C.5 LINER STRESSES

ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner Stresses Sheet No. 0 of 20

Chkd. By WS Date 3/7/96 Proj. No. 95-284

LINER STRESSES

US ECOLOGY HAZARDOUS WASTE LANDFILL

BEATTY, NV

ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner stresses Sheet No. 1 of 20

Chkd. By LB Date 3/7/96 Proj. No. 95-284

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1.0 PURPOSE

Evaluate tension/elongation of the design slope liner system to prevent rupture or damage to liner system due to gravity, thermal expansion/contraction, wind uplift, seismic deformation, and waste settlement.

2.0 APPROACH

The following causes of liner stresses are considered:

- Load due to gravity
- Thermal expansion/contraction
- wind uplift
- Seismic deformation
- Settlement of waste fill

Load Due To Gravity (Assume stable slopes)

Gravity load is calculated as follows:

$$T_1 = W \sin\theta + F_u - F_L$$

where W = weight of liner component.

θ = slope angle [63.4° FOR 0.5:1 (H:V) slope]

F_u = Friction Force above the liner component.

F_L = Friction Force below the liner component.

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Strain caused by self weight is denoted as ε_1.

Thermal Expansion/Contraction

Thermal expansion is considered for HDPE geomembrane and geonet. A coefficient of linear thermal expansion of 1.2×10^{-4} cm/cm-°c is selected (See Ref. 3). Assume a temperature variation of 40°c (Ref. 4), the induced thermal strain is

$$\varepsilon_2 = 1.2 \times 10^{-4} \times 40 \doteqdot 0.5\%$$

Wind Uplift

Sand bags and suction devices will be used to hold down the liner system during installation and waste placement. As a result, wind uplift will be balanced by sand bags and suction devices and will not generate stresses in liner system.

Seismic Deformation

Seismic deformation during waste placement will be small (less than 1.6", see Ref. 13). Consider a slope length of 84', seismic deformation is $\doteqdot 0.2\%$, which will generate negligible stresses.

$$\Rightarrow \quad \varepsilon_3 = 0.2\%$$

Although negligible, this strain is included in the calculation for completeness. This strain will not occur below Interface No. 3, see Figure 1 and discussions below.

Settlement of Waste fill

From Ref. 8, waste fill settlement will be less than 4% which includes settlements during waste placement and after closure of landfill. Waste fill settlement will induce upto 4% strains in the upper layers (non-woven geotextile and geonet) of the liner system, See Figure 1.

The liner system is designed such that slippage will occur between geonet and the smooth side of HDPE membrane (i.e., slippage will occur at Interface No. 3).

As a result, waste fill settlement will not affect the liner system below Interface No. 3. (Similarly, strain induced by seismic deformation will not be transferred below this interface.)

Induced Stresses

The overall strains caused by the above ~~factors~~ are added and the corresponding liner component stresses are determined from stress-strain curves or the elastic (secant) modulus of the material.

allowable Stresses of Geotextile

The geotextile is used for separation purposes and the following partial factors of safety are used to calculate allowable tensile stress:

$$T_{allow} = T_{ult} \left(\frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}} \right) \qquad \text{(Ref. 10)}$$

where $FS_{ID} = 2.5$, $FS_{CR} = 1.2$, $FS_{CD} = 1.5$, and $FS_{BD} = 1.2$.

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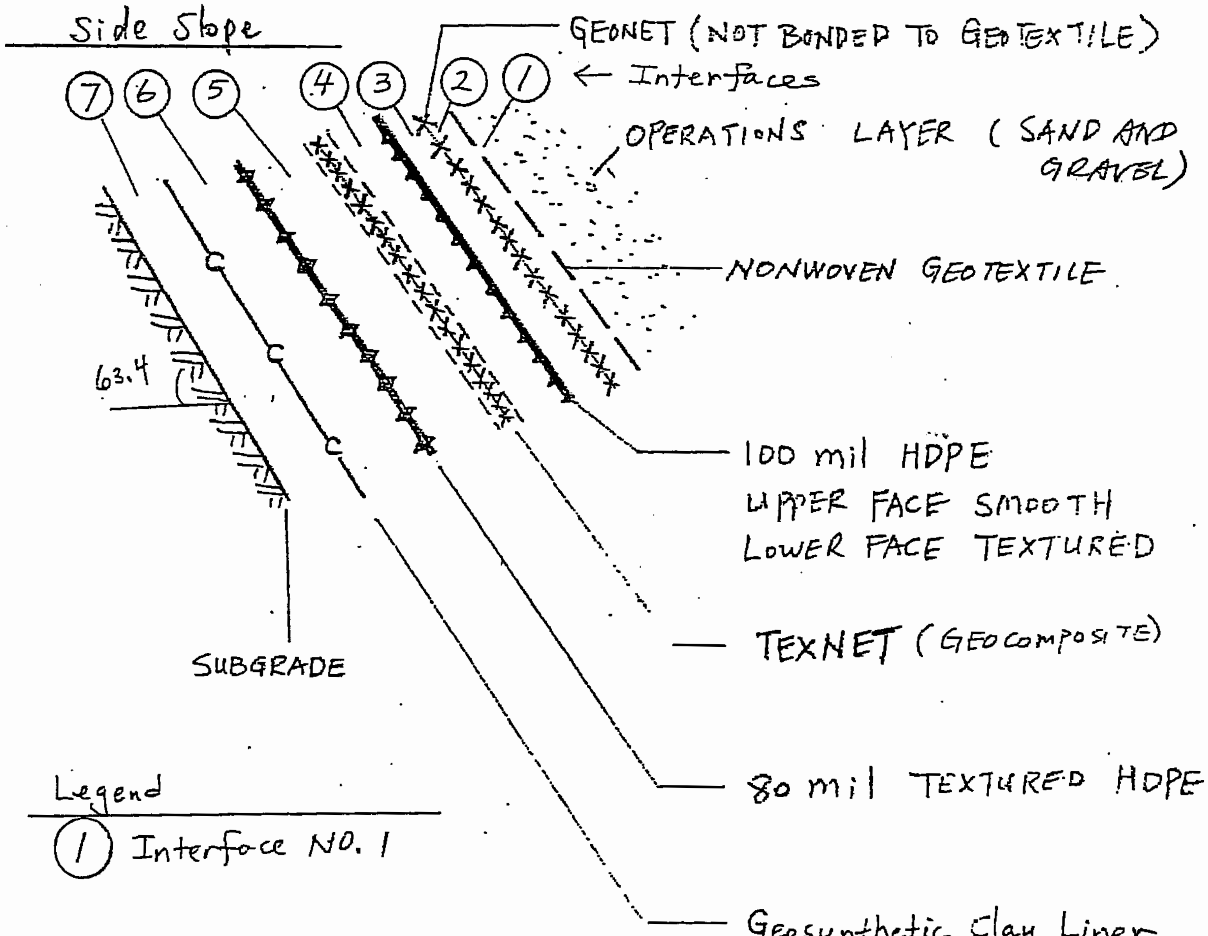
Design Profile:



Legend

(1) Interface NO. 1

Figure 1 Side Slope Liner System

Note: see Tables 1, 2, and 3 for material properties of liner components.

Ref (10) 6/20

TABLE 2.12 RECOMMENDED PARTIAL FACTOR OF SAFETY VALUES FOR USE IN EQUATION 2.18

Application area	Various partial factors of safety: Installation damage	Creep*	Chemical degradation	Biological degradation
separation	1.1 to 2.5	1.0 to 1.2	1.0 to 1.5	1.0 to 1.2
cushioning	1.1 to 2.0	1.2 to 1.5	1.0 to 2.0	1.0 to 1.2
unpaved roads	1.1 to 2.0	1.5 to 2.5	1.0 to 1.5	1.0 to 1.2
walls	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
embankments	1.1 to 2.0	2.0 to 3.0	1.0 to 1.5	1.0 to 1.3
bearing capacity	1.1 to 2.0	2.0 to 4.0	1.0 to 1.5	1.0 to 1.3
slope stabilization	1.1 to 1.5	1.5 to 2.0	1.0 to 1.5	1.0 to 1.3
pavement overlays	1.1 to 1.5	1.0 to 1.2	1.0 to 1.5	1.0 to 1.1
railroads	1.5 to 3.0	1.0 to 1.5	1.5 to 2.0	1.0 to 1.2
flexible forms	1.1 to 1.5	1.5 to 3.0	1.0 to 1.5	1.0 to 1.1
silt fences	1.1 to 1.5	1.5 to 2.5	1.0 to 1.5	1.0 to 1.1

*The low end of the range refers to results that have been compensated for creep in the performance of the tests.

$$T_{\text{allow}} = T_{\text{ult}} \left(\frac{1}{FS_{ID} \times FS_{CR} \times FS_{CD} \times FS_{BD}} \right) \tag{2.18}$$

where

T_{allow} = the allowable tensile strength,
T_{ult} = the ultimate tensile strength,
FS_{ID} = the factor of safety for installation damage,
FS_{CR} = the factor of safety for creep,
FS_{CD} = the factor of safety for chemical degradation, and
FS_{BD} = the factor of safety for biological degradation.

Note that this equation could just as well have been formulated as fractional multipliers (≤ 1.0) and placed in the numerator of the equation. It is placed in this form because other studies have done likewise (e.g., Voskamp and Risseeuw [37]). While the equation indicates tensile strength, it can equally well be applied to burst strength, tear strength, puncture strength, seam strength, etc.

For problems dealing with flow through or within a geotextile, the formulation takes the following form with typical values given in Table 2.13. Note that these values must be tempered with site-specific conditions as was the case with the previous table.

$$q_{\text{allow}} = q_{\text{ult}} \left(\frac{1}{FS_{SCB} \times FS_{CR} \times FS_{IN} \times FS_{CC} \times FS_{BC}} \right) \tag{2.19}$$

Allowable Stresses of Geotextile

$\therefore T_{allow} = T_{ult} / (2.5 \times 1.2 \times 1.5 \times 1.2) =$, $T_{ult} = 150$ lbs/in.

$= 150/5.4 = 27.8$ lbs/in

Allowable Stresses of Geonet

To avoid rupture of geonet, a factor of safety of 4 is used to calculate allowable stresses in geonet.

$T_{allow} = T_{ult}/4$

$= 50/4 = 12.5$ lbs/in , $T_{ult} = 50$ lbs/in

Allowable Stresses of HDPE

To avoid rupture of HDPE, a factor of safety of 40 is used (See Ref. 10) to calculate allowable stresses in geomembrane. This factor of safety is considered very conservative.

$T_{allow} = T_{ult}/40$

where $T_{ult} = 500$ lbs/in for 100-mil HDPE and 400 lbs/in for 80-mil HDPE (see Ref. 11)

For 100-mil HDPE,
$T_{allow} = 500/40 = 12.5$ lbs/in

For 80-mil HDPE
$T_{allow} = 400/40 = 10$ lbs/in

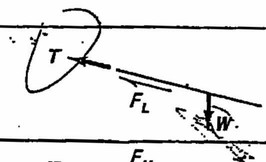
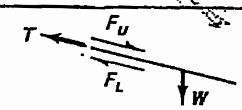
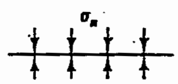
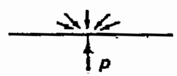
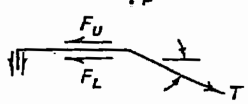
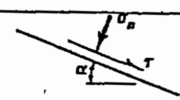
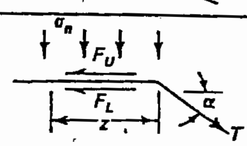
Allowable Stresses of Geocomposite

The geocomposite is composed of a geonet heat bonded to non-woven geotextile on both the upper and lower face of the geonet. As a result, the allowable stresses can be significantly higher than a single layer of geotextile or a geonet. For convenience, the allowable stresses of a geotextile can be used conservatively as the allowable stress of the geocomposite.

Ref 10

8/20

TABLE 5.17 VARIOUS DESIGN MODELS FOR GEOMEMBRANES IN WASTE DISPOSAL SITUATIONS (REF: KOERNER AND RICHARDSON, 48)

Problem	Liner stress	Free body diagram	Required properties: Geomembrane	Required properties: Landfill	Typical factor of safety
1. liner self weight	tensile		$G, t, \sigma_{allow}, \delta_L$	β, H	10 to 100
2. weight of filling	tensile		$t, \sigma_{allow}, \delta_U, \delta_L$	β, h, γ, H	0.5 to 10
3. impact during construction	impact		I	d, w	0.1 to 5
4. weight of landfill	compression		σ_{allow}	γ, H	10 to 50
5. puncture	puncture		σ_p	γ, H, P, A_p	0.5 to 10
6. anchorage	tensile		$t, \sigma_{allow}, \delta_U, \delta_L$	β, γ, ϕ	0.7 to 5
7. settlement of landfill	shear		τ, δ_U	β, γ, H	10 to 100
8. subsidence under landfill	tensile		$t, \sigma_{allow}, \delta_U, \delta_L, \chi$	α, γ, H	0.3 to 10

Notes:

Geomembrane properties

- G = specific gravity
- t = thickness
- σ_{allow} = allowable stress (yield or break)
- τ = shear stress
- I = impact energy
- σ_p = puncture stress
- δ_U = friction with material above
- δ_L = friction with material below
- χ = mobilization distance

Landfill properties

- β = slope angle
- H = height
- γ = unit weight
- h = lift height
- α = subsidence angle
- ϕ = friction angle
- d = drop height
- W = weight
- p = puncture force
- A_p = puncture area

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For this analysis, an allowable stress of 27.8 lbs/in is used for geocomposite.

Allowable Stresses of GCL

To avoid rupture of GCL, a conservative factor of safety of 10 is used in this calculation.

$$T_{allow} = T_{ult}/10 = 45/10 = 4.5 \text{ lbs/in}$$

3.0 Calculations (see Tables 1, 2, and 3)

Table 1

COMPONENT	UNIT WEIGHT (lbs/ft²)	Tensile Load Due To Self WT (lbs/in) (2)	Strain Due To Self Weight, ε_1 (%)	Strain Due To Thermal Expansion ε_2 (%)	Strain Due To Seismic Deformation ε_3 (%)	Strain Due To Settlement of Waste Fill ε_4 (%)	Total Strain ε_T (%)	Total Induced Stresses (lbs/in)	Tult (lbs/in)	Tyield (lbs/in)	Tallow (lbs/in)	Ref.
NON-WOVEN GEOTEXTILE (TREVIRA SPUNBOND 1125)	0.052	0.3	0 (7)	0.5	0.2	4	4.7	12 (3)	150	NR (1)	27.8	9
GEONET (POLY-NET PN 3000)	0.18	1.1	0.51 (4)	0.5	0.2	4	5.2	11.3 (4)	NA (9)	50 (8)	12.5	10, 14
100-mil HDPE (Textured Hyperflex)	0.54	2.6	0.16 (5)	0.5	0	0	0.66	10.6 (5)	500	240	12.5	11
GEOCOMPOSITE (TEXTNET TN3000/1125)	0.26	1.3	0 (7)	0	0	0	0	0	150	NR	27.8	9
80-mil HDPE (Textured Hyperflex)	0.44	2.6	0.2 (5)	0.5	0	0	0.7	9 (5)	400	192	10	11
GCL (CLAYMAX 500SP)	1.2	2.4	0.8 (6)	0	0	0	0.8	2.4 (6)	NA	45 (10)	4.5	2

NOTES

(1) "NR" represents Not Reported. Stress-strain curve does not indicate a pronounced yield point.

(2) See Calculations in Table 2.

(3) See stress-strain curve, Ref 9.

(4) Calculated using an assumed elongation at yield of about 23% (Ref. 10)

(5) Calculated using a tensile elongation at yield of 15%; (Ref. 11)

(6) Calculated using tensile elongation at rupture of 15% (Ref. 2)

(7) See Stress-strain curve attached (Ref 9).

(8) Ref. 14

(9) Not Available.

(10) Calculated using the GCL grab strength of 180 lbs (Ref. 2) devided by the width (4") of the test specimen, 180/4 = 45 lbs/in.

Ref. 9

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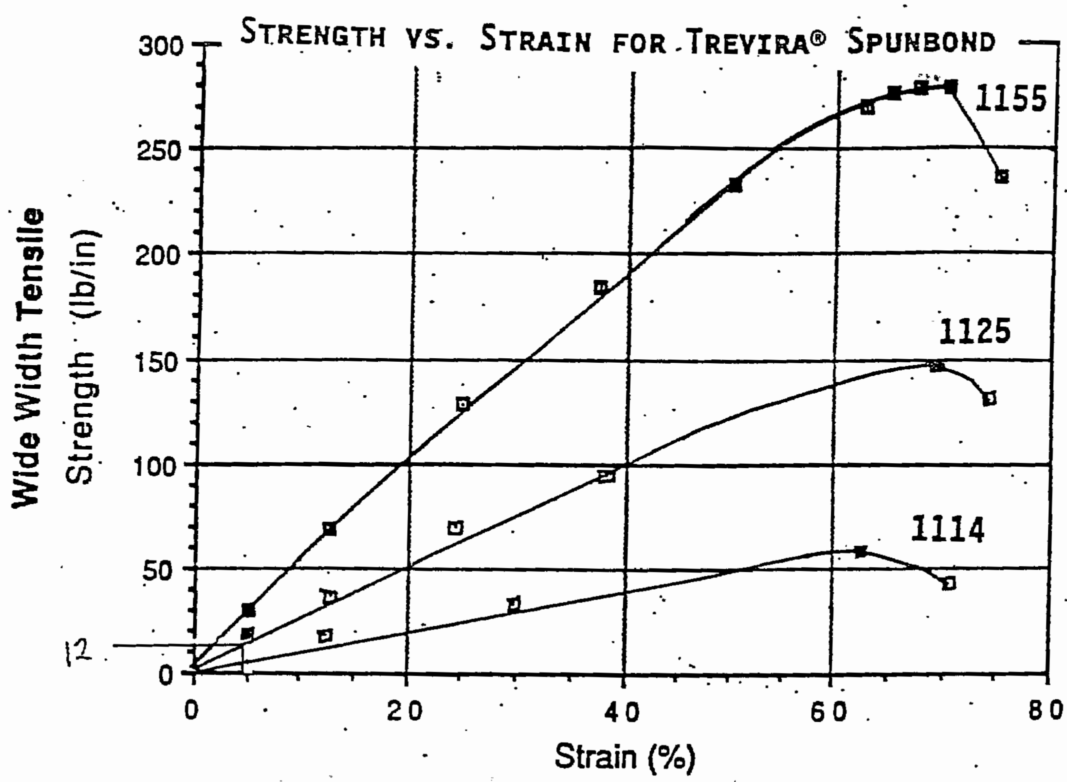
~~TABLE 4.~~ STRENGTH CHARACTERISTICS OF TREVIRA® SPUNBOND GEOTEXTILES

	CBR Puncture Strength (lb)	CBR Puncture Elongation (in)	Measured Wide Width Tensile (lb/ft) Machine	Cross-M	Average	Measured Wide Width Strain % Machine	Cross-M	Average
Trevira 1114	341	1.9	674	529	602	63%	61%	62%
Trevira 1125	701	1.95	1770	1450	1610	69%	70%	70%
Trevira 1155	1420	1.99	3360	2670	3015	68%	77%	73%



~~FIGURE 4~~ WIDE WIDTH TENSILE STRENGTH/STRAIN CURVES FOR TREVIRA® SPUNBOND GEOTEXTILES (MACHINE DIRECTION)

Ref (10)

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4.1 GEONET PROPERTIES AND TEST METHODS

Since the primary function of a geonet is to convey liquid within the plane of its structure, the in-plane hydraulic flow rate, or transmissivity, is of major importance. However, other features, which may influence this value over the service lifetime of the geonet, are also of importance. Thus a number of properties will be presented in this section.

4.1.1 Physical Properties

The primary physical property needed to characterize a geonet is its thickness, which can be determined using ASTM D1777. In this test, it is recommended that geotextile thickness be measured under a normal pressure of 42 lb./ft.^{2} (2.0 kPa). There are no current guidelines for geonets. The pressures used in obtaining the values listed in Table 4.1 are not known, but it should be noted that geonets are not nearly as sensitive to thickness variation under normal pressure as are geotextiles.

Mass per unit area can be determined using ASTM D1910. For a 200-mil (5.1-mm)-thick, extruded, solid-rib geonet, the mass per unit area is usually in the range of 20 to 30 oz./yd.^{2} (680 to 1020 g/m^2). It is not a design property per se, but it is informative from a manufacturer's point of view.

Other physical properties such as rib dimensions, planar angles made by the intersecting ribs, vertical angles made at the juncture point, aperture size and shape, color, hardness, etc., can be measured directly and are relatively straightforward to obtain.

4.1.2 Mechanical Properties

A number of strength aspects of geonets are important to consider.

4.1.2.1 Tensile Strength

The wide-strip tensile properties of geonets are sometimes called for in various specifications. Using ASTM D4595 which uses a test specimen 8.0 in. (200 mm) in width by 4.0 in. (100 mm) in length, the curves of Figure 4.4 resulted for a 200-mil (5.1-mm) thick solid-rib geonet in the machine and cross machine directions. Note the differences in behavior, suggesting that there is a preferential direction in strength between the machine and cross-machine directions. If site-specific conditions warrant a high-strength direction, the geonet should be oriented with its machine direction positioned accordingly. Also to be noted is that geonets do indeed possess a measurable tensile strength. For the solid-rib geonet illustrated in Figure 4.1 and shown in Figure 4.4, the average of a series of wide-strip tensile tests gave the following information:

- machine direction:
  - Peak strength = 680 lb./ft. (120 kN/m) = 680/12 lb./in = 56.7 lbs/in
  - (*) Strain at peak = 23% (*)
  - Strain at failure = 290%

Ref (10)

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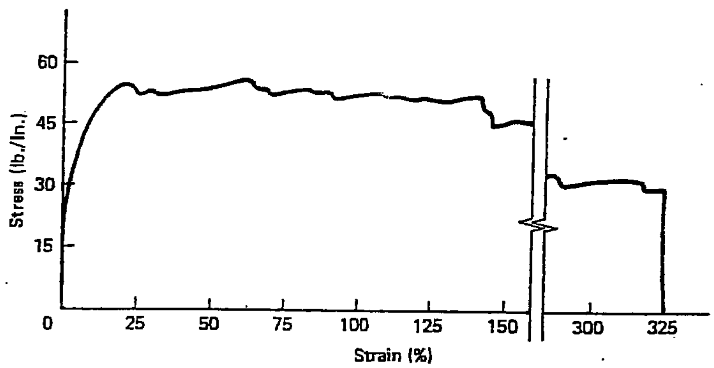
- cross-machine direction:
  Peak strength = 390 lb./ft. (68 kN/m)
  Strain at peak = 170%
  Strain at failure = 240%



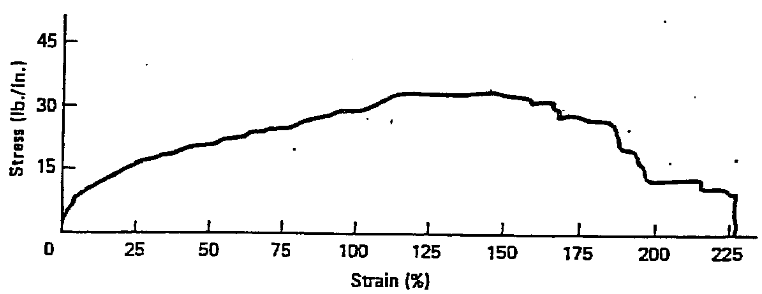


Figure 4.4. Tensile strength behavior of a 200-mil (5.1-mm) solid-rib extruded geonet. Upper curve, machine direction; lower curve, cross-machine direction.

4.1.2.2 Compressive Strength

Of greater importance than the above described in-plane tensile strength of geonets is the cross-plane compressive strength. This is due to the influence that compressive yielding or collapse has on the ability of the geonet to conduct liquid within its open spaces. There are a number of approaches to measuring a geonet's compressive strength, and the ASTM has a task commitee working on the topic. Using 6.0-in. (150-mm)-square test specimens normally loaded under a constant strain rate load of 0.002 in./min. (= 0.05 mm/min.), the curves of Figure 4.5 resulted. The upper figure illustrates deformation behavior to applied normal stress, while the lower figure presents strain versus applied normal stress. Here it is seen that both the foamed rib extruded geonet and the solid rib extruded geonet are initially very stiff but begin to deform at approximately 15,000 lb./ft.^{2} ($\cong$ 720 kPa). The solid extruded ribs deform into the valleys created by their intersecting

HDPE DRAINAGE NET — GEOTEXTILE GEOCOMPOSITE 14/20

Recommended TEX-NET® Specifications Ref. 14

1. DESCRIPTION

These specifications describe a high density polyethylene (HDPE) drainage net - geotextile geocomposite. The supply and installation of this material shall be in strict accordance with these specifications and contract drawings.

2. MATERIALS AND PRODUCT CONSTRUCTION

The geocomposite drainage material shall be TEX-NET® by Fluid Systems, Inc. and shall meet or exceed the following criteria:

2.01

Drainage net shall be manufactured by extruding two sets of strands to form a three (3) dimensional structure to provide planar water flow.

The drainage net shall contain stabilizers to prevent ultraviolet light degradation.

2.02

The drainage net shall be POLY-NET® PN-3000 or approved equal. In addition to the material properties listed above, the drainage net shall conform to the following properties detailed in the table below.

POLY-NET® PN-3000

PROPERTY	TEST METHOD	UNIT	QUALIFIER	VALUE
POLYMER DENSITY	ASTM D-1505	g/cm³	range	.937 ± .002
POLYMER MELT INDEX	ASTM D-1238	g/10 min	maximum	1.0
CARBON BLACK CONTENT	ASTM D-1603	%	range	2-3%
NOMINAL THICKNESS	ASTM D-1777	inches	range	0.220 ± 0.022
NOMINAL MASS PER UNIT AREA	ASTM D-3776	lbs/1000 ft²	range	180 ± 18
TRANSMISSIVITY at 15,000 psf	*ASTM D-4716	m²/sec	minimum	1 X 10⁻³
TENSILE STRENGTH MACHINE DIRECTION	ASTM D-1682	lbs/in	range	50 ± 10

*Per ASTM D4716-87. The transmissivity was measured using water @ 20°C (68°F) with a gradient of one, between two steel plates, after one hour. Value may vary, based on dimensions of the transmissivity specimen and specific laboratory.

2.03

The geotextile filter fabric shall meet or exceed the following:

TREVIRA® 1120 OR EQUAL MEETING THE PROPERTIES LISTED BELOW

FABRIC PROPERTY	UNIT	TEST METHOD	*MINIMUM REQUIREMENT
FABRIC WEIGHT	oz/yd²	ASTM D-3776	5.7
THICKNESS, t	mils	ASTM D-1777	75
GRAB STRENGTH	lbs	ASTM D-4632	160
GRAB ELONGATION	%	ASTM D-4632	60
TRAPEZOID TEAR STRENGTH	lbs	ASTM D-4533	60
PUNCTURE RESISTANCE	lbs	ASTM D-4833	80
MULLEN BURST STRENGTH	psi	ASTM D-3786	275
WATER FLOW RATE	gpm/ft²	ASTM D-4491	130
PERMITTIVITY, Ψ	sec⁻¹	ASTM D-4491	1.74
PERMEABILITY, k = Ψ t	cm/sec	ASTM D-4491	.33
AOS	Sieve Size mm	ASTM D-4751	70 .210

*These minimum values represent minimum test values determined from Q.C. testing on all lots produced in 1989.

For environmental lining solutions...the world comes to SLT.®
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For environmental lining solutions...the world comes to SLT.

Ref (11) 15/20

FrictionFlex® Textured HyperFlex® Lining Material

SLT's FrictionFlex patented texturing process provides the industry's leading textured liners. Uniquely produced from a specially formulated virgin HDPE geomembrane resin, FrictionFlex has outstanding chemical resistance, mechanical properties, environmental stress crack resistance, dimensional stability and thermal aging characteristics. HyperFlex, textured with the FrictionFlex process, contains approximately 97.5% polymer and 2.5% carbon black, anti-oxidants and heat stabilizers, and contains no additives, fillers or extenders. SLT textured liners have excellent resistance to UV radiation and are suitable for exposed conditions.

PROPERTY	TEST METHOD	NOMINAL VALUES			
Thickness, mils	ASTM D751/374/1593	40	60	80	100
Density (g/cc)	ASTM D792/1505	0.944	0.944	0.944	0.944
Melt Flow Index (g/10 minutes)	ASTM D1238-E	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
Tensile Properties Either Direction	ASTM D638 Type IV Dumbell, 2 ipm				
Tensile Strength at Break (lbs/in, width)	Gauge length per	200	300	400	500
Tensile Strength at Yield (lbs/in, width)	N.S.F. Std. 54	96	144	192	240
Elongation at Break (percent)		600	600	600	600
Elongation at Yield (percent)		15	15	15	15
Tear Resistance Initiation (lbs)	ASTM D1004 Die C	33	50	66	83
Low Temperature Brittleness	ASTM D746 B	<-120°F	<-120°F	<-120°F	<-120°F
Dimensional Stability Each Direction (percent)	ASTM D1204 248°F 1 hr.	± 1	± 1	± 1	± 1
Ozone Resistance	ASTM D1149 7 days 100 ppm 104°F	No Cracks	No Cracks	No Cracks	No Cracks
Environmental Stress Crack Resistance (hrs)	ASTM D1693 Cond. C	>2000	> 2000	> 2000	> 2000
Puncture Resistance (lbs)	FTMS 101C Method 2065	60	90	120	150
Water Absorption (percent weight change)	ASTM D570	<0.01	<0.01	<0.01	<0.01
Moisture Vapor Transmission (g/m²day)	ASTM E96	<0.001	<0.001	<0.0009	<0.00085
Oxidative Induction Time (minutes) Pure O_2 at 1 Atmosphere	ASTM D3895 200°C	100	100	100	100
Tensile Impact Strength (ft-lbs/in²)	ASTM D1822	381	381	381	381
Carbon Black Content (percent)	ASTM D1603	2-3	2-3	2-3	2-3
Carbon Black Dispersion	ASTM D3015	A1/A2	A1/A2	A1/A2	A1/A2

SLT FrictionFlex is available in 24-foot widths and up to 8,000 lb. rolls. Special length rolls and other material thicknesses are available upon request.

This data is provided for informational purposes only and is not intended as a warranty or guarantee. SLT assumes no liability in connection with the use of this data.

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ENVIRONMENTAL SOLUTIONS, INC.

By JH Date 3/6/96 Subject Liner Stresses Sheet No. 17 of 20

Chkd. By MB Date 3/7/96 Proj. No. 95-284

Table 2

material	Self weight (lb/ft) [1]	Accumulated Weight (lb/ft)	F_u (lb/ft) [2]	F_L (lb/ft) [2]	Tensile Load Due To Gravity (lbs/in) [3]
Geotextile	4.4	4.4	0	0.7	0.3
Geonet	15.1	19.5	0.7	1.2	1.1
100-mil HDPE	45.4	63.9	1.2	11	2.6
Geocomposite	21.8	85.7	11	14.7	1.3
80-mil HDPE	37	122.7	14.7	16.8	2.6
GCL	100.8	223.5	16.8	78.2	2.4

NOTES

(1) Self Weight = unit weight (in lbs/ft^2) * Slope Length
Slope Length = 84 feet.
unit weight is listed in Table 1.

(2) Friction Forces (F_u & F_L) are calculated as follows:

$$F = \text{Accumulated Wt.} \times \cos 63.4 \times \tan \delta$$

where δ = residual interface friction angle (see Table 3).

(3) Tensile Load Due To Gravity $= (\text{Self Wt.} * \sin 63.4 + F_u - F_L)/12''$
(in lbs/in)

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Chkd. By WS Date 3/7/96 Proj. No. 95-284

Table 3

Interface No.	Residual Friction angle (degree)	Reference
2	19	1
3	8	1
4	21	1
5	21	1
6	17	2
7	38	2

4.0 CONCLUSIONS

1. The outer layers of the liner system will withstand the relatively large strains (up to ≈ 4.7%) primarily caused by waste fill settlement. Settlement induced stresses will occur gradually as the waste fill is being placed. This slow loading process will allow the upper materials (geotextile and geonet) to deform without inducing significant stresses. The calculated stresses are conservative and are within the allowable limits. This slow load application, creep relaxation of stresses should be measured in the laboratory to verify design parameters (see item 6).

2. The design slip plane between geonet and the smooth side of the 100-mil HDPE will prevent the settlement induced strains (and stresses) from being transferred to the lower layers of the liner system.

3. Self weight of liner components are not an issue. Up to one percent of strain can occur in the GCL material. The calculated stress in GCL is less than the allowable stress.

4. Thermal stresses are negligible. Based on our experience, we do not expect wrinkles to occur in the liner system when textured HDPE is used. However, in case minor wrinkles do occur, care should be taken to avoid placing fill (soil or waste) over wrinkles such that thermal stresses (and strains) are "locked in" and thus could accumulate from the bottom to the top.

5. Wind uplift is balanced by using sand bags and suction devices, and are not included in the liner stress calculations.

6. Actual materials used in construction should be tested for stress-strain properties and interface shear strength parameters.

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By JH Date 2/9/96 Subject Tension / Elongation Sheet No. 20 of 20

Chkd. By KB Date 2/19/96 Proj. No. 95-284

5.0 References

1. ESI, Internal Data Base.

2. CETCO, October, 1995, Technical Data.

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4. US Ecology Calculations, Thermal Expansion and Contraction, Dec. 1992.

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6. Polyfelt, Design and Practice Manual, June, 1989.

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9. Hoechst Celanese Corp, Catalog, Trevira Spunbond, 1990.

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1997

LINER STRESS CALCULATION REVISION

HMA environmental

SUBJECT US Ecology Beatty, NV
Side Slope Friction Forces
DESIGNER J. Ellison
CHECKER RGSpoon

AEP NO. 023801
SHEET 1 OF 10
DATE 1-29-97
DATE [illegible] 97

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all sheets

I. INTRODUCTION

The Purpose of this calculation is to provide a detailed explanation of how friction forces F_L (as outlined in Cell 12 Design Report, p. [illegible] 18) are calculated.

The free body diagram shown in Figure 1 identify forces present in the overall system. Figure 2 shows an exploded view of the interactive forces resulting from the components of the liner system.

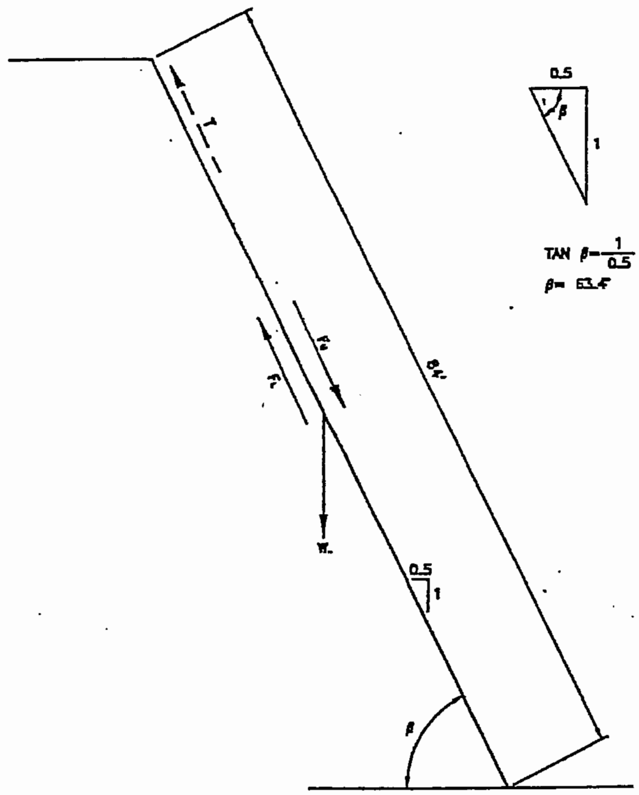
LINER SYSTEM COMPONENTS ARE AS FOLLOWS:

1. Geotextile (Trevira Spunbound 1125)
2. Geonet (Poly-Net PN-3000)
3. 100 mil HDPE (Textured Hyperflex)
   smooth upper face
   textured lower face
4. Geocomposite (Texnet TN 3002/1125)
5. 80 mil HDPE (Textured Hyperflex)
   textured upper and lower faces
6. GCL (Claymax 600 SP)

DEFINITIONS:

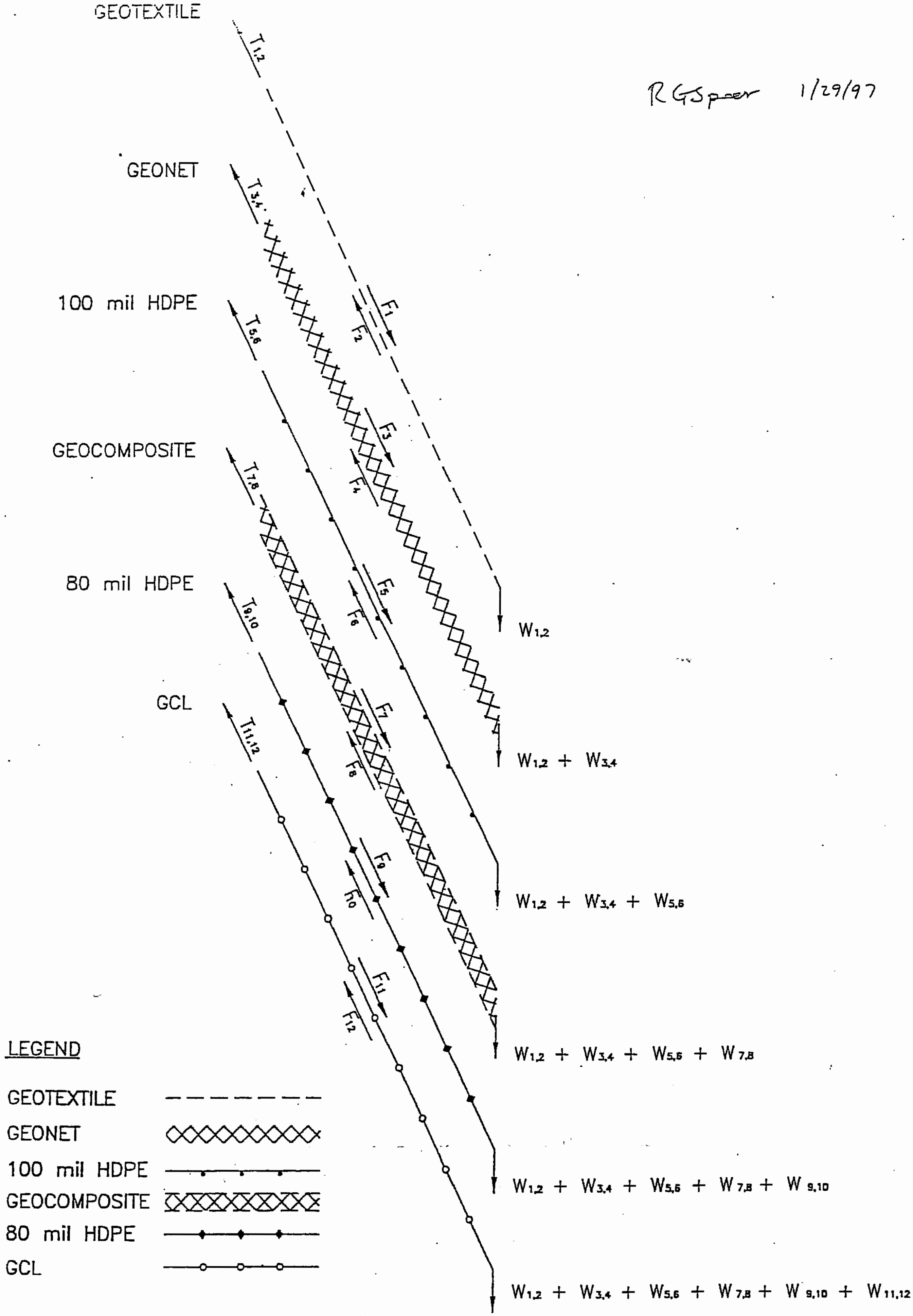
T = Tensile Force
W = Weight of Liner Component
F_u = Upper Face Friction Force
F_L = Lower Face Friction Force
β = Slope Angle
δ = Friction Angle Between Liner Components

RGSpeer 1/29/97



FREE BODY DIAGRAM

FIGURE 1



EXPLODED VIEW OF THE SIDE SLOPE LINER SYSTEM

FIGURE 2

SUBJECT US Ecology Beatty, NV	AEP NO 023801		
Side Slope Friction Forces	SHEET 4	OF 10	
DESIGNER J. Ellison	DATE 1-28-97		
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SUM FORCES IN THE HORIZONTAL DIRECTION

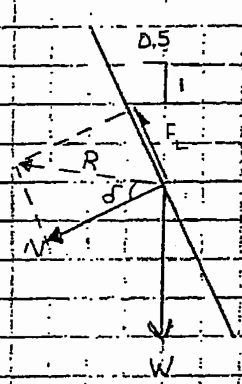
$\Sigma F_H = 0$ Orient Horizontal Axis Along Slope

$$T + F_L = W \sin B + F_U$$

$$T = W \sin B \pm F_U - F_L$$

SUM FORCES IN THE VERTICAL DIRECTION

$\Sigma F_V = 0$ Orient Vertical Axis Perpendicular To The Slope (Further detail must be shown in order to completely develop this equation) (Eshbach's Handbook of Engineering Fundamentals, 4th edition, Byron O. Tapley)



F_L, friction force, is a component of the resultant force that opposes motion.

N, normal force, is always normal or perpendicular to the plane of motion.

δ is the friction angle

$\Sigma F_V = 0$: Normal force, $N = W \cos B$

$$\tan\delta = \frac{F_L}{N} \quad \therefore \quad N = \frac{F_L}{\tan\delta}$$

Substitute for the Normal force, N

$$\frac{F_L}{\tan\delta} = W \cos B$$

$$F_L = W \cos B \tan\delta$$

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Therefore $\Sigma F_H = 0 \quad T = W \sin\beta + F_U - F_L$

$\Sigma F_V = 0 \quad F_L = W \cos\beta \tan\delta$

The following equations are utilized to determine friction forces within the liner system:

(1) SELF WEIGHT = UNIT WEIGHT · SLOPE LENGTH

(2) $F_L = \text{WEIGHT}_{accumulated} \cdot \cos\beta \cdot \tan\delta$

(3) $T = \left[(\text{SELF WEIGHT} \cdot \sin\beta) + F_U - F_L\right] / 12$

COMPONENT	UNIT WEIGHT (lbs/ft²)	INTERFACE	RESIDUAL FRICTION ANGLE (degrees)
Geotextile	0.052	Geotextile/Geonet	19
Geonet	0.180	Geonet/100 mil HDPE	12
100 mil HDPE	0.54	100 mil HDPE -to- Geocomposite	26
Geocomposite	0.26	Geocomposite -to- 80 mil HDPE	26
80 mil HDPE	0.44	80 mil HDPE/GCL	19
GCL	1.02	GCL/Soil	36

All friction angle values are based upon information received from SLT, NSC, and CETCO, geosynthetics representatives. Values used in the original calculation are conservative. Typical residual friction angle values are included in Enclosure No. 1.

This calculation is prior to slippage of the smooth face of the 100 mil HDPE liner.

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SLOPE LENGTH = 84 ft

(1) Geotextile / Geonet Interface:

1. Self Weight = 0.052 lb/ft^2 (84 ft) = 4.37 lb/ft

2. $F_r \cong 0$ (since soil deforms as it moves along liner)

$F_2 = W_{accumulated} \cdot \cos\beta \cdot \tan\delta$

$F_2 = (4.37 \text{ lb/ft}) \cos 63.4° \tan 19°$

$F_2 = 0.67$ lb/ft

3. $T_{1,2} = \left[(4.37 \text{ lb/ft}) \sin 63.4° + 0 - 0.67 \text{ lb/ft}\right] / 12 \text{ in/ft}$

$T_{1,2} = 0.27$ lb/in

(2) Geonet / 100 mil HDPE Interface:

1. Self Weight = 0.18 lb/ft^2 (84 ft) = 15.12 lb/ft

2. $F_2 = F_3$; $F_3 = 0.67$ lb/ft

$F_4 = (4.37 + 15.12) \cos 63.4° \tan 12°$

$F_4 = 1.85$ lb/ft

3. $T_{3,4} = (15.12 \sin 63.4° + 0.7 - 1.85) / 12$

$T_{3,4} = 1.03$ lb/in

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(3) 100 mil HDPE / Geocomposite :

1. Self Weight $= 0.54\ lb/ft^2 (84\ ft) = 45.36\ lb/ft$

2. $F_4 = F_5 \therefore F_5 = 1.85\ lb/ft$

$F_6 = (4.37 + 15.12 + 45.36) \cos 63.4° \tan 26°$

$F_6 = 14.16\ lb/ft$

3. $T_{5,6} = (45.36 \sin 63.4° + 1.85 - 14.16)/12$

$T_{5,6} = 2.35\ lb/in$

(4) Geocomposite / 80 mil HDPE

1. Self Weight $= 0.26\ lb/ft^2 (84\ ft) = 21.84\ lb/ft$

2. $F_6 = F_7 \therefore F_7 = 14.16\ lb/ft$

$F_8 = (4.37 + 15.12 + 45.36 + 21.84) \cos 63.4° \tan 26°$

$F_8 = 18.93\ lb/ft$

3. $T_{7,8} = (21.84 \sin 63.4° + 14.16 - 18.93)/12$

$T_{7,8} = 1.23\ lb/in$

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(5) 80 mil HDPE/GCL

1. Self Weight = $0.44\ lb/ft^2 (84\ ft) = 36.96\ lb/ft$

2. $F_8 = F_9 \therefore F_9 = 18.93\ lb/ft$

$F_{10} = (4.37 + 15.12 + 45.36 + 21.84 + 36.96) \cos 63.4° \tan 19°$

$F_{10} = 19.06\ lb/ft$

3. $T_{9,10} = (36.96 \sin 63.4° + 18.93 - 19.06)/12$

$T_{9,10} = 2.74\ lb/in$

(6) GCL/Soil

GCL - Claymax 600 SP bentonite weight = 0.75 lb/ft² @ 0% moisture
The industry standard reports bentonite weight = 0.95 lb/ft²
@ 20 moisture, this value is conservative considering the very
dry climate of Nevada ∴ Bentonite = 0.95 lb/ft²

Upper geosynthetic = $3.2\ oz/yd^2 \left(\frac{1\ lb}{16\ oz}\right)\left(\frac{yd^2}{9\ ft^2}\right) = 0.022\ lb/ft^2$

Lower geosynthetic = $6.6\ oz/yd^2 \left(\frac{1\ lb}{16\ oz}\right)\left(\frac{yd^2}{9\ ft^2}\right) = 0.046\ lb/ft^2$

Weight = $0.95 + 0.022 + 0.046 = 1.02\ lb/ft^2$

1. Self Weight = $1.02\ lb/ft^2 (84\ ft) = 85.7\ lb/ft$

2. $F_{10} = F_{11} \therefore F_{11} = 19.06\ lb/ft$

$F_{12} = (4.37 + 15.12 + 45.36 + 21.84 + 36.96 + 85.7) \cos 63.4° \tan 36°$

$F_{12} = 68.10\ lb/ft$

3. $T_{11,12} = (85.7 \sin 63.4° + 19.06 - 68.10)/12$

$T_{11,12} = 2.30\ lb/in$

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Side Slope Friction Forces SHEET 9 OF 10
DESIGNER J. Ellison DATE 1-28-97
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The following table summarizes forces in tabular form. These forces are very similar to the liner forces calculated in the Cell 12 Design Report included in Enclosure 2. Please note that this condition is prior to loading and waste settlement. Once settlement occurs, slippage will take place at the 100 mil HDPE (smooth) face and the geonet. Available material data sheets are included in Enclosure No. 3.

TABLE OF DERIVED FRICTIONAL FORCES PRIOR TO SLIPPAGE						
MATERIAL	UNIT WEIGHT (lb/ft^2)	SELF WEIGHT (lb/ft)	ACCUMULATED WEIGHT (lb/ft)	F_U (lb/ft)	F_L (lb/ft)	TENSILE LOAD DUE TO GRAVITY (lb/in)
Geotextile (Trevira Spunbond 1125)	0.052	4.37	4.37	$F_1 = 0$	$F_2 = 0.67$	0.27
Geonet (Poly-Net PN-3000)	0.180	15.12	19.49	$F_3 = 0.67$	$F_4 = 1.85$	1.03
100 mil HDPE (Textured Hyperflex)	0.54	45.36	64.85	$F_5 = 1.85$	$F_6 = 14.16$	2.35
Geocomposite (Texnet TN 3002/1125)	0.26	21.84	86.69	$F_7 = 14.16$	$F_8 = 18.93$	1.23
80 mil HDPE (Textured Hyperflex)	0.44	36.96	123.65	$F_9 = 18.93$	$F_{10} = 19.06$	2.74
GCL (Claymax 600 SP)	1.02	85.7	209.35	$F_{11} = 19.06$	$F_{12} = 68.10$	2.30

RG Spoon 1-25-97