

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

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

Base Equation :

$$\text{Total Load (Wtot)} = Wc + Wl$$

A) Dead Load (Wc) = Cd * w * Bc * Bd

[Marston Formula, pg.187, D.C.S.S.S.]

Where :

$$\begin{aligned} \text{Cd} &= \text{loading coefficient} \\ &= (1 - e^{(-2 * \text{ku}' * H/\text{Bd})}) / (2 * \text{ku}') \end{aligned}$$

[pg.188, 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 (pcf)	=	120.00 pcf
Bc = diameter of pipe (in.)	=	8.00 in.
Bd = trench width (ft.)	=	6.00 ft.

Dead Load (Wc)	=	<u>896.2 lb/ft.</u>
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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	=	1.000
= for depths to the top of the pipe	=	1.000
1 + (0.766 - 0.133*H)	=	1.000

Therefore: Live Load (Wl)	=	<u>16.00 lb/ft.</u>
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Therefore: Total Load (Wtot = Wc + Wl)	=	<u><u>912.198 lb/ft</u></u>
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2. Determine External Pressure on Pipe

Base equation:

$$q_a \text{ (psi)} = Y_w * H_w + (R_w * W_c) / D + (W_l / D)$$

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

where: $W_c = \text{vertical soil load} = (Y_s * H * D) / 144$

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

Modified equation:

$$q_a \text{ (psi)} = Y_w * H_w * 12 \text{ in./ft.} + (R_w * Y_s * H) / 144 + (W_l / (D * 12 \text{ in./ft.}))$$

where:

$Y_w = \text{specific weight of water (lb/in.}^3)$	=	0.0361 lb/in. ³
$H_w = \text{height of water (ft.), from top of pipe to water level}$	=	15.33 ft.
$R_w = \text{water buoyancy factor} = 1 - .33(hw/H)$	=	0.67
$Y_s = \text{soil density (lb/ft.}^3)$	=	120.00 lb/ft. ³
$H = \text{height of soil (ft.), above crown of pipe}$	=	15.33 ft.
$W_l = \text{live load (lb/ft.)}$	=	16.00 lb/ft.
$D = \text{pipe diameter (in.)}$	=	8.00 in.

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

3A. Thickness Required for Buckling Pressure

Base Equation:

$$q_a = (C/N) * [(32 * R_w * B' * E_s * EI)/D^3]^{(1/2)}$$

[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:

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

Modified Equation:

$$t = 0.721 * D * [(N * q_a / C)^2 / EI * R_w * B' * E_s]^{(1/3)}$$

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
q _a = external pressure on pipe (psi)	= 15.37 psi
C = ovality factor	
= [$\frac{1 - \% \text{ ovality}/100}{(1 + \% \text{ ovality}/100)^2}$] ³	= 0.836
EI = Long-term modulus of elasticity (psi)	= 108750 psi
R _w = water buoyance factor	= 0.67
B' = coefficient of elastic support	
= $\frac{1}{1 + 4 * e^{(-0.065 * H)}}$	= 0.40
E _s = Modulus of soil reaction (psi)	= 1000.00 psi

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

When lining ar 8.00 inch diameter pipe,
utilize ar 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):

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

[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) $W_{tot}/12 = Wc + Wl$

Modified Equation :

$$y = (DI * K * W_{tot}) / ((EI / (1.5 * (SDR^3))) + 0.061 * E')$$

where:

y = deflection (ft.)	
DI = deflection lag factor	= 1.50
	[Section A.3.4.2.1, pg.30, F.P.P.]
K = bedding factor	[Table A.2, pg.31, F.P.P.] = 0.11
W _{tot} = load on unit cross section of pipe (lb/in.)	= 76.02 lb/in.
EI = 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.]

$$y / D = 0.0248 \text{ in./in.}$$

$$\underline{\underline{2.48 \% < 5.00 \%}}$$

Therefore the thickness is within acceptable limits.

3C. Check Thickness for Ring-Bending Stress

Base Formula:

$$Ob = Df * El * \frac{(ya)}{D} * \frac{(t)}{D} < \frac{Sb}{FS} \quad \text{[Eq A.6, pg.27, F.P.P.]}$$

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.

$$Df * El * (ya / D) * (t / D) = 1338.46 \text{ psi}$$

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

$$\underline{\underline{1338.46 \text{ psi} < 2050 \text{ psi}}}$$

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

3D. Check Thickness for Minimum Stiffness

Base Equation:

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

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

where:

$$\begin{aligned} EI &= \text{Modulus of elasticity (psi)} &= & 145000 \text{ psi} \\ SDR &= \text{ratio of liner diameter to liner thickness} &= & 32.5 \end{aligned}$$

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

$$\frac{0.352 \text{ psi}}{0.093 \text{ psi}} > 1$$

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.]

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

where:

n = Manning's Coefficient

a) Existing host pipe n = 0.015

(pg.84, D.C.S.S.S.)

b) Liner pipe n = 0.011

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

R (original pipe) = 0.1667 ft.

R (lined pipe) = 0.1564 ft.

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

M.H.#A invert depth = 16.000 ft.

M.H.#B invert depth = 15.000 ft.

Distance = 300.000 ft.

Therefore: s = 0.0033

$$(2) \quad A = \text{flow area of the pipe} \\ = 0.85 * (D^2) / 4 * (\pi) \quad , \quad [0.85 = 85\% \text{ of pipe's full capacity }]$$

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

y = 0.199 inch

Allowable Deflection

5% = 0.400 inch

0.199 < 0.400

Deflection is within acceptable limits.

3. Computed Ring Bending

OI = 1338 psi

Maximum Ring Bending

OI (max) = 2050 psi

1338 < 2050

Ring Bending is within acceptable limits.

4. 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 %