GEOTEXTILE DESIGN ANALYSIS

GeoSyntec Consultants
COMPUTATION COVER SHEET

Client: Tennessee Valley Authority (TVA)

Project: Kingston Fossil Plant Gypsum Disposal Facility **Project/Proposal #:** GR3731 **Task #:** 06

Title of Computations: *Geotextile Design Analysis*

Computation Package: ______

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Approval Notes: ______

Revisions: (Number and Initial All Revisions)

No.	Sheet	Date	By	Checked By	Approval

Written by:	JFR	Date:	06 /04 /12 (YY MM DD)	Reviewed by:	B. Gross	Date:	06 04 19 (YY MM DD)
Client:	TVA	Project:	Kingston Fossil Plant	Project/Proposal No.:	GR3731	Task No:	06

GEOTEXTILE DESIGN ANALYSIS

PURPOSE

The purpose of this calculation package is to evaluate the minimum requirements of the geotextile filter to be used for the internal drainage system of the gypsum disposal facility at Kingston Fossil Plant-Peninsula Site. The filter will be located around the gravel material of the central drainage corridor and perimeter drainage trenches to separate the sluiced gypsum from the drainage gravel material. The geotextile filter will be specified as needlepunched and non-woven.

This design evaluates the filtration and survivability requirements for the geotextile, and minimum specifications to meet these requirements are provided.

METHODOLOGY

Geotextile Filtration

The filtration characteristics of the geotextile will be evaluated using a retention criterion, a permeability criterion, and an anti-clogging criterion, based on methods presented in the technical literature (Christopher and Holtz 1984, Giroud 1982, Koerner et al. 1994, USEPA 1987).

Geotextile Survivability

Survivability requirements (grab, tear, puncture, and burst strengths) will also be considered so that the geotextile will have adequate resistance to stresses applied on the geotextile during construction (i.e., when concentrated stresses should be the highest), using the method presented in GRI-GT13 (2004).

As each criterion is evaluated and specifications are derived, characteristics of geotextile products on the current market will be checked to make sure the specification is reasonable and that products are available that can meet the specification.

FILTRATION EVALUATION RESULTS

The filtration criteria used for the geotextile filter design are presented below in Table 1, followed by a description justifying selection of the required design values.

Table 1. Filtration Criteria for Geotextile (adapted From Christopher and Holtz, 1984; Giroud, 1982; and USEPA, 1987)

1. Retention Criterion

1.1. Soils with less than 50% particles < 0.075 mm (US Sieve No. 200)

Density index of the soil (Relative density)		Linear coefficient of uniformity of the soil	
		$1 < C'_u < 3$	$C'_u > 3$
loose soil	$I_D < 35\%$	$O_{95} < C'_u\, d_{50}$	$O_{95} < \frac{9}{C'_u} d_{50}$
medium dense soil	$35\% < I_D < 65\%$	$O_{95} < 1.5\, C'_u\, d_{50}$	$O_{95} < \frac{13.5}{C'_u} d_{50}$
dense soil	$I_D > 65\%$	$O_{95} < 2\, C'_u\, d_{50}$	$O_{95} < \frac{18}{C'_u} d_{50}$

1.2. Soils with more than 50% particles < 0.075 mm (US Sieve No. 200)
$O_{95} \leq 210\ \mu m$ (US Sieve No. 70)

2. Permeability Criterion

2.1. Critical and/or Severe Applications
$k_{geotextile} > 10\, k_{soil}$

2.2. Noncritical and Nonsevere Applications
$k_{geotextile} > k_{soil}$

3. Anti-Clogging Criterion

Nonwoven geotextiles: porosity, $n_g > 30\%$

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Table 1 (Continued). Filtration Criteria

Notes: - O_{95} is the apparent opening size (AOS) of the geotextile

-C'_u = linear coefficient of uniformity = $\sqrt{d'_{100}/d'_0}$

where d'_{100} and d'_0 are the top and bottom extremities, respectively, of a line drawn through the central portion of a soil particle-size distribution curve

- d_{50} and d_{85} are soil particle sizes for which 50% and 85%, respectively, of particles are finer by weight

- I_D = relative density or density index = $(e - e_{min})/(e_{max} - e_{min})$, where e = soil void ratio; e_{min} = soil minimum void ratio, and e_{max} = soil maximum void ratio

- $k_{geotextile}$ = geotextile hydraulic conductivity; k_{soil} = soil hydraulic conductivity

- porosity, n_g (dimensionless) is calculated as follows: $n_g = 1 - \mu_g/(\rho_g\, t_g)$, where: μ_g = geotextile mass per unit area, ρ_g = polymer density, and t_g = geotextile thickness.

Geotextile Retention (Filter Design)

The geotextile must have openings that are small enough to retain fine-grained soil particles to avoid clogging or flow capacity reduction of the gravel in the drainage corridor. Therefore, the apparent opening size (AOS, hereafter referred to as O_{95}) of the geotextile must be less than a required minimum value. The retention criterion is given in Table 1.

The gravel drainage material will be wrapped by the geotextile which in turn will be overlain by sedimented gypsum with primarily silt-sized particles. A copy of a typical grain size distribution curve for fine grained gypsum material obtained from a similar TVA gypsum disposal facility is shown in Figure 1. According to this grain size distribution curve, the gypsum material is characterized as having more than 50% particles finer than 0.075 mm (i.e., U.S. Sieve No. 200). As shown in Table 1, for this type of soil, the geotextile retention criterion is as follows:

$O_{95} \leq 210\ \mu m$ (U.S. Sieve No. 70) [USE AS PRODUCT SPECIFICATION]

Geotextile Permeability

The geotextile must have openings that are large enough to allow gypsum drainage water to pass through the gypsum/geotextile interface without significant flow impedance. Thus, the hydraulic conductivity or permeability of the geotextile must be greater than a minimum required value. The permeability criterion is given in Table 1. For severe or critical applications, the hydraulic conductivity of the geotextile $k_{geotextile}$ should be at least ten times greater than the hydraulic conductivity of the retained soil k_{soil}. Given the importance of long-term function of the drainage layer, the geotextile is designed so that:

$$k_{geotextile} > 10\ k_{soil}$$

As discussed previously, the upgradient side of the geotextile will be in contact with gypsum. A typical hydraulic conductivity evaluated for gypsum material from a similar disposal facility [MACTEC, 2004] is approximately $k_{soil} = 5 \times 10^{-4}$ cm/s (Figure 2). Therefore the geotextile permeability criterion is as follows:

$\underline{k_{geotextile} > 10 \times (5.0 \times 10^{-4}\text{ cm/s}) = 5.0 \times 10^{-3}\text{ cm/s.}}$ [USE AS PRODUCT SPECIFICATION]

Note that some manufacturers report the permeability property as "permittivity" (Ψ), which is defined as Ψ=k/t. Based on the range of geotextile mass per unit areas and thicknesses anticipated for the project (6 to 16 oz/yd^2 (200 to 540 g/m^2) and 1.3 to 5.7 mm, respectively), typical $k_{geotextile}$ values (calculated from typical permittivities and thicknesses) for needlepunched non-woven geotextiles are 0.2 to 0.4 cm/sec. Therefore, needlepunched non-woven geotextiles for this project are anticipated to have permeabilities well above the minimum required permeability value recommended to prevent flow impedance.

Geotextile Anti-Clogging

The geotextile filter must have enough openings so that blocking some of them will not significantly clog the geotextile and inhibit flow into the granular drainage layer. Thus, the porosity of the geotextile must be greater than a required minimum value. The clogging criterion is given in Table 1. As shown in Table 1, for non-woven geotextiles, the geotextile porosity n_g is required to be:

$$\underline{n_g > 30\%}$$

Geotextile porosity is not a property that is directly measured or reported by manufacturers, however it can be calculated as indicated in Table 1 above (i.e., $n_g = 1 - \mu_g/(\rho_g\ t_g)$). Typical resulting n_g values for non-woven geotextiles are 50 to 95%. Based on the geotextile density of polypropylene or polyethylene and the range of mass per unit areas and thicknesses anticipated for the project (6 to 16 oz/yd^2 (200 to 540 g/m^2)

and 1.3 to 5.7 mm, respectively), the calculated n_g values range from approximately 80% to 90%, which is well in excess of the minimum required porosity required to prevent clogging.

SURVIVABILITY EVALUATION RESULTS

Survivability refers to the ability of the geotextile to withstand the stresses during installation and handling in the field. The survivability criteria used for the geotextile filter design are presented below in Tables 2 and 3 using a two-step method outlined by GRI-GT13 (2004), followed by a discussion on the assumptions used to select the required design values.

Table 2. Required Degree of Survivability as a Function of Subgrade Conditions and Construction Equipment (GRI-GT13)*

Subgrade Conditions	Low ground-pressure equipment (≤ 25 kPa)	Medium ground-pressure equipment (> 25 kPa, ≤ 50 kPa)	High ground-pressure equipment (> 50 kPa)
Subgrade has been cleared of all obstacles except grass, leaves, and fine wood debris. Surface is smooth and level so that any shallow depressions and humps do not exceed 450 mm in depth or height. All larger depressions are filled. Alternatively, a smooth working table may be placed.	Low	Moderate	High
Subgrade has been cleared of obstacles larger than small to moderate-sized tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 450 mm in depth or height. Larger depressions should be filled.	Moderate	High	Very High
Minimal site preparation is required. Trees may be felled, delimbed, and left in place. Stumps should be cut to project not more than ± 150 mm above subgrade. Fabric may be draped directly over the tree trunks, stumps, large depressions and humps, holes, stream channels, and large boulders. Items should be removed only if placing the fabric and cover material over them will distort the finished road surface.	High	Very High	Not Recommended

* Recommendations are for 150 to 300 mm initial lift thickness. For other initial lift thicknesses:
- 300 to 450 mm: reduce survivability requirement one level;
- 450 to 600 mm: reduce survivability requirement two levels;
- > 600 mm: reduce survivability requirement three levels

For special construction techniques such as prerutting, increase the fabric survivability requirement one level. Placement of excessive initial cover material thickness may cause bearing failure of the soft subgrade.

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Table 3. GRI-GT13 Geotextile Strength Property Requirements

Tests	Test Methods	Units	Geotextile Classification (1)					
			Class 1 (high)		Class 2 (moderate)		Class 3 (low)	
			Elongation < 50%	Elongation ≥ 50%	Elongation < 50%	Elongation ≥ 50%	Elongation < 50%	Elongation ≥ 50%
Grab strength	ASTM D 4632	N	1400	900	1100	700	800	500
Trapezoid Tear strength	ASTM D 4533	N	500	350	400	250	300	180
CBR Puncture strength	ASTM D 6241	N	2800	2000	2250	1400	1700	1000
Permittivity	ASTM D 4491	s^{-1}	0.02	0.02	0.02	0.02	0.02	0.02
Apparent opening size	ASTM D 4751	mm	0.6	0.6	0.6	0.6	0.6	0.6
Ultraviolet stability (2)	ASTM D 4355	% Ret. @ 500 hrs	50	50	50	50	50	50

Notes: (1) All values are MARV except UV stability (which is a minimum value) and AOS which is a maximum value).
(2) Evaluation to be on 50 mm strip tensile specimens after 500 hours exposure.

As shown above, the degree of survivability is first evaluated using Table 2 with the anticipated installation conditions. The following conditions are assumed to apply: (i) smooth and level subgrade condition; and (ii) maximum equipment ground pressure of less than 3.6 psi (25 kPa) (i.e., low ground-pressure due to equipment use considering the material is sluiced into place). Using Table 2, a "low" degree of survivability is used.

In the second step, the minimum required values for the mechanical properties of the geotextile are established from Table 3 based on the "low" or "Class 3" survivability requirement. The chart provides minimum required values for two ranges of geotextile extensibility. Values were selected for the more extensible range because this range is applicable to non-woven materials that are proposed for the geotextile filter.

CONCLUSIONS

Based on the evaluations herein, the following minimum specifications are recommended for the geotextile filter.

- Retention and Filtration:
  - Apparent Opening Size, $O_{95} \leq 210$ μm (U.S. Sieve No. 70)
  - Water Permeability, $k_{geotextile} \geq 5.0 \times 10^{-3}$ cm/s
- Survivability, Mechanical Properties:
  - Grab Strength = 500 N (113 lbs)
  - Trapezoid Tear Strength = 180 N (41 lbs)
  - CBR Puncture Strength = 1,000 N (225 lbs)

REFERENCES

Christopher, B.R., and Holtz, R.D., "*Geotextile Engineering Manual*", FHWA-DTFH61-80-C-00094, 1984.

Geosynthetic Research Institute (GRI), "Standard Specification for Test Methods and Properties for Geotextiles Used as Separation Between Subgrade Soil and Aggregate", *GRI Standard GT-13,* 2004.

Giroud, J.P., "Filter Criteria for Geotextiles", *Proceedings, Second International Conference on Geotextiles,* Vol. 1, Las Vegas, NV, August 1982, pp. 37-42.

Koerner, G.R., Koerner, R.M., and Martin, J.P., "Design of Landfill Leachate-Collection Filters", *ASCE Journal of Geotechnical Engineering*, Vol. 120, No.10, October 1994, pp. 1792-1803.

MACTEC, "*Laboratory Testing Results – Samples from Gypsum Pond at Cumberland Fossil Plant,*" MACTEC Project 3043041009/001, prepared for Parsons E&C on behalf of TVA, Knoxville, TN, May 2004, 48 p.

USEPA, "*Background Document: Proposed Liner and Leak Detection Rule*", EPA\530-SW-87-015, Prepared by GeoServices Inc., May 1987, 526 p.

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Figure 1. TYPICAL GRAIN SIZE DISTRIBUTION CURVE FOR CUMBERLAND GYPSUM (Unpublished Data)

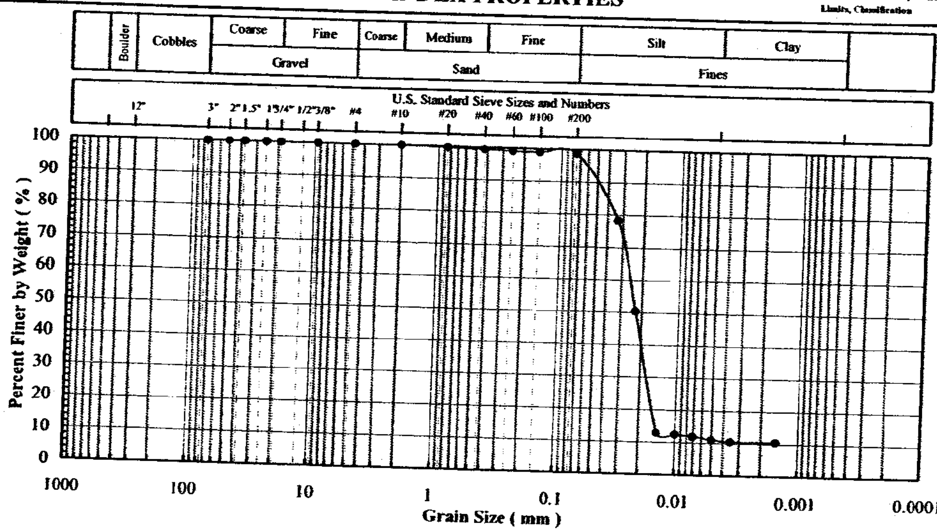
Excel Geotechnical Testing, Inc.
"Excellence in Testing"
941 Forrest Street, Roswell, Georgia 30075
Tel: (770) 650 1666 Fax: (770) 650 5786

Project Name:	KIF-Peninsula Site
Project No:	182
Client Sample ID:	Sample-01
Lab Sample No:	D017

ASTM C 136, D 2216
D 1140, D 422, D 854

SOIL INDEX PROPERTIES

Moisture Content, Grain Size, Atterberg Limits, Classification



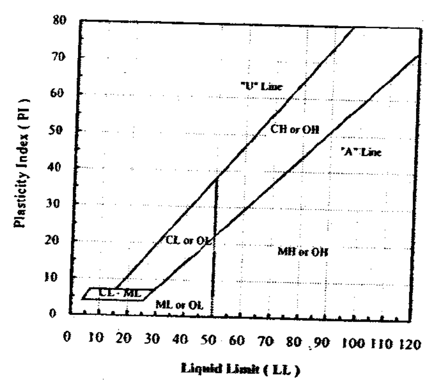
Sieve No.	Size (mm)	% Finer
3"	75	100.0
2"	50	100.0
1.5"	37.5	100.0
1"	25	100.0
3/4"	19	100.0
3/8"	9.5	100.0
#4	4.75	100.0
#10	2.00	100.0
#20	0.850	99.7
#40	0.425	99.4
#60	0.250	99.1
#100	0.150	98.9
#200	0.075	98.7

Specific Gravity (-):	2.45

Hydrometer Particle Diameter (mm)	% Finer
0.0332	78.3
0.0142	12.8
0.0071	11.9
0.0035	10.5
0.0015	10.5

Gravel (%):	
Sand (%):	1.3
Fines (%):	98.7
Silt (%):	87.7
Clay (%):	11.0

Coeff. Unif. (Cu):	
Coeff. Curv. (Cc):	



Client Sample ID.	Lab Sample No:	Moisture Content (%)	Fines Content < No. 200 (%)	Atterberg Limits LL (-)	PL (-)	PI (-)	Engineering Classification
Sample-01	D017	34.6	98.7	NP	NP	NP	ML - Silt

Note(s):

Some of the tests may not be applicable for the material (gypsum) tested.

An assummed specific gravity of 2.45 was used when analysing the hydrometer test results.

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Figure 2. TYPICAL PERMEABILITY FOR CUMBERLAND GYPSUM (MACTEC, 2004)

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 5.04
Specimen Diameter (cm): 7.33
Dry Unit Weight (pcf): 68.0
Moisture Before Test (%): 29.0
Moisture After Test (%): 48.6
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 57.0
Test Pressure(psi): 52.0
Back Pressure(psi): 50.7
Diff. Head (psi): 1.3
Flow Rate (cc/sec): 4.14 x 10^-1
Perm. (cm/sec): 5.02 x 10^-4

SAMPLE DATA:

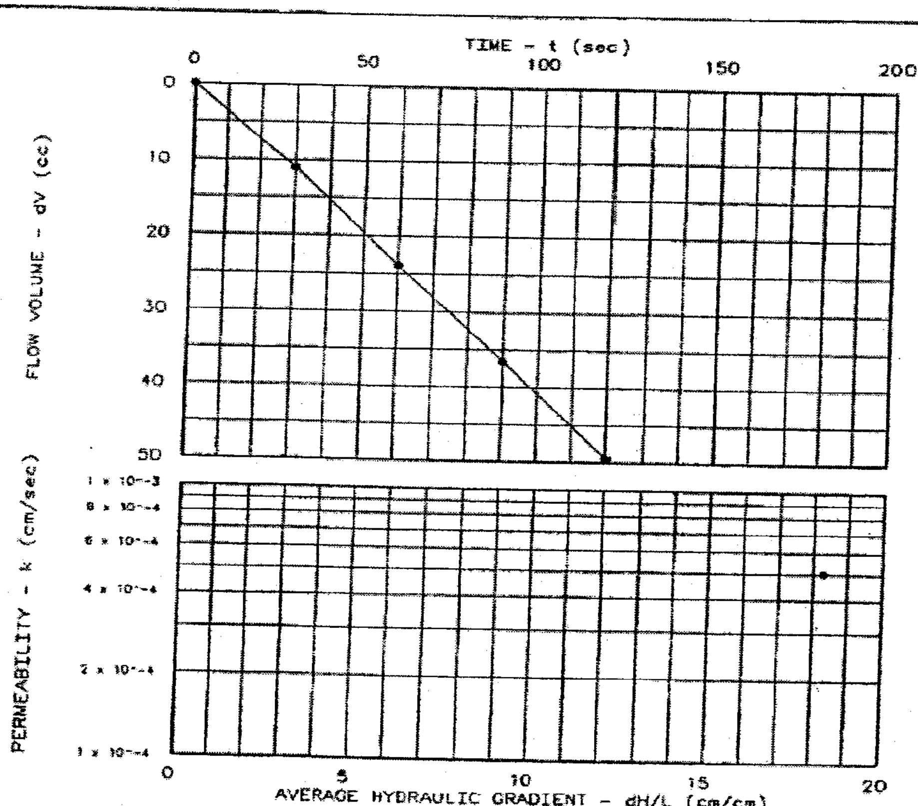
Sample Identification: Hole #3

Visual Description: Gypsum

Remarks:

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexible Wall
Sample type: Shelby Tube



Project: TVA Kingston Fossil Plant - CUF Gypsum
Location:
Date: 05-04-04

PERMEABILITY TEST REPORT

Project No.: 3043041009
File No.: As# 2651
Lab No.: 6226
Tested by: JA
Checked by: MH
Test: CH - Constant head