# Chapter 7
## Design Guidelines

### 1.0 Introduction

Due to the high cost associated with excavation, restoration, and traffic re-routing, it is frequently cost effective to restore existing culverts rather than replace. The main advantages of rehabilitation over restoration include:

- Traffic disruption is minimized or even completely eliminated.
- Contamination of watercourses is avoided.
- Existing slope and vegetation need not be disturbed therefore there is little need for concern regarding slope stability and/or erosion. The cost of restoring trees, fences, embankments, guard rails and reinstating vegetation is avoided.
- Existing pavement is undisturbed therefore there is no concern regarding pavement settlement or jointing.
- Due to the very smooth inside surface of the liner pipe the flow capacity of the restored culvert may frequently exceed that of the original culvert even when in new condition.

### 2.0 Select a Liner Pipe Diameter

To maximize flow capacity the largest feasible diameter of liner pipe should be selected. This is limited by the size and condition of the existing culvert, through which it will be inserted. Sufficient clearance will be required to ensure trouble-free insertion. Consider the length of pull, severity of any off-set joints, localized deflected areas, and structural integrity of the existing culvert.

The selection of a polyethylene liner that has an outside diameter 10% less than the inside diameter of the existing culvert will generally serve two purposes. First, this size differential usually provides adequate clearance to accommodate the insertion process. And second, 90–100% or more of the original flow capacity may be maintained.
A differential of less than 10% may provide adequate clearance in larger diameter culverts. It is quite common to select a 5–10% differential for culverts with a diameter greater than 24 inches, assuming that the condition of the existing culvert will permit its insertion.

Field inspection of the existing culvert is vital to ensure a proper liner selection and installation.

### 3.0 Determine the Structural Requirements for the Liner Pipe

The polyethylene liner pipe may be required to withstand the following loading conditions:

- Insertion, i.e. push/pull forces
- Grouting pressures
- Ground water pressure
- Earth pressures
- Traffic loads

### 3.1 Insertion Forces

It is extremely difficult to estimate the amount of force required to push or pull a polyethylene liner pipe into an existing CSP culvert. These forces can, however, be minimized by properly inspecting and cleaning the existing culvert to ensure that all sharp edges are repaired and that all debris has been removed. Flowing water within the culvert during installation will actually aid the installation process rather than hamper it.

Fortunately, high density polyethylene (HDPE) is very tolerant of deformation, scratches, scrapes and gouges. For the purposes of a culvert liner it is quite safe to assume that if the liner has been installed without obvious damage, i.e. tears through the wall, kinks or cracks, the liner will function adequately.

### 3.2 Grouting Pressures

Prior to its initial set-up, grout will act as a fluid and apply an external hydrostatic pressure to the liner. Care must be taken to ensure that any unbalanced grouting pressures do not exceed the safe allowable limits for the HDPE liner. Unbalanced grouting pressures can be minimized by utilizing low density grout and/or by installing the grout in lifts. Tables 1 and 2 below provide the allowable grout pressures for Snap-Tite Pro Line and Snap-Tite Solid.

Table 1: Allowable Grouting Pressures for Snap-Tite Pro Line Profile Wall HDPE Pipe

| NOMINAL PIPE SIZE (in) | ALLOWABLE GROUTING PRESSURE (psi) |
|---|---|
| 10 | 7.8 |
| 12 | 7.8 |
| 15 | 7.8 |
| 18 | 8.0 |
| 21 | 7.8 |
| 24 | 7.9 |
| 27 | 7.9 |
| 30 | 7.8 |
| 36 | 8.1 |
| 40 | 8.0 |
| 42 | 8.0 |

Notes:
1. Based on an assumed maximum grout set-up time of 10 hours.
2. Based on a maximum pipe temperature of 23$^{o}$C.
3. No assumed initial ovality.
4. Includes a factor of safety of 1.5.

Table 2
Ring Compression Strength for Solid Wall Snap-Tite Liner

| SERVICE LIFE | PIPE DR 17 | PIPE DR 21 | PIPE DR 26 | PIPE DR 32.5 |
|---|---|---|---|---|
| 1 day | 65 ft of water | 36 ft of water | 18 ft of water | 10 ft of water |
| | 28 psi | 16 psi | 8 psi | 4 psi |
| 1 month | 34 ft of water | 25 ft of water | 10 ft of water | 6 ft of water |
| | 15 psi | 11 psi | 4 psi | 2 psi |
| 1 year | 32 ft of water | 19 ft of water | 10 ft of water | 6 ft of water |
| | 14 psi | 8 psi | 4 psi | 2 psi |
| 50 years | 29 ft of water | 17 ft of water | 9 ft of water | 4 ft of water |
| | 13 psi | 7 psi | 4 psi | 2 psi |

“Data from Phillips Driscopipe Design Manual". This data may be used for liners using solid wall high-density polyethylene pipe. This data applies to unsupported pipe only. Temperature is 73 F.

*Note: Direct burial or grouting of the pipe supports the pipe increasing structural differential-pressure capability about four-fold.

### 3.3 Ground Water Pressure

In the unlikely situation that the ground water level is above the top of the culvert and the annular space is not to be grouted, the liner pipe's ability to withstand this external pressure should also be considered. Tables 2 and 3 provide the allowable external pressures which can be safely applied to Snap-Tite Pro Line and Snap-Tite Solid pipe indefinitely. If the annular space is to be grouted over the full length of the culvert, these allowable pressures may be increased by a factor of three or more depending on the load bearing capabilities of the grout.

Table 3: Allowable Ground Water Pressures for Snap-Tite Pro Line Profile Wall HDPE Pipe

| NOMINAL PIPE SIZE (in) | ALLOWABLE PRESSURE (psi) |
|---|---|
| 10 | 5.5 |
| 12 | 5.5 |
| 15 | 5.5 |
| 18 | 5.6 |
| 21 | 5.5 |
| 24 | 5.6 |
| 27 | 5.6 |
| 30 | 5.5 |
| 36 | 5.7 |
| 40 | 5.7 |
| 42 | 5.7 |

Notes:

1. Based on an assumed load duration of 50+ years.
2. Based on a maximum pipe temperature of $23^{\circ}$ C.
3. No assumed initial ovality
4. Includes a factor of safety of 1.5.

### 3.4 Earth and Traffic Loads

Buried culverts and pipelines under roadways are subject to static and dynamic loading. The static load is the weight of the pavement, soil and bedding above the pipe. The dynamic load comes from cars and trucks travelling on the roadway.

When working with Snap-Tite and Snap-Tite Pro liner, one must make assumptions about the load that the liner will experience. When the existing culvert or pipeline is in good condition, the liner may not be exposed to any load. If the old culvert is badly deteriorated, the liner will be exposed to both static and dynamic loading.

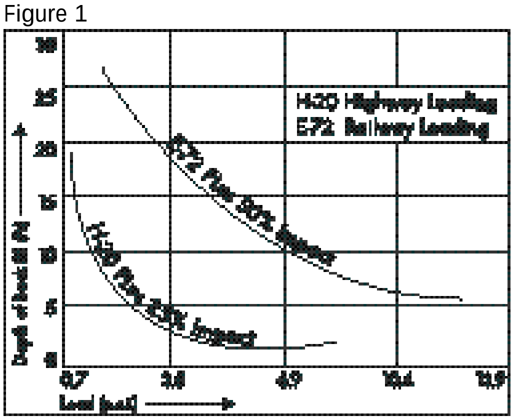
Grouting is commonly used to provide additional support to the liner and the roadway. Much work has been done with grouting materials for the reinforcement of liners. Liners when properly grouted in place offer an excellent long term repair for old culverts.

The compressive strength of the grout and correct placement influences the strength of the liner and rehabilitated culvert system. Grouts with strengths of 100 psi are similar to a sand/cement backfill. When the a compressive strength of 300 psi is reached, the grout is hard like cement. Many state highway departments are specifying 100 psi to 150 psi grout strength. If one assumes that the annular space between the Snap-Tite liner and the old culvert is filled with soil, then direct burial calculations can be used to determine the load carrying capabilities of the liner. Sections 3.4.1, Verticals Deflection, 3.4.2, Localized Wall Buckling, and 3.4.3, Wall Crushing show how to make these direct burial calculations. These calculations can be used if one assumes the annular space between the liner and culvert is filled with soil or be direct burial of Snap-Tite liner pipe.

#### 3.4.1 Vertical Deflection

A flexible pipe is by definition a pipe which will deflect when subjected to external loads (traffic, ground water changes, frost actions, soil settlement, etc.) - as opposed to a rigid pipe, which carries all external loads by itself.

Figure 1




The degree of deflection of a flexible pipe will depend on the pipe stiffness, support from the surrounding soil, and on external loads.

$$\Delta y = \frac{(D_l W_c + W_L) K_x r_m^3}{EI + 0.061 E' r_m^3}$$

Where:

$\Delta y$ = 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 1.0 to 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 4 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 1 by the outside diameter (in inches) of the pipe.

$K_x$ = deflection coefficient, dimensionless. (0.103 for relining)

$t_w$ = minimum wall thickness, in inches

$r_m$ = mean pipe radius, in inches
= $(OD - t_w)/2$ (for solid wall HDPE)
= $(ID + Ph)/2$ (for Snap-Tite Pro)

Ph = Average profile wall height in inches.
= value from ISCO engineer.

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 unit moment of inertia of the pipe wall for ring bending, in $inches^4$/inch.
= $t_w^3/12$ (for solid wall HDPE)
= obtain value from ISCO engineer for Snap-Tite Pro

Table 4
Vertical Soil Loads in lbs./$in^2$

| DEPTH TO TOP OF PIPE IN FT | SOIL DENSITY 90 lbs./$ft^3$ | SOIL DENSITY 100 lbs./$ft^3$ | SOIL DENSITY 110 lbs./$ft^3$ | SOIL DENSITY 120 lbs./$ft^3$ |
|---|---|---|---|---|
| 1 | 0.6 | 0.7 | 0.8 | 0.8 |
| 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 |

E' = modulus of soil reaction, in psi. The appropriate value for E' should be selected from Table 5.
ID = Inside Diameter, in inches.

### 3.4.2 Localized Wall Buckling

The allowable buckling load for a buried flexible pipe can be estimated using the following equation:

$$q_a = (1/F.S.) * (32\ R_w\ B'\ E'\ EI/D_m{}^3)^{1/2}$$

Where:

F.S. = Factor of safety use 2.5.
$R_w$ = Water buoyancy factor, dimensionless.
= $1 - 0.33(H_w/H_c)$; $(0 \le H_w \le H_c)$
B' = Empirical coefficient of elastic support, dimensionless.
= $(1 + 4e^{-0.065Hc})^{-1}$
$D_m$ = Mean Pipe diameter, in inches.
= Avg. O.D. – $t_w$ for solid wall HDPE pipe
= Nominal I.D. + Avg. Profile Height for Snap-Tite Pro
$H_w$ = Height of ground water table above pipe, in feet.
$H_c$ = Burial depth to top of pipe, in feet.

Satisfaction of the buckling requirement is assured by using the following equation:

$$\gamma_w H_w/144 + R_w W_c / O.D. + P_v \le q_a$$

Where:
$\gamma_w$ = specific weight of water, in lbs/ft$^3$
= 62.4 lbs/ft$^3$
$P_v$ = Differential Vacuum Pressure from inside pipe to outside, in psi

### 3.4.3 Wall Crushing

The maximum long-term compressive stress applied to the walls of the culvert liner can be estimated as follows;

CS = $(W_c + W_L) /(2t_w)$ for solid wall HDPE pipe
and = $(W_c + W_L)$ /(Average Profile Area x 2) for Snap-Tite Pro

Where:
CS = Compressive stress, in psi.

The allowable long-term compressive stress for HDPE is 800 psi.

Table 5
Values of E'
Based on Soil Type (ASTM D2321) and Degree of Compaction

| Soil Type of Initial Backfill Embedment Material | Description | E' (psi) for Degree of Compaction (Proctor Density, %) | | | |
|---|---|---|---|---|---|
| | | Loose | Slight (70-85%) | Moderate (85-95%) | High (95%) |
| I | Manufactured angular, granular materials (crushed stone or rock, broken coral, cinders, etc.) | 1,000 | 3,000 | 3,000 | 3,000 |
| II | Coarse grained soils with little or no fines | N.R. | 1,000 | 2,000 | 3,000 |
| III | Coarse grained soils with fines | N.R. | N.R. | 1,000 | 2,000 |
| IV | Fine-grained soils | N.R. | N.R. | N.R. | N.R. |
| V | Organic soils (peat, muck, clay, etc.) | N.R. | N.R. | N.R. | N.R. |

N.R. = Not Recommended for use by ASTM D2321 for pipe wall support

## 4.0 Analyze the Flow Capacity

The next step in the design process is to analyze the flow capacity of the rehabilitated culvert in comparison with the existing CSP culvert and more importantly with the specific site requirements of the culvert. The flow capacity of a culvert may be estimated using the commonly accepted Manning Equation as follows:

$$Q = \frac{.275\ ID^{2.667}\ S^{0.5}}{n}$$

Where:

Q = Flow capacity, in GPM

S = The slope of the culvert, in ft/ft.

n = Manning flow factor for the pipe material

= 0.009 for solid wall Snap-Tite

= 0.012 for Snap-Tite Pro

= 0.024 for CSP

## 5.0 Grouting the Annular Space

When the old culvert pipe is leaking but the bedding around the culvert and under the roadway is still in place, only end seals are needed for the new Snap-Tite liner. By sealing the ends of the liner in place, the leaking culvert pipe is effectively sealed.

There are two common sealing techniques. The first is to grout the annular space between the liner and the culvert for a distance of 1.5 times the culvert diameter from each end only. This is frequently sufficient to prevent the flow of water along the annular space.

Since the surface of a corrugated culvert or concrete culvert is rough and corroded, it is often difficult to get a complete seal. The use of special sealing techniques is required. One of the methods used to seal is the use of water activated urethane foams in combination with okum. The activated okum is wrapped around the liner and packed tightly between the liner and the culvert. When water is added the urethane expands up to ten times its original size. This increase in volume seals most leaks quickly.

- When the existing culvert has deteriorated to such an extent that bedding material has been falling into the culvert leaving voids beneath the road base, grout can be flowed into these voids. This effectively stabilizes the surrounding soils and eliminates the potential for settlement or collapse of the roadway.

- The grout around the liner provides extra support for the liner. This support increases the collapse strength of the liner. The liner better resists ground water collapse pressure.

- When old culverts begin to collapse, there is the danger of point loads and deflection. The old culvert may fail in a random fashion and create loads on the liner. The grout again supports the old culvert and prevents point loading.

Chapter 10 of this manual is devoted to grouting. Please read this Chapter for additional information on grouting.

## 6.0 Example Calculations

### 6.1 Example Parameters

- 18" I.D. existing CSP showing advanced corrosion but no serious deflections or joint misalignments.

- Depth of cover is 5 ft to the crown of the culvert where highway traffic exists.

- Water table is below the bottom of the pipe.

- The original CSP culvert was installed in a well compacted granular material with an average density of 120 lbs/ft$^3$.

- The existing culvert has a slope of 0.05 ft/ft.

### 6.2 Select a Trial Liner Pipe

Since this culvert appears to have minimal obstructions to the insertion process we will consider liner pipes which have an O.D. which is between 5 – 10% smaller than the I.D. of the existing culvert.

Consider 16” DR 32.5 standard Snap-Tite:

I.D. = 15.02 in.
O.D. = 16.00 in
I = $0.00994\ in^4/in$

The O.D. of this pipe is approximately 11% smaller than the I.D. of the existing culvert.

## 6.3 Check Long-Term Earth and Traffic Loading Conditions

### 6.3.1 Vertical Deflection

$D_L$ = 1.0

$W_c$ = From Table 4
$4.2\ lbs/in^2 * 16\ in.$
= 67.2 lb/in

$W_L$ = From Figure 1
$2.4\ lbs/in^2 * 16\ in.$
= 38.4 lb/in.

$r_m$ = (16 - .49) / 2
= 7.75 in

E’ = 2,000 psi conservative value From Table 5

$$\Delta y = \frac{(67.2 * 1.0 + 38.4) * 0.103 * 7.963^3}{30{,}000*0.00994 + 0.061*2{,}000*7.963^3}$$
= 0.089 in

$\Delta y$ = 0.55% O.K. for HDPE

### 6.3.2 Check Local Wall Buckling

$R_w$ = 1.0 (no ground water effects)

$B' = (1 + 4*e^{-0.065*5})^{-1} = 0.257$

$D_m$ = 16 - .49 = 15.51 in

$q_a = (1/2.5)(32 * 1.0 * 0.257 * 2{,}000 * 30{,}000 * 0.00994/15.51^3)^{1/2}$

$q_a$ = 14.5 psi

check: 62.4 * 0/144 + 1.0 * 67.2/16 + 0
= 4.2 psi

$q_a \geq 4.2$ therefore O.K.

### 6.3.3 Check Wall Crushing

CS = (67.2+38.4)/(2 * 0.492) = 107.3 psi

CS ≥ 800 psi therefore O.K.

Since the trial selection meets all three earth and traffic loading criteria the trial liner should perform adequately even in the worst case anticipated loading condition.

## 6.4 Analyze Flow Capacity

### 6.4.1 Consider the Existing CSP Culvert

$$Q = \frac{.275 * 18^{2.667} * 0.05^{0.5}}{0.024}$$
= 5707 GPM

### 6.4.2 Consider the Rehabilitated Culvert

$$Q = \frac{.275 * 15.02^{2.667} * 0.05^{0.5}}{0.009}$$
= 9392 GPM

Therefore, the rehabilitated culvert has 164% of the flow capacity of the original CSP culvert.

## 7.0 References

7.1 Plastic Pipe Institute (PPI) – Chapter 10 – “Pipeline Rehabilitation by Sliplining with Polyethylene Pipe”, 1993.

7.2 Plastic Pipe Institute (PPI) – TR 14/92 – "Water Flow Characteristics of Thermoplastic Pipe", 1992.

7.3 Ministry of the Environment – Interim Guidelines for the Design of Storm Sewer Systems, July 1985.

7.4 ANSI/AWWA C950-88 – AWWA Standard for Fiberglass Pressure Pipe.

7.5 "Greenbook" Standard Specifications for Public Works Construction, 1997 Edition; BNi Building News, 1612 So. Clementine St: Anaheim, CA 92802

7.6 "Driscopipe Design Manual," The Performance Pipe Division of Chevron-Phillips Chemical Company, Richardson, TX

7.7 "WEHOLITE Design Information", KWH Pipe, Huntsville, Ontario.