CHAPTER 3–LITERATURE REVIEW

INTRODUCTION

In order to address the objective of determining available lining methods, the fore-mentioned literature sources were reviewed. Review of the literature produced five (5) general lining methods. For clarification purposes, some methods have been divided further into sub-methods. A list of the five (5) methods used to describe the state-of-the-practice in culvert lining techniques is presented below:

1. Sliplining
2. Close-fit Lining
3. Spirally Wound Lining
4. Cured-in-place Pipe Lining
5. Spray-on Lining

For each of the culvert lining techniques, the following characteristics were described in each section of this chapter for each method:

1. Description
2. Effective Uses, Advantages, and Limitations
3. Costs
4. General Installation Guidelines
5. Standards/Specifications
6. Contractors and Manufacturers

SLIPLINING

Sliplining involves inserting a flexible, usually thermoplastic, liner of smaller diameter directly into a deteriorated culvert. Liners are inserted into the host by either pulling or pushing the liner into place. After insertion, the annular space between the existing culvert and liner is generally grouted with a cementitious material providing a watertight seal. Annular space is the space between the outside diameter of the pipe being installed and existing pipe.(4) Once installed, lateral and service connections are reopened. Sliplining can further be categorized into segmental and continuous sliplining.

Segmental Sliplining

Description

Segmental sliplining consists of lining the deteriorated culvert with sections shorter than that of the existing culvert. A bell or spigot joint is commonly used to join culvert segments. Segments of the liner are assembled at entry points and forced into the host culvert. As each segment is added, the liner is forced further into the existing culvert until lining has been completed. Once installed, the annular space is generally grouted and service connections are reopened. Figure 3 illustrates the segmental sliplining process.

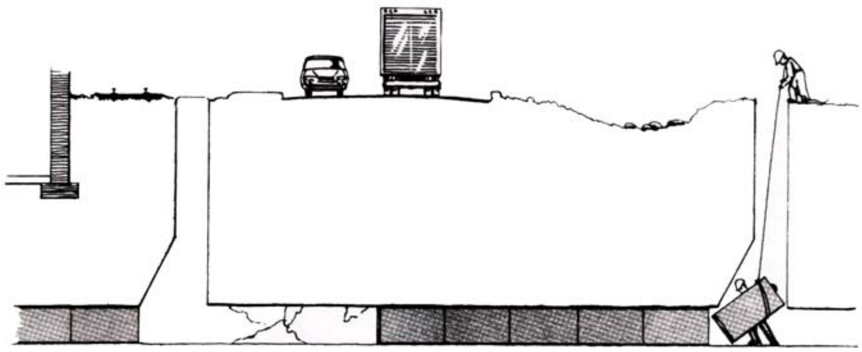

Figure 3. Drawing. Duratron System's Segmental Sliplining.(5)

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of segmental sliplining are presented in Table 1. Advantages and limitations associated with the method of segmental sliplining are presented in Table 2.

Table 1. General Characteristics and Effective Uses of Segmental Sliplining.(5,6,7)

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity & Pressure Pipelines	100 - 4,000 millimeters (4 - 157.5 inches)	PE, HDPE, PP, PVC, GRP (-EP & -UP)	1,600 meters (5,248 feet)

[1]PE – Polyethylene, HDPE – High Density Polyethylene, PP – Polypropylene, PVC – Poly(Vinyl Chloride), GRP – Glassfiber Reinforced Polyester

Table 2. Advantages and Limitations of Segmental Sliplining.[5,6,7,8]

Advantages	Limitations
Access pit (no digging) may be avoided with short lengths	Existing culvert must be longitudinally uniform (diameter changes or discontinuous culverts may prohibit this method)
Applicable to all types of existing culvert materials	Reduction in flow capacity may be significant
Existing pipe can be corroded, deformed, badly damaged, and/or near collapse	Annular space grouting is generally required
Custom shaped liner installation possible	Numerous joints
Simplistic method	Excavation required for lateral reconnection and sealing

Costs

According to the U.S. Forest Service (USFS) Draft Report on trenchless technology for Forest Service culverts,[9] the range of costs for segmental sliplining is approximated to be $50 per linear foot for 45.7-centimeter (18-inch) diameter pipes and $400 to $500 per linear foot for 1.5-meter (60-inch) diameter pipes. Information based on specific case study costs is presented below.

The case study "Marion County Culvert Lining" presented in the *Oregon Roads Newsletter* (Fall 2001)[10] provided information on the sliplining of a 30.5-meter (100-feet) long, 76-centimeter (30-inch) diameter corrugated metal pipe (CMP) that was covered by more than 6 meters (20 feet) of fill. Six (6) 6-meter (20-feet) long, 71-centimeter (28-inch) diameter sections of polyethylene pipe were used. The project cost totaled $12,080, with the liner costing a total of $7,140, or $59 per linear foot.

In the October-November 1997 issue of *Technology News*, an article titled "Plastic culvert liners the "in" thing,"[11] presented cost information from two (2) segmental sliplining case studies. The first case study was the lining of a 91.4-centimeter (36-inch) diameter deteriorated corrugated metal pipe located in Audubon County, Iowa. For this project, a 31-meter (102-ft) long, 81-centimeter (32-inch) diameter liner was used with a total liner cost of $6,500, or approximately $64 per linear foot. In the second case study, a 103-meter (339-feet) long, 1-meter (42-inch) diameter culvert located in Hamilton County, Iowa was sliplined due to the 14 meters (46 feet) of fill above it. A 107-meter (352-feet) long, 81-centimeter (32-inch) diameter liner was used with a total liner cost of $21,655, or approximately $62 per linear foot.

William Sunley from the Illinois DOT presented typical liner material costs as $13 per linear foot for 30.5-centimeter (12-inch) diameter and $42 per linear foot for 91.4-centimeter (36-inch) diameter in the June, 1994 *Illinois Municipal Review*.[12] In the Fall 1997 edition of *Crossroads*, the Wisconsin DOT reported that sliplining was 52% less expensive when compared to conventional metal culvert replacement on one of their sliplining projects.[13]

General Installation Guidelines

A general list of installation guidelines for segmental sliplining is provided below:[5,8,14,15]

1. Thoroughly inspect the existing culvert to determine the smallest diameter located within the culvert to be lined (structural deterioration and wall collapse may have reduced the original culvert diameter). For non-man entry culverts, a foam bullet-shaped device used for cleaning, known as a "pig," can be used to determine the smallest diameter.
2. Inspect the existing culvert for lateral and service connections, as well as protrusions such as roots and sediment.
3. Clean and clear the existing culvert.
4. Determine the diameter of the liner (in general, the outside diameter of the liner should be at least 10 % smaller than the inside diameter of the existing culvert. A 5% reduction should be sufficient for existing culvert diameters greater than 61 centimeters (24 inches)).
5. Determine the material of the liner. The material chosen should meet the designed load requirements. Factors to be considered in design load requirements include, but are not limited to, hydraulic loads caused by groundwater, soil conditions and loads, traffic loads, and temperature.
6. If excavation is required, excavations should be minimal and comply with local, State, or Federal regulations regarding excavation safety. Excavations at elbows minimize the total number of excavations required because the liner can be installed in two directions from one location.
7. Determine if the bypassing of flow is necessary. Flow bypass is necessary if the annular space and pulling head openings are incapable of handling the existing flow capacity. If possible, maintaining the flow will often reduce the force required for installation, but may cause accessibility problems and difficulty for workers.
8. Cut the existing culvert and initiate installation. Install the liner segments either with the push method or the pull method, making sure liner segments are connected properly. Figure 4 illustrates the use of heavy machinery to push a segmental sliplining into a large diameter culvert. Continue installation until the entire section of existing culvert has been lined.

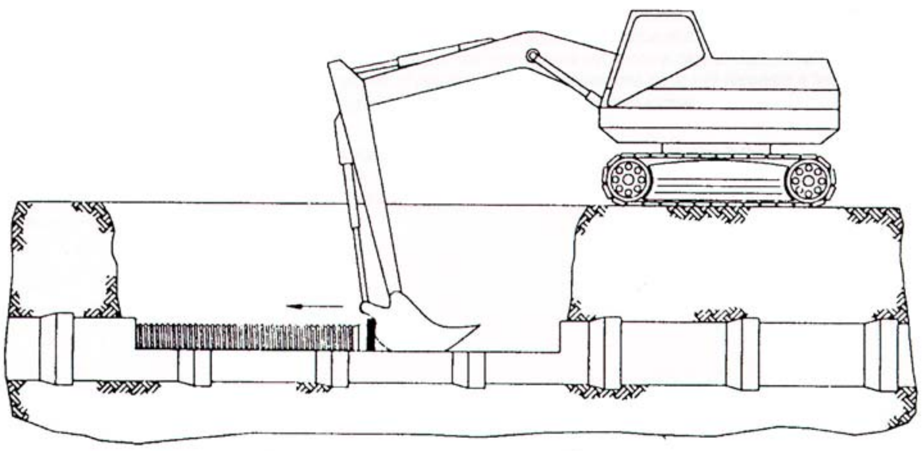

Figure 4. Drawing. Segmental Sliplining Installation Using the Push Method.[(15)]

9. Once installation has been completed, a 24-hour relaxation period is recommended prior to reopening lateral and service connections.
10. Inspect the completed lining by closed-circuit TV or manually if the diameter permits man-entry. The liner should be continuous over the entire length.
11. If leakage or other testing is required, perform testing to specifications and prior to the re-opening of lateral and service connections.
12. Reopen lateral and service connections. Dependent upon installation conditions, reconnection may be possible from within the lined culvert or may require point excavation.
13. After lateral and service connections have been reopened, reconnect and stabilize terminal connections. Fill the annular space between the liner and the original culvert with grout or another cementitious material. The allowable grout pressure of the liner should not be exceeded during the grouting process. Hydrostatically pressurizing the liner will allow for higher grouting pressures and help prevent collapse of the liner during the grouting process.
14. Finally, restore flow if bypass was required and initiate site cleanup.

Annular Grouting

Annular space between the liner pipe and the original pipe may be filled with grout or other material if required by the design engineer. Grouting will stabilize the line against flotation off-grade and collapse due to external ground water pressure.[(15)] Cement mortar is the most commonly used grout mixture.[(4)] Standards and specifications associated with cement mortar annular grouting are presented in Table 3.

Table 3. Standards and Specifications for Cement-mortar Annular Grouting.

Standard/Specification	Description
ASTM C 109 – Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (2002)[16]	This test method covers determination of the compressive strength of hydraulic cement mortars, using 2-inch or 50-millimeter cube specimens.
ASTM C 138 – Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete (2001)[17]	Describes the determination of the weight per cubic foot or cubic meter of freshly mixed concrete and gives formulas for calculating the yield, cement content, and the air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.
ASTM C 144 – Standard Specification for Aggregate for Masonry Mortar (2003)[18]	Covers aggregate use in masonry mortar.
ASTM C 150 – Standard Specification for Portland Cement (2002)[19]	Covers the use of eight (8) types of Portland cement. When the special properties specified for any other type are not required,where air-entrainment is, when moderate sulfate resistance or moderate heat of hydration is desired, when high early strength is desired, when a low heat of hydration is desired, and for use when high sulfate resistance is desired.
ASTM C 403 – Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance (1999)[20]	Covers the determination of the time of setting of concrete, with slump greater than zero, by means of penetration resistance measurements on mortar sieved from the concrete mixture.
ASTM C 495 – Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance (1999)[21]	Covers the preparation of specimens and the determination of the compressive strength of lightweight insulating concrete having an oven-dry weight not exceeding 800 killogram/meter (50 lb/foot) as determined by the procedures described herein. This test method covers the preparation and testing of molded 75- by 150-millimeter (3- by 6-inch) cylinders.
ASTM C 618 – Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete (2003)[22]	Covers coal fly ash and raw or calcined natural pozzolan for use in concrete where cementitious or pozzolanic action, or both, is desired, or where other properties normally attributed to fly ash or pozzolans may be desired, or where both objectives are to be achieved.

In addition to the standards and specifications listed in Table 3, the following list of related standards are associated with annular grouting of segmental sliplining:

- ASTM F 585 – Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers (2000)[15]
- NASSCO Specification for Sliplining, Segmented, Polyethylene (as provided by Duratron Systems for BUTTRESS-LOC® Pipe)(1999)[14]
- NASSCO Specification for Sliplining, Segmented, PVC (as provided by Lamson Vylon Pipe for large diameter Vylon® Slipliner Pipe) (1999)[14]
- NASSCO Specification for Sliplining, Segmented, PVC (as provided by Lamson Vylon Pipe for small diameter Vylon® Slipliner Pipe) (1999)[14]

Standards/Specifications

Table 4 presents the current standards and specifications associated with the method of segmental sliplining.

Table 4. Standards Associated with the Segmental Sliplining Method.[14,23]

Standard/Specification	Description
ASTM D 3212 – Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals (1996)[24]	Covers joints for plastic pipe systems intended for drain and gravity sewage pipe at internal or external pressure less than 7.6-meter (25-foot) head using flexible watertight elastomeric seals. Test requirements, test methods, and acceptable materials are specified.
ASTM F 585 – Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers (2000)[15]	Describes the design considerations, material selection considerations, and installation procedures for the construction of sanitary and storm sewers by the insertion of polyethylene pipe through existing pipe, along the previously existing line and grade.
NASSCO Specification for Sliplining, Segmented, Polyethylene (as provided by Duratron Systems for BUTTRESS-LOC® Pipe) (1999)[14]	Describes the specifications, design considerations, and installation procedures for the segmented sliplining utilizing polyethylene liners.
NASSCO Specification for Sliplining, Segmented, PVC (as provided by Lamson Vylon Pipe for large diameter Vylon® Slipliner Pipe) (1999)[14]	Describes the specifications, design considerations, and installation procedures for the segmented sliplining utilizing large diameter PVC liners.
NASSCO Specification for Sliplining, Segmented, PVC (as provided by Lamson Vylon Pipe for small diameter Vylon® Slipliner Pipe) (1999)[14]	Describes the specifications, design considerations, and installation procedures for the segmented sliplining utilizing small diameter PVC liners.

In addition to the two (2) specific ASTM standards presented in Table 4, the following list of related standards were also associated with segmental sliplining:

- ASTM D 543 – Test Method for Resistance of Plastics to Chemical Reagents[25]
- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[26]
- ASTM D 1600 – Terminology for Abbreviated Terms Relating to Plastics[27]
- ASTM D 2122 – Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings[28]
- ASTM D 2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings (1997)[29]
- ASTM D 3350 – Specification for Polyethylene Plastics Pipe and Fittings Materials[30]
- ASTM F 412 – Terminology Relating to Plastic Piping Systems[31]
- ASTM F 477 – Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe[32]
- ASTM F 714 – Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter[33]
- ASTM F 894 – Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe[34]

- ASTM F 913 – Specification for Thermoplastic Elastomeric Seals (Gaskets) for Joining Plastic Pipe[35]

Contractors and Manufacturers

A listing of manufacturers and contractors of segmental sliplining is presented in Table 5.

Table 5. Listing of Manufacturers and Contractors of Segmental Sliplining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Affholder Inc.	(800) 325-3997	(636) 537-2533	17988 Edison Ave. Chesterfiled, MO 63005	N/A[2]	N/A
Ameron International[1]	(626) 683-4000	(626) 683-4060	245 South Los Robles Ave. Pasadena, CA 91101	National	N/A
A.P. Construction, Inc. *New Jersey Office*	(856) 227-2030	(856) 227-2273	915 S. Black Horse Pike Blackwood, NJ 08012	N/A	N/A
A.P. Construction, Inc. *Pennsylvania Office*	(215) 922-2323	(215) 922-2700	1080 N. Delaware Ave. Suite 1500 Philadelphia, PA 19125	N/A	N/A
Bown Plumbing	(530) 244-7473	N/A	3990 RailRoad Ave. Redding, CA 96001	CA	N/A
The Crow Company	(520) 294-3344	(520) 294-4770	2275 E. Ginter Tucson, AZ 85706	N/A	N/A
The Crow Company	(602) 246-6940	(602) 269-8677	3735 W. Cambridge Ave. Phoenix, AZ 85009	N/A	N/A
The Crow Company	(303) 571-4444	(303) 572-8888	9700 E. 104th Ave., #G Henderson, CO 80640	N/A	N/A
Gelco Services, Inc. *California Office*	(530) 406-1199	(530) 406-7991	1244 Wilson Way Woodland, CA 95695	N/A	N/A
Gelco Services, Inc. *Oregon Office*	(888) 223-8017	(503) 391-8317	1705 Salem Industrial Dr. NE Salem, OR 97303	N/A	N/A
Gelco Services, Inc. *Washington Office*	(888) 322-1199	(253) 876-9932	3411 C St. NE, Suite 16 Auburn, WA 98002	N/A	N/A
HMIM, Inc.	(504) 626-1072	(504) 626-9169	N/A	LA, MS, AL, GA	Rich Vanek Sr.
Hopas Pipe USA, Inc.	(800) 856-7473	(281) 821-7715	1413 Richey Road Houston, TX 77073	N/A	N/A
ISCO-Industries, LLC[1]	(800) 345-4726	(502) 584-9713	926 Baxter Ave. P.O. Box 4545 Louisville, KY 40204	National	N/A
ISCO-Industries, LLC	(800) 345-4726	(866) 369-0539	N/A	West	Larry Case
ISCO-Industries, LLC	(800) 345-4726	(866) 580-8963	N/A	Midwest	Redgie Huftel
ISCO-Industries, LLC	(800) 233-1305	(866) 580-8991	N/A	East, South	Bruce Larson
Lamson Vlyon Pipe[1]	(800) 382-0892	(216) 766-6577	25701 Science Park Dr. Cleveland, OH 44122	National	N/A
Lee Mastell & Associates, Inc.	(405) 752-5000	(405) 752-5002	N/A	NE, KS, IA, MO, OK, AR, TX	Lee Mastell Scott Mastell
Lee Mastell & Associates, Inc.	(316) 722-5612	(316) 722-6351	N/A	NE, KS, IA, MO, OK, AR, TX	Russ Krueger
Municipal Associates	(614) 846-7529	(614) 885-1110	N/A	OH, KY	Mike Killian
Ten Point Sales	(303) 233-3883	(303) 233-0117	N/A	CO, UT, WY	Bob Wagenhals Dana Frew
Trenchless Resources International, Inc.	(916) 681-0689	(916) 681-0690	N/A	WA, OR, ID, HI, CA, NV, AK	Dave Gellings
Trenchless Resources International, Inc.	(503) 364-1199	(503) 391-8317	N/A	WA, OR, ID, HI, CA, NV, AK	Gary Korte
Trenchless Resources International, Inc.	(916) 686-8055	(916) 686-0601	N/A	WA, OR, ID, HI, CA, NV, AK	Rocky Capehart

[1]Designates company headquarters, [2]N/A – not available

Continuous Sliplining

Description

Continuous sliplining involves the lining of a deteriorated culvert with a continuous liner. Liners are generally made from polyethylene or high-density polyethylene pipe segments that are butt-fused together. The continuous liner is pulled, pushed, or simultaneously pushed and pulled into the host culvert. Once installed, the annular space is generally grouted and service connections are reopened. A typical, continuous sliplining process where the liner is pulled into the host culvert is shown in Figure 5.

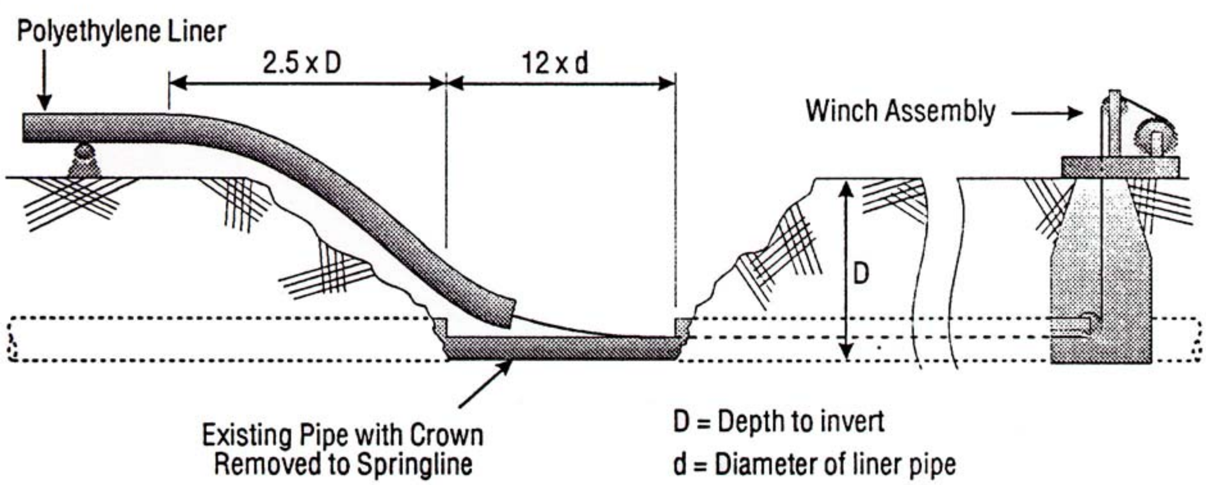

Figure 5. Drawing. Continuous Sliplining Installation Process.[(5)]

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of continuous sliplining are presented in Table 6. Advantages and limitations associated with the method of continuous sliplining are presented in Table 7.

Table 6. General Characteristics and Effective Uses of Continuous Sliplining.[(5,6,7)]

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity & Pressure Pipelines	100 - 1,600 millimeters (4 - 63 inches)	PE, HDPE, PP, PVC, PE/EPDM	1,600 meters (5,248 feet)

[1]PE – Polyethylene, HDPE – High Density Polyethylene, PP – Polypropylene, PVC – Poly(Vinyl Chloride), EPDM – Ethylene Polypelene Diene Monomer

Table 7. Advantages and Limitations of Continuous Sliplining.[5,6,7,8]

Advantages	Limitations
Applicable to all types of existing culvert materials	Existing culvert must be longitudinally uniform (diameter changes or discontinuous culverts may prohibit this method)
Capable of accommodating large radius bends	Reduction in flow capacity may be significant
Few or no joints	Annular space grouting is usually required
Flow bypass is seldom required	Excavation required for access pits
Simplistic method	Excavation required for lateral reconnection and sealing
Existing pipe can be corroded, deformed, badly damaged, and/or near collapse	

Costs

According to the USFS Draft Report on trenchless technology for Forest Service culverts,[9] the range of costs for continuous sliplining is approximated to be $50 per linear foot for 45.7-centimeter (18-inch) diameter pipes and $400 to $500 per linear foot for 1.5-meter (60-inch) diameter pipes.

General Installation Guidelines

A general list of installation guidelines for continuous sliplining is provided below:[5,8,14,15,36]

1. Thoroughly inspect the existing culvert to determine the smallest diameter located within the culvert to be lined (structural deterioration and wall collapse may have reduced the original culvert diameter). For non-man entry culverts, a foam bullet-shaped device used for cleaning, known as a “pig,” can be used to determine the smallest diameter.
2. Inspect the existing culvert for lateral and service connections, as well as protrusions such as roots and sediment.
3. Clean and clear the existing culvert.
4. Determine the diameter of the liner (in general, the outside diameter of the liner should be at least 10 % smaller than the inside diameter of the existing culvert. A 5% reduction should be sufficient for existing culvert diameters greater than 61 centimeters (24 inches)).
5. Determine the material of the liner. High density or medium density polyethylene is generally chosen for liner material. The material chosen should meet the designed load requirements. Factors to be considered in design load requirements include, but are not limited to, hydraulic loads caused by groundwater, soil conditions and loads, traffic loads, and temperature.
6. Excavate insertion pits to a 2.5H:1V slope from the ground surface to the top of the existing culvert. Excavation should comply with local, State, or Federal regulations regarding excava-

tion safety. The length of level excavation should be at least twelve (12) times the outside diameter of the existing culvert. Insertion pit width should be a minimum of the outside diameter plus 30.5 centimeters (12 inches) for culverts smaller than 45.7 centimeters (18 inches) in diameter, a minimum of the outside diameter plus 45.7 centimeters (18 inches) for culverts less than 1.2 meters (48 inches) in diameter, and a minimum of the outside diameter plus 61 centimeters (24 inches) for culverts greater than 1.2 meters (48 inches) in diameter. Excavations at elbows minimize the total number of excavations required because the liner can be installed in two directions from one location.

7. Determine if the bypassing of flow is necessary. Flow bypass is necessary if the annular space and pulling head openings are incapable of handling the existing flow capacity. If possible, maintaining the flow will often reduce the force required for installation, but may cause accessibility problems and difficulty for workers.
8. Cut the existing culvert and initiate installation. Join/fuse liner segments prior to insertion and above ground. Thermal butt fusion or thermal welding are the general methods of joining liner segments. Once joined, use the push method, the pull method, or a combination of both to install the liner into the existing culvert. Figure 6 illustrates the push and pull sliplining methods used for butt fusion welded HDPE. Continue installation until the entire section of existing culvert has been lined.

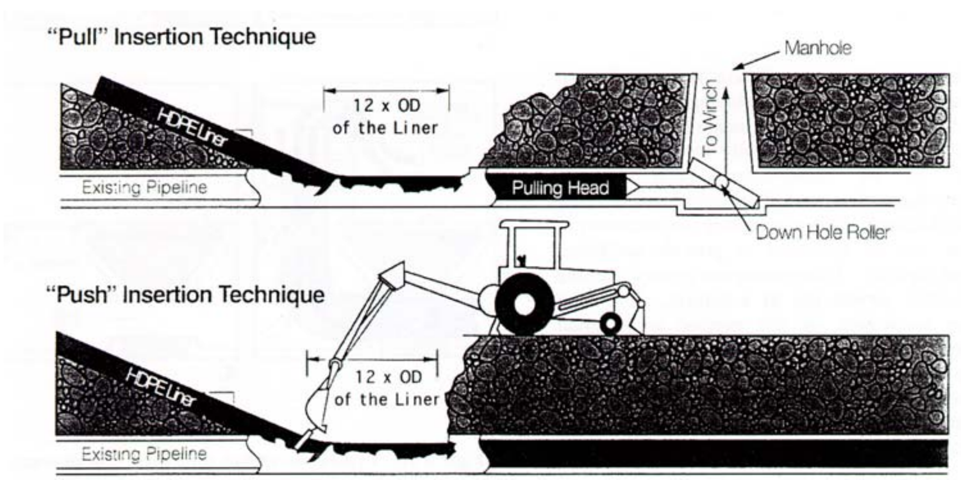

Figure 6. Drawing. Insertion Method for Butt Fusion Welded HDPE Liner.[37]

9. Once installation has been completed, a 24-hour relaxation period is recommended before reopening lateral and service connections. If the pull method was used for liner insertion, stretching of about 1% of the total length may be observed.
10. Inspect the completed lining by closed-circuit TV or manually if the diameter permits man-entry. The liner should be continuous over the entire length.

11. If leakage or other testing is required, perform testing to specifications and prior to the re-opening of lateral and service connections.
12. Reopen lateral and service connections. Dependent upon installation conditions, reconnection may be possible from within the lined culvert or may require point excavation.
13. After lateral and service connections have been reopened, reconnect and stabilize terminal connections. Fill the annular space between the liner and the original culvert with grout or another cementitious material. The allowable grout pressure of the liner should not be exceeded during the grouting process. Hydrostatically pressurizing the liner will allow for higher grouting pressures and help prevent collapse of the liner during the grouting process.
14. Finally, restore flow if bypass was required and initiate site cleanup.

Annular Grouting

Annular grouting is generally required in continuous sliplining in order to prevent a collapsing or seriously weakened pipe from eventually crushing the liner. In addition to the standards and specifications listed in Table 3, the following list of related standards are associated with annular grouting of continuous sliplining:

- NASSCO Specification for Sliplining, Continuous, Polyethylene (as provided by Plastics Pipe Institute (PPI) for generic polyethylene pipe) (1999)[14]
- Plastic Pipe Institute Guide-1/95 – Guidance and Recommendations on the Use of Polyethylene (PE) Pipe for the Sliplining of Sewers (1995)[36]

Standards/Specifications

Table 8 presents the current standards and specifications associated with the method of continuous sliplining.

Table 8. Standards Associated with Continuous Sliplining.[14,23,36]

Standard/Specification	Description
ASTM D 2657 – Standard Practice for Heat Fusion Joining Polyolefin Pipe and Fittings (1997)[29]	Describes the general procedures for making joints with polyolefin pipe and fittings by means of heat fusion joining techniques.
ASTM F 585 – Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers (2000)[15]	Describes the design considerations, material selection considerations, and installation procedures for the construction of sanitary and storm sewers by the insertion of polyethylene pipe through existing pipe, along the previously existing line and grade.
NASSCO Specification for Sliplining, Continuous, Polyethylene (as provided Plastics Pipe Institute for generic polyethylene pipe) (1999)[14]	Describes the specifications, design considerations, and installation procedures for continuous sliplining utilizing polyethylene liners.
Plastic Pipe Institute Guide-1/95 – Guidance and Recommendations on the Use of Polyethylene (PE) Pipe for the Sliplining of Sewers (1995)[36]	Describes the specifications, design considerations, and installation procedures for continuous sliplining utilizing polyethylene liners.

In addition to the two (2) specific ASTM standards presented in Table 8, the following list of related standards were also associated with continuous sliplining:

- ASTM D 543 – Test Method for Resistance of Plastics to Chemical Reagents[25]
- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[26]
- ASTM D 1600 – Terminology for Abbreviated Terms Relating to Plastics[27]
- ASTM D 2412 – Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading[38]
- ASTM D 2657 – Practice for Heat-Joining of Polyolefin Pipe and Fittings (1997)[29]
- ASTM D 3035 – Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter[39]
- ASTM D 3350 – Specification for Polyethylene Plastics Pipe and Fittings Materials[30]
- ASTM F 412 – Terminology Relating to Plastic Piping Systems[31]
- ASTM F 477 – Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe[32]
- ASTM F 714 – Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter[33]
- ASTM F 894 – Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe[34]
- ASTM F 905 – Practice for Qualification of Polyethylene Saddle Fusion Joints[40]
- ASTM F 1056 – Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings[41]
- ASTM F 1417 – Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air[42]

Contractors and Manufacturers

A listing of manufacturers and contractors of continuous sliplining is presented in Table 9.

Table 9. Listing of Manufacturers and Contractors of Continuous Sliplining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
The Crow Company	(520) 294-3344	(520) 294-4770	2275 E. Ginter Tucson, AZ 85706	N/A[2]	N/A
The Crow Company	(602) 246-6940	(602) 269-8677	3735 W. Cambridge Ave. Phoenix, AZ 85009	N/A	N/A
The Crow Company	(303) 571-4444	(303) 572-8888	9700 E. 104th Ave., #G Henderson, CO 80640	N/A	N/A
Insituform Technologies, Inc. [1]	(800) 234-2992	(636) 519-8010	702 Spirit 40 Park Dr. Chesterfiled, MO 63005	National	N/A
Southeast Pipe Survey	(912) 647-2847	(912) 647-2869	3523 Williams St. Patterson, GA 31557	AL, FL, GA, NC, SC, TN	N/A

[1]Designates company headquarters, [2]N/A – not available

CLOSE-FIT LINING

Sometimes referred to as modified sliplining, close-fit lining involves the insertion of a thermoplastic pipe with an outside diameter the same or slightly larger than the inside diameter of the host culvert. As a result, the liner must be modified in cross section before installation. A modified liner is winched into place and reformed/re-rounded to provide a close-fit with the existing culvert. Once reformed, grouting is unnecessary due to the tight fit. Close-fit lining methods can be categorized into two main groups based upon the method used for cross-sectional modification and reformation. These two groups are classified as symmetrical reduction systems and folded systems. Both groups, with associated sub-groupings are presented and described.

Symmetrical Reduction Method for Close-fit Lining

Symmetrical reduction methods use either a static die or a series of compression rollers that temporality reduce the diameter of the liner. Once reduced, a winch is used to apply tension while the liner is pulled through the host culvert. After insertion, the tension applied by the winch is released and the pipe reverts to its original dimensions due to the material’s molecular “memory.” Pressure, generally provided by air, is sometimes used to speed up the reformation process. Symmetrical reduction can further be classified as the swagelining/drawdown method and the rolldown method.

Swagelining/Drawdown Method for Close-fit Lining

Description:

Swagelining, also referred to as the drawdown method, uses a static-diameter reduction die to reduce the diameter of the liner directly before insertion. During insertion, a winch system is used to maintain tension in the liner as it is pulled through the section to be lined. After the full length of the liner is pulled through, the tension is released and the liner rapidly reverts to its original diameter forming a close-fit with host conduit. Due to the limited reduction in diameter size that is provided by the swagelining/drawdown method, the technique is better suited for pressure pipelines, but can be used in certain gravity applications. Currently, the swagelining/ drawdown method is rarely used,[8] and consequently the literature review provided only minimal information. Figure 7 illustrates the swagelining process.

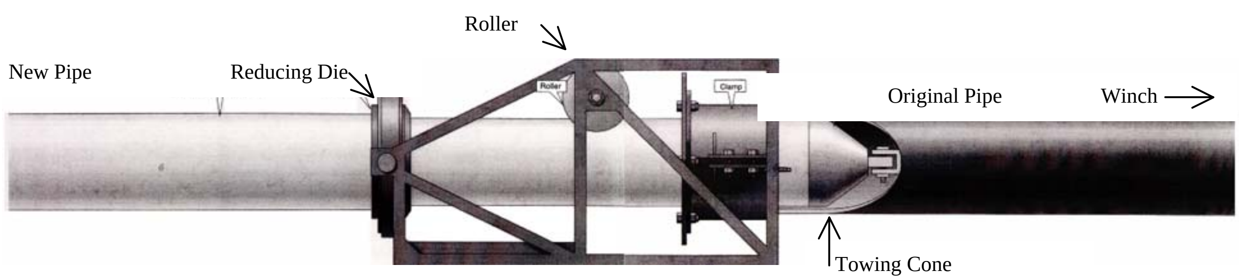

Figure 7. Drawing. Swagelining Process for Close-fit Lining.[43]

Effective Uses, Advantages, and Limitations:

General characteristics and effective uses of the swagelining/drawdown method for close-fit lining are presented in Table 10. Advantages and limitations associated with the swagelining/ drawdown method are presented in Table 11.

Table 10. General Characteristics and Effective Uses of the Swagelining/Drawdown Method for Close-fit Lining.[5,6]

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity & Pressure Pipelines	62 - 600 millimeters (2.5 - 23.6 inches)	HDPE, MDPE	320 meters (1,050 feet)

[1]HDPE – High Density Polyethylene, MDPE – Medium Density Polyethylene

Table 11. Advantages and Limitations of the Swagelining/Drawdown Method for Close-fit Lining.(5,6,8)

Advantages	Limitations
Minimal or no reduction in flow capacity	Existing culvert must be longitudinally uniform (diameter changes or discontinuous culverts may prohibit this method)
Few or no joints	Excavation is required for installation
	Flow bypass is required
No grouting required	Unable to negotiate bends, requiring local excavation at these locations
	Relatively complex method requiring special machinery
	Not applicable to structurally deteriorated host culverts

Costs:

No literature sources were acquired detailing the general costs associated with the swagelining/drawdown method for close-fit lining.

General Installation Guidelines:

Due to the minimal information obtained regarding the swagelining/drawdown method for Close-fit lining, no general installation guidelines were provided. Manufacturers should be contacted for job-specific installation guidelines.

Standards/Specifications:

Due to the minimal information obtained regarding swagelining/drawdown method, no general standards were provided. Manufacturer’s standards should be obtained and followed.

Contractors and Manufacturers:

A listing of manufacturers and contractors of the swagelining/drawdown method for close-fit lining is presented in Table 12.

Table 12. Listing of Manufacturers and Contractors of the Swagelining/Drawdown Method for Close-fit Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Advantica Technologies, Inc.	(713) 622-0426	(713) 626-9308	5444 Westheimer, Suite 1430 Houston, TX 77056	N/A[2]	N/A
ARB Inc. [1]	(800) 622-2699	(949) 454-7190	26000 Commercentre Dr. Lake Forest, CA 92630	N/A	N/A
ARB Inc. *Pittsburg, CA Office*	(800) 898-3478	(925) 432-2958	1875 Loveridge Rd. Pittsburg, CA 94565	N/A	N/A
ARB Inc. *Thousand Palms, CA Office*	(800) 243-4188	(760) 343-2740	72400 Vista Chino Dr. Thousand Palms, CA 92276	N/A	N/A
ARB Inc. *Ventura, CA Office*	(805) 643-4188	(805) 643-7268	2235-A North Ventura Ave. Ventura, CA 93001	N/A	N/A
ARB Inc. *Texas Office*	(800) 443-3805	(936) 756-8671	10617 Jefferson Chemical Rd. Conroe, TX 77301	N/A	N/A
Inland Waters *Michigan Office*	(800) 992-9118	(313) 841-5270	2021 S. Schaefer Hwy. Detroit, MI 48217	N/A	N/A
Inland Waters *Ohio Office*	(800) 869-3949	(216) 861-3156	2195 Drydock Ave. Cleveland, OH 44113	N/A	N/A

[1]Designates company headquarters, [2]N/A – not available

Rolldown Method for Close-fit Lining

Description:

Rolldown method is similar to the swagelining/drawdown method for close-fit lining except that a cold rolling machine, instead of a die, is used to temporarily reduce the diameter of the liner. Molecular structure of the liner is rearranged in the cold rolling machine to form a smaller diameter pipe with thicker walls and minimal elongation.[(44)] Unlike the swagelining/drawdown method for close-fit lining, this process is not dependent upon tension or other mechanical means to prevent the liner from reverting to its original size during insertion. Once the diameter has been reduced, a winch is used to pull the liner into place and the liner reverts to its original diameter (although much slower than in the swagelining/drawdown process). Rolldown method is illustrated in Figure 8, while Figure 9 presents a picture of the rolldown method for close-fit lining being used. Similar to the swagelining/drawdown method for close-fit lining, this technique is better suited for pressure pipelines and used commonly in the gas and mining industries. As such, the literature sources obtained for review provided only minimal information pertaining to the rolldown method.

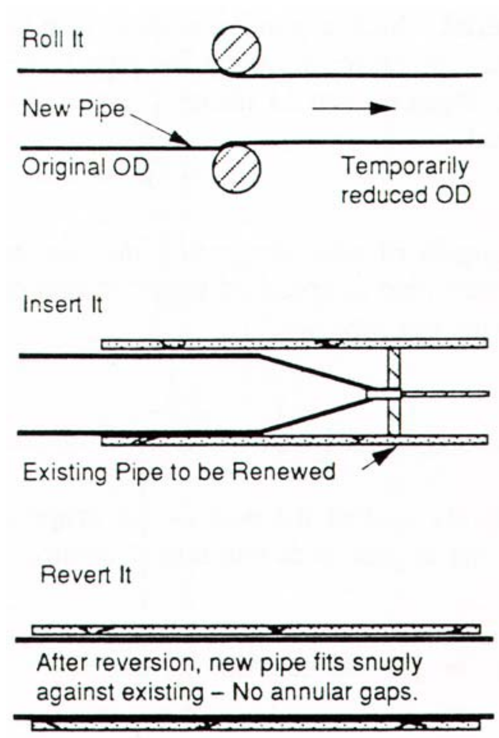

Figure 8. Drawing. Rolldown Process for Close-fit Lining.[(5)]

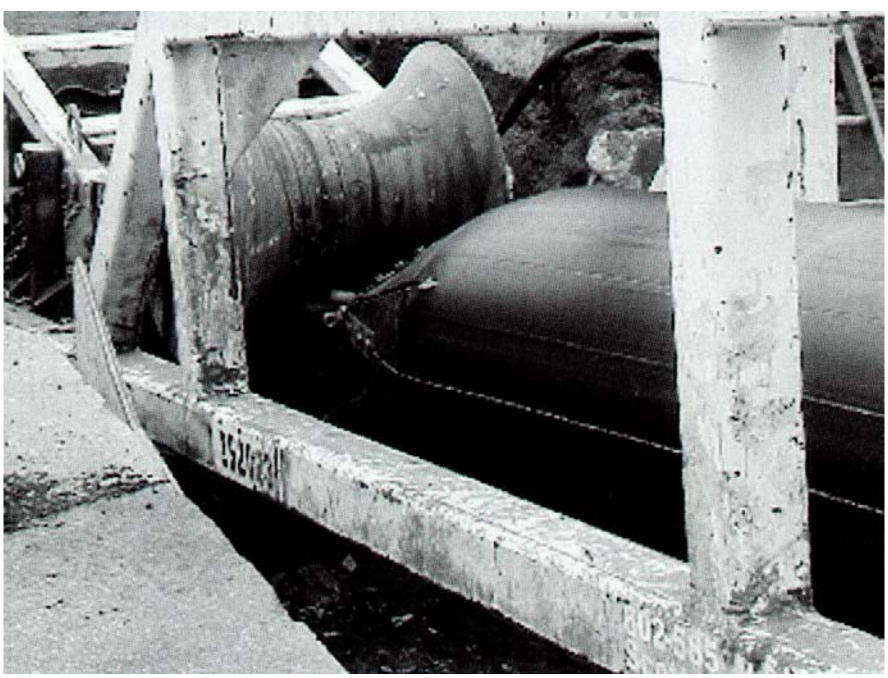

Figure 9. Photo. Culvert Lining Utilizing the Rolldown Method for Close-fit Lining.[(8)]

Effective Uses, Advantages, and Limitations:

General characteristics and effective uses of the rolldown method are presented in Table 13. Advantages and limitations associated with the rolldown method are presented in Table 14.

Table 13. General Characteristics and Effective Uses of the Rolldown Method for Close-fit Lining.(5,6)

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity & Pressure Pipelines	62 - 600 millimeters (2.5 - 23.6 inches)	HDPE, MDPE	320 meters (1,050 feet)

[1]HDPE – High Density Polyethylene, MDPE – Medium Density Polyethylene

Table 14. Advantages and Limitations of the Rolldown Method for Close-fit Lining.(5,6,8)

Advantages	Limitations
Minimal or no reduction in flow capacity	Existing culvert must be longitudinally uniform (diameter changes or discontinuous culverts may prohibit this method)
Few or no joints	Excavation is required for installation
	Flow bypass is required
No grouting required	Unable to negotiate bends, requiring local excavation at these locations
	Relatively complex method requiring special machinery
	Not applicable to structurally deteriorated host culverts

Costs:

No literature sources were acquired detailing the general costs associated with the rolldown method.

General Installation Guidelines:

Due to the minimal information obtained regarding the rolldown method, no general installation guidelines were provided. Manufacturers should be contacted for job-specific installation guidelines.

Standards/Specifications:

Due to the minimal information obtained regarding the rolldown method, no general standards were provided. Manufacturer's standards should be obtained and followed.

Contractors and Manufacturers:

A listing of manufacturers and contractors of the rolldown method are presented in Table 15.

Table 15. Listing of Manufacturers and Contractors of the Rolldown Method for Close-fit Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
PIM Corporation	(800) 293-6224	(732) 469-8959	201 Circle Dr. No., Suite 106 Piscataway, NJ 08854	N/A[1]	N/A
United Pipeline Systems USA, Inc.	(800) 938-6483	(970) 259-0356	135 Turner Dr. Durango, CO 81302	N/A	N/A

[1]N/A – not available

Folded Method for Close-fit Lining

Liners used in the folded method are generally folded into "C"-, "U"-, or "H"-shapes during manufacturing or by site-equipment before installation. When shaped at the factory, liners are wound into a reel or coiled for ease of transportation. Figure 10 illustrates a liner folded into an "H"-shape and ready for insertion. Unlike symmetrical reduction systems that dominantly rely on the "memory" of the material for reformation, folded systems are reformed by pressure or a combination of heat and pressure. A minimum fifty (50) year design life was generally applicable to the liners installed with the folded method. Due to the materials and installation procedure associated with folded liners, they can typically be considered environmentally safe. The folded method can further be classified into the deformed/reformed method and the fold and form method.

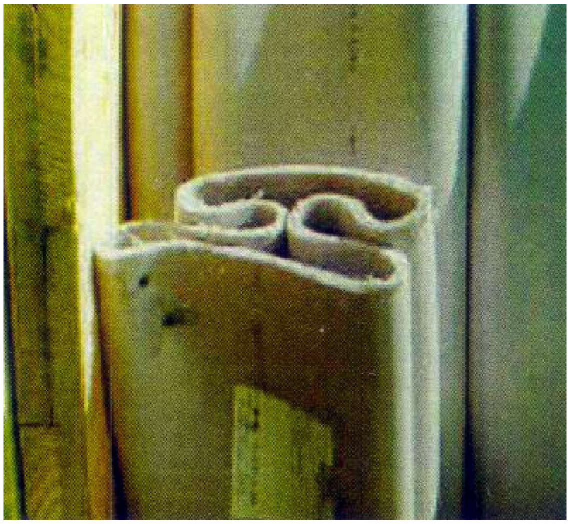

Figure 10. Photo. Ultraliner's PVC Alloy Pipeline Folded into an "H"-shape.[45]

Deformed/Reformed Method for Close-fit Lining

Description:

Before installation, a polyethylene liner is heated and folded to reduce cross-sectional area for insertion. The folded liner is then inserted into the host culvert and pulled into place with a winch. Once in place, the liner is reformed to a shape, with applied heat and pressure (generally steam), that forms a close fit with the host culvert. Liners used in this method are not mechanically rounded with a rounding device. Figure 11 presents a picture showing an inserted deformed pipe and Figure 12 presents the close-fit, reformed pipe.

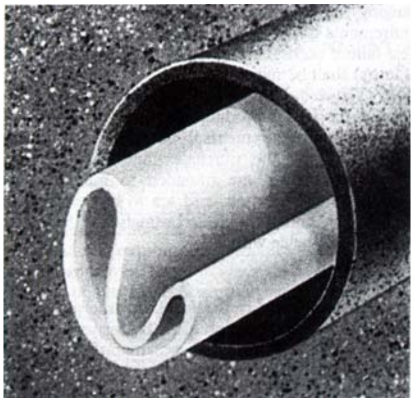

Figure 11. Drawing. Deformed Method for Close-fit Lining.[46]

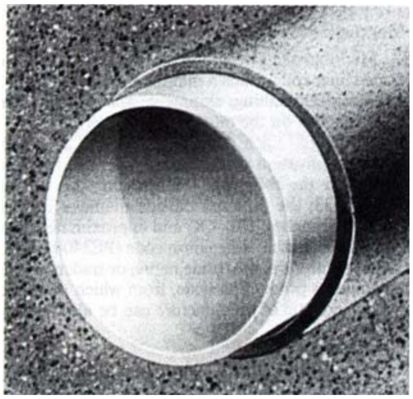

Figure 12. Drawing. Reformed Method for Close-fit Lining.[46]

Effective Uses, Advantages, and Limitations:

General characteristics and effective uses of the deformed/reformed method are presented in Table 16. Advantages and limitations associated with the deformed/reformed method are presented in Table 17.

Table 16. General Characteristics and Effective Uses of the Deformed/Reformed Method for Close-fit Lining.(5,6)

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity & Pressure Pipelines	100 - 400 millimeters (4 - 15.7 inches)	HDPE	800 meters (2,624 feet)

[1]HDPE – High Density Polyethylene

Table 17. Advantages and Limitations of the Deformed/Reformed Method for Close-fit Lining.(5,6,8)

Advantages	Limitations
Minimal or no reduction in flow capacity	Liner lengths are limited by pull-in forces or coil length
Few or no joints	Flow bypass is usually required
Fast installation	Chemical grouting may be required at lateral, service, and end connections
Capable of accommodating large radius bends	Relatively complex method requiring special machinery
	Not applicable to structurally deteriorated host culverts

Costs:

No literature sources were acquired detailing the general costs associated with the deformed/reformed method.

General Installation Guidelines:

The following provides a general list of installation guidelines for the deformed/reformed method for close-fit lining:(5,14,46)

1. Prior to entering access areas and performing inspection or cleaning operations, test the atmosphere in the insertion pits to determine the presence of toxic or flammable vapors, or the lack of oxygen in accordance with local, State, or Federal safety regulations.
2. Thoroughly clean the existing culvert. Gravity culverts should be cleaned with hydraulically powered equipment (high-velocity jet cleaners).

3. Inspect the existing culvert to determine the location of any conditions that may hinder proper insertion of the deformed liner, such as protrusions, collapsed sections, deflected joints, etc.
4. Clear line obstructions discovered during inspecting prior to inserting the liner. Typically, changes in pipe size and bends in excess of 30° cannot be accommodated and local excavation is necessary. If obstructions cannot be cleared, point repair excavation should be used to remove and repair the obstruction.
5. Bypassing of flow is required, unless flow can be shut off during installation.
6. Insert the deformed liner with a power winch. Pulling forces should be limited to not exceed the axial strain limits of the liner.
7. Once inserted, relieve winch tension and cut the insertion and termination ends to install the processing manifolds used to control heat and pressure within the liner. Attach temperature and pressure measuring instruments at both ends of the liner to ensure proper temperatures and pressures are reached during the reformation process.
8. Apply steam and air pressure through the inlet to conform the deformed liner to the existing culvert wall. Keeping the termination point open, pressurize the liner up to a maximum of 99.9 kPa (14.5 psig), with a steam temperature in excess of 112.8°C (235°F) and less than 126.7°C (260°F). If required, increase pressure in increments up to a maximum of 179.1 kPa (26 psig).
9. Cool the reformed liner to a temperature of 37.8°C (100°F). Then increase the pressure slowly to a maximum of 227.4 kPa (33 psig), while applying air or water for continued cooling.
10. After the cool down process, trim the terminating ends to a minimum of 7.6 centimeters (3 inches) beyond the existing culvert to account for possible shrinkage effects during cooling of the liner to ambient temperature.
11. Inspect the completed installation by closed-circuit TV. The reformed pipe should be continuous over the entire length and conform to the walls of the existing culvert.
12. If leakage or other testing is required, perform testing to specifications and prior to the reopening of lateral and service connections.
13. Reconnect lateral and service connections with a television camera and a remote control cutting device. After reopening the lateral and service connections, reconnect the termination points of the liner to the existing culvert. If specially requested, seal the termination points to the existing culvert with a watertight seal.
14. Finally, restore flow and initiate site cleanup.

Standards/Specifications:

Table 18 presents the current standards and specifications associated with the deformed/ reformed method.

Table 18. Standards Associated with the Deformed/Reformed Method for the Close-fit Lining.[14,23]

Standard/Specification	Description
ASTM F 1533 – Standard Specification for Deformed Polyethylene (PE) Liner (2001)[47]	Covers the requirements and test methods for materials of deformed PE liner intended for the rehabilitation of gravity flow and nonpressure pipelines.
ASTM F 1606 – Standard Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner (1995)[46]	Covers the requirements for the installation of deformed PE liner for pipeline rehabilitation.
NASSCO Specification for Deformed Pipe Installation, Polyethylene (as provided by Pipe Liners, Inc. for the U-Liner® Process) (1999)[14]	Describes the specifications, design considerations, materials, transportation, equipment, and installation of deformed and reformed polyethylene liners.
NASSCO Specification for Formed-in-place Pipe, (as provided by Pipelining Products Inc. for the Sure-Line® Process (1999)[14]	Describes the specifications, design considerations, materials, and installation of a temporarily deformed and reformed HDPE liners.

In addition to the two (2) specific ASTM standards presented in Table 18, the following list of related standards were also associated with the deformed/reformed method for the close-fit lining:

- ASTM D 618 – Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[48]
- ASTM D 638 – Test Method for Tensile Properties of Plastics[49]
- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[26]
- ASTM D 1600 – Terminology for Abbreviated Terms Relating to Plastics[27]
- ASTM D 1693 – Test Method for Environmental Stress-Cracking of Ethlene Plastics[50]
- ASTM D 2122 – Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings[28]
- ASTM D 2412 – Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading[38]
- ASTM D 2837 – Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe and Fittings[51]
- ASTM D 3350 – Specification for Polyethylene Plastics Pipe and Fittings Materials[30]
- ASTM F 412 – Terminology Relating to Plastic Piping Systems[31]
- ASTM F 1248 – Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe[52]

- ASTM F 1417 – Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air[42]

Contractors and Manufacturers:

A listing of manufacturers and contractors of the deformed/reformed method for the close-fit lining is presented in Table 19.

Table 19. Listing of Manufacturers and Contractors of the Deformed/Reformed Method for the Close-fit Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Azurix-Madsen/Barr *Longwood, FL Office*	(800) 547-6193	(407) 260-9668	109 Applewood Longwood, FL 32750	AL, FL	N/A[2]
Azurix-Madsen/Barr *Ft. Lauderdale, FL Office*	(954) 561-0942	(954) 491-5427	1117 NW 55th St. Ft. Lauderdale, FL 33309	Ft. Lauderdale, FL	N/A
Azurix-Madsen/Barr *Miami, FL Office*	(305) 591-0001	(305) 591-0854	8609 NW 64th St. Miami, FL 33166	Miami, FL	N/A
Boh Brothers Construction Co.	(504) 821-2400	(504) 821-0714	730 S. Tonti St. New Orleans, LA 70119	Southern LA, Southern MS	N/A
Cullum Pipe Systems	(800) 858-0894	(972) 278-0980	2814 Industrial Dr. Garland, TX 75041	TX	N/A
Hydro Tech Inc.	(775) 575-4100	(775) 575-4100	155 Lyon Dr. Fernley, NV 89408	NV, UT	N/A
Insight Pipe Contracting	(724) 452-6060	(724) 452-3226	344 Little Creek Rd. Harmony, PA 16037	PA, OH	Mike Marburger
New Hope Pipe Liners	(845) 369-0873	(845) 369-1098	143 Rt. Rd. Building #6 Hillburn, NY 10931	CT, DE, MD, NJ, NY, PA	N/A
Pipelining Products, Inc. *New York Office*	(718) 747-9000	(718) 747-1186	151-45 6th Rd. Whitestone, NY 11357	NY	N/A
Pipelining Products, Inc. *North Carolina Office*	(919) 319-9696	(919) 319-0046	251 West Chatham St. Cary, NC 27511	NC	N/A
Rinker Pipeline Systems[1]	(800) 344-3744	N/A	1539 Jackson Ave. New Orleans, LA 70130	National	N/A
Rinker Pipeline Renewal	(800) 939-1277	(614) 529-6441	4143 Weaver Courtt Hilliard, OH 43026	AR, AZ, CO, GA, HI, ID, IL, IN, KS, KY, LA, MA, ME, MI, MO, MS, MT, NC, NE, NH, NM, OH, OK, OR, RI, SC, TN, UT, VA, VT, WA, WV, WY, parts of TX, Western PA	N/A
Suncoast Infrastructure, Inc.	(901) 385-3863	(901) 266-0655	6376 Daybreak Dr. Bartlet, TN 38135	MS, LA, AR, FL, Southern AL	David Peaks
U-Liner North, Inc.	(907) 479-3118	(907) 474-0619	3691 Cameron St. Fairbanks, AK 99709	AK	N/A
U-Liner West, Inc.	(888) 570-3534	(310) 329-0981	547 W. 140th St. Gardena, CA 90802	CA	N/A
Visu-Sewer Clean & Seal	(800) 876-8478	(262) 695-2359	W230 N4855 Betker Rd. Pewaukee, WI 53072	IA, MN, ND, SD, WI	N/A
W.L. Hailey & Co. Inc.	(615) 255-3161 Ext. 144	(615) 256-1316	P.O. Box 40646 2971 Kraft Dr. Nashville, TN 37204	TN, KY, Northern AL, GA, MS	Randy Houston

[1]Designates company headquarters, [2]N/A – not available

Fold and Form Method for Close-fit Lining

Description:

Generally, the fold and form method consists of inserting a PVC liner in the same fashion as in the deformed/reformed method. Fold and form liners are also expanded with heat and pressure, in similar fashion to the deformed/reformed method, but a rounding device is usually used to un-fold the pipe and form a close-fit between the liner and host pipe. A folded and formed liner is illustrated in Figure 13.

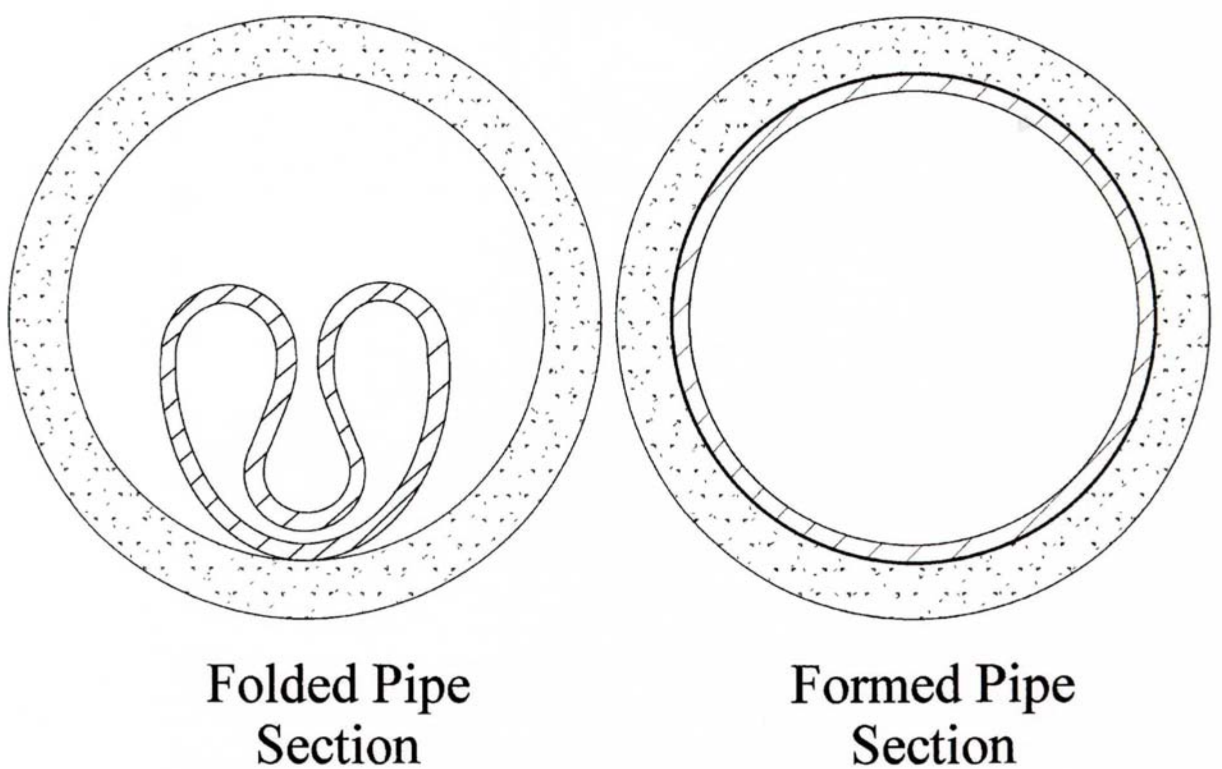

Figure 13. Drawings. Fold and Form Method for Close-fit Lining.[(53)]

An alternative fold-and-form method is to fold the liner on site. This method requires site-based equipment that cold-folds the liner and applies thin plastic straps to restrict the expansion of the liner during installation. A folded and banded liner is winched into the host culvert and re-rounded when the binding straps are broken by expanding the liner with internal pressure. Figure 14 presents a photo of an on-site folded and banded liner being inserted into the host culvert.

Figure 14. Photo. Installation of Cold-folded and Banded Liner.[8]

Effective Uses, Advantages, and Limitations:

General characteristics and effective uses of the fold and form method were similar to those presented for the deformed/reformed method and are presented in Table 20. Advantages and limitations associated with the fold and form method are presented in Table 21.

Table 20. General Characteristics and Effective Uses of the Fold and Form Method for Close-fit Lining.[5,6]

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity & Pressure Pipelines	100 - 400 millimeters (4 - 15.7 inches)	PVC	210 meters (689 feet)

[1]PVC – Poly(Vinyl Chloride)

Table 21. Advantages and Limitations of the Fold and Form Method for Close-fit Lining.[5,6,8]

Advantages	Limitations
Minimal or no reduction in flow capacity	Liner lengths are limited by pull-in forces or coil length
Few or no joints	Flow bypass is usually required
Fast installation	Chemical grouting may be required at lateral, service, and end connections
Capable of accommodating large radius bends	Relatively complex method requiring special machinery
	Not applicable to structurally deteriorated host culverts

Costs:

According to the USFS Draft Report on trenchless technology for Forest Service culverts,[9] the range of costs for the fold and form method is approximated to be $160 per linear foot for 45.7-centimeter (18-inch) diameter pipes and $300 per linear foot for 1.2-meter (48-inch) diameters.

A review of *Structural Renovation of a Water Main by Lining with Polyester Reinforced Polyethylene Pipe* by Hodnik and Heavens,[54] presented a case study wherein a fold and form liner was used to rehabilitate a 427-meter (1,400-feet) long, 20-centimeter (8-inch) diameter, cast iron water main in Highland, Indiana. After considering six (6) alternative methods of repair, including cured-in-place lining and pipe bursting, the fold and formed liner was chosen due to its strength and low cost. Installation costs for the system were $89 per linear foot with an average construction cost of $118.60 per linear foot.

Kupskay's case study titled *B&B Relines Deep Culverts in Coquitlam Improvement Project* presented the lining of two (2) corrugated metal pipe culverts in the City of Coquitlam, located approximately 48 kilometers (30 miles) east of Vancouver.[55] Fold and form liners were chosen for the rehabilitation of both culverts. Total project costs reached $81,000, with an average construction cost of approximately $210 per linear foot.

General Installation Guidelines:

A general list of installation guidelines for the fold and form method is provided below:[5,14,56,57]

1. Prior to entering access areas and performing inspection or cleaning operations, test the atmosphere in the insertion pits to determine the presence of toxic or flammable vapors, or the lack of oxygen in accordance with local, State, or Federal safety regulations.
2. Thoroughly clean the existing culvert. Gravity culverts should be cleaned with hydraulically powered equipment (high-velocity jet cleaners).

3. Inspect the existing culvert to determine the location of any conditions that may hinder proper insertion of the fold and form liner, such as protrusions, collapsed sections, deflected joints, etc.
4. Clear line obstructions discovered during the inspection before inserting the liner. Typically, changes in pipe size and bends in excess of 30° cannot be accommodated and local excavation is necessary. If obstructions cannot be cleared, point repair excavation should be used to remove and repair the obstruction.
5. Bypassing of flow is required, unless flow can be shut off during installation.
6. If recommended by the manufacturer, heat the coil or reel containing the folded liner prior to insertion. Use a heating chamber to heat the liner for a minimum of one (1) hour at the temperature recommended by the manufacturer (usually around 43°C (110°F)).
7. If required by the manufacturer's specifications, pull a containment tube through the existing culvert and inflate with air at low pressure and heat for liner installation.
8. Insert the deformed liner with a power winch. Pulling forces should be limited to not exceed the axial strain limits of the liner.
9. Once inserted, relieve the winch tension and cut the insertion and termination ends to install the processing manifolds used to control heat and pressure within the liner. Attach temperature and pressure measuring instruments at both ends of the liner to ensure proper temperatures and pressures are reached during the reformation process.
10. Expand the folded liner using heat and pressure, or using heat, pressure, and a rounding device. Apply the recommended temperatures and pressures provided by the manufacturer to overcome the extrusion memory of the liner. If a rounding device is needed, propel the flexible device at a controlled rate (not to exceed 1.2 to 1.8 meters (4 to 6 feet) per minute) within the liner, to expand and conform the liner to the existing culvert in a sequential manner. Maintain the expansion pressure for a minimum period of five (5) minutes within the liner after the rounding device has reached the termination point.
11. Cool the liner to a temperature of 37.8°C (100°F) before relieving the pressure required to expand the liner.
12. After cool down, the terminating ends are trimmed to a minimum of 7.6 centimeters (3 inches) beyond the existing culvert for possible shrinkage effects during the cooling to ambient temperature.
13. Inspect the completed installation by closed-circuit TV. The reformed pipe should be continuous over the entire length and conform to the walls of the existing culvert.
14. If leakage or other testing is required, perform testing to specifications and prior to the reopening of lateral and service connections.

15. Reconnect lateral and service connections with a television camera and a remote- control cutting device. After reopening the lateral and service connections, reconnect the termination points of the liner to the existing culvert. If specially requested, seal the termination points to the existing culvert with a watertight seal.
16. Finally, restore flow and initiate site cleanup.

Standards/Specifications:

Table 22 presents the current standards and specifications associated with the fold and form method.

Table 22. Standards Associated with the Fold and Form Method for Close-fit Lining.[14,23]

Standard/Specification	Description
ASTM F 1504 – Standard Specification for Folded Poly(Vinyl Chloride) (PVC) Pipe for Existing Sewer and Conduit Rehabilitation (1997)[58]	Covers the requirements and test methods for materials, dimensions, workmanship, flattening resistance, impact resistance, pipe stiffness, extrusion quality, and a form of marking for folded PVC pipe for existing sewer and conduit rehabilitation.
ASTM F 1867 – Standard Practice for Installation of Folded/Formed Poly(Vinyl Chloride) (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation (1998)[56]	Covers the procedures for the rehabilitation of sewer lines and conduits by the insertion of a folded/formed PVC pipe that is heat, pressurized, and expanded to conform to the wall of the original conduit.
ASTM F 1871 – Standard Specification for Folded/Formed Poly(Vinyl Chloride) (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation (1998)[53]	Covers the requirements and test methods for materials, dimensions, workmanship, flattening resistance, impact resistance, pipe stiffness, extrusion quality, and a form of marking for folded/formed PVC pipe for existing sewer and conduit rehabilitation.
ASTM F 1947 – Standard Practice for Installation of Folded Poly(Vinyl Chloride) (PVC) Pipe into Existing Sewers and Conduits (1998)[57]	Describes the procedures for the rehabilitation of sewer lines and conduits by the insertion of a folded PVC pipe, which is heated, pressurized, and expanded against the interior surface of an existing pipe with either a mechanical rounding device or steam pressure.
NASSCO Specification for Fold and Form Pipe Installation, PVC (as provided by American Pipe and Plastics for the AM-Liner® II Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of fold and form PVC liners.
NASSCO Specification for Fold and Form Pipe Installation, PVC (as provided by Insituform® Technologies, Inc. for the NuPipe® Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of fold and form PVC liners.
NASSCO Specification for Fold and Form Pipe Installation, PVCAlloy (as provided by Ultraliner™ Inc., for the Ultraliner™ Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of fold and form PVCAlloy liners.

In addition to the four (4) specific ASTM standards presented in Table 22, the following list of related standards were also associated with the fold and form method:

- ASTM D 618 – Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[48]
- ASTM D 638 – Test Method for Tensile Properties of Plastics[49]
- ASTM D 648 – Test Method for Deflection Temperature of Plastics Under Flexural Load[59]
- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[26]
- ASTM D 1600 – Terminology for Abbreviated Terms Relating to Plastics[27]
- ASTM D 1784 – Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds[60]
- ASTM D 2122 – Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings[28]
- ASTM D 2152 – Test Method for Degree of Fusion of Extruded Poly(Vinyl Chloride) (PVC) Pipe and Molded Fittings by Acetone Immersion[61]
- ASTM D 2412 – Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading[38]
- ASTM D 2444 – Test Method for Impact Resistance of Thermoplastic Pipe and Fittings be Means of a Tup (Falling Weight)[62]
- ASTM F 412 – Terminology Relating to Plastic Piping Systems[31]
- ASTM F 1057 – Practice for Estimating the Quality of Extruded Poly(Vinyl Chloride) (PVC) Pipe by Heat Reversion Technique[63]
- ASTM F 1417 – Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air[42]

Contractors and Manufacturers:

A listing of manufacturers and contractors of the fold and form method is presented in Table 23.