APPENDIX VI-D

LINER SYSTEM CALCULATIONS

APPENDIX VI-D.1

GEOMEMBRANE PUNCTURE RESISTANCE - LINER

Geosyntec consultants

COMPUTATION COVER SHEET

Client: DRPI **Project:** DRPI Landfill Expansion **Project #:** ME1571 **Task #:** 1

TITLE OF COMPUTATIONS LINER GEOMEMBRANE PUNCTURE RESISTANCE

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NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

LINER GEOMEMBRANE PUNCTURE RESISTANCE

PURPOSE

A total of 18.3 acres of remaining liner system will be constructed at the Cells 1-3 Overlay area of Delaware Recyclable Products, Inc. (DRPI) landfill (see Figure 1). A 60-mil textured geomembrane will be a component of the proposed liner system at the. The geomembrane material will be in direct contact with a geosynthetic clay liner (GCL) and a geocomposite drainage layer. In order for the geomembrane to work efficiently as a barrier layer, puncturing of the geomembrane should be avoided. The purpose of this analysis is to evaluate the puncture resistance of the 60-mil geomembrane under construction for the remaining liner system to be installed. Additionally, the puncture resistance for the existing liner system in the other areas under the pressure of waste is also evaluated. Also presented in this calculation package is a bearing capacity calculation for failure of the overlying soil due to construction equipment.

METHOD

Figure 2 shows the liner system cross section. The puncture resistance will be evaluated for construction equipment working above the 60-mil geomembrane liner.

Geomembrane Allowable Pressures

The allowable pressure on the geomembrane (p_{allow}) is computed based on a methodology presented by Koerner [2005]. The governing equation for the methodology presented by Koerner is as follows:

$$p_{allow} = \left(50 + 0.00045\,\frac{M}{H^2}\right) \times \left(\frac{1}{MF_S \times MF_{PD} \times MF_A}\right) \times \left(\frac{1}{RF_{CR} \times RF_{CBD}}\right) \quad (1)$$

where:

p_{allow}	=	Allowable pressure on geomembrane, (kPa)
M	=	Mass per unit area of a protective geotextile separation layer, (g/m^2)
H	=	Height of protrusions within the adjoining soil mass, (m)
MF_S	=	Modification factor for protrusions shape
MF_{PD}	=	Modification factor for packing density
MF_A	=	Modification factor for arching in solids
RF_{CR}	=	Reduction factor for creep
RF_{CBD}	=	Reduction factor for chemical and biological degradation

The first term in Equation 1, requires input of the mass per unit area property of the geotextile used to protect the geomembrane along with the expected protrusion height of the soil. The second term in equation 1 involves modification factors to account for shape, packing density and arching of soil

used. The modification factors used in current calculations are based on Koerner [2005] and presented in Table 1.

Table 1: Modification factors for geomembrane puncture

Notation	*Liner System - 60 mil HDPE Geomembrane*	
	Factor	Comments
MF_S	0.5	Sub-rounded particles (conservative)
MF_{PD}	1.0	Isolated protrusions (conservative)
MF_A	1.0	Hydrostatic conditions (conservative)

The third term in Equation 1 represents the reduction factors to account for long-term creep and degradation of the geomembrane. To evaluate the geomembrane puncture resistance under worst-case scenario, highest reduction factor for creep, RF_{CR} of 1.5 based on Koerner [2005] is used for the protective cover/drainage layer which is assumed to be AASHTO 57 stone with average particle size of 12 mm (selected based on typical gradation curve shown in Figure 3). Also, assuming conservative estimates for reduction factor for chemical and biological degradation, RF_{CBD} value of 1.5 for the harsh leachate conditions is assumed as shown in Table 2.

Table 2: Reduction factors for geomembrane puncture

Notation	*Liner System - 60 mil HDPE Geomembrane*	
	Factor	Comments
RF_{CR}	1.5	For protrusion height of 12 mm
RF_{CBD}	1.5	Conservatively assume harsh leachate condition

For the analysis presented herein, the protection provided by an overlying geotextile component of the geocomposite is neglected and the first term in equation 1 is replaced with a value F_{lab}, which is defined as the ultimate puncture resistance (force, lbs) of the geomembrane as measured according to the procedure, *Standard Test Method, for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products*, ASTM D4833. The revised equation is presented as follows:

$$F_{allow} = \left(F_{lab}\right) \times \left(\frac{1}{MF_S \times MF_{PD} \times MF_A}\right) \times \left(\frac{1}{RF_{CR} \times RF_{CBD}}\right) \qquad (2)$$

In Equation 2, the value of F_{lab} is equal to the minimum material property that is required by the liner geomembrane as per the project specifications for liner system. The puncture resistance for GSE 60 mil HD textured geomembrane is specified as 130 lbs (see Figure 4) and used as a basis for this calculation. In Equation 2, the term p_{allow} (from equation 2) is also converted from pressure to force by replacing it with the term F_{allow}. Based on above inputs, the allowable force on geomembrane is calculated as:

$$F_{allow} = 130 \times \frac{1}{0.5\times1.0\times1.0} \times \frac{1}{1.5\times1.5} = 115.6 \text{ lbs or } 0.512 \text{ kN}$$

Assuming that the full diameter of the particle is in contact with the geomembrane, the allowable pressure applied by the particle to the geomembrane is calculated as follows:

$$p_{allow} = \frac{F_{allow}}{(\frac{\pi D_{aveage}{}^2}{4})} = 0.512/(\frac{3.14\times\left(\frac{12}{1000}\right)^2}{4}) = 4{,}529 \quad \text{kPa or 93,442 psf (648 psi)}$$

Design Pressures

The total vertical stress on the geomembrane is calculated as the sum of the overlying soil pressure and the pressure exerted by the construction equipment.

$$p_{act} = (\gamma_{ave} \times T) + q_{eqp} \tag{3}$$

Where:

p_{act} = vertical stress on the geomembrane
γ_{ave} = average unit weight of the material above geomembrane
T = thickness of the soil material above geomembrane
q_{eqp} = equipment ground pressure

To evaluate the maximum pressure of a construction vehicle above the geomembrane, two typical dozers are assumed: (i) a CAT D6H, Series II; and (ii) a CAT D6H, Series II LGP. For this evaluation, a minimum lift thickness of 1 foot of soil will be evaluated as the most conservative case. As the amount of soil above the geomembrane increases the allowable ground pressure of construction traffic increases. The following table lists the required information about the assumed construction equipment and the calculated design pressures.

Load Type	Contact Area(in^2)	Ground pressure q_{eqp} (psi)	Design pressure (2) p_{act} (psi)
CAT D6H, Series II(1)	4564	8.56	9.32
CAT D6H, Series II, LGP(1)	9255	4.71	5.47
Waste(3)	-	-	87.5

NOTES:

(1) Equipment data taken from Caterpillar Performance Handbook, 23 edition, Oct, 1992.
(2) including 1 foot of overlying soil with a unit weight 110 pcf.

(3) Assume waste thickness and unit weight of 180 ft and 70 pcf, respectively, based on the proposed vertical expansion condition.

Factor of Safety against Puncture Failure

The factor of safety against puncture resistance for the load above the geomembrane is defined as:

$$FS = \frac{p_{allow}\ (psi)}{p_{act}\ (psi)} \tag{4}$$

Based on the pressures calculated, the factors of safety against puncture resistance for the cap and liner geomembrane are:

Load	60-mil Geomembrane Liner
CAT D6H, Series II	69.5
CAT D6H, Series II, LGP	118.5
Waste	7.4

Bearing Capacity

A factor of safety against bearing capacity failure of the soils overlying the geomembrane during construction is calculated. The construction equipments are the same as the ones in the previous section. The bearing capacity equation used for analysis is taken from NAV-FAC Design Manual 7.2 [1982] for a continuous strip footing.

$$q_{ult} = \left(\frac{1}{2}\gamma\ B\ N_{\gamma}\right) + \left(\gamma\ D_f\ N_q\right) \tag{5}$$

Where:

q_{ult}	=	ultimate capacity of the soil
B	=	footing width (Standard shoe width)
γ	=	unit weight of foundation soil
D_f	=	depth of the footing
N_γ, N_q	=	bearing capacity factors

The construction equipment will work on the surface of the soil. Therefore, the footing depth in the first term of the bearing capacity equation will go to zero leaving only the second term. The bearing

capacity factor N_γ is taken from the chart in Figure 2 and assumes consertively a soil friction angle of 30 degrees.

q_{ult} = 0.5(110 pcf) (22 in./12 in.) (18) (1 ft^2 / 144 in^2) = 12.6 (CAT D6H, Series II)

q_{ult} = 0.5(110 pcf) (36 in./12 in.) (18) (1 ft^2 / 144 in^2) = 20.6 (CAT D6H, Series II, LGP)

The factor of safety for bearing capacity of the soil is calculated as the ratio of the ultimate bearing capacity, q_{ult}, to the applied ground pressure, q_{eqp}, of the construction equipment. The following table summarizes the ultimate bearing capacity of the ground and the calculated factor of safety against bearing capacity failure.

Equipment	Standard Shoe Width, B (inches)	N_γ (From Figure 2)	q_{ult}(1) (psi)	Ground Pressure, q_{eqp}, (psi)	Factor of safety, (q_{ult}/q_{eqp})
CAT D6H, Series II,	22	18	12.6	8.56	1.5
CAT D6H, Series II, LGP	36	18	20.6	4.71	4.4

NOTES: (1) Soil unit weight is assumed to be 110 pcf.

SUMMARY OF RESULTS

Based on the analysis presented here, the Caterpillar D6H Series II LGP and D6H Series II operating with a minimum of one foot of cover soil will not compromise the geomembrane puncture resistance or cause a bearing capacity failure of the overlying soil. Other vehicles with equal or lower ground pressures may also operate safely.

REFERENCES

Caterpillar Performance Handbook, 35th edition, October 2004.

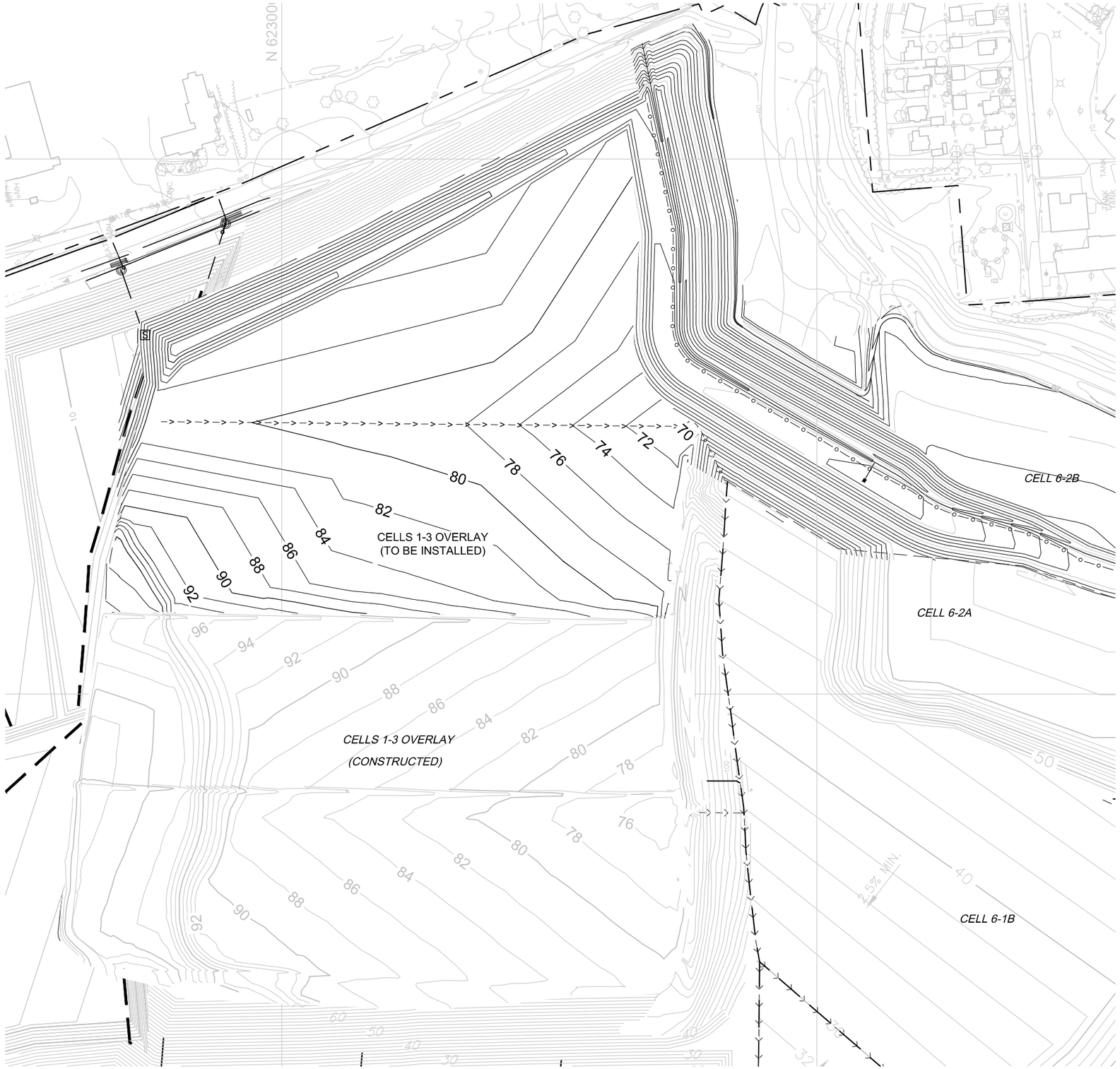
"Foundations and Earth Structures Design Manual 7.2", Department of the Navy, Naval Facilities Engineering Command, Alexandria, Virginia, May 1982.

Geosynthetics Research Institute, GM13, 1999.

Koerner, R.M, "*Designing with Geosynthetics*", 5th edition, 2005

Narejo, D RM. Koerner and RF Wilson-Fahmy,"Puncture Protection of Geomembranes, Part II; Experimental", Geosynthetics International, Vol 3 No. 5 1996.

FIGURES



N

LEGEND

- PROPERTY BOUNDARY
- EXISTING GRADE CONTOUR (FEET–MSL)
- LEACHATE MANAGEMENT SYSTEM CONTOUR (FEET–MSL)
- EXISTING TREELINE
- EXISTING ROAD
- EXISTING BUILDING
- EXISTING DEEP GROUNDWATER MONITORING WELL, LOCATED 9/2001
- EXISTING AND PROPOSED LEACHATE COLLECTION PIPE (SEE NOTE 6)

GENERAL NOTES:

1. EXISTING CONDITIONS (WITH THE EXCEPTION OF LANDFILL GAS FEATURES) ARE FROM A 14 DECEMBER 2017 PHOTOGRAMMETRIC SURVEY BY AERIAL SURVEY CORPORATION OF DULLES, VIRGINIA. EXISTING LANDFILL GAS FEATURES ARE FROM AN ELECTRONIC FILE OF THE DRAWING ENTITLED "GAS EXTRACTION SYSTEM AND MONITORING PLAN AS OF DECEMBER 2011, DELAWARE RECYCLABLE PRODUCTS, INC.," BY VANDEMARK AND LYNCH, INC., DATED 7 FEBRUARY 2012.
2. DRPI PROPERTY LINE WAS OBTAINED FROM VANDEMARK AND LYNCH, INC.
3. PROPERTY LINES FOR ADJACENT PROPERTIES WERE OBTAINED FROM VANDEMARK AND LYNCH, INC., BUT ARE FROM FILES WHICH MAY NOT BE UP TO DATE. THEREFORE, THESE PROPERTY LINES SHOULD BE CONSIDERED APPROXIMATE.
4. GRID IS BASED ON DELAWARE STATE PLANE COORDINATE SYSTEM (NAD 1927).
5. ELEVATIONS ARE IN FEET ABOVE SEA LEVEL DATUM ("SEA LEVEL DATUM" REFERS TO THE NORTH GEODETIC VERTICAL DATUM OF 1929 [NGVD 29].)
6. DETAILS ARE SHOWN TO SCALE AS NOTED EXCEPT FOR THE GEOSYNTHETICS, WHICH ARE SHOWN AT AN EXAGGERATED SCALE FOR CLARITY.

0 200'
SCALE IN FEET

PLAN VIEW OF LINER SYSTEM TO BE INSTALLED

Geosyntec consultants
COLUMBIA, MARYLAND

DATE:	JULY 2018
PROJECT NO.	ME1571
DOCUMENT NO.	
FILE NO.	1571f005–liner
FIGURE NO.	1

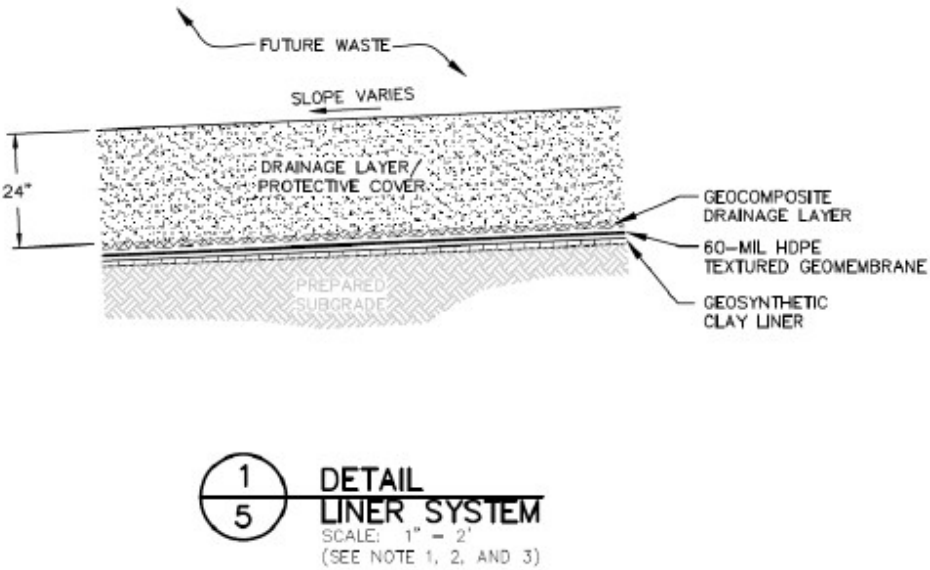


Figure 2. Proposed Liner System Details

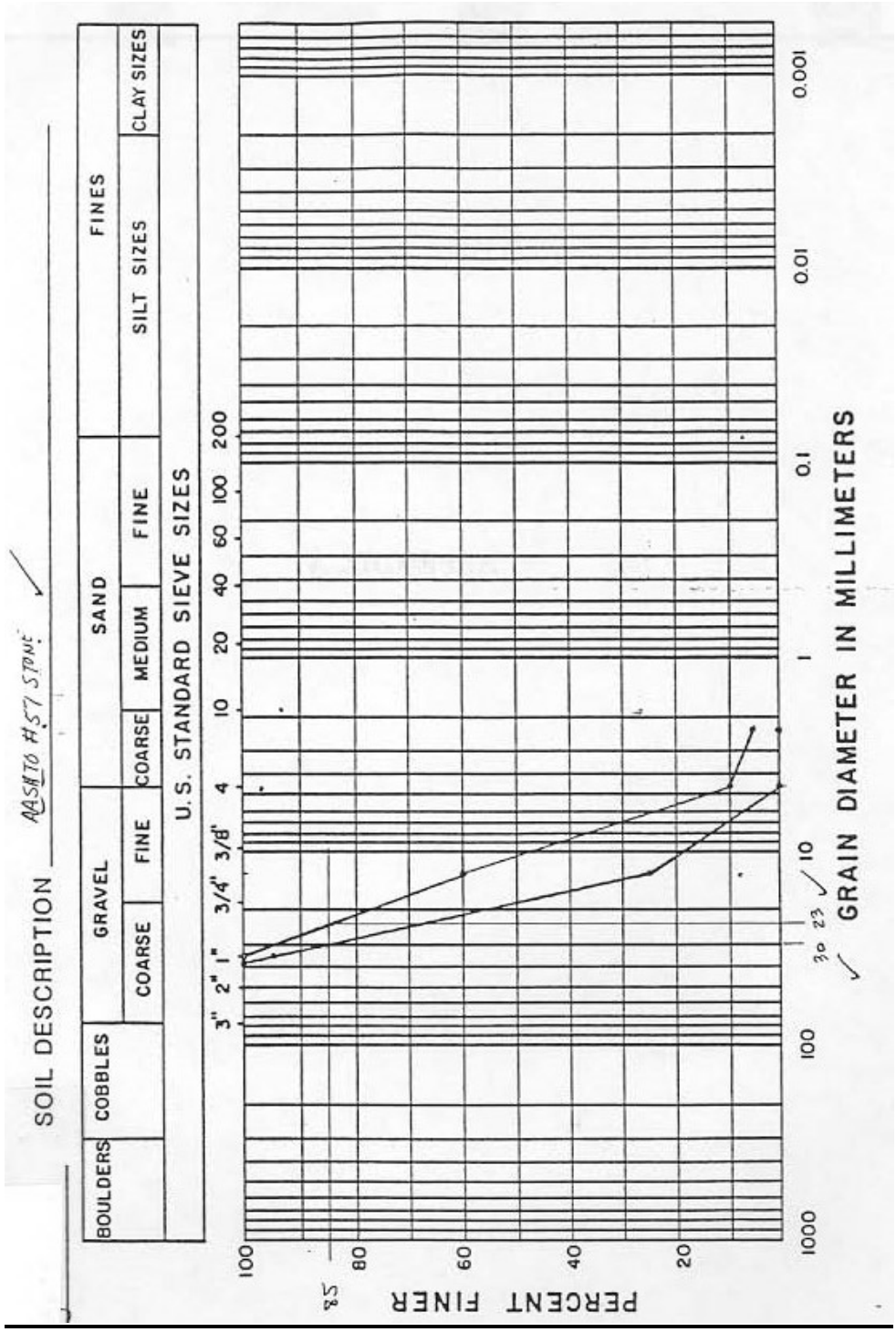


Figure 3: Grain size distribution curve for AASHTO No.57 Stone

Product Data Sheet

GSE

The Pioneer Of Geosynthetics

GSE HD Textured Geomembrane

GSE HD Textured is a co-extruded textured high density polyethylene (HDPE) geomembrane available on one or both sides. It is manufactured from the highest quality resin specifically formulated for flexible geomembranes. This product is used in applications that require increased frictional resistance, excellent chemical resistance and endurance properties.

Product Specifications *These product specifications meet or exceed GRI GM13.*

TESTED PROPERTY	TEST METHOD	FREQUENCY	MINIMUM AVERAGE VALUE				
			30 mil	40 mil	60 mil	80 mil	100 mil
Thickness, (minimum average) mil (mm)	ASTM D 5994	every roll	30 (0.75)	40 (1.00)	60 (1.50)	80 (2.00)	100 (2.50)
Lowest individual reading (-10%)			27 (0.69)	36 (0.91)	54 (1.40)	72 (1.80)	90 (2.30)
Density, g/cm³	ASTM D 1505	200,000 lb	0.94	0.94	0.94	0.94	0.94
Tensile Properties (each direction)	ASTM D 6693, Type IV	20,000 lb					
Strength at Break, lb/in-width (N/mm)	Dumbell, 2 ipm		66 (11)	75 (13)	115 (20)	155 (27)	230 (40)
Strength at Yield, lb/in-width (N/mm)			68 (11)	90 (15)	132 (23)	177 (31)	225 (39)
Elongation at Break, %	G.L. 2.0 in (51 mm)		100	100	100	100	100
Elongation at Yield, %	G.L. 1.3 in (33 mm)		12	12	12	12	12
Tear Resistance, lb (N)	ASTM D 1004	45,000 lb	24 (106)	32 (142)	45 (200)	60 (266)	75 (333)
Puncture Resistance, lb (N)	ASTM D 4833	45,000 lb	65 (289)	95 (422)	130 (578)	160 (711)	190 (845)
Carbon Black Content, % (Range)	ASTM D 1603*/4218	20,000 lb	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Carbon Black Dispersion	ASTM D 5596	45,000 lb	Note[1]	Note[1]	Note[1]	Note[1]	Note[1]
Asperity Height, mil (mm)	ASTM D 7466	second roll	16 (0.40)	18 (0.45)	18 (0.45)	18 (0.45)	18 (0.45)
Notched Constant Tensile Load[2], hr	ASTM D 5397, Appendix	200,000 lb	1,000	1,000	1,000	1,000	1,000
Oxidative Induction Time, min	ASTM D 3895, 200° C; O_2, 1 atm	200,000 lb	>140	>140	>140	>140	>140
TYPICAL ROLL DIMENSIONS							
Roll Length[3], ft (m)	Double-Sided Textured		830 (253)	700 (213)	520 (158)	400 (122)	330 (101)
	Single-Sided Textured		840 (256)	650 (198)	420 (128)	320 (98)	250 (76)
Roll Width[3], ft (m)			22.5 (6.9)	22.5 (6.9)	22.5 (6.9)	22.5 (6.9)	22.5 (6.9)
Roll Area, ft² (m²)	Double-Sided Textured		18,675 (1,735)	15,750 (1,463)	11,700 (1,087)	9,000 (836)	7,425 (690)
	Single-Sided Textured		18,900 (1,755)	14,625 (1,359)	9,450 (878)	7,200 (669)	5,625 (523)

NOTES:
- [1] Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.
- [2] NCTL for GSE HD Textured is conducted on representative smooth membrane samples.
- [3] Roll lengths and widths have a tolerance of ± 1%.
- GSE HD Textured Double-Sided is available in rolls weighing approximately 4,000 lb (1,800 kg) and Single-Sided weighing approximately 3,000 lb (1,360 kg).
- All GSE geomembranes have dimensional stability of ±2% when tested according to ASTM D 1204 and LTB of <-77° C when tested according to ASTM D 746.
- *Modified.

Figure 4: Textured HDPE Geomembrane Data Sheet

APPENDIX VI-D.2

LINER SYSTEM VENEER STABILITY ON SIDE SLOPES

Geosyntec consultants

COMPUTATION COVER SHEET

Client: DRPI **Project:** DRPI Landfill Expansion **Project #:** ME1571 **Task #:** 1

TITLE OF COMPUTATIONS LINER SYSTEM VENEER STABILITY ON SIDESLOPE

COMPUTATIONS BY:

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COMPUTATIONS CHECKED BY:

Signature _____ 3/13/2018 DATE

Printed Name and Title: Andrew Stallings, Senior Staff Engineer

COMPUTATIONS BACKCHECKED BY: (Originator)

Signature _____ 3/13/2018 DATE

Printed Name and Title: Chunling Li, Project Engineer

APPROVED BY: (PM or Designate)

Signature _____ 3/13/2018 DATE

Printed Name and Title: David Espinoza, Senior Principal

APPROVAL NOTES:

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

LINER SYSTEM VENEER STABILITY ON SIDE SLOPES

PURPOSE:

The purpose of this engineering calculation is to evaluate the factor of safety against veneer slope stability failure along the interfaces of the various components of the liner system to be used in the Cells 1 through 3 overlay area at the Delaware Recyclable Products, Inc. (DRPI) landfill in New Castle, Delaware. Specifically, this calculation analyzes stability of the leachate collection/protection cover zone under open cell condition.

Figure 1 shows the liner system to be installed. The existing liner system in other cells are buttressed by waste placed. Therefore, liner system veneer stability is not an issue applicable to these cells.

PROCEDURE:

The veneer slope stability factor of safety of the liner system will be evaluated based on a method presented by Giroud, et al. [1995a,b]. The method is based on a limit equilibrium analysis and takes into account soil buttressing effect, geosynthetic tensile forces, and seepage forces within the liner system caused by leachate and is based on the most critical interface that exists within the liner system. This method considers failure surfaces both above (Case 1) and below (Case 2) the geomembrane.

The veneer stability factor of safety will be calculated using the following equation from Giroud et al. [1995a,b]:

$$FS = \lambda \frac{\tan\delta}{\tan\beta} + \frac{a/\sin\beta}{\gamma_t(t-t_w)+\gamma_{sat}t_w} + \frac{\gamma_t(t-t_w^*)+\gamma_b t_w^*}{\gamma_t(t-t_w)+\gamma_{sat}t_w}\frac{t}{h}\frac{\sin\phi}{\sin 2\beta\cos(\beta+\phi)} + \frac{ct/h}{\gamma_t(t-t_w)+\gamma_{sat}t_w}\frac{\cos\phi}{\sin\beta\cos(\beta+\phi)} + \frac{T/h}{\gamma_t(t-t_w)+\gamma_{sat}t_w} \qquad \text{Eq. (1)}$$

where:

$$\lambda = \begin{cases} \dfrac{\gamma_t(t-t_w)+\gamma_b t_w}{\gamma_t(t-t_w)+\gamma_{sat}t_w} & \text{for failure surface above the geomembrane (dimensionless)} \\ 1 & \text{for failure surface below the geomembrane (dimensionless)} \end{cases}$$

FS = Factor of Safety (dimensionless)
γ_t = total unit weight of soil (pcf)
γ_{sat} = saturated unit weight of soil (pcf)
γ_b = buoyant unit weight of soil (pcf)

t = thickness of soil layer (ft)
t_w = thickness of water flow along slope (ft)
t^*_w = thickness of water flow in toe of slope (ft)
β = slope angle (degrees)
δ = interface friction angle along slip surface (degrees)
a = interface adhesion (psf)
ϕ = internal friction angle of soil above critical surface (degrees)
h = height of slope (ft)
T = tension in geosynthetics (lbs/ft)
c = cohesion of soil above critical surface (psf)

According to a technical manual published by the USEPA entitled "Solid Waste Disposal Facility Criteria" [USEPA, 1993], when there is no imminent danger to human life or threat of major environmental impact, the minimum recommended slope stability factor of safety is 1.25. Because a veneer stability failure of the liner system does not pose a threat to human life or the environment and a failure could be easily repaired, the stability of the liner system will be considered acceptable if the factor of safety is greater than or equal to 1.25.

SOIL AND GEOSYNTHETIC PROPERTIES

The maximum slope inclination for the liner system is 3H:1V and the maximum vertical slope height is approximately 25 ft for the Cells 1 through 3 Overlay Area. The liner system on the side slopes consists of the following components, from top to bottom, as shown in Figure 2:

- a 24-in thick drainage layer / protective cover;
- a geocomposite drainage layer;
- a 60-mil thick high-density polyethylene (HDPE) textured geomembrane;
- a geosynthetic clay liner (GCL); and
- prepared subbase.

Based on the assumed soil friction angle (ϕ) and the interface friction angles (δ), two sliding surfaces are evaluated for the liner system. Case 1 evaluates the critical slip surface above the geomembrane. Case 2 evaluates the critical slip surface below the geomembrane. The interface shear strength used for the analysis is selected based on geosynthetics/soil interface shear strength conducted for materials used for Cell 6 construction. The test results are included as Attachment A. It is noted that the confining pressure used for these tests are higher than the pressure applied to these interfaces under open cell condition. Using these results are considered conservative because the secant friction angle is generally larger at lower confining pressure. The data used for the veneer stability analyses is summarized in the table below.

Case 1: Above geomembrane

Interface/Material	Selected Properties
Drainage Layer/Geocomposite (geotextile)	δ = 34° a = 276 psf
（Geotextile） Geocomposite / 60-mil Thick Textured HDPE Geomembrane	δ = 24.5° a = 505 psf

Case 2: Below geomembrane

Interface/Material	Selected Properties
60-mil Thick Textured HDPE Geomembrane / GCL Reinforced with nonwoven geotextile	δ = 29.9° a = 0 psf
GCL Reinforced with nonwoven geotextile/ Prepared Subgrade	δ = 29.8° a = 69 psf

See Attachment A for interface shear strength test results.

For Case 1, short term liner stability above the geomembrane liner, the critical interface shear strength is δ = 24.5° (conservatively neglect adhesion). For Case 2, short term stability below the geomembrane liner, the critical interface friction angle is δ = 29.9° with no adhesion.

The average depth of water within the protective/drainage layer is evaluated using the HELP model [USEPA, 1994]. The HELP model simulation was performed for a period of 5 years, assuming the landfill cell is open (i.e. prior to waste placement) with the leachate collection zone or protective soil zone placed on a 3H:1V slope. Output of the HELP analysis is included as Attachment B. As shown in Attachment B，the calculated peak daily average hydraulic head on the liner system is 0.497 in. (0.04 ft) for the proposed liner system at a hypothetical slope length of 2000 ft. For the remaining liner system to be constructed on the liner overlay area, the maximum slope height on the 3H:1V sideslope is approximately 40 ft and the corresponding slope length is approximately 79 ft. For a drainage distance of 126 ft, the average hydraulic heads on the liner system should be less than 0.497 in. Thus, using the calculated 0.497 in. head for the 126 ft long maximum liner slope is considered conservative.

The input parameters for equation 1 are provided below. For this analysis the resisting force due to tension in geosynthetics (T) is neglected (that is, the effect of the anchor trench is conservatively neglected and the protective layer is supported by frictional forces only.

γ_t = 110 pcf
γ_{sat} = 110 pcf
γ_b = 47.6 pcf

t_w = 0.04 ft for the proposed (failure surface above geomembrane), 0 ft for failure surface below geomembrane.

t^*_w = 0.04 ft for the proposed (failure surface above geomembrane), 0 ft for failure surface below geomembrane.

β = 18.43°

a = 0

ϕ = 30° (selected based on properties of soil above geomembrane)

h = 40 ft

T = 0 (neglect tension contribution)

c = 0

CALCULATION

The following two critical interfaces were evaluated in this calculation:

- Above the liner: Drainage Layer and Geocomposite (δ = 24.5˚)
- Below the liner: HDPE Geomembrane and GCL (δ = 29.9˚)

The calculation was conducted using Excel Spreadsheet. The output for the calculated cases is shown in Attachment C. The calculated FS are 1.41 and 1.79 for critical sliding surface above and below the geomembrane, respectively, which are greater than the minimum recommended FS of 1.25.

The above results show that adequate factor of safety for the liner system veneer slope stability can be maintained based on the interface shear strength laboratory test results conducted for Cell 6 construction. Should different materials are used for liner construction, additional tests should be conducted for verification.

REFERENCES

Giroud, J.P., Williams, N.D., Pelte, T., and Beech, J.F., "Stability of Geosynthetic - Soil Layered Systems on Slopes," Industrial Fabrics Association International, *Geosynthetics International*, Vol. 2, No. 6, St. Paul, MN, pp. 1115-1148, 1995a.

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

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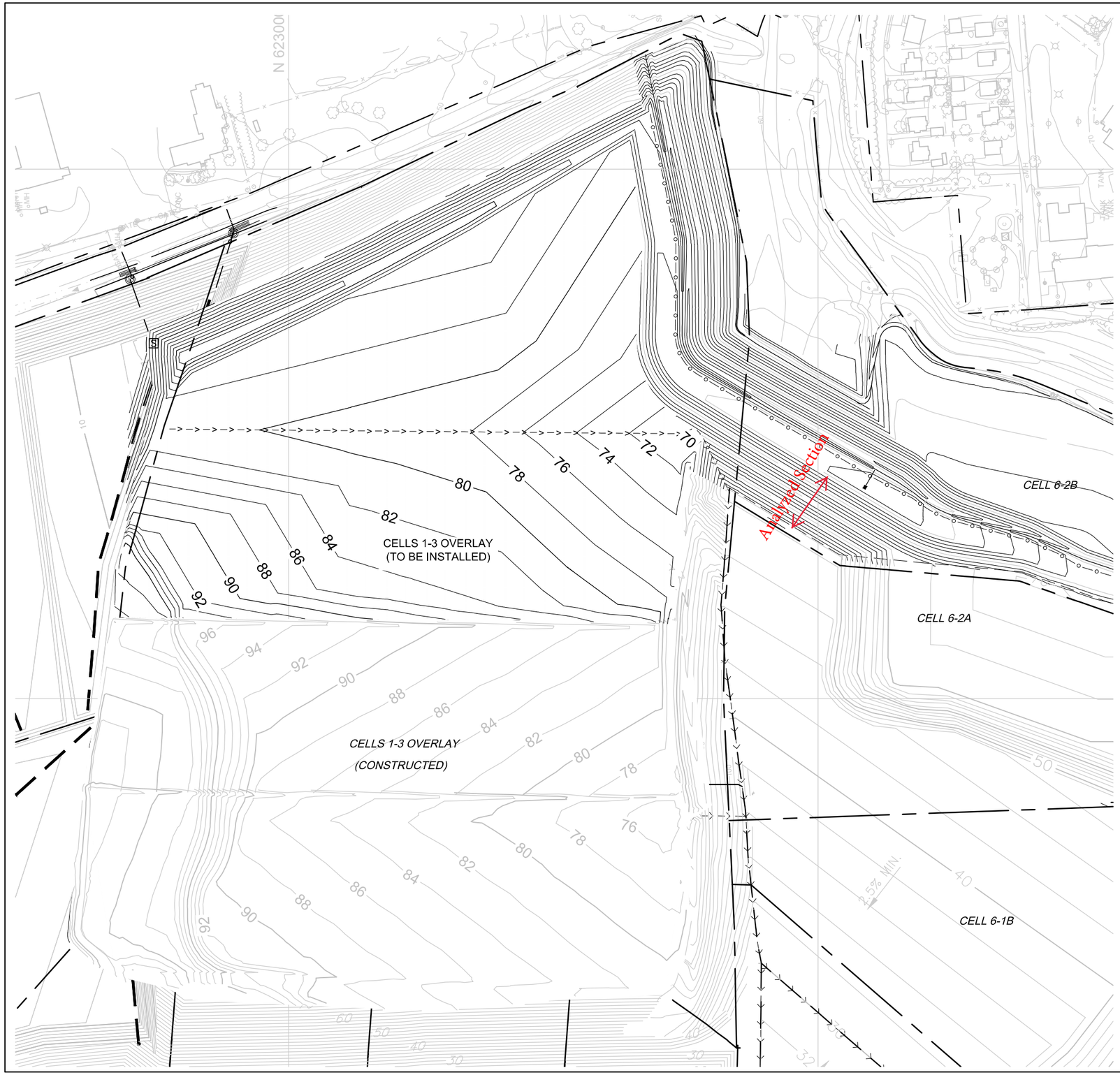
FIGURES



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LEGEND

- PROPERTY BOUNDARY
- 60 — EXISTING GRADE CONTOUR (FEET–MSL)
- 60 — LEACHATE MANAGEMENT SYSTEM CONTOUR (FEET–MSL)
- EXISTING TREELINE
- EXISTING ROAD
- EXISTING BUILDING
- W — EXISTING DEEP GROUNDWATER MONITORING WELL, LOCATED 9/2001
- EXISTING AND PROPOSED LEACHATE COLLECTION PIPE (SEE NOTE 6)

GENERAL NOTES:

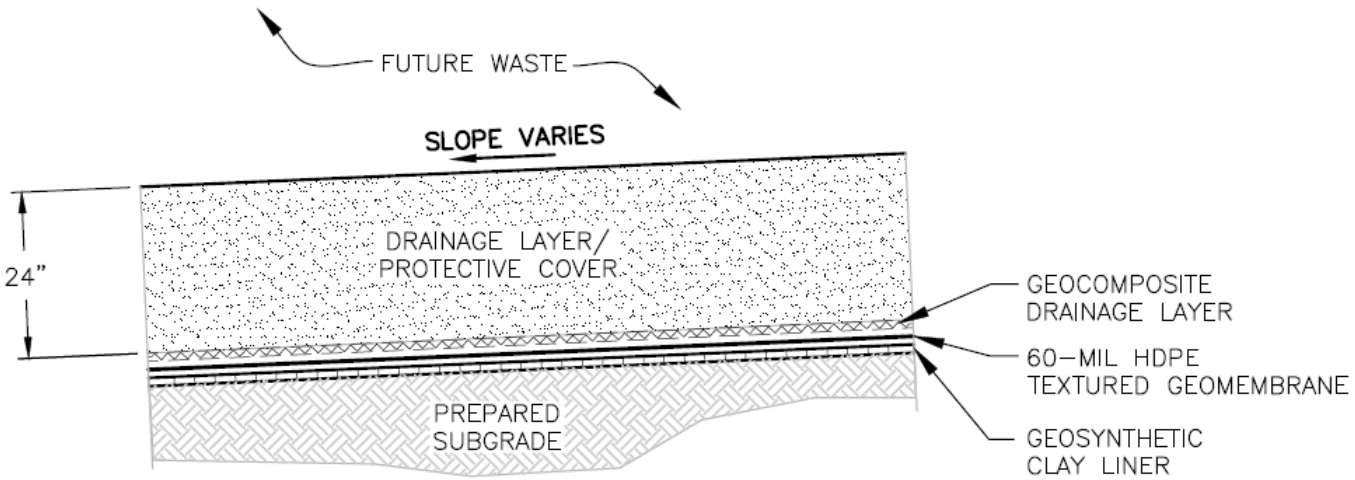
1. EXISTING CONDITIONS (WITH THE EXCEPTION OF LANDFILL GAS FEATURES) ARE FROM A 14 DECEMBER 2017 PHOTOGRAMMETRIC SURVEY BY AERIAL SURVEY CORPORATION OF DULLES, VIRGINIA. EXISTING LANDFILL GAS FEATURES ARE FROM AN ELECTRONIC FILE OF THE DRAWING ENTITLED "GAS EXTRACTION SYSTEM AND MONITORING PLAN AS OF DECEMBER 2011, DELAWARE RECYCLABLE PRODUCTS, INC.," BY VANDEMARK AND LYNCH, INC., DATED 7 FEBRUARY 2012.
2. DRPI PROPERTY LINE WAS OBTAINED FROM VANDEMARK AND LYNCH, INC.
3. PROPERTY LINES FOR ADJACENT PROPERTIES WERE OBTAINED FROM VANDEMARK AND LYNCH, INC., BUT ARE FROM FILES WHICH MAY NOT BE UP TO DATE. THEREFORE, THESE PROPERTY LINES SHOULD BE CONSIDERED APPROXIMATE.
4. GRID IS BASED ON DELAWARE STATE PLANE COORDINATE SYSTEM (NAD 1927).
5. ELEVATIONS ARE IN FEET ABOVE SEA LEVEL DATUM ("SEA LEVEL DATUM" REFERS TO THE NORTH GEODETIC VERTICAL DATUM OF 1929 [NGVD 29].)
6. DETAILS ARE SHOWN TO SCALE AS NOTED EXCEPT FOR THE GEOSYNTHETICS, WHICH ARE SHOWN AT AN EXAGGERATED SCALE FOR CLARITY.

0 200'
SCALE IN FEET

PLAN VIEW OF LINER SYSTEM TO BE INSTALLED

Geosyntec consultants
COLUMBIA, MARYLAND

DATE:	JUNE 2018
PROJECT NO.	ME1571
DOCUMENT NO.	
FILE NO.	1571f005–liner
FIGURE NO.	1



PROPOSED LINER SYSTEM DETAILS

Geosyntec consultants

Figure 2

Maryland | July 2018

Scale: NTS

ATTACHMENT A

INTERFACE SHEAR STRENGTH TEST RESULTS

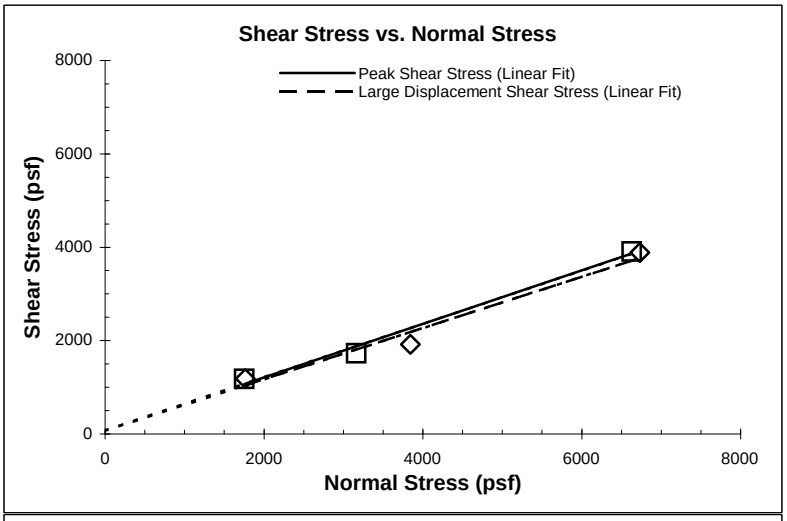
Interface Friction Test Report

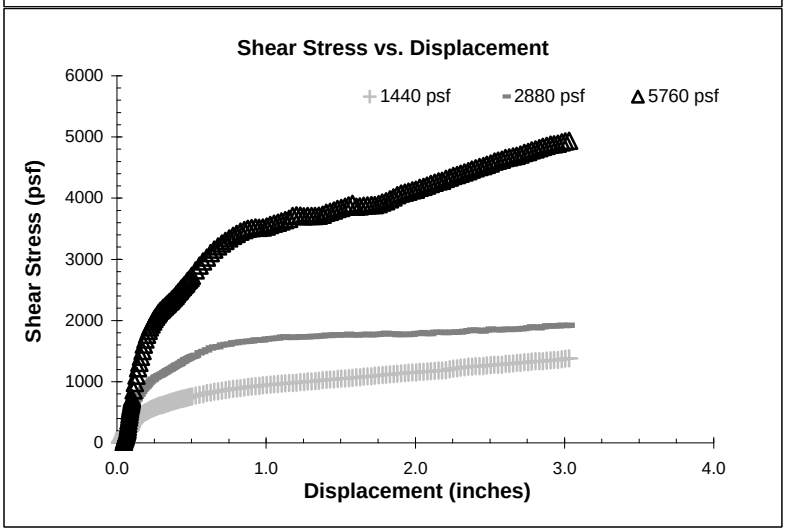
Client: **Waste Management**
Project: **DRPI- Cell 6-1B**
Test Date: 09/20/10-09/21/10

TRI Log#: E2337-97-02
Test Method: ASTM D 6243

John M. Allen, P.E., 09/21/2010
Quality Review/Date

Tested Interface: Bentomat DN GCL (3695) vs. Structural Fill (SF-11A)





Test Results

	Peak	Large Displacement (@ 1.5 in.)
Friction Angle (degrees):	**29.8**	**28.9**
Y-intercept or Adhesion (psf):	**69**	**59**

Note: Regression angles include an area correction. Shearing occurred at the interface.

Test Conditions

Upper Box & Bentomat DN GCL (white side)

Lower Box Structural Fill (SF-11A) remolded to 115.0 pcf at 11.9% moisture content

Box Dimensions: 12"x12"x4"

Interface Conditioning: Interface soaked and loading applied for a minimum of 24 hours prior to shear.

Test Condition: Wet

Shearing Rate: 0.04 inches/minute

Test Data

Specimen No.	1	2	3
Bearing Slide Resistance (lbs)	22	35	63
Area Corrected Normal Stress (psf)	1751	3164	6632
Area Corrected Peak Shear Stress (psf)	1179	1726	3908
Area Corrected Large Displacement Normal Stress (psf)	1764	3843	6730
Area Corrected Large Displacement Shear Stress (psf)	1187	1920	3888
Peak Secant Angle (degrees)	34.0	28.6	30.5
Large Displacement Secant Angle (degrees)	33.9	26.5	30.0

The testing herein is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested. TRI neither accepts responsibility for nor makes claim as to the final use and purpose of the material. TRI observes and maintains client confidentiality. TRI limits reproduction of this report, except in full, without prior approval of TRI.

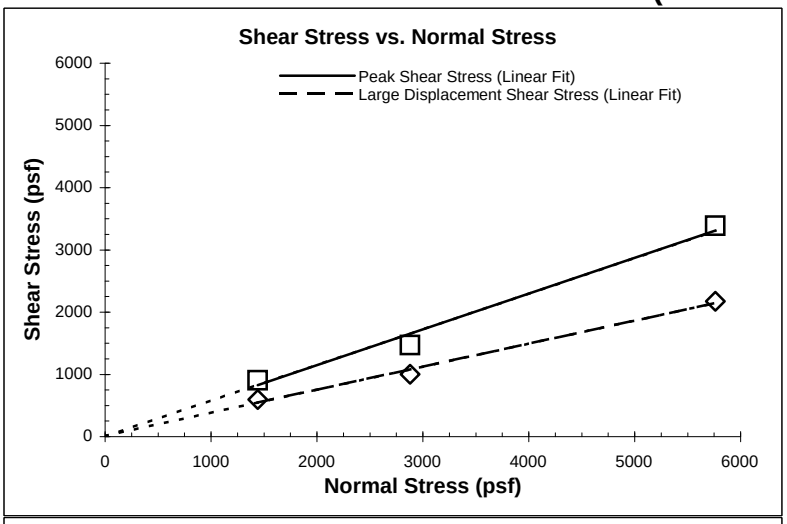
Interface Friction Test Report

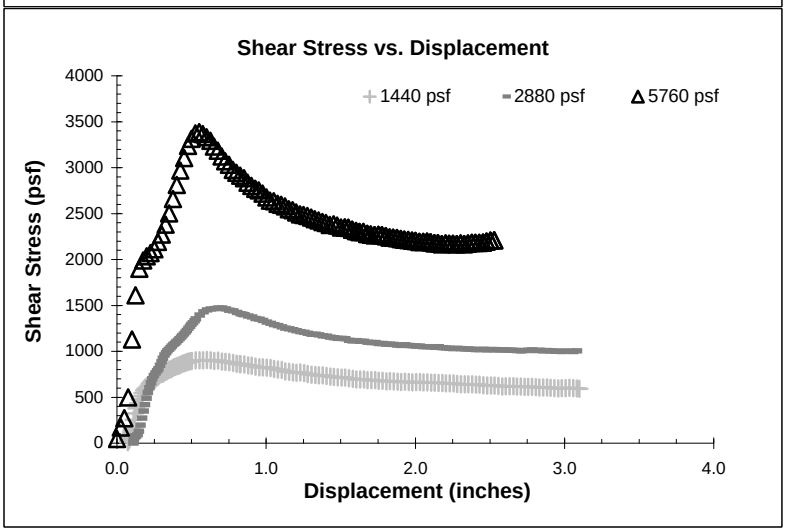
Client: **Waste Management**
Project: **DRPI- Cell 6-1B**
Test Date: 09/08/10-09/09/10

TRI Log#: E2337-97-02
Test Method: ASTM D 6243

John M. Allen, P.E., 09/15/2010
Quality Review/Date

Tested Interface: Bentomat DN GCL (3695) vs. GSE 60 mil HDPE Textured Geomembrane (108153135)





Test Results

	Peak	Large Displacement (@ 3.0 in.)
Friction Angle (degrees):	**29.9**	**20.4**
Y-intercept or Adhesion (psf):	**0**	**8**

Shearing occurred at the interface. The peak friction angle regression analysis was adjusted to fit a zero y-intercept.

Test Conditions

Upper Box & Bentomat DN GCL (black side)

Lower Box GSE 60 mil HDPE textured geomembrane

Box Dimensions: 12"x12"x4"

Interface Conditioning: Interface soaked and loading applied for a minimum of 24 hours prior to shear.

Test Condition: Wet

Shearing Rate: 0.04 inches/minute

Test Data

Specimen No.	1	2	3
Bearing Slide Resistance (lbs)	22	35	63
Normal Stress (psf)	1440	2880	5760
Corrected Peak Shear Stress (psf)	905	1470	3387
Corrected Large Displacement Shear Stress (psf)	594	1004	2176
Peak Secant Angle (degrees)	32.1	27.0	30.5
Large Displacement Secant Angle (degrees)	22.4	19.2	20.7
Asperity (mils)	24.4	25.6	28.6

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9063 Bee Caves Road □ Austin, TX 78733-6201 □ (512) 263-2101 □ (512) 263-2558 □ 1-800-880-TEST

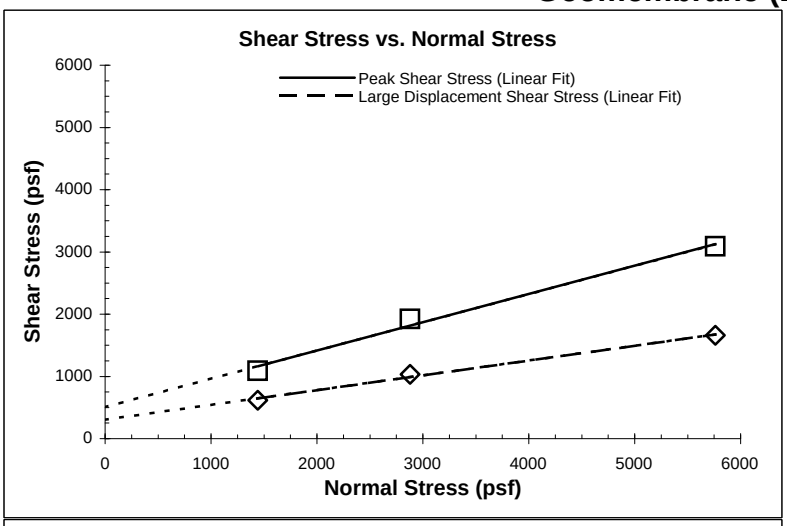
Interface Friction Test Report

Client: **Waste Management**
Project: **DRPI- Cell 6-1B**
Test Date: 09/16/10-09/17/10

TRI Log#: E2337-97-02
Test Method: ASTM D 5321

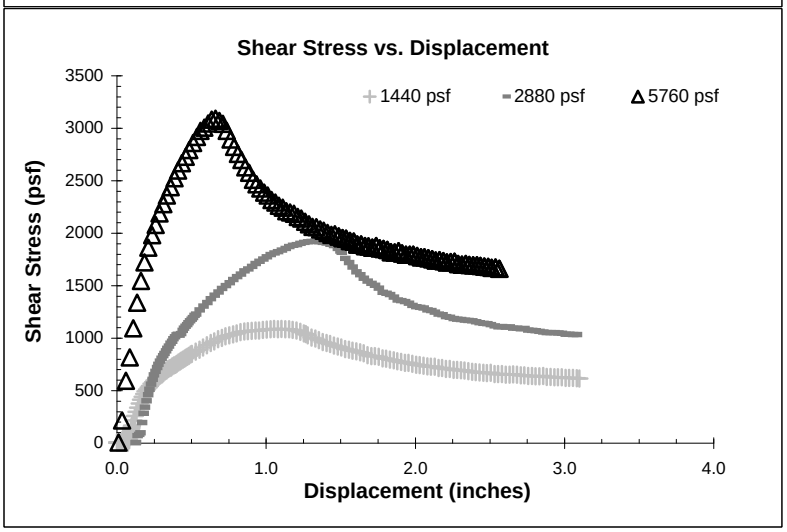
John M. Allen, P.E., 09/17/2010
Quality Review/Date

Tested Interface: Skaps GE180 Non-woven Geotextile (17337.01) vs. GSE 60 mil HDPE Textured Geomembrane (108153135)



Test Results		
	Peak	**Large Displacement (@ 3.0 in.)**
Friction Angle (degrees):	**24.5**	**13.4**
Y-intercept or Adhesion (psf):	**505**	**302**

Shearing occurred at the interface.



Test Conditions

Upper Box & Lower Box: Skaps GE180 non-woven geotextile; GSE 60 mil HDPE textured geomembrane

Box Dimensions: 12"x12"x4"

Interface Conditioning: Interface soaked and loading applied for a minimum of 24 hours prior to shear.

Test Condition: Wet

Shearing Rate: 0.04 inches/minute

Test Data

Specimen No.	1	2	3
Bearing Slide Resistance (lbs)	22	35	63
Normal Stress (psf)	1440	2880	5760
Corrected Peak Shear Stress (psf)	1089	1922	3091
Corrected Large Displacement Shear Stress (psf)	615	1033	1660
Peak Secant Angle (degrees)	37.1	33.7	28.2
Large Displacement Secant Angle (degrees)	23.1	19.7	16.1
Asperity (mils)	27.0	32.2	22.8

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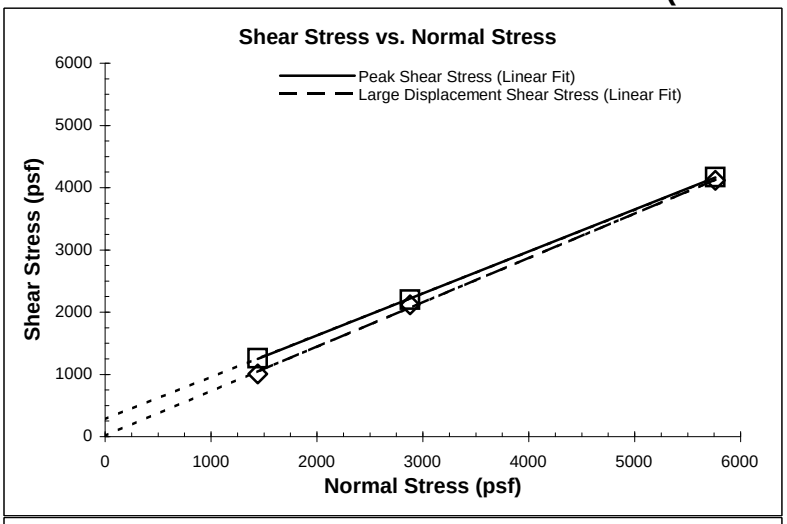
Interface Friction Test Report

Client: **Waste Management**
Project: **DRPI- Cell 6-1B**
Test Date: 09/21/10-09/22/10

TRI Log#: E2337-97-02
Test Method: ASTM D 5321

John M. Allen, P.E., 09/22/2010
Quality Review/Date

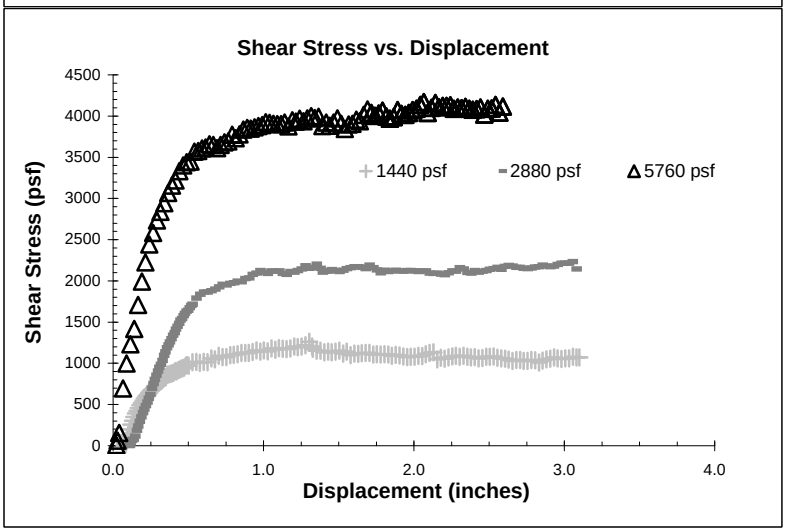
Tested Interface: Drainage Aggregate (PC-2A) vs. Skaps GE180 Non-woven Geotextile (17337.01)



Test Results

	Peak	Large Displacement (@ 3.0 in.)
Friction Angle (degrees):	34.0	35.6
Y-intercept or Adhesion (psf):	276	9

Shearing occurred at the interface.



Test Conditions

Upper Box & Lower Box: Drianage Aggregate (PC-2A) remolded at 99.6 pcf at air dry condition; Skaps GE180 non-woven geotextile

Box Dimensions: 12"x12"x4"

Interface Conditioning: Interface soaked and loading applied for a minimum of 24 hours prior to shear.

Test Condition: Wet

Shearing Rate: 0.04 inches/minute

Test Data

Specimen No.	1	2	3
Bearing Slide Resistance (lbs)	22	35	63
Normal Stress (psf)	1440	2880	5760
Corrected Peak Shear Stress (psf)	1262	2200	4171
Corrected Large Displacement Shear Stress (psf)	1009	2116	4116
Peak Secant Angle (degrees)	41.2	37.4	35.9
Large Displacement Secant Angle (degrees)	35.0	36.3	35.5

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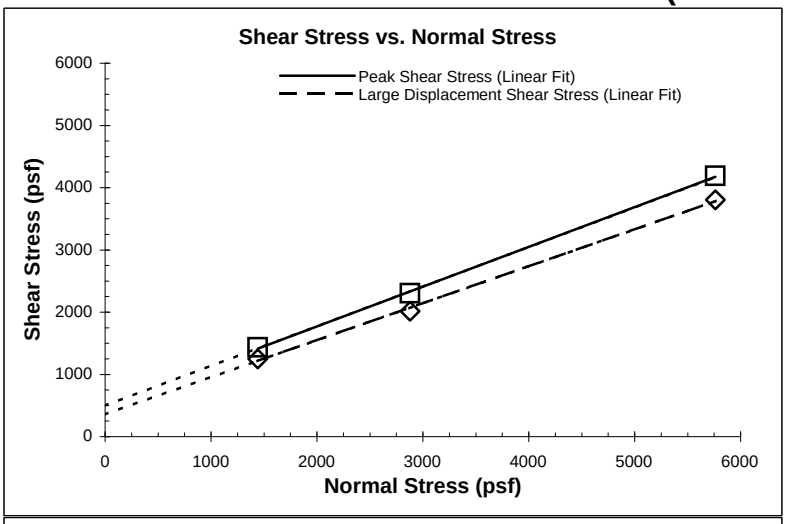
Interface Friction Test Report

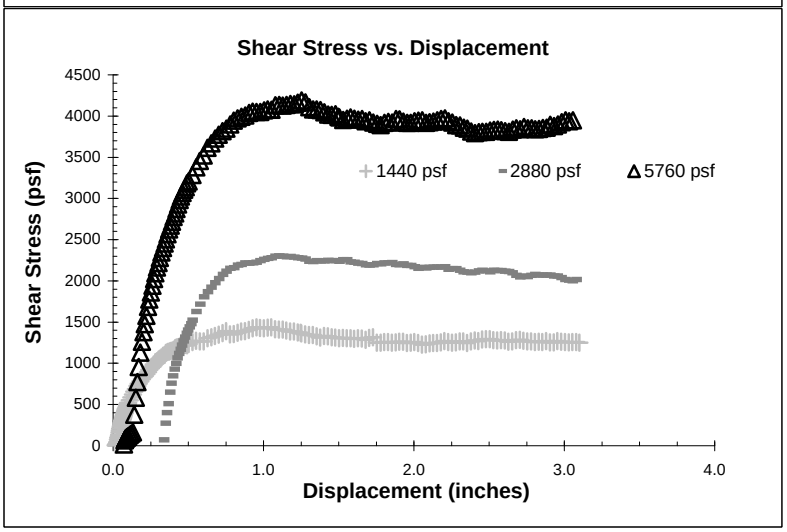
Client: **Waste Management**
Project: **DRPI- Cell 6-1B**
Test Date: 09/21/10-09/22/10

TRI Log#: E2337-97-02
Test Method: ASTM D 5321

John M. Allen, P.E., 09/22/2010
Quality Review/Date

Tested Interface: Drainage Aggregate (PC-1A) vs. Skaps GE180 Non-woven Geotextile (17337.01)





Test Results

	Peak	Large Displacement (@ 3.0 in.)
Friction Angle (degrees):	**32.6**	**30.8**
Y-intercept or Adhesion (psf):	**493**	**353**

Shearing occurred at the interface.

Test Conditions

Upper Box & Lower Box: Drianage Aggregate (PC-1A) remolded at 101.8 pcf at air dry condition; Skaps GE180 non-woven geotextile

Box Dimensions: 12"x12"x4"

Interface Conditioning: Interface soaked and loading applied for a minimum of 24 hours prior to shear.

Test Condition: Wet

Shearing Rate: 0.04 inches/minute

Test Data

Specimen No.	1	2	3
Bearing Slide Resistance (lbs)	22	35	63
Normal Stress (psf)	1440	2880	5760
Corrected Peak Shear Stress (psf)	1437	2301	4188
Corrected Large Displacement Shear Stress (psf)	1249	2015	3807
Peak Secant Angle (degrees)	44.9	38.6	36.0
Large Displacement Secant Angle (degrees)	40.9	35.0	33.5

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ATTACHMENT B

HELP ANALYSIS RESULTS

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     P:\PRJ1\MDENG\HELP3\ME0319\DATA4.D4
TEMPERATURE DATA FILE:       P:\PRJ1\MDENG\HELP3\ME0319\DATA7.D7
SOLAR RADIATION DATA FILE:   P:\PRJ1\MDENG\HELP3\ME0319\DATA13.D13
EVAPOTRANSPIRATION DATA:     P:\PRJ1\MDENG\HELP3\ME0319\DATA11.D11
SOIL AND DESIGN DATA FILE:   P:\PRJ1\MDENG\HELP3\ME0319\OPEN.D10
OUTPUT DATA FILE:            P:\PRJ1\MDENG\HELP3\ME0319\OPEN.OUT


TIME:  22: 4     DATE:   3/25/2004


******************************************************************************

     TITLE:  DRPI - OPEN CELL

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                LAYER  1
                                --------

                     TYPE 2 - LATERAL DRAINAGE LAYER
                       MATERIAL TEXTURE NUMBER  10
          THICKNESS                  =     24.00   INCHES
          POROSITY                   =      0.3980 VOL/VOL
          FIELD CAPACITY             =      0.2440 VOL/VOL
          WILTING POINT              =      0.1360 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.2707 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.119999997000E-03 CM/SEC
     NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.96
              FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                LAYER  2
                                --------

                     TYPE 2 - LATERAL DRAINAGE LAYER
                       MATERIAL TEXTURE NUMBER  20
          THICKNESS                  =      0.20   INCHES
          POROSITY                   =      0.8500 VOL/VOL
          FIELD CAPACITY             =      0.0100 VOL/VOL
          WILTING POINT              =      0.0050 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.0403 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =   10.0000000000     CM/SEC
          SLOPE                      =     33.00   PERCENT
          DRAINAGE LENGTH            =   1150.0    FEET


                                LAYER  3
                                --------

                     TYPE 4 - FLEXIBLE MEMBRANE LINER
                       MATERIAL TEXTURE NUMBER  35
          THICKNESS                  =      0.06   INCHES
          POROSITY                   =      0.0000 VOL/VOL
          FIELD CAPACITY             =      0.0000 VOL/VOL
          WILTING POINT              =      0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.199999996000E-12 CM/SEC
          FML PINHOLE DENSITY        =      1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS   =      1.00   HOLES/ACRE
          FML PLACEMENT QUALITY      =  4 - POOR


                                LAYER  4
                                --------

                     TYPE 3 - BARRIER SOIL LINER
                       MATERIAL TEXTURE NUMBER  17
          THICKNESS                  =      0.30   INCHES
          POROSITY                   =      0.7500 VOL/VOL
          FIELD CAPACITY             =      0.7470 VOL/VOL
```

WILTING POINT	=	0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.7500 VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.300000003000E-08 CM/SEC

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #10 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 33.% AND A SLOPE LENGTH OF 2000. FEET.

SCS RUNOFF CURVE NUMBER	=	93.70	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	1.000	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	5.883	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	8.756	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	2.992	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	6.729	INCHES
TOTAL INITIAL WATER	=	6.729	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM WILMINGTON DELAWARE

STATION LATITUDE	=	39.80	DEGREES
MAXIMUM LEAF AREA INDEX	=	4.20	
START OF GROWING SEASON (JULIAN DATE)	=	107	
END OF GROWING SEASON (JULIAN DATE)	=	298	
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
AVERAGE ANNUAL WIND SPEED	=	9.20	MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	67.00	%
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	67.00	%
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	72.00	%
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	71.00	%

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
3.11	2.99	3.87	3.39	3.23	3.51
3.90	4.03	3.59	2.89	3.33	3.54

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
31.20	33.20	41.80	52.40	62.20	71.20
76.00	74.80	67.80	56.30	45.60	35.50

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR WILMINGTON DELAWARE AND STATION LATITUDE = 39.80 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 5

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	3.24	2.51	4.08	2.94	3.87	5.39
	3.97	4.06	4.53	3.13	2.08	2.62
STD. DEVIATIONS	2.80	1.49	1.56	0.98	2.43	2.18
	2.03	2.06	1.93	0.83	0.44	2.54
RUNOFF						
TOTALS	1.157	0.732	1.343	0.113	0.685	0.889
	0.980	0.803	1.435	0.727	0.165	0.418
STD. DEVIATIONS	1.489	0.747	1.537	0.075	0.732	0.704

	1.629	0.536	0.935	0.507	0.070	0.765

EVAPOTRANSPIRATION

TOTALS	0.796	1.018	2.208	3.430	3.929	4.377
	3.395	2.904	2.136	1.452	1.110	0.829
STD. DEVIATIONS	0.311	0.536	0.260	0.438	0.929	1.924
	0.891	1.418	1.075	0.128	0.290	0.192

LATERAL DRAINAGE COLLECTED FROM LAYER 2

TOTALS	0.9740	0.6527	1.5312	0.1914	0.0761	0.0977
	0.0035	0.0005	0.0001	0.2499	0.2915	1.3437
STD. DEVIATIONS	1.0191	0.7067	1.2307	0.1845	0.1664	0.2180
	0.0072	0.0007	0.0000	0.4637	0.4524	1.5569

PERCOLATION/LEAKAGE THROUGH LAYER 4

TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3

AVERAGES	0.0021	0.0016	0.0034	0.0004	0.0002	0.0002
	0.0000	0.0000	0.0000	0.0005	0.0007	0.0030
STD. DEVIATIONS	0.0022	0.0017	0.0027	0.0004	0.0004	0.0005
	0.0000	0.0000	0.0000	0.0010	0.0010	0.0034

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 5

	INCHES		CU. FEET	PERCENT
PRECIPITATION	42.42	(5.306)	153977.3	100.00
RUNOFF	9.446	(3.4744)	34289.88	22.269
EVAPOTRANSPIRATION	27.585	(2.1369)	100131.77	65.030
LATERAL DRAINAGE COLLECTED FROM LAYER 2	5.41222	(1.18109)	19646.359	12.75925
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.00000	(0.00000)	0.004	0.00000
AVERAGE HEAD ON TOP OF LAYER 3	0.001	(0.000)		
CHANGE IN WATER STORAGE	-0.025	(0.3351)	-90.67	-0.059

PEAK DAILY VALUES FOR YEARS 1 THROUGH 5

	(INCHES)	(CU. FT.)
PRECIPITATION	5.26	19093.801
RUNOFF	3.735	13556.8018
DRAINAGE COLLECTED FROM LAYER 2	0.37890	1375.41357
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.000000	0.00008
AVERAGE HEAD ON TOP OF LAYER 3	0.026	
MAXIMUM HEAD ON TOP OF LAYER 3	0.497	
LOCATION OF MAXIMUM HEAD IN LAYER 2 (DISTANCE FROM DRAIN)	0.0 FEET	
SNOW WATER	2.14	7777.3130

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.3221

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1360

*** Maximum heads are computed using McEnroe's equations. ***

Reference: Maximum Saturated Depth over Landfill Liner
by Bruce M. McEnroe, University of Kansas
ASCE Journal of Environmental Engineering
Vol. 119, No. 2, March 1993, pp. 262-270.

FINAL WATER STORAGE AT END OF YEAR 5

LAYER	(INCHES)	(VOL/VOL)
1	6.3768	0.2657
2	0.0027	0.0139
3	0.0000	0.0000
4	0.2250	0.7500
SNOW WATER	0.000	

DTM 9/24/08

Fd/28

ATTACHMENT C

VENEER STABILITY RESULTS

Table 1: Veneer Slope Stability Analysis
Slope Height =40 ft

Factors of Safety for Slope Stability Calculated with Method Presented in 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.

Input Parameters

Total γ (pcf)	110	β (deg)	18.43	β (rad)	0.322
Sat. γ (pcf)	110	δ (deg) (above)	24.5	δ (rad) (above)	0.428
Buoyant γ (pcf)	47.6	a (psf) (above)	0		
thickness (ft)	2	δ (deg) (below)	29.9	δ (rad) (below)	0.522
t_w (ft)	0.04	a (psf) (below)	0		
t^*_w (ft)	0.04	slope height (ft)	40		
		ϕ (deg)	30	ϕ (rad)	0.524
		T	0		
		c (psf)	0		

Output

Lambda (calculated) 0.989

Factor of Safety for failure surface above the geomembrane:	**1.41**
Factor of Safety for failure surface below the geomembrane:	**1.79**

APPENDIX VI-D.3

SETTLEMENT OF LINER SYSTEM

Geosyntec consultants

COMPUTATION COVER SHEET

Client: DRPI **Project:** DRPI Landfill Expansion **Project #:** ME1571 **Task #:** 1

TITLE OF COMPUTATIONS LINER SETTLEMENT EVALUATION

COMPUTATIONS BY:

Signature _____ 7/10/2018 DATE

Printed Name and Title: Chunling Li, Project Engineer

ASSUMPTIONS AND PROCEDURES CHECKED BY: (Peer Reviewer)

Signature _____ 7/10/2018 DATE

Printed Name and Title: Sean O'Donnell, Senior Staff Engineer

COMPUTATIONS CHECKED BY:

Signature _____ 7/10/2018 DATE

Printed Name and Title: Sean O'Donnell, Senior Staff Engineer

COMPUTATIONS BACKCHECKED BY: (Originator)

Signature _____ 7/10/2018 DATE

Printed Name and Title: Chunling Li, Project Engineer

APPROVED BY: (PM or Designate)

Signature _____ 7/10/2018 DATE

Printed Name and Title: David Espinoza, Senior Principal

APPROVAL NOTES:

REVISIONS (Number and initial all revisions)

NO.	SHEET	DATE	BY	CHECKED BY	APPROVAL

LINER SETTLEMENT EVALUATION

PURPOSE

The purpose of this calculation is to evaluate the settlement of the liner system for the proposed vertical expansion of Delaware Recyclable Products, Inc. (DRPI) landfill.

BACKGROUND

DRPI Landfill was originally developed in 5 phases. Phases 1 through 3 were originally unlined, while Phases 4 and 5 are lined with a double liner system. The landfill expansion proposed in 2004 consists of an increase in the vertical height of the waste mass over the existing cells as well as a lateral increase in the disposal limit along the south side of the facility. As a part of this landfill expansion, the existing Phases 1 through 3 would be lined with an overlay liner system, and a new Phase 6 with double liner was proposed. Approximately 17.2 acres of overlay liner have been constructed over Cells 1, 2, and 3 and the rest (about 16 acres) is to be constructed.

For this proposed landfill vertical expansion, the maximum final landfill elevation is proposed to be increased from currently permitted 130 ft-msl to 190 ft-msl. To ensure that leachate is adequately collected, it is necessary to maintain an adequate slope for the liner system. The purpose of this calculation package is to evaluate the settlement of the existing liner system under the proposed landfill expansion. The results of this evaluation will be used to verify that: 1) the landfill liner system will maintain its integrity; and 2) the post-settlement drainage slope will be sufficient to convey the collected leachate to the sumps.

SUBSURFACE STRATIGRAPHY

The liner grading plan is shown in Figure 1. The final grading plan proposed in this permit application is shown in Figure 2. Figures 1 and 2 also show the locations of the ten cross sections analyzed in this analysis (A-A', B-B', C-C', D-D', E-E', F-F', G-G', H-H', J-J', K-K').

There are four major subsurface layers considered in this analysis. These are: existing waste, the Columbia Formation, the Upper Potomac Formation, and the Lower Potomac Formation. Existing waste overlies the Columbia Formation, which in turn overlies the Upper and Lower Potomac Formations. Based on previous reports [Geosyntec, 1994; JCA, 1994], the bulk of the Columbia Formation was likely removed during mining operations, which reached approximate elevation 20 ft-msl within the footprint of Cells 1-3. The bottom of existing waste, and the top of the Columbia Formation, is estimated based on the original excavation of the site. The bottom of the Columbia Formation is assumed to be at 15 ft-msl from Blazosky (2004). The Upper Potomac Formation is estimated to extend from the base of the

Columbia Formation to elevation 0 ft-msl, while the Lower Potomac Formation is expected to extend from elevation 0 ft-msl to elevation -30 ft-msl (Blazosky, 2004).

ANALYSIS

Settlement of the existing waste and foundation soils due to the loads imposed by the grading layer and waste placement can be estimated using one-dimensional consolidation theory [Holtz and Kovacs, 1981]. Total settlement (δ) can be calculated as the sum of the primary settlement (δ_p) and secondary settlement (δ_s) as:

$$\delta = \delta_p + \delta_s \tag{1}$$

$$\delta_p = \begin{cases} H_o \frac{C_c}{1+e_o} \log\left(\frac{\sigma'_{vo}+\Delta\sigma'_v}{\sigma'_{vo}}\right), if\ \sigma'_{vo} = \sigma'_p\ and\ \sigma'_{vo} + \Delta\sigma'_v \geq \sigma'_p \\ H_o \frac{1}{1+e_o}\left[C_r \log\left(\frac{\sigma'_p}{\sigma'_{vo}}\right) + C_c \log\left(\frac{\sigma'_{vo}+\Delta\sigma'_v}{\sigma'_p}\right)\right], if\ \sigma'_{vo} < \sigma'_p < \sigma'_{vo} + \Delta\sigma'_v \\ H_o \frac{C_r}{1+e_o} \log\left(\frac{\sigma'_{vo}+\Delta\sigma'_v}{\sigma'_{vo}}\right), if\ \sigma'_{vo} \leq \sigma'_p\ and\ \sigma'_{vo} + \Delta\sigma'_v \leq \sigma'_p \end{cases} \tag{2}$$

$$\delta_s = H_o \frac{C_\alpha}{1+e_o} \log\left(\frac{t_s}{t_p}\right) \tag{3}$$

where:

C_c = coefficient of consolidation;
C_r = coefficient of recompression;
C_α = coefficient of secondary compression;
e_o = initial void ratio of soily/waste layer;
H_o = thickness of the soil/waste layer (ft);
δ_p = primary settlement (ft);
δ_s = secondary settlement (ft);
δ = total settlement (ft);
σ'_{vo} = initial vertical effective stress (psf);
$\Delta\sigma_v'$ = additional vertical effective stress (psf);
σ'_p = preconsolidation stress (psf);
t_s = future time for consideration of secondary consolidation (years); and
t_p = time at completion of primary consolidation (years).

Settlement was evaluated approximately every 100 ft along each analyzed section (Figures 1 and 2). The differential settlement between each point was calculated and used to determine the change in slope according to Equations 4 and 5.

$$\delta_n - \delta_{n-1} = \delta_D \tag{4}$$

$$\frac{\delta_D}{L} = \Delta S \tag{5}$$

where:

δ_n = calculated settlement at point n (ft);
δ_{n-1} = calculated settlement at point n-1 (ft);
δ_D = differential settlement (ft);
L = distance between points (ft); and
ΔS = change in slope (%).

The tensile strain induced by differential settlement can be calculated using [Giroud, 1977]:

$$\varepsilon = \frac{8}{3}\left[\frac{\delta_D}{L}\right]^2 100 \tag{6}$$

MATERIAL PROPERTIES

The table below shows the properties of each subsurface layer used in this settlement calculation. Parameters for the Columbia and Upper and Lower Potomac Formations were obtained from previous reports [Geosyntec, 1994; JCA, 1994]. The unit weight of the grading layer was assumed to be 120 pcf.

Waste properties were assumed based on previous experience and data reported in the literature. There is very limited data on compressibility of CDD waste. Sowers [1973] related compression coefficient index (C_c) of municipal solid waste (MSW) to the initial void ratio e_o and organic content and indicated that C_c falls within the range of $0.15e_o$ (for MSW with low organic content) and $0.55e_o$ (for MSW with high organic content). CDD landfills are expected to have moderate to low organic content. Thus, for this settlement calculations, an average compression coefficient index (C_c) equal to $0.35e_o$ is considered reasonable. For a void ratio of 0.54 (i.e., n = 0.35), C_c = 0.19. The corresponding modified compression index $C_{c\varepsilon}$ (=C_c/(1+ e_o)) is estimated to be 0.12. Any additional settlement of waste is due to secondary compression (i.e., creep). The modified secondary compression index ($C_{\alpha\varepsilon}$) for waste for typical municipal landfills is assumed to be 0.07, which is conservative compared to typical range reported (0.01 to 0.03 for MSW according to Fasset et al.[1994]).

The Potomac Formation is a heavily over-consolidated clay. For this analysis, the Potomac Formation is assumed to have a preconsolidation pressure of 20,000 psf, which is consistent with previous analysis [Geosyntec, 2005]. Because the Potomac Formation is heavily over consolidated, secondary consolidation of this layer is considered negligible. The Columbia Formation is granular, and is expected to be very thin and strong at all locations beneath the site. As such, it is expected to experience very small settlement. Settlement of this layer is neglected for this analysis.

For secondary settlements of waste in this analysis, t_s and t_p are assumed to be 60 and 30 years, respectively. Time for primary settlement is based on the average age of the waste and time for secondary settlement is based on the average age of waste plus time for post-closure care.

Property	Waste (Existing and Proposed)	Grading Layer	Columbia Formation	Upper Potomac Formation	Lower Potomac Formation
γ, Unit Weight (pcf)	70	120	125	120	120
$C_{c\varepsilon}$, Modified Coefficient of Consolidation = $C_c/(1+e_o)$	0.12	-	-	0.09	0.15
$C_{r\varepsilon}$, Modified Coefficient of Recompression = $C_r/(1+e_o)$	-	-	-	0.02	0.02
C_α, Modified Coefficient of Secondary Consolidation = $C_\alpha/(1+e_o)$	0.07	-	-	-	-

RESULTS

Tables 1 through 10 show the calculated settlement for the ten (10) analyzed cross sections. The total settlement ranges from 2.7 to 5.9 ft for Section A-A', 4.6 to 6.1 ft for Section B-B', 0.2 to 0.7 ft for Section C-C', 0.5 to 1.7 ft for Section D-D', 0.5 to 0.7 ft for Section E-E', 0.1 to 0.5 ft for Section F-F', 4.4 to 5.0 ft for Section G-G', 1.2 to 5.5 ft for Section H-H', 0.4 to 0.5 ft for Section J-J', and 3.8 to 5.5 ft for Section K-K'. These settlements include primary settlement and secondary settlement within 30 years after closure. The largest liner settlement occurs in the area of Cells 1-3 with underlying existing waste, where liners are placed at least

30 to 40 ft above the groundwater table. Liner settlement in other areas is calculated to be as much as 0.7 ft, where minimum separation between groundwater table and the liner system is approximately 6 ft. Using these results, it is expected that the minimum difference in elevation between the liner system and the ground water table is 5 ft for the sections analyzed.

Grade change due to differential settlement is also calculated in this analysis. A positive grade change indicates the post-settlement slope becomes steeper than pre-settlement slope, while a negative value indicates that the post-settlement slope becomes flatter. As shown in Tables 1 through 10, the post-settlement grade along leachate collection pipes (Sections A-A', B-B', C-C', F-F') is consistently greater than or equal to 0.5%, the minimum required slope to maintain positive drainage along collection pipes. Similarly, on the liner slopes (Sections D-D', E-E', G-G', H-H', J-J', and K-K'), post-settlement grades are consistently maintained above 2%, the minimum slope required to maintain positive drainage along the liner slopes.

Using Equation 6, the maximum liner strain induced by differential settlement is approximately 0.1%, which occurs on Cross Section A-A' between points 9 and 10 and on Section H-H' between points 3 and 4. This calculated strain is much smaller than the typical yield strain of HDPE geomembrane (about 13%).

Based on the results of this analysis, the leachate collection system will maintain a sufficient post-settlement drainage slope and the liner system will maintain its integrity for the proposed vertical expansion.

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TABLES

TABLE 1

Settlement Analysis Section A-A
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Future Max. Waste Elevation (ft)	128.4	142.2	152.1	150.0	161.4	176.6	188.2	168.6	139.4	110.1	81.3
Base Liner Elevation (ft)	84.9	80.8	79.8	79.3	78.8	78.3	77.3	75.3	73.3	71.3	69.2
Top of Old Waste Elevation (ft)	75	75	75	75	75	75	75	75	75	75	75
Elevation of Top of Columbia (ft)	20	20	20	20	20	20	20	20	20	20	20
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15	15	15	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	0	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	0.2	0.1	6.1	12.0	18.9	26.2	29.5	30.5	31.2	31.7	32.3
Initial Stress in old waste	3111	2625	2504	2444	2384	2324	2202	1964	1725	1481	1229
Initial Stress in Columbia (psf)	5397	5407	5031	4663	4006	3621	3413	3349	3310	3274	3240
Initial Stress in Upper Potomac (psf)	5375	5375	5375	5095	4664	4209	4002	3937	3899	3862	3829
Initial Stress in Lower Potomac (psf)	7126	7136	6759	6391	5960	5505	5298	5233	5195	5158	5125
$\Delta\sigma$ (psf)	3044	4294	5062	4949	5778	6879	7765	6527	4623	2718	845
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	1.96	2.78	3.17	3.17	3.53	3.94	4.33	4.20	3.73	2.99	1.50
Primary Settlement (Upper Potomac) δ_P (ft)	0.06	0.08	0.09	0.09	0.10	0.13	0.14	0.13	0.10	0.07	0.03
Primary Settlement (Lower Potomac) δ_P (ft)	0.09	0.12	0.15	0.15	0.18	0.21	0.24	0.21	0.17	0.11	0.04
Secondary Settlement (Existing Waste) δ_S (ft)	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16
Total Settlement δ_P (ft)	3.27	4.14	4.56	4.57	4.97	5.44	5.86	5.69	5.16	4.33	2.72
Pre-settlement Grade	-	4.1%	1.0%	0.5%	0.5%	0.5%	1.0%	2.0%	2.0%	2.0%	2.1%
Change in Grade	-	0.87%	0.42%	0.01%	0.40%	0.47%	0.42%	-0.17%	-0.53%	-0.84%	-1.60%
Post-settlement Grade	-	4.9%	1.4%	0.5%	0.9%	1.0%	1.4%	1.8%	1.5%	1.2%	0.5%
Post-Settlement Elevation	81.6	76.7	75.3	74.8	73.9	72.9	71.4	69.6	68.2	67.0	66.5
Post-Settlement Liner-GW Seperation	81.4	76.6	69.2	62.8	55.0	46.7	41.9	39.1	37.0	35.2	34.2
Strain in Liner, ε (%)	-	0.020	0.005	0.000	0.004	0.006	0.005	0.001	0.008	0.019	0.068

TABLE 2

Settlement Analysis Section B-B
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Future Max. Waste Elevation (ft)	189.3	188.2	189.8	188.1	189.9	189.5	189.8	189.0	189.2
Base Liner Elevation (ft)	87.1	84.7	83.2	81.7	80.2	78.7	77.2	75.8	74.4
Top of Old Waste Elevation (ft)	74	74	74	74	74	74	74	74	74
Elevation of Top of Columbia (ft)	20	20	20	20	20	20	20	20	20
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	0.6	0.3	0.1	2.7	6.6	10.3	14.2	21.3	25.6
Initial Stress in old waste	3463	3178	2998	2818	2638	2458	2278	2101	1936
Initial Stress in Columbia (psf)	5304	5320	5335	5170	4932	4695	4457	3856	3588
Initial Stress in Upper Potomac (psf)	5305	5305	5305	5305	5305	5127	4890	4444	4177
Initial Stress in Lower Potomac (psf)	7033	7048	7064	6899	6660	6423	6186	5740	5473
$\Delta\sigma$ (psf)	7157	7246	7456	7446	7677	7752	7880	7930	8040
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20000	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	3.15	3.34	3.51	3.64	3.84	4.01	4.21	4.40	4.61
Primary Settlement (Upper Potomac) δ_P (ft)	0.11	0.11	0.11	0.11	0.12	0.12	0.13	0.13	0.14
Primary Settlement (Lower Potomac) δ_P (ft)	0.18	0.18	0.19	0.19	0.20	0.21	0.21	0.23	0.24
Secondary Settlement (Existing Waste) δ_S (ft)	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Total Settlement δ_P (ft)	4.59	4.78	4.95	5.08	5.29	5.47	5.68	5.90	6.13
Pre-settlement Grade	-	2.4%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.4%
Change in Grade	-	0.19%	0.18%	0.13%	0.21%	0.18%	0.21%	0.21%	0.23%
Post-settlement Grade	-	2.6%	1.7%	1.6%	1.7%	1.7%	1.7%	1.7%	1.6%
Post-Settlement Elevation	82.5	80.0	78.3	76.7	74.9	73.3	71.6	69.9	68.3
Post-Settlement Liner-GW Seperation	81.9	79.6	78.2	73.9	68.4	62.9	57.4	48.6	42.7
Strain in Liner, ε (%)	-	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001

TABLE 3

Settlement Analysis Section C-C
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Future Max. Waste Elevation (ft)	97.3	121.5	146.8	168.5	182.2	188.5	189.1	189.0	189.6	189.7	188.3	181.8
Base Liner Elevation (ft)	48.1	46.1	44.2	42.3	40.3	37.9	35.6	33.2	31.1	29.2	27.5	26.5
Top of Old Waste Elevation (ft)	48	46	44	42	40	38	36	34	31	29	28	26
Elevation of Top of Columbia (ft)	48	46	44	42	40	38	36	34	31	29	28	26
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15	15	15	15	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	0	0	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	31.9	31.3	30.7	30.1	29.0	27.9	26.8	25.9	25.2	19.8	12.9	9.5
Initial Stress in old waste	-	-	-	-	-	-	-	-	-	-	-	-
Initial Stress in Columbia (psf)	3048	1997	1734	2266	780	718	655	593	500	1449	1755	1715
Initial Stress in Upper Potomac (psf)	3505	3291	3077	2862	2682	2504	2318	2124	1798	1882	2188	2148
Initial Stress in Lower Potomac (psf)	4801	4587	4373	4158	3978	3800	3614	3420	3094	3178	3484	3444
$\Delta\sigma$ (psf)	3454	5288	7206	8872	9970	10535	10700	10811	11105	11259	11193	10928
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	-	-	-	-	-	-	-	-	-	-	-	-
Primary Settlement (Upper Potomac) δ_P (ft)	0.09	0.12	0.16	0.18	0.20	0.21	0.22	0.24	0.26	0.25	0.24	0.24
Primary Settlement (Lower Potomac) δ_P (ft)	0.14	0.20	0.25	0.30	0.33	0.35	0.36	0.37	0.40	0.39	0.37	0.37
Secondary Settlement (Existing Waste) δ_S (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Settlement δ_P (ft)	0.23	0.32	0.41	0.48	0.53	0.56	0.58	0.61	0.65	0.65	0.61	0.61
Pre-settlement Grade	-	1.9%	1.9%	1.9%	2.0%	2.4%	2.3%	2.4%	2.1%	1.9%	1.7%	1.0%
Change in Grade	-	0.09%	0.09%	0.07%	0.05%	0.03%	0.02%	0.02%	0.05%	-0.01%	-0.04%	0.00%
Post-settlement Grade	-	2.0%	2.0%	2.0%	2.0%	2.4%	2.4%	2.4%	2.2%	1.9%	1.7%	1.0%
Post-Settlement Elevation	47.8	45.8	43.8	41.8	39.8	37.4	35.0	32.6	30.4	28.6	26.9	25.9
Post-Settlement Liner-GW Seperation	16.0	14.5	13.1	11.7	10.7	9.5	8.2	6.7	5.3	8.8	14.0	16.4
Strain in Liner, ε (%)	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 4

Settlement Analysis Section D-D
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Future Max. Waste Elevation (ft)	186.6	184.8	164.9	145.9	132.9	110.3	84.2
Base Liner Elevation (ft)	39.2	41.8	52.1	70.5	72.4	74.4	78.4
Top of Old Waste Elevation (ft)	39	42	54	70	72	74	80
Elevation of Top of Columbia (ft)	39	42	50	62	64	68	70
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	28.4	29.7	30.5	31.1	31.7	32.4	33.0
Initial Stress in old waste	0	0	140	280	280	210	350
Initial Stress in Columbia (psf)	2071	1704	3685	5424	5636	5956	6448
Initial Stress in Upper Potomac (psf)	2594	2890	4121	5861	6073	6394	6885
Initial Stress in Lower Potomac (psf)	3890	4186	5417	7157	7369	7690	8181
$\Delta\sigma$ (psf)	10340	9982	7668	5339	4281	2561	212
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	-	-	0.84	1.25	1.16	0.81	0.25
Primary Settlement (Upper Potomac) δ_P (ft)	0.21	0.19	0.14	0.08	0.07	0.04	0.00
Primary Settlement (Lower Potomac) δ_P (ft)	0.34	0.32	0.23	0.15	0.12	0.07	0.01
Secondary Settlement (Existing Waste) δ_S (ft)	0.00	0.00	0.08	0.17	0.17	0.13	0.21
Total Settlement δ_P (ft)	0.55	0.51	1.29	1.65	1.52	1.05	0.47
Pre-settlement Grade	-	2.6%	10.4%	18.3%	1.9%	2.0%	4.0%
Change in Grade	-	0.03%	-0.78%	-0.36%	0.13%	0.47%	0.58%
Post-settlement Grade	-	2.6%	9.6%	18.0%	2.0%	2.4%	4.6%
Post-Settlement Elevation	38.6	41.3	50.8	68.8	70.9	73.3	77.9
Post-Settlement Liner-GW Seperation	10.2	11.6	20.4	37.7	39.1	41.0	45.0
Strain in Liner, ε (%)	-	0.000	0.016	0.003	0.000	0.006	0.009

TABLE 5

Settlement Analysis Section E-E
Delaware Recyclable Products, Inc. Landfill
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Future Max. Waste Elevation (ft)	191.8	190.8	189.8	188.7	184.1	183.1	187.6	177.6
Base Liner Elevation (ft)	28.5	31.0	33.6	36.2	38.8	41.4	43.8	46.3
Top of Old Waste Elevation (ft)	28	31	34	36	39	41	44	46
Elevation of Top of Columbia (ft)	28	31	34	36	39	41	44	46
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	20.8	25.3	26.1	27.0	27.8	28.6	29.4	30.1
Initial Stress in old waste	-	-	-	-	-	-	-	-
Initial Stress in Columbia (psf)	1260	902	1085	1739	749	811	2726	2931
Initial Stress in Upper Potomac (psf)	1693	1792	2113	2310	2633	2834	3161	3366
Initial Stress in Lower Potomac (psf)	2989	3088	3409	3606	3929	4130	4457	4662
$\Delta\sigma$ (psf)	11491	11186	10882	10701	10152	9965	10046	9227
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	-	-	-	-	-	-	-	-
Primary Settlement (Upper Potomac) δ_P (ft)	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.17
Primary Settlement (Lower Potomac) δ_P (ft)	0.41	0.40	0.37	0.36	0.33	0.32	0.31	0.28
Secondary Settlement (Existing Waste) δ_S (ft)	-	-	-	-	-	-	-	-
Total Settlement δ_P (ft)	0.68	0.66	0.61	0.58	0.54	0.52	0.49	0.46
Pre-settlement Grade	-	2.5%	2.6%	2.7%	2.6%	2.5%	2.5%	2.4%
Change in Grade	-	-0.02%	-0.05%	-0.03%	-0.05%	-0.02%	-0.02%	-0.04%
Post-settlement Grade	-	2.5%	2.5%	2.6%	2.6%	2.5%	2.4%	2.4%
Post-Settlement Elevation	27.8	30.3	33.0	35.7	38.3	40.9	43.3	45.8
Post-Settlement Liner-GW Seperation	7.0	5.1	6.8	8.7	10.5	12.3	14.0	15.7
Strain in Liner, ε (%)	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 6

Settlement Analysis Section F-F
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Future Max. Waste Elevation (ft)	54.0	83.6	113.3	143.0	172.0	186.3	189.9	188.0
Base Liner Elevation (ft)	6.7	8.2	9.3	10.5	11.6	12.7	13.8	14.9
Top of Old Waste Elevation (ft)	30	30	32	32	32	32	32	32
Elevation of Top of Columbia (ft)	15	14	13	12	11	9	8	6
Elevation of Top of Upper Potomac (ft)	15	14	13	12	11	9	8	6
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	1.1	1.8	2.0	2.1	2.2	2.3	2.3	2.0
Initial Stress in old waste	-	-	-	-	-	-	-	-
Initial Stress in Columbia (psf)	1916	1880	2014	2015	2019	2031	2037	2070
Initial Stress in Upper Potomac (psf)	1950	1960	2110	2120	2130	2150	2160	2180
Initial Stress in Lower Potomac (psf)	3644	3550	3627	3570	3516	3413	3361	3279
$\Delta\sigma$ (psf)	513	2664	4555	6693	8779	9834	10146	10067
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	-	-	-	-	-	-	-	-
Primary Settlement (Upper Potomac) δ_P (ft)	0.03	0.10	0.13	0.15	0.16	0.13	0.12	0.09
Primary Settlement (Lower Potomac) δ_P (ft)	0.03	0.15	0.21	0.28	0.33	0.35	0.36	0.37
Secondary Settlement (Existing Waste) δ_S (ft)	-	-	-	-	-	-	-	-
Total Settlement δ_P (ft)	0.06	0.25	0.34	0.42	0.48	0.49	0.48	0.46
Pre-settlement Grade	-	1.6%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
Change in Grade	-	-0.19%	-0.09%	-0.08%	-0.06%	-0.01%	0.00%	0.03%
Post-settlement Grade	-	1.4%	1.0%	1.0%	1.1%	1.1%	1.1%	1.2%
Post-Settlement Elevation	6.6	8.0	9.0	10.0	11.1	12.2	13.3	14.5
Post-Settlement Liner-GW Seperation	5.5	6.2	7.0	7.9	8.9	9.9	11.0	12.5
Strain in Liner, ε (%)	-	0.001	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 7

Settlement Analysis Section G-G
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	98

Point	**0**	**1**	**2**	**3**
Future Max. Waste Elevation (ft)	189.9	189.4	189.2	189.0
Base Liner Elevation (ft)	90.0	87.6	85.1	82.7
Top of Old Waste Elevation (ft)	74	74	74	74
Elevation of Top of Columbia (ft)	20	20	20	20
Elevation of Top of Upper Potomac (ft)	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30
Water Table elevation (ft-msl)	1.0	0.6	0.3	0.2
Initial Stress in old waste	3810	3516	3222	2928
Initial Stress in Columbia (psf)	5281	5301	5321	5330
Initial Stress in Upper Potomac (psf)	5305	5305	5305	5305
Initial Stress in Lower Potomac (psf)	7010	7030	7050	7058
$\Delta\sigma$ (psf)	6992	7130	7290	7444
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	2.93	3.12	3.33	3.56
Primary Settlement (Upper Potomac) δ_P (ft)	0.11	0.11	0.11	0.11
Primary Settlement (Lower Potomac) δ_P (ft)	0.18	0.18	0.19	0.19
Secondary Settlement (Existing Waste) δ_S (ft)	1.14	1.14	1.14	1.14
Total Settlement δ_P (ft)	4.36	4.55	4.76	5.00
Pre-settlement Grade	-	2.5%	2.5%	2.5%
Change in Grade	-	0.19%	0.22%	0.24%
Post-settlement Grade	-	2.7%	2.7%	2.7%
Post-Settlement Elevation	85.6	83.0	80.3	77.7
Post-Settlement Liner-GW Seperation	84.7	82.4	80.0	77.5
Strain in Liner, ε (%)	-	0.001	0.001	0.002

TABLE 8

Settlement Analysis Section H-H
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	81

Point	**0**	**1**	**2**	**3**	**4**
Future Max. Waste Elevation (ft)	97.9	123.7	132.5	154.4	177.0
Base Liner Elevation (ft)	86.0	83.1	81.5	79.9	78.3
Top of Old Waste Elevation (ft)	75	75	75	75	75
Elevation of Top of Columbia (ft)	20	20	20	20	20
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	30.0	28.8	27.7	26.9	26.3
Initial Stress in old waste	3244	2900	2705	2512	2322
Initial Stress in Columbia (psf)	3380	3458	3528	3575	3615
Initial Stress in Upper Potomac (psf)	3968	4046	4117	4164	4203
Initial Stress in Lower Potomac (psf)	5264	5342	5413	5460	5499
$\Delta\sigma$ (psf)	833	2843	3573	5215	6908
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20001
Primary Settlement (Existing Waste) δ_P (ft)	0.65	1.96	2.41	3.22	3.96
Primary Settlement (Upper Potomac) δ_P (ft)	0.02	0.07	0.08	0.11	0.13
Primary Settlement (Lower Potomac) δ_P (ft)	0.04	0.11	0.13	0.17	0.21
Secondary Settlement (Existing Waste) δ_S (ft)	1.16	1.16	1.16	1.16	1.16
Total Settlement δ_P (ft)	1.88	3.30	3.79	4.66	5.45
Pre-settlement Grade	-	3.6%	2.0%	2.0%	2.0%
Change in Grade	-	1.76%	0.60%	1.08%	0.98%
Post-settlement Grade	-	5.3%	2.6%	3.1%	2.9%
Post-Settlement Elevation	84.1	79.8	77.7	75.2	72.9
Post-Settlement Liner-GW Seperation	54.1	51.0	50.1	48.3	46.6
Strain in Liner, ε (%)	-	0.083	0.010	0.031	0.026

TABLE 9

Settlement Analysis Section J-J
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	100

Point	**0**	**1**	**2**
Future Max. Waste Elevation (ft)	186.8	172.6	153.7
Base Liner Elevation (ft)	16.0	13.1	10.9
Top of Old Waste Elevation (ft)	32	32	32
Elevation of Top of Columbia (ft)	10	10	10
Elevation of Top of Upper Potomac (ft)	10	10	10
Elevation of Top of Lower Potomac (ft)	0	0	0
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30
Water Table elevation (ft-msl)	2.1	2.2	2.2
Initial Stress in old waste	-	-	-
Initial Stress in Columbia (psf)	2030	2029	2028
Initial Stress in Upper Potomac (psf)	2140	2140	2140
Initial Stress in Lower Potomac (psf)	3470	3469	3468
$\Delta\sigma$ (psf)	10035	8898	7468
Preconsolidation Pressure Potomac (psf)	20000	20000	20000
Primary Settlement (Existing Waste) δ_P (ft)	-	-	-
Primary Settlement (Upper Potomac) δ_P (ft)	0.15	0.14	0.13
Primary Settlement (Lower Potomac) δ_P (ft)	0.35	0.33	0.30
Secondary Settlement (Existing Waste) δ_S (ft)	-	-	-
Total Settlement δ_P (ft)	0.51	0.47	0.43
Pre-settlement Grade	-	2.9%	2.2%
Change in Grade	-	-0.03%	-0.04%
Post-settlement Grade	-	2.8%	2.2%
Post-Settlement Elevation	15.5	12.7	10.5
Post-Settlement Liner-GW Seperation	13.3	10.5	8.3
Strain in Liner, ε (%)	-	0.000	0.000

TABLE 10

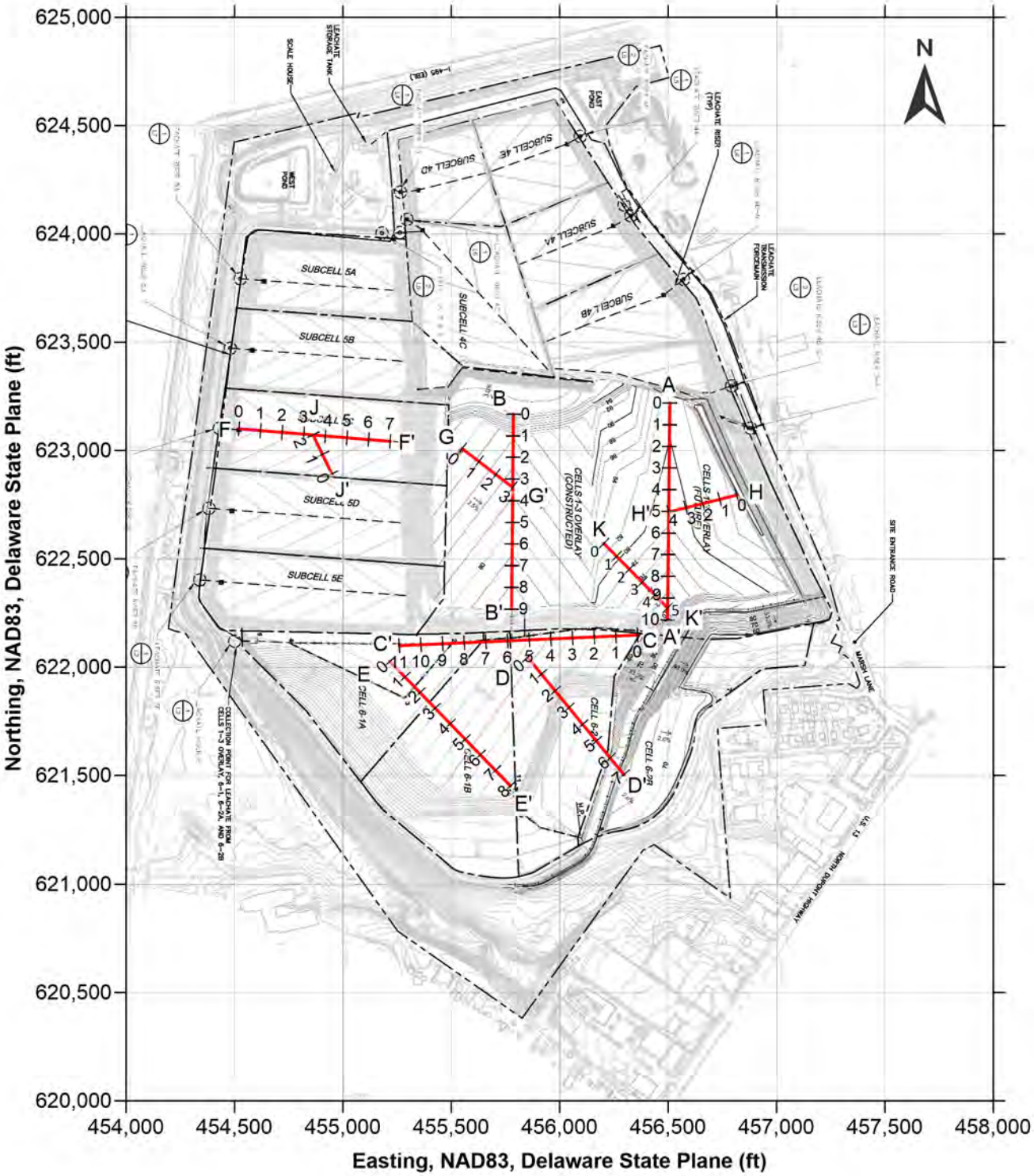
Settlement Analysis Section K-K
Delaware Recyclable Products, Inc. Landfill Vertical Expansion
New Castle, Delaware

Soil Properties	Upper Potomac	Lower Potomac	Columbia	Waste	Water	Grading Layer
Modified Compression Index	0.09	0.15	-	0.12	-	-
Modified Recompression Index	0.02	0.02		-		
Modified Secondary Compression Index	-	-		0.07		
Unit Weight, γ (pcf)	120	120	125	70	62.4	120

t_1 (years)	30
t_2 (years)	60
Distance Between Points (ft)	84

Point	**0**	**1**	**2**	**3**	**4**	**5**
Future Max. Waste Elevation (ft)	189.5	188.1	164.6	141.4	117.6	95.9
Base Liner Elevation (ft)	82.0	79.9	77.7	75.6	73.1	70.6
Top of Old Waste Elevation (ft)	75	75	75	75	75	76
Elevation of Top of Columbia (ft)	20	20	20	20	20	21
Elevation of Top of Upper Potomac (ft)	15	15	15	15	15	16
Elevation of Top of Lower Potomac (ft)	0	0	0	0	0	1
Elevation of bottom of Lower Potomac (ft)	-30	-30	-30	-30	-30	-30
Water Table elevation (ft-msl)	25.7	28.0	30.1	30.7	31.3	32.0
Initial Stress in old waste	2766	2518	2253	1995	1693	1279
Initial Stress in Columbia (psf)	3648	3507	3378	3339	3298	3321
Initial Stress in Upper Potomac (psf)	4236	4096	3967	3927	3887	3909
Initial Stress in Lower Potomac (psf)	5532	5392	5263	5223	5183	5234
$\Delta\sigma$ (psf)	7528	7571	6078	4607	3117	1767
Preconsolidation Pressure Potomac (psf)	20000	20000	20000	20000	20001	20002
Primary Settlement (Existing Waste) δ_P (ft)	3.77	3.98	3.75	3.43	2.99	2.49
Primary Settlement (Upper Potomac) δ_P (ft)	0.13	0.14	0.12	0.10	0.08	0.05
Primary Settlement (Lower Potomac) δ_P (ft)	0.22	0.23	0.20	0.16	0.12	0.08
Secondary Settlement (Existing Waste) δ_S (ft)	1.16	1.16	1.16	1.16	1.16	1.16
Total Settlement δ_P (ft)	5.28	5.50	5.23	4.86	4.35	3.77
Pre-settlement Grade	-	2.5%	2.6%	2.6%	3.0%	2.9%
Change in Grade	-	0.26%	-0.33%	-0.45%	-0.60%	-0.69%
Post-settlement Grade	-	2.7%	2.3%	2.1%	2.4%	2.2%
Post-Settlement Elevation	76.7	74.4	72.5	70.7	68.7	66.8
Post-Settlement Liner-GW Seperation	51.0	46.4	42.4	40.0	37.4	34.9
Strain in Liner, ε (%)	-	0.002	0.003	0.005	0.010	0.013

FIGURES



BASE GRADES

Settlement Analysis
Delaware Recyclable Products, Inc. Landfill Vert. Exp.
New Castle, Delaware

Geosyntec consultants

Columbia, Maryland | July 2018

FIGURE 1

FINAL GRADES

Settlement Analysis
Delaware Recyclable Products, Inc. Landfill Vert. Exp.
New Castle, Delaware

Geosyntec consultants

Columbia, Maryland | July 2018

FIGURE 2