Technically Complete, March 11, 2016

ATTACHMENT D.6-A

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENTS

1. LOADS ON THE LEACHATE COLLECTION SYSTEM
2. RING DEFLECTION
3. STRUCTURAL CAPACITY OF THE LEACHATE COLLECTION SYSTEM
4. COMPRESSED THICKNESS AND HYDRAULIC CONDUCTIVITY OF THE GEONET
5. HELP MODEL ANALYSIS
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9. LEACHATE TANK SIZE

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ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 1: LOADS ON THE LEACHATE COLLECTION SYSTEM (III-D.6-A.1)

3-2-2015

STATE OF TEXAS
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Client:	Rancho Viejo Waste Management, LLC		
Project:	Pescadito Environmental Resource Center		
Project #:	148866		
Calculated By:	LJC	Date:	1/26/15
Checked By:	RDS	Date:	2/06/15

TITLE: LOADS ON THE LEACHATE COLLECTION SYSTEM

Problem Statement

Determine the maximum loading (W) on the leachate conveyance pipes (leachate collection pipe, leachate riser pipe and leachate cleanout pipe). Two loading scenarios are considered:

- ❑ Full Loading: W_{FL} = Loading on pipe due to landfill at final grade.
- ❑ Point-Source Loading: W_{IL} = Loading on pipe due to 5 feet of waste (half of one 10-foot lift) and compactor concentrated load.

The greatest loading will be used in subsequent calculations to determine the pipes' ability to resist the load.

Given

- ❑ Joint Task Force on Sanitary Sewers of the American Society of Civil Engineers and Water Pollution Control Federation. (2007). *Gravity Sanitary Sewer Design and Construction*. American Society of Civil Engineers, Manuals and Reports on Engineering Practice, No. 60, Pages 166-191.
- ❑ Budhu, Muni (2000). *Soil Mechanics & Foundations,* John Wiley & Sons, Inc., New York.
- ❑ KWH Pipe. (2006). *Sclairpipe: Versatile High Density Polyethylene Pipe*.
- ❑ Caterpillar, Inc. (2014). *Caterpillar Performance Handbook*. Edition 44, Pages 25-13.
- ❑ Leachate design details, Appendix - III-D.3.
- ❑ Geotechnical Analysis Report, Appendix - III-D.5.

Assumptions

General Assumptions

- ❑ Three different leachate conveyance pipes are present in the landfill that must be analyzed:
  - o Case 1: 6-inch SDR-7.3 Leachate Collection Pipe in Leachate Chimney
  - o Case 2: 18-inch SDR-11 Leachate Riser Pipe On Side-Wall
  - o Case 3: 6-inch SDR-11 Leachate Cleanout Pipe On Side-Wall
- ❑ Outer Pipe Diameters for Cases 1-3:

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Case #	Outer Diameter (B_C)
Case 1: 6-inch SDR-7.3 Leachate Collection Pipe	6.517 in = 0.54 ft
Case 2: 18-inch SDR-11 Leachate Riser Pipe	17.803 in = 1.48 ft
Case 3: 6-inch SDR-11 Leachate Cleanout Pipe	6.552 in = 0.55 ft
B_C obtained from reference KWH Sclairpipe "General Information"	

Full Loading Assumptions (Final Landform Constructed)

- ❑ Marston's formula utilized to calculate the prism load (Equation 9.1 in reference ASCE No. 60):

$$W_c = C_c w B_c^2$$

Where,

W_c=Linear load on pipe (lb/ft)
C_c = Load coefficient, obtained from Table 9-4 of ASCE No. 60
w = Unit weight of overlying fill (pcf)
B_c = Outer diameter of pipe (ft)
H = Height of fill above the top of the pipe (ft)

- ❑ It is assumed that the soil conditions immediately under the pipe are the same as those surrounding the pipe trench, in which case the settlement ratio can be considered equal to zero, and thus the load coefficient (C_c) is equal to the height of fill (H) divided by the outer diameter on the pipe (B_c) (reference ASCE No. 60). The equation then simplifies to:

$$W_c = C_c w B_c^2 = \left(\frac{H}{B_c}\right) w B_c^2 = H w B_c$$

- ❑ Assumed embankment conditions over a positive projecting pipe since the pipe is located in a wide trench and the top of the pipe is near the surface of compacted soil.

- ❑ Maximum overlying waste thickness of 380 feet for the leachate collection pipe in the chimney.

- ❑ Maximum overlying waste thickness of 175 for the leachate riser pipe and the leachate cleanout pipe.

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- ❑ Cohesive soil density is 129 lb/ft^3 based on the average moist density for onsite soils, as determined in the Geotechnical Analysis Report, Appendix III-D.5.
- ❑ Assume waste density is 65 pcf, from Geotechnical Analysis Report, Appendix III-D.5.
- ❑ Assume density of aggregate used in leachate collection trench is 135 pcf, see Soil Mechanics and Foundations.

Point-Source Loading Assumptions

- ❑ D.L. Holl's integration of Boussinesq's formula utilized to calculate the load on the pipe due to a superimposed concentrated load (corresponding to a landfill compactor, Equation 9.13 from reference ASCE No. 60):

$$W_{sc} = C_s \frac{PF}{L}$$

Where,

W_{sc} = Load on pipe (lb/ft)
P = Concentrated load (lb)
F = Impact Factor
C_s = Load Coefficient, a function of $B_c/2H$
H = Height of fill above top of pipe (ft)
B_c = Outer diameter of pipe (ft)
L = Effective length of pipe (ft)

- ❑ Five feet of waste is placed (minimum anticipated waste thickness prior to use of compactor)
- ❑ P = Total weight of compactor divided by 2 axles = 123,319 lb/2 = 61,660 lb (reference Caterpillar).
- ❑ F = 1.0 (recommend per ASCE No. 60 for H > 3 ft)
- ❑ L = 3 ft (recommended per ASCE No. 60 for pipe lengths > 3 ft)
- ❑ H for each case is shown in the following table:

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Case	H
Case 1: 6-inch SDR-7.3 Leachate Collection Pipe	1.5 ft of drainage layer material + 5 ft of waste (1/2 lift) = 6.5 ft
Case 2: 18-inch SDR-11 Leachate Riser Pipe	4 ft of drainage layer material + 5 ft of waste (1/2 lift) = 9 ft
Case 3: 6-inch SDR-11 Leachate Cleanout Pipe	2 ft of drainage layer material + 5 ft of waste (1/2 lift) = 7 ft

- Load coefficient C_s obtained from ASCE No. 60, Table 9-4, based on the following ratios:

Case	B_c	H	L	$\frac{B_c}{2H}$	$\frac{L}{2H}$	C_s
1	0.54	6.5	3	0.042	0.21	0.037
2	1.48	9	3	0.082	0.21	0.037
3	0.55	7	3	0.039	0.21	0.037

Calculations

Case 1: Leachate Collection Pipe

Full Loading – Final Landform Constructed (W_{FL})

AVERAGE LOAD ON LEACHATE COLLECTION PIPE - FINAL GRADE			
Layer	**Thickness, t (ft)**	**Density, γ_{sat} (pcf)**	**t x γ_{sat} (psf)**
Final Cover	3.08	129	397
Waste	380	65	24,700
Granular Drainage Material	1.5	135	202.5
TOTAL THICKNESS, H:	**385**	**SUM OF (t x γ):**	**25,300**
		(t x γ)/total thickness = AVERAGE DENSITY, w (pcf):	**65.7**

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The total weight is divided by the pipe thickness to get a load per linear unit for comparison to the value that is reported for point-source loading:

$$W_{FL} = H*w*B_c = (385\text{ ft})(65.7\text{ pcf})(0.54\text{ ft}) = 13{,}659\text{ lb/ft} = 1{,}138\text{ lb/in}$$

Point Source Loading - Concentrated Compactor Load (W_{IL})

AVERAGE LOAD ON LEACHATE COLLECTION PIPE – HALF OF INITIAL LIFT OF WASTE			
Layer	**Thickness, t (ft)**	**Density, γ_{sat} (pcf)**	**t x γ_{sat} (psf)**
Waste	5	65	325
Granular Drainage Material	1.5	135	202.5
TOTAL THICKNESS:	**6.5**	**SUM OF (t x γ):**	**527.5**
(t x γ)/total thickness = AVERAGE DENSITY, w (pcf):			81.2

$$W_c = H \times w \times B_c = (6.5)(81.2)(0.54) = 285.01\,\frac{\text{lb}}{\text{ft}} = 23.75\,\frac{\text{lb}}{\text{in}}\ \text{(half initial lift of waste)}$$

$$W_{sc} = C_s\frac{PF}{L} = (0.037)\frac{(61{,}660\text{ lb})(1.0\text{ lb})}{3\text{ ft}} = 760.47\,\frac{\text{lb}}{\text{ft}} = 63.37\,\frac{\text{lb}}{\text{in}}\ \text{(compactor load)}$$

$$W_{IL} = W_c + W_{sc} = 23.75 + 63.37 = 87.12\,\frac{\text{lb}}{\text{in}}$$

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Case 2: Leachate Riser Pipe

Full Loading – Final Landform Constructed (W_{FL})

AVERAGE LOAD ON LEACHATE RISER PIPE - FINAL GRADE			
Layer	**Thickness, t (ft)**	**Density, γ_{sat} (pcf)**	**t x γ_{sat} (psf)**
Final Cover	3.08	129	397
Waste	175	65	11,375
Granular Drainage Material	4	135	540
TOTAL THICKNESS, H:	**182**	**SUM OF (t x γ):**	**12,312**
		(t x γ)/total thickness = AVERAGE DENSITY, w (pcf):	**67.6**

The total weight is divided by the pipe thickness to get a load per linear unit for comparison to the value that is reported for point-source loading:

$$W_{FL} = H*w*B_c = (182\text{ ft})(67.6\text{ pcf})(1.48\text{ ft}) = 18{,}208\text{ lb/ft} = 1{,}517\text{ lb/in}$$

Point Source Loading - Concentrated Compactor Load (W_{IL})

AVERAGE LOAD ON LEACHATE RISER PIPE - INITIAL LIFT OF WASTE			
Layer	**Thickness, t (ft)**	**Density, γ_{sat} (pcf)**	**t x γ_{sat} (psf)**
Waste	5	65	325
Granular Drainage Layer	4	135	540
TOTAL THICKNESS:	**9**	**SUM OF (t x γ):**	**865**
		(t x γ)/total thickness = AVERAGE DENSITY, w (pcf):	**96.1**

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$$W_c = H \times w \times B_c = (9)(96.1)(1.48) = 1{,}280\,\frac{\text{lb}}{\text{ft}} = 106.7\,\frac{\text{lb}}{\text{in}}\ \text{(initial lift of waste)}$$

$$W_{sc} = C_s\frac{PF}{L} = (0.037)\frac{(61{,}660\ \text{lb})(1.0\ \text{lb})}{3\ \text{ft}} = 760.5\,\frac{\text{lb}}{\text{ft}} = 63.4\,\frac{\text{lb}}{\text{in}}\ \text{(compactor load)}$$

$$W_{IL} = W_c + W_{sc} = 106.7 + 63.4 = 170.1\,\frac{\text{lb}}{\text{in}}$$

Case 3: Leachate Cleanout Pipe

Full Loading – Final Landform Constructed (W_{FL})

AVERAGE LOAD ON LEACHATE CLEANOUT PIPE - FINAL GRADE			
Layer	**Thickness, t (ft)**	**Density, γ_{sat} (pcf)**	**t x γ_{sat} (psf)**
Final Cover	3.08	129	397
Waste	175	65	11,375
Granular Drainage Layer	2	135	270
TOTAL THICKNESS, H:	**180**	**SUM OF (t x γ):**	**12,042**
		(t x γ)/total thickness = AVERAGE DENSITY, w (pcf):	**66.9**

The total weight is divided by the pipe thickness to get a load per linear unit for comparison to the value that is reported for point-source loading:

$W_{FL} = H*w*B_c$ = (180 ft)(66.9 pcf)(0.55 ft) = 6,623 lb/ft = 551.9 lb/in

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Point Source Loading - Concentrated Compactor Load (W_{IL})

AVERAGE LOAD ON LEACHATE CLEANOUT PIPE - INITIAL LIFT OF WASTE			
Layer	**Thickness, t (ft)**	**Density, γ_{sat} (pcf)**	**t x γ_{sat} (psf)**
Waste	5	65	325
Granular Drainage Layer	2	135	270
TOTAL THICKNESS:	**7**	**SUM OF (t x γ):**	**595**
(t x γ)/total thickness = AVERAGE DENSITY, w (pcf):			**85**

$$W_c = H \times w \times B_c = (7)(85)(0.55) = 327.25\,\frac{\text{lb}}{\text{ft}} = 27.27\frac{\text{lb}}{\text{in}}\ \text{(initial lift of waste)}$$

$$W_{sc} = C_s\frac{PF}{L} = (0.037)\frac{(61{,}660\ \text{lb})(1.0\ \text{lb})}{3\ \text{ft}} = 760.47\,\frac{\text{lb}}{\text{ft}} = 63.37\frac{\text{lb}}{\text{in}}\ \text{(compactor load)}$$

$$W_{IL} = W_c + W_{sc} = 27.27 + 63.37 = 90.64\frac{\text{lb}}{\text{in}}$$

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TITLE: **LOADS ON THE LEACHATE COLLECTION SYSTEM**

Results

The maximum loads per unit length on the leachate pipes are summarized in the table below.

Case #	Load From Final Grade (W_{FL}) (lb/in)	Load From Initial Lift (W_{IL}) (lb/in)
Case 1: Leachate Collection Pipe	1,138	87.12
Case 2: Leachate Riser Pipe	1,517	170.1
Case 3: Leachate Cleanout Pipe	551.9	90.64

The full-loading scenario has been determined to provide a greater loading on the pipe than point-source loading. Therefore, all calculations will use the full loading values to analyze the pipe strength.

Case #	Load From Final Grade (psf)
Case 1: Leachate Collection Pipe	25,300
Case 2: Leachate Riser Pipe	12,312
Case 3: Leachate Cleanout Pipe	12,042

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ASCE—MANUALS AND REPORTS ON ENGINEERING PRACTICE—NO. 60

WPCF—MANUAL OF PRACTICE—NO. FD-5

Gravity Sanitary Sewer Design and Construction

AMERICAN SOCIETY of CIVIL ENGINEERS

WATER POLLUTION CONTROL FEDERATION

Table 9-3 "At-Rest" Pressure Coefficients

Soil Type (1)	"At-Rest" Coefficient (2)
Granular soils	0.5 to 0.67
Cohesive soils, medium to hard	0.67 to 0.88
Cohesive soils, soft	0.75 to 1.0

sewer pipe are automatically generated from the specified boundary conditions, the material properties, and the constitutive relationships of material behavior. Most solutions consider elastic behavior of the materials. Elasto-plastic behavior and nonlinear analysis are also available.

The arch analysis method requires specification of vertical and lateral loads. The vertical loads can be determined by the Marston method, as described in preceding sections, and distributed uniformly over the full width of the sewer pipe. Lateral loads depend on the soil type and geologic history of the soil deposit. Design parameters should be obtained from a soils consultant knowledgeable of the subsurface conditions in the area. For sewer pipe installed in tunnel or in a trench with properly compacted backfill, the recommended design lateral pressures are those corresponding to "at-rest" conditions. Where the backfill on the sides of the sanitary sewer may be loosely placed or insufficiently compacted, "active" pressure coefficients should be used to determine the lateral pressures. For preliminary analysis, the "at-rest" pressure coefficients in Table 9-3 are suggested. Since active and passive earth pressures are the result of lateral strain in the soil mass, the at-rest condition refers to the lateral pressures existing in a large soil mass not subject to horizontal forces or strains except those resulting from its own weight.

C. SUPERIMPOSED LOADS ON SANITARY SEWERS

1. General Method

Two types of superimposed loads are encountered commonly in the structural design of sanitary sewers, concentrated load and distributed load. Loads on sewer pipe caused by these loadings can be determined by application of Boussinesq's solution for stresses in a semi-infinite elastic medium through the convenience of an integration developed by D.L. Holl for concentrated loads and tables of influence coefficients developed by Newmark for distributed loads (26).

Other methods, such as that given in the AASHTO Code, can be used to determine loads on sewer pipe from superimposed loads (27). The AASHTO method is intended for use with wheel loads directly over the pipe and may not be conservative or applicable for other types of loads, such as those from adjacent building foundations. Empirical studies indicate the difficulties of accurately predicting the actual loads on the pipe. Therefore, the method presented in this text is based on the more general and theoretically correct Boussinesq equations.

In the design of buried sewer pipe systems, proper consideration of construction loads is necessary. Construction loads resulting from heavy equipment and reduced backfill heights can produce loads on the sewer pipe that exceed final design loads.

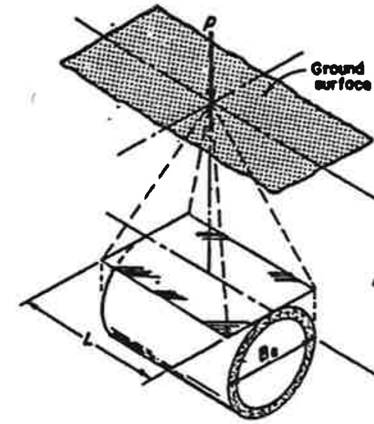

Fig. 9-14. Concentrated superimposed load vertically centered over sewer pipe.

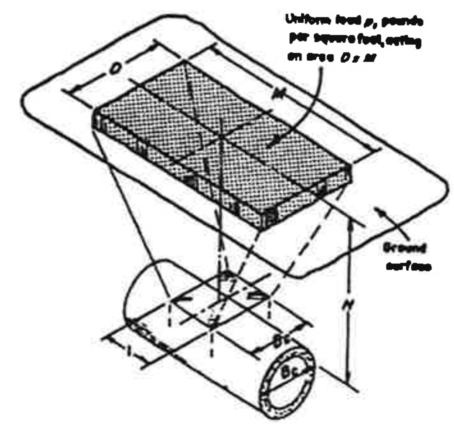

Fig. 9-15. Distributed superimposed load vertically centered over sewer pipe (psf × 47.9 = Pa).

2. Concentrated Loads

The formula for load caused by a superimposed concentrated load, such as a truck wheel (Fig. 9-14), is given the following form by D.L. Holl's integration of Boussinesq's formula:

$$\boxed{W_{sc} = C_s \frac{PF}{L}} \qquad (9.13)$$

in which W_{sc} is the load on the sewer pipe, in newtons per unit length (pounds per unit length); P is the concentrated load, in newtons (pounds); F is the impact factor; C_s is the load coefficient (Table 9-4), a function of $B_c/(2H)$ and $L/(2H)$; H is the height of fill from the top of sewer pipe to ground surface, in meters (feet); B_c is the width of sewer pipe, meters (feet); and L is the effective length of sewer pipe, in meters (feet).

The effective length of a sewer pipe is defined as the length over which the average load caused by surface traffic wheels produces nearly the same stress in the sewer pipe wall as does the actual load which varies in intensity from point to point. Little research information is available on this subject. Tentative recommendations are to use an effective length equal to 1.0 m (3 ft) for sewer pipe greater than 1.0 m (3 ft) long. The actual length should be used for sewer pipe shorter than 1.0 m (3 ft).

If the concentrated load is displaced laterally and longitudinally from a vertically centered location over the section of sewer pipe under construction, the load on the pipe can be computed by adding algebraically the effect of the concentrated load on various rectangles each with a corner centered under the concentrated load. Values of C_s in Table 9-4 divided by 4 equal the load coefficient for a rectangle whose corner is vertically centered under the concentrated load.

3. Impact Factor

le 9-4 Values of Load Coefficients, C_s, for Concentrated and Distributed Superimposed Loads Vertically Centered over Sewer Pipe*

$\frac{D}{2H}$ or $\frac{B_c}{2H}$ (1)	$\frac{M}{2H}$ or $\frac{L}{2H}$: 0.1 (2)	0.2 (3)	0.3 (4)	0.4 (5)	0.5 (6)	0.6 (7)	0.7 (8)	0.8 (9)	0.9 (10)	1.0 (11)	1.2 (12)	1.5 (13)	2.0 (14)	5.0 (15)
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

*nfluence coefficients for solution of Holl's and Newmark's integration of the Boussinesq equation for vertical stress.

Table 9-5 Suggested Values of Impact Factor, F

Traffic Type (1)	F (2)
Highway	1.30
Railway	1.40
Airfield runways (for taxiways, consult FAA)	1.00

traffic at the ground surface. Suggested values for various kinds of traffic are shown in Table 9-5.

The impact effect decreases with increasing cover. The AASHTO (highway) Code (27) recommends a reduction to 1.00 where depth of cover exceeds 1 m (3 ft) or the pipe outside diameter, whichever is larger. The AREA (railway) Code (30) recommends 10 ft (3 m) of cover for the elimination of impact effect. In design of airfield pavements, it is customary not to design for impact on runways because of the counterbalancing effect of the lift provided by aircraft wings. Similarly, for taxiways the slower speed reduces the lift, but it also is considered to reduce impact to a negligible amount in most cases. Since airfield pavement design involves empirical procedures, the design engineer should exercise judgment as to the amount of impact to be included in the design of buried sewer pipes. Common practice is to use an impact factor of 1.0 for runways and 1.5 for taxiways, aprons, hardstands, and run-up pads.

4. Distributed Loads

For the case of a superimposed load distributed over an area of considerable extent (Fig. 9-15), the formula for load on the sewer pipe is:

$$W_{sd} = C_s p F B_c \qquad (9.14)$$

in which W_{sd} is the load on the sewer pipe, in newtons per unit length (pounds per unit length); p is the intensity of distributed load, in pascals (pounds per square foot); F is the impact factor; B_c is the width of the sewer pipe, in meters (feet); C_s is the load coefficient, a function of $D/(2H)$ and $(M/2H)$ from Table 9-4; H is the height from the top of the sewer pipe to the ground surface, in meters (feet); and D and M are the width and length, respectively, of the area over which the distributed load acts, in meters (feet).

For the case of a uniform load offset from the center of the sewer pipe, the loads per unit length of the sewer pipe may be determined by a combination of rectangles. For determination of the stress below a point such as A in Fig. 9-16, as a result of the loading in the rectangle BCDE, the area may be considered to consist of four rectangles: AJDF−AJCG−AHEF+AHBG. Each of these four rectangles has a corner at point A. By computing $D/2H$ and $M/2H$ for each rectangle, the load coefficient for each rectangle can be taken from Table 9-4. Since point A is at the corner of each rectangle, the load coefficients from Table 9-4 should be divided by 4. A combination of the stresses from the four rectangles, with signs as indicated above, gives the desired stress.

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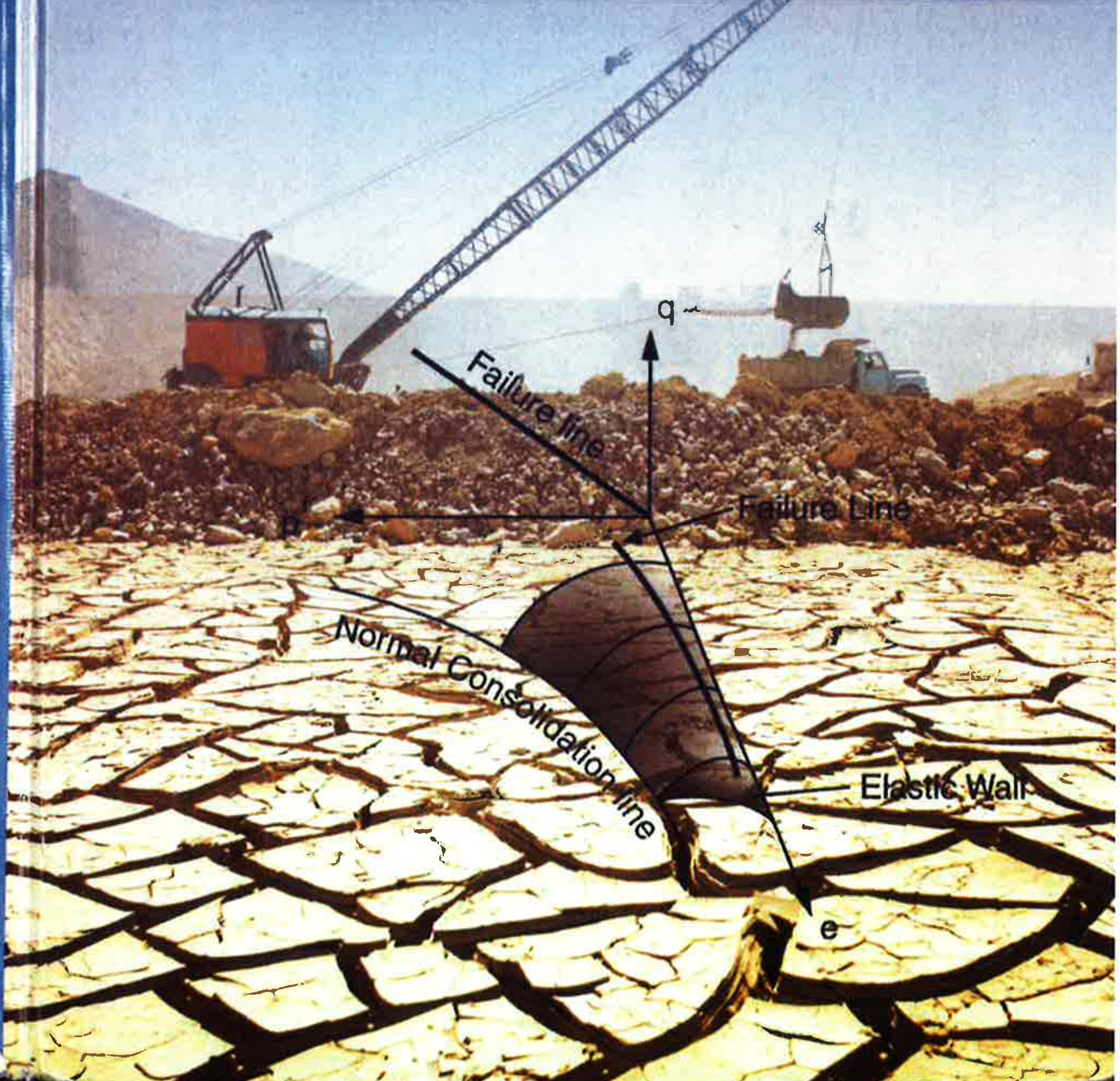
MUNI BUDHU

Soil Mechanics & Foundations



APPENDIX A

A COLLECTION OF FREQUENTLY USED SOIL PARAMETERS AND CORRELATIONS

TABLE A.1 Typical Values of Unit Weight for Soils

Soil type	γ_{sat} (kN/m³)	γ_d (kN/m³)
Gravel	(127-137) 20–22	(95-107)(lb/ft³) 15–17
Sand	18–20	13–16
Silt	18–20	14–18
Clay	16–22	14–21

TABLE A.2 Description Based on Relative Density

D_r (%)	Description
0–15	Very loose
15–35	Loose
35–65	Medium dense
65–85	Dense
85–100	Very dense

TABLE A.3 Soil Types, Description, and Average Grain Size According to USCS

Soil type	Description	Average grain size
Gravel	Rounded and/or angular bulky hard rock	Coarse: 75 mm to 19 m Fine: 19 mm to 4 mm
Sand	Rounded and/or angular bulky hard rock	Coarse: 4 mm to 1.7 m Medium: 1.7 mm to 0.380 Fine: 0.380 mm to 0.075
Silt	Particles smaller than 0.075 mm exhibit little or no strength when dried	0.075 mm to 0.002 mm
Clay	Particles smaller than 0.002 mm exhibit significant strength when dried; water reduces strength	<0.002 mm

Technically Complete, March 11, 2016

Sclairpipe

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KWH PIPE

Printed in Canada 02/12

		DR13.5 (160 psi)			DR11 (200 psi)			DR9 (250 psi)			DR7.3 (317 psi)		
Nominal Pipe Size	Average Outside Diameter (inches)	Average Inside Diameter (inch)	Minimum Wall Thickness (inch)	Average Weight (lbs/ft)	Average Inside Diameter (inch)	Minimum Wall Thickness (inch)	Average Weight (lbs/ft)	Average Inside Diameter (inch)	Minimum Wall Thickness (inch)	Average Weight (lbs/ft)	Average Inside Diameter (inch)	Minimum Wall Thickness (inch)	Average Weight (lbs/ft)
3	3.50	2.950	0.259	1.16	2.825	0.318	1.39	2.676	0.389	1.66	2.484	0.479	1.99
4	4.50	3.793	0.333	1.92	3.633	0.409	2.31	3.440	0.500	2.75	3.193	0.616	3.29
5	5.56	4.689	0.412	2.93	4.490	0.506	3.52	4.252	0.618	4.20	3.947	0.762	5.02
6	6.63	5.585	0.491	4.15	5.348	0.602	5.00	5.064	0.736	5.96	4.701	0.908	7.12
7	7.13	6.010	0.520	4.80	5.756	0.640	5.78	5.450	0.792	6.90	5.059	0.977	8.24
8	8.63	7.271	0.639	7.04	6.963	0.784	8.47	6.593	0.958	10.11	6.120	1.182	12.07
10	10.75	9.062	0.796	10.93	8.678	0.977	13.16	8.218	1.194	15.70	7.628	1.473	18.75
12	12.75	10.748	0.944	15.38	10.293	1.159	18.51	9.747	1.417	22.08	9.047	1.747	26.38
13	13.38	11.275	0.991	16.92	10.797	1.216	20.37	10.224	1.486	24.30	9.491	1.832	29.03
14	14.00	11.801	1.037	18.54	11.302	1.273	22.31	10.702	1.556	26.63	9.934	1.918	31.81
16	16.00	13.487	1.185	24.22	12.916	1.455	29.15	12.231	1.778	34.78	11.353	2.192	41.54
18	18.00	15.173	1.333	30.65	14.531	1.636	36.89	13.760	2.000	44.02	12.773	2.466	52.58
20	20.00	16.859	1.481	37.84	16.145	1.818	45.54	15.289	2.222	54.34	14.192	2.740	64.91
22	22.00	18.545	1.630	45.78	17.760	2.000	55.10	16.818	2.444	65.75	15.611	3.014	78.54
24	24.00	20.231	1.778	54.49	19.375	2.182	65.58	18.347	2.667	78.25	17.030	3.288	93.47
26	26.00	21.917	1.926	63.95	20.989	2.364	76.96	19.876	2.889	91.84			
28	28.00	23.603	2.074	74.16	22.604	2.545	89.26	21.404	3.111	106.51			
30	30.00	25.289	2.222	85.14	24.218	2.727	102.46	22.933	3.333	122.27			
32(M)	31.59	26.629	2.340	94.41	25.502	2.872	113.62						
32	32.00	26.975	2.370	96.87	25.833	2.909	116.58						
36	36.00	30.347	2.667	122.60									
40(M)	39.47												
42	42.00												
48(M)	47.38												
48	48.00												
54	54.00												
55(M)	55.30												
63(M)	63.21												

Innovative joining methods and equipment

Sclairpipe piping systems can be assembled by heat fusion (butt, electrofusion, socket and saddle fusion), flanged connections, compression couplings and various mechanical couplings. The superior performance of Sclairpipe results from the combination of pipe and fittings designed to work together as a complete system. A full range of pressure rated fittings is available to suit any application.

The most popular method of joining Sclairpipe is thermal butt fusion. This fast and economical technique permits the quick assembly of long continuous lengths and the joining of fittings to the pipe. The fused joints are as reliable and strong as the pipe itself, fully restrained, providing continuous leak proof systems.

Technically Complete, March 11, 2016

Caterpillar Performance Handbook

44

CATERPILLAR®

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CATERPILLAR PERFORMANCE HANDBOOK

a publication by Caterpillar, Peoria, Illinois, U.S.A.

JANUARY 2014

Please direct any inquiries about the Performance Handbook to the Caterpillar Performance Handbook Coordinator at *Sherman_Ashley_E@cat.com*.

Performance information in this booklet is intended for estimating purposes only. Because of the many variables peculiar to individual jobs (including material characteristics, operator efficiency, underfoot conditions, altitude, etc.), neither Caterpillar nor its dealers warrant that the machines described will perform as estimated.

NOTE: Always refer to the appropriate Operation and Maintenance Manual for specific product information.

Materials and specifications are subject to change without notice.

Printed in U.S.A. SEBD0351-44

MODEL	816F2		826K		836K	
Gross Power	189 kW	253 hp	320 kW	430 hp	419 kW	562 hp
Operating Weight*	23 744 kg	52,364 lb	40 666 kg	89,653 lb	55 927 kg	$\boxed{123,319 \text{ lb}}$
Engine Model	C9 ACERT		C15 ACERT		C18 ACERT	
Rated Engine RPM	2100		1800		1800	
No. Cylinders	6		6		6	
Displacement	8.8 L	537 in³	15.2 L	928 in³	18.1 L	1105 in³
Speeds:						
Forward	2		2		2	
Reverse	2		2		2	
Turning Radius with Straight Blade						
Inside Wheels	3.5 m	11'6"	2.8 m	9'2"	3.6 m	11'11"
Outside Blade Corner	6.5 m	21'2"	7.23 m	23'9"	8.8 m	28'11"
Fuel Tank Refill Capacity	464 L	122.6 U.S. gal	782 L	206.6 U.S. gal	793 L	209 U.S. gal
DEF Tank Refill Capacity	—		32.8 L	9.0 U.S. gal	32.8 L	9.0 U.S. gal
WHEELS:	PLUS TIP		PLUS TIP		PLUS TIP	
Each Drum Width	1.02 m	3'4"	1.2 m	3'11"	1.4 m	4'7"
Diameters, over Tips	1.7 m	5'10"	1.97 m	6'6"	2125 mm	7'0"
Drum only	1.3 m	4'3"	1.61 m	5'3"	1.77 m	5'10"
Tips per Wheel	20		30		40	
Tip Height	158 mm	6.5"	178 mm	7"	178 mm	7"
Chopper Blades per Wheel	20		24		28	
Blade Height	152 mm	6"	158 mm	6"	158 mm	6"
Width of Two Pass Coverage	4.5 m	14'9"	4.78 m	15'8"	5.67 m	18'7"
GENERAL DIMENSIONS:						
Height (Overall)	3.8 m	12'8"	4.76 m	15'7"	4.85 m	15'11"
Height (Top of Cab)	3.4 m	11'3"	4.19 m	13'9"	4.3 m	14'1"
Wheel Base	3.35 m	11'0"	3.7 m	12'2"	4.55 m	14'11"
Overall Length with Dozer	7.85 m	25'7"	8.27 m	27'2"	10.18 m	33'5"
Width over Drums	3.33 m	10'11"	3.8 m	12'8"	4.18 m	14'1"
Ground Clearance	456 mm	1'5"	645 mm	2'1"	632 mm	2'1"
STRAIGHT BLADE:						
Width	3.65 m	12'0"	4.5 m	14'9"	5.19 m	17'0"
Height**	1.91 m	6'3"	1.91 m	6'3"	2.24 m	7'4"

/2axles= 61,660lb

*Operating Weight includes coolant, full hydraulics, full fuel tank, all heaviest options and 82 kg (180 lb) operator.
**Height (stripped top) — without ROPS cab, exhaust, seat back or other easily removed encumbrances.

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 2: RING DEFLECTION OF LEACHATE PIPE (III-D.6-A.2)

3-2-2015

STATE OF TEXAS
MICHAEL W. ODEN
67165
REGISTERED
PROFESSIONAL ENGINEER

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CB&I

Client:	Rancho Viejo Waste Management, LLC		
Project:	Pescadito Environmental Resource Center		
Project #:	148866		
Calculated By:	LJC	Date:	1/27/15
Checked By:	RDS	Date:	2/6/15

TITLE: RING DEFLECTION OF LEACHATE PIPES

Problem Statement

Determine the ring deflection of the leachate collection pipe, leachate riser pipe, and leachate cleanout pipe.

Given

- WL Plastics Corp. (2005). *WLPipeCalc V2.0 Supplement*.
- Loads on the Leachate Collection System calculation (III-D.6-A.1).
- Leachate design details, Appendix III-D.3.
- Geotechnical Analysis Report, Appendix III-D.5.

Assumptions

- Pipe deflection may be determined with a variation of the Modified Iowa formula shown below (reference Equation 30 from WL Plastics WL PipeCalc™ Supplement):

$$\text{Percent Deflection} = \frac{PT}{144}\left(\frac{K \times D_L}{\frac{2E}{3}\left(\frac{1}{DR-1}\right)^3 + 0.061E'}\right) \times 100\%$$

Where:
P_T = total load pressure at pipe crown (lb/ft^2)
K = bedding factor
D_L = deflection lag factor
E' = modulus of soil reaction (psi)
E = modulus of elasticity for the pipe (psi)
DR = SDR = standard dimension ratio

- The following pipes to be analyzed:
  - Case 1: 6-inch SDR-7.3 Leachate Collection Pipe
  - Case 2: 18-inch SDR-11 Leachate Riser Pipe On Side-Wall
  - Case 3: 6-inch SDR-11 Leachate Cleanout Pipe On Side-Wall

Client:	Rancho Viejo Waste Management, LLC
Project:	Pescadito Environmental Resource Center
Project #:	148866
Calculated By:	LJC — Date: 1/27/15
Checked By:	RDS — Date: 2/6/15

TITLE: RING DEFLECTION OF LEACHATE PIPES

- It is noted that deflection is a function of standard dimensional ratio (SDR) and is independent of pipe diameter.
- D_L = 1.0 (see WL Plastics WL PipeCalc™ Supplement)
- P_T varies depending on the pipe being considered:
  - P_T = 25,300 psf for final conditions overlying the leachate collection pipe (see Loads on the Leachate Collection System calculation)
  - P_T = 12,312 psf for final conditions overlying the leachate riser pipe (see Loads on the Leachate Collection System calculation)
  - P_T = 12,042 psf for final conditions overlying the leachate cleanout pipe (see Loads on the Leachate Collection System calculation)
- K = 0.1 (reference WL Plastics WL PipeCalc™ Supplement)
- E' = 3,000 psi for leachate chimney, riser pipe, and leachate cleanout pipe (reference WL Plastics WL PipeCalc™ Supplement)
- E = 15,000 psi (reference WL Plastics WL PipeCalc™ Supplement)
- The WL Plastics WL PipeCalc™ Supplement, which states that long-term deflection is typically limited to 8% for non-pressure PE3408 pipes.

Calculation

The maximum pipe deflection is incurred with the maximum loading on the pipe. Maximum loading occurs when the landfill is fully constructed and final grades are achieved.

Calculations were conducted for all cases using the following formula:

$$\text{Percent Deflection} = \frac{P_T}{144}\left(\frac{K \times D_L}{\frac{2E}{3}\left(\frac{1}{DR\text{-}1}\right)^3 + 0.061E'}\right) \times 100\%$$

Client:	Rancho Viejo Waste Management, LLC
Project:	Pescadito Environmental Resource Center
Project #:	148866
Calculated By:	LJC	Date: 1/27/15
Checked By:	RDS	Date: 2/6/15

TITLE: RING DEFLECTION OF LEACHATE PIPES

Case 1: Leachate Collection Pipe

6-inch, SDR-7.3 Pipe:

$$\text{Percent Deflection} = \frac{25{,}300}{144}\left(\frac{(0.1)(1.0)}{\frac{(2)(15{,}000)}{3}\left(\frac{1}{7.3\text{-}1}\right)^3 + (0.061)(3{,}000)}\right)\times 100\% = 7.88\%$$

Case 2: Leachate Riser Pipe

18-inch, SDR-11 Pipe:

$$\text{Percent Deflection} = \frac{12{,}312}{144}\left(\frac{(0.1)(1.0)}{\frac{(2)(15{,}000)}{3}\left(\frac{1}{11\text{-}1}\right)^3 + (0.061)(3{,}000)}\right)\times 100\% = 4.43\%$$

Case 3: Leachate Cleanout Pipe

6-inch, SDR-11 Pipe:

$$\text{Percent Deflection} = \frac{12{,}042}{144}\left(\frac{(0.1)(1.0)}{\frac{(2)(15{,}000)}{3}\left(\frac{1}{11\text{-}1}\right)^3 + (0.061)(3{,}000)}\right)\times 100\% = 4.33\%$$

Results

The calculated ring deflections represent the worst-case loading conditions at the landfill. The calculated maximum percent ring deflection is 7.88% for the SDR-7.3 pipe in the leachate chimney, 4.43% for the leachate riser pipe, and 4.33% for the leachate cleanout pipe. The ring deflections for each of the cases are less than 8.0%. Therefore, the maximum deflection of the pipes is acceptable.

WLPipeCalc™ V2.0 Supplement

WL PLASTICS

WLPipeCalc™ V2.0 Supplement – Equations & Information

Contents

Notice

The WLPipeCalc™ CD-ROM and this supplement are intended for use as piping system guides. These publications should not be used in place of a professional engineer's judgment or advice and they are not intended as installation instructions. The information in or generated by the WLPipeCalc™ CD-ROM and this supplement does not constitute a guarantee or warranty for piping installations and cannot be guaranteed because the conditions of use are beyond our control. The user of the information assumes all risk associated with its use. WL Plastics Corporation has made every reasonable effort to ensure accuracy, but the information in or generated by the WLPipeCalc™ CD-ROM and this supplement may not be complete, especially for special or unusual applications. Changes to the WLPipeCalc™ CD-ROM and this supplement may occur from time to time without notice. Contact WL Plastics Corporation to determine if you have the most current edition.

The WLPipeCalc™ CD-ROM allows the user to enter values for variables and determine a result using the equations in the CD-ROM publication. This publication, WL120, provides equations used for WLPipeCalc™ CD-ROM calculation screens, and related information.

Other equations and methods for determining piping system design may be applicable. As part of piping system design, the user should determine the design equations and methods that are appropriate for the intended use.

1 – Pipe Pressure Rating

See publications WL102, WL104 and WL118, and "Working Pressure Rating for Water" for additional information.

$$PR = \frac{2HDB f_T f_E}{(DR-1)} \qquad (1)$$

Where

PR	=	pressure rating, psi.
HDB	=	hydrostatic design basis at 73°F (Table 1)
f_T	=	operating temperature multiplier (Table 2)
f_E	=	environmental design factor (table 3)
DR	=	pipe dimension ratio

$$DR = \frac{D}{t} \qquad (2)$$

D	=	pipe outside diameter, in (WL102; WL104)
t	=	pipe minimum wall thickness, in

Table 1 HDB – WL Plastics PE3408 HDPE

	HDB at 73°F	*HDB at 140°F*
WL Plastics PE3408	1600 psi	800 psi

Table 2 Operating Temperature Multiplier, f_T

Maximum Operating Temperature °F	°C	*Multiplier, f_T*
≤ 40*	≤ 4	1.3
$> 40 \leq 60$*	$> 4 \leq 16$	1.1
$> 60 \leq 80$	$> 16 \leq 27$	1.0
$> 80 \leq 90$	$> 27 \leq 32$	0.9
$> 90 \leq 100$	$> 32 \leq 38$	0.8
$> 100 \leq 110$	$> 38 \leq 43$	0.71
$> 110 \leq 120$	$> 43 \leq 49$	0.64
$> 120 \leq 130$	$> 49 \leq 54$	0.57
$> 130 \leq 140$	$> 54 \leq 60$	0.50

* For water distribution and transmission applications, multipliers for 60°F (16°C) and lower temperatures are not used.

Table 3 Environmental Design Factor, f_E

Factor, f_E	*Environmental and Applications Conditions*
0.50*	Liquids that are chemically benign to polyethylene such as potable and process water, municipal sewage, wastewater, reclaimed water, salt water, brine solutions, glycol/antifreeze solutions, alcohol; Buried pipes for gases that are chemically benign to polyethylene such as dry natural gas (in Class 1 or 2 locations where Federal Regulations (49 CFR Part 192) do not limit pressure), methane, propane, butane, carbon dioxide, hydrogen sulfide.
0.32	Buried pipes for compressed air at ambient temperature; Buried pipes for fuel gases such as natural gas, LP gas, propane, butane in distribution systems and Class 3 or 4 locations where Federal Regulations limit pipe pressure to the lesser of 100 psi or the design pressure rating.
0.25	Permeating or solvating liquids in the pipe or the surrounding soil such as gasoline, fuel oil, kerosene, crude oil, diesel fuel, liquid hydrocarbon fuels, vegetable and mineral oils.

* The maximum design factor, 0.50, is a cumulative factor based on variability in materials, testing and processing, handling and installation abuse, and variability in operating conditions. It is widely accepted for thermoplastic pressure pipe design in North America.

2 – Hazen-Williams Pressure Water Flow

Hazen and Williams developed an empirical formula for friction (head) loss for water flow at 60° F that can be applied to liquids having a kinematic viscosity of 1.130 centistokes (0.00001211 ft²/sec), or 31.5 SSU. Some error can occur at other temperatures because the viscosity of water varies with temperature,

Hazen-Williams formula for friction (head) loss in feet:

$$h_f = \frac{0.002083\,L}{d^{4.8655}}\left(\frac{100\,Q}{C}\right)^{1.85} \qquad (3)$$

Hazen-Williams formula for friction (head) loss in psi:

$$p_f = \frac{0.0009015\,L}{d^{4.8655}}\left(\frac{100\,Q}{C}\right)^{1.85} \qquad (4)$$

Where

- h_f = friction (head) loss, ft
- L = pipe length, ft
- Q = flow, gal/min
- d = pipe inside diameter, in (WL102; WL104)
- C = Hazen-Williams Friction Factor, dimensionless
- p_f = friction (head) loss, lb/in²

Table 4 Hazen-Williams Friction Factor, C

Pipe Material	*Values for C* *Range High / Low*	*Average Value*	*Typical Design Value*
Butt fused polyethylene pipe with internal beads	160 / 130	155	150
Cement or mastic lined iron or steel pipe	160 / 130	148	140
Copper, brass, lead, tin or glass pipe or tubing	150 / 120	140	130
Wood stave	145 / 110	120	110
Welded and seamless steel	150 / 80	130	100
Cast and ductile iron	150 / 80	130	100
Concrete	152 / 85	120	100
Corrugated steel	–	60	60

Full Pipe Flow Velocity

Water flow velocity in a full, circular pipe:

$$V = 0.40853\frac{Q}{d^2} \qquad (5)$$

Where

- V = water flow velocity, ft/sec
- Q = flow, gal/min
- d = pipe inside diameter, in (WL102; WL104)

3 – Manning Gravity Water Flow

The Manning equation is limited to water or liquids with a kinematic viscosity equal to water. A derived version of the Manning equation for circular pipes flowing full or half full is:

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$$Q = 0.275\frac{d^{8/3}\,S^{1/2}}{n} \quad (6)$$

or

$$Q_{CFS} = \left(6.136\times10^{-4}\right)\frac{d^{8/3}\,S^{1/2}}{n} \quad (7)$$

Where

- Q = flow, gal/min
- Q_{CFS} = flow, ft^3/sec
- d = pipe inside diameter, in (WL102; WL104)
- S = hydraulic slope, ft/ft

$$S = \frac{h_1 - h_2}{L} \quad (8)$$

- h_1 = upstream pipe elevation, ft
- h_2 = downstream pipe elevation, ft
- n = roughness coefficient, dimensionless

Table 5 Manning Equation n Values

Surface	*n, range*	*n, typical design*
Polyethylene pipe	0.008 – 0.011	$\boxed{0.009}$
Uncoated cast or ductile iron pipe	0.012 – 0.015	0.013
Corrugated steel pipe	0.021 – 0.030	0.024
Concrete pipe	0.012 – 0.016	0.015
Vitrified clay pipe	0.011 – 0.017	0.013
Brick and cement mortar sewers	0.012 – 0.017	0.015
Wood stave	0.010 – 0.013	0.011
Rubble masonry	0.017 – 0.030	0.021

Circular pipes will carry more liquid when slightly less than full compared to completely full because there is a slight reduction in flow area compared to a significant reduction in the wetted surface of the pipe. Maximum flow occurs at about 93% of full pipe flow, and maximum velocity at about 78% of full pipe flow.

4 – Low Pressure Gas Flow

Caution – To minimize the risk of mechanical damage, pressure gas piping is buried, installed at heights and in areas where moving equipment cannot contact or damage piping, and encased in shatter resistant materials. Pressure gas piping is restrained to prevent movement in case of mechanical damage.

Where inlet and outlet gas pressures are less than 1 psig (27.7 in H_2O) the Mueller low pressure gas flow equation may be used.

$$Q_h = \frac{2971 d^{2.725}}{S_g^{\;0.425}}\left(\frac{h_1 - h_2}{L}\right)^{0.575} \quad (9)$$

Where

- S_g = gas specific gravity (Table 6)
- h_1 = inlet pressure, in H_2O
- h_2 = outlet pressure, in H_2O
- L = pipe length, ft
- d = pipe inside diameter, in (WL102; WL104)

Table 6 Approximate Specific Gravity (14.7 psi & 68°F)

Gas	*Specific Gravity, S_g*
Acetylene (ethylene), C_2H_2	0.907
Air	1.000
Ammonia, NH_3	0.596
Argon, A	1.379
Butane, C_4H_{10}	2.067
Carbon Dioxide, CO_2	1.529
Carbon Monoxide, CO	0.967
Ethane, C_2H_6	1.049
Ethylene, C_2H_4	0.975
Helium, He	0.138
Hydrogen Chloride, HCl	1.286
Hydrogen, H	0.070
Hydrogen Sulfide, H_2S	1.190
Methane, CH_4	0.554
Methyl Chloride, CH_3Cl	1.785
Natural Gas	0.667
Nitric Oxide, NO	1.037
Nitrogen, N_2	0.967
Nitrous Oxide, N_2O	1.530
Oxygen, O_2	1.105
Propane, C_3H_8	1.562
Propene (Propylene), C_3H_6	1.451
Sulfur Dioxide, SO_2	2.264
Landfill Gas (approx. value)	1.00
Carbureted Water Gas	0.63
Coal Gas	0.42
Coke-Oven Gas	0.44
Refinery Oil Gas	0.99
"Wet" Gas (approximate value)	0.75

5 – Working Pressure Rating for Water

Working Pressure Rating (WPR) for water at ≤ 80°F (≤ 27°C) has application pressure components for steady long-term internal pressure and momentary surge pressure from sudden water velocity change. WPR application pressure components are compared to pipe capabilities, pressure class, PC, which includes allowances for recurring or occasional surge, P_{RS} or P_{OS}.

The pipe's capacity for internal water pressure at ≤ 80°F is its pressure class, PC. PC includes components for long-term steady pressure and momentary pressure surge.

$$PC_S = \frac{2HDBf_E}{(DR-1)} \qquad (10)$$

Where

PC_S = Steady pressure for water at ≤ 80°F, psi
HDB = hydrostatic design basis, psi
= 1600 psi
f_E = environmental design factor for water
= 0.50
DR = pipe dimension ratio

The pipe's allowance for momentary surge pressure is for either recurring or occasional surge pressure, and it is applied above the steady pressure. Recurring surge pressures occur frequently and are inherent in system design and operation. The recurring surge pressure allowance is:

$$P_{RS} = 0.5PC \qquad (11)$$

Where

P_{RS} = Recurring surge pressure allowance, psi

Occasional surge pressures are caused by emergency operations. The occasional surge pressure allowance is:

$$P_{OS} = 1.0PC \qquad (12)$$

Where

P_{OS} = Occasional surge pressure allowance, psi

The maximum pressure in the pipe depends on the operating condition. For steady pressure conditions, the surge allowance is not used. For a momentary surge event, the maximum pressure is the steady pressure plus the applicable surge allowance.

For steady pressure conditions:

$$PC = PC_S \qquad (13)$$

For a momentary recurring surge event:

$$PC = PC_S + P_{RS} \qquad (14)$$

For a momentary occasional surge event:

$$PC = PC_S + P_{OS} \qquad (15)$$

Application requirements are determined using working pressure rating, WPR, which has steady pressure and surge pressure components. The steady internal water pressure component, working pressure, WP, is determined by the designer, who also determines if the potential for surge pressure is recurring or occasional.

Surge pressure magnitude is dependent on sudden velocity change.

$$P_S = a\left(\frac{\Delta v}{2.31g}\right) \qquad (16)$$

Where

P_S = Surge pressure, psi
a = Surge pressure wave velocity (celerity), ft/sec

$$a = \frac{4660}{\sqrt{1+\frac{K}{E_d}(DR-2)}} \qquad (17)$$

K = bulk modulus of water, psi
= 300,000 psi
E_d = Dynamic instantaneous effective modulus of pipe material, psi
= 150,000 psi
DR = Pipe dimension ratio
Δv = Sudden velocity change*, ft/sec
g = gravitational acceleration, ft/sec^2
= 32.2 ft/sec^2

* Pressure surge does not occur unless the sudden velocity change occurs within the Critical Time

$$\text{Critical Time, sec} = \frac{2L}{a} \qquad (18)$$

Where

L = Pipe length, ft

WLPipeCalc assumes Δv occurs within the Critical Time, but does not calculate Critical Time.

WLPipeCalc calculates celerity within the surge pressure calculation, but not as a separate value.

WLPipeCalc determines the sustained pressure and surge pressure components of WPR separately using the following relationships.

During steady pressure operation, WP never exceeds WPR and never exceeds PC_S for steady pressure conditions (Equation 13).

$$WP \le WPR \le PC_S \qquad (19)$$

During a momentary surge event, the maximum pressure in the pipe, WPR, never exceeds PC plus the applicable surge allowance (Equations 14 or 15).

$$WP + P_s \le WPR \le PC_S + P_{RS} \qquad (20)$$

or

$$WP + P_S \le WPR \le PC_S + P_{OS} \qquad (21)$$

If the potential for surge pressure, P_S, exceeds the surge pressure allowance, P_{OS} or P_{RS}, allowable steady pressure, WP is reduced and the difference allocated to surge pressure so that Equations 19, 20 and 21 are maintained. Surge pressure allowance is never applied to steady pressure.

WLPipeCalc determines WPR in terms of its steady pressure and surge pressure components. A negative steady pressure value indicates an unsuitable application.

6 – Buried Polyethylene Pipe

For typical burial cover depths of 1½ pipe diameters (minimum 4 ft (1.9 m)) to approximately 50 ft (23.6 m), static earthloads and surface live loads on buried (constrained) pipe can result in pipe wall crushing, pipe wall buckling, and pipe deflection. Static (prism) loads and live loads are compared to the pipe's resistance properties. Safety factors against compressive crushing and wall buckling are calculated. Deflection is controlled by installation quality and embedment material quality. Long-term and short-term percent deflections are calculated for comparison to industry standard deflection criteria.

Prism Load Static Soil Pressure:

$$P_E = w\,H \qquad (22)$$

Where

P_E = soil pressure at pipe crown, lb/ft²
w = soil density, lb/ft³
H = height of soil above pipe crown, ft

Table 7 Densities of Typical Soils

Type of Soil	*Dry Density, lb/ft³*	*Saturated Density, lb.ft³*
Organic silts, clays	31-94	81-112
Crushed rock	94-125	119-137
Glacial tills	106-144	131-150
Silts; clays	37-112	87-131
Sands; gravels	93-114	118-150

Saturated soil has greater density because of the liquid it contains; however, the effective unit weight of flooded soil is reduced by groundwater floatation of soil particles. If appropriate, soil density should be adjusted to compensate for flooding conditions.

Live Load Pressure:.

Live load pressure results from intermittently applied loads on the surface such as from various kinds of traffic. Live loads may be applied directly to the surface or through rigid pavement. AISI H20 and HS20 truck and semi-trailer truck live loads simulate a 20-ton truck through 12-in thick rigid pavement and include a 1.5 impact factor.

Table 8 H20 & HS20 Highway Live Load

Height Above Pipe Crown, ft	*Live Load, lb/ft²*
1	1800
2	800
3	600
4	400
5	250
6	200
7	175
8	100

Live load pressure without pavement, such as for heavy off-highway vehicles on unpaved surfaces, are determined using the Boussinesq method.

$$P_L = 1.5\frac{I_I\, W_L\, H^3}{\pi\left(X^2 + H^2\right)^{2.5}} \qquad (23)$$

Where

P_L = live load pressure at pipe crown, lb/ft²
I_I = impact factor (2.0 through 4.5 or higher)
W_L = wheel load, lb
H = vertical distance from pipe crown to wheel load application surface, ft
X = horizontal distance from center of pipe crown to center of wheel load, ft

Railroad live loads are typically described using AISI Cooper E80 values which are applied as three, 80,000 lb loads over three, 2ft x 8 ft areas spaced 5 ft apart.

Table 9 E80 Cooper Railroad Live Loading

Height Above Pipe Crown, ft	*Live Load, lb/ft²*
2	3800
5	2400
8	1600
10	1100
12	800
15	600
20	300
30	100

Live loads may be determined using other appropriate methods.

__Total Load Pressure:__

$$P_T = P_E + P_L \tag{24}$$

Where

P_T = total load pressure at pipe crown, lb/ft²

__Wall Crushing Resistance:__

$$N_C = \frac{460800}{P_T\,DR} \tag{25}$$

Where

N_C = safety factor against wall crushing

__Wall Buckling Resistance__

$$N_B = \frac{144\,P_{WC}}{P_T} \tag{26}$$

Where

N_B = safety factor against wall buckling

$$P_{WC} = 5.65\sqrt{\frac{R\,B'\,E'\,E}{12(DR-1)^3}} \tag{27}$$

Where

P_{WC} = constrained buckling pressure, psi
R = reduction factor for buoyancy

$$R = 1 - 0.33\frac{H'}{H} \tag{28}$$

H' = height of groundwater above pipe, ft
H = soil cover above pipe, ft
B' = elastic support factor

$$B' = \frac{1}{1 + 10.87312^{(-0.065H)}} \tag{29}$$

E' = modulus of soil reaction, psi (Table 10)
E = modulus of elasticity, psi (Table 17)
= 28,200 psi for long-term at 73°F
= 110,000 psi for short-term at 73°F

Table 10 Modulus of Soil Reaction, E'

Degree of Bedding Compaction,	*Soil Type Pipe Bedding Material (Unified Classification System[a])* A	B	C	D	E
	Average Value for E', psi (MPa)				
Dumped	1000 (6.89)	200 (1.38)	100 (0.69)	50 (0.34)	
Slight, <85% Proctor, 40% Relative Density	3000 (20.68)	1000 (6.89)	400 (2.76)	200 (1.38)	No data available; consult a competent soils engineer; otherwise use E'= 0
Moderate, 85-95% Proctor, 40-70% Relative Density	3000 (20.68)	2000 (13.79)	1000 (6.89)	400 (2.76)	
High, >95% Proctor, >70% Relative Density	3000 (20.68)	3000 (20.68	2000 (13.79)	1000 (6.89) Protective Cover on Slopes	

A - Crushed rock In pipe envelope on floor
B – Coarse grained soils; little or no fines GW, GP, SW, SP[c] contains less than 12% fines
C – Fine grained soils (LL<50); soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse grained particles. Coarse grained soils with fines GM, GC, SM, SC contains more than 12% fines
D – Fine grained soils (LL<50); soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse grained particles
E – Fine-grained soils (LL[b]>50) Soils with medium to high plasticity, CH, MH, CH-MH

Note – Standard Proctors in accordance with ASTM D 698 are used with this table. Values applicable only for fills less than 50 ft (15 m). Table does not include a safety factor. For use in predicting initial deflections only; appropriate Deflection Lag Factor must be applied for long-term deflections
[a] ASTM D2487; USBR E-3. [b] LL = liquid limit [c] Or any borderline soil beginning with one of these symbols (i.e., GM-GC, GC-SC).

__Percent Deflection__

$$\left(\frac{\Delta X}{D_M}\right) = \frac{P_T}{144}\left(\frac{K\,D_L}{\frac{2E}{3}\left(\frac{1}{DR-1}\right)^3 + 0.061\,E'}\right)100 \tag{30}$$

Where

ΔX = horizontal deflection, in
D_M = pipe mean diameter, in

$\left(\frac{\Delta X}{D_M}\right)=$ percent deflection

$$D_M = D\left(1-\frac{1.06}{DR}\right) \quad (31)$$

D = pipe outside diameter, in (WL102; WL104)
K = bedding factor (typically 0.1)
D_L = deflection lag factor (Table 11)

Flow

Table 11 Deflection Lag Factor

D_L	Typical Value
1.0	Minimum value for use only with granular backfill and if the full soil prism load is assumed to act on the pipe.
1.5	Minimum value for use with granular backfill and assumed trench loadings
2.5	Minimum value for use with CL, ML backfills, for conditions where the backfill can become saturated, etc.

Safe deflection for non-pressure PE3408 piping generally depends on ring bending wall strain, which is typically limited to 8%.

$$\left(\frac{\Delta X}{D_M}\right) \le \frac{\varepsilon (DR-1.06)}{1.06 f_D} \quad (32)$$

Where

ε = wall strain percent
≤ 8.0% for non-pressure PE3408
f_D = deformation shape factor
= 6.0 for typical non-elliptical pipe deformation

Wall strain in pressurized PE3408 pipes is more complex because internal pressure increases wall strain.

Table 12 Safe % Deflection for PE3408 Pressure Pipe

Safe % Deflection	DR
2.5	≤ 9
3.0	11
4.0	13.5
5.0	17
6.0	21
7.0	26
8.5	32.5

7 – Submerged Pipe Ballast

Ballast weights are attached to or placed over the pipe for submergence. Ballast weights are typically bottom heavy and shaped to prevent pipe rolling. Design incorporates pipe and ballast weight and displacement, the fluids inside and outside the pipe, and environmental conditions.

$$V_P = \frac{\pi D^2}{576} \quad (33)$$

Where

V_P = displaced volume of pipe, ft³/ft
π = Pi (approximately 3.1416)
D = pipe outside diameter, in (WL102; WL104)

$$B_P = V_P\, K\, \omega_{LO} \quad (34)$$

Where

B_P = pipe displacement uplift force, lb/ft
K = submerged environment factor
ω_{LO} = specific weight of liquid outside pipe, lb/ft³

Table 13 Submerged Environment Factor

Submerged Environment	Factor, K
Significant tidal flows, roving currents, stream currents	1.5
Low tidal flows or slow moving stream , river, lake or pond currents	1.3
Neutral buoyancy condition	1.0

Table 14 Specific Weights at 60°F (15°C)

Fluid	Specific Weight, ω, lb/ft³
Air and other gases	0.0
Fresh water	62.4
Seawater	64.0
Gasoline	42.5
Kerosene	50.2
Crude oil	53.1
Brine, 6% NaCl	65.1
Brine, 24% NaCl	73.8
Brine, 12% CaCl	69.0
Brine, 30% CaCl	80.4
Concrete	110 to 150
Steel	490
Brick	112 – 137
Sand, Gravel	100 – 109
Cast iron	440 – 480
Brass	511 – 536
Bronze	548

$$V_B = \frac{\pi d^2}{576} \quad (35)$$

Where

V_B = pipe ID volume, ft³/ft
d = inside diameter of pipe, in (WL102; WL104)

$$B_N = V_B \ \omega_{LI} + w_P \tag{36}$$

Where

B_N = submergence force of pipe and contents, lb/ft
ω_{LI} = pipe contents specific weight, lb/ft³
w_P = weight of pipe, lb/ft (WL102 or WL104)

$$W_{BS} = B_P - B_N \tag{37}$$

Where

W_{BS} = required weight for submerged ballast, lb/ft

$$W_{BD} = \frac{W_{BS} \ \omega_B \ L}{(\omega_B - \omega_{LO})} \tag{38}$$

Where

W_{BD} = dry weight of individual blast weights, lb
ω_B = ballast material specific weight, lb/ft³
L = distance between ballast weights, ft

The distance between ballast weights should not exceed 15 ft (7 m) to minimize pipe bending stresses during installation.

8 – Length Change with Temperature Change

Unconstrained pipe will increase in length with temperature increase. Unconstrained applications include floating pipes. To a lesser degree, suspended and surface pipelines, and loose fitting pipes within casings (sliplining) are nearly unconstrained as surface friction acts against thermal expansion movement.

Unconstrained length change:

$$\Delta L = 12 \, L \, \alpha \, \Delta T \tag{39}$$

Where

ΔL = length change, in
L = pipe length, ft
α = coefficient of linear thermal expansion, in/in/°F
= 0.8×10^{-4} in/in/°F (WL106)
ΔT = temperature change, °F

9 – Groundwater Flotation

Flotation should be considered where empty or partially full pipelines buried at depths less than 1½ pipe diameters can encounter high groundwater or flooding conditions. Embedment soil particles immersed in liquid are buoyed, reducing embedment and backfill earthload on the pipe. Liquid in the pipe adds weight to counter buoyant groundwater lifting force. A concrete cap, concrete anti-flotation anchors, soil stabilization, or other anchoring measures may be used to prevent groundwater flotation.

Groundwater flotation does not occur if:

$$F_B \le F_D \tag{40}$$

Where

F_B = groundwater buoyant force, lb/ft

$$F_B = \frac{\pi \ \omega_G \ D^2}{48} \tag{41}$$

ω_G = groundwater specific weight, lb/ft³ (Table 8)
π = pi, approximately 3.1416
D = pipe outside diameter, in (WL102; WL104)
F_D = downforce on pipe, lb/ft

$$F_D = w_P + W_F + W_D + W_{LI} \tag{42}$$

w_P = weight of pipe, lb/ft (WL102 or WL104)
W_F = flooded soil weight, lb/ft

$$W_f = (\omega_D - \omega_G)\frac{D}{12}\left(H_f + \frac{D(4-\pi)}{1152}\right) \tag{43}$$

ω_D = dry soil specific weight, lb/ft³
H_f = flooded soil height above pipe, ft
W_D = dry soil weight, lb/ft

$$W_D = \omega_D \frac{D}{12}(H - H') \tag{44}$$

H = soil cover above pipe, ft
H' = height of groundwater above pipe, ft
W_{LI} = liquid inside pipe weight, lb/ft

For empty pipe,

$$W_{LI} = 0 \tag{45}$$

For half-full pipe,

$$W_{LI} = \omega_{LI} \frac{\pi d^2}{96} \tag{46}$$

For full pipe,

$$W_{LI} = \omega_{LI} \frac{\pi d^2}{48} \tag{47}$$

d = inside diameter of pipe, in (WL102; WL104)
ω_{LI} = pipe contents specific weight, lb/ft³

$$N = \frac{F_D}{F_B} \quad (48)$$

N = safety factor

10 – ATL for Pull-In Installation

During pull-in installation, a tensile load on the pipe greater than the Allowable Tensile Load, ATL, for the pipe can permanently damage the pipe. Tensile pull-in loads at or below the ATL will not damage the pipe. During pull-in installation, both ends of the pull should be monitored for continuous movement, and if pull-in equipment can apply tensile loads exceeding the ATL, a "weak-link" or breakaway device should be installed where the pipe attaches to pulling equipment. The ATL calculation is based on ASTM F1804.

$$ATL = f_y\, f_t\, T_y\, \pi D^2 \left(\frac{1}{DR} - \frac{1}{DR^2} \right) \quad (49)$$

Where

ATL = Allowable Tensile Load, lb
f_y = tensile yield design (safety) factor
= 0.4
f_t = time under tension design (safety) factor.

Table 15 Time under Tension Factor, f_t

Time under tension	*f_t*
Up to 1 hour	1.00
1 to 12 hours	0.95
12 to 24 hours	0.91

T_y = nominal pipe material tensile yield strength, psi
= 3200 psi for PE3408 pipe at 60-80°F (15-27°C)

Tensile yield strength will vary with temperature, and should be adjusted for the pipe temperature at the time of installation. Black PE3408 pipe in the summer sun can reach temperatures of 140°F (60°C). To obtain the pipe installation temperature pipe material yield strength, multiply the nominal yield strength by the appropriate temperature multiplier from Table 2.

$$T_{y-Install} = f_T\, T_y \quad (50)$$

Where

$T_{y\text{-INSTALL}}$ = pipe material yield strength for pipe temperature at time of installation, psi

f_T = temperature multiplier (Table 2)

11 – Minimum Field Bending Radius

Field bending radius depends on pipe diameter, wall thickness (DR) and whether or not fittings are or will be present in the bend. The minimum diameter of a pipe loop is twice the minimum field bending radius.

$$R_F = \frac{D}{12} f_R \quad (51)$$

Where

R_F = minimum field bending radius, ft
D = pipe outside diameter, in (WL102; WL104)
f_R = bending radius factor

Table 16 Bending Radius Factor, f_R

Pipe DR	*Bending Radius Factor, f_R*
≤ 9	20
$> 9 \leq 13.5$	25
$> 13.5 \leq 21$	27
> 21	30
Fitting in bend	100

12 – High Pressure Gas Flow

Caution – To minimize the risk of mechanical damage, pressure gas piping is buried, installed at heights and in areas where moving equipment cannot contact or damage piping, and encased in shatter resistant materials. Pressure gas piping is restrained to prevent movement in case of mechanical damage.

The Mueller equation for gas pressures greater than 1 psig has been modified for gauge pressure rather than absolute pressure for inlet and outlet pressures.

$$Q_h = \frac{2826\, d^{2.725}}{S_g^{\;0.425}} \left(\frac{(p_1 + 14.7)^2 - (p_2 + 14.7)^2}{L} \right)^{0.575} \quad (52)$$

Where

Q_h = flow, standard ft^3/hour
S_g = gas specific gravity
p_1 = inlet pressure, lb/in^2
p_2 = outlet pressure, lb/in^2
L = pipe length, ft
d = pipe inside diameter, in (WL102; WL104)

13 – Above Grade Pipe Support

At a minimum, above grade pipe supports should cradle the bottom third of the pipe, and be one-half pipe diameter long. Long-term vertical deflection between supports should not exceed 1-in (25 mm).

$$L_S = \frac{1}{12}\left(\frac{4608\,E\,I\,y_s}{5\,(w_p + w_{LI})}\right)^{0.25} \tag{53}$$

$$y_S = \frac{5\,(w_P + w_{LI})(12\,L_S)^4}{4608\,E\,I} \tag{54}$$

L_S = support spacing, ft
y_s = vertical deflection at center of span, in
E = modulus of elasticity, psi (Table 10)
= 28,200 psi for long-term at 73°F
I = moment of inertia, in^4

$$I = \frac{\pi\,(D^4 - d^4)}{64} \tag{55}$$

D = pipe outside diameter, in (WL102; WL104)
d = pipe inside diameter, in (WL102; WL104)
w_P = weight of pipe, lb/ft (WL102 or WL104)
w_{LI} = liquid inside pipe weight, lb/ft

For empty pipe,

$$w_{LI} = 0 \tag{56}$$

For half-full pipe,

$$w_{LI} = \omega_{LI}\,\frac{\pi\,d^2}{1152} \tag{57}$$

For full pipe,

$$w_{LI} = \omega_{LI}\,\frac{\pi\,d^2}{576} \tag{58}$$

ω_{LI} = pipe contents specific weight, lb/ft^3

14 – External Pressure/Vacuum Resistance

Circumferentially applied external pressure or internal vacuum or a combination of external pressure and vacuum will attempt to flatten the pipe. Freestanding pipe such as pipe in surface, sliplining and submerged applications is not supported by embedment or other external confinement that can significantly enhance resistance to flattening from external pressure. The resistance of freestanding pipe to flattening from external pressure depends on wall thickness (pipe DR), elastic properties (time and temperature dependent elastic modulus and Poisson's ratio), and roundness.

$$P_{CR} = \frac{2\,E\,f_O}{(1-\mu^2)}\left(\frac{1}{DR-1}\right)^3 \tag{59}$$

Where

P_{CR} = flattening resistance limit, psi
E = modulus of elasticity, psi
μ = Poisson's Ratio
= 0.35 for short-term stress
= 0.45 for long-term stress
f_O = roundness factor
DR = pipe dimension ratio,

$$P_{AL} = \frac{P_{CR}}{N} \tag{60}$$

P_{AL} = safe external pressure, psi
N = safety factor (typically ≥ 2)

Table 17 Modulus of Elasticity for PE3408

Temperature, °F (°C)	*Modulus of Elasticity for Load Time, kpsi (MPa)*						
	Short-term	10 h	100 h	1000 h	1 y	10 y	50 y
-20 (-29)	300.0 (2069)	140.8 (971)	125.4 (865)	107.0 (738)	93.0 (641)	77.4 (534)	69.1 (476)
0 (-18)	260.0 (1793)	122.0 (841)	108.7 (749)	92.8 (640)	80.6 (556)	67.1 (463)	59.9 (413)
40 (4)	170.0 (1172)	79.8 (550)	71.0 (490)	60.7 (419)	52.7 (363)	43.9 (303)	39.1 (270)
60 (16)	130.0 (896)	61.0 (421)	54.3 (374)	46.4 (320)	40.3 (278)	33.5 (231)	29.9 (206)
73 (23)	110.0 (758	57.5 (396	51.2 ((353)	43.7 (301)	38.0 (262)	31.6 (218)	28.2 (194)
100 (38)	100.0 (690)	46.9 (323)	41.8 (288)	35.7 (246)	31.0 (214)	25.8 (178)	23.0 (159
120 (49)	65.0 (448)	30.5 (210)	27.2 (188)	23.2 (160)	20.2 (139)	16.8 (116)	$\boxed{15.0}$ (103)
140 (60)	50.0 (345)	23.5 (162)	20.9 (144)	17.8 (123)	15.5 (107)	12.9 (89)	11.5 (79)

15,000psi

Table 18 Roundness Factor, f_O

% Deflection	*f_O*	*% Deflection*	*f_O*
0	1.00	6	0.52
1	0.92	7	0.48
2	0.88	8	0.42
3	0.78	9	0.39
4	0.70	≤ 10	0.36
5	0.62		

15 – Thermal Contraction Tensile Load

During temperature decrease, straight, unconstrained pipe on a "frictionless" surface that is anchored at both ends, will apply a tensile load against the anchored ends.

$$F = E\,\alpha\,\Delta T\,\pi\,D^2\left(\frac{1}{(0.944\,DR)} - \frac{1}{(0.944\,DR)^2}\right) \qquad (61)$$

Where

- F = tensile load, lb
- E = modulus of elasticity, psi (Table 17)
- α = coefficient of linear thermal expansion, in/in/°F
- = 0.8×10^{-4} in/in/°F (WL106)
- ΔT = temperature change, °F
- D = pipe outside diameter, in (WL102; WL104)
- DR = dimension ratio

16 – Poisson Pullback Force

When a tensile force is applied to a ductile material, it extends in the direction of pull, and dimensions at right angles to the direction of pull decrease. When PE pipe is pressurized, it expands slightly, and its length decreases slightly. The ratio of dimensional increase to decrease is the Poisson ratio.

Pressurized PE pipe expands slightly in the hoop direction, and if unrestrained, it decreases slightly in length. When restrained, a longitudinal pullback force develops along the length of the pipe. Joints in the system must withstand the Poisson pull back force or disjoining can occur. Pullback force varies with the duration of internal pressure because the Poisson ratio varies for short-term or long-term load (stress).

$$F_P = P\left(DR - 1\right)\mu\frac{\pi}{8}\left(D^2 - d^2\right) \qquad (62)$$

Where

- F_P = Pullback force, lb
- P = Internal pressure, psi
- DR = pipe dimension ratio, dimensionless
- μ = Poisson Ratio
- = 0.35 for short-term stress
- = 0.45 for long-term stress
- D = pipe outside diameter, in (WL102; WL104)
- d = pipe inside diameter, in (WL102; WL104)

Poisson pullback force results from steady pressure (long-term Poisson ratio applied), during pressure leak testing (short-term-Poisson ratio applied), and during a surge pressure event (long-term Poisson ratio applied to steady pressure and short-term Poisson ratio applied to surge pressure).

17 – End Anchor Load, Temperature Increase

During temperature increase, end anchored, constrained pipe will apply a compressive load against the end anchors. If the distance between pipe constraints is greater than the critical distance, L_c, the pipe will deflect laterally between constraints and the compressive load, P_T, against the anchors will not exceed the critical compressive load, P_C.

$$L_c = \frac{1}{12}\sqrt{\frac{\pi^3 E\left(D^4 - d^4\right)}{64\,P_C}} \qquad (63)$$

$$P_C = S_C\frac{\pi}{4}\left(D^2 - d^2\right) \qquad (64)$$

$$P_T = E\,\alpha\,\Delta T\frac{\pi}{4}\left(D^2 - d^2\right) \qquad (65)$$

$$SF = \frac{P_C}{P_T} \qquad (66)$$

$$y = 12L\sqrt{\frac{\alpha\,\Delta T}{2}} \qquad (67)$$

Where

- L_c = critical distance between constraints, ft
- E = elastic modulus, psi (Table 17)
- D = pipe outside diameter, in (WL102; WL104)
- d = pipe inside diameter, in (WL102; WL104)
- S_C = compressive strength, psi (Table 19)
- P_C = critical compressive load, lb
- P_T = for $L < L_c$, thrust force at end anchors, lb
- L = distance between pipe constraints, ft
- SF = compressive load safety factor
- α = coefficient of linear thermal expansion, in/in/°F
- = 0.8×10^{-4} in/in/°F (WL106)
- ΔT = temperature change, °F
- y = for $L > L_c$, maximum lateral deflection at L/2, in

Table 19 Approximate Compressive Strength at 73°F

Load Duration	*Compressive Strength, S_c, psi*
short term	1800
1 day	1600
1 month	850

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18 – Trench Width

For conventional excavation, the trench needs to be wide enough to properly place embedment below the pipe springline. Minimum trench width for up to three parallel pipes in a common trench is determined using:

$$B_d = C_1 + D_1 + [C_1 \, or \, C_2] + D_2 + [C_2 \, or \, C_3] + D_3 + C_3 \quad (68)$$

Where

B_d = minimum trench width, in
D_x = outside diameter of pipe 1, 2, or 3, in
C_x = clearance between pipes for larger pipe, or between pipe and trench wall, in

Table 20 Trench Clearance

Pipe Outside Diameter, D_x in	Clearance between pipes for the larger pipe, or between pipe and trench wall, C_x in
<3	5
$3 \leq 16$	6
$> 16 \leq 34$	9
$> 34 \leq 54$	12

19 – Pipe Volume

$$V = 0.0408 \, d^2 \, L \quad (69)$$

Where

V = pipe volume, U.S. gal
d = pipe inside diameter, in (WL102; WL104)
L = length of pipe, ft

20 – Temperature Conversion

Converting temperatures on Fahrenheit and Celsius (Centigrade) temperature scales:

$$C = (F - 32)\frac{5}{9} \quad (70)$$

$$F = \frac{9}{5}C + 32 \quad (71)$$

Where

C = degrees Celsius
F = degrees Fahrenheit

Example: A temperature of 73° on the Fahrenheit scale is equal to a temperature of 23° on the Celsius (Centigrade) scale.

Converting degrees on Fahrenheit and Celsius temperature scales:

$$C = F\frac{5}{9} \quad (72)$$

$$F = \frac{9}{5}C \quad (73)$$

Where

C = degrees Celsius
F = degrees Fahrenheit

Example: A temperature change of 20°F is equal to a temperature change of 11.1°C.

21 – HDPE Thermal Properties

Table 21 HDPE Thermal Properties

Property	*Typical Value*
R, Thermal Resistance (1" thickness)	0.28 (hr-ft²-°F)/Btu
C_T, Thermal Conductance (1" thickness)	3.50 Btu/(h-ft²-°F)
K, Thermal Conductivity (ASTM C177)	3.50 Btu/(h-ft²-°F-/in)

$$R = \frac{1}{C_T} \quad (74)$$

$$R = \frac{t}{k} \quad (75)$$

$$C_T = \frac{k}{t} \quad (76)$$

Where

R = Thermal resistance, (hr-ft²-°F)/Btu
C_T = Thermal conductance, Btu/(h-ft²-°F)
t = thickness, in
k = thermal conductivity, Btu/(h-ft²-°F-/in

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 3: STRUCTURAL CAPACITY OF THE LEACHATE COLLECTION SYSTEM (III-D.6-A.3)

3-2-2015

STATE OF TEXAS
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CB&I

Client:	**Rancho Viejo Waste Management, LLC**		
Project:	**Pescadito Environmental Resource Center**		
Project #:	**148866**		
Calculated By:	**LJC**	**Date:**	**1/26/15**
Checked By:	**RDS**	**Date:**	**2/6/15**

TITLE: **STRUCTURAL CAPACITY OF THE LEACHATE PIPES**

Problem Statement

Determine if the proposed leachate pipes (leachate collection pipe, leachate riser pipe, leachate cleanout pipe) possess sufficient strength to support the overlying landfill materials due to:

1. Wall crushing
2. Wall buckling

Given

- ❑ Loads on the Leachate Collection System calculation (III-D.6-A.1).

- ❑ The safety factor against wall crushing is determined by the following formula (see Equation 25 from WL Plastics WL PipeCalc™ Supplement in III-D.6-A.2).

$$N_c = \frac{460{,}800}{P_T \times DR}$$

Where:

N_c = safety factor against wall crushing
P_T = total load pressure at pipe crown (psf)
$P_T = P_E + P_L$
P_E = overburden pressure at pipe crown (lb/ft^2)
$P_E = wH$
w = material density (pcf)
H = height of material above the pipe crown (ft)
P_L = live load pressure at pipe crown = 0
(S)DR = pipe dimension ratio
= (pipe outer diameter)/(pipe wall thickness)

- ❑ The safety factor against wall buckling is determined by the following formula (see Equation 26 from WL Plastics WL PipeCalc™ Supplement from III-D.6-A.2)

$$N_B = \frac{144 P_{WC}}{P_T}$$

Where:

N_B = safety factor against wall buckling
P_T = total load pressure at pipe crown (psf)
P_{WC} = constrained bulking pressure (psi) (Equation 27 from WL Plastics)

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Checked By:	**RDS**	**Date:**	**2/6/15**

TITLE: STRUCTURAL CAPACITY OF THE LEACHATE PIPES

$$P_{WC}=5.65\sqrt{\frac{RB'E'E}{12(DR\text{-}1)^3}}$$

R = reduction factor for buoyancy (Equation 28 from WL Plastics)

$$R=1\text{-}0.33\frac{H'}{H}$$

H' = height of leachate above pipe (ft)
H = material cover above pipe (ft)
B' = elastic support factor (Equation 29 from WL Plastics)

$$B'=\frac{1}{1+10.87312^{(-0.065H)}}$$

E' = modulus of soil reaction (psi)
E = modulus of elasticity for the pipe (psi)
= 15,000 psi for long term conditions at 120°F
(S)DR = pipe dimension ratio
= (pipe outer diameter)/(pipe wall thickness)

Assumptions

- The following pipes to be analyzed:
  - Case 1: 6-inch SDR-7.3 Leachate Collection Pipe in Leachate Chimney
  - Case 2: 18-inch SDR-11 Leachate Riser Pipe On Side-Wall
  - Case 3: 6-inch SDR-11 Leachate Cleanout Pipe On Side-Wall
- H' = 1.0 ft in the proposed landfill (based on the TCEQ requirement for a maximum leachate head of 30 cm which is approximately 1 ft, should H' be equal to 0, R will still be equal to 1, which will produce the same results.
- H = The aggregate thickness, total waste thickness and final cover:

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TITLE: STRUCTURAL CAPACITY OF THE LEACHATE PIPES

Case	Aggregate Thickness (ft)	Waste Thickness (ft)	Final Cover Thickness (ft)	H (ft)
Case 1: Leachate Collection Pipe	2	380	3.08	385
Case 2: Leachate Riser Pipe	4	175	3.08	182
Case 3: Leachate Cleanout Pipe	2	175	3.08	180

- ❑ The values for P_E, taken from the Loads on the Leachate Collection System calculation are shown in the table below

Case #	Load From Final Grade (psf)
Case 1: Leachate Collection Pipe	25,300
Case 2: Leachate Riser Pipe	12,312
Case 3: Leachate Cleanout Pipe	12,042

- ❑ E = 15,000 psi (see WL Plastics WL PipeCalc™ Supplement – Table 17)
- ❑ E' = 3,000 psi (see WL Plastics WL PipeCalc™ Supplement – Table 10)

Calculations

Wall Crushing

Case 1: Leachate Collection Pipe (6")

Calculate the safety factor against wall crushing for the 6-inch SDR-7.3 HDPE pipe:

$$P_T = P_E + P_L = 25{,}300 \text{ psf} + 0 = 25{,}300 \text{ psf}$$

$$N_c = \frac{460{,}800}{P_T \times DR} = \frac{460{,}800}{(25{,}300)(7.3)} = 2.49$$

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TITLE: STRUCTURAL CAPACITY OF THE LEACHATE PIPES

Calculate the safety factor against wall buckling for the 6-inch SDR-7.3 HDPE pipe in landfill:

$$R=1-0.33\left(\frac{H'}{H}\right)=1-0.33\left(\frac{1.0\text{ ft}}{385\text{ ft}}\right)=1.00$$

$$B'=\frac{1}{1+10.87312^{-0.065H}}=\frac{1}{1+10.87312^{-(0.065\times 385)}}=1.00$$

$$P_{WC}=5.65\sqrt{\frac{RB'E'E}{12(DR-1)^3}}=5.65\sqrt{\frac{(1.00)(1.00)(15{,}000)(3{,}000)}{12(7.3-1)^3}}=692$$

$$N_B=\frac{144P_{WC}}{P_T}=\frac{(144)(692)}{25{,}300}=3.94$$

Case 2: Leachate Riser Pipe (18")

Calculate the safety factor against wall crushing for the 18-inch SDR-11 HDPE pipe:

$$P_T = P_E + P_L = 12{,}312\text{ psf} + 0 = 12{,}312\text{ psf}$$

$$N_c=\frac{460{,}800}{P_T\times DR}=\frac{460{,}800}{(12{,}312)(11)}=3.40$$

Calculate the safety factor against wall buckling for the 18-inch SDR-11 HDPE pipe in landfill:

$$R=1-0.33\left(\frac{H'}{H}\right)=1-0.33\left(\frac{1.0\text{ ft}}{182\text{ ft}}\right)=1.00$$

$$B'=\frac{1}{1+10.87312^{-0.065H}}=\frac{1}{1+10.87312^{-(0.065\times 182)}}=1.00$$

$$P_{WC}=5.65\sqrt{\frac{RB'E'E}{12(DR-1)^3}}=5.65\sqrt{\frac{(1.00)(1.00)(15{,}000)(3{,}000)}{12(11-1)^3}}=346$$

$$N_B=\frac{144P_{WC}}{P_T}=\frac{(144)(346)}{12{,}312}=4.04$$

Client: Rancho Viejo Waste Management, LLC
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TITLE: STRUCTURAL CAPACITY OF THE LEACHATE PIPES

Case 3: Leachate Cleanout Pipe (6")

Calculate the safety factor against wall crushing for the 6-inch SDR-11 HDPE pipe:

$$P_T = P_E + P_L = 12{,}042\ psf + 0 = 12{,}042\ psf$$

$$N_c = \frac{460{,}800}{P_T \times DR} = \frac{460{,}800}{(12{,}042)(11)} = 3.48$$

Calculate the safety factor against wall buckling for the 6-inch SDR-11 HDPE pipe in landfill:

$$\mathrm{R} = 1\text{-}0.33\left(\frac{\mathrm{H'}}{\mathrm{H}}\right) = 1\text{-}0.33\left(\frac{1.0\ \mathrm{ft}}{180\ \mathrm{ft}}\right) = 1.00$$

$$\mathrm{B'} = \frac{1}{1+10.87312^{-0.065\mathrm{H}}} = \frac{1}{1+10.87312^{-(0.065\times 180)}} = 1.00$$

$$\mathrm{P_{WC}} = 5.65\sqrt{\frac{\mathrm{RB'E'E}}{12(\mathrm{DR}\text{-}1)^3}} = 5.65\sqrt{\frac{(1.00)(1.00)(15{,}000)(3{,}000)}{12(11\text{-}1)^3}} = 346$$

$$\mathrm{N_B} = \frac{144\mathrm{P_{WC}}}{P_T} = \frac{(144)(346)}{12{,}042} = 4.14$$

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TITLE: **STRUCTURAL CAPACITY OF THE LEACHATE PIPES**

Results

The proposed leachate collection pipes will possess sufficient strength to support the overlying landfill, as shown by the calculated factors of safety against pipe wall buckling and pipe wall crushing for each of the leachate pipes.

Leachate Pipe Factors of Safety			
Pipe Failure Mode	Factor of Safety		
	Leachate Collection Pipe (6-inch, SDR-7.3)	Leachate Riser Pipe (18-inch, SDR-11)	Leachate Cleanout Pipe (6-inch, SDR-11)
Wall Crushing	2.49	3.40	3.48
Wall Buckling	3.94	4.05	4.14

The leachate pipes will be surrounded by a granular envelope that serves as an additional level of protection if the leachate collection pipe would be crushed.

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 4: COMPRESSED THICKNESS AND HYDRAULIC CONDUCTIVITY OF THE GEONET (III-D.6-A.4)

3-2-2015

STATE OF TEXAS
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Client:	Rancho Viejo Waste Management, LLC
Project:	Pescadito Environmental Resource Center
Project #:	148866
Calculated By:	LJC	Date: 1/22/15
Checked By:	RDS	Date: 1/30/15

TITLE **Compressed Thickness and Hydraulic Conductivity of the Geonet**

Problem Statement

Determine the hydraulic conductivity of the geonet component of the geocomposite for open conditions, intermediate conditions, and closed conditions.

Given

- ❑ GSE Lining Technology, LLC. (2010). *Performance & Properties - GSE PermaNet Geonets & Geocomposites.*
- ❑ Koerner, Robert M. (2005). *Designing with Geosynthetics.* Fifth Edition, Prentice Hall, New Jersey.
- ❑ Appendix III-D.5 Geotechnical Analysis Report

Assumptions

- ❑ The waste thickness for open conditions is assumed to be 10 feet, which is equal to one lift of waste.
- ❑ The assumed waste thickness for intermediate conditions is 190 feet (half of the waste thickness for closed conditions).
- ❑ The waste thickness for closed conditions is assumed to be 380 feet, based on peak waste thickness determination AutoCAD Civil 3D 2014.
- ❑ The final cover thickness is 3.08 feet of soil cover for an alternative water balance cover.
- ❑ Maximum average unit weight of cover soils is 129 pcf, see Geotechnical Analysis – Appendix III-D.5
- ❑ Unit weight of waste is 65 pcf, see Geotechnical Analysis – Appendix III-D.5.
- ❑ Properties for a typical geocomposite that may be used at this landfill are taken from page 2 of the GSE PermaNet reference:
  - o The thickness of unloaded geonet is 0.27 inches (270 mil)
  - o Compression strength is 40,000 psf
  - o Transmissivity is 19 gal/min/ft (4×10^{-3} m^2/sec)

Client:	Rancho Viejo Waste Management, LLC
Project:	Pescadito Environmental Resource Center
Project #:	148866
Calculated By:	LJC	Date: 1/22/15
Checked By:	RDS	Date: 1/30/15

TITLE Compressed Thickness and Hydraulic Conductivity of the Geonet

Calculations

Calculate the compressed geonet thickness for the different scenarios:

Layer	Thickness (ft)	Unit Weight (pcf)	Load on Geonet (psf)	Total Load on Geonet (psi)	Geonet Compression (in)[1]	Resultant Geonet Thickness (in)
Open Conditions						
Daily Cover	0.5	129	64.5	7	0.005	0.265
Waste	10	65	650			
Protective Cover	2	129	258			
		Total	972.5			
Intermediate Conditions						
Intermediate Cover	1	129	129	88	0.015	0.255
Waste	190	65	12,350			
Protective Cover	2	129	258			
		Total	12,737			
Closed Conditions						
Final Cover	3.08	129	397.32.3	176	0.03	0.240
Waste	380	65	24700			
Protective Cover	2	129	258			
		Total	25,355			

1. Geocomposite compression is determined from the figure on page 2 of the GSE PermaNet reference.

Use Equation 4.5 from *Designing with Geosynthetics* to determine the allowable transmissivity of the geonet for each scenario:

$$T_{allow} = T_{ult}\left(\frac{1}{RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{bc}}\right)$$

Where: T_{allow} = Allowable Transmissivity of the geonet;
T_{ult} = 4 x 10^{-3} m^2/sec from GSE reference;
RF_{CR} = Creep reduction factor;
RF_{IN} = Intrusion reduction factor;
RF_{CC} = Chemical clogging reduction factor; and
RF_{BC} = Biological Clogging reduction factor.

Conservatively assume from Table 4.2 in *Designing with Geosynthetics* that all reduction factors are 2 for geonet used for primary leachate collection for all scenarios.

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TITLE Compressed Thickness and Hydraulic Conductivity of the Geonet

$$T_{allow} = 4 \times 10^{-3} \frac{m^2}{sec} \left(\frac{1}{2 \times 2 \times 2 \times 2} \right) = 2.5 \times 10^{-4} \frac{m^2}{sec}$$

Calculate the allowable hydraulic conductivity of the compressed geonet for each scenario:

$$k_{allow} = \frac{T_{allow}}{t}$$

Scenario	Compacted Geonet Thickness (in)	Compacted Geonet Thickness (m)	T_{allow} (m^2/sec)	k_{allow} (cm/sec)
Open Conditions	0.265	0.006731	2.5×10^{-4}	3.714
Intermediate Conditions	0.255	0.006477	2.5×10^{-4}	3.860
Closed Conditions	0.240	0.006096	2.5×10^{-4}	4.101

Results

The calculated thickness and hydraulic conductivities for the geonet for each scenario are listed above. The thicknesses and hydraulic conductivities are used in the HELP model scenarios to calculate leachate head on the liner.

Technically Complete, March 11, 2016

Performance & Properties

GSE PermaNet

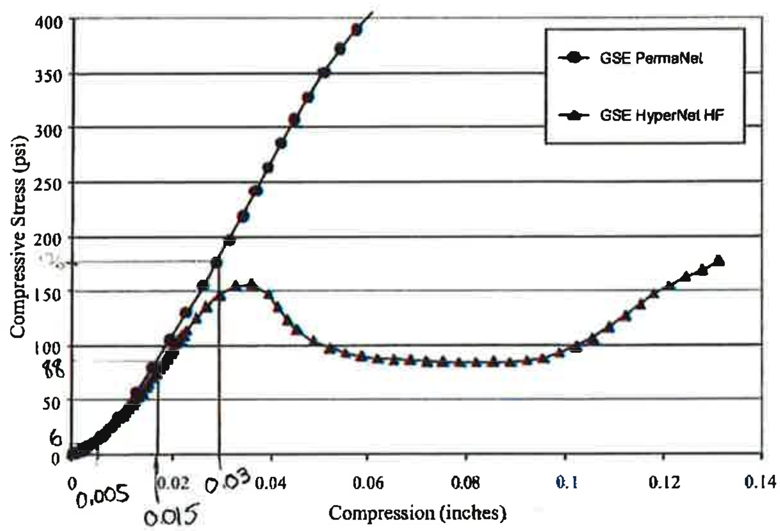
Geonets & Geocomposites

GSE

2.0 Superior Compression Strength

One of the most important properties of a geonet is its compression strength - the stress level at which its ribs bend or collapse during a compression test. The transmissivity of geonets and geocomposites decreases sharply after such bending or collapse often by an order of magnitude. It is therefore crucial that the compression strength of a geonet be high enough to withstand overburden stress throughout the design life of a project.

The graph on this page illustrates the difference in stress-compression behavior between a conventional and a GSE PermaNet geonet. Note that the GSE PermaNet is not subject to the distinct roll-over that is typical of biplanar and triplanar geonets. This means that GSE PermaNet geonets can sustain high transmissivity even at high stress levels. The curve for GSE PermaNet shows no failure even when subjected to a stress of 400 psi (57,600 psf), which is equivalent to a landfill height of 576 feet at a waste density of 100 pounds/cubic feet. If your project involves high stress levels, or if you simply require a higher factor of safety, GSE PermaNet is clearly the material of choice.



Stress-Compression Behavior of GSE PermaNet and GSE HyperNet Geonets

3.0 Superior Creep Resistance

Geonets progressively decrease in thickness when subjected to constant stress, in a process called compression creep. Since the transmissivity of geonets and geocomposites depends primarily on the thickness and structure of their core, any eventual decrease in thickness or distortion in structure will diminish their transmissivity. A product with higher resistance to creep will sustain a higher transmissivity and is therefore a superior product.

The effect of creep on transmissivity is represented by the reduction factor for creep in the following equation (GRI 2001):

Technically Complete, March 11, 2016

DESIGNING WITH GEOSYNTHETICS

FIFTH EDITION

ROBERT M. KOERNER

Technically Complete, March 11, 2016

Library of Congress Cataloging-in-Publication Data

Koerner, Robert M., 1933-
Designing with geosynthetics / Robert M. Koerner.—5th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-13-145415-3
1. Geosynthetics. I. Title.

TA455.G44K64 2005
624.1'8923--dc22 2005045837

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About the Cover: *Cover images courtesy of the author.*

Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, NJ 07458

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-145415-3

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte. Ltd.
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compressibility section, however, fabrics deform under load (recall Figure 2.6). Thus a new term, permittivity (Ψ) as was previously defined as equation (2.8), is repeated here:

$$\Psi = \frac{k_n}{t}$$

where

Ψ = permittivity (sec^{-1}),
k_n = permeability (properly called *hydraulic conductivity*) normal to the geotextile where the subscript n is often omitted (m/sec), and
t = thickness of the geotextile (m).

The above equation is used in Darcy's formula as follows:

$$q = k_n i A$$

$$q = k_n \frac{\Delta h}{t} A$$

$$\frac{k_n}{t} = \Psi = \frac{q}{(\Delta h)(A)} \tag{2.16}$$

where

q = flow rate (m^3/sec),
i = hydraulic gradient (dimensionless),
Δh = total head lost (m), and
A = total area of geotextile test specimen (m^2).

The formulation above is used for constant head tests in an identical manner as with soil permeability testing. Typically, the flow rate (q) is measured at one value of Δh, and then the test is repeated at different values of Δh. These different values of Δh produce correspondingly different values of q. When plotted as ($\Delta h A$) on the horizontal axis and (q) on the vertical axis, the slope of the resulting straight line yields the desired value of Ψ.

The test can also be conducted using a falling (variable) head procedure as is also performed on soils. In this case, Darcy's formula is integrated over the head drop in an interval of time and used in the following equation:

$$\frac{k_n}{t} = \Psi = 2.3 \frac{a}{A \Delta t} \log_{10} \frac{h_o}{h_f} \tag{2.17}$$

where

Ψ = permittivity (sec^{-1}),
a = area of water supply standpipe (m^2),

and Risseeuw [65]). Although the equation indicates tensile strength, it can be applied to burst strength, tear strength, puncture strength, impact strength, and so on.

2.4.2 Flow-Related Problems

For problems dealing with flow through or within a geotextile, such as filtration and drainage applications, the formulation of the allowable values takes the form of equation (2.25a). Typical values for reduction factors are given in Table 2.12. Note that these values must be tempered by the site-specific conditions, as in Section 2.4.1. If the laboratory test includes the mechanism listed, it appears in the equation as a value of 1.0.

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}}\right) \quad (2.25a)$$

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{\Pi RF}\right) \quad (2.25b)$$

where

q_{allow} = allowable flow rate,
q_{ult} = ultimate flow rate,
RF_{SCB} = reduction factor for soil clogging and blinding (≥ 1.0),
RF_{CR} = reduction factor for creep reduction of void space (≥ 1.0),
RF_{IN} = reduction factor for adjacent materials intruding into geotextile's void space (≥ 1.0),
RF_{CC} = reduction factor for chemical clogging (≥ 1.0),

TABLE 2.12 RECOMMENDED FLOW-REDUCTION FACTOR VALUES FOR USE IN EQUATION (2.25a)

	Range of Reduction Factors				
Application	Soil Clogging and Blinding(1)	Creep Reduction of Voids	Intrusion into Voids	Chemical Clogging(2)	Biological Clogging
Retaining wall filters	2.0–4.0	1.5–2.0	1.0–1.2	1.0–1.2	1.0–1.3
Underdrain filters	2.0–10	1.0–1.5	1.0–1.2	1.2–1.5	2.0–4.0(3)
Erosion control filters	2.0–10	1.0–1.5	1.0–1.2	1.0–1.2	2.0–4.0
Landfill filters	2.0–10	1.5–2.0	1.0–1.2	1.2–1.5	2.0–5.0(3)
Gravity drainage	2.0–4.0	2.0–3.0	1.0–1.2	1.2–1.5	1.2–1.5
Pressure drainage	2.0–3.0	2.0–3.0	1.0–1.2	1.1–1.3	1.1–1.3

1. If stone riprap or concrete blocks cover the surface of the geotextile, use the upper values or include an addition reduction factor.

2. Values can be higher, particularly for high alkalinity groundwater.

3. Values can be higher for turbidity and/or microorganism contents greater than 5000 mg/l.

One way of doing this is to ascribe reduction factors on each of the items not adequately assessed in the laboratory test. For example,

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right] \tag{4.5}$$

or if all of the reduction factors are considered together:

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\Pi RF}\right] \tag{4.6}$$

where

- q_{ult} = flow rate determined using ASTM D4716 or ISO 12958 for short-term tests between solid platens using water as the transported liquid under laboratory test temperatures,
- q_{allow} = allowable flow rate to be used in equation (4.3) for final design purposes,
- RF_{IN} = reduction factor for elastic deformation, or intrusion, of the adjacent geosynthetics into the geonet's core space,
- RF_{CR} = reduction factor for creep deformation of the geonet and/or adjacent geosynthetics into the geonet's core space,
- RF_{CC} = reduction factor for chemical clogging and/or precipitation of chemicals within the geonet's core space,
- RF_{BC} = reduction factor for biological clogging within the geonet's core space, and
- ΠRF = product of all reduction factors for the site-specific conditions.

Some guidelines as to the various reduction factors to be used in different situations are given in Table 4.2. Please note that some of these values are based on relatively sparse information. Other reduction factors, such as overlapping connections, temperature effects, and liquid turbidity, could also be included. If needed, they can be included on a site-specific basis. On the other hand, if the actual laboratory test procedure has included the particular item, it would appear in the above formulation as a value of unity. Examples 4.2 and 4.3 illustrate two of the uses of geonets and serve to point out that high reduction factors are warranted in critical situations.

Example 4.2

What is the allowable geonet flow rate to be used in the design of a secondary leachate collection (or leak detection) system? Assume that laboratory testing at proper design load and proper hydraulic gradient gave a short-term between-rigid-plates value of 2.5×10^{-4} m^2/s.

TABLE 4.2 RECOMMENDED REDUCTION FACTOR VALUES FOR EQUATION (4.5) DETERMINING ALLOWABLE FLOW RATE OR TRANSMISSIVITY OF GEONETS

	Reduction Factor Values in Equation (4.5)			
Application Area	RF_{IN}*	RF_{CR}*	RF_{CC}	RF_{BC}
Sport fields	1.0–1.2	1.0–1.5	1.0–1.2	1.1–1.3
Capillary breaks	1.1–1.3	1.0–1.2	1.1–1.5	1.1–1.3
Roof and plaza decks	1.2–1.4	1.0–1.2	1.0–1.2	1.1–1.3
Retaining walls, seeping rock, and soil slopes	1.3–1.5	1.2–1.4	1.1–1.5	1.0–1.5
Drainage blankets	1.3–1.5	1.2–1.4	1.0–1.2	1.0–1.2
Infiltrating water drainage for landfill covers	1.3–1.5	1.1–1.4	1.0–1.2	1.5–2.0
Secondary leachate collection (landfill)	1.5–2.0	1.4–2.0	1.5–2.0	1.5–2.0
Primary leachate collection (landfills)	1.5–2.0	1.4–2.0	1.5–2.0	1.5–2.0

*These values are sensitive to the type of geonet, rib separation distance, and density of the resin used in the geonet's manufacture. The magnitude of the applied load is also of major importance.

Solution: Average values from Table 4.2 are used in equation (4.5) (however, note the large reduction).

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right]$$

$$= 2.5 \times 10^{-4}\left[\frac{1}{1.75 \times 1.7 \times 1.75 \times 1.75}\right]$$

$$= 2.5 \times 10^{-4}\left[\frac{1}{9.11}\right]$$

$$q_{\text{allow}} = 0.27 \times 10^{-4}\ \text{m}^2/\text{s}$$

Example 4.3

What is the allowable geonet flow rate to be used in the design of a capillary break beneath a roadway to prevent frost heave? Assume that laboratory testing was done at the proper design load and hydraulic gradient and that this testing yielded a short-term between-rigid-plates value of 2.5×10^{-4} m²/s.

Solution: Since better information is not known, average values from Table 4.2 are used in equation (4.5).

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right]$$

$$= 2.5 \times 10^{-4}\left[\frac{1}{1.2 \times 1.1 \times 1.3 \times 1.2}\right]$$

$$= 2.5 \times 10^{-4}\left[\frac{1}{2.06}\right]$$

$$q_{\text{allow}} = 1.21 \times 10^{-4}\ \text{m}^2/\text{s}$$

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 5: HELP MODEL ANALYSIS (III-D.6-A.5)

3-2-2015

STATE OF TEXAS
MICHAEL W. ODEN
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CB&I

Client:	Rancho Viejo Waste Management, LLC		
Project:	Pescadito Environmental Resource Center		
Project #:	148866		
Calculated By:	LJC	Date:	1/25/15
Checked By:	RDS	Date:	2/6/15

TITLE: HELP MODEL ANALYSIS

Overview

The USEPA Hydrologic Evaluation of Landfill Performance (HELP) Model was used to predict the leachate generation rates, leachate head on the bottom liner system and percolation through the bottom liner for the proposed landfill design. The HELP model is an unsaturated flow, water balance model that uses site-specific climate, soil and design data to simulate landfill conditions over a specified time period.

The following scenarios were modeled for the proposed conditions:

- Open (Daily Cover) Conditions
- Intermediate Conditions
- Closed Conditions

Input Parameters

The HELP model input parameters for the modeled scenarios are described in the following sections. The input parameters were determined based on the proposed landfill design details, 30 TAC Chapter 330 requirements, site-specific data collected during geotechnical site investigations, and local weather data.

Groundwater Inflow

It was assumed that there will be no groundwater inflow into the landfill.

Evapotranspiration Data

Evapotranspiration data was generated by HELP from Brownsville, Texas data within the HELP model. Brownsville was selected as the nearest and most representative location of the site from the available locations within the HELP model. The evaporative zone depth was set to 60 inches based on the HELP model User's Manual for a clay material.

A leaf area index of 0 (bare ground) was used for the open conditions model, a leaf area index of 1 (poor stand of grass) was used for intermediate conditions, and a leaf area index of 2 (fair stand of grass) was used for closed conditions.

Climate Data

The climate data was synthetically generated using coefficients for Brownsville, Texas. The default temperature and precipitation coefficients were modified by using data obtained from the NOAA Climate Online Database for the last 45 years (1968-2013) at the weather station located in Laredo, Texas, **Refer to Table D.6-A.5-1.**

Table D.6-A.5-1 HELP Model Weather Input Parameters		
Month	Avg. Precip. (in)	Avg. Temp (°F)
January	0.82	56.54
February	0.86	61.01
March	0.88	68.83
April	1.37	76.04
May	2.65	82.01
June	2.68	86.48
July	1.93	87.88
August	2.29	87.94
September	3.09	82.92
October	2.41	75.4
November	1.07	65.5
December	0.91	57.73

Runoff Potential

Runoff potential for the open conditions was conservatively assumed to be zero, although operational daily cover will allow runoff on graded portions of the operational areas. Runoff potential for intermediate conditions was assumed to be 75%, as areas with intermediate cover will be rough graded to drain. The closed conditions model assumes a runoff potential for 100% of the surface area, since the vegetative cover and grading of the final landform will be constructed and maintained to effectively control stormwater runoff and minimize ponding on top of the final cover.

Runoff Curve Number

A runoff curve number of 85 was conservatively chosen based on the site-specific soil properties and the final cover design.

Daily and Intermediate Cover Soil Layers

The open conditions model assumes that 6 inches of daily cover soil is in place and the intermediate

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TITLE: HELP MODEL ANALYSIS

conditions model assumes that twelve inches of intermediate soil cover is in place. The hydraulic conductivity was modified from the HELP default value to be $1x10^{-5}$ cm/sec; which is higher than the actual hydraulic conductivities of on-site soils as detailed in Appendix III-D.5 – Geotechnical Analysis Report.

Final Cover Soil Layers

The closed conditions were modeled with a seven inch erosion layer (six inches required by regulations plus one inch to account for calculated erosion) and a 30 inch infiltration layer. The hydraulic conductivity was conservatively modified from the HELP default hydraulic conductivity to be $1x10^{-5}$ cm/sec; the geotechnical report indicates that existing on-site soils exhibit a much lower hydraulic conductivity.

Waste Layer

The waste layers were modeled at the following thicknesses for the three scenarios:

- ❑ Open Conditions – 10 feet
- ❑ Intermediate Conditions – 190 feet
- ❑ Closed Conditions – 380 feet

The HELP default soil texture 18 was used to represent the waste layers.

Protective Cover Soil Layer

The protective cover soil layer will consist of a 24 inch layer of on-site soils. The HELP default soil texture 28 was used for the protective cover soils based on the classification of on-site soils in the geology report.

Leachate Collection Layer

The leachate collection layer will consist of a double sided drainage geocomposite. The layer properties were modified to reflect the hydraulic conductivity values calculated in III-D.6-A.4 for the overlying loads in each model scenario. The geonet thickness was set to 0.265 inches for open conditions, 0.255 inches for intermediate conditions, and 0.240 inches for closed conditions, which are the minimum thicknesses calculated in Appendix III-D.6-A.4. The slope and drainage length for the geocomposite drainage layer were determined from the proposed drainage grades shown on drawings in Appendix III-D.3. The slopes of the leachate collection layer are either 2.0% or 2.5% and the drainage lengths ranged from 461 ft to 614 ft. Analyses were run for all the combinations of the slopes and lengths for Open Conditions, results showed that a slope of 2.5% and a drainage length of 461 ft resulted in the highest peak daily and average annual leachate generation rates, therefore the models for intermediate and closed conditions were run with the same parameters.

Composite Liner System

The composite liner will consist of two components per TCEQ 330.331(b). The upper layer will consist of a 60-mil thick High Density Polyethylene (HDPE) and the bottom layer will consist of a 24 inch thick re-compacted soil with a maximum hydraulic conductivity of 1 $x10^{-7}$ cm/sec.

- Geomembrane Layer

  The geomembrane liner will consist of a 60-mil HDPE geomembrane; HELP default soil texture 35 was used to model the geomembrane. It was conservatively assumed that the liner will have a "good" installation quality, with 3 pinholes per acre and 3 installation defects per acre. However, adherence to the CQA Plan (Appendix III-D.7) will greatly minimize the likelihood of holes and installation defects in the geomembrane liner.

- Compacted Soil Liner Layer

  The compacted soil layer (CSL) will consist of a 24 inch thick layer of compacted soil, with a recompacted hydraulic conductivity of at least $1x10^{-7}$ cm/sec, per 30 TAC Chapter 330. It should be noted that cells to contain Class I non-hazardous waste will have 36 inch layer of compacted soil. The 24-inch CSL was used to be conservative.

Moisture Content of Soil Layers

The initial moisture content for each soil layer was conservatively set equal to the field capacity of each soil layer for the open conditions model. The exception to this is the waste layer, where an initial moisture content of 20% was used for all scenarios based on the average moisture content of waste from the *HELP Model User's Guide for Version 3*. The moisture content of the other soil layers were generated by the HELP model.

Leachate Recirculation

Leachate recirculation is assumed to take place during all conditions; 100% of the leachate collected from the leachate collection layer is recirculated into the waste mass.

Additional analyses were ran which modeled introducing leachate into the waste layer. Leachate from the evaporation ponds or storage tanks may be introduced into the landfill, instead of being trucked offsite. Three scenarios were considered for introducing leachate into the landfill, the first was open conditions with 20 feet of waste, the second was intermediate conditions with 50 feet of

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TITLE: HELP MODEL ANALYSIS

waste and the third scenario was intermediate conditions with 100 feet of waste. All three scenarios were modeled for 1 year with 10 in/year of subsurface inflow to simulate the introduction of contaminated water other than what is being collected from the landfill. This is the equivalent of 744 gal/acre/day. All three of the scenarios showed that the landfill can handle the additional 744 gal/acre/day without the leachate head being greater than the thickness of the geocomposite.

HELP Model Results

The peak leachate generation rate of all modeled operating conditions (including open, intermediate, closed, open with introduced leachate, and intermediate with introduced leachate) is 8.9 cf/acre-day. This peak daily leachate generation rate is based on open conditions, and is the same whether or not leachate is introduced. The maximum leachate head on the liner is 0.009 inches, which is less than the maximum 30 cm required under 30 TAC Chapter 330 and the minimum compressed thickness of the geonet, which is 0.24 inches under closed conditions.

The HELP model soil layer inputs and results are summarized on **Table D.6-A.5-2**. The HELP model output files for all runs are provided in **Attachment III-D.6-B**.

Technically Complete, March 11, 2016

	ter Introduced to Waste at 744 gal/ac-day	
	Intermediate Conditions	
	)-ft Waste Layer	100-ft Waste Layer
General Design and Evapotranspiration Data		
Number of Years Modeled	1	1
Runoff Curve Number	85	85
Area Allowing Runoff (%)	75	75
Evaporative Zone Depth (in)	60	60
Maximum Leaf Area Index	1	1
Average Annual Wind Speed (mph)	11.6	11.6
Erosion Layer		
Layer No.	N/A	N/A
Layer Type (HELP Model Layer Type Value)		
HELP Soil Texture		
Thickness (in)		
Hydraulic Conductivity (cm/sec)		
Infiltration Layer		
Layer No.	N/A	N/A
Layer Type (HELP Model Layer Type Value)		
HELP Soil Texture		
Thickness (in)		
Hydraulic Conductivity (cm/sec)		
Intermediate/Daily Cover		
Layer No.	1	1
Layer Type	tical Percolation (1)	Vertical Percolation (1)
Layer Type (HELP Model Layer Type Value)	0	0
Thickness (in)	12	12
Hydraulic Conductivity (cm/sec)	$1x10^{-5}$	$1x10^{-5}$
Solid Waste		
Layer No.	2	2
Layer Type (HELP Model Layer Type Value)	tical Percolation (1)	Vertical Percolation (1)
Initial Water Content	0.2381	0.2508
HELP Soil Texture	18	18
Thickness (in)	600	1200
Hydraulic Conductivity (cm/sec)	$1x10^{-3}$	$1x10^{-3}$
Protective Soil Cover		
Layer No.	3	3
Layer Type (HELP Model Layer Type Value)	tical Percolation (1)	Vertical Percolation (1)
HELP Soil Texture	0	0
Thickness (in)	24	24
Hydraulic Conductivity (cm/sec)	$1x10^{-5}$	$1x10^{-5}$
Geocomposite (Geonet)		
Layer No.	4	4
Layer Type (HELP Model Layer Type Value)	teral Drainage (2)	Lateral Drainage (2)
HELP Soil Texture	0	0
Thickness (in)	0.265	0.265
Slope (%)	2.5	2.5
Drainage Length (ft)	461	461
Leachate Recirculation (Y/N)	Y	Y
Hydraulic Conductivity (cm/sec)	3.86	3.86
Geomembrane		
Layer No.	5	5
Layer Type (HELP Model Layer Type Value)	Fle Membrane Liner (4)	Flexible Membrane Liner (4)
HELP Soil Texture	35	35
Thickness (in)	0.06	0.06
Installation Quality	Good (3)	Good (3)
Defects per Acre	3	3
Pinholes per Acre	3	3
Hydraulic Conductivity (cm/sec)	$2x10^{-13}$	$2x10^{-13}$
Compacted Soil Liner		
Layer No.	6	6
Layer Type (HELP Model Layer Type Value)	rrier Soil Liner (3)	Barrier Soil Liner (3)
HELP Soil Texture	28	28
Thickness (in)	24	24
Hydraulic Conductivity (cm/sec)	$1x10^{-7}$	$1x10^{-7}$
Results		
Avg. Annual Leachate Production (cf/yr/ac)	16.20	16.20
Peak Daily Leachate Production (cf/day/ac)	5.91	5.91
Leachate Recirculated from Geonet (cf/day/ac)	5.91	5.91
Leachate Introduced (in/year/ac)	10.0	10.0
Total Leachate Recirculated (cfs/acre)	0.00122	0.00122
Max. Leachate Head on Liner (in)	0.009	0.009
Final Water Content of Waste	25.08%	25.72%

Technically Complete, March 11, 2016

THE HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) MODEL

USER'S GUIDE FOR VERSION 3

by

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- **Location**

- **Evaporative zone depth**. The user must specify an evaporative zone depth and can use the guidance given under the default option along with specific design information to select a value. The program does not permit the evaporative depth to exceed the depth to the top of the topmost barrier soil layer. Similarly, the evaporative zone depth would not be expected to extend very far into a sand drainage layer. The evaporative zone depth must be greater than zero. The evaporative zone depth is the maximum depth from which water may be removed by evapotranspiration. The value specified influences the storage of water near the surface and, therefore, directly affects the computations for evapotranspiration and runoff. Where surface vegetation is present, the evaporative depth should at least equal the expected average depth of root penetration. The influence of plant roots usually extends somewhat below the depth of root penetration because of capillary suction to the roots. The depth specified should be characteristic of the maximum depth to which the moisture changes near the surface due to drying over the course of a year, typically occurring during peak evaporative demand or when peak quantity of vegetation is present. Setting the evaporative depth equal to the expected average root depth would tend to yield a low estimate of evapotranspiration and a high estimate of drainage through the evaporative zone. An evaporative depth should be specified for bare ground to account for direct evaporation from the soil; this depth would be a function of the soil type and vapor and heat flux at the surface. The depth of capillary draw to the surface without vegetation or to the root zone may be only several inches in gravels; in sands the depth may be about 4 to 8 inches, in silts about 8 to 18 inches, and in clays about 12 to 60 inches. Rooting depth is dependent on many factors -- species, moisture availability, maturation, soil type and plant density. In humid areas where moisture is readily available near the surface, grasses may have rooting depth of 6 to 24 inches. In drier areas, the rooting depth is very sensitive to plant species and to the depth to which moisture is stored and may range from 6 to 48 inches. The evaporative zone depth would be somewhat greater than the rooting depth. The local Agricultural Extension Service office can provide information on characteristic rooting depths for vegetation in specific areas.

- **Maximum leaf area index**. The user must enter a maximum value of leaf area index (LAI) for the vegetative cover. LAI is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the land on which the vegetation is growing. The program provides the user with a maximum LAI value typical of the location selected if the value entered by the user cannot be supported without irrigation because of low rainfall or a short growing season. This statement should be considered only as a warning. The maximum LAI for bare ground is zero. For a poor stand of grass the LAI could approach 1.0; for a fair stand of grass, 2.0; for a good stand of grass, 3.5; and for an excellent stand of grass, 5.0. The LAI for dense stands of trees and shrubbery would also approach 5. The program is largely insensitive to values above 5. If

The initial moisture content of municipal solid waste is a function of the composition of the waste; reported values for fresh wastes range from about 0.08 to 0.20 vol/vol. The average value is about 0.12 vol/vol for compacted municipal solid waste. If using default waste texture 19, where 75% of the volume is inactive, the initial moisture content should be that of only the active portion, 25% of the values reported above.

The soil water storage or content used in the HELP model is on a per volume basis (θ), volume of water (V_w) per total (bulk--soil, water and air) soil volume ($V_t = V_s + V_w + V_a$), which is characteristic of practice in agronomy and soil physics. Engineers more commonly express moisture content on a per mass basis (w), mass of water (M_w) per mass of soil (M_s). The two can be related to each other by knowing the dry bulk density (ρ_{db}), dry bulk specific gravity (Γ_{db}) of the soil (ratio of dry bulk density to water density (ρ_w)), wet bulk density (ρ_{wb}), wet bulk specific gravity (Γ_{wb}) of the soil (ratio of wet bulk density to water density.

$$\theta = w \frac{\rho_{db}}{\rho_w} = w \, \Gamma_{db} \tag{2}$$

$$\theta = \frac{w}{1 + w} \frac{\rho_{wb}}{\rho_w} = \frac{w}{1 + w} \Gamma_{wb} \tag{3}$$

3.6 GEOMEMBRANE CHARACTERISTICS

The user can assign geomembrane liner characteristics (vapor diffusivity/saturated hydraulic conductivity) to a layer using the default option, the user-defined soil option, or the manual option. Saturated hydraulic conductivity for geomembranes is defined in terms of its equivalence to the vapor diffusivity. The porosity, field capacity, wilting point and intial moisture content are not needed for geomembranes. Table 4 shows the default characteristics for 12 geomembrane liners. The user assigns default soil characteristics to a layer simply by specifying the appropriate geomembrane liner texture number. The user-defined option accepts user specified geomembrane liner characteristics for layers assigned textures greater than 42. Manual geomembrane liner characteristics can be assigned any texture greater than 42.

Regardless of the method of specifying the geomembrane "soil" characteristics, the program also requires values for geomembrane liner thickness, pinhole density, installation defect density, geomembrane placement quality, and the transmissivity of geotextiles separating geomembranes and drainage limiting soils. These parameters are defined below.

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 6: LEACHATE COLLECTION SYSTEM FLOW RATES (III-D.6-A.6)

3-2-2015

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CB&I

Client:	**Rancho Viejo Waste Management, LLC**		
Project:	**Pescadito Environmental Resource Center**		
Project #:	**148866**		
Calculated By:	**LJC**	**Date:**	**1/25/15**
Checked By:	**RDS**	**Date:**	**2/6/15**

TITLE: LEACHATE COLLECTION SYSTEM FLOW RATES

Problem Statement

Determine the daily generation rate into leachate collection system components to ensure that they are adequately sized.

Given

- The HELP model results included in Attachment B to Appendix III-D.6.
- Leachate liner grades and cell configuration shown in Appendix III-D.3.

Assumptions

- The maximum leachate generation rate occurs during operational (open) conditions, as determined from multiple HELP Model Runs. See "HELP Model Analysis". The peak daily leachate generation rate associated with this run is 8.871 cf/acre-day
- All leachate collection system components will be uniformly sized. All will be sized to handle leachate conveyance volumes associated with the largest cell.
- The largest cell size is approximately 46 acres.

Results

The maximum peak daily leachate generation rate calculated by the HELP model is for the open conditions scenario:

Peak Daily Rate (from the HELP model) = 8.871(cf/acre-day)

(8.871 cf/acre-day) x (46 acres) x (1 day/ 86,400 sec) = 0.0047 cfs

Therefore, the peak leachate generation rate is 0.0047 cfs.

Technically Complete, March 11, 2016

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 7: GEOTEXTILE PERMITTIVITY (III-D.6-A.7)

3-2-2015

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Client:	Rancho Viejo Waste Management, LLC		
Project:	Pescadito Environmental Resource Center		
Project #:	148866		
Calculated By:	LJC	Date:	1/23/15
Checked By:	RDS	Date:	2/6/15

TITLE: GEOTEXTILE PERMITTIVITY

Problem Statement

Determine the necessary permittivity for the geotextile at installation to ensure continued performance after reduction factors are considered. Geotextile will be placed around the leachate drainage aggregate and is also a component of the geocomposite.

Given

- HELP Model results included in Appendix III-D.6-A5.
- Leachate flow rates calculated in Appendix III-D.6-A6.
  - Peak inflow rate = 0.0047 cfs
- Leachate design details shown in Drawings located in Appendix III-D.3.
  - The leachate chimney will extended the entire length of the leachate collection trench, from the high point in the middle of each cell to the toes on either end of each cell. The maximum length for a leachate chimney is 1,680 ft.
  - The width of leachate chimney = 2 ft
- Koerner, Robert M. (2005). *Designing with Geosynthetics.* Fifth Edition, Prentice Hall, New Jersey (see III-D.6-A.4).

Assumptions

- The maximum head will be equal to the allowable head on the geotextile which is 30 cm or approximately 1.0 ft, in accordance with TCEQ 330.331(a)(2).
- Geotextile performance reduction factors, typical for landfilling operations (see Table 2.12 from Koerner in III-D.6-A.4).

  RF_{SCB} = Soil clogging/binding reduction factor = Range, 2.0-10.0;
  RF_{CR} = Creep reduction factor = Range, 1.5-2.0;
  RF_{IN} = Intrusion reduction factor = Range, 1.0-1.2;
  RF_{CC} = Chemical clogging reduction factor = Range, 1.2-1.5; and
  RF_{BC} = Biological Clogging reduction factor = Range, 2.0-5.0.

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TITLE: GEOTEXTILE PERMITTIVITY

Calculations

1. Leachate Collection Trench Geotextile

First, calculate the needed permittivity for the geotextile to pass the flow rates calculated in "LCS Flow Rates" using Equation 2.16 from Koerner:

$$\Psi = \frac{q}{\Delta h A}$$

Where: Ψ = Permittivity
q = Peak inflow rate = 0.0047 cfs
Δh = maximum allowable head on geotextile = 1.0 ft
L = Total chimney length = 1,680 ft
W = Design width of leachate chimney = 2 ft
A = inflow area into trench = L x W = 1,680 ft x2 ft= 3,360 ft^2

$$\Psi_{reduced} = \frac{q}{\Delta h A} = \frac{0.0047cfs}{1ft \times 3{,}360ft^2} = 1.399 \times 10^{-6}\frac{1}{sec}$$

Next, determine the amount that the specified permittivity must be increased to account for performance reduction factors that will be encountered during landfill operations. Reduction factors are taken from Table 2.12 from Koerner and calculated using Equation 2.25a from the same refrerence. Due to the wide range of values for the reduction factors, the low, median, and high values are selected to determine a range of anticipated effective permittivities:

$$\Psi_{reduced} = \Psi_{installed}\left(\frac{1}{RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}}\right)$$

Therefore:

$$\Psi_{installed} = (\Psi_{reduced}) \, x \, RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}$$

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TITLE: GEOTEXTILE PERMITTIVITY

Table D.6-A.7-1 – Required Installed Permittivity for Leachate Collection Trench

Run	RF_{SCB}	RF_{CR}	RF_{IN}	RF_{CC}	RF_{BC}	$\Psi_{reduced}$	$\Psi_{installed}$
Low Reduction	2.0	1.5	1.0	1.2	2.0	$1.399 \times 10^{-6}\frac{1}{sec}$	$1.0 \times 10^{-5}\frac{1}{sec}$
Average Reduction	6.0	1.75	1.1	1.35	3.5	$1.399 \times 10^{-6}\frac{1}{sec}$	$7.6 \times 10^{-5}\frac{1}{sec}$
High Reduction	10.0	2.0	1.2	1.5	5.0	$1.399 \times 10^{-6}\frac{1}{sec}$	$2.5 \times 10^{-4}\frac{1}{sec}$

2. Geocomposite Geotextile

First, calculate the needed permittivity for the geotextile using Equation 2.16 from Koerner, assuming no performance reduction:

$$\Psi = \frac{q}{\Delta h A}$$

Where: Ψ = Permittivity
q = Peak inflow rate = 0.0047 cfs
Δh = maximum allowable head on geotextile = 1.0 ft
A = maximum cell area = 46acres = 2,003,760 ft^2

$$q_{reduced} = \frac{q}{\Delta h A} = \frac{0.0047\ cfs}{1ft \times 2{,}003{,}760 ft^2} = \frac{2.35 \times 10^{-9}}{sec}$$

Next, determine the amount that the specified permittivity must be increased to account for performance reduction factors that will be encountered during landfill operations. Reduction factors are taken from Table 2.12 from Koerner and calculated using Equation 2.25a from the same refrerence. Due to the wide range of values for the reduction factors, the low, median, and high values are selected to determine a range of anticipated effective permittivities:

$$\Psi_{installed} = (\Psi_{reduced})\ x\ RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}$$

Client:	**Rancho Viejo Waste Management, LLC**
Project:	**Pescadito Environmental Resource Center**
Project #:	**148866**
Calculated By:	**LJC** — **Date: 1/23/15**
Checked By:	**RDS** — **Date: 2/6/15**

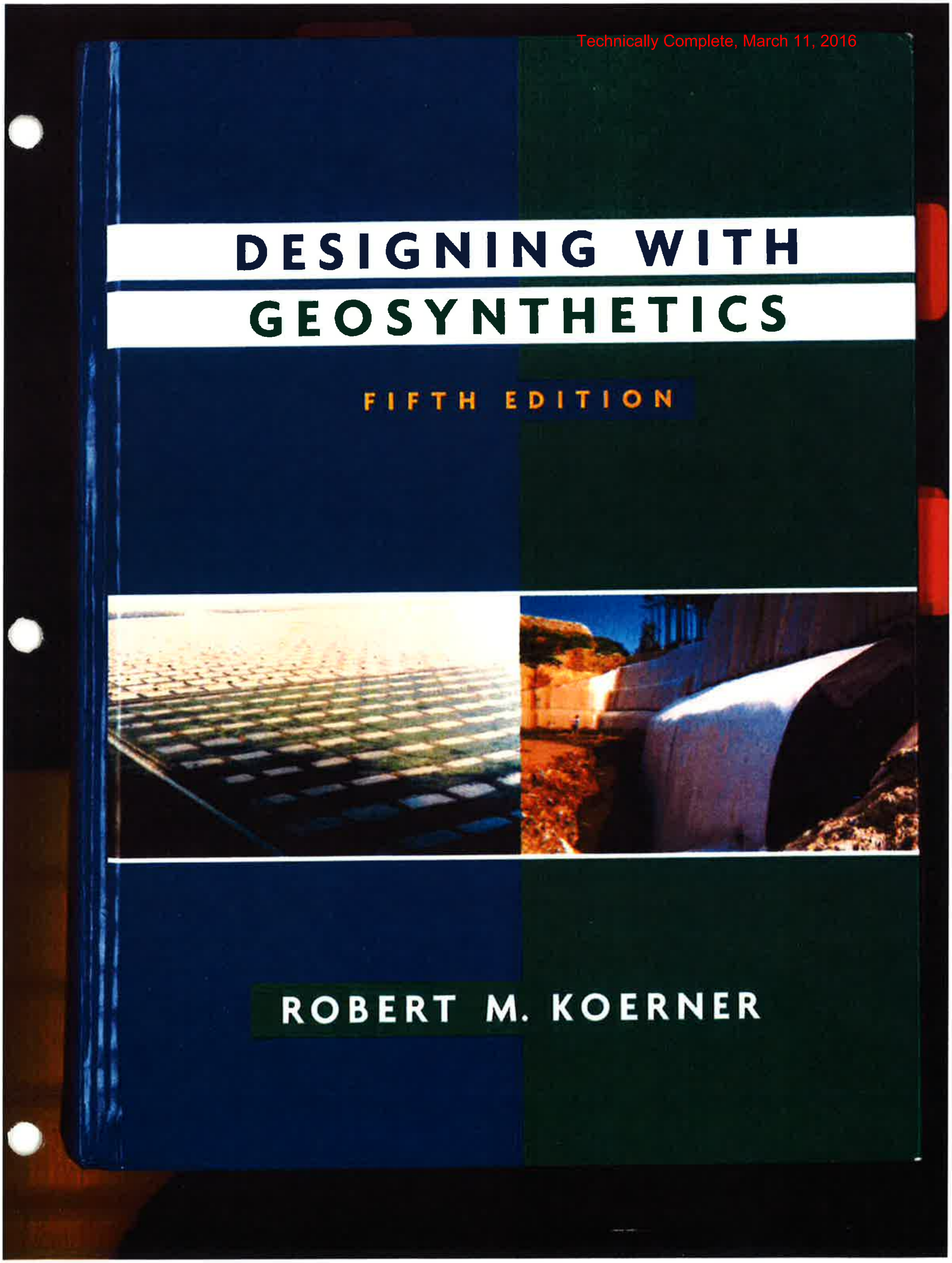
TITLE: GEOTEXTILE PERMITTIVITY

Table D.6-A.7-2 – Required Installed Permittivity for Geocomposite							
Run	**RF_{SCB}**	**RF_{CR}**	**RF_{IN}**	**RF_{CC}**	**RF_{BC}**	$\Psi_{reduced}$	$\Psi_{installed}$
Low Reduction	2.0	1.5	1.0	1.2	2.0	$2.35 \times 10^{-9} \frac{1}{sec}$	$1.69 \times 10^{-8} \frac{1}{sec}$
Average Reduction	6.0	1.75	1.1	1.35	3.5	$2.35 \times 10^{-9} \frac{1}{sec}$	$1.28 \times 10^{-7} \frac{1}{sec}$
High Reduction	10.0	2.0	1.2	1.5	5.0	$2.35 \times 10^{-9} \frac{1}{sec}$	$4.23 \times 10^{-7} \frac{1}{sec}$

Results

The initial permittivity of an installed geotextile will be reduced based on multiple performance factors. This calculation has identified the minimum acceptable initial permittivity at the time of installation in order to pass the leachate flow rates at the Pescadito Landfill once performance factors are considered. The most conservative reduction factors identify a minimum acceptable permittivity for the leachate collection trench to be 2.5×10^{-4}/s and 4.23×10^{-7}/s for the geocomposite, respectively. Engineer discretion may be used to refine performance factor assumptions based on site specific or other appropriate data.

Technically Complete, March 11, 2016



Library of Congress Cataloging-in-Publication Data

Koerner, Robert M., 1933-
Designing with geosynthetics / Robert M. Koerner.—5th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-13-145415-3
1. Geosynthetics. I. Title.

TA455.G44K64 2005
624.1'8923--dc22 2005045837

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About the Cover: *Cover images courtesy of the author.*

Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, NJ 07458

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-145415-3

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte. Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
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compressibility section, however, fabrics deform under load (recall Figure 2.6). Thus a new term, permittivity (Ψ) as was previously defined as equation (2.8), is repeated here:

$$\Psi = \frac{k_n}{t}$$

where

Ψ = permittivity (sec^{-1}),
k_n = permeability (properly called *hydraulic conductivity*) normal to the geotextile where the subscript n is often omitted (m/sec), and
t = thickness of the geotextile (m).

The above equation is used in Darcy's formula as follows:

$$q = k_n i A$$

$$q = k_n \frac{\Delta h}{t} A$$

$$\frac{k_n}{t} = \Psi = \frac{q}{(\Delta h)(A)} \qquad (2.16)$$

where

q = flow rate (m^3/sec),
i = hydraulic gradient (dimensionless),
Δh = total head lost (m), and
A = total area of geotextile test specimen (m^2).

The formulation above is used for constant head tests in an identical manner as with soil permeability testing. Typically, the flow rate (q) is measured at one value of Δh, and then the test is repeated at different values of Δh. These different values of Δh produce correspondingly different values of q. When plotted as ($\Delta h A$) on the horizontal axis and (q) on the vertical axis, the slope of the resulting straight line yields the desired value of Ψ.

The test can also be conducted using a falling (variable) head procedure as is also performed on soils. In this case, Darcy's formula is integrated over the head drop in an interval of time and used in the following equation:

$$\frac{k_n}{t} = \Psi = 2.3 \frac{a}{A \Delta t} \log_{10} \frac{h_o}{h_f} \qquad (2.17)$$

where

Ψ = permittivity (sec^{-1}),
a = area of water supply standpipe (m^2),

and Risseeuw [65]). Although the equation indicates tensile strength, it can be applied to burst strength, tear strength, puncture strength, impact strength, and so on.

2.4.2 Flow-Related Problems

For problems dealing with flow through or within a geotextile, such as filtration and drainage applications, the formulation of the allowable values takes the form of equation (2.25a). Typical values for reduction factors are given in Table 2.12. Note that these values must be tempered by the site-specific conditions, as in Section 2.4.1. If the laboratory test includes the mechanism listed, it appears in the equation as a value of 1.0.

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{\text{RF}_{SCB} \times \text{RF}_{CR} \times \text{RF}_{IN} \times \text{RF}_{CC} \times \text{RF}_{BC}}\right) \tag{2.25a}$$

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{\Pi \text{RF}}\right) \tag{2.25b}$$

where

q_{allow} = allowable flow rate,
q_{ult} = ultimate flow rate,
RF_{SCB} = reduction factor for soil clogging and blinding (≥ 1.0),
RF_{CR} = reduction factor for creep reduction of void space (≥ 1.0),
RF_{IN} = reduction factor for adjacent materials intruding into geotextile's void space (≥ 1.0),
RF_{CC} = reduction factor for chemical clogging (≥ 1.0),

TABLE 2.12 RECOMMENDED FLOW-REDUCTION FACTOR VALUES FOR USE IN EQUATION (2.25a)

	Range of Reduction Factors				
Application	Soil Clogging and Blinding(1)	Creep Reduction of Voids	Intrusion into Voids	Chemical Clogging(2)	Biological Clogging
Retaining wall filters	2.0–4.0	1.5–2.0	1.0–1.2	1.0–1.2	1.0–1.3
Underdrain filters	2.0–10	1.0–1.5	1.0–1.2	1.2–1.5	2.0–4.0(3)
Erosion control filters	2.0–10	1.0–1.5	1.0–1.2	1.0–1.2	2.0–4.0
Landfill filters	2.0–10	1.5–2.0	1.0–1.2	1.2–1.5	2.0–5.0(3)
Gravity drainage	2.0–4.0	2.0–3.0	1.0–1.2	1.2–1.5	1.2–1.5
Pressure drainage	2.0–3.0	2.0–3.0	1.0–1.2	1.1–1.3	1.1–1.3

1. If stone riprap or concrete blocks cover the surface of the geotextile, use the upper values or include an addition reduction factor.
2. Values can be higher, particularly for high alkalinity groundwater.
3. Values can be higher for turbidity and/or microorganism contents greater than 5000 mg/l.

One way of doing this is to ascribe reduction factors on each of the items not adequately assessed in the laboratory test. For example,

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\text{RF}_{IN} \times \text{RF}_{CR} \times \text{RF}_{CC} \times \text{RF}_{BC}}\right] \tag{4.5}$$

or if all of the reduction factors are considered together:

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{\Pi\text{RF}}\right] \tag{4.6}$$

where

q_{ult} = flow rate determined using ASTM D4716 or ISO 12958 for short-term tests between solid platens using water as the transported liquid under laboratory test temperatures,

q_{allow} = allowable flow rate to be used in equation (4.3) for final design purposes,

RF_{IN} = reduction factor for elastic deformation, or intrusion, of the adjacent geosynthetics into the geonet's core space,

RF_{CR} = reduction factor for creep deformation of the geonet and/or adjacent geosynthetics into the geonet's core space,

RF_{CC} = reduction factor for chemical clogging and/or precipitation of chemicals within the geonet's core space,

RF_{BC} = reduction factor for biological clogging within the geonet's core space, and

ΠRF = product of all reduction factors for the site-specific conditions.

Some guidelines as to the various reduction factors to be used in different situations are given in Table 4.2. Please note that some of these values are based on relatively sparse information. Other reduction factors, such as overlapping connections, temperature effects, and liquid turbidity, could also be included. If needed, they can be included on a site-specific basis. On the other hand, if the actual laboratory test procedure has included the particular item, it would appear in the above formulation as a value of unity. Examples 4.2 and 4.3 illustrate two of the uses of geonets and serve to point out that high reduction factors are warranted in critical situations.

Example 4.2

What is the allowable geonet flow rate to be used in the design of a secondary leachate collection (or leak detection) system? Assume that laboratory testing at proper design load and proper hydraulic gradient gave a short-term between-rigid-plates value of 2.5×10^{-4} m²/s.

TABLE 4.2 RECOMMENDED REDUCTION FACTOR VALUES FOR EQUATION (4.5) DETERMINING ALLOWABLE FLOW RATE OR TRANSMISSIVITY OF GEONETS

Application Area	Reduction Factor Values in Equation (4.5)			
	RF_{IN}*	RF_{CR}*	RF_{CC}	RF_{BC}
Sport fields	1.0–1.2	1.0–1.5	1.0–1.2	1.1–1.3
Capillary breaks	1.1–1.3	1.0–1.2	1.1–1.5	1.1–1.3
Roof and plaza decks	1.2–1.4	1.0–1.2	1.0–1.2	1.1–1.3
Retaining walls, seeping rock, and soil slopes	1.3–1.5	1.2–1.4	1.1–1.5	1.0–1.5
Drainage blankets	1.3–1.5	1.2–1.4	1.0–1.2	1.0–1.2
Infiltrating water drainage for landfill covers	1.3–1.5	1.1–1.4	1.0–1.2	1.5–2.0
Secondary leachate collection (landfill)	1.5–2.0	1.4–2.0	1.5–2.0	1.5–2.0
Primary leachate collection (landfills)	1.5–2.0	1.4–2.0	1.5–2.0	1.5–2.0

*These values are sensitive to the type of geonet, rib separation distance, and density of the resin used in the geonet's manufacture. The magnitude of the applied load is also of major importance.

Solution: Average values from Table 4.2 are used in equation (4.5) (however, note the large reduction).

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right]$$
$$= 2.5 \times 10^{-4}\left[\frac{1}{1.75 \times 1.7 \times 1.75 \times 1.75}\right]$$
$$= 2.5 \times 10^{-4}\left[\frac{1}{9.11}\right]$$
$$q_{\text{allow}} = 0.27 \times 10^{-4}\ \text{m}^2/\text{s}$$

Example 4.3

What is the allowable geonet flow rate to be used in the design of a capillary break beneath a roadway to prevent frost heave? Assume that laboratory testing was done at the proper design load and hydraulic gradient and that this testing yielded a short-term between-rigid-plates value of 2.5×10^{-4} m²/s.

Solution: Since better information is not known, average values from Table 4.2 are used in equation (4.5).

$$q_{\text{allow}} = q_{\text{ult}}\left[\frac{1}{RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC}}\right]$$
$$= 2.5 \times 10^{-4}\left[\frac{1}{1.2 \times 1.1 \times 1.3 \times 1.2}\right]$$
$$= 2.5 \times 10^{-4}\left[\frac{1}{2.06}\right]$$
$$q_{\text{allow}} = 1.21 \times 10^{-4}\ \text{m}^2/\text{s}$$

ATTACHMENT A

TO APPENDIX III-D.6

CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 8: LEACHATE COLLECTION SYSTEM DESIGN (III-D.6-A.8)

3-2-2015

STATE OF TEXAS
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CB&I

Client:	**Rancho Viejo Waste Management, LLC**		
Project:	**Pescadito Environmental Resource Center**		
Project #:	**148866**		
Calculated By:	**LJC**	**Date:**	**1/29/15**
Checked By:	**RDS**	**Date:**	**2/6/15**

TITLE: LEACHATE COLLECTION SYSTEM DESIGN

Problem Statement

Determine whether the following components of the leachate collection system for the Pescadito Environmental Resource Center landfill are appropriately sized.

1. Leachate Collection Pipe
2. Leachate Sump

Given

- ❑ HELP Model results included in III-D.6-A.5.
- ❑ Leachate flow rates calculated in III-D.6-A.6.
- ❑ Leachate design grades shown in drawings in Appendix III-D.3

Assumptions

- ❑ The largest cell is approximately 46 acres and produces a peak flow rate of 0.0047 cfs (see Leachate Flow Rate calculation).
- ❑ Each leachate collection trench is comprised of a pipe placed in aggregate and wrapped with geotextile, as detailed in the drawings provided in Appendix III-D.3.
- ❑ The leachate collection pipes must be sized to collect and convey all leachate from its contributing cell area without backing up.
- ❑ The leachate collection pipe within the trench is 6-inch SDR-7.3. This pipe has an inner diameter of 4.7 inches or 0.4 feet and an outer diameter of 0.54 feet.
- ❑ The typical Manning's roughness coefficient for HDPE pipe is 0.009.
- ❑ The leachate collection pipe has a 0.5 percent slope.
- ❑ The minimum permeability of the aggregate used in the sumps shall be 0.01 cm/sec and the porosity shall be 0.3.
- ❑ The leachate sump will be sized to store the volume from the peak leachate flow rate for the largest cell over 3 days. The peak flow rate occurs during open conditions, therefore the

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TITLE: LEACHATE COLLECTION SYSTEM DESIGN

sump will provide sufficient storage during open conditions and will have more than sufficient storage during subsequent conditions.

Calculations

1. Leachate Collection Pipe

Determine the full flow capacity of the 0.4-ft inner diameter pipe using Manning's equation:

$$Q = \left(\frac{1.486}{n}\right) A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where: Q = Peak flow rate during open conditions = 0.0047 cfs;
n = Manning's number = 0.009
A = cross-sectional area of pipe = $\pi d^2/4$ ft^2 = $(\pi(0.4ft)^2/4)$ = 0.125 ft^2
R = hydraulic radius of pipe = d/4 ft = 0.4/4 = 0.10
S = slope of pipe = 0.005

$$Q = \left(\frac{1.486}{n}\right) A R^{\frac{2}{3}} S^{\left(\frac{1}{2}\right)}$$

$$Q = \left(\frac{1.486}{0.009}\right)(0.125)(0.1)^{\frac{2}{3}}(0.005)^{\left(\frac{1}{2}\right)}$$

$$Q = 0.314\ cfs$$

It is noted that the capacity of the pipe to convey 0.314 cfs significantly exceeds the peak flow rate that will develop for a 46 acre cell (0.0047 cfs). Therefore, it is appropriately sized to handle peak flow rates.

2. Leachate Sump

Determine the required dimensions for a 4-foot deep sump to accommodate the maximum volume of leachate produced over 3 days during the open conditions.

Calculate the volume of 3 days of leachate.

$$V = Q \times 3\ days$$

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TITLE: LEACHATE COLLECTION SYSTEM DESIGN

Where: Q = Peak flow rate during open conditions for the largest cell = .0047 cfs;

$$V = .0047\ cfs \times 3\ days\ \times (\frac{24hrs}{1day}) \times (\frac{60min}{1hr}) \times (\frac{60sec}{1min}) = 1218.24\ cf$$

Calculate the volume of a sump (truncated pyramid) that is 45 feet wide by 45 feet long at the top with a depth of 4 feet and sidelsopes of 3H:1V.

$$V = \frac{1}{3}(a^2 + ab + b^2)h$$

Where: a = 45 ft
b = 45 ft-(2*(slope*height)) = (45 ft-(2*(3 ft*4 ft)) = 21'
h = 4 ft

$$V_{sump} = \frac{1}{3}(45^2 + 45 * 21 + 21^2)4 = 4{,}548\ ft^3$$

Calculate the available volume in the sump.

$$V_{avail} = V_{sump} \times P$$

Where: V_{sump} =4,548 ft^3
P = Porosity of gravel fill in sump = 0.3

$$V_{avail} = 4{,}548\ ft^3 \times 0.3 = 1364.4\ ft^3$$

The available volume of the leachate sump is 1364.4 ft^3, which is greater than the required 1218.2 ft^3.

Results

The leachate collection pipe and leachate sump are both designed to adequately handle the maximum leachate production of the largest cell during operational conditions.

ATTACHMENT A
TO APPENDIX III-D.6
CONTAMINATED WATER/LEACHATE COLLECTION SYSTEM DESIGN ANALYSIS

PROBLEM STATEMENT 9: LEACHATE TANK SIZE (III-D.6-A.9)

3-2-2015

STATE OF TEXAS
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Client:	Rancho Viejo Waste Management, LLC		
Project:	Pescadito Environmental Resource Center		
Project #:	148866		
Calculated By:	LJC	Date:	1/5/15
Checked By:	RDS	Date:	2/6/15

TITLE: **LEACHATE TANK SIZE**

Problem Statement

Determine size of the leachate storage tanks and the volume of the secondary containment area.

Given

- The peak daily leachate generation rate is 8.871 cf/day/ac from III–D.6-A.6 – Leachate Collection System Flow Rates.
- Design Drawings provided in Appendix III-D.3
- The depth of the 100-year, 24-hour rainfall event is 9.8 in.
- Secondary containment will be provided to accommodate 110% of one tanks volume or the volume of 1 tank plus the rainfall for the 100-year, 24-hour event

Assumptions

- There will be 2 equally sized leachate storage tanks
- The rational method will be used to determine the amount of rainfall generated from a 100-year, 24-hour storm event
- The tanks will provide enough storage to accommodate the leachate generated for 7 days during open conditions
- The area where tanks and spill containment will be placed is 1,482 sf, determined from Drawings in Appendix III-D.3.

Calculations

1. Tank Volume

$$V_{tank} = Q_{leach} \times A_{LF} \times 1\,week$$

Where: V_{tank} = Volume of the leachate storage tanks
Q_{leach} = Peak daily leachate generation rate (cf/day/ac)
A_{LF} = Area of the largest cell (46 acres)

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Checked By:	RDS	Date:	2/6/15

TITLE: LEACHATE TANK SIZE

$$V_{tank} = 8.871\ \frac{cf}{day \cdot ac} \times\ 46\ ac\ \times 1\ week\ \times \frac{7\ days}{1\ week} = 2{,}856\ ft^3 = 21{,}367\ gal$$

Two 15,000 gallon storage tanks will adequately store one week's worth of leachate generated at the landfill at the peak generation rate for one week.

2. Secondary Containment Size

Method A

Secondary containment shall be large enough to hold 110% of one tank:

One tank is 15,000 gallons, therefore the secondary containment required will be 16,500 gallons or 2,206 ft^3.

Method B

Secondary containment will be large enough to hold the volume of one 15,000 gallon (2,005 ft^3) tank plus the runoff from the 100-year, 24-hour storm event.

The formula for the rational method is:

$$Q = CiA$$

Where: *Q = total volume of runoff*
C = runoff coefficient, 1.0 (no runoff)
i = depth of water for the 100-year, 24-hour storm event, 9.8 in
A = area the rainfall is landing on (sf)

$$Q = 1.0\ \times 9.8\ in \times 1{,}482\ sf\ = 1{,}210\ ft^3$$

The total volume required is 2,005 ft^3 + 1,210 ft^3 = 3,215 ft^3

3. Secondary Containment Determination

The height of the wall for secondary containment will be determined by the largest volume of storage required (Method B) divided by the total area available for storage.

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Checked By:	RDS	Date:	2/6/15

TITLE: **LEACHATE TANK SIZE**

The area available for storage is the total area minus the footprint one of the 16 ft diameter tanks.

$$A_{avail} = 1{,}482\ ft^2 - (\pi r^2) = 1{,}482\ ft^2 - \pi(8\ ft)^2 = 1{,}281\ ft^2$$
$$h_{req} = 3{,}215\ ft^3/1{,}281\ ft^2 = 2.44\ ft{\sim}2.5ft$$

Results

Two 16-ft diameter, 15,000 gallon tanks are appropriately sized to contain one week's worth of leachate. Secondary containment is appropriately sized when placed in the location shown on the Design Drawings to a height of three feet. Tanks of different size and quantity may be used as long as the required secondary containment is provided.