AM-LINER II

SAMPLE
FOLDED/FORMED PVC LINER DESIGN

LINER THICKNESS
AND
FLOW QUALITY
CALCULATIONS

AMERICAN PIPE & PLASTICS
BINGHAMTON, NEW YORK

8" PIPE/LINER
REHABILITATION

MARCH 21, 2006

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Design References

Design and Construction of Sanitary and Storm Sewers
ASCE Manuals & Reports on Engineering Practice No. 37
WPCF Manual of Practice No.9, 6th Printing
7th Printing, Copyright 1969 by ASCE & WPCF
[Labeled hereafter as D.C.S.S.S.]

AWWA Standard for Fiberglass Pressure Pipe
American National Standard
ANSI/AWWA C950-88, Copyright 1989
[Labeled hereafter as F.P.P.]

American Society for Testing and Materials
ASTM Standard Practice Designation: D 3839 - 89
Underground Installation of "Fiberglass" (Glass-Fiber Reinforced Thermosetting Resin) Pipe
Approved January 27, 1989
[Labeled hereafter as ASTM D 3839-89]

American Society for Testing and Materials
ASTM Standard Practice Designation: F 1216-93
Approved 1993
[Labeled hereafter as ASTM F 1216-93]

Design Parameters

Liner Dimensions

Liner diameter (in.)	8.0 in.
Liner thickness (in.)	0.246 in.
Liner SDR	32.5

Liner Physical Properties

Initial Tensile Stress (psi)	3600 psi
Initial Flexural Stress (psi)	4100 psi
Initial Flexural Modulus of Elasticity (psi)	145000 psi
Long-Term Modulus of Elasticity (psi)	108750 psi

Existing Pipe Characteristics

Existing pipe fully deteriorated

Ovality (%)	2.0 %

Soil Characteristics

Type of soil	sand/clay
w = soil density (pcf)	120.0 pcf
Es = soil modulus (psi)	1000.0 psi

Factor of Safety	2.000

1. Determine the Loading on the Pipe Using the Modified Marston Formula and the Boussinesq Formula

Base Equation :

Total Load (Wtot) = Wc + Wl

A) Dead Load (Wc) = Cd * w * Bc * Bd [Marston Formula, pg.187, D.C.S.S.S.]

Where :

Cd = loading coefficient

= (1 - e^(-2 * ku' * H/Bd)) / (2*ku') [pg188, D.C.S.S.S.]

Where:

H =	Height of soil above crown of pipe (ft.)	=	15.33 ft.
Bd =	trench width (ft.)	=	6.00 ft.
ku'	[see fig.55, pg.202, D.C.S.S.S.]	=	0.130
	Therefore: Cd	=	1.867
w =	soil density (psf)	=	120.00 pcf
Bc =	diameter of pipe (in.)	=	8.00 in.
Bd =	trench width (ft.)	=	6.00 ft.
	Dead Load (Wc)	=	896.2 lb/ft.

B) Live Load (Wl) = Cl * P * (Imf) [Section X1.3.4, pg.5, ASTM D 3839-89] & [Eq. A.11, pg 32, F.P.P.]

Where:

Cl =	Live Load Coefficient (/ft.)	=	0.001 /ft.
P =	wheel load (lb)	=	16000.0 lb
Imf =	impact factor		
=	for depths to the top of the pipe	=	1.000

1 + (0.766 - 0.133*H)

Therefore: Live Load (Wl) = 16.00 lb/ft.

Therefore: Total Load (Wtot = Wc + Wl) = 912.198 lb/ft

2. Determine External Pressure on Pipe

Base equation:

$$qa\ (psi) = Yw * Hw + (Rw * Wc) / D + (Wl / D)$$

[Eg A.20, pg.39, F.P.P.]

where: Wc = vertical soil load = $(Ys * H * D) / 144$

[Eq A.10, pg.31, F.P.P]

Modified equation:

$$qa\ (psi) = Yw * Hw * 12\ in./ft. + (Rw * Ys * H) / 144 + (Wl / (D*12\ in./ft.))$$

where:

Yw =	specific weight of water (lb/in.^3)	=	0.0361	lb/in.^3
Hw =	height of water (ft.), from top of pipe to water level	=	15.33	ft.
Rw =	water buoyancy factor = 1 - .33(hw/H)	=	0.67	
Ys =	soil density (lb/ft.^3)	=	120.00	lb/ft.^3
H =	height of soil (ft.), above crown of pipe	=	15.33	ft.
Wl =	live load (lb/ft.)	=	16.00	lb/ft.
D =	pipe diameter (in.)	=	8.00	in.

Therefore: External Pressure on the pipe (qa) = **15.37 psi**

3A. Thickness Required for Buckling Pressure

Base Equation:

$$qa = (C / N) * [(32 * Rw * B' * Es * EI)/D^3]^{(1/2)}$$

[Eq A.17, pg.38, F.P.P.])
& [Eq X1.4, pg.5, ASTM F 1216-91]

Modify the Base Equation by adding the following substitution:

$$EI = \text{Pipe Wall Stiffness Factor} = (El / 12) * t^3$$

Modified Equation:

$$t = 0.721 * D * [((N * qa / C)^2) / El*Rw*B'*Es]^{(1/3)}$$

where:

I	=	Moment of Inertia (in.^4/in.) = t^3/12		
t	=	minimum liner thickness (in.)		
D	=	pipe diameter (in.)	=	8.00 in.
N	=	safety factor	=	2.00
qa	=	external pressure on pipe (psi)	=	15.37 psi
C	=	ovality factor		
	=	$\left[\frac{1 - \%\ ovality/100}{(1 + \%\ ovality/100)^2} \right]^3$	=	0.836
El	=	Long-term modulus of elasticity (psi)	=	108750 psi
Rw	=	water buoyance factor	=	0.67
B'	=	coefficient of elastic support		
	=	$\frac{1}{1 + 4 * e^{(-0.065*H)}}$	=	0.40
Es	=	Modulus of soil reaction (psi)	=	1000.00 psi

Therefore: The minimum liner thickness (t) = 0.207 in

When lining an 8.00 inch diameter pipe, utilize an 8.00 inch outer diameter liner with a thickness of 0.246 inches, exceeding the required minimum of 0.207 inches.

3B. Check Thickness For Deflection

Base Equation (Modified Iowa Formula):

$$y = Dl * \frac{(K * (Wc + Wl) * r^3)}{(EI + 0.061 * E' * r^3)}$$

[Eq.15, pg.218, D.C.S.S.S.]
& [Eq.A.9, pg.29, F.P.P.]

Modify the Base Equation by adding the following four substitutions:

(1) r * 2 = D , (2) SDR / t = D , (3) I = t^3 , (4) Wtot / 12 = Wc + Wl

Modified Equation :

y = (Dl * K * Wtot) / ((EI / (1.5*(SDR^3))) + 0.061*E')

where:

y	=	deflection (ft.)		
Dl	=	deflection lag factor [Section A.3.4.2.1, pg.30, F.P.P.]	=	1.50
K	=	bedding factor [Table A.2, pg.31, F.P.P.]	=	0.11
Wtot	=	load on unit cross section of pipe (lb/in.)	=	76.02 lb/in.
El	=	Long-term modulus of elasticity (psi)	=	108750.0 psi
SDR	=	ratio of liner diameter to liner thickness	=	32.5
E'	=	Modulus of soil reaction (psi)	=	1000.0 psi

Therefore: The deflection (y) = 0.199 in.

As a standard requirement, deflection should not exceed a 5% change in the vertical cross-section of the pipe. [Eg A.8, pg 29, F.P.P.]

y / D = 0.0248 in./in.

2.48 % < 5.00 %

Therefore the thickness is within acceptable limits.

3C. Check Thickness for Ring-Bending Stress

Base Formula:

$$Ob = Df * El * \frac{(ya)}{D} * \frac{(t)}{D} \leq \frac{Sb}{FS}$$

[Eq A.6, pg.27, F.P.P.]

where:

Ob =	maximum ring-bending stress due to deflection (psi)			
t =	liner thickness (in.)	=	0.246	in.
Df =	shape factor [Table A.1, pg28, F.P.P.]	=	8.0	
El =	long- term modulus of elasticity (psi)	=	108750	psi
y =	deflection (in.)	=	0.199	in.
ya =	maximum allowable deflection (in.)	=	0.400	in.
Sb =	ring-bending strength of pipe (psi)	=	4100.0	psi
FS =	factor of safety	=	2.00	
D =	liner diameter (in.)	=	8.000	in.

Df * El * (ya / D) * (t / D) = 1338.46 psi

$\frac{Sb}{FS}$ = 2050 psi

1338.46 psi < 2050 psi

Therefore the liner thickness is adequate to resist ring-bending stresses.

3D. Check Thickness for Minimum Stiffness

Base Equation:

$$\frac{EI}{D^3} = \frac{EI}{12 * (SDR^3)} \geq 0.093 \text{ psi}$$

[Eq X1.4, pg.5, ASTM F 1216-91]

where:

El	=	Modulus of elasticity (psi)	=	145000 psi
SDR	=	ratio of liner diameter to liner thickness	=	32.5

$$\frac{E}{12 * (SDR^3)} = 0.352 \text{ psi}$$

$$0.352 \text{ psi} > 0.093 \text{ psi}$$

Therefore the liner thickness is adequate for the required minimum stiffness.

4. Calculate Increase In Flow Capacity

Base Equation:

Q = V * A [pg.80, D.C.S.S.S.]

(1) $V = \frac{(1.486)}{n} * R^{(2/3)} * s^{(1/2)}$

where:

n = Manning's Coefficient

a) Existing host pipe (pg.84, D.C.S.S.S.)	n =	0.015
b) Liner pipe	n =	0.011

R = Hydraulic Radius = $\frac{\text{pipe diameter (ft.)}}{4}$

R (original pipe)	=	0.1667 ft.
R (lined pipe)	=	0.1564 ft.

s = slope of pipeline = $\frac{\text{change in invert elevation}}{\text{distance between manholes}}$

M.H.#A invert depth	=	16.000 ft.
M.H.#B invert depth	=	15.000 ft.
Distance	=	300.000 ft.
Therefore: s	=	0.0033

(2) A = flow area of the pipe

= 0.85 * (D^2) / 4 * (pi) , [0.85 = 85% of pipe's full capacity]

A (original pipe)	=	0.297 sq.ft.
A (lined pipe)	=	0.261 sq.ft.

Modified Equation:

$$Q = \frac{1.486 * A * R^{(2/3)} * s^{(1/2)}}{n}$$

Q (CP)	=	0.51 cu.ft./sec.	=	232.61 gal/min
Q (Lined pipe)	=	0.59 cu.ft./sec.	=	267.77 gal/min
Q (Increase)	=	0.08 cu.ft./sec.	=	35.16 gal/min

Therefore: Increase in Flow Capacity (Q) = 15.12 %

SUMMARY OF RESULTS

1. Buckling Pressure

Minimum Liner Thickness	t =	0.207 inch
Actual Liner Thickness	t =	0.246 inch

2. Computed Deflection

Computed Deflection	y =	0.199 inch
Allowable Deflection	5% =	0.400 inch

0.199 < 0.400

Deflection is within acceptable limits.

3. Computed Ring Bending

Computed Ring Bending	Ol =	1338 psi
Maximum Ring Bending	Ol (max) =	2050 psi

1338 < 2050

Ring Bending is within acceptable limits.

4. Computed Minimum Stiffness

Computed Minimum Stiffness	=	0.352 in-lb
Allowable Minimum Stiffness	=	0.093 in-lb

0.352 > 0.093

The liner thickness meets the minimum Long-Term Stiffness requirements.

5. Percent Increase In Flow Capacity = 15.118 %