SUB-APPENDIX D6-E

Leachate Collection System Pipe Structural Stability Calculations

Leachate Collection System Pipe Structural Stability Calculations Ridge Landfill Expansion Environmental Assessment, Blenheim, Ontario		
Project: 18111331 (2000)	Prepared by: S. Rimal Reviewed by: F. Gondim	Date: September 2019

References:

Ref. 1 - Handbook of Polyethylene Pipe, Plastics Pipe Institute, Second Edition.
Ref. 2 - Large Scale Constrained Modulus Test, Final Report, Prepared by MCG Geotechnical Engineering, Morrison, CO for Plastics Pipe Institute (February 2010)
Ref. 3 - High Density Polyethylene Pipe, Systems Design, Sclairpipe, KWH Pipe.
Ref. 4 - PolyPipe Design and Engineering Guide for Polyethylene Piping (September 2008)

Thickness (H) of fills above the Leachate Collection System (LCS) Pipe

H_{cover} = 1 m
H_{waste} = 50 m
H_{sand} = 0.2 m
H_{stone} = 0.3 m

Unit weights (γ)

γ_{cover} = 21 kN/m^3
γ_{waste} = 13 kN/m^3
γ_{sand} = 19 kN/m^3
γ_{Stone} = 18 kN/m^3

Applied vertical stress on the pipe (σ_v)

σ_v = 680 kPa
= 14206 psf

10" HDPE Pipe, DR = 11, Designation Code PE4710

(a) Check for pipe wall crushing

From Ref. 1 (page 229), the pipe wall compressive stress:

$$S = \frac{P_{RD} \times D_o}{288 \times t}$$

where,

S = pipe wall compressive stress [lb/in^2]
P_{RD} = radial directed earth pressure [lb/ft^2] = VAF x σ_v (Eq. 3-23 Ref. 1)
VAF = vertical arching factor [-] = 0.88 -0.71 x (S_A - 1)/(S_A + 2.5) (Eq. 3-21 Ref. 1)
S_A = hoop stress stiffness ratio [-] = (1.43 x M_s x r_{CENT})/ (E x t) (Eq. 3-22 Ref. 1)
r_{CENT} = radius to centroidal axis of pipe [in] = (D_o - t)/2
M_s = one-dimensional modulus of soil [psi]
E = apparent modulus of elasticity of pipe material [psi]
D_o = pipe outside diameter [in]
t = wall thickness [in]
σ_v = applied vertical stress on pipe (psf)

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		English Units		SI Units		
D_o	=	10.75	in	0.273	m	(for 10 in. DR = 11 Sclairpipe PE4710)
t	=	0.977	in	0.025	m	
r_{CENT}	=	4.887	in	0.124	m	
M_s	=	5000	psi	34475	kPa	(Table 2 - Ref. 2 for 1.5 inch granite with high compactive effort)
E	=	30000	psi	206850	kPa	(Refs. 3 and 4, long term apparent modulus of elasticity)
σ_v	=	14206	psf	680	kPa	
S_A	=	1.19	[-]	1.19	[-]	
VAF	=	0.843	[-]	0.843	[-]	
P_{RD}	=	11977	psf	573	kPa	
S	=	458	psi	3155	kPa	

S_{allow} = allowable pipe wall compressive stress = 1150 psi (Ref 1 - Chapter 3, Table C.1 for PE4710 pipe)

= 7929 kPa

Factor of Safety = $\frac{S_{allow}}{S} = \frac{1150}{458} =$ 2.5 Okay [Typical Recommended F.S. = 1.0 Ref. 1]

(b) Check for ring deflection (Watkins - Gaube Graph)

From Ref. 1 (Eqn. 3-28), percent ring deflection is:

$$\left(\frac{\Delta x}{D_M}\right) \times 100 = D_F \times \varepsilon_S$$

where,

Δx = ring deflection [in]

D_M = mean diameter [in] (i.e. Do - t)

D_F = deformation factor (from Watkins - Gaube Graph)

ε_S = soil strain [%] = σ_v /(144 x E_s) (Eq. 3-27 Ref. 1)

σ_v = applied vertical stress on pipe (psf)

E_s = secant modulus of soil [psi] = $M_s (1 + \mu) (1-2\mu) / (1 - \mu)$ (Eq. 3-26 Ref. 1)

M_s = one dimensional soil modulus [psi]

μ = soil's Poisson ratio [-]

Ridgity factor, R_F for Watkins - Gaube Graph is:

$$R_F = \frac{12\, E_S\, (DR\ - 1)^3}{E}$$

DR = standard dimension ratio of pipe [-] i.e pipe outside diameter / wall thickness

E_s = secant modulus of soil [psi]

E = apparent modulus of elasticity of pipe material [psi]

		English Units		SI Units		
E	=	30000	psi	206850	kPa	(Refs. 3 and 4, long term apparent modulus of elasticity)
D_o	=	10.75	in	0.273	m	(for 10 in. DR = 11 Sclairpipe PE4710)
t	=	0.977	in	0.025	m	
D_M	=	9.773	in	0.249	m	
σ_v	=	14206	psf	680	kPa	
μ	=	0.15	[-]	0.15	[-]	(Ref. 1 Table 3-13)
M_s	=	5000	psi	34475	kPa	
E_s	=	4735	psi	32650	kPa	
R_F	=	1894	[-]	1894	[-]	
D_F	=	1.4	[-]	1.4	[-]	(deformation factor from Watkins-Gaube Graph, Ref. 1)
ε_S	=	2.1%		2.1%		
$\Delta x/D_M$	=	2.9%		2.9%		(Percent Ring Deflection)

allowable ring deflection = 5% (Ref. 1 page 218)

$$\text{Factor of Safety} = \frac{\text{Allowable ring def.}}{\Delta x/D_M} = \frac{5\%}{2.9\%} = 1.7$$ Okay [Typical Recommended F.S. = 1.0 Ref. 1]

(c) Check for wall buckling

Moore-Selig Equation for critical buckling pressure:

$$P_{CR} = \frac{2.4\,\emptyset\,R_H}{D_M}(E\,I)^{\frac{1}{3}}\,(E_S^*)^{\frac{2}{3}}$$

where,

P_{CR} = critical constrained buckling pressure [psi]
Φ = calibration factor [-]
R_H = geometry factor [-]
D_M = mean diameter [in] (i.e. D_o - t)
E = apparent modulus of elasticity of pipe material [psi]
I = pipe wall moment of inertia [in^4/in] = (t^3/12, for a solid wall pipe)
E_s = secant modulus of soil [psi] = $M_s\,(1 + \mu)\,(1-2\mu) / (1 - \mu)$ (Eq. 3-26 Ref. 1)
E^*_s = $E_s / (1-\mu)$
μ = soil's Poisson ratio [-]

		English Units		SI Units		
Φ	=	0.55	[-]	0.55	[-]	(Ref. 1 Page 233)
R_H	=	1	[-]	1	[-]	(Ref. 1 Page 233)
D_M	=	9.773	in	0.249	m	
E	=	30000	psi	206850	kPa	(Refs. 3 and 4, long term apparent modulus of elasticity)
t	=	0.977	in	0.025	m	
I	=	0.0777	in^3	1.27E-06	m	
E_s	=	4735	psi	32650	kPa	
μ	=	0.15	[-]	0.15	[-]	(Ref. 1 Table 3-13)
E^*_s	=	5571	psi	38412	kPa	
P_{CR}	=	563	psi	3881	kPa	

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Applied vertical pressure on the pipe:

$$P_B = \frac{\sigma_v}{144}$$

where,

P_B = applied verical pressure on the pipe (psi)

σ_v = applied vertical pressure on pipe (psf)

		English Units		SI Units	
σ_v	=	14206	psf	680	kPa
P_B	=	98.7	psi	680	kPa

P_{CR} = critical constrained buckling pressure = 563 psi

= 3881 kPa

$$\text{Factor of Safety} = \frac{P_{CR}}{P_B} = \frac{563}{98.7} = 5.7$$ Okay [Typical Recommended F.S. = 2.0 Ref. 1]