ATTACHMENT 9

Shaw®

Shaw® Shaw Environmental, Inc.

Client:	Clinton Landfill No. 3, Inc		
Project:	Clinton Landfill No. 3 Chemical Waste Unit		
Proj. #:	128017		
Calculated By:	JWP	Date:	2/6/09
Checked By:	JPV	Date:	2/9/09

TITLE: STRENGTH PARAMETERS OF THE 18" RISER PIPES

Problem Statement:

Demonstrate that the proposed leachate cleanouts will have sufficient access and strength to resist crushing, kinking and consolidation downdrag forces.

EARTHLOADS CALCULATION

Determine the maximum earthload (W) on the 18" risers due to landfill at final grade.

Given:

1. *Gravity Sanitary Sewer Design and Construction*, ASCE Manuals and Reports on Engineering Practice - No. 60, pp. 166-191 (refer to October, 2007 application).
2. *Caterpillar Performance Handbook*, Edition 37 (refer to October, 2007 application).
3. KWH Sclairpipe® product information (refer to attached pages).
4. Maximum waste thickness (MSW and chemical waste) overlying leachate collection sumps taken from design specifications.
5. Landfill design specifications contained in the October, 2007 application.
6. Laboratory test data contained in the October, 2007 application.

Assumptions:

Final Landform

1. Marston's formula utilized to calculate the prism load (reference ASCE No. 60):

$$W_c = C_c w B_c^2$$

Where,

W_c = Load on pipe (psf)
C_c = Load coefficient, obtained from figure 9-7 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)

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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. Therefore, Marston's formula equals:

$$W_c = HwB_c$$

2. B_c = 18 in = 1.5 ft for an 18-inch SDR 17 pipe (reference KWH Sclairpipe®)

3. Moist unit weight of final cover soil is based on the average dry density and water content values determined from Standard Proctor data (refer to Appendix H of the October, 2007 application).

$$\gamma_m = \gamma_d(1 + w)$$

4. The chemical waste will have a maximum thickness over the riser pipes of 115.8 feet.

5. The MSW waste will have a maximum thickness over the riser pipes of 12.8 feet.

6. Unit weight of the chemical waste is conservatively assumed to be 90 pcf.

7. Unit weight of the MSW is conservatively assumed to be 75 pcf.

Calculations:

Loading on Pipe due to Landfill at Final Grade (W)

MAXIMUM LOAD ON LEACHATE COLLECTION PIPE - FINAL GRADE			
Layer	**Thickness, t (ft)**	**Density, γ (pcf)**	**t x γ (psf)**
Final Cover	4	128	512
MSW Waste	12.8	75	960
Chemical Waste	115.8	90	10,422
Granular Drainage Material	1	130	130
Total Thickness =	**133.6 feet**	**∑(t x γ) =**	**12,024 psf**
		∑(t x γ) / total thickness = Average Density (w) =	**90.0 pcf**

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For a 6-inch SDR 11 Pipe:

$W = H^*w^*B_c$ = (133 ft) (90.0 pcf) (1.54 ft) = 18,433 lb/ft = 1,536.1 lb/in

Results:

The maximum load on the leachate collection pipe (W) was determined to be 1,543.1 lb/in for an 18-inch SDR 17 pipe. The maximum load corresponds to the load imposed by the weight of the landfill after final cover has been placed. The results are summarized below.

For an 18-inch SDR 17 Pipe:

W = 1,536.1 lb/in

WALL BUCKLING, WALL CRUSHING AND RING DEFLECTION

Problem Statement

Determine if the proposed leachate collection pipe possesses sufficient strength to support the overlying landfill materials, in accordance with 35 Ill. Admin. Code Section 811.308 (e), considering the following failure modes:

1. Wall buckling
2. Wall crushing
3. Ring Deflection

Given

1. Calculation *Earthloads on the Leachate Collection System* contained in this response.
2. KWH Sclairpipe® product information (refer to attached pages).
3. ISCO product information (refer to attached pages).
4. ASTM Standard F 1962-99, *Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings* (see October, 2007 application).

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5. Harrison, Steven and Watkins, Reynold K., *HDPE Leachate Collection Pipe Design By Fundamentals of Mechanics*, presented at the Nineteenth International Madison Waste Conference, September 25-26, 1996.

6. Formula used to calculate the safe allowable buckling load for the pipe (reference KWH Sclairpipe®):

$$q_a = (DF)\left(\frac{32R_w B'E'EI}{D_{avg}^3}\right)^{0.5}$$

Where,

q_a = Safe allowable buckling load (psi)
DF = Design Factor
R_w = Water Buoyancy factor = $1-0.33(h_w/h)$
B' = Coefficient of elastic support = $(1+4e^{-0.065H})^{-1}$
D_{avg} = Mean pipe diameter = O.D. - t_{min}
E = Long-term modulus of elasticity of the pipe material (psi)
I = Moment of inertia of the pipe wall for ring bending (in^4/inch) = $t_{min}^3/12$

e = 2.718
H = Height of fill above pipe (ft)
h = Height of fill above pipe (in)
h_w = Height of water above pipe (in)
E' = Modulus of soil reaction (psi)

An equivalent form of the equation is derived as follows:

$$\frac{32I}{D_{avg}^3} = \frac{32\left(\frac{t_{min}^3}{12}\right)}{(O.D.-t_{min})^3} = 2.67\left(\frac{t_{min}}{(O.D.-t_{min})}\right)^3 = \frac{2.67}{\left(\frac{O.D.}{t_{min}}-1\right)^3} = \frac{2.67}{(SDR-1)^3}$$

$$\therefore q_a = (DF)\left(\frac{2.67R_w B'E'E}{(SDR-1)^3}\right)^{0.5}$$

Where,

SDR = (Standard) Dimension Ratio = (pipe outer diameter)/(pipe wall thickness)

7. Formula used to calculate compressive stress which will exist in the leachate collection pipe due to overlying loads (reference KWH Sclairpipe®):

Where,

σ_c = compressive stress acting on leachate collection pipe (psi)

$$\sigma_c = \frac{W}{2t_{min}}$$

W = Maximum earthloads acting on leachate collection pipe (lb/in)
t_{min} = thickness of leachate collection pipe wall (inch)

8. Modified Iowa formula was conservatively used to calculate the deflection of a cylindrical horizontal pipe under earth load (reference KWH Sclairpipe®):

$$\Delta y = \frac{D_l W K_x r^3}{EI + 0.061E' r^3}$$

Where,
Δy = Vertical deflection of pipe (in)
D_l = Deflection lag factor
W = Earthload on pipe (lb/in)
K_x = Bedding constant
r = Mean pipe radius (in) = (O.D. - t_{min})/2
O.D. = Pipe outer diameter (in)
t_{min} = Minimum wall thickness of pipe (in)
E = Modulus of elasticity of polyethylene (psi)
I = Moment of inertia of pipe wall = $t_{min}^3/12$
E' = Modulus of soil reaction (psi)

An equivalent form of the equation is derived as follows:

$$\Delta y = \frac{D_l W K_x r^3}{EI + 0.061E' r^3} = \frac{D_l W K_x}{\frac{EI}{r^3} + 0.061E'}$$

$$Where \quad \frac{I}{r^3} = \frac{\frac{t_{min}^3}{12}}{\left(\frac{O.D.-t_{min}}{2}\right)^3} = \frac{2}{3}\left(\frac{1}{\frac{O.D.}{t_{min}}-1}\right)^3 = \frac{2}{3}\left(\frac{1}{SDR-1}\right)^3.$$

$$\therefore \Delta y = \frac{D_l W K_x}{\frac{2E}{3(SDR-1)^3} + 0.061E'}$$

9. The worst case scenario is the leachate collection piping within the Chemical Waste Unit which specifies an 18-inch SDR 17 HDPE pipe.

10. DF = 0.4 (reference KWH Sclairpipe®)

11. hw = 1.0 inch (conservative estimate)

12. H = 133.6 ft (reference attached "Earthloads" calculation)

13. h =1,603.2 inches

14. E = 30,000 psi (reference KWH Sclairpipe®)

15. E' = 3,000 psi (reference KWH Sclairpipe®)

16. O.D. = 18 inches for an 18-inch SDR 17 Pipe (reference KWH Sclairpipe®)

17. t_{min} = 01.059 inches for an 18-inch SDR 17 Pipe (reference ISCO pipe specifications)

18. W = 1,536.1 lb/in for an 18-inch SDR 17 Pipe (reference "Earthloads" calculation)

19. σ_c (max allowable) = 800 psi (reference KWH Sclairpipe®)

20. D_l = 1.5 (reference KWH Sclairpipe®)

21. K_x = 0.083 (reference KWH Sclairpipe®)

22. Landfill design literature recommends a maximum allowable pipe deflection of 7% of the pipe diameter to allow for cleaning (refer to Harrison and Watkins in the October, 2007 application).

Calculations

Wall Buckling

Calculate q_a for an 18-inch SDR 17 Pipe:

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$$R_w = 1 - 0.33\left(\frac{h_w}{h}\right) = 1 - 0.33\left(\frac{1}{1,603.2}\right) = 0.99979$$

$$B' = \left(1 + 4e^{-0.065H}\right)^{-1} = \left(1 + 4\left(2.718\right)^{-0.065\cdot 133.61}\right)^{-1} = 1.0$$

$$q_a = (DF)\left(\frac{2.67R_wB'E'E}{(SDR-1)^3}\right) = (0.4)\left(\frac{(2.67)(0.99979)(1)(3,000)(30,000)}{(17-1)^3}\right)^{0.5} = 96.9$$

Verify that the landfill load is less than the safe allowable buckling load for an 18-inch SDR 17 Pipe:

$$R_w\left(\frac{W}{D_{avg}}\right) \le q_a$$

$$R_w\left(\frac{W}{D_{avg}}\right) = 0.99979\left(\frac{1,536.1}{18-1.059}\right) = 90.65$$

$$\text{Factor of Safety} = \frac{96.9}{90.69} = 1.07$$

Wall Crushing

Verify that the compressive stress, σ_c, is less than 800 psi for an 18-inch SDR 17 Pipe:

$$\sigma_c = \frac{W}{2t_{min}} = \frac{1,543.1}{2(1.059)} = 729\text{ psi}$$

$$\text{Factor of Safety} = \frac{800}{729} = 1.10$$

Ring Deflection

For an 18-inch SDR 17 Pipe the deflection is calculated as follows:

$$Dy = \frac{D_lWK_x}{\frac{2E}{3(SDR-1)^3} + 0.061E'} = \frac{(1.5)(1,536.1)(0.083)}{\frac{2(30,000)}{3(17-1)^3} + 0.061(3,000)} = 1.018\text{ in}$$

$$\%\text{Deflection} = \frac{1.018\text{ in}}{18\text{ in}}(100\%) = 5.65\%$$

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Results

In accordance with 35 Ill. Admin. Code Section 811.308 (e), 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 and the calculated ring deflection for an 18-inch SDR 17 Pipe.

18-inch SDR-17	
Pipe Failure Mode	**Factor of Safety/Deflection**
Wall Buckling	FS = 1.06
Wall Crushing	FS = 1.10
Ring Deflection	Deflection = 5.65%

AXIAL THRUST CALCULATION

Determine the axial thrust on the leachate sumps due to the 18" leachate riser pipe with the landfill at final grade.

Given

1. Maximum waste thickness (MSW and chemical waste) overlying leachate collection sumps taken from design specifications.
2. ISCO product information (refer to attached pages).
3. Landfill design specifications and drawings contained in the October, 2007 application.
4. Information from the Geosynthetic Institute (refer to attached pages).
5. ASTM Standard D4833 – Standard Test Method for Index Puncture Resistance of Geomembrane and Related Products

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Assumptions

1. The axial thrust exerted from the end of the pipe on the geomembrane rub sheet can be calculated as follows:

$$T = F_p \sin(\beta) + F_s - F_f$$

Where,
T = Axial thrust on the pipe (psf)
F_p = Stress exerted by the weight of the pipe (psf)
F_s = Stress on the pipe due to overlying waste and final cover downdrag (psf)
F_f = Stress of the pipe due to frictional resistance (psf)
β = angle of pipe

$$F_p = W_p \times L_p$$

Where,
W_p = Unit weight of the pipe
L_p = Length of the pipe

$$F_f = q'_v \times \cos(\beta) \times \tan(\phi) + C_o$$

and

$$F_s = q'_v \times \sin(\beta) \times \tan(\phi) + C_o$$

Where,
q'_v = average vertical stress exerted on the pipe by the waste and final cover
β = angle of pipe
ϕ = friction angle of waste-to-HDPE pipe interface
C_o=cohesion of waste-to-HDPE pipe interface

2. The riser pipes are 18" diameter SDR-17 HDPE pipes.

3. The unit weight of the 18" HDPE pipe is 24.638 lbs/ft. (See ISCO pipe sepcifications)

4. The thickness of the 18" HDPE pipe sidewall is 1.059 in. Knowing that the outside

pipe diameter is 18", the cross-sectional area of the pipe (A_p) can be calculated as 56.35 in^2 (0.391 ft^2). (ISCO)

5. The length of the pipe is 210 feet. (See design drawings)

6. The angle of the pipe (cell sideslope) is 18.4°.

7. The friction angle and cohesion for a smooth HDPE-to-cohesive soil (chemical waste) interface are 11° and 146 psf, respectively. (Geosynthetic Institute)

8. The friction angle and cohesion for a smooth HDPE-to-geonet interface are 11° and 0 psf, respectively. (Geosynthetic Institute)

9. The thicknesses of the final cover, MSW waste and chemical waste are 4 feet, 0 feet and 100 feet, respectively, at the point where the average vertical stress will be acting on the 18" riser pipe. (Calculated from design drawings)

10. The in-place densities of the final cover, MSW and chemical waste are conservatively assumed to be 128 pcf, 75 pcf and 90 pcf, respectively.

11. The puncture resistance of 60 mil HDPE geomembrane is 108 lb (Geosynthetic institute). ASTM D4833 states that the steel rod used to test for puncture resistance has a diameter of 0.315 in; by calculating the surface area of the steel rod, the stress exerted by the rod on the geomembrane is shown to be 199,561 psf.

Calculations

Stress exerted by the weight of the pipe

$$F_p = \frac{\left(W_p \times L_p\right)}{A_p}$$

$$F_p = \frac{\left(24.638 lb/ft \times 210 ft\right)}{0.391 ft^2} = 13,222 psf$$

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Stress on pipe due to overlying waste and final cover downdrag

$$q'_v = \sum(\text{thickness of each overlying layer} \times \text{ density of each layer})$$
$$q'_v = (4ft \times 128pcf) + (0ft \times 75pcf) + (100ft \times 90pcf)$$
$$q'_v = 9{,}512psf$$
$$F_s = q'_v \times \sin(\beta) \times \tan(\phi) + C_o$$
$$F_s = 9{,}512psf \times \sin(18.4°) \times \tan(11°) + 146psf$$
$$F_s = 729.6psf$$

Stress on the pipe due to frictional resistance

$$F_s = q'_v \times \cos(\beta) \times \tan(\phi) + C_o$$
$$F_s = 9{,}512psf \times \cos(18.4°) \times \tan(11°) + 0psf$$
$$F_s = 1{,}754.4psf$$

Axial thrust on the pipe

$$T = F_p \sin(\beta) + F_s - F_f$$
$$T = (13{,}222psf \times \sin(18.4°)) + 729.6psf - 1{,}754.4psf$$
$$T = 3{,}148.7psf$$
$$\text{Factor of Safety} = \frac{\text{Allowable Stress}}{\text{Axial Thrust}} = \frac{199{,}561}{3{,}149} = 63$$

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Results

The design of the landfill sump will ensure adequate protection of the underlying liner system from forces associated with deflection, kinking or consolidation.

high density polyethylene pipe

Sclairpipe®

Systems Design

KWH PIPE

Rules for Choice of Pipe Weight

PRESSURE CLASS DESIGNATION

SCLAIRPIPE® high density polyethylene (HDPE) pipe pressure class ratings are designated by a Dimension Ratio (DR) number. This is a common "rating" system specified by ASTM, AWWA and CSA for polyethylene pipes. The DR number is also used for pressure classification of other non-metallic piping materials such as PVC, ABS and polypropylene.

A dimension ratio is defined as the ratio of outside pipe diameter to minimum allowable wall thickness. The relationship of a pipe's dimension ratio to a pipe's standard pressure rating is described in the modified ISO formula as detailed below:

$$P = \frac{(2)(HDS)(t)}{D_o - t}$$

where:
- P = maximum operating pressure at 73.4°F under steady state conditions
- HDS = Hydrostatic Design Stress at 73.4°F
- t = minimum pipe wall thickness
- D_o = pipe outside diameter

and: $DR = D_o/t$

By substituting the above relationship into the modified ISO formula, it reduces to:

$$P = \frac{2\,(HDS)}{DR - 1}$$

This simplified relationship shows the pipe pressure rating, P, as a function of the pipe DR number and the hydrostatic design stress of the resin used to extrude the pipe.

The HDS is derived from the extrapolation of a series of hydrostatic pressure tests used to define the pipe's time-to-failure envelope. Circumferential wall stress (hoop stress) is developed by pressurizing a number of pipe samples and recording the time to failure. This data is analyzed according to the method described in ASTM D2837 to extrapolate and pinpoint the pipe compounds Long-Term Hydrostatic Strength (LTHS). The LTHS is then used to categorize the pipe's Hydrostatic Design Basis (HDB) based on the respective range that it fits into. Once the HDB is assigned to the pipe's hydrostatic capabilities, it is reduced by a design factor of 0.50 to determine the Hydrostatic Design Stress (HDS). This allows an appropriate safety margin and permits operation with the reasonable expectation that the pipe will have indefinite life (i.e. 50 years or more).

DESIGN CRITERIA

For each pipe DR number, there is a corresponding maximum allowable continuous operating pressure at 73.4°F when used in water service. This pressure rating varies when different pipe design hoop stress values (HDS) are substituted into the pipe design equation. Typically, HDPE pipes are made from materials qualified as PE 3408 which means the compound has a HDS of 800 psi.

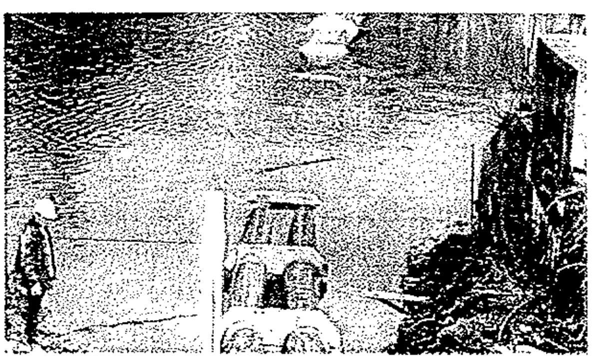
This pipe design methodology has been checked against long term pipe strain. Strain in polyethylene pipe has been found to govern the life of the pipe system. Operation at the design stress level should induce no greater than 3% strain over 50 years of continuous service at 73.4°F. This is consistent with other investigations where the long term strain design limit of 3% to 4%, incorporating a 0.5 design factor, has been designated.

SUMMARY OF RULES FOR PIPE SELECTION

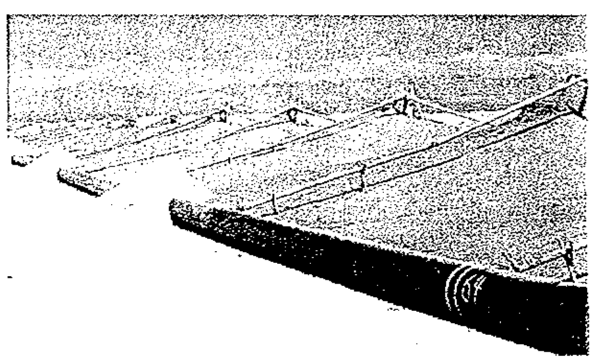
As described previously, a specific DR and material hydrostatic design stress, HDS, produces the same continuous standard maximum operating pressure for 50 years life at 73.4°F incorporating a 2:1 safety factor, regardless of the nominal pipe size (NPS).

In design, it is this "pressure" rating which can be factored to provide a "service" rating depending on the conditions of service. Service factors can vary from 1.0 (or more) to 0.25 (or less) and will depend on the relationship between the pipes' operating conditions, the pipes' intended use and expected lifetime.

Certain operating conditions may not necessarily utilize a design service factor such a buckling and pipe deflection in buried pipe applications. Here, design performance limits have been defined for each pipe DR rating. How service factors and design performance limits are defined, are discussed in the appropriate sections of this manual.



Installation of 24 inch SCLAIRPIPE for a twin sewage siphon line in Victoria, B.C. The pipe is completely resistant to seawater and its smooth surface discourages the adherence of algae and other marine growths.



SCLAIRPIPE used in a tailing applications at a molybdenum mine in Arizona. Inclusion of 2% finely dispersed carbon black ensures that the pipe is resistant to ultraviolet light degradation enabling it to be installed at grade. Anchoring of the pipeline is achieved simply by dumping a load of tails on the pipe at regular intervals.

Internal Pipe Pressure

Pressure performance requirements for SCLAIRPIPE at 73.4°F are as follows:

ASTM F714 The pipe shall not fail, when tested by the methods detailed in ASTM D1599, in 60 to 70 seconds at a pressure less than 3.63 times the standard pressure rating.

ASTM F714 The pipe shall not fail, when tested in accordance with ASTM D1598, in 1,000 hours at a pressure equal to 2 times the pipe standard pressure rating.

ASTM D2837 The pipe shall withstand a pressure equivalent to 1.97 times the pipe's standard pressure rating for a period of 11.4 years (100,000 hours).

It should be noted that the above requirements are test requirements under laboratory conditions and therefore must be adjusted by a design factor to be used for pipe pressure rating purposes. Although a basic design factor of 0.5 is used for determining long-term (50 years) operating limits, shorter term phenomena may be related to the "safe strain limit" which laboratory investigations demonstrate to be approximately 3% to 4%. The following maximum stress levels are therefore recommended for protection against varying terms of pressure exposure for Sclairpipe produced from a PE3408 material:

Duration of Surge or Pressure Phenomena	Maximum Allowable Hoop Stress at 73.4°F
Instantaneous (up to 60 sec.)	1600 psi
Up to 1 hour	1465 psi
1 hour to 1,000 hours	1070 psi
Sustained pressure, 50 years	800 psi

The above recommendations are based on the assumption that the pipe will not be subjected to other imposed stresses. They refer to phenomena which cease within the time limits given and the pipe then returns to a "normal" operating pressure. These phenomena may be repeated with reasonable expectation that the service life expectancy of the piping will not be significantly affected.

Regular pressure cycling, outside of hydraulic transient situations, should not be accommodated in this way. When such cycling is expected as a regular condition of operation, the highest pressure anticipated for the majority of the operating time should be considered as the operating pressure and treated as though it would persist continuously for the design life of the system.

SHOCK LOADS

Hydraulic shock loads (sometimes called "water hammer") can be difficult to calculate in complex systems, however, their presence and cause can be predicted. For further information reference should be made to the "Waterhammer and Hydraulic Transients" section of this manual.

It is often more economical to eliminate the cause rather than attempt to accommodate stresses by increasing the standard pressure rating of the selected pipe. It is known that under some conditions, a lighter weight pipe will be more resistant to damage under these conditions than a heavier weight pipe and that rigid materials and structures will increase the magnitude of the stresses. Overpressure is not likely to be a limiting factor in design. Negative pressures, resulting from column separation and pressure shocks resulting from the collapse of the separation, are more likely to be limiting factors in design.

EXTERNAL LOADS

Performance limits with regard to earthloading design and external hydraulic loading follow the recommendations given in "Earthloading - Design of Underground Piping Systems" and "Vacuum and External Hydraulic Overpressure" sections of this manual. Strength requirements under these conditions are functions of the cube of the Dimension Ratio (DR).

ENVIRONMENTAL CONDITIONS

Temperature is the most important environmental consideration. For operation at temperatures in excess of 73.4°F, a thermal service factor should be applied to the pressure rating as described in "Design Considerations Related to Environment" section of this manual.

Corrosive conditions are normally not a consideration with SCLAIRPIPE, but they do occur in industrial processing uses associated with strong oxidizing chemicals (see section on "Chemical Resistance and Permeability"). Oxidation, which results from exposure to certain aggressive chemicals is usually manifested by embrittlement of the surface and a significant reduction in the long-term stress resistance of the material.

The polyethylene material used in the manufacture of SCLAIRPIPE has a high resistance to environmental stress cracking. However, when the pipe is stressed in the presence of certain surface active chemicals, e.g. wetting agents, environmental stress cracking can take place with a detrimental effect to the products projected long-term life.

When chemical resistance is in doubt, exposure tests are recommended. Generally these tests follow the procedures described in ASTM D543. Changes in tensile properties can be measured on ring tensile specimens in accordance with the procedures described in ASTM D2513, paragraph 8.6. Significant variation between control specimens and those exposed to the chemical is generally accepted as evidence of corrosive degradation and decisions as to use of SCLAIRPIPE in this application shall be made accordingly.

Direct assistance of KWH technical personnel is recommended where further explanation and assistance is required.

Earthloading - Design of Underground Piping Systems

INTRODUCTION

This section defines the performance limits for SCLAIRPIPE polyethylene pipe in the following three burial environments - in varying soils and soil compaction levels, in firm soils where the buried pipe is subjected to external hydrostatic pressure and in firm and loose soils with the buried pipe subjected to internal vacuum or net external hydrostatic pressure. In all cases, the pipe is considered to be empty with no resistance to deflection contributed by internal pressure.

Flexible conduits react to earthloads or external hydrostatic loads very differently than rigid pipes do. The natural ring stiffness of the flexible pipe contributes only a small portion of the total resistance to deflection; most of the resistance arises from the soil stiffness. When the buried pipe deflects slightly in the vertical axis, the accompanying outward movement of the pipe side walls mobilizes the support available due to the stiffness of the surrounding soil envelope. Figure 2 provides an illustration of this mobilization process. The pipe is supported against further movement and exhibits load-bearing capabilities far greater than unsupported pipe. The amount of support which is available in the embedment soil is a direct consequence of the installation procedure. The stiffer the embedment materials are; the less deflection occurs and the more stable the pipe-soil system is.

DESIGN CRITERIA

When selecting the most appropriate wall thickness or DR for Sclairpipe to resist anticipated burial conditions or when confirming the adequacy of a selection which was made based on pressure class requirements three design criterion are considered separately; vertical deflection, wall buckling and wall compression or crushing. The amount of deflection which can be expected under specific burial conditions may be estimated using the form of the Iowa pipe deflection formula presented below. The estimated vertical deflection as a percentage of the mean pipe diameter is then compared to the safe design limits presented in Table 1. In order to verify the adequacy of the pipe-soil system against wall buckling or collapse the *safe allowable buckling load (q_a)* is determined using the equation presented and compared to the anticipated applied loads. Compressive stress in the pipe walls may also be estimated and compared to the safe compressive strength of HDPE which is conservatively estimated as 800 psi.

DEFLECTION

$$\Delta y = \frac{(D_L W_c + W_L)\, K_x\, r^3}{EI + 0.061E'r^3} \qquad (1.0)$$

Where;
- Δy = predicted vertical pipe deflection in inches.
- D_L = the deflection lag factor to compensate for the time-consolidation rate of the soil, dimensionless. Normally estimated as 1.5.
- W_c = vertical soil load on the pipe per unit length, in pounds per linear inch. W_c is estimated by multiplying the appropriate value from Table 2 by the outside diameter (in inches) of the pipe.
- W_L = live load on the pipe per unit length, in pounds per linear inch. W_L is estimated by multiplying the appropriate value from Figure 3 by the outside diameter (in inches) of the pipe.
- K_x = deflection coefficient, dimensionless, Use 0.083 for most installations.
- r = mean pipe radius in inches.
- r = (O.D. $-t_{min}$)/2
- t_{min} = minimum wall thickness of pipe in inches.
- E = Apparent modulus of elasticity of the pipe material in psi. A long-term apparent modulus of 30,000 psi may be used in most situations.
- I = the moment of inertia of the pipe wall for ring bending in inches^4/inch.
- I = $t_{min}^3/12$
- E' = modulus of soil reaction, in psi. The appropriate value for E' should be selection from Table 3.

WALL BUCKLING

The safe allowable buckling load for the soil-pipe structure (q_a) is estimated as follows;

$$q_a = (DF)\,(32\, R_w\, B'\, E'\, EI/D_{avg}^3)^{0.5} \qquad (2.0)$$

Where:
- q_a = safe allowable buckling load in psi.
- DF = design factor, 0.40
- R_w = water buoyancy factor, calculated as follows;
- R_w = $1 - 0.33(h_w/h)$; $0 \leq h_w \leq h$
- Where:
  - h_w = height of ground water surface above top of pipe in inches.
  - h = height of ground surface above top of pipe in inches.

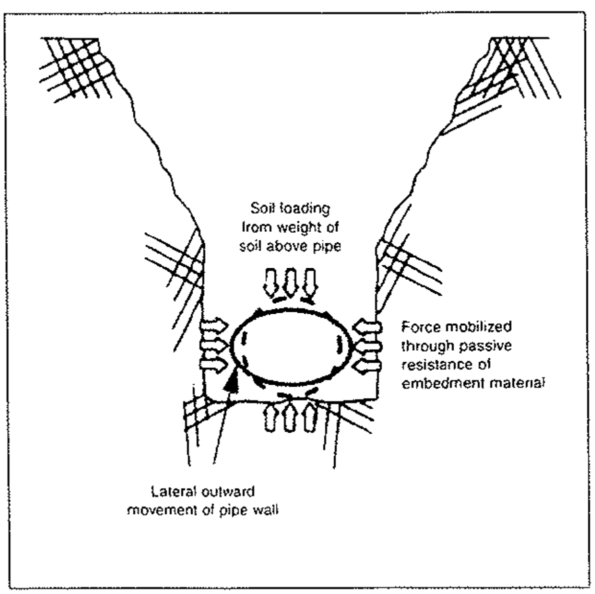


Figure 2: Mobilization of Enveloping Soil through Pipe Deformation

Table 1
SAFE DESIGN LIMITS

Dimension Ratio	Allowable Vertical Ring Deflection as a % of Diameter
32.5	8.6
26	6.5
21	5.0
17	4.0
11	3.3
9	2.6

Table 2

Vertical Soil Load in lbs./in²				
Depth to Top of Pipe in ft.	Soil Density 90 lbs.ft³	Soil Density 100 lbs.ft³	Soil Density 110 lbs.ft³	Soil Density 120 lbs.ft³
1	0.6	0.7	0.8	.8
2	1.3	1.4	1.5	1.7
3	1.9	2.1	2.3	2.5
4	2.5	2.8	3.1	3.3
5	3.1	3.5	3.8	4.2
6	3.8	4.2	4.6	5.0
7	4.4	4.9	5.3	5.8
8	5.0	5.6	6.1	6.7
9	5.6	6.3	6.9	7.5
10	6.3	6.9	7.6	8.3
12	7.5	8.3	9.2	10.0
14	8.8	9.7	10.7	11.7
16	10.0	11.1	12.2	13.3
18	11.3	12.5	13.8	15.0
20	12.5	13.9	15.3	16.7
25	15.6	17.4	19.1	20.8
30	18.8	20.8	22.9	25.0

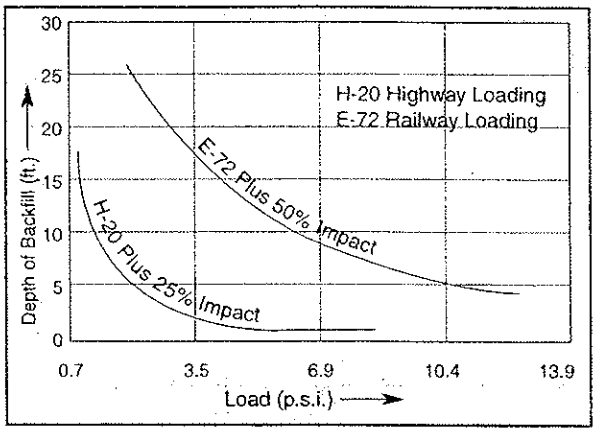


Figure 3: Live loading due to vehicle traffic

Table 3
Embedment Classes per ASTM D-2321

			Average Value of E'			
			Degree of Compaction of Embedment Material ' (Standard Proctor)			
Class	Soil Description	Soil Group Symbol	Dumped	Slight 85%	Moderate 90%	Heavy > 95%
IA	Manufactured aggregate angular open-graded and clean. Includes crushed slone, crushed shells.	None	500	1000	3000	3000
IB	Processed aggregate, angular dense-graded and clean. Includes Class 1A material mixed with sand and gravel to minimize migration.	None	200	1000	2000	3000
II	Coarse-grained soils, clean. Includes gravels, gravel-sand mixtures, and well and poorly graded sands. Contains little to no fines (less than 5% passing #200).	GW, GP, SW, SP	200	1000	2000	3000
II	Coarse-grained soils, borderline clean to "with lines". Contains 5% to 12% fines (passing #200).	GW-GC, SP-SM	200	1000	2000	3000
III	Coarse-grained soils containing 12% to 50% lines. Includes clayey gravel, silly sands, and clayey sands.	GM, GC, SM, SC	100	200	1000	2000
IVa	Fine-grained soils (inorganic). Includes inorganic silts, rock flour, silty-line sands, clays of low to medium plasticily, and silty or sandy clays.	ML, CL	50	200	400	1000
IVb	Fine-grained soils (inorganic). Includes diatomaceous sills, elastic silts, lat clays.	MH, CH	No date available; consult a competent soils engineer. Otherwise use E' equals zero.			
V	Organic soils. Includes organic sills or clays and peat.	OL, OH, PT	No date available; consult a competent soils engineer. Otherwise use E' equals zero.			

E' values taken from Bureau ol Reclamation lable of average values and modified slighlly herein to make lhe values more conservative.

B' = empirical coefficient of elastic support, dimensionless. Calculated as follows;

$B' = (1 + 4e^{-0.065H})^{-1}$

Where: H = burial depth to the top of the pipe in ft.

D_{avg} = mean pipe diameter (O.D. - t_{min})

For most pipe installations satisfaction of the wall buckling requirement is assured when the following equation is true;

$$\gamma_w h_w + R_w(W_c/D_{avg}) + P_v \leq q_a \qquad (2.1)$$

Where; γ_w = specified weight of water (that is, 0.0361 lbs./in.³) in pounds per cubic inch.

P_v = internal vacuum pressure (that is, atmospheric pressure less the absolute pressure inside of the pipe), in pounds per square inch.

In some situations, consideration of live loads in addition to dead loads may be appropriate. However, simultaneous application of the live-load and internal vacuum transients need not normally be considered. When live loads are being considered, the buckling requirement is assured when the following equation is true;

$$\gamma_w h_w + R_w(W_c/D_{avg}) + W_L/D_{avg} \leq q_a \qquad (2.2)$$

COMPRESSION

The compressive stress which will exist in the pipe wall due to anticipated burial loads (σ_c) can be estimated using the following equation;

$$\sigma_c = (W_c + W_L) / (2t_{min}) \qquad (3.0)$$

Satisfaction of the wall compression is assured when the following equation is true;

$$\sigma_c \leq 800 \text{ psi} \qquad (3.1)$$

CRITICAL PRESSURE FOR UNSUPPORTED PIPE:

In locations such as bogs, swamps or underwater, empty polyethylene pipelines can collapse if subjected to an excessive external/internal pressure differential. Such differential pressures may be caused by drawing a vacuum or by simply increasing the external hydraulic loading. Limiting critical pressures have been calculated from the modified Iowa Equation using a modulus (pipe stiffness) equivalent to 50 years of exposure to the critical pressure. Table 4 shows the critical pressure at 73.4°F for various pipe DRs or wall thicknesses. These critical pressures will cause full collapse of a pipe which has no initial deflection and is subjected to no stresses other than the net external pressure. However, damage can result to the pipe through excessive straining before full collapse, necessitating other safety factor considerations. For more information on the selection of pressure rating for unsupported pipe, see the section on Vacuum & External Hydraulic Overpressure.

Table 4
CRITICAL PRESSURES FOR PIPE WITHOUT SUPPORT

Dimension Ratio	Net External Critical Pressure (Pcr) (psi)
32.2	1.0
26	1.9
21	3.6
17	6.8
15.5	8.9
13.5	13.5
11	25.0
9	45.7

CRITICAL PRESSURE FOR SOIL-SUPPORTED PIPE:

Experimental work has shown that soil-supported pipe has a much greater capacity to withstand vacuum or net external pressures than pipe without support. This is particularly important when evaluating the effect of negative hydraulic transient pressures that may arise in pressure lines with sudden valve closures or pump failures. Treatment of this problem should be referred to your nearest KWH Pipe office.

Bedding Limitations:

- Always level the trench bottom, taking care to remove all sharp rocks and/or protrusions within 6 inches of the pipe.
- Ensure that the bedding material is worked into uniform contact with the pipe at the haunches.
- When bedding soil is non-compactible by its own weight, use mechanical compactions - DO NOT MECHANICALLY COMPACT DIRECTLY ON TOP OF THE PIPE - PLACE ONE FOOT OF BEDDING BEFORE COMPACTING DIRECTLY OVER THE PIPE.
- Do not allow rocks or frozen clods within a one foot bedding "envelope" around the pipe.
- See the Construction brochure for further details and burial information.

SAMPLE PROBLEM:

Problem

A 48" DR32.5 sewer pipe is to be buried with a depth of cover of 10 feet to the top of the pipe and must withstand H-20 truck traffic.

If the pipe is above the groundwater table and embedded in Type IB material (γ_s = 110 lbs/ft.) compacted to 85% Standard Proctor Density, is the pipe selection adequate?

Solution

Part 1 Deflection;

W_c = 7.6 x 48 = 364.8 lbs/in.
W_L = 1.4 x 48 = 67.2 lbs/in.
r = (48 - 1.453)/2 = 23.274 in.
I = 1.453^3 / 12 = 0.256 in.
E' = 1,000 psi

$$\therefore y = \frac{(1.5 \times 364.8 + 67.2)\ 0.083 \times 23.274^3}{30{,}000 \times 0.256 + 0.061 \times 1{,}000 \times 23.274^3} \quad (1.0)$$

= 0.828 in.
= 1.78 % of the mean pipe diameter

∴ Pipe selection is adequate for deflection criteria

Part 2 Wall Buckling;

h_w = 0.00 in.
R_w = 1.00
B' = $(1 + 4e^{-0.065 \times 10})^{-1}$
= 0.324
D_{avg} = 48 - 1.453
= 46.547 in.
$\therefore q_a = (1/2.5)(32 \times 0.324 \times 1{,}000 \times 30{,}000 \times 0.256 / 46.547^3)^{0.5}$ (2.0)
= 11.24 psi

Now check:

$0.0361 \times 0.00 + 1.00 \times 364.8/46.547 + 67.2/46.547 \leq q_a$ (2.2)
9.281 psi ≤ 11.24 psi
∴ Pipe selection is adequate for buckling criteria

Part 2 Wall Compression; (3.0)

σ_c = (364.8 + 67.2) / (2x1.453)
= 148.658 psi
$\sigma_c \leq 800$ psi (3.1)
∴ Pipe selection is adequate for wall crushing criteria

Since the selected pipe meets the requirements of all three of the design criteria the pipe selection is structurally adequate.

ISCO Pipe Specifications

PE 3608/3408 IPS HDPE PIPE SIZES

Pressure Rating		DR 7 (267psi)			DR 7.3 (254psi)			DR 9 (200psi)			DR 11 (160psi)			DR 13.5 (128psi)			DR 15.5 (110psi)		
Nominal Size	Actual O.D.	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf
3/4"	1.05"	0.150"	0.732"	0.184	0.144"	0.745"	0.178	0.117"	0.803"	0.150	0.095"	0.848"	0.125	---	---	---	---	---	---
1"	1.315"	0.188"	0.917"	0.289	0.180"	0.933"	0.279	0.146"	1.005"	0.234	0.120"	1.062"	0.197	---	---	---	---	---	---
1 1/4"	1.66"	0.237"	1.157"	0.460	0.227"	1.178"	0.444	0.184"	1.269"	0.372	0.151"	1.340"	0.312	---	---	---	---	---	---
1 1/2"	1.90"	0.271"	1.325"	0.603	0.260"	1.348"	0.582	0.211"	1.452"	0.488	0.173"	1.534"	0.409	---	---	---	---	---	---
2"	2.375"	0.339"	1.656"	0.943	0.325"	1.685"	0.762	0.264"	1.816"	0.762	0.216"	1.917"	0.639	0.176"	2.002"	0.531	0.153"	2.050"	0.467
3"	3.500"	0.500"	2.440"	2.047	0.479"	2.484"	1.656	0.389"	2.676"	1.656	0.318"	2.825"	1.387	0.259"	2.950"	1.153	0.226"	3.021"	1.015
4"	4.500"	0.643"	3.137"	3.384	0.616"	3.193"	2.737	0.500"	3.440"	2.737	0.409"	3.633"	2.294	0.333"	3.793"	1.906	0.290"	3.885"	1.678
5"	5.375"	0.768"	3.747"	4.830	0.736"	3.814"	4.663	0.597"	4.109"	3.903	0.489"	4.339"	3.272	0.398"	4.531"	2.718	0.347"	4.640"	2.396
5"	5.563"	0.795"	3.878"	5.172	0.762"	3.947"	4.182	0.618"	4.253"	4.182	0.506"	4.491"	3.505	0.412"	4.689"	2.912	0.359"	4.802"	2.564
6"	6.625"	0.946"	4.619"	7.336	0.908"	4.701"	5.932	0.736"	5.064"	5.932	0.602"	5.348"	4.971	0.491"	5.585"	4.130	0.427"	5.719"	3.637
7"	7.125"	1.018"	4.967"	8.195	0.976"	5.056"	8.200	0.792"	5.447"	6.863	0.648"	5.752"	5.750	0.528"	6.006"	4.779	0.460"	6.150"	3.985
8"	8.625"	1.232"	6.013"	12.433	1.182"	6.120"	10.054	0.958"	6.593"	10.054	0.784"	6.963"	8.425	0.639"	7.271"	7.001	0.556"	7.445"	6.164
10"	10.750"	1.536"	7.494"	19.314	1.473"	7.628"	15.618	1.194"	8.218"	15.618	0.977"	8.678"	13.089	0.796"	9.062"	10.875	0.694"	9.280"	9.576
12"	12.750"	1.821"	8.889"	27.170	1.747"	9.047"	21.970	1.417"	9.747"	21.970	1.159"	10.293"	18.412	0.944"	10.748"	15.298	0.823"	11.006"	13.471
14"	14.000"	2.000"	9.760"	32.758	1.918"	9.934"	26.489	1.556"	10.702"	26.489	1.273"	11.302"	22.199	1.037"	11.801"	18.445	0.903"	12.085"	16.242
16"	16.00"	2.286"	11.154"	42.786	2.192"	11.353"	34.598	1.778"	12.231"	34.598	1.455"	12.916"	28.994	1.185"	13.487"	24.092	1.032"	13.812"	21.214
18"	18.00"	2.571"	12.549"	54.151	2.466"	12.773"	43.788	2.000"	13.760"	43.788	1.636"	14.531"	36.696	1.333"	15.173"	30.491	1.161"	15.538"	26.849
20"	20.00"	2.857"	13.943"	66.853	2.740"	14.192"	54.059	2.222"	15.289"	54.059	1.818"	16.145"	45.304	1.481"	16.859"	37.643	1.290"	17.265"	33.146
22"	22.00"	3.143"	15.337"	80.170	3.014"	15.611"	65.412	2.444"	16.818"	65.412	2.000"	17.760"	54.818	1.630"	18.545"	45.548	1.419"	18.991"	40.107
24"	24.00"	3.429"	16.731"	96.267	3.288"	17.030"	92.988	2.667"	18.347"	77.845	2.182"	19.375"	65.237	1.778"	20.231"	54.206	1.548"	20.717"	47.731
26"	26.00"	---	---	---	3.562"	18.449"	110.192	2.889"	19.876"	92.050	2.364"	20.989"	76.563	1.926"	21.917"	63.617	1.677"	22.444"	56.018
28"	28.00"	---	---	---	---	---	---	3.111"	21.404"	106.750	2.545"	22.604"	88.795	2.074"	23.603"	73.781	1.806"	24.170"	64.967
30"	30.00"	---	---	---	---	---	---	3.333"	22.933"	121.633	2.727"	24.218"	101.934	2.222"	25.289"	84.697	1.935"	25.897"	74.580
32"	32.00"	---	---	---	---	---	---	3.556"	24.462"	139.452	2.909"	25.833"	116.670	2.370"	26.975"	96.367	2.065"	27.623"	84.855
34"	34.00"	---	---	---	---	---	---	---	---	---	3.091"	27.447"	130.930	2.519"	28.661"	109.332	2.194"	29.350"	96.209
36"	36.00"	---	---	---	---	---	---	---	---	---	3.273"	29.062"	146.780	2.667"	30.347"	121.960	2.323"	31.076"	107.395
42"	42.00"	---	---	---	---	---	---	---	---	---	---	---	---	3.111"	35.404"	166.800	2.710"	36.255"	146.176
48"	48.00"	---	---	---	---	---	---	---	---	---	---	---	---	3.556"	40.462"	217.895	3.097"	41.435"	175.891
54"	54.00"	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3.484"	46.614"	242.649
63"	62.99"	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

NOTE:

- Items highlighted in Blue indicates standard stocking items that are more readily available.
- Pressures are based on using water at 23°C (73°F).
- Average inside diameter calculated using nominal OD and minimum wall plus 6% for use in estimating fluid flows. Actual ID will vary.
- Service factors should be utilized to compensate for the effect of liquids other than water, and for other temperatures.
- Other piping sizes or DR's may be available upon request.
- Standard Lengths: 40' for 2"-24" / 50' for 26" and larger / Coils available for 3/4"-6"(8" by special order)

PE 3608/3408 IPS HDPE PIPE SIZES

Pressure Rating		[redacted]			DR 19 (89psi)			DR 21 (80psi)			DR 26 (65psi)			DR 32.5 (50psi)		
Nominal Size	Actual O.D.	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf	Min. wall	Average I.D.	Weight lb/lf
3/4"	1.050"	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1"	1.315"	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1 1/4"	1.660"	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1 1/2"	1.900"	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
2"	2.375"	0.140"	2.079"	0.429	---	---	---	---	---	---	---	---	---	---	---	---
3"	3.500"	0.206"	3.064"	0.932	---	---	---	---	---	---	---	---	---	---	---	---
4"	4.500"	0.265"	3.939"	1.540	0.237"	3.998"	1.387	0.214"	4.046"	1.262	0.173"	4.133"	1.030	0.138"	4.206"	0.831
5"	5.375"	0.316"	4.705"	2.197	0.283"	4.775"	1.980	0.256"	4.832"	1.801	0.207"	4.937"	1.470	0.165"	5.024"	1.186
5"	5.563"	0.327"	4.869"	2.353	0.293"	4.942"	2.120	0.265"	5.001"	1.929	0.214"	5.109"	1.574	0.171"	5.200"	1.270
6"	6.625"	0.390"	5.799"	3.338	0.349"	5.886"	3.007	0.315"	5.956"	2.736	0.255"	6.085"	2.233	0.204"	6.193"	1.801
7"	7.125"	0.419"	6.236"	3.860	0.375"	6.330"	3.478	0.339"	6.406"	3.165	0.274"	6.544"	2.582	0.219"	6.660"	2.083
8"	8.625"	0.507"	7.549"	5.657	0.454"	7.663"	5.097	0.411"	7.754"	4.637	0.332"	7.922"	3.784	0.265"	8.062"	3.053
10"	10.750"	0.632"	9.409"	8.788	0.566"	9.551"	7.918	0.512"	9.665"	7.204	0.413"	9.873"	5.878	0.331"	10.049"	4.742
12"	12.750"	0.750"	11.160"	12.362	0.671"	11.327"	11.138	0.607"	11.463"	10.134	0.490"	11.710"	8.269	0.392"	11.918"	6.671
14"	14.000"	0.824"	12.254"	14.905	0.737"	12.438"	13.429	0.667"	12.587"	12.218	0.538"	12.858"	9.970	0.431"	13.087"	8.044
16"	16.00"	0.941"	14.005"	19.467	0.842"	14.215"	17.540	0.762"	14.385"	15.959	0.615"	14.695"	13.022	0.492"	14.956"	10.506
[redacted]					0.947"	15.992"	22.199	0.857"	16.183"	20.198	0.692"	16.532"	16.480	0.554"	16.826"	13.296
20"	20.00"	1.176"	17.506"	30.418	1.053"	17.768"	27.406	0.952"	17.981"	24.936	0.769"	18.369"	20.346	0.615"	18.695"	16.415
22"	22.00"	1.294"	19.256"	36.805	1.158"	19.545"	33.162	1.048"	19.779"	30.172	0.846"	20.206"	24.619	0.677"	20.565"	19.863
24"	24.00"	1.412"	21.007"	43.801	1.263"	21.322"	39.465	1.143"	21.577"	35.907	0.923"	22.043"	29.299	0.738"	22.434"	23.638
26"	26.00"	1.529"	22.758"	51.406	1.368"	23.099"	46.316	1.238"	23.375"	42.141	1.000"	23.880"	34.385	0.800"	24.304"	27.742
28"	28.00"	1.647"	24.508"	59.618	1.474"	24.876"	53.716	1.333"	25.173"	48.874	1.077"	25.717"	39.879	0.862"	26.174"	32.174
30"	30.00"	1.765"	26.259"	68.439	1.579"	26.653"	61.664	1.429"	26.971"	56.105	1.154"	27.554"	45.779	0.923"	28.043"	36.934
32"	32.00"	1.882"	28.009"	77.869	1.684"	28.429"	70.160	1.524"	28.770"	63.835	1.231"	29.391"	52.086	0.985"	29.913"	42.023
34"	34.00"	2.000"	29.760"	87.907	1.789"	30.206"	79.204	1.619"	30.568"	72.064	1.308"	31.228"	58.814	1.046"	31.782"	47.440
36"	36.00"	2.118"	31.511"	98.553	1.895"	31.983"	88.796	1.714"	32.366"	80.791	1.385"	33.065"	65.922	1.108"	33.652"	53.186
42"	42.00"	2.471"	36.762"	134.141	2.211"	37.314"	120.861	2.000"	37.760"	109.966	1.615"	38.575"	89.727	1.292"	39.260"	72.392
48"	48.00"	2.824"	42.014"	175.205	2.526"	42.644"	157.857	2.286"	43.154"	143.629	1.846"	44.086"	117.194	1.477"	44.869"	94.552
54"	54.00"	3.176"	47.266"	222.547	2.842"	47.975"	199.791	2.571"	48.549"	182.298	2.077"	49.597"	148.324	1.662"	50.478"	119.668
63"	62.99"	---	---	---	---	---	---	3.000"	56.631"	247.800	2.423"	57.854"	202.010	1.938"	58.881"	162.980

NOTE:

- Items highlighted in Blue indicates standard stocking items that are more readily available.
- Pressures are based on using water at 23°C (73°F).
- Average inside diameter calculated using nominal OD and minimum wall plus 6% for use in estimating fluid flows. Actual ID will vary.
- Service factors should be utilized to compensate for the effect of liquids other than water, and for other temperatures.
- Other piping sizes or DR's may be available upon request.
- Standard Lengths: 40' for 2"-24" / 50' for 26" and larger / Coils available for 3/4"-6"(8" by special order)

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GRI GEI GSI GII GAI GCI

Direct Shear Database of Geosynthetic-to-Geosynthetic and Geosynthetic-to-Soil Interfaces

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GRI Report #30

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Inte ; 1*	Interface 2*	Peak Str a					Residual Strength				
		Fig. No.	δ (deg)	Ca (kPa)	Points	R^2	Fig. No.	δ (deg)	Ca (kPa)	Points	R^2
HDPE-S	Granular Soil	1a	21	0	162	0.93	1b	17	0	128	0.92
HDPE-S	Cohesive Soil										
	Saturated	1c	11	7	79	0.94	1d	11	0	59	0.95
	Unsaturated	1c	22	0	44	0.93	1d	18	0	32	0.93
HDPE-S	NW-NP GT	1e	11	0	149	0.93	1f	9	0	82	0.96
HDPE-S	Geonet	1g	11	0	196	0.90	1h	9	0	118	0.93
HDPE-S	Geocomposite	1i	15	0	36	0.97	1j	12	0	30	0.93
HDPE-T	Granular Soil	2a	34	0	251	0.98	2b	31	0	239	0.96
HDPE-T	Cohesive Soil										
	Saturated	2c	18	10	167	0.93	2d	16	0	150	0.90
	Unsaturated	2c	19	23	62	0.91	2d	22	0	35	0.93
HDPE-T	NW-NP GT	2e	25	8	254	0.96	2f	17	0	217	0.95
HDPE-T	Geonet	2g	13	0	31	0.99	2h	10	0	27	0.99
HDPE-T	Geocomposite	2i	26	0	168	0.95	2j	15	0	164	0.94
LLDPE-S	Granular Soil	3a	27	0	6	1.00	3b	24	0	9	1.00
LLDPE-S	Cohesive Soil	3c	11	12.4	12	0.94	3d	12	3.7	9	0.93
LLDPE-S	NW-NP GT	3e	10	0	23	0.63	3f	9	0	23	0.49
LLDPE-S	Geonet	3g	11	0	9	0.99	3h	10	0	9	1.00
LLDPE-T	Granular Soil	4a	26	7.7	12	0.95	4b	25	5.2	12	0.95
LLDPE-T	Cohesive Soil	4c	21	5.8	12	1.00	4d	13	7.0	9	0.98
LLDPE-T	NW-NP GT	4e	26	8.1	9	1.00	4f	17	9.5	9	0.96
LLDPE-T	Geonet	4g	15	3.6	6	0.97	4h	11	0	6	0.98
PVC-S	Granular Soil	5a	26	0.4	6	0.99	5b	19	0	6	0.99
PVC-S	Cohesive Soil	5c	22	0.9	11	0.88	5d	15	0	9	0.95
PVC-S	NW-NP GT	5e	20	0	89	0.91	5f	16	0	83	0.74
PVC-S	NW-HB GT	5g	18	0	3	1.00	5h	12	0.1	3	1.00
PVC-S	Woven GT	5i	17	0	6	0.54	5j	7	0	6	0.93
PVC-S	Geonet	5k	18	0.1	3	1.00	5l	16	0.6	3	1.00

Table 1(a) – High Density Polyethylene (HDPE) Geomembrane -Smooth

Properties	Test Method	Test Value							Testing Frequency (minimum)
		30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness (min. ave.)	D5199	nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Per roll
• lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density mg/l (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	200,000 lb
Tensile Properties *(1)* (min. ave.) • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	 63 lb/in. 114 lb/in. 12% 700%	 84 lb/in. 152 lb/in. 12% 700%	 105 lb/in. 190 lb/in. 12% 700%	 126 lb/in. 228 lb/in. 12% 700%	 168 lb/in. 304 lb/in. 12% 700%	 210 lb/in. 380 lb/in. 12% 700%	 252 lb/in. 456 lb/in. 12% 700%	20,000 lb
Tear Resistance (min. ave.)	D 1004	21 lb	28 lb	35 lb	42 lb	56 lb	70 lb	84 lb	45,000 lb
Puncture Resistance (min. ave.)	D 4833	54 lb	72 lb	90 lb	108 lb	144 lb	180 lb	216 lb	45,000 lb
Stress Crack Resistance *(2)*	D5397 (App.)	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	300 hr.	per GRI-GM10
Carbon Black Content (range)	D 1603 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	20,000 lb
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	45,000 lb
Oxidative Induction Time (OIT) (min. ave.) *(5)* (a) Standard OIT — or — (b) High Pressure OIT	 D 3895 D 5885	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	 100 min. 400 min.	200,000 lb
Oven Aging at 85°C *(5)*, *(6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	 55% 80%	per each formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	GM 11 D 3895 D 5885	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	 N.R. *(8)* 50%	per each formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 1.3 inches
Break elongation is calculated using a gage length of 2.0 in.

(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(3) Other methods such as D 4218 (muffle furnace) or microwave methods are acceptable if an appropriate correlation to D 1603 (tube furnace) can be established.

(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

Designation: D 4833 – 07

Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products[1]

This standard is issued under the fixed designation D 4833; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method is used to measure the index puncture resistance of geomembranes and related products.

1.2 The use of Test Method D 4833 may be inappropriate for testing some woven geotextiles or related products which have large openings, such as geonets and geogrids.

1.3 It is recommended that geotextile and geotextile related products be tested using Test Method D 6241.

1.4 The values stated in SI units are to be regarded as the standard. The values provided in inch-pound units are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 76 Specification for Tensile Testing Machines for Textiles

D 123 Terminology Relating to Textiles

D 1776 Practice for Conditioning and Testing Textiles

D 2905 Practice for Statements on Number of Specimens for Textiles

D 4354 Practice for Sampling of Geosynthetics for Testing

D 4439 Terminology for Geosynthetics

D 6241 Test Method for the Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe

3. Terminology

3.1 *Definitions:*

3.1.1 *atmosphere for testing geotextiles, n*— air maintained at a relative humidity of 65 ± 5 % and a temperature of 21 ± 2°C (70 ± 4°F).

3.1.2 *geomembrane, n*—very low permeability synthetic membrane liners or barriers used with any geotechnical engineering related material so as to control fluid migration in a man-made project, structure, or system.

3.1.3 *index test, n*—a test procedure which may contain a known bias but which may be used to establish an order for a set of specimens with respect to the property of interest.

3.1.4 *puncture resistance (F), n*—the inherent resisting mechanism of the test specimen to the failure by a penetrating or puncturing object.

3.2 For definitions of other terms relating to geosynthetics used in this standard, refer to Terminology D 4439.

4. Summary of Test Method

4.1 A test specimen is clamped without tension between circular plates of a ring clamp attachment secured in a tensile testing machine. A force is exerted against the center of the unsupported portion of the test specimen by a solid steel rod attached to the load indicator until rupture of the specimen occurs. The maximum force recorded is the value of puncture resistance of the specimen.

5. Significance and Use

5.1 This test method is an index test for determining the puncture resistance of geomembranes and related products. The use of this test method is to establish an index value by providing standard criteria and a basis for uniform reporting.

5.2 This test method is considered satisfactory for acceptance testing of commercial shipments of geomembranes and related materials since the test method has been used extensively in the trade for acceptance testing.

5.2.1 In case of a dispute arising from differences in reported test results when using this test method for acceptance testing of commercial shipments, the purchaser and the supplier should conduct comparative tests to determine if there is a statistical bias between their laboratories. Competent statistical assistance is recommended for the investigation of bias. As a minimum, the two parties should take a group of test specimens that are as homogeneous as possible and that are

[1] This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.01 on Mechanical Properties.

Current edition approved Dec. 1, 2007. Published January 2008. Originally approved in 1988. Last previous edition approved in 2000 as D 4833–00^ε1.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

from a lot material of the type in question. The test specimens should then be randomly assigned in equal numbers to each laboratory for testing. The average results from the two laboratories should be compared using Student's *t*-test for unpaired data and an acceptable probability level chosen by the two parties before the testing is begun. If a bias is found, either its cause must be found and corrected or the purchaser and the supplier must agree to interpret future test results in the light of the known bias.

6. Apparatus

6.1 *Tensile/Compression Testing Machine*, of the constant-rate-of extension (CRE) type, with autographic recorder conforming to the requirements of Specification D 76. See Fig. 1.

6.2 *Ring Clamp Attachment*, consisting of concentric plates with an open internal diameter of 45 ± 0.025 mm (1.772 ± 0.001 in.), capable of clamping the test specimen without slippage. A suggested clamping arrangement is shown in Fig. 1 and Fig. 2. The external diameter is to be a minimum of 100 (3.937). The diameter of the six holes used for securing the ring clamp assembly is suggested to be 8 mm (0.135 in.) and equally spaced at a radius of 37 mm (2.95 in.). The surfaces of these plates can consist of grooves with O-rings or coarse sandpaper bonded onto opposing surfaces.

6.3 *Solid Steel Rod*, with a diameter of 8 ± 0.1 mm (0.315 ± 0.004 in.) having a flat end with a 45° = 0.8 mm (0.315 in.) chamfered edge contacting the test specimen's surface. See Fig. 1 and Fig. 3.

7. Sampling

7.1 *Lot Sample*—Divide the product into lots and take the lot sample as directed in Practice D 4354.

7.2 *Laboratory Sample*—For the laboratory sample, take a swatch extending the full width and of sufficient length along the selvage, from each sample roll so that the requirements of 7.3 and 8.1 can be met. Take a sample that will exclude

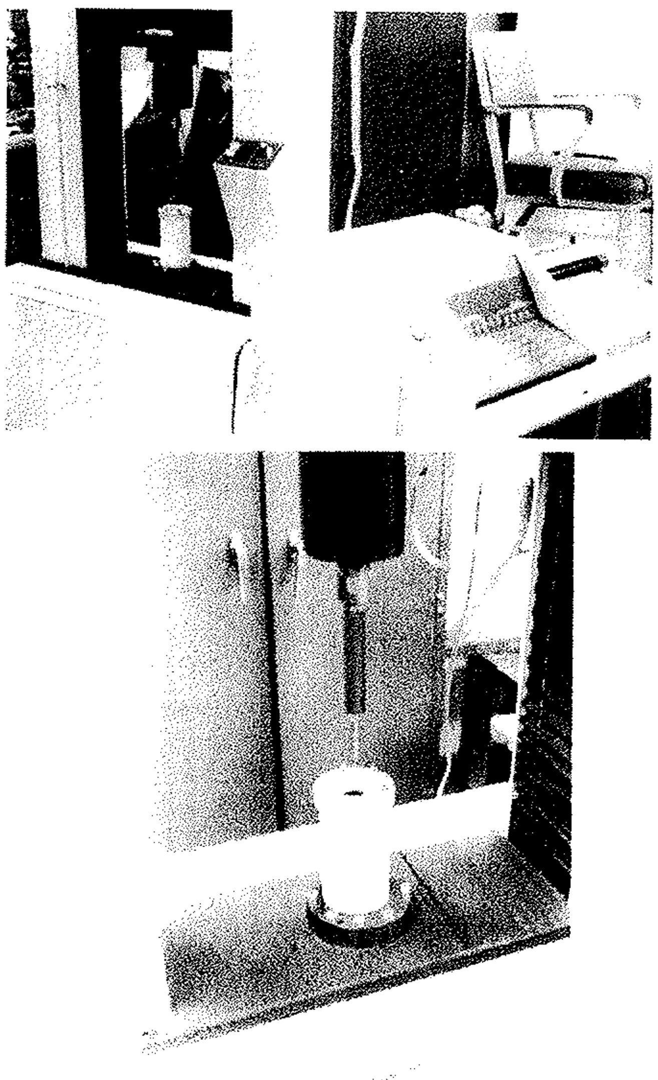

FIG. 1 Photographs of Test Setup and Fixture

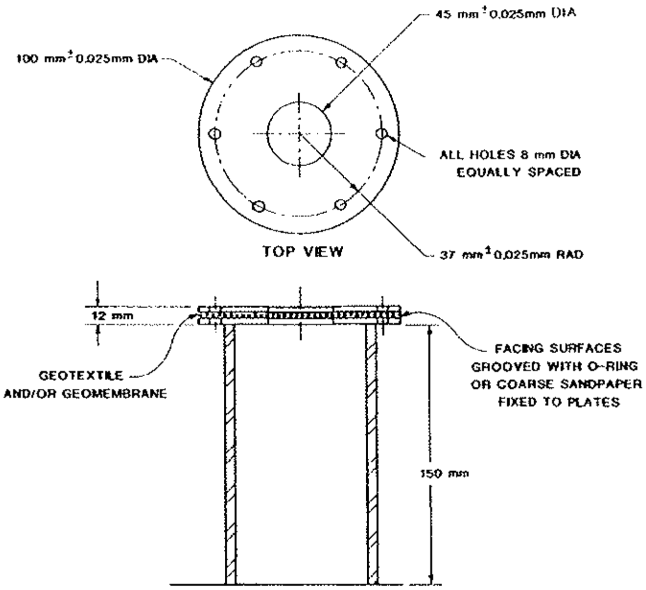

FIG. 2 Test Fixture Detail (Not to Scale)

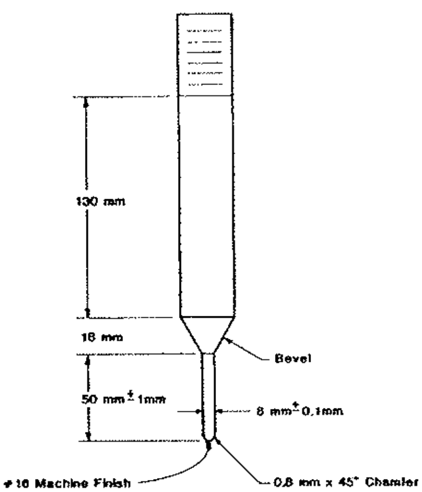

FIG. 3 Test Probe Detail (Not to Scale)

material from the outer wrap and inner wrap around the core unless the sample is taken at the production site, then inner and outer wrap material may be used.

7.3 *Test Specimens*—Select from the laboratory sample the number of specimens directed in Section 8. Minimum specimen diameter is 100 mm (4 in.) to facilitate clamping. Space the specimens along a diagonal on the unit of the laboratory sample. Take no specimens nearer the selvage or edge of the geotextile sample than 1/10 the width of the geotextile sample.

8. Number of Specimens

8.1 *Reliable Estimate of v*—When there is a reliable estimate of v based on extensive past records for similar materials tested in the user's laboratory, calculate the number of specimens per unit in the laboratory sample using Eq 1:

$$n = (tv/A)^2 = (tv)^2/36 \quad (1)$$

where:

n = number of specimens (rounded upward to a whole number),

v = reliable estimate of the coefficient of variation for individual observations on similar materials in the user's laboratory under conditions of single-operator precision,

t = value of Student's test for two-sided limits (see Table 1) a 95 % probability level, and the degrees of freedom associated with the estimate of v, and

A = 6 % of the average, the value of the allowable variable.

8.2 *No Reliable Estimate of v*—When there is no reliable estimate of v in the user's laboratory, specify the fixed number of 5 specimens for geomembranes per swatch in the laboratory sample and 5 for other related products. This number of specimens is calculated using v = 10 % of the average, which is a somewhat larger value of v than is usually found in practice. When a reliable estimate of v for the user's laboratory

TABLE 1 Values of Student's *t* for Two-Sided Limits and the 95 % Probability[A]

df	t.025	df	t.025	df	t.025
1	12.706	11	2.201	21	2.080
2	4.303	12	2.179	22	2.074
3	3.182	13	2.160	23	2.069
4	2.776	14	2.145	24	2.064
5	2.571	15	2.131	25	2.060
6	2.447	16	2.120	26	2.056
7	2.365	17	2.110	27	2.052
8	2.306	18	2.101	28	2.048
9	2.262	19	2.093	29	2.045
10	2.228	20	2.086	inf.	1.960

[A]Values in this table were calculated using Hewlett Packard HP 67/97 Users' Library Programs 03848D, "One-Sided and Two-Sided Critical Values of Student's t" and 00350D, "Improved Normal and Inverse Distribution." For values at other than the 95 % probability level, see published tables of critical values of Student's t in any standard statistical text. Further use of this table is defined in Practice D 2905.

becomes available. Eq 1 will usually require fewer than 15 specimens per swatch in the laboratory sample.

9. Conditioning

9.1 Bring the specimens to moisture equilibrium in the atmosphere for testing (3.1). Equilibrium is considered to have been reached when the increase in the mass of the specimen, in successive weighings made at intervals of not less than 2 h, does not exceed 0.1 % of the mass of the specimen.

10. Procedure

10.1 Select the load range of the tensile/compression testing machine such that the rupture occurs between 10 and 90 % of the full-scale load.

10.2 Center and secure the specimen between the holding plates ensuring that the test specimen extends to or beyond the outer edges of the clamping plates.

10.3 Test at a machine speed of 300 ± 10 mm (12 in. ± ½ in.)/min until the puncture rod completely ruptures the test specimen.

NOTE 1—The rate of testing specified is not an indication of the performance of the specimen for its end use.

10.4 Read the puncture resistance from the greatest force registered on the recording instrument during the test. For the testing of composite geomembrane materials, there may be a double peak. If so, the initial value should be reported even if the second peak is higher than the first one.

11. Calculation

11.1 Calculate the average puncture resistance and standard deviation for all tests as read directly from the recording instrument.

12. Report

12.1 State that the specimens were treated as directed in Test Method D 4833.

12.2 Report on the following information:

12.2.1 The method of holding the test specimen in the clamping device.

12.2.2 The average puncture resistance of the specimens tested.

12.2.3 The coefficient of variation (if known) and standard deviation for each group of specimens.

12.2.4 The variation, if any, from the described test method.

13. Precision and Bias

13.1 *Precision*—The precision of the procedure in this test method for measuring the puncture resistance of geotextiles, geomembranes, and related materials is being established.

13.2 *Bias*—The procedure in this test method for measuring the puncture resistance of geomembranes and related materials has no bias because the value of that property can be defined only in terms of a test method.

14. Keywords

14.1 geomembranes; puncture; puncture resistance