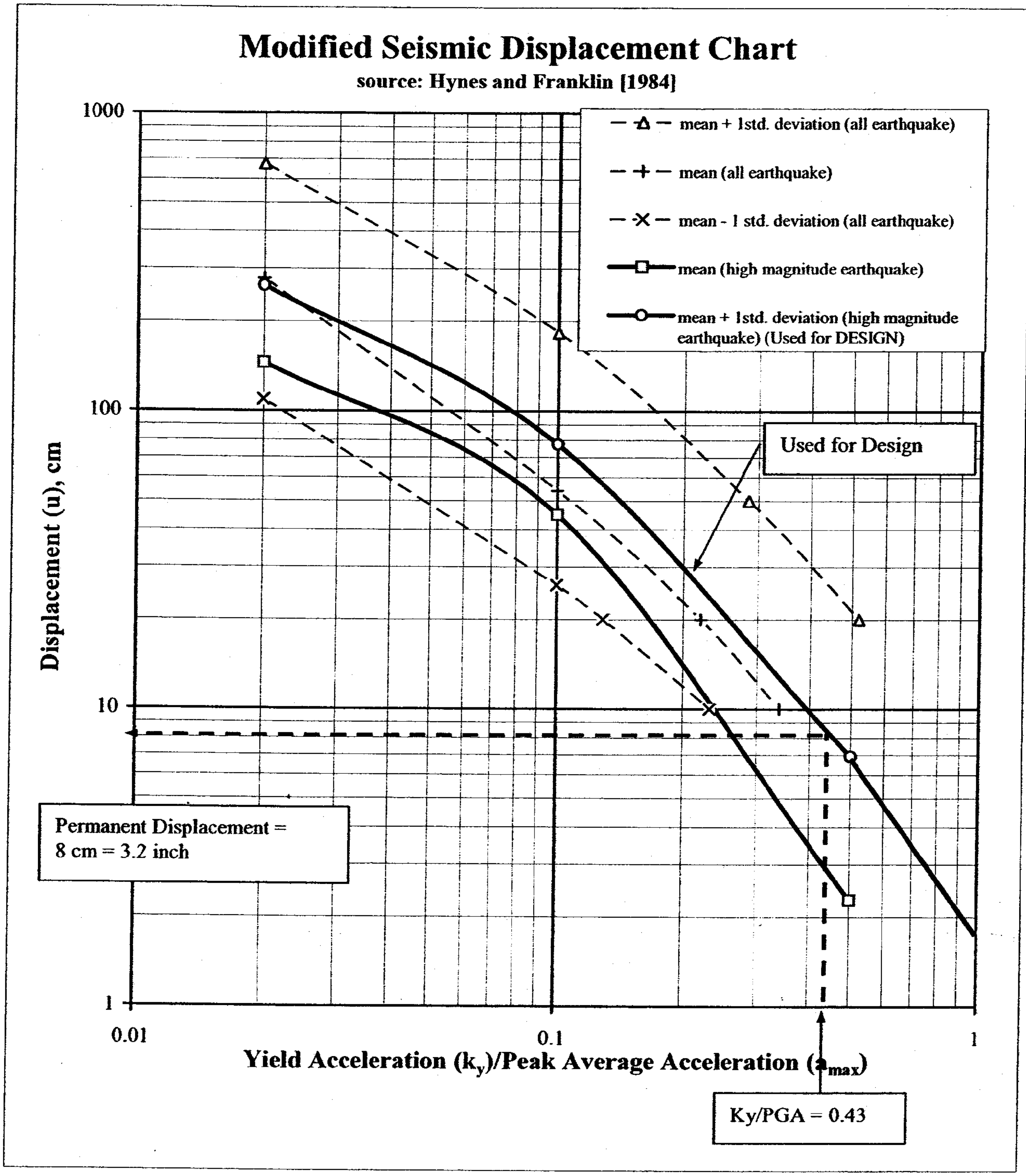

Figure 4. Seismic Displacement versus Yield Acceleration/Peak Average Acceleration Ratio.

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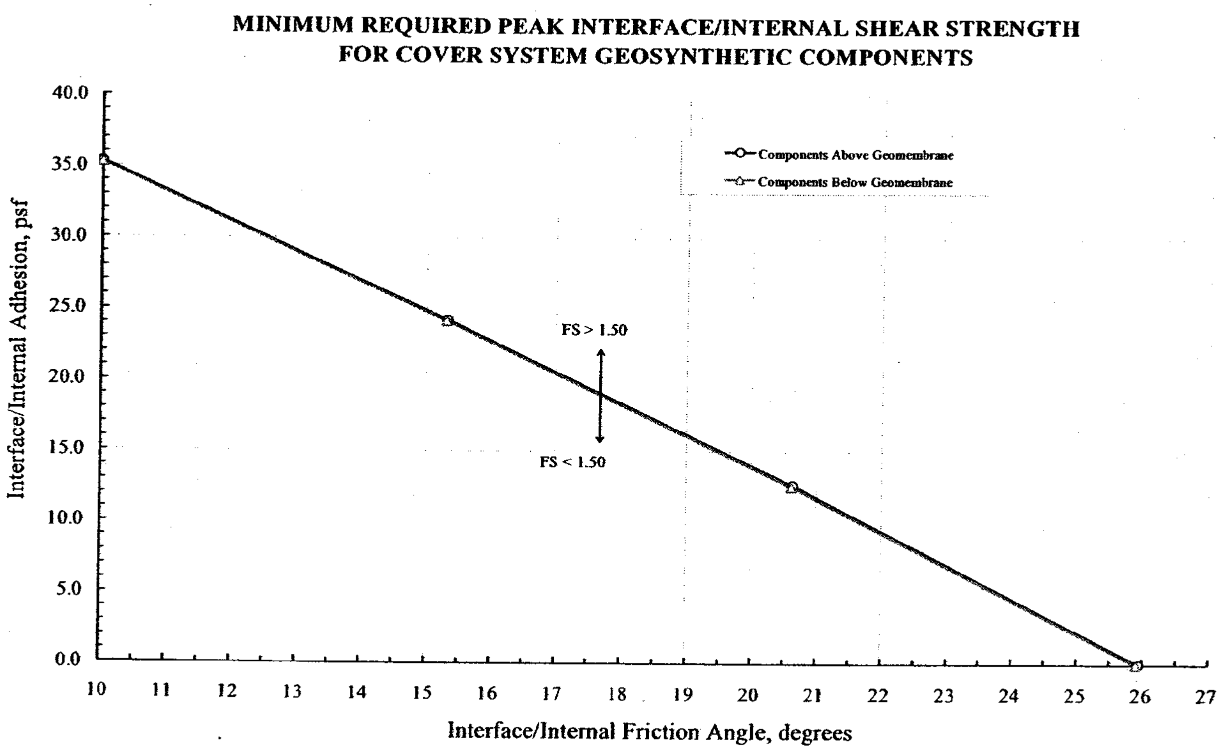

Figure 5. Peak Interface/Internal Shear Strength Graph

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Table 1. Peak Interface/Internal Shear Strength

FS Above GEOMEMBRANE		
Input Parameters:		
γ_t (Unit wt of soil):	120	pcf
γ_{sat} (Saturated unit wt of soil):	120	pcf
γ_w (Unit wt of water):	62.4	pcf
γ_b (Buoyant unit wt of soil):	57.6	pcf
t_w (water thickness):	0.002	ft
t* (water thickness at slope toe):	0.002	ft
δ (weakest interface friction angle):	10.00	deg
ϕ (friction angle of soil):	30	deg
a (interface adhesion)	35.28	psf
c (cohesion of soil above geomembrane)	0	psf
T (Tension in Geosynthetics)	0	psf
h (height of slope):	30	ft
t (thickness of soil layer)	1.0	ft
β (slope angle)	18.4	deg
FS	1.50	

FS Below GEOMEMBRANE		
Input Parameters:		
γ_t (Unit wt of soil):	120	pcf
γ_{sat} (Saturated unit wt of soil):	120	pcf
γ_w (Unit wt of water):	62.4	pcf
γ_b (Buoyant unit wt of soil):	57.6	pcf
t_w (water thickness):	0.002	ft
t* (water thickness at slope toe):	0.002	ft
δ (weakest interface friction angle):	10.00	deg
ϕ (friction angle of soil):	30	deg
a (interface adhesion)	35.25	psf
c (cohesion of soil above geomembrane)	0	psf
T (Tension in Geosynthetics)	0	psf
h (height of slope):	30	ft
t (thickness of soil layer)	1.0	ft
β (slope angle)	18.4	deg
FS	1.50	

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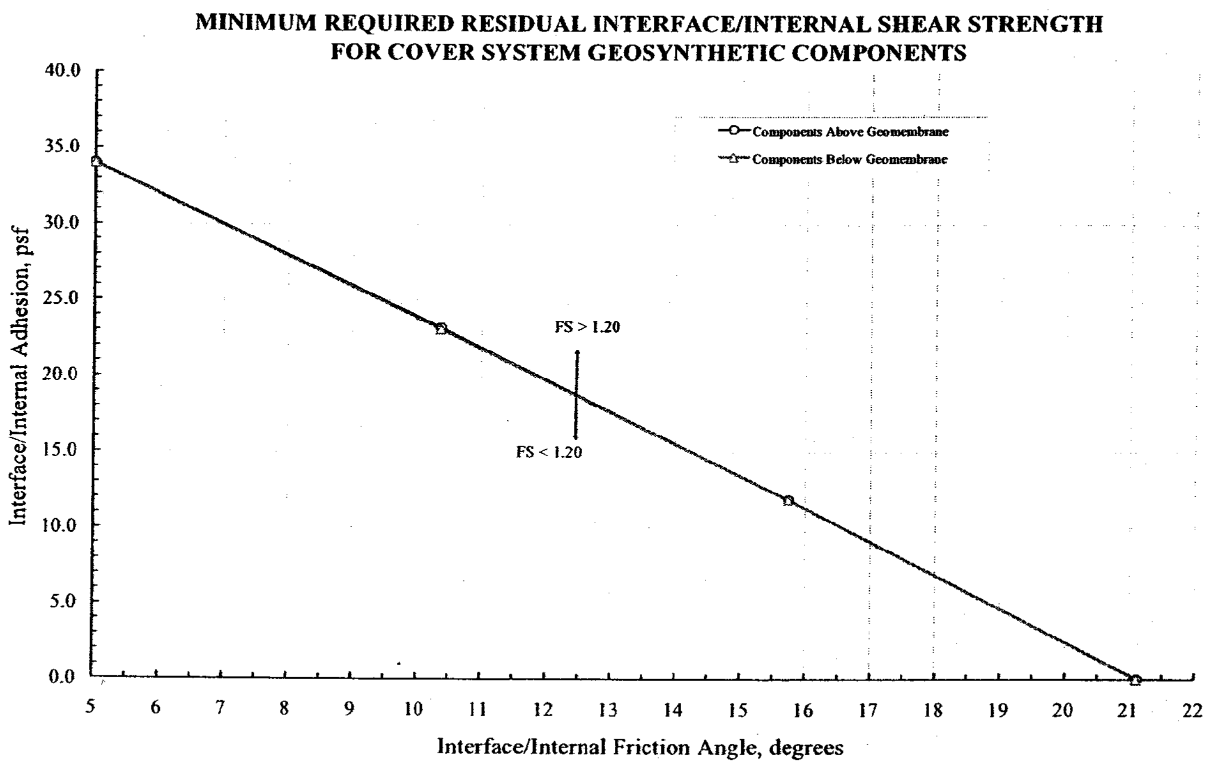

Figure 6. Residual Interface/Internal Shear Strength Graph.

Table 2. Residual Interface/Internal Shear Strength.

FS Above GEOMEMBRANE		
Input Parameters:		
γ_t (Unit wt of soil):	120	pcf
γ_{sat} (Saturated unit wt of soil):	120	pcf
γ_w (Unit wt of water):	62.4	pcf
γ_b (Buoyant unit wt of soil):	57.6	pcf
t_w (water thickness):	0.002	ft
t* (water thickness at slope toe):	0.002	ft
δ (weakest interface friction angle):	5.00	deg
ϕ (friction angle of soil):	30	deg
a (interface adhesion)	34.00	psf
c (cohesion of soil above geomembrane)	0	psf
T (Tension in Geosynthetics)	0	psf
h (height of slope):	30	ft
t (thickness of soil layer)	1.0	ft
β (slope angle)	18.4	deg
FS	1.20	

FS Below GEOMEMBRANE		
Input Parameters:		
γ_t (Unit wt of soil):	120	pcf
γ_{sat} (Saturated unit wt of soil):	120	pcf
γ_w (Unit wt of water):	62.4	pcf
γ_b (Buoyant unit wt of soil):	57.6	pcf
t_w (water thickness):	0.002	ft
t* (water thickness at slope toe):	0.002	ft
δ (weakest interface friction angle):	5.00	deg
ϕ (friction angle of soil):	30	deg
a (interface adhesion)	33.98	psf
c (cohesion of soil above geomembrane)	0	psf
T (Tension in Geosynthetics)	0	psf
h (height of slope):	30	ft
t (thickness of soil layer)	1.0	ft
β (slope angle)	18.4	deg
FS	1.20	

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Table 3. Seismic Analysis Using Peak Interface/Internal Shear Strength.

Calculation of Factor of Safety and Yield Acceleration For Infinite Slope Conditions Using Equation from Matasovic [1991]

$$k_y = \frac{\left(\dfrac{c}{\gamma z \cos^2 \beta} + \tan\delta\left(1 - \dfrac{\gamma_w (z - d_w)}{\gamma z}\right) - \tan\beta\right)}{1 + \tan\beta \tan\delta}$$

Where:

k_y = yield acceleration, g.;
γ = unit weight of soil cover, pcf;
γ_w = unit weight of water, pcf;
c = cohesion along the assumed failure surface, psf;
δ = friction angle along the assumed failure surface, degrees;
β = slope angle, degrees;
z = depth of the assumed failure surface, ft; and
d_w = depth of water surface (assumed parallel to the slope), ft.
k_s = peak average horizontal acceleration for potential slide mass, g. = a_{max}

Input parameters:	
γ, pcf	120
z, ft	1
β, degrees	18.43
γ_w, pcf	62.4
d_w, ft	0.996
ks, g	0.32

δ (degrees)	c (psf)	FS	k_y (g)	k_y/a_{max}	
26.4	0	0.677	0.139	0.43	<== minimum
20.9	12.96	0.705	0.149	0.47	
15.5	24.85	0.730	0.158	0.49	
10	36.34	0.756	0.169	0.53	