CULVERT PIPE LINER GUIDE AND SPECIFICATIONS

Publication No. FHWA-CFL/TD-05-003 July 2005

U.S. Department of Transportation
Federal Highway Administration

CTIP

Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
12300 West Dakota Avenue
Lakewood, CO 80228

FOREWORD

The Federal Lands Highway (FLH) of the Federal Highway Administration (FHWA) promotes development and deployment of applied research and technology applicable to solving transportation related issues on Federal Lands. s within the FHWA.

The objective of this study was to produce guidelines and specifications for the use of culvert liners. Drainage facilities, such as culverts, decay due to the processes of abrasion, corrosion, and erosion, shortening the anticipated service life of the facility. Many culverts have deteriorated and need repair or replacement. Until recently, most repair or replacement of culverts required open-cutting (trench digging). State Departments of Transportation (DOTs), the Federal Highway Administration (FHWA), and others have turned toward trenchless technology as a cost effective solution to culvert rehabilitation.

Trenchless technology can be used with a wide range of methods, materials, and equipment for rehabilitation or replacement. Rehabilitation of existing culverts through lining techniques has gained popularity in the United States. To date, several trenchless lining techniques have been used for the rehabilitation of existing culverts. However, choosing an optimum lining technique can be complicated considering the vast amount of organizations specializing in the manufacturing and installation of culvert liners, as well as the various materials, applications, and limitations associated with each lining technique. A user-friendly Microsoft® Excel-based Multi-criteria Decision Analysis (MCDA) tool that allows the user to customize the decision aid model was developed.

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16. Abstract

Trenchless technology can be used with a wide range of methods, materials, and equipment for rehabilitation or replacement of damaged or deteriorated pipe culverts. To date, several trenchless lining techniques have been used for the rehabilitation of existing culverts. Colorado State University was contracted to establish guidelines and specifications for the use of culvert liners. Task 1 involved a thorough literature review to collect information describing the state-of-the-practice in culvert pipe lining. Task 2 involved the development of a decision-making methodology for choosing appropriate culvert liners based on various factors. Task 3 required CSU to prepare and submit a final report whereby providing guidance to both the Design and Construction Branches of the FHWA and to State DOTs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

Actual	actual rating of alternative
AASHTO	American Association of State Highway and Transportation Officials
ADS	Advanced Drainage Systems, Inc.
AK	Alaska
AL	Alabama
ANSI	American National Standards Institute
AR	Arkansas
AZ	Arizona
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
Best	best rating of alternative for a specified criterion
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
C	Celsius
CA	California
Caltrans	California Department of Transportation
CFL	close-fit lining
CIPP	cured-in-place pipe
CIPPL	cured-in-place pipe lining
cm	centimeter
CMP	corrugated metal pipe
CO	Colorado
CORP	Corporation
CP	discrete compromise programming method
CPVC	chlorinated poly(vinyl chloride)
CSU	Colorado State University
CT	Connecticut
DC	District of Columbia
DE	Delaware
DE	does not enhance structural integrity
DOT	departments of transportation
EPDM	ethylene polypelene diene monomer
ESCR	environmental stress crack resistance
F	Fahrenheit
FHWA	Federal Highway Administration
FL	Florida
FLH	Federal Lands Highway
ft	feet
GA	Georgia
GRP	glass fiber reinforced polyester
H	height
H	horizontal

HI	Hawaii
HDPE	high-density polyethylene
in.	inches
IA	Iowa
ID	Idaho
IL	Illinois
IN	Indiana
ISO	International Organization for Standardization
kPa	kiloPascal
KS	Kansas
KY	Kentucky
LA	Louisiana
LLC	Limited Liability Company
m	meter
MA	Massachusetts
MCDA	Multi-criteria Decision Analysis
MD	Maryland
MDPE	medium density polyethylene
ME	Maine
MI	Michigan
MN	Minnesota
MO	Missouri
MS	Mississippi
MT	Montana
N/A	not available
N/S	not supplied
NA	not applicable
NE	Nebraska
NASSCO	National Association of Sewer Service Companies
NC	North Carolina
NCHRP	National Cooperative Highway Research Program
ND	North Dakota
NE	Nebraska
NH	New Hampshire
NJ	New Jersey
NM	New Mexico
NPS	National Park Service
NTIS	National Technical Information Service
NUCA	National Utility Contractors Association
NV	Nevada
NY	New York
NYC	New York City
OH	Ohio
OK	Oklahoma
OR	Oregon
p	exponent determining weight of rating

PA	Pennsylvania
PDF	portable document format
PE	polyethylene
PLF	price per linear foot
Prohibits	existence of prohibits the use
PSF	price per square foot
psig	pounds per square inch, gauge
PP	polypropylene
PPI	Plastics Pipe Institute
PVC	poly(vinyl chloride)
PVDF	poly-vinylidene chloride
R	relative importance of criterion i
RI	Rhode Island
RI	restores structural integrity
S	overall score for alternative j
SD	South Dakota
SC	South Carolina
Sliplining	sliplining
SOL	spray-on lining
STP	special technical report
SWL	spirally wound lining
T	waterway minimum wall
TN	Tennessee
TRB	Transportation Research Board
TV	television
TX	Texas
US	United States
USFS	U.S. Forest Service
UT	Utah
V	vertical
VA	Virginia
VT	Vermont
W	weight
WA	Washington
WAM	weighted average method
WI	Wisconsin
Worst	worst rating of alternative for a specified criterion
WV	West Virginia
www	World Wide Web
WY	Wyoming

CHAPTER 1 – INTRODUCTION

Culverts form an important part of the transportation infrastructure in the United States. A culvert can be considered a conduit or waterway usually placed under a fill, such as a highway or railroad embankment, to convey surface flow from the uphill side of the fill to the downhill side.(1) Drainage facilities, such as culverts, decay due to the processes of abrasion, corrosion, and erosion, shortening the anticipated service life of the facility. Many culverts in the United States have deteriorated and need repair or replacement. Until recently, most repair or replacement of culverts required open-cutting (trench digging). Due to higher traffic density, social and environmental impacts, and high construction costs associated with open-cutting techniques, State Departments of Transportation (DOTs), consultants, and Federal agencies such as the Federal Highway Administration (FHWA) have turned toward trenchless technology as a cost effective solution to culvert rehabilitation.

Trenchless technology can be used with a wide range of methods, materials, and equipment for rehabilitating existing or installing new underground infrastructure.(2) Within the category of trenchless technology, the rehabilitation of existing culverts through lining techniques has gained popularity in the United States. To date, several trenchless lining techniques have been used for the rehabilitation of existing culverts. However, choosing an optimum lining technique can be complicated considering the vast amount of organizations specializing in the manufacturing and installation of culvert liners as well as the various materials, applications, and limitations associated with each lining technique.

Due to the complexity and lack of standards/specifications associated with culvert lining techniques, past culvert lining projects were usually addressed on a project-by-project basis. To aid the FHWA and State DOTs, Colorado State University (CSU) was contracted to establish guidelines and specifications for the use of culvert liners. In order to accomplish this goal, the study was divided into three (3) tasks. Task 1 involved a thorough literature review to collect information describing the state-of-the-practice in culvert pipe lining for culverts up to 1.22 meters (4 feet) in diameter. Task 2 involved the development of a decision-making methodology for choosing appropriate culvert liners based on various factors. A user-friendly Microsoft® Excel-based Multi-criteria Decision Analysis (MCDA) tool that allows the user to customize the decision aid model was created for Task 2. Task 3 required the preparation and submittal of a final report whereby providing guidance to both the Design and Construction Branches of the FHWA and to State DOTs. Objectives associated with Task 3 are encompassed in the following report.

CHAPTER 2 – LITERATURE COMPILATION

BACKGROUND INFORMATION

An examination of trenchless technology was the starting point for the review of information pertaining to culvert pipe liners. Trenchless technology can be defined as the use of construction methods to install and repair underground infrastructure without digging a trench or open cutting.[3] Although considered a relatively new term, some trenchless technology methods have been practiced since the early 1900s.[2] Rapid development and expansion of trenchless technology has been observed over the past couple of decades due to the desire to cost-effectively install or rehabilitate underground infrastructure with minimal social and environmental impacts.

From this background review, it was determined how culvert lining relates to trenchless technology. Figure 1 presents a classification of trenchless technology showing the relationship of lining methods to trenchless technology. Specific methods pertaining to the installation of new infrastructure, under the categories of horizontal earth boring, pipe jacking and utility tunneling (i.e., auger boring, horizontal directional drilling, etc.) have been excluded. Culvert-lining methods were classified as a specialized trenchless rehabilitation method for existing infrastructure.[3] Five (5) different methods of culvert lining are currently used in practice and have been presented in the shaded boxes in Figure 1. As specified in the scope of work, culvert-lining methods were the focus of this report. Consequently, the five (5) culvert-lining methods presented in Figure 1 were researched and addressed in detail. Several lining methods had subsequent methods; these methods are presented in the shaded boxes in Figure 2.

Typically, trenchless technology methods have offered a more cost-efficient solution than open-cutting techniques, but successful installations required more rigorous planning, site investigations, and installation methods. Due to the technical nature of trenchless technology rehabilitation methods, previous trenchless technology rehabilitation installations were frequently addressed on a project-by-project basis. To aid the FHWA in gathering guidelines and specifications regarding culvert liners, the following literature sources were gathered and thoroughly reviewed.

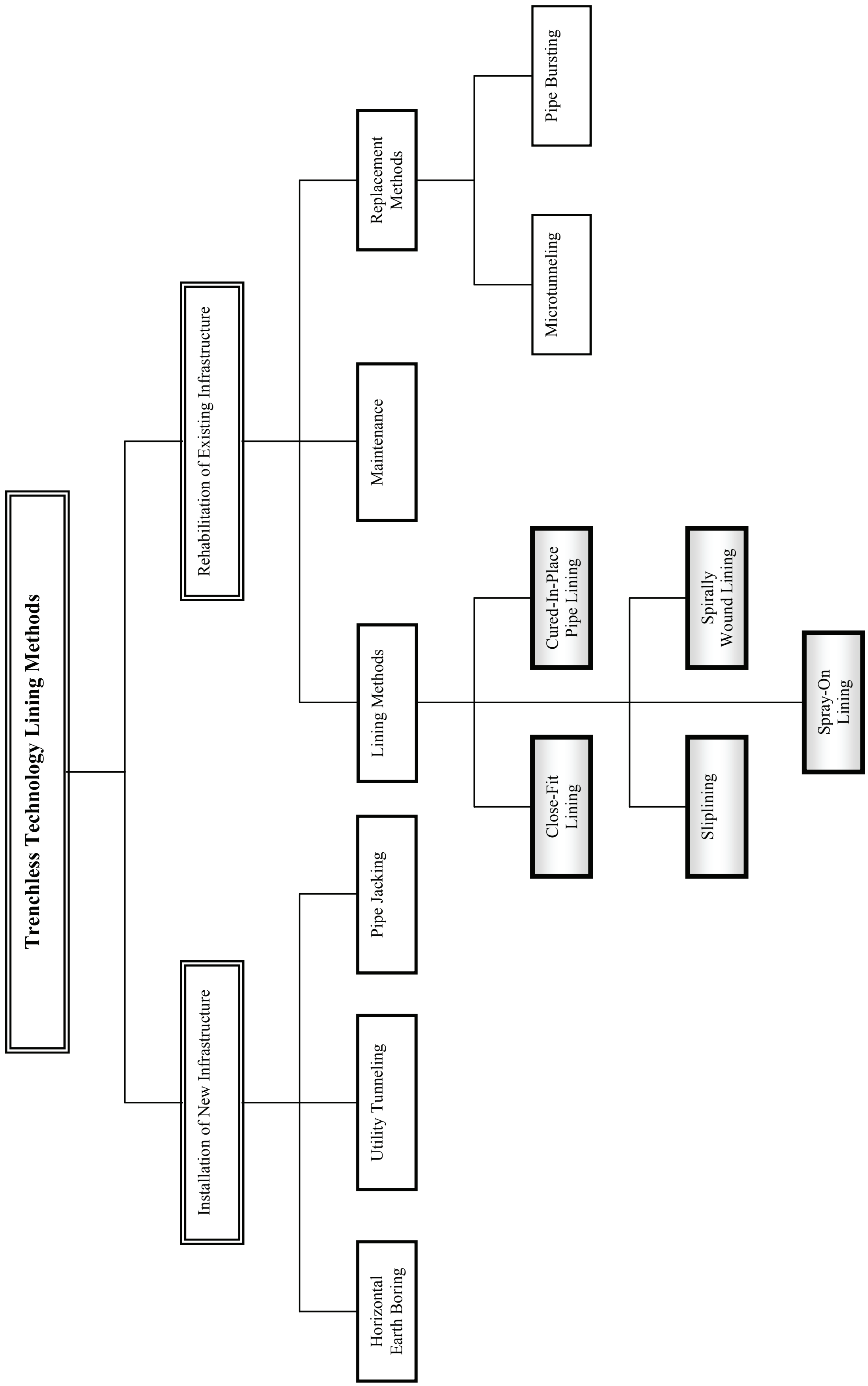


Figure 1. Flow Chart. Classification of Trenchless Technology Methods.[2]

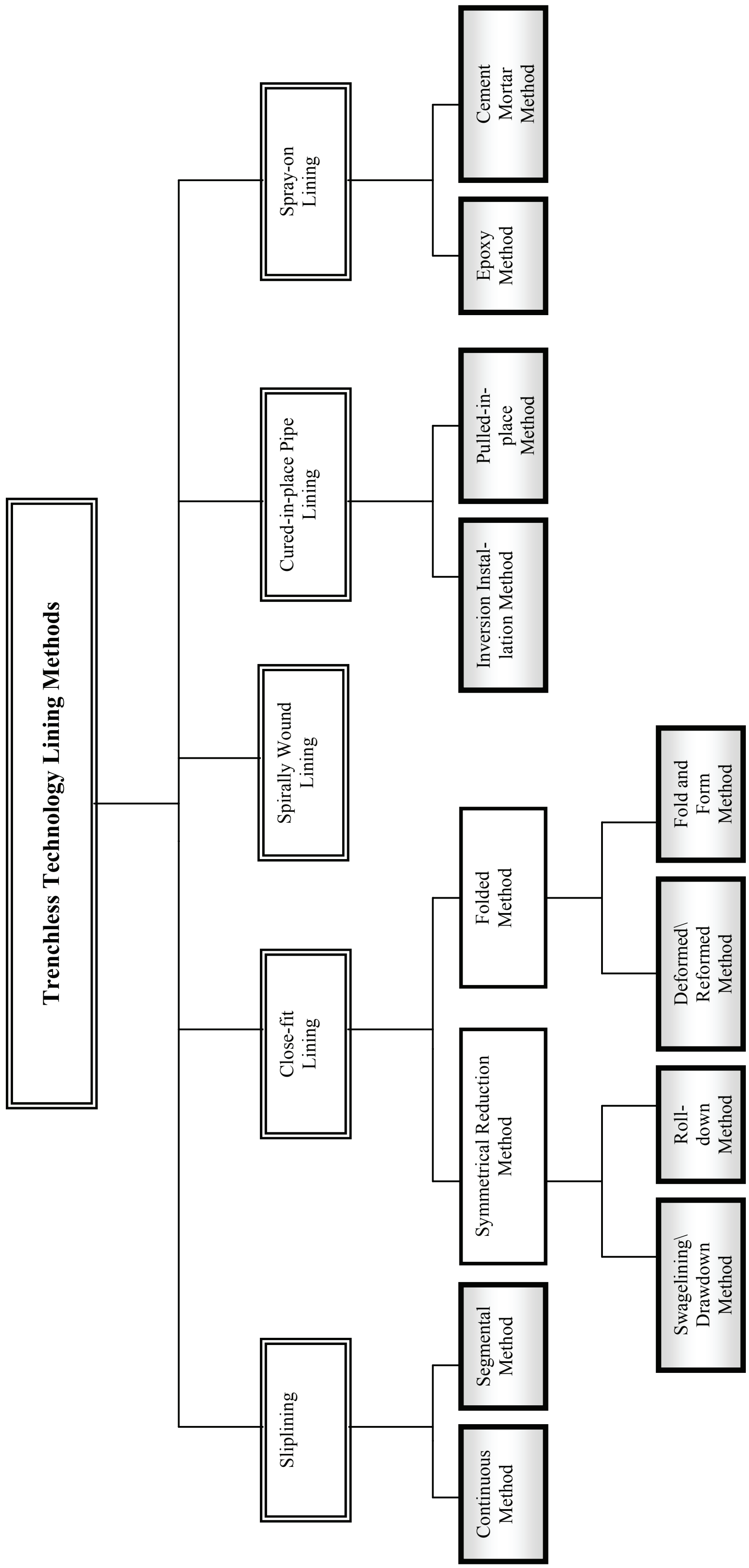


Figure 2. Flow Chart. Classification of Trenchless Technology Lining Methods.

LITERATURE SOURCES

Several methods and databases were used to locate relevant literature for review. First, the standards published by the American Society for Testing and Materials (ASTM) were reviewed. Keyword Internet searches were then performed upon several databases including the FHWA, the U.S. DOT, Transportation Research Board (TRB), American Association of State Highway and Transportation Officials (AASHTO), National Technical Information Service (NTIS), American National Standards Institute (ANSI), National Association of Sewer Service Companies (NASSCO), CSU Library, and separate databases of several State DOTs. Utilizing Internet search engines, keyword searches of the World Wide Web (www) were also performed yielding information from manufacturers and case studies of culvert liner installations. Finally, appropriate personnel of the FHWA and Bureau of Land Management (BLM) were asked to provide any additional resources for inclusion in the literature review. Once sources were acquired and reviewed, the literature references from each source were cross-referenced for additional sources. Subsequent sections present the pertinent literature assembled for review, describing the state-of-the-practice in culvert lining. For presentational purposes, literature sources have been categorized into the five (5) following categories:

1. ASTM Standards
2. Government Agencies
3. Other Agencies, Organizations, Contractors, and Manufacturers
4. FHWA and BLM Personnel
5. Case Studies

ASTM Standards

Review of ASTM Standards pertaining to culvert lining produced five (5) literature sources from which specific standards and guidelines were thoroughly reviewed. In conjunction with the specific standards obtained for lining methods, general information on trenchless technology was also acquired from the ASTM Standards review. A complete list of the five (5) ASTM sources used for review can be found in Appendix A.

Government Agencies

Several government publications offered valuable information on culvert lining. Acquired publications were discovered through searches of government databases and the Internet. Upon review, these publications offered information regarding trenchless technology, descriptions of current lining methods, and three specific State DOT guidelines for culvert lining. In total, six (6) sources were acquired, reviewed, and categorized under government agency sources. These sources are listed in Appendix A.

Other Agencies, Organizations, Contractors, and Manufacturers

Most of the references classified under other agencies, organizations, contractors and manufacturers were discovered through keyword Internet searches and in references of previously acquired material. Due to the numerous agencies, organizations, and manufacturers involved with culvert lining, sixteen (16) literature sources were acquired and reviewed. These sources included manuals, evaluations, standards, guidelines, and installation requirements for various culvert-lining methods. Sources that were acquired and reviewed for inclusion in this report are listed in Appendix A.

FHWA and BLM Personnel

To ensure that all relevant literature sources had been obtained, a complete list of acquired literature sources was sent to appropriate personnel in the FHWA and BLM for review. FHWA provided the listing of appropriate personnel. FHWA personnel were contacted via e-mail and provided the literature source list for review. Appendix A contains sources and agencies used as resources and their contributions.

Case Studies

During the search and collection of the aforementioned literature sources, approximately twenty (20) case studies involving culvert-lining rehabilitation were obtained. Although these case studies did not provide design information, many of them did include project costs and cost analysis. Cost information was extracted from the case studies when applicable.

INFORMATIONAL SURVEY

In order to more effectively gather general information and costs associated with each lining method and generate a list of manufacturers and contractors by state, an informational survey was generated for distribution. Before developing a survey, sample surveys from government agencies and other organizations were reviewed for content and format. These sample surveys provided insight into the type of format that would likely yield the most information while keeping the time to fill out the survey to a minimum. To accomplish this, a survey format was developed and converted to portable document format (PDF) via Adobe Acrobat 5.0.

Interactive buttons and text boxes were used to create a survey form that could be completed quickly and easily on a computer using Adobe Acrobat Reader. In order to receive up-to-date information pertaining to the cost and installation of different lining methods, as well as to generate a listing of culvert lining manufacturers and contractors by state, the form was sent via e-mail to a current list of State DOTs, manufacturers, and private consultants. A copy of the disseminated survey form is located in Appendix B.

SUMMARY

Information describing the state-of-the-practice in culvert lining was obtained from various sources, utilizing different searching techniques. Culvert lining was determined to be a specialized category of trenchless technology. For presentational purposes, the reviewed collection of literature sources was categorized into four categories. Individual sources were then categorized within these four categories and listed in bibliography format. Information was collected describing lining methods, their effective uses, advantages, limitations, general installation guidelines, and associated standards. Information collected on liner costs, manufacturers, and contractors was inadequate and incomplete. Thus, an informational survey was developed in an effort to obtain up-to-date cost information and to generate a complete listing of manufacturers and contractors by state. Information regarding the informational survey is presented in Chapter 4.

CHAPTER 3 – LITERATURE REVIEW

INTRODUCTION

In order to address the objective of determining available lining methods, the aforementioned 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.

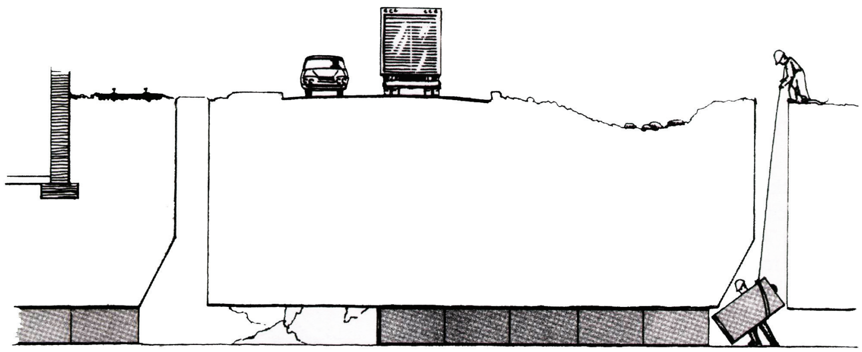


Figure 3. Drawing. Duratron System's Segmental Sliplining.(5)

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.

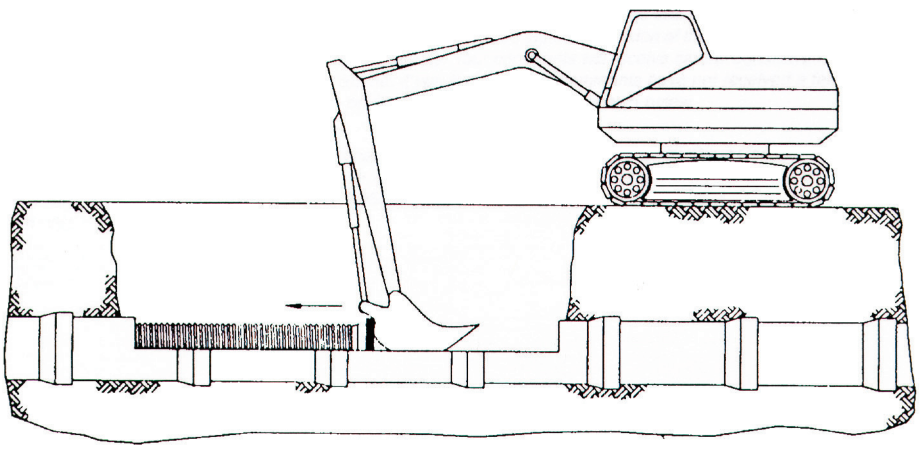


Figure 4. Drawing. Segmental Sliplining Installation Using the Push Method.[15]

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.

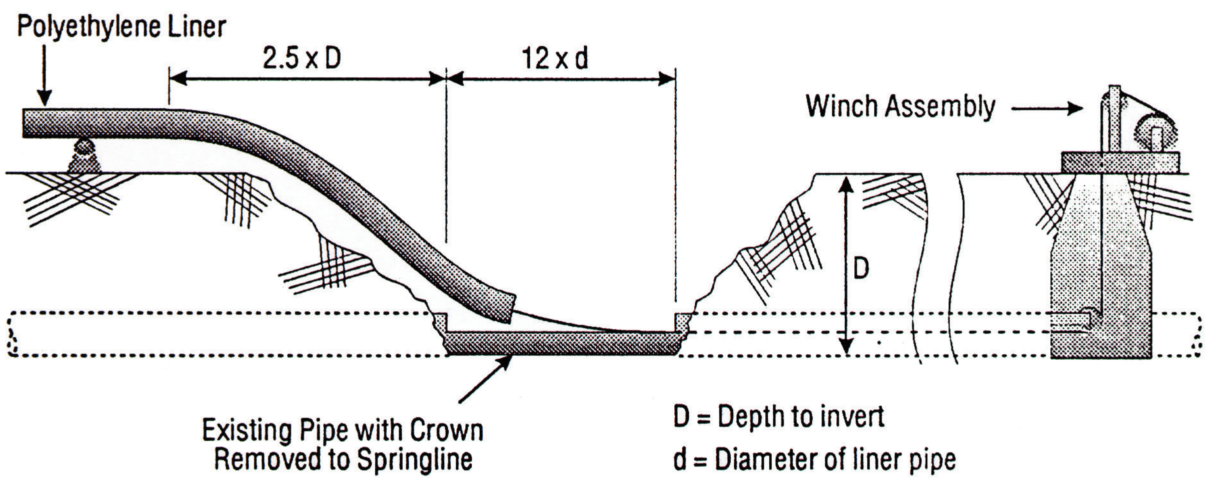


Figure 5. Drawing. Continuous Sliplining Installation Process.[5]

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.

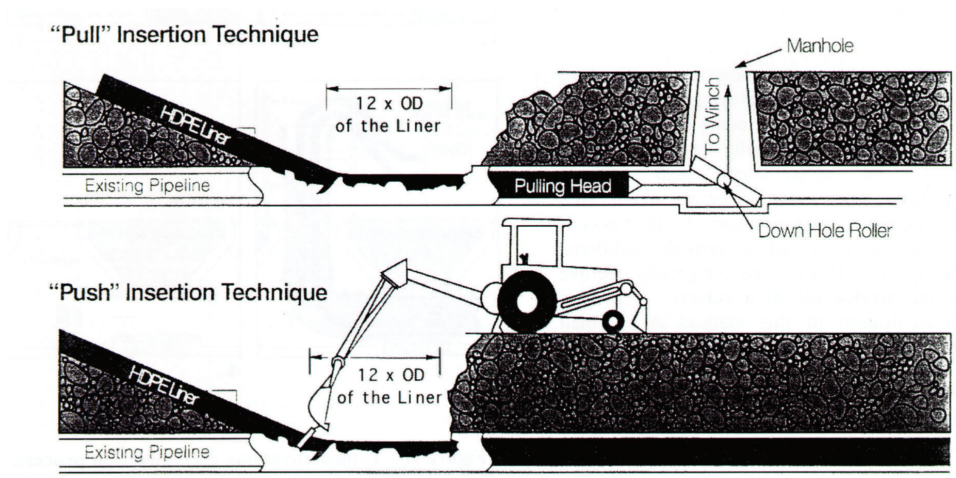


Figure 6. Drawing. Insertion Method for Butt Fusion Welded HDPE Liner.[(37)]

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 temporarily 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.

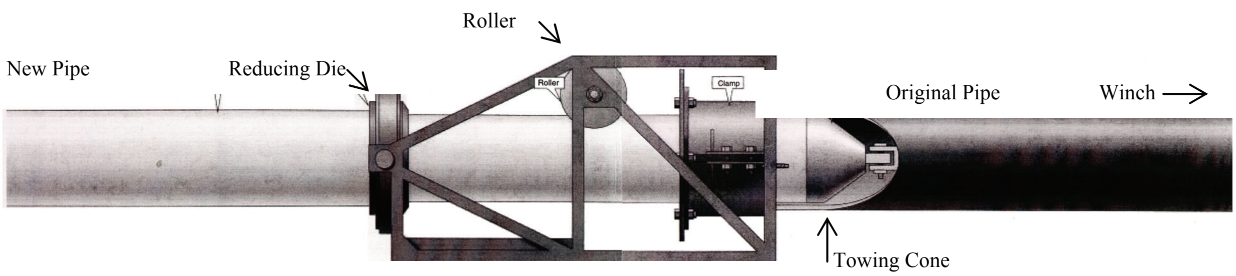


Figure 7. Drawing. Swagelining Process for Close-fit Lining.[43]

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.

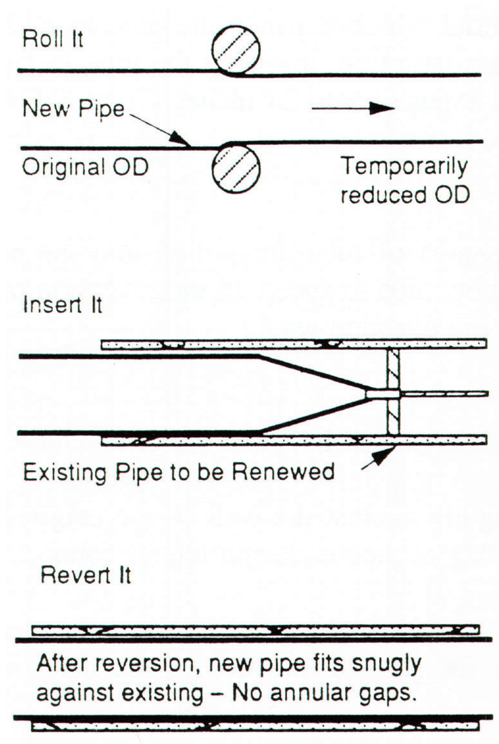


Figure 8. Drawing. Rolldown Process for Close-fit Lining.[5]

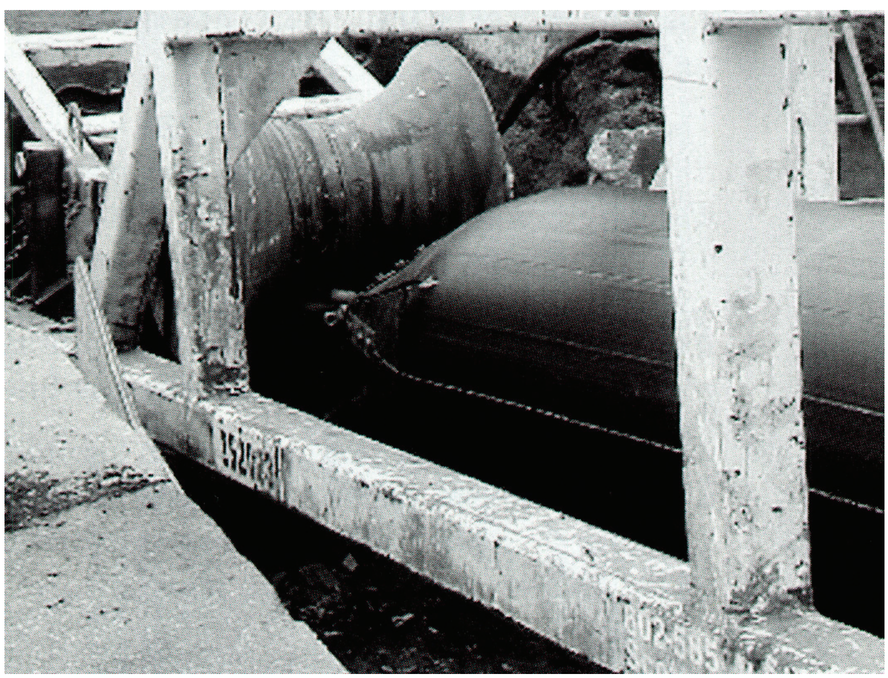


Figure 9. Photo. Culvert Lining Utilizing the Rolldown Method for Close-fit Lining.[8]

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.

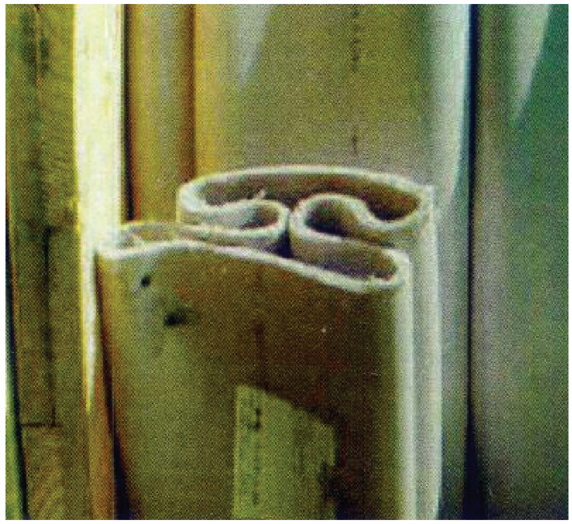


Figure 10. Photo. Ultraliner's PVC Alloy Pipeline Folded into an "H"-shape.[45]

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.

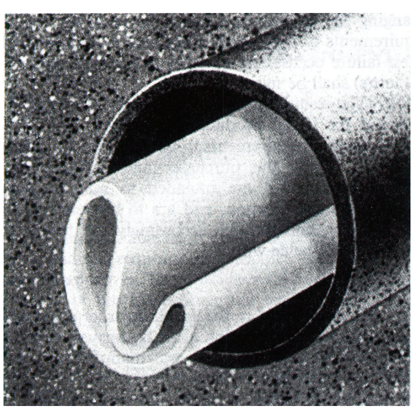


Figure 11. Drawing. Deformed Method for Close-fit Lining.[46]

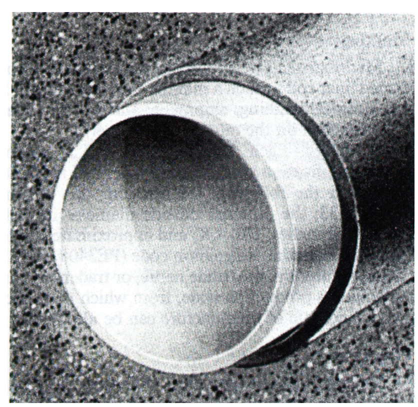


Figure 12. Drawing. Reformed Method for Close-fit Lining.[46]

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 unfold the pipe and form a close-fit between the liner and host pipe. A folded and formed liner is illustrated in Figure 13.

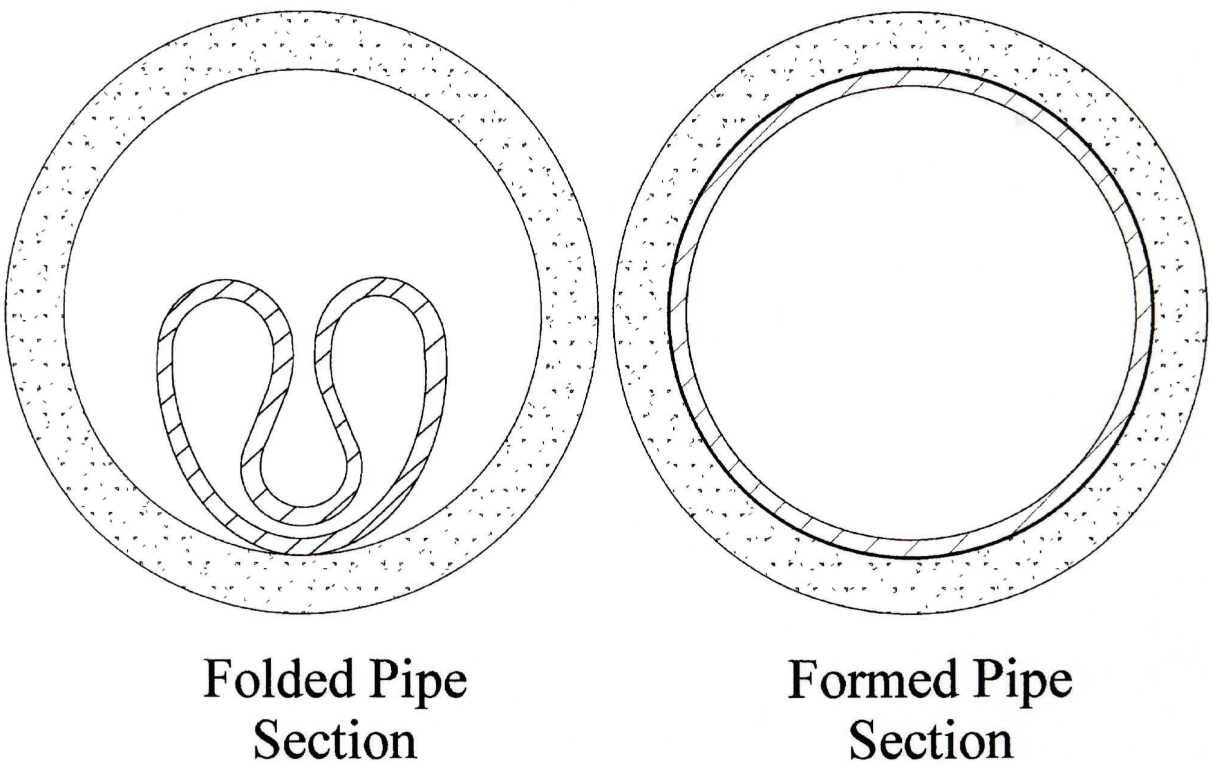


Figure 13. Drawings. Fold and Form Method for Close-fit Lining.[53]

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.

Table 23. Listing of Manufacturers and Contractors of the Fold and Form Method for Close-fit Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
American Pipe & Plastics, Inc. [1]	(607) 775-4340	(607) 775-2707	P.O. Box 577 Binghamton, NY 13902	National	N/A[2]
AM-Liner East, Inc.	(703) 430-4120	(703) 721-4977	1402 Shepard Dr. Suite 101 Sterling, VA 20164	PA, MD, NC, SC, VA, Wash. DC, FL,	David Giuliani
Associate Distributors, Inc.	(800) 737-0531	(314) 781-3240	P.O. Box 9172 St. Louis, MO 63117	AR, IA, MO, parts of IL	N/A
Atlantic Coast Contractors, Inc.	(704) 483-7120	(704) 483-7310	7680 Townsend Dr. P.O. Box 463 Denver, NC 28037	N/A	N/A
Boatman Construction	(615) 793-6721	(615) 793-6722	430 Dick Buchanan Dr. P.O. Box 868 Lavergne, TN 37086	AL, FL, GA, KY, MS, NC, SC, TN	N/A
C & C Service Supply	(800) 280-7981	(254) 662-3945	P.O. Box 11305 Waco, TX 76716	TX	N/A
Cisco Specialty Products	(714) 633-0698	(714) 633-2831	137 West Bristol Lane Orange, CA 92865	CA, NV	N/A
Columbia Pumping-Environmental Services Division	(800) 510-1103	(509) 547-4841	1005 S. Maitland Ave. Pasco, WA 99302	OR, parts of ID, WA	N/A
Con Line Co.	(540) 389-2927	(540) 387-4365	P.O. Box 6068 Roanoke, VA 24017	VA, WV, parts of NC	N/A
Darby Pipeline Rehabilitators, Inc.	(740) 477-8600	(740) 477-9865	6790 Brooksmiller Rd. Circleville, OH 43133	OH, parts of IN, KY, MI, WV	N/A
D.A. Van Dam & Associates	(888) 818-0016	(330) 759-9661	1540 Fisher Dr. Hubbard, OH 44425	OH, MI, parts of PA	N/A
Eastern Pipe Service	(603) 424-4600	(603) 424-466?	26B Columbia Circle Merrimack, NH 03054	CT, ME, MA, NH, RI, VT	N/A
Environmental Pipeliners, Inc.	(614) 792-9295	(614) 792-0426	6200 Eiterman Rd. Dublin, OH 43016	KY, IN, OH, Western PA	Lori Jackson
Five V Corporation	(770) 939-3924	(770) 934-7629	P.O. Box 2722 Tucker, GA 30085	GA, parts of TN	N/A
Greenville Rooter, Inc.	(864) 848-0105	(864) 877-3418	P.O. Box 575 Greer, SC 29652	GA	Floyd Miner
Ground & Pipe Technologies	(334) 388-5640	(344) 264-8980	1120 Parker St. P.O. Box 9204 Montgomery, AL 36108	AL, FL	N/A
Hi-Tech Pipeline Services, Inc.	(831) 757-2774	N/A	20520 Spence Rd. Salinas, CA 93908	Northern CA, NV	Billy Haendiges
InfraCor, Inc.	(804) 272-6600	N/A	7400 Beaufont Springs Dr, Suite 415 Richmond, VA 23225	N/A	N/A
InfraCorps of Virginia	(877) 231-3426	(804) 231-9613	2210 East Belt Blvd. P.O. Box 24205 Richmond, VA 23224	VA, parts of NJ, NY, WV	N/A
InfraTech International	(800) 568-1707	(717) 763-8665	3605 Hartzdale Dr. Camp Hill, PA 17011	PA, MD, parts of NJ, NY, WV	N/A
Insituform Technologies, Inc. [1]	(800) 234-2992	(636) 519-8010	702 Spirit 40 Park Dr. Chesterfield, MO 63005	National	N/A
J.F. Pacific Liners, Inc.	(707) 446-8222	(707) 447-3361	70 Union Way Vacaville, CA 95687	Northern CA	Jay Fox
Jim Jolly Sales, Inc.	(847) 458-0382	(847) 458-0383	3571 Persimmon Dr. Algonquin, IL 60102	IL, WI, IN	N/A

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

Table 23 (cont.). Listing of Manufacturers and Contractors of the Fold and Form Method for Close-fit Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Jones Bros, Inc.	(615) 754-4710	(615) 758-9934	P.O. Box 727 Mt. Juliet, TN 37121	TN	N/A[2]
Kana Pipeline, Inc.	(714) 986-1400	(714) 986-1416	172 East Orangethrope Ave. Placentia, CA 92870	CA, parts of NV	N/A
Lash Contracting	(518) 783-7832	(518) 783-7341	794 Watervliet-Shaker Rd. Latham, NY 12110	Upstate NY	Robert Lashway
Lauderdale Environmental Services	(256) 765-0036	(256) 765-0036	614 North Poplar St. Florence, AL 35630	AL	N/A
MaS Sales, Inc *North Carolina Office*	(704) 482-9647	(704) 482-9647	1429 Fallston Rd. Shelby, NC 28150	NC	N/A
MaS Sales, Inc. *South Carolina Office*	(843) 692-0669	(888) 627-1017	819 Forest Dr. Myrtle Beach, SC 29577	NC, SC	N/A
Miksis Services, Inc	(888) 867-5848	(707) 937-8173	P.O. Box 591-I Healdsburg, CA 95448	CA	N/A
Miller Pipeline Corporation	(317) 293-0278	(317) 293-8502	8850 Crawfordville Rd. Indianapolis, IN 46234	N/A	N/A
Next Generation Renovation, Inc. [1]	(800) 267-9810	(705) 645-1122	3442 Lauderdale Dr., Suite 212 Richmond, VA 23233	National	N/A
Northwest Industrial Equipment	(253) 872-6060	(243) 872-6059	22023 70th Ave. South Kent, WA 98032	ID, OR, WA	N/A
PEC, Inc.	(406) 447-5030	(406) 447-5046	825 Custer Helena, MT 59604	MT, ND, SD, WY, parts of WA	N/A
PIM Corporation	(800) 293-6224	(732) 469-8959	201 Circle Dr. No. Suite 106 Piscataway, NJ 08854	N/A	N/A
Raleigh & Associates	(623) 972-9238	(623) 972-9250	11124 California Ave. Youngtown, AZ 85363	AZ	N/A
Sancon Technologies Inc.	(714) 902-0115	(714) 902-0121	5881 Engineer Dr. Huntington Beach, CA 92649	Southern CA	Nick DiBenedetto
Southland Contracting	(817) 572-3331	(817) 293-5065	P.O. Box 40664 Fort Worth, TX 76140	TX, parts of CA, OK	N/A
Tele Environmental Systems	(970) 945-2866	(970) 625-8315	1419 Airport Rd. Rifle, CO 81650	WY, UT, CO	Charlie Lanphear
Triad Western Constructors	(970) 565-4257	(970) 565-1057	512 North Broadway Cortez, CO 81321	CO, NM, parts of TX, AZ	N/A
Tri-State Utilities	(757) 366-9505	(757) 366-5150	2111 Smith Ave. Chesapeake, VA 23320	VA, NC	N/A
Ultraliner, Inc.	(256) 831-5515	(256) 831-5575	P.O. Drawer 3630 201 Snow St. Oxford, AL 36203	AL, parts of FL, KY, MS, NC, SC, GA, TN	N/A
Ultraliner Sales, Inc. [1]	(256) 835-6767	(256) 835-6766	P.O. Drawer 3630 201 Snow St. Oxford, AL 36203	National	N/A
Utility Lining Corp.	(631) 242-5155	(631) 242-4146	1940 Deer Park Ave. Deer Park, NY 11729	NYC	Gregg Penza
Val Kotter and Sons	(435) 734-9598	(435) 734-9870	1035 West Forest St. Brigham City, UT 84302	UT, Parts of ID, NV	N/A
Valley Isle Pumping Inc.	(808) 242-5692	(808) 244-3596	RR 1, Box 146E Wailuku, HI 96793	HI	N/A
Williams Testing	(888) 921-7473	(941) 925-1901	P.O. Box 15877 Sarasota, FL 34277	Southwest FL	Jean Dunlop

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

SPIRALLY WOUND LINING

Description

Spirally wound lining uses interlocking profile strips, most commonly made from PVC, to line a deteriorated culvert. Coiled, interlocking profile strips, shown in Figure 15, are fed through a winding machine that mechanically forces the strips to interlock and form a smooth, continuous, spirally wound liner. During the interlocking process, a sealant is applied to each joint to form a watertight seam. As the material is wound and snapped together, it is forced into the existing culvert.

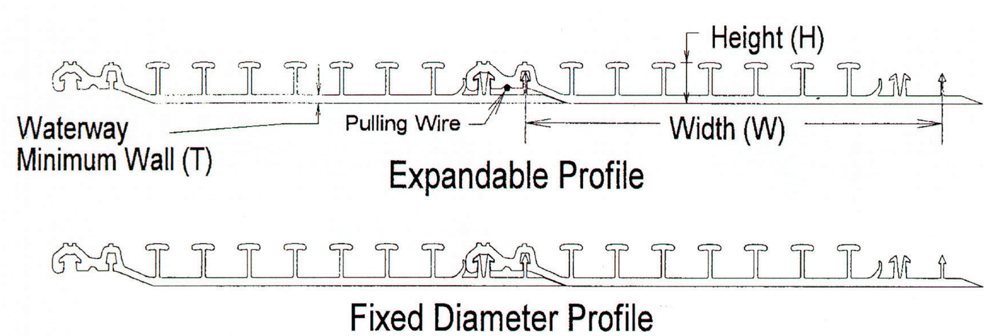


Figure 15. Drawings. Expandable and Fixed Diameter Profile Strips.[(64)]

Generally, the liner is wound and inserted from existing manholes without excavation. For larger diameter culverts (larger than 91 centimeters (36 inches)), preformed panels are spirally wound, rather than profile strips. Grouting of the annular space is generally required when fixed diameter profile strips are used. If expandable profile strips are used, grouting is unnecessary. Figure 16 presents the expandable profile liner and the fixed diameter profile liner requiring annular grouting.

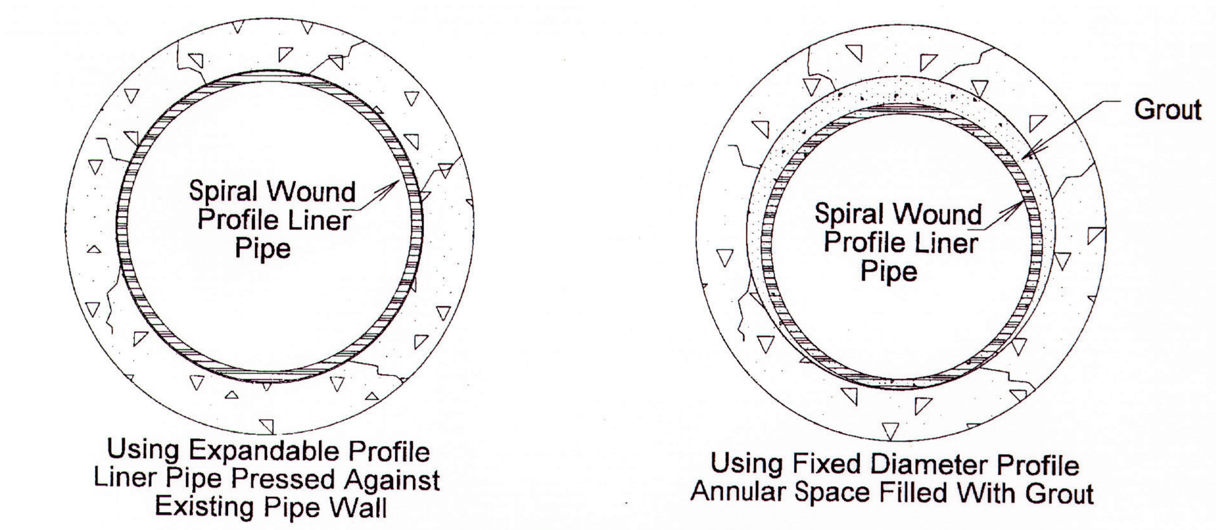


Figure 16. Drawings. Inserted Expandable and Fixed Diameter Spirally Wound Lining.[64]

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of the spirally wound lining are presented in Table 24. Advantages and limitations associated with spirally wound lining are presented in Table 25.

Table 24. General Characteristics and Effective Uses of Spirally Wound Lining.[5,6,7]

Applications	Diameter Range	Liner Material[1]	Maximum Installation
Gravity Pipelines Only	100 - 3,050 millimeters (4 - 120 inches)	PE, PVC, PP, PVDF	Unlimited

[1]PE – Polyethylene, PVC – Poly(Vinyl Chloride), PP – Polypropylene, PVDF – Poly-Vinylidene Chloride

Table 25. Advantages and Limitations of Spirally Wound Lining.[5,6]

Advantages	Limitations
Liner formed on site	Continuous fusion or sealant of joints is required
No pipe storage on site required	
Any diameter (within range of winding machine) can be selected	Requires trained personnel to operate winding machine and equipment
Grouting is not required if expandable joints are used	Grouting usually required if fixed diameter joints are used
Capable of accommodating large radius bends	
Accommodating of diameter changes may be possible	Reduction in flow capacity may be significant
Flow bypass is not always required	Lateral connections, service connections, and termination ends may require watertight sealing
Excavation is usually not required	

Costs

According to the USFS Draft Report on trenchless technology for Forest Service culverts,[9] the range of costs for spiral wound lining is approximated to be $100 per linear foot for 45.7-centimeter (8-inch) diameter pipes and $750 per linear foot for the largest diameters placed by hand.

General Installation Guidelines

A general list of installation guidelines for spirally wound lining is provided below:[5,14,64,65]

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 spirally wound lining, such as protrusions, collapsed sections, deflected joints, etc.
4. Clear line obstructions discovered during the inspection prior to inserting the liner. Angles that can be negotiated depend upon a variety of factors. Depending upon the method of installation and type of profile strip used, diameter changes in the existing culvert may be accommodated for a determination of whether a bend or diameter changes can be accommodated, consult the manufacturer.
5. Installation does not require a dry pipeline, thus flow bypass may not be required. If necessary, flow bypass should be carried out in the necessary fashion.
6. If required or recommended by the manufacturer, excavate an insertion pit to comfortably accommodate all equipment necessary for installation.
7. Insert winding machine within insertion pit (or manhole) and orient the machine so that the liner can be spirally wound and properly inserted directly into the existing culvert. As the profile strip is wound in the machine, place the required sealant or adhesive within the primary and secondary locks of the locking configuration at the edge of the strip (unless already in place). Figure 17 presents the installation procedure of a fixed diameter spirally wound liner.

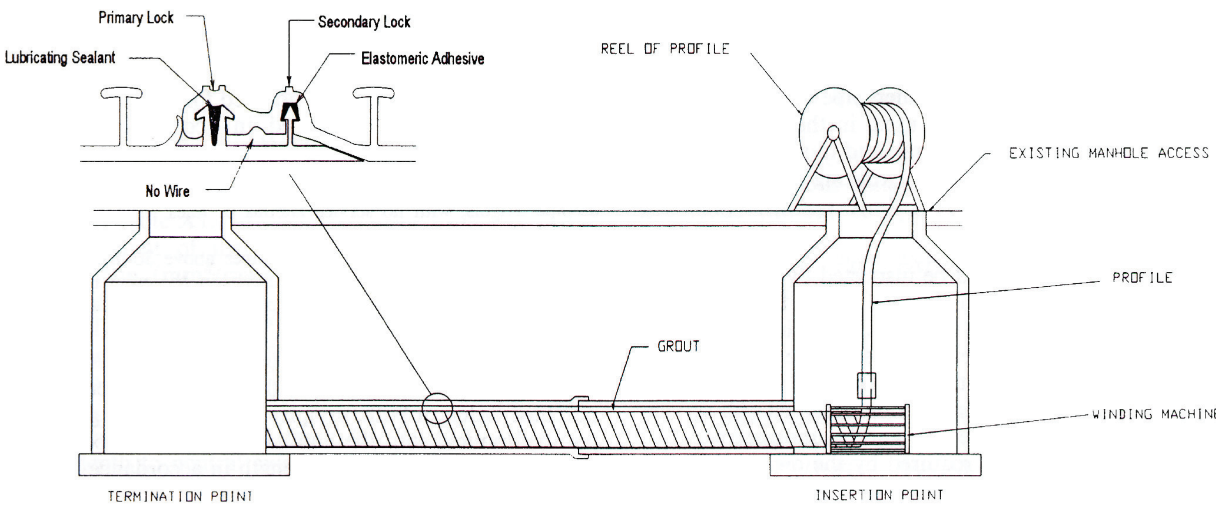


Figure 17. Drawing. Installation of Fixed Diameter Spirally Wound Lining.(64)

8. The wound liner is to be expanded, torsionally restrain the liner at the termination point. To accomplish this, release a specific length of the inserted spirally wound lining at the termination point by pulling the wire out of the expandable interlocked joint. Recommence the winding operation, which will create a torque to the released end, causing a radial growth over the released length of the liner. Allow the growth to continue until the released end of the liner is pressed against the existing culvert, causing the growth to cease. Repeat this process until the spirally wound lining is pressed against the full length of the existing culvert. Obtain and follow specific guidelines provided by the manufacturer for installation if applicable. Figure 18 presents the installation of an expandable spirally wound lining.

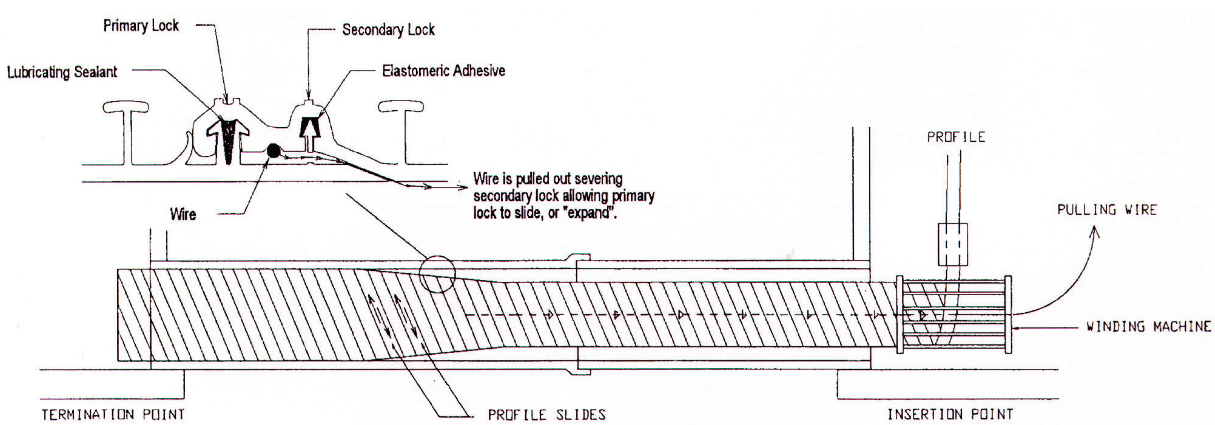


Figure 18. Drawing. Installation of an Expandable Spirally Wound Lining.(64)

9. If the job requires the use of profile strips to be provided in the form of panels, cut and trim the panels to fit as near as practical to the internal diameter of the existing culvert or to produce the required annulus. Place the panels square with the culvert wall, circumferentially, and lock adjacent panels together as specified by the manufacturer. Seal termination joints with a manufacturer-supplied connecter and approved sealant.
10. Inspect the completed installation by closed-circuit TV or manually if the diameter permits man-entry. The spirally wound lining 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. Reconnect lateral and service connections with a television camera and a remote- control cutting device or manually where the diameter permits man-entry. After reopening the lateral and service connections, seal the annular space between the liner and the existing culvert at the termination points with a watertight seal.
13. If grouting is necessary, inject grout into the annular space between the existing culvert and liner through openings in the end seals, at reconnected service connections, or through holes drilled into the liner at appropriate points. Carry out the grouting procedure in one of two ways. Either apply the grout in a series of lifts/stages or apply the grout continuously. Appropriate standards or the manufacturer should be consulted further for more specific information pertaining to grouting procedure.
14. Finally, restore flow if bypass was required and initiate site cleanup.

Annular Grouting

Annular Grouting is generally required for spirally wound lining in cases where the liner is of fixed diameter or does not expand to fit tightly against the existing pipe wall. In addition to the standards and specifications listed in Table 3, the following list of related standards are associated with annular grouting of spirally wound lining:

- ASTM F 1741 – Standard Specification for Installation of Machine Spiral Wound Poly(Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits (2001)[64]
- ASTM F 1697 – Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for Machine Spiral-Wound Liner Pipe Rehabilitation of Existing Sewers and Conduit (1996)[66]
- ASTM F 1698 – Standard Practice for Installation of PVC Profile Strip Liner and Cementitious Grout for Rehabilitation of Existing Man-Entry Sewers and Conduits (1996)[65]
- NASSCO Specification of Profiled PVC Lining, Man-entry Sewers (as provided by Danby™ of North America, Inc. for the Danby™ -Sliplining/PL Process)[14]
- NASSCO Specification of Spiral Wound Pipe, 8 inch to 24 inch, Profiled PVC (as provided by Danby™ of North America, Inc. for the Danby™ -TL Process) (1999)[14]

Standards/Specifications

Table 26 presents the current standards and specifications associated with the spirally wound lining method.

Table 26. Standards Associated with Spirally Wound Lining.[14,23]

Standard/Specification	Description
ASTM F 1697 – Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for Machine Spiral-Wound Liner Pipe Rehabilitation of Existing Sewers and Conduit (1996)[66]	Covers the requirements and test methods for materials, dimensions, workmanship, stiffness factor, extrusion quality, and a form of marking for extruded PVC profile strips for machine-made field fabrication of spirally wound pipe liners.
ASTM F 1698 – Standard Practice for Installation of PVC Profile Strip Liner and Cementitious Grout for Rehabilitation of Existing Man-Entry Sewers and Conduits (1996)[65]	Describes the procedures for the rehabilitation of sewer lines and conduits by the installation of a field-fabricated PVC liner. After installation of the liner, cementitious grout is injected into the annular space between the liner and the existing sewer or conduit.
ASTM F 1735 – Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for PVC Liners for Rehabilitation of Existing Man-Entry Sewers and Conduits (2001)[67]	Covers the requirements and test methods for materials, dimensions, workmanship, extrusion quality, and a form of marking for extruded PVC profile strips used for field fabrication of PVC liner for existing man-entry in vertical sewer and conduit rehabilitation.
ASTM F 1741 – Standard Specification for Installation of Machine Spiral Wound Poly(Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits (2001)[64]	Describes the procedures for the rehabilitation of sewer lines and conduits by the installation of a field-fabricated spiral wound liner pipe into an existing pipeline. After insertion, the spiral wound liner pipe is expanded until it presses against the interior surface of the existing pipeline, or, alternatively, the spiral wound liner pipe is inserted as a fixed diameter into the existing pipeline and is not expanded, and the annular space between the spiral wound liner and existing pipe is grouted.
NASSCO Specification of Spiral Wound Pipe, 8 inch to 24 inch, Profiled PVC (as provided by Danby™ of North America, Inc. for the Danby™ -TL Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of spirally wound PVC profile strip liners.
NASSCO Specification of Spiral Wound Pipe, 8 inch to 36 inch, Profiled PVC (as provided by Rib Loc® Group Limited for Rib Loc® Expanda Pipe Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of spirally wound PVC profile strip liners.
NASSCO Specification of Profiled PVC Lining, Man-entry Sewers (as provided by Danby™ of North America, Inc. for the Danby™ -Sliplining/PL Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of spirally wound PVC panels.

In addition to the four (4) specific ASTM standards presented in Table 26, the following list of related standards were also associated with spirally wound lining:

- ASTM C 39 – Test Method for Compressive Strength of Cylindrical Concrete Specimens[68]
- ASTM C 969 – Practice for Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines[69]
- ASTM D 618 – Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[48]

- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[(26)]
- ASTM D 883 – Terminology Relating to Plastics[(70)]
- 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 2240 – Test Method for Rubber Property – Durometer Hardness[(71)]
- 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 spirally wound lining is presented in Table 27.

Table 27. Listing of Manufacturers and Contractors of Spirally Wound Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
BRH-Garver, Inc.	(713) 921-2929	(713) 921-2487	5402 Lawndale Houston, TX 77023	KS, LA, NM, OK, TX	N/A[2]
Danby Pipe Renovation[1]	(919) 467-7799	(919) 467-7754	P.O. Box 5127 Cary, NC 27512	National	N/A
PPR Pipe Rehabilitation, Inc.	(714) 428-4515	(714) 428-4519	2615 S. Rousselle St. Santa Ana, CA 92707	CA	N/A

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

CURED-IN-PLACE PIPE LINING

Cured-in-place lining, also known as “in-situ lining,” installations involve the insertion of a flexible fiber tube coated with a thermosetting resin into an existing culvert by hydrostatic or air inversion or by mechanically pulling. Once installed, the resin is cured under ambient conditions or through applied heat provided by circulating stream or hot water throughout the tube. Unlike other lining methods, the flexible fiber lining tube is manufactured to suit specific existing culvert dimensions. Many cured-in-place lining systems are used that differ in tube composition, resin type, installation procedure, and curing process. Flexible fabric and thermosetting resin are the primary components of cured-in-place lining.

For typical installations, the resin is the primary structural component of the system.[5] Resins are categorized into three (3) different categories and are chosen based upon design conditions and the functionality of the deteriorated culvert. The three (3) types of resin categories are unsaturated polyester, vinyl ester, and epoxy. Unsaturated polyester resins are the most widely used resins in cured-in-place lining systems due to their chemical resistance to municipal sewage, excellent workability during installation, and economic feasibility. For industrial and pressure pipeline rehabilitations that require special corrosion and higher temperature performance needs, vinyl ester and epoxy resin systems are used. Epoxy resins are required for the rehabilitation of potable water pipelines.

Cured-in-place lining systems can also be designed and categorized into the three (3) types of lining tubes for installation. These systems consist of felt-based systems, woven hose systems, and membrane systems. Felt-based lining tubes are produced from nonwoven polyester felt that is coated on one face with a layer of elastomer. Due to the varying thickness and introduction of reinforcing fibers during manufacturing, felt-based tubes offer solutions to a wide range of design requirements. Manufactured out of a circular woven, seamless, polyester fiber hose that is coated on one face with a layer of elastomer, woven hose systems are primarily designed to rehabilitate pressure pipelines suffering from corrosion and leakage. Membrane systems are composed of a very thin elastomeric membrane designed for the rehabilitation of leaking, low-pressure gas mains and offer internal corrosion protection. Cured-in-place lining systems can further be categorized based upon the installation process used to install the liner.

Inversion Installation Method for Cured-in-place Lining

Description

Inversion installation method for cured-in-place lining, or inverted-in-place installation method, involves the installation and simultaneous inversion of a thermosetting, resin-impregnated tube into a deteriorated culvert. This method requires the placement of a vertical standpipe, or other apparatus, at the insertion end. After connecting the resin-impregnated tube to the vertical standpipe, the tube is forced through the existing culvert by applying hydrostatic water pressure, or pressurized air/steam, while simultaneously being inverted. As the liner is inverted, the resin allows the liner to attach and conform to the existing culvert walls. Once installed, the thermosetting resin is cured through heat provided by circulating hot water or steam. Figure 19 presents Insituform's cured-in-place lining inversion installation process.

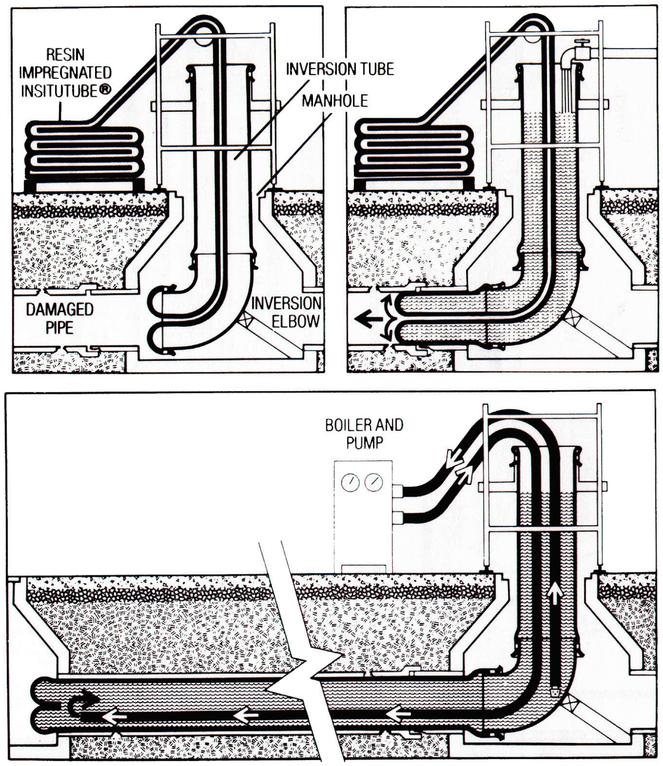


Figure 19. Drawings. Insituform's Cured-in-place Lining Inversion Installation Method.[8]

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of the inversion installation method for cured-in-place lining are presented in Table 28. Advantages and limitations associated with the inversion installation method for cured-in-place lining are presented in Table 29.

Table 28. General Characteristics and Effective Uses of the Inversion Installation Method for Cured-in-place Lining.[5,6]

Applications	Diameter Range	Liner Material	Maximum Installation
Gravity & Pressure Pipelines	100 - 2,700 millimeters (4 - 106 inches)	Thermoset Resin/ Fabric Composite	900 meters (275 feet)

Table 29. Advantages and Limitations of the Inversion Installation Method for Cured-in-place Lining.[5,6,7]

Advantages	Limitations
No joints	Flow bypass is required
Capable of accommodating bends and pipe deformations	Requires trained personnel to operate special equipment
Grouting is not normally required	Tubing must be specially constructed for each project
Minimal or no reduction in flow capacity	Lateral connections, service connections, and termination ends may require watertight sealing
Minor or no excavation required	
Non-circular shapes can be accommodated	Resin requires a long time period to cure
Long installations possible	Styrene monomer-based resins used in making the liner are potentially toxic prior to completion of the curing process
	Possible thermal pollution from the discharge waters used to heat the resin liner

Costs

According to the USFS Draft Report on trenchless technology for Forest Service culverts,[9] the range of costs for inversion installation method for cured-in-place lining is approximated to be $100 per linear foot for 45.7-centimeter (18-inch) diameter pipes and approximately $800 per linear foot or more for the largest diameters.

General Installation Guidelines

A general list of installation guidelines for the inversion installation method for cured-in-place lining is provided below:[14,72]

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 cured-in-place lining liner, such as protrusions, collapsed sections, deflected joints, etc.
4. Clear line obstructions discovered during the inspection prior to inserting the liner. Generally, most bend angles and changes in existing culvert diameter can be accommodated. If obstructions cannot be cleared, point repair excavation should be used to remove and repair the obstruction.

5. Vacuum-impregnate the insertion tube with the specified resin under controlled conditions. Apply a resin volume sufficient to fill all voids in the tube material. Add 5% to 10% excess resin to the estimated volume to account for the change in resin volume due to polymerization and migration of resin into cracks and joints in the deteriorated culvert. Lubricate the tube before installation. This can be achieved by applying lubricant to the fluid in the standpipe or by applying lubricant directly to the tube.
6. Bypassing of flow is required, unless flow can be shut off during installation.
7. If inverting the resin-impregnated tube with hydrostatic head, insert the tube into the vertical inversion standpipe. Insert the tube with the impermeable plastic membrane side out, while at the lower end of the standpipe, turn the tube inside out and attach it to the standpipe so that a watertight seal is created. Fill the standpipe with water, creating a sufficient head to cause the tube to invert throughout the pipe and bond to the existing culvert.
8. If inverting the resin-impregnated tube with air/steam pressure, insert the tube into the guide chute with the impermeable plastic membranes side out. Attach the tube to the upper end of the chute so that a seal is created. Obtain the minimum air/stream pressure needed to hold the tube tight against the existing culvert and the maximum allowable pressure from the manufacturer. Apply the appropriate air/steam pressure to cause the tube to invert throughout the pipe and bond to the existing culvert.
9. After inversion is completed, circulate hot water or steam throughout the liner with approved equipment. Equipment should be suited with temperature gages and be capable of circulating the hot water or steam uniformly throughout the liner. The initial cure will occur during the heat-up process. After initial cure, raise the temperature to the resin manufacturer's recommended post-cure temperature. Hold this temperature for the recommended period of time by recirculating the water or steam throughout the liner and heating apparatus. Maintain the recommended pressures throughout the curing process.
10. If heated water was used to cure the resin, drain the heated water from a small hole made in the downstream end and replace with the introduction of cool water into the inversion standpipe. Cool the liner to a temperature below 37.8°C (100°F) before relieving the static head in the inversion standpipe.
11. If air/steam was used to cure the resin, drain the air/steam through a small hole made in the downstream end and replace with the introduction of cool water into the guide chute. Cool the liner to a temperature below 45°C (113°F) before relieving the pressure within the section.
12. Cut and seal the termination ends with a resin mixture compatible with the installed liner if the liner does not fit tightly against the original pipe.
13. Inspect the completed installation by closed-circuit TV or manually if the diameter permits man-entry. The liner should be continuous over the entire length.
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 or manually where the diameter permits man-entry.
16. Finally, restore flow and initiate site cleanup.

Standards/Specifications

Table 30 presents the current standards and specifications associated with the inversion installation method for cured-in-place lining.

Table 30. Standards Associated with the Inversion Installation Method for Cured-in-place Lining.[14,23]

Standard/Specification	Description
ASTM D 5813 – Standard Specification for Cured-In-Place Thermosetting Resin Sewer Pipe (1995)[73]	Covers specification, evaluation, and testing of materials used in the rehabilitation of existing pipes by the installation and cure of a resin-impregnated fabric liner.
ASTM F 1216 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube (1998)[72]	Describes the procedures for the reconnection of pipelines and conduits by the installation of a resin-impregnated, flexible tube which is inverted into the existing conduit by use of a hydrostatic head or air pressure.
NASSCO Specification for Cured-in-place Pipe (CIPP) (as provided by Insituform® Technologies, Inc. for the Insituform® process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of CIPP installed by inversion.
NASSCO Specification for Cured-in-place Pipe (CIPP) (as furnished by Pipelining Products Inc. for the Cure-Line Pipe® Process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of CIPP installed by inversion.
NASSCO Specification for Cured-in-place Pipe (CIPP) (as provided by National Envirotech Group LLC for the National Liner™ Process[14]	Describes the specifications, design considerations, materials, equipment, and installation of CIPP installed by inversion.

In addition to the two (2) specific ASTM standards presented in Table 30, the following list of related standards were also associated with the inversion installation method for cured-in-place lining:

- ASTM D 543 – Test Method for Resistance of Plastics to Chemical Reagents[25]
- ASTM D 638 – Test Method for Tensile Properties of Plastics[49]
- ASTM D 695 – Test Method for Compressive Properties of Rigid Plastics (2001)[74]
- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[26]
- ASTM D 883 – Terminology Relating to Plastics[70]
- ASTM D 903 – Test Method for Peel or Stripping Strength of Adhesive Bonds[75]
- ASTM D 1600 – Terminology for Abbreviated Terms Relating to Plastics[27]
- ASTM D 1682 – Test Methods for Breaking Load and Elongation of Textile Fabric[76]

- ASTM D 3039 – Test Method for Tensile Properties of Fiber-Resin Composites[77]
- ASTM D 3567 – Practice for Determining Dimensions of "Fiberglass" (Class-Fiber-Thermosetting Resin) Pipe and Fittings[78]
- ASTM D 3681 – Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe in a Deflected Condition[79]
- ASTM D 3839 – Practice for Underground Installation of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe[80]
- ASTM D 4814 – Specification for Automotive Spark—Ignition Engine Fuel[81]
- ASTM F 412 – Terminology Relating to Plastic Piping Systems[31]

Contractors and Manufacturers

A listing of manufacturers and contractors of cured-in-place lining installed by the inversion method is presented in Table 31.

Table 31. Listing of Manufacturers and Contractors of Cured-in-place Lining Installed by Inversion.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Advanced Pipe Inspection, Inc.	(617) 469-6062	(617) 469-3369	P.O. Box 120648 Boston, MA 02112	MA	Joe Walsh
Advanced Sewer Technology, Inc.	(888) 543-1664	(513) 944-4323	9337 Seward Rd. Fairfield, OH 45014	OH	N/A[2]
Allen Electric	(912) 764-9975	(912) 681-2970	P.O. Box 172 Statesboro, GA 30459	GA	Barney Allen
Amethyst Environmental, LTD.	(603) 659-4442	N/A	22 Lee Hill Rd. Lee, NH 03824	NH	Karen Long
Amy Plumbing, Heating & Cooling, Inc.	(847) 742-6523	(847) 742-6791	58 Kimball St. Elgin, IL 60120	IL	James Krenz
AquaLine Services LLC	(303) 684-9631	(303) 684-9631	1903 12th Ave. Longmont, CO 80501	CO	Jeff Anderson
Araco, Inc	(800) 654-0605	(508) 238-8067	920 Washington St. P.O. Box 314 S. Easton, MA 02375	MA, RI, NH, ME, VT, CT	N/A
Associated Products Services, Inc.	(800) 433-2070	(717) 766-4299	2 East Rd. P.O. Box 231 Mechanicsburg, PA 17055	PA	Bill Bonney
Atlantic Pipe Cleaning & Lining Company	(910) 362-0810	(910) 362-0820	4704 N. College Rd. Wilmington, NC 28429	NC	Dale Nichols
Azurix Underground Infrastructure	(800) 547-6193	(407) 260-9668	109 Applewood Dr. Longwood, FL 32750	FL, AL, GA, SC, ME, MA, NH, RI, VT	N/A
Bay Area Environmental Services, Inc.	(813) 677-7655	(813) 677-4457	P.O. Box 1720 Riverview, FL 33569	FL	N/A
Bio Remedies	(915) 590-0163	(915) 590-2228	P.O. Box 26966 El Paso, TX 79926	AZ, TX	Jerry Fannon
Boh Bros.	(800) 248-3377	(504) 821-0714	730 S. Tonti St. New Orleans, LA 70119	LA, MS	N/A
BRH-Garver, Inc.	(713) 921-2929	(713) 921-2487	5402 Lawndale Houston, TX 77023	TX	N/A
Brown Plumbing	(530) 244-7473	(530) 244-1000	3990 Railroad Ave. Redding, CA 96001	CA	Steve Poirier
Commercial Plumbing	(808) 845-4112	(808) 847-1865	1820 Colburn St. Honolulu, HI 96819	HI	Randal Hiraki
D & D, Inc.	(732) 222-6810	(732) 571-2158	2723 West Ave. Long Branch, NJ 07740	NJ	David Gizzi
D.R. Plumbing, Inc.	(412) 885-5300	(412) 885-5302	2526 Library Rd. Pittsburgh, PA 15234	PA	Donald Redinger
Dupree Sewer Service	(847) 746-6403	(847) 746-5972	11323 West 33rd St. Beach Park, IL 60099	IL	Doug Dupree
Dutch Enterprises, Inc.	(573) 243-3193	(573) 243-4370	4832 Old Cape Rd. East P.O. Box 438 Jackson, MO 63755	MO	Bill Bonney
Emergency Service Plumbing	(952) 920-2690	(952) 920-2881	622 Southeast 9th St. Minneapolis, MN 55414	MN	Larry Dawson
Enviro-Flow Companies	(740) 453-9935	(740) 453-8622	4830 North Pointe Dr. Zanesville, OH 43710	OH	Tim Evans
Enviro Pump Plus/Diagnostic Sewer	(507) 734-4661	N/A	1018 County Rd. 63 Balaton, MN 56115	MN	Glenn Larson
Green Bay Pipe & TV Contractors	(920) 490-5501	(920) 490-6242	1768 West Paulson Rd. Green Bay, WI 54313	WI, MI	Tom Debauche

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

Table 31 (cont.). Listing of Manufacturers and Contractors of Cured-in-place Lining Installed by Inversion.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Griner's Pipeline Services, Inc.	(352) 383-1222	(352) 383-6607	21902 State Rd. 46 Mount Dora, FL 32757	FL, GA	N/A[2]
The Groce Company, Inc.	(713) 941-2525	(713) 645-5900	P.O. Box 34605 Houston, TX 77234	TX	David Groce
Hall Albert	(817) 624-9391	(817) 625-2941	201 N.E. 29th St. Fort Worth, TX 76106	TX	Phillip Stephenson
Hytek Pipe Restoration	(800) 886-8434	N/A	3755 Avocado Blvd., Suite 202 La Mesa, CA 91941	CA	N/A
Insight Pipe Contracting	(724) 452-6060	(724) 452-3226	344 Little Creek Rd. Harmony, PA 16037	Western PA	Mike Marburger
Insituform Technologies, Inc. [1]	(800) 234-2992	(636) 519-8010	702 Spirit 40 Park Dr. Chesterfield, MO 63005	National	N/A
Jim Dandy Sewer Services, Inc	(206) 633-1141	(206) 784-2095	1327 N. Northlake Way Seattle, WA 98103	WA	Doug Harris
Kottke Underground Technologies, Inc.	(888) 664-4233	(541) 664-5417	P.O. Box 937 Medford, OR 97501	OR	N/A
McCann's Sewer and Drain Cleaning Service, Inc.	(608) 835-7797	(608) 835-2497	611 North Burr Oak Ave. Oregon, WI 53575	WI	Kelly McCann
Merlo, Inc.	(314) 581-7575	(314) 842-2216	33 Fox Meadows St. Louis, MO 63127	MO, IL	Steve Merlo
Mr. Rooter	(208) 772-3091	(208) 772-5187	P.O. Box 3364 Haden, ID 83835	WA, ID	Brian Wells
Naperville Plumbing, Inc.	(630) 355-1020	(630) 717-0171	455 Davey Rd. Lemont, IL 60439	IL	Mickey Mounts
National Envirotech Group, Inc. [1]	(800) 547-1235	(281) 874-0333	12707 N. Freeway, Suite 592 Houston, TX 77060	National	N/A
NO-DIG Pipeliners, LLC	(610) 384-9612	(610) 384-9615	P.O. Box 608 Downingtown, PA 19335	PA	Charlie Johnson
Northwest Plumbing Drain Station	(248) 615-1700	(248) 879-2942	1459 East 9 Mile Ferndale, MI 48220	MI	Joe Piscopo
Olthoff, Inc.	(708) 758-6540	(708) 758-1087	1800 East Joe Orr Chicago Heights, IL 60411	IL, IN	Dale Olthoff
Performance Liner National Sales	(407) 898-1091	(407) 898-1092	P.O. Box 547797 Orlando, FL 32854	National	Walter Huber
Performance Pipelining, Inc. [1]	(815) 433-1275	(815) 433-0107	1779 Chessie Lane Ottawa, IL 61350	National	N/A
Perma-Liner Industries, Inc. [1]	(727) 507-9749	(727) 507-9849	6196 126th Ave. North Largo, FL 33773	National	Jerry D'Hulster
Perma-Liner Mid Atlantic	(301) 353-1100	(301) 528-2809	26946 Ridge Rd. Damascus, MD 20872	MD	Jerry Shields
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
Pipeline Rehabilitation Services	(888) 588-8943	N/A	34145 Pacific Coast Hwy, Suite #351 Dana Point, CA 92629	CA	Steve Poirier
Plumber-Rooter	(800) 525-6295	(203) 857-4881	P.O. Box 546 Norwalk, CT 06852	CT, NY	Greg Cooper
Plummer's Environmental Services, Inc.	(616) 452-1313	(616) 452-1293	1518 Steele Ave., Southwest Grand Rapis, MI 49507	MI	Tom Gilder

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

Table 31 (cont.). Listing of Manufacturers and Contractors of Cured-in-place Lining Installed by Inversion.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Retro-Line Technologies	(321) 228-2246	(321) 228-2246	4850 South U.S. Hwy. 1 Grant, FL 32949	FL	Craig McEwen
Richards & Sons Plumbing	(916) 933-4199	N/A[2]	P.O. Box 5045 El Dorado Hills, CA 95762	CA	Ed Richards
Rinker Materials Pipeline Renewal	(800) 939-1277	(614) 529-6441	4143 Weaver Court Hilliard, OH 43026	Southern IL, IN, KY, MI, OH	N/A
Roche Plumbing & Heat-ing, Inc.	(970) 870-7922	(970) 870-6001	16 East Logan St. Steamboat Springs, CO 80477	CO	Ken Roche
Roy's Plumbing, Inc.	(716) 873-5000	(716) 877-7752	140 Cooper Ave. Tonawanda, NY 14150	NY	Mike Dooen-dorf
Sancon Engineering	(800) 726-2664	(714) 891-2524	5841 Engineering Dr. Huntington Beach, CA 92649	CA	Chuck Parsons
SewerTV	(714) 871-1414	(714) 871-1418	2316 East Amerige Fullerton, CA 92831	CA	Dave Flynn
Site Lines, Inc.	(517) 552-1367	(517) 552-1368	2681 Golf Club Dr. Howell, MI 48843	MI	Todd Summers
South Baldwin Plumbing	(334) 947-6246	(850) 478-4507	23790 US Hwy. 90 Robertsdale, AL 36567	AL, MS, FL	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
Southern Utilities, Inc.	(941) 574-2743	(941) 772-3045	2525 Southeast 19th Place Cape Coral, FL 33904	FL	Mike Angel
Southwest Pipeline	(888) 570-3534	N/A	225 W. Third St., Suite E. Long Beach, CA 90802	HI	N/A
Southwestern Packing & Seals	(800) 843-4950	(318) 687-4337	P.O. Box 19369 Shreveport, LA 71129	LA, TX	David Neath-ery
Spray Com, Inc.	(660) 826-0274	N/A	1620 West 14th St. Sedalia, MO 65301	MO	Gary Bartley
Stewart's De Rooting	(805) 965-8813	(805) 963-3095	208 Palm Ave. Santa Barbara, CA 93101	CA	Skip Stewart
Suncoast Infrastructure, Inc.	(901) 385-3863	(901) 266-0655	6376 Daybreak Dr. Bartlet, TN 38135	MS, LA, AR, FL, Southern AL	David Peaks
T-C, Inc.	(317) 542-9291	(317) 542-0352	973 N. Shadeland Av. #166 Indianapolis, IN 46219	IN, KY	Dennis Denney
Technical Inspections, Inc.	(954) 563-4233	(954) 563-5598	1098 Northeast 35th St. Oakland Park, FL 33334	FL	Pat Dean
Trenchless Rehabilitation Services	(610) 431-5973	(610) 431-5974	P.O. Box 836 West Chester, PA 19380	PA	Lou Anzalone
Tri-State Grouting	(302) 286-0701	(302) 286-0704	567 Walther Rd. Newark, DE 197024	DE, MD	Mark Schnei-der
Visu-Sewer	(800) 876-8478	(262) 695-2359	W230 N4855 Betker Rd. Pewaukee, WI 53072	Northern IL, IA, SD, ND, WI, MN	N/A
Walden Associated Tech-nologies, Inc.	(800) 495-6036	(618) 397-0098	7895 Saint Clair Ave. East St. Louis, IL 62203	IL, MO	Ken Walden
Wastewater Services, Inc.	(318) 335-4904	(318) 335-0157	P.O. Drawer 957 Oakdale, LA 71463	LA	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 Hous-ton
Young & Sons Enterprises	(801) 282-1806	(801) 280-7369	5276 West Legacy Hill Dr. West Jordan, UT 84084	UT	Jon Young
ZZ Liner, Inc.	(310) 329-8717	N/A	539 W. 140th St. Gardena, CA 90248	CA	N/A

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

Pulled-in-place Installation Method for Cured-in-place Lining

Description

Pulled-in-place installation method for cured-in-place lining uses a winch to pull a resin-impregnated tube through a deteriorated culvert. A calibration hose is then inserted into the center of the installed tube. Both the calibration hose and the resin-impregnated tube are attached to the vertical standpipe, or other apparatus, to create a leak-proof seal. Hydrostatic water pressure, or pressurized air/steam, is applied into the vertical standpipe, or apparatus, which forces the calibration hose to invert the resin-impregnated tube. As the liner is inverted, the resin allows it to attach and conform to the existing culvert walls. Once installed, the thermosetting resin is cured through heat provided by circulating hot water or steam. Figure 20 presents the pulled-in-place installation method.

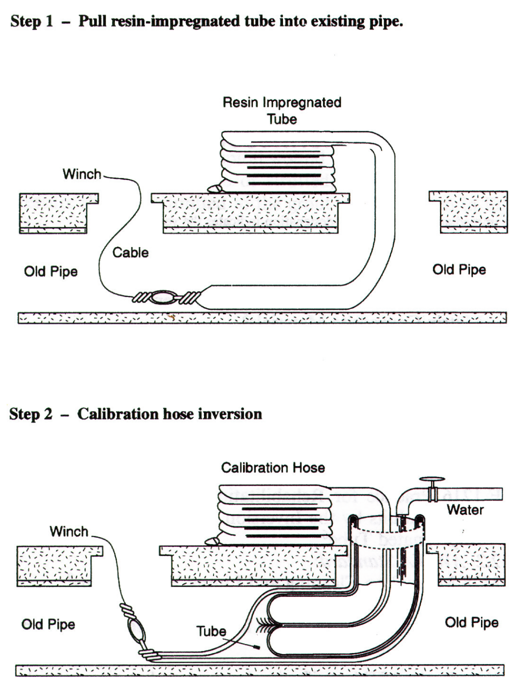


Figure 20. Drawing. Pulled-in-place Installation Method for Cured-in-place Lining.[82]

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of the pulled-in-place installation method for cured-in-place lining are presented in Table 32. Advantages and limitations associated with the pulled-in-place installation method for cured-in-place lining are presented in Table 33.

Table 32. General Characteristics and Effective Uses of the Pulled-in-place Installation Method for Cured-in-place Lining.[5,6]

Applications	Diameter Range	Liner Material	Maximum Installation
Gravity & Pressure Pipelines	100 - 1,400 millimeters (4 - 55 inches)	Thermoset Resin/ Fabric Composite	150 meters (492 feet)

Table 33. Advantages and Limitations of the Pulled-in-place Installation Method for Cured-in-place Lining.[5,6,7]

Advantages	Limitations
No joints	Flow bypass is required
Grouting is not normally required	Requires trained personnel to operate special equipment
Minimal or no reduction in flow capacity	Tubing must be specially constructed for each project
Minor or no excavation required	Lateral connections, service connections, and termination ends may require watertight sealing
Non-circular shapes can be accommodated	Resin requires a long time period to cure
	Liner lengths are limited by pull-in forces
	Styrene monomer-based resins used in making the liner are potentially toxic prior to completion of the curing process

Costs

According to the USFS Draft Report on trenchless technology for Forest Service culverts,[9] the range of costs for pulled-in-place installation method for cured-in-place lining is approximated to be $100 per linear foot for 45.7-centimeter (18-inch) diameter pipes and approximately $800 per linear foot or more for the largest diameters.

General Installation Guidelines

Installation guidelines for the pulled-in-place installation method for cured-in-place lining are presented below:[14,82]

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 Cured-in-place lining, such as protrusions, collapsed sections, deflected joints, etc.
4. Clear line obstructions discovered during the inspection before inserting the liner. Generally, most bend angles and changes in existing culvert diameter can be accommodated. If obstructions cannot be cleared, point repair excavation should be used to remove and repair the obstruction.
5. Completely impregnate the fabric tube with resin and run through a set of rollers separated by a space to properly distribute the resin. Apply a resin volume sufficient to fill all voids in the tube material and fully saturate all resin absorbing materials. Add 3% to 15% excess resin to the estimated volume to account for changes in resin volume due to polymerization and migration of resin into cracks and joints in the deteriorated culvert. Lubricate the calibration hose prior to installation. This can be achieved by applying lubricant to the fluid in the standpipe or by applying lubricant directly to the calibration hose.
6. Bypassing of flow is required, unless flow can be shut off during installation.
7. If the resin-impregnated tube is to be inverted utilizing air/steam pressure, perforate the impermeable plastic coasting of the resin-impregnated fabric. Perforating will allow resin to be forced against the inner wall of the calibration hose, permanently becoming part of the fabric tube.
8. Utilizing a power winch, pull the resin-impregnated tube through the deteriorated culvert.
9. If inverting the resin-impregnated tube with hydrostatic head, insert the calibration hose with the impermeable plastic membrane side out into the center of the resin-impregnated tube. At the lower end of the standpipe, turn the calibration hose inside out and attach both the calibration hose and the resin-impregnated tube to the standpipe, or other apparatus so that a watertight seal is created. Fill the standpipe with water, creating a sufficient head to cause the calibration hose to invert throughout the pipe, forcing the resin-impregnated tube to bond to the existing culvert.
10. If inverting the resin-impregnated tube with air/steam pressure, insert the calibration hose through the guide chute with the impermeable plastic membranes side out into the center of the resin-impregnated tube. Attach the calibration hose and resin-impregnated tube to the upper end of the chute so that a leak-proof seal is created. Obtain the minimum air/steam pressure needed to hold the tube tight against the existing culvert and the maximum allowable pressure from the manufacturer. Apply the appropriate air/steam pressure to cause the calibration hose to invert throughout the pipe, forcing the resin-impregnated tube to bond to the existing culvert.
11. After inversion is completed, circulate hot water or steam throughout the liner with approved equipment. Equipment should be suited with temperature gages and be capable of circulating the hot water or steam uniformly throughout the liner. The initial cure will occur during the heat-up process is completed when exposed portions of the liner appear to be hard and sound.

After initial cure, raise the temperature to the resin manufacturer's recommended post-cure temperature. Hold this temperature for the recommended period of time by recirculating the water or steam throughout the liner and heating apparatus. Maintain the recommended pressures throughout the curing process.

12. If heated water was used to cure the resin, drain the heated water from a small hole made in the downstream end and replace with the introduction of cool water into the inversion standpipe. Cool the liner to a temperature below 37.7°C (100°F) before relieving the static head in the inversion standpipe.
13. If air/steam was used to cure the resin, drain the air/steam through a small hole made in the downstream end and replace with the introduction of cool water in the guide chute. Cool the liner to a temperature below 43.3°C (110°F) before relieving the pressure within the section.
14. Cut and seal the termination ends with a resin mixture compatible with the installed liner if the liner does not fit tightly against the original pipe.
15. Inspect the completed installation by closed-circuit TV or manually if the diameter permits man-entry. The liner should be continuous over the entire length.
16. If leakage or other testing is required, perform testing to specifications and prior to the re-opening of lateral and service connections.
17. Reconnect lateral and service connections with a television camera and a remote- control cutting device or manually where the diameter permits man-entry.
18. Finally, restore flow and initiate site cleanup.

Standards/Specifications

Table 34 presents the current standards and specifications associated with the pulled-in-place installation method for cured-in-place lining.

Table 34. Standards Associated with the Pulled-in-place Installation Method for Cured-in-place Lining.[14,23]

Standard/Specification	Description
ASTM D 5813 – Standard Specification for Cured-In-Place Thermosetting Resin Sewer Pipe (1995)[73]	Covers specification, evaluation, and testing of materials used in the rehabilitation of existing pipes by the installation and cure of a resin-impregnated fabric liner.
ASTM F 1743 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Pulled-In-Place Installation of Cured-in-Place Thermosetting Resin Pipe (1996)[82]	Describes the procedures for the reconnection of pipelines and conduits by the pulled-in-place installation of a resin-impregnated, flexible fabric tube into an existing conduit and secondarily inflated through the inversion of a calibration hose by the use of hydrostatic head or air pressure.
NASSCO Specification for Cured-in-place Pipe (CIPP) (as provided by Lanzo Lining Services for the Inliner® Pull-In-Place process) (1999)[14]	Describes the specifications, design considerations, materials, equipment, and installation of CIPP installed by the pull-in-place process.

In addition to the two (2) specific ASTM standards presented in Table 34, the following list of related standards were also associated with the pulled-in-place installation method for cured-in-place lining:

- ASTM D 543 – Test Method for Resistance of Plastics to Chemical Reagents[25]
- ASTM D 638 – Test Method for Tensile Properties of Plastics[49]
- ASTM D 695 – Test Method for Compressive Properties of Rigid Plastics(2001)[74]
- ASTM D 790 – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[26]
- ASTM D 883 – Terminology Relating to Plastics[70]
- ASTM D 903 – Test Method for Peel or Stripping Strength of Adhesive Bonds[75]
- ASTM D 1600 – Terminology for Abbreviated Terms Relating to Plastics[27]
- ASTM D 1682 – Test Methods for Breaking Load and Elongation of Textile Fabric[76]
- ASTM D 3039 – Test Method for Tensile Properties of Fiber-Resin Composites[77]
- ASTM D 3567 – Practice for Determining Dimensions of "Fiberglass" (Class-Fiber-Thermosetting Resin) Pipe and Fittings[78]
- ASTM D 3681 – Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe in a Deflected Condition[79]
- ASTM D 4814 – Specification for Automotive Spark—Ignition Engine Fuel[81]
- ASTM F 412 – Terminology Relating to Plastic Piping Systems[31]
- ASTM F 1216 – Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube[72]

Contractors and Manufacturers

A listing of manufacturers and contractors of cured-in-place lining installed by the pulled-in-place method is presented in Table 35.

Table 35. Listing of Manufacturers and Contractors of Cured-in-place Lining Installed by the Pulled-in-place Method.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
CAT Contracting, Inc. [1]	(281) 449-5218	(281) 449-5234	5000 Askins Lane Houston, TX 77093	National	Art Kidder
Eckard Brandes, Inc.	(808) 486-0016	(808) 486-0042	98-030 Hekaha St., Suite 22 Aiea, HI 96701	N/A[2]	Jeff Higbee
E.E. Cruz, Inc.	(732) 946-9700	(732) 946-7592	Cruz Plaza Holmdel, NJ 07733	NJ, CT	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. *California Office*	(530) 406-1199	(530) 406-7991	1244 Wilson Way Woodland, CA 95695	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
Ground & Pipe Technologies	(334) 388-5640	(344) 264-8980	1120 Parker St. P.O. Box 9204 Montgomery, AL 36108	N/A	N/A
InfraCorps Technologies, Inc.	(804) 272-6600	(804) 272-1110	7400 Beaufont Springs, Suite 415 Richmond, VA 23225	N/A	Richard Herrick
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
Inliner Technologies[1]	(812) 723-0704	(812) 723-5998	1468 West Hospital Rd. Paoli, IN 47454	National	N/A
Kenny Construction Co.	(847) 541-8200	(847) 541-8838	250 Northgate Parkway Wheeling, IL 60090	IL	N/A
Lametti & Sons	(651) 426-1380	(651) 426-0044	16028 Forest Blvd. North Hugo, MN 55038	MN, NE, ND, SD, WI, IA	N/A
Lanzo Lining Services *Roseville, MI Office*	(810) 775-7566	(810) 775-2328	28135 Groesbeck Hwy. Roseville, MI 48066	N/A	N/A
Lanzo Lining Services *Detroit, MI Office*	(313) 965-8840	(313) 961-6769	65 Cadillac Tower, Suite 2200 Detroit, MI 48226	N/A	N/A
Lanzo Lining Services *Pompano Beach, FL Office*	(954) 979-0802	(954) 979-9897	1900 N.W. 44th St. Pompano Beach, FL 33064	N/A	N/A
Lanzo Lining Services *Miami, FL Office*	(305) 663-5559	(305) 663-9515	4659 Ponce De Leon Blvd., Ste. 301 Coral Gables, FL 33146	N/A	N/A
Masterliner Incorporated[1]	(888) 344-3733	(985) 386-0250	42305 South Airport Rd. Hammond, LA 70403	National	N/A
Pacific Rehab Construction	(907) 272-3000	(907) 272-3004	P.O. Box 230628 Anchorage, AK 99523	N/A	Ken Ihde
Reynolds Inliner, LLC	(812) 865-3232	(812) 865-3075	4520 N. State Rd. 37 Orleans, IN 47452	IN, FL, GA, KY, LA, TN, MS, NC SC, OH, TX, WV	N/A
S.O.S. Construction	(305) 477-6847	(305) 477-6745	2909 N.W. 82nd Ave. Miami, FL 33122	N/A	Ray Sanchez
Southeast Pipe Survey[1]	(912) 647-2847	(912) 647-2869	3523 Williams St. Patterson, GA 31557	AL, FL, GA, NC, SC, TN	N/A
Western Slope Utilities	(970) 453-6176	(970) 453-4044	P.O. Box 2098 68 Continental Ct. Suite B-8 Breckenridge, CO 80424	AZ, CO, NM, UT, WY	N/A

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

SPRAY-ON LINING

Spray-on lining techniques are used to protect existing culverts from corrosion and repair small point leaks. For man-entry culverts, reinforced sprayed mortars can effectively be used. Non-man entry culverts require the lining to be applied with a centrifugal lining machine. Lining material is pumped to the high-speed, rotating application head of the centrifugal lining machine. As the machine moves through the culvert, a uniform thickness liner is applied. Cement-mortar lining and epoxy lining are the two (2) most common spray-on lining techniques.

Cement-mortar Spray-on Lining

Description

Cement-mortar spray-on liners are usually applied to existing steel and iron culverts to provide protection against corrosion. Lining is applied by the rotating head of an electric or air-powered machine. Mortar is supplied to the machine through a system of high-pressure hoses or by other mechanical means. A uniform thickness liner is applied as the machine moves through the existing culvert at a constant speed. Thus, the thickness of the liner applied is directly related to the speed at which the machine moves. After the liner has been applied, rotating or conical drag trowels provided a smooth troweled finish. Figure 21 presents a finished installation of cement-mortar spray-on lining. Unless reinforced, cement-mortar spray-on lining adds little or no structural integrity to the existing culvert. Reinforced cement-mortar spray-on lining is limited to man-entry culverts. Installations are limited by pipe diameter, valve locations, bends, and length of supply hose.

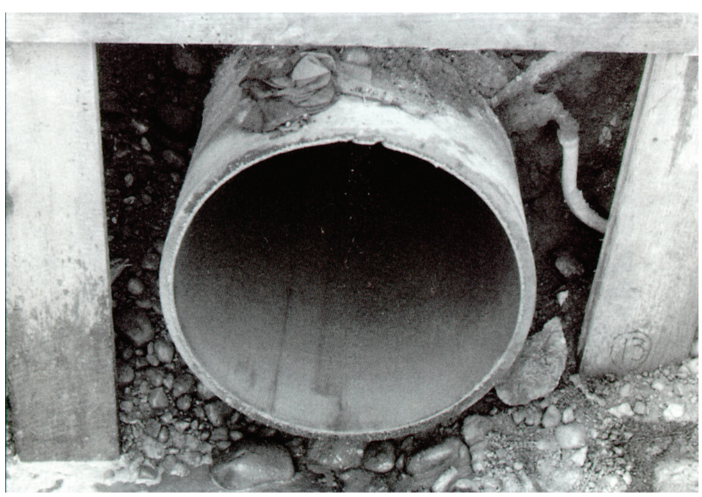


Figure 21. Photo. Completed Installation of Cement-mortar Spray-on Lining.[8]

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of cement-mortar spray-on lining are presented in Table 36. Advantages and limitations associated with cement-mortar spray-on lining are presented in Table 37.

Table 36. General Characteristics and Effective Uses of Cement-mortar Spray-on Lining.(5,8,83)

Applications	Diameter Range	Liner Material	Maximum Installation
Gravity & Pressure Pipelines	76 - 4,500 millimeters (3 - 177 inches)	Cement-mortar	450 meters (1,476 feet)

Table 37. Advantages and Limitations of Cement-mortar Spray-on Lining.(5,8,83)

Advantages	Limitations
Does not block lateral and service connections	Flow bypass is required
	Existing culvert must be dry prior to applying the cement-mortar
Protects against corrosion	Long curing time (up to seven days)
	Possible reduction in flow capacity
Reinforcement can be used	Generally does not enhance the structural integrity of the existing pipe
	It has been observed in steep terrain that it is difficult to maintain a constant rate of speed through the culvert while applying the lining, which results in the liner being sprayed on too thin (would crack off later during curing) or too thick (slump or tear off due to gravity)

Costs

Currently, the only cost information available from the gathered literature sources was extracted from case studies. Specific case study costs are presented as follows.

Water Main Cleaning and Lining – A Utility Perspective by Mac Ewen and Naef (1988)[84] presented a case study on the rehabilitation of water mains with cement-mortar spray-on lining. The cast iron water mains had lost significant hydraulic capacity due to corrosion and the build up of mineral deposits (tuberculation). Rehabilitation procedures took place over a thirteen (13) year period (1974 through 1987) with cleaning and lining costs ranging from approximately $7.50 to $25.00 per linear foot. Note that these costs were reported for 1974 through 1987 and have not been adjusted to include inflation.

General Installation Guidelines

A general list of installation guidelines for cement-mortar spray-on lining is provided below:(8,83)

1. Inspect the existing culvert to determine the location of bends, in-line valves, changes in diameter and other discontinuities. Remove all 22.5°, 45°, and 90° bends for 30.5-centimeter (2-inch) diameter pipe and smaller and 45° and 90° bends for 40.6-centimeter (16-inch) diameter pipe.
2. Shut off or bypass the flow to dewater the culvert. Clean and inspect the culvert for leaking valves. Allow the culvert to completely dry prior to lining.
3. Place the lining machine into the culvert to be lined. Obtain the pre-mixed cement-mortar from a mixing van or nearby concrete plant.
4. Immediately prior to lining, remove all foreign material, including sand and loose debris that might have accumulated after the initial cleaning.
5. If the deteriorated culvert is not sufficient to allow man-entry, use a remote- or winch-powered lining machine similar to that illustrated in Figure 22. Supply cement-mortar to the machine through high-pressure hoses. Uniformly apply the cement mortar by ensuring the machine travels through the system at a constant rate.

Figure 22. Photo. Lining Machine for Non-man Entry Culverts.(8)

6. If deteriorated culvert is large enough to permit man entry, use a remote- or man-operated machine. A man-operated lining machine is pictured in Figure 23. For pipe twenty-four (24) inches in diameter and larger, temporarily cover or plug all openings in the existing culvert, such as manholes, lateral connections, and service connections, before lining. Supply cement-mortar through high-pressure hoses or by other mechanical means if the machine is man operated. Uniformly apply the cement mortar by ensuring the machine travels through the system at a constant rate.

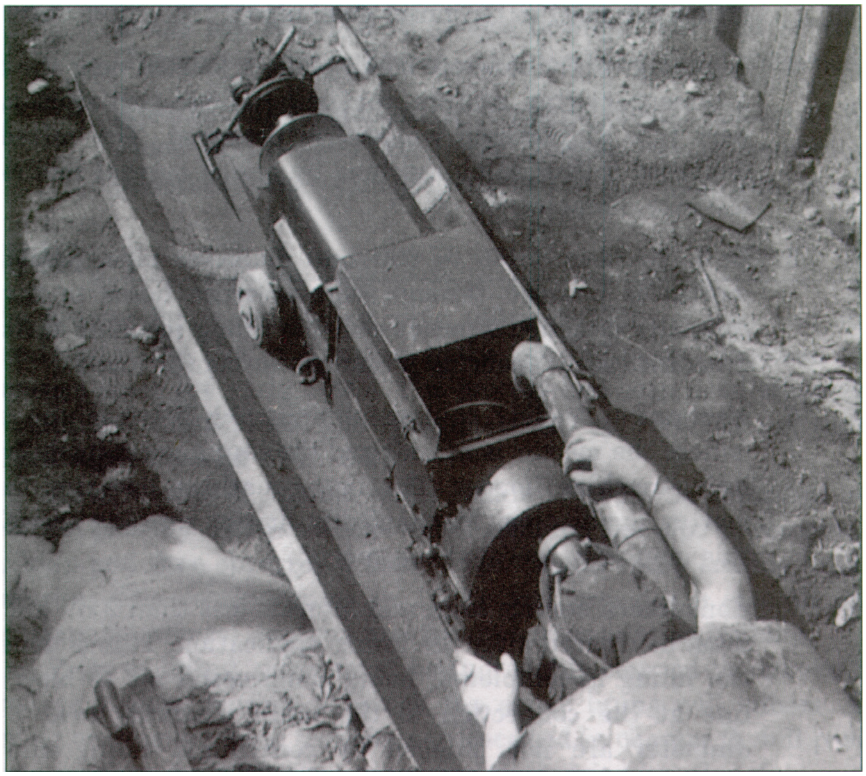


Figure 23. Photo. Lining Machine for Man Entry Culverts.[(8)]

7. Troweling of the newly applied cement-mortar should be done mechanically with either rotating trowels or a conical drag trowel attached to the lining machine. Hand place cement-mortar and trowel in places where machine lining is impractical (such as sharp bends and areas closely adjacent to valves).
8. Cap and cure the newly lined culvert with non-pressurized water immediately after lining operations have been completed. Allow cure to continue until accepted by the user, but no longer than seven (7) days.

9. If the newly cement-mortar lined pipe was less than 61 centimeters (24 inches) in diameter, clear lateral and service connections measuring 5 centimeters (2 inches) in diameter or less by back flushing with air or water before the final set of the cement occurs.
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 testing or chlorination are required, perform operations to specifications.
12. Finally, restore flow and initiate site cleanup.

Standards/Specifications

Table 38 presents the current standards and specifications associated with cement-mortar spray-on lining.

Table 38. Standards Associated with Cement-mortar Spray-on Lining.[8,83]

Standard/Specification	Description
AWWA C602 – Standard for Cement-Mortar Lining of water Pipelines in Place-4 in (100 mm) and Larger (2000)[85]	Describes the specifications, design considerations, materials, equipment, and installation method for cement-mortar spray-on lining of existing pipelines
AWWA M28 – Rehabilitation of Water Mains (2001)[8]	Provides common operating procedures used when lining a pipe with nonstructural cement-mortar

In addition to the two (2) standards presented in Table 38, the following American Water Works Association (AWWA) standard was also associated with cement-mortar spray-on lining:

- AWWA C205 – Cement-Mortar Protective Lining and Coating for Steel Water Pipe – 4 in. (100 mm) and Larger – Shop Applied[7]

Contractors and Manufacturers

A listing of manufacturers and contractors of cement-mortar spray-on lining is presented in Table 39.

Table 39. Listing of Manufacturers and Contractors of Cement-mortar Spray-on Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
A.P. Construction, Inc. *New Jersey Office*	(856) 227-2030	(856) 227-2273	915 S. Black Horse Pike Blackwood, NJ 08012	N/A[2]	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
ARB Inc. [1]	(800) 622-2699	(949) 454-7190	26000 Commercentre Dr. Lake Forest, CA 92630	National	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
Cement Lining Company, Inc.	(713) 840-0415	(713) 840-1319	Five Greenway Plaza Suite 1775 Houston, TX 77046	N/A	N/A
Spiniello Companies *Eastern Operations*	(973) 539-6363	(973) 539-4802	35 Airport Rd. Morristown, NJ 07962	N/A	N/A
Spiniello Companies *Western Division*	(562) 903-8888	(562) 903-8869	13241 Lakeland Rd. Santa Fe Springs, CA 90670	N/A	N/A
W. Walsh Company, Inc.	(508) 226-4300	(508) 266-8449	32 Walton St. Attleboro, MA 02703	N/A	N/A

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

Epoxy Spray-on Lining

Description

Epoxy spray-on lining systems are effectively used to line potable water systems. Similar to cement-mortar spray-on lining, epoxy spray-on lining requires the use of a specialized machine for lining. At a constant rate of speed, the applicator head and supply hoses are pulled through the existing culvert, while centrifugally applying a uniform thickness (minimum of one (1) mm) of epoxy. After the lining is applied, curing begins and continues for approximately sixteen (16) hours.

Effective Uses, Advantages, and Limitations

General characteristics and effective uses of epoxy spray-on lining are presented in Table 40. Advantages and limitations associated with epoxy spray-on lining are presented in Table 41.

Table 40. General Characteristics and Effective Uses of Epoxy Spray-on Lining.[5,8]

Applications	Diameter Range	Liner Material	Maximum Installation
Gravity & Pressure Pipelines	76 - 4,500 millimeters (3 - 177 inches)	Epoxy	450 meters (137 feet)

Table 41. Advantages and Limitations of Epoxy Spray-on Lining.[5,8]

Advantages	Limitations
Does not block lateral and service connections	Flow bypass is required
	Existing culvert must be dry prior to applying the epoxy
	Possible reduction in flow capacity
Protects against corrosion	Generally does not enhance the structural integrity of the existing pipe

Costs

No literature sources were acquired that detailed the general costs associated with epoxy spray-on lining.

General Installation Guidelines

The following provides a general list of installation guidelines for epoxy spray-on lining:[8,83]

1. Inspect the existing culvert to determine the location of bends, in-line valves, changes in diameter, and other discontinuities.
2. Shut off or bypass the flow to dewater the culvert. Clean and inspect the culvert for leaking valves. Allow the culvert to completely dry prior to lining.
3. Check equipment used to pump and mix the epoxy. Prior to inserting delivery hoses into the culvert, pump and recirculate the epoxy until the temperature specified by the manufacturer is reached.
4. Insert the lining machine into the deteriorated culvert and connect supply hoses. Before the initiation of lining, visually test the epoxy material by test spraying the epoxy onto a test card. A typical epoxy-lining application head is presented in Figure 24.

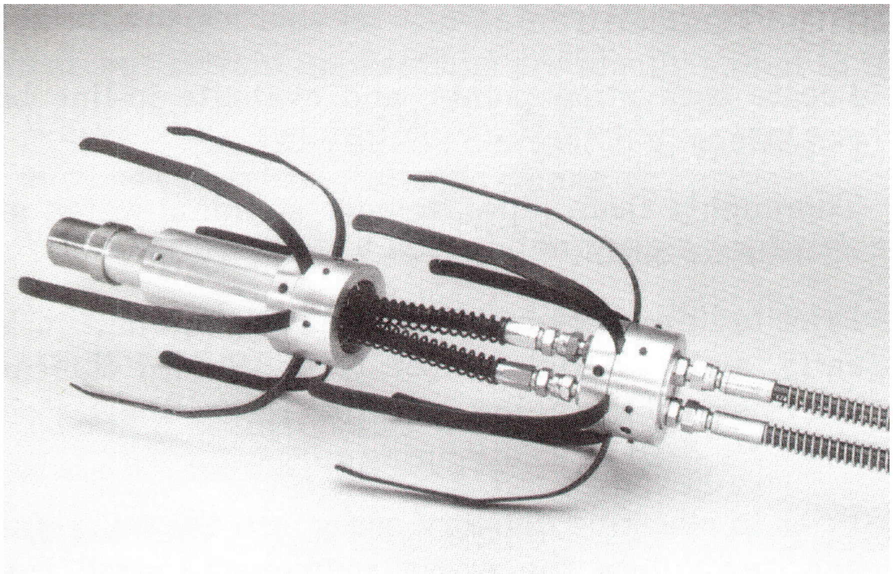


Figure 24. Photo. Typical Epoxy Application Head.[8]

5. Begin lining the deteriorated culvert. Closely monitor the winch speed and the rate of supply hose withdrawal. The lining machine should be pulled at a constant and slow enough speed to produce a uniform and minimum epoxy liner thickness of one (1) millimeter. Epoxy lining should only be applied to culverts with temperatures above 3.33°C (38°F).
6. Cap and cure the newly lined culvert immediately after lining operations have been completed. Allow cure to continue for a minimum of sixteen (16) hours or as specified by the manufacturer.
7. 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.
8. If testing or chlorination is required, perform operations to specifications.
9. Finally, restore flow and initiate site cleanup.

Standards/Specifications

Table 42 presents the current standard associated with epoxy spray-on lining.

Table 42. Standard Associated with Epoxy Lining.[8]

Standard/Specification	Description
AWWA M28 - Rehabilitation of Water Mains (2001)[8]	Provides common operating procedures used when lining a pipe with nonstructural epoxy

Contractors and Manufacturers

A listing of manufacturers and contractors of epoxy spray-on lining are presented in Table 43.

Table 43. Listing of Manufacturers and Contractors of Epoxy Spray-on Lining.

Manufacturer/ Contractor	Telephone Number	Fax Number	Address	Coverage Area	Contact Person
Ground & Pipe Technologies	(334) 388-5640	(344) 264-8980	1120 Parker St. P.O. Box 9204 Montgomery, AL 36108	N/A[2]	N/A
PIM Corporation	(800) 293-6224	(732) 469-8959	201 Circle Dr. No. Suite 106 Piscataway, NJ 08854	N/A	N/A
Raymond International, Inc. [1]	(562) 923-9600	N/A	9603 John St. Santa Fe Springs, CA 90670	National	N/A

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

CHAPTER 4 – SURVEY RESULTS

GENERAL INFORMATION RESULTS

Completed surveys were collected and compiled for analysis (refer to Appendix B for the informational survey format). Out of the one hundred (100) State and Federal agency personnel contacted to participate in the informational survey, thirty (30) responded. Agencies who responded are listed in Appendix C and summaries of their responses are presented in Appendix D. Analysis of the thirty (30) returned surveys showed that two-thirds (20 respondents) had previously been involved with the design or installation of culvert pipe liners, while one-third (10 respondents) indicated that they had no previous experience with culvert pipe liners. Agencies that had previously been involved with the design and installation of culvert pipe liners were asked to provide the year they became familiar with using lining techniques for rehabilitation purposes. Survey results indicated that the average year agencies became familiar with lining techniques was around 1990, with 1980 being the earliest year. This indicates that the majority of surveyed agencies have been utilizing lining techniques for at least the past decade. Table 44 presents a summary of the State and Federal agencies that responded to the informational survey, as well as those who had previous knowledge or experience with pipe liners.

Table 44. Summary of Personnel Responding to Informational Survey.

General Survey Analysis	
Number of Personnel Contacted	100
Number of Personnel Responded	30
Percent Responded	30%

Analysis of Respondents			
Agency[1]	**Respondents With Prior Design or Installation Experience**	**Respondents With No Prior Design or Installation Experience**	**Total Number of Respondents Per Agency**
BLM	0	1	1
BOR	1	0	1
CORP	0	1	1
DOT	14	6	20
USFS	4	1	5
NPS	1	1	2
Column Totals	**20**	**10**	**30**

[1] BOR – Bureau of Reclamation, CORP – Corporation, NPS – National Park Service

Responses were compiled from the specific data provided by the agencies that had previously been involved with the design and installation of culvert pipe liners. Agencies were asked to identify which types of liners (refer to Appendix B for the lining methods as defined in the informational survey) they had previously designed or installed, as well as the total approximate length of pipe lined with each liner. Total approximate lengths obtained from each agency were categorized according to lining method and combined with the lengths provided from all other agencies in corresponding categories. Results indicated that sliplining was by far the most used method (80.5%) of those responding to the survey. However, several agencies indicated that sliplining was the only lining method they were familiar with or had previously used. Spray-on lining was the second most used method (13.0%), while methods not defined in the survey (Other) and the cured-in-place pipe lining method were the third (4.0%) and fourth (1.6%) most used methods, respectively. Agencies who provided information for the "Other" category were most often referring to paving the culvert invert as an alternative rehabilitation method. Close-fit lining and spirally wound lining were the methods used the least to rehabilitate deteriorated pipes (0.7% and 0.2%, respectively). Since some agencies provided information for more than one lining method, the total number of respondents providing data for each method was also computed. Table 45 provides a categorized summary of total approximate lengths of pipe lined by all agencies and the number of respondents used to compute the total lengths.

Table 45. Categorized Summary of Total Approximate Lengths of Pipe Lined by All Agencies.

Number of Respondents	19

Lining Method	**Approximate Total Length**	**Percent of Total**	**Number of Respondents**
Sliplining	45.4 kilometers (149,025 feet)	80.5%	14
Spray-on lining	7.4 kilometers (24,120 feet)	13.0%	3
Other[1]	2.2 kilometers (7,300 feet)	4.0%	4
Cured-in-place lining	908 meters (2,980 feet)	1.6%	6
Close-fit lining	380 meters (1245 feet)	0.7%	4
Spirally wound lining	137 meters (450 feet)	0.2%	2
Column Totals	**56.4 kilometers (185,120 feet)**	**100%**	**33**

[1]Indicates a method that does not fall into the predefined categories

Respondents were asked to provide any standards, specifications, and guidelines used in the design and installation of pipe liners. Standards, specifications, and guidelines were categorized into the following: ASTM, Government/State, Manufacturers, Owner Agencies, and Other Organizations. Sources of information gathered regarding standards, specifications, and guidelines were compiled and are presented in Table 46. Table 46 indicates that several ASTM and manufacturer standards are used during the design and installation process. Additionally, Table 46 suggests that several State DOTs have developed their own standards, which demonstrates the need for the development of a national standard for use by Federal and State agencies.

Table 46. Summary of Sources of Information for Standards, Specifications, and Guidelines for Culvert Liners.

Category	Standard/Specification/Guideline
ASTM	ASTM A 615 – Standard Specification for Deformed and Plain Billet Steel Bars for Concrete Reinforcement(86)
	ASTM C 94 – Standard Specification for Ready-Mixed Concrete(87)
	ASTM C 150 – Standard Specification for Portland Cement
	ASTM C 260 – Air Entraining Admixtures for Concrete(88)
	ASTM C 494 – Standard Specification for Chemical Admixture for Concrete(89)
	ASTM C 618 – Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
	ASTM C 796 – Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam(90)
	ASTM C 869 –Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete(91)
	ASTM D 256 – Test Method for Determining the Pendulum Impact Resistance of Notched Specimens of Plastics(92)
	ASTM D 638[1] – Test Method for Tensile Properties of Plastics
	ASTM D 790[1] – Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
	ASTM D 1248 – Specification for Polyethylene Plastic Molding and Extrusion Material(93)
	ASTM D 1784[1] – Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
	ASTM D 2122[1] – Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
	ASTM D 2152[1] – Test Method for Degree of Fusion of Extruded Poly(Vinyl Chloride) (PVC) Pipe and Molded Fittings by Acetone Immersion
	ASTM D 2321 – Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications(94)
	ASTM D 2412[1] –Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
	ASTM D 2417 – Specification for Perforated, Laminated Wall Bituminized Fiber Pipe for General Drainage(95)
	ASTM D 2444[1] – Test Method for Impact Resistance of Thermoplastic Pipe and Fittings be Means of a Tup (Falling Weight)
	ASTM D 2584 – Standard Test Method for Ignition Loss of Cured Reinforced Resins(96)
	ASTM D 2657[1] –Practice for Heat-Joining of Polyolefin Pipe and Fittings
	ASTM D 3212[1] – Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
	ASTM D 3350[1] – Specification for Polyethylene Plastics Pipe and Fittings Materials

Table 46 (cont.). Summary of Sources of Information for Standards, Specifications, and Guidelines for Culvert Liners.

Category	Standard/Specification/Guideline
ASTM (cont.)	ASTM D 5260 – Standard Classification for Chemical Resistance of Poly(Vinyl Chloride) (PVC) Homopolymer and Copolymer Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds(97)
	ASTM D 5813[1] – Standard Specification for Cured-In-Place Thermosetting Resin Sewer Pipe
	ASTM F 585[1] – Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers
	ASTM F 714[1] – Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
	ASTM F 894[1] – Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe
	ASTM F 949 – Standard Specification for Poly(Vinyl Chloride) (PVC) Corrugated Sewer Pipe With a Smooth Interior and Fittings(98)
	ASTM F 1216[1] – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
	ASTM F 1504[1] – Standard Specification for Folded Poly(Vinyl Chloride) (PVC) Pipe for Existing Sewer and Conduit Rehabilitation
	ASTM F 1697[1] – Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for Machine Spiral-Wound Liner Pipe Rehabilitation of Existing Sewers and Conduit
	ASTM F 1698[1] – Standard Practice for Installation of Poly(Vinyl Chloride) (PVC) Profile Strip Liner and Cementitious Grout for Rehabilitation of Existing Man-Entry Sewers and Conduits
	ASTM F 1743 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe
	ASTM F 1803 – Standard Specification for Poly (Vinyl Chloride) (PVC) Closed Profile Gravity Pipe and Fittings Based on Controlled Inside Diameter(99)
Government	FHWA Culvert Repair Practices Manual (1995) [1]
	FHWA FP-96 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects[1]
	BOR Specification Paragraphs
Manufacturer	Advanced Drainage Systems, Inc. (ADS)
	Broad Cove Associates
	CPChem™ Performance Pipe (Plexco®, Spirolite™, and DriscoPlex™)[1]
	Contech Construction Products, Inc.
	Danby™ of North America[1]
	Environmental Pipeliners, Inc.[1]
	Fusion Seal Corporation
	Hancor
	Hawkeye Tile
	Hobas Pipe USA, Inc.[1]
	Insituform® Technologies, Inc.[1]
	ISCO Industries, LLC (Snap-Tite®)[1]

Table 46 (cont.). Summary of Sources of Information for Standards, Specifications, and Guidelines for Culvert Liners.

Category	Standard/Specification/Guideline
Manufacturer (cont.)	KHW Pipe (Sclairpipe® and Weholite)
	Lane Enterprises, Inc.
	Lanzo Lining Services[1]
	Metal Culverts, Inc.
	National Envirotech Group, LLC[1]
	Phillips
	Pipe Liners, Inc. (U-Liner®)[1]
	Pipelining Products, Inc. (Sure-Line Pipe® and Cure-Line Pipe®)[1]
	Plexco
	Poly Profiles Technology, Inc. [1]
	PSI
	Rib Loc® Group Limited[1]
	S.O.S. Construction[1]
	Spiniello Companies[1]
	Tompson Culverts
	Ultraliner™ Inc. [1]
Owner Agencies (cont.)	Caltrans[2] Culvert Restoration Techniques Insituform
	Caltrans Design Information Bulletin No. 76 - Culvert Rehabilitation Using Plastic Liners[1]
	Caltrans Study #F90Tl15 - Culvert Restoration Techniques
	Colorado DOT Specifications
	U.S. Forest Service Specifications
	Maryland DOT Specifications
	Michigan DOT Specifications
	Missouri DOT Specifications
	Montana DOT Specifications
	New Hampshire DOT Specifications
	Ohio DOT Specifications
	Southern California Greenbook
	Vermont DOT Specifications
Other Organizations	AWWA M11 Steel Pipe – A Guide for Design and Installation
	WRc Sewerage Rehabilitation Manual 4th Edition
	PPI Guidance and Recommendations on the Use of Polyethylene Pipe for the Sliplining of Sewers[1]

[1]Designates those Standards/Specifications/Guidelines obtained by CSU personnel prior to distribution of informational survey,
[2]California Department of Transportation

A series of questions was also presented for respondents to provide personal opinions and information regarding pipelining techniques. Questions that were asked included: “Which types of pipe liners have proven to be easiest to install, most successful, most unsuccessful, most expensive, and least expensive?” Responses showed that sliplining was overwhelmingly the respondents’ choice for easiest to install, most successful, and least expensive. Survey results also suggested that the most expensive lining technique was cured-in-place lining. Table 47 presents the results of the subjective questions asked in the survey. It should be noted that not all respondents provided answers for each question, while other respondents provided multiple answers for some questions.

Table 47. Results of Subjective Questions.

Question: "Which Liners Were Easiest to Install?"	
Number of Personnel Responding to Question: 18	
Lining Method	**Total Number of Answers Received**
Sliplining	14
Other	2
Spirally wound lining	1
Cured-in-place lining	1
Spray-on lining	1
All	1
Close-fit lining	0
Column Total	**20**

Question: "Which Liners Were Most Successful?"	
Number of Personnel Responding to Question: 18	
Lining Method	**Total Number of Answers Received**
Sliplining	15
Cured-in-place lining	2
Spray-on lining	2
Close-fit lining	1
Other	1
All	1
Spirally wound lining	0
Column Total	**22**

Table 47 (cont.). Results of Subjective Questions.

Question: "Which Liners Were Most Unsuccessful?"	
Number of Personnel Responding to Question: 9	
Lining Method	**Total Number of Answers Received**
Sliplining	3
Spirally wound lining	2
Other	2
None	2
Close-fit lining	1
Cured-in-place lining	1
Spray-on lining	0
Column Total	**11**

Question: "Which Liners Were Most Expensive?"	
Number of Personnel Responding to Question: 13	
Lining Method	**Total Number of Answers Received**
Cured-in-place lining	7
Sliplining	3
Other	2
Spray-on lining	1
Close-fit lining	0
Spirally wound lining	0
Column Total	**13**

Question: "Which Liners Were Least Expensive?"	
Number of Personnel Responding to Question: 12	
Lining Method	**Total Number of Answers Received**
Sliplining	8
Other	4
Spray-on lining	1
Close-fit lining	0
Spirally wound lining	0
Cured-in-place lining	0
Column Total	**13**

Agency personnel were finally asked if they could provide the project team with average costs, design life criteria, maintenance procedures, and environmental issues associated with each of the lining methods. Responses indicated that average costs can vary widely and are dependent upon the size of liner and type of material used. Sliplining and close-fit lining had similar average price ranges. Spirally wound lining and cured-in-place lining were also similar in cost and had the highest average cost of all lining methods. Costs for spray-on lining and "Other" (specifically paving the invert) were reported in dollars per square foot. The average price ranges for each lining method are presented in Table 48.

Table 48. Average Price Range for Each Lining Method.

Number of Respondents	8

Lining Method	Average Price Range			
	Per Linear Meter	Per Square Meter	Per Linear Foot	Per Square Foot
Sliplining	$82 to $656		$25 to $200	
Close-fit lining	$164 to $394		$50 to $120	
Spirally wound lining	$984		$300	
Cured-in-place lining	$984		$300	
Spray-on lining		$108 to $269		$10 to $25
Other		$161 to $323		$15 to $30

Additionally, four (4) respondents provided information regarding the design life of the lining techniques. Generally, design life of all lining methods was determined to be within the range of 10 to 50 years. Agencies who responded, commented that design life was dependent upon may factors, such as but not limited to, water quality, environmental conditions, corrosion resistance, and liner thickness.

Only three (3) respondents indicated that their agency has or uses standard maintenance procedures for culvert pipe liners. This demonstrates the need to develop standard maintenance procedures once a pipe has been lined.

Two environmental issues were provided by several respondents to the survey. The first issue was associated with the cured-in-place lining technique. In this method, water or steam is used to heat and cure the liner to create a strong bond between the host pipe and the liner. Due to the chemicals and resins used in this process, this installation method may be hazardous to an environmentally sensitive area. Fish passage through newly lined pipes was mentioned as the second environmental issue. Often times, the velocities in a newly lined pipe will increase due to the smooth surface of the liner, thereby inhibiting fish passage.

PROJECT SPECIFIC RESULTS

In addition to the results obtained from the general information section of the survey, as previously discussed, respondents were asked if they could provide any project-specific information associated with documented case studies. In total, eight (8) project-specific case studies were provided by the respondents and are listed in Table 49.

Table 49. Summary of Eight Project-specific Case Studies Provided by the Respondents.

	Case Study Provided by:							
	Maryland State Highway Administration	**Michigan DOT**	**Oregon DOT**	**Vermont Agency of Transportation, Maintenance & Aviation Division**	**USFS in Cass Lake, Minnesota**	**USFS (Ottawa National Forest) in Ironwood, Michigan**	**USFS in Cleveland, Tennessee**	**NPS (Pacific West Region) in Oakland, California**
Project name	Not submitted	I-96	Foster Reservoir Culvert	Brighton Culvert Relining (VT 105, BR 90)	Forest Road 2171 Third River Road	Paulding Creek Dam Repair	Peavine-Sheeds Creek Road	Point Reyes National Seashore
Project description	Paving the invert of 52 small structures	Lining of 61 meters (200 feet) of 107-centimeter (42-inch) deteriorated corrugated metal pipe	Lining of 85.4 meters (280 feet) of 76-centimeter (30-inch) deteriorated corrugated metal pipe	Lining 25 meters (82 feet) of 213-centimeter (84-inch) deteriorated corrugated metal pipe	Bituminous overlay and culvert rehabilitation	Lining existing 1.2-meter (48-inch) corrugated metal spillway pipe	Lining two existing 45.7-centimeter (18-inch) deteriorated corrugated metal pipe	Lining existing 30.5- to 45.7-centimeter (12-to18-inch) deteriorated corrugated metal pipe
Type of liner used	Spray-on lining	Cured-in-place lining	Continuous sliplining utilizing 12-meter (40-foot) segments fusion welded together	Sliplining	Sliplining	Sliplining	Sliplining	Close-fit lining
Time to complete installation	1 year	Not submitted	5 days	25 days	10 days	16 to 24 hours	2 days	5 days
Year project was completed	2002	1998	2002	2002	2002	2002	2000	2001
Cost of project	$2,000,000	approximately $100,000	$45,000	$70,460	$350,000	approximately $25,000	$2,700	$30,000
Length of pipe lined	3.5 kilometers (11,500 feet)	61 meters (200 feet)	85.4 meters (280 feet)	25 meters (82 feet)	236.3 meters (775 feet)	14.6 meters (48 feet)	27 meters (90 feet)	152 meters (500 feet)

Table 49 (cont.). Summary of Eight Project-specific Case Studies Provided by the Respondents.

	Case Study Provided by:							
	Maryland State Highway Administration	**Michigan DOT**	**Oregon DOT**	**Vermont Agency of Transportation, Maintenance & Aviation Division**	**USFS in Cass Lake, Minnesota**	**USFS (Ottawa National Forest) in Ironwood, Michigan**	**USFS in Cleveland, Tennessee**	**NPS (Pacific West Region) in Oakland, California**
Original size of pipe lined	Not submitted	107-centimeter (42-inch)	76-centimeter (30-inch)	213-centimeter (84-inch)	38-centimeter (15-inch)	1.2-meter (48-inch)	45.7-centimeter (18-inch)	30.5 to 45.7-centimeter (12- to 18-inch)
Material of pipe lined	Concrete	Corrugated metal pipe	Corrugated metal pipe	Corrugated metal pipe	Corrugated metal pipe	Corrugated metal pipe	Corrugated metal pipe	Corrugated metal pipe
Other lining methods proposed	Sliplining, spirally wound lining, and other	None	Spirally wound lining and cured-in-place lining	None	None	Not submitted	None	Sliplining, spirally wound lining, and cured-in-place lining
Deciding factor for choosing the liner used in project	Cost	Not applicable	Cost: Sliplining was the most cost effective and grouting was necessary to fill the voids surrounding the deteriorated pipe	Not applicable	Availability, cost, and the contractors ability to install it	Not submitted	Availability and type of installation	Amount of diameter reduction and cost
How the liner has performed	So far so good	Not submitted	As expected	Liner has only been in service a few months	So far, so good	Liner has only been in service for a little under a year	Good	So far, fine

SUMMARY

In December of 2002, CSU sent e-mail to approximately one-hundred (100) State and Federal agency personnel to inform them about the informational survey intended to provide CSU and the FHWA Federal Lands Highway (FLH) with information pertaining to current methodologies used in culvert pipe liner design and installation. Out of the approximate one-hundred (100) State and Federal agency personnel contacted, thirty (30) responded to the survey. Analysis of the thirty (30) returned surveys showed that two-thirds (20 respondents) had previously been involved with the design or installation of culvert pipe liners, while one-third (10 respondents) indicated that they had no previous experience with culvert pipe liners. From the collected responses of those with previous experience in the design or installation of culvert pipe liners, it was determined that sliplining was the technique most often used by Federal and State agency personnel (80.5%). In fact, many agencies indicated that sliplining was the only lining method their agency had previously used. Additionally, survey results indicated that the average year agencies became familiar with lining techniques was around 1990, with 1980 being the earliest year, indicating that the majority of agencies surveyed have been utilizing lining techniques for over a decade.

Respondents to the survey also indicated that numerous standards, specifications, and guidelines have been used in the design and installation of culvert pipe liners. Several of the agencies who responded stated that their agency had developed its own specifications for culvert pipe liners, which demonstrates the need for the development of a national standard for use by Federal and State agencies. A series of subjective questions showed that the respondents overwhelmingly choose the method of sliplining as the easiest liner to install, the most successful, and the least expensive.

Average general costs of liner methods varied widely and were dependent upon the size of liner and type of material used. Responses showed that sliplining and close-fit lining had similar average price ranges ($20 to $200 per linear foot and $50 to $120 per linear foot, respectively). Spirally wound lining and cured-in-place lining were also similar in cost (both at $300 per linear foot) and had the highest average cost of all lining methods. Design life estimates provided by the respondents ranged from ten (10) to fifty (50) years for all lining methods. Only three (3) respondents reported that their agency has or uses standard maintenance procedures for culvert pipe liners, indicating the need to develop standard maintenance procedures once a pipe has been lined. Lastly, two environmental issues were provided by respondents and are of concern when using liners to rehabilitate deteriorated culverts. First, a concern was expressed associated with the cured-in-place lining technique. Due to the chemicals and resins used in the cured-in-place lining method, the installation process may be hazardous to an environmentally sensitive area. Secondly, fish passage through newly lined pipes may become an issue if velocities are increased enough that fish cannot swim upstream.

CHAPTER 5 – MULTI-CRITERIA DECISION ANALYSIS SOFTWARE

INTRODUCTION

Through quantitative evaluation of the data and information compiled in the literature review and survey, an explicitly defined list of alternatives and decision criteria to evaluate rehabilitation alternatives was developed for culverts 122 centimeter (48 inch) in diameter or smaller. Relative weights of each criterion were assigned in comparison to the defined alternatives, thereby allowing a dynamic interaction between criteria and alternatives as the decision maker varies preferences. Results were input into a Microsoft® Excel workbook. Using a Multi-Criteria Decision Analysis (MCDA) technique, the user-friendly workbook minimizes the cognitive effort of the decision maker. An MCDA workbook allows the user to customize the decision aid model to a situation to select the appropriate culvert-lining method. A simplified graphical representation of the successive decision analysis steps was provided in the form of a user flow chart in the Microsoft® Excel workbook. Development of the MCDA was assisted by Dr. Darrell G. Fontane, Professor, CSU.

BACKGROUND

Often engineers are faced with making a choice among various options. The selection of the most appropriate culvert-rehabilitation technique is a good example of this. If the only consideration were cost, economic principles could be used to guide our selection. However, the choice of a culvert-rehabilitation strategy involves costs and non-economic measures such as structural integrity provided. In general, the considerations might include both quantitative and qualitative measures. In such cases, a process must be used to approximately "quantify" all measures on a similar, numerical scale so that mathematical calculations can be performed. Initially, the scope of Task 2 encompassed building a decision tree for determination of a trenchless-technology technique for culvert rehabilitation. Decision trees are useful tools for well-defined problems but are limited in the ability of providing decision guidelines. For example, a designer could use a decision tree to determine an alternative that provides the greatest cost benefit or the greatest structural integrity, but would be restricted in determining an outcome if both guidelines were of equal importance. For the decision problem presented by the FHWA, a more sophisticated method of decision-making was needed. Multi-Criterion Decision Analysis is a numerical process to compare or "score" alternatives on a comparable scale.

MCDA is a systematic process used for analyzing discrete decision problems where the circumstances are not clearly defined. MCDA is based on the concept of deriving an overall score for the decision option, or alternative, being analyzed. A primary advantage to MCDA is the provision of a highly structured decision-making technique. Within a decision problem, objectives (criteria) are used to evaluate the performance of an alternative. The decision maker defines the relative importance factors of criteria as they pertain to a specific project. Relative importance factors are numerical representations of the preference of the decision maker, commonly based on background information and experience. MCDA provides a numerical score, or rating, assigned to a given alternative with respect to each criterion. In decision-making scenarios there may exist disagreement between varying decision makers as to the relative importance given to criteria. It is possible, with MCDA techniques, to easily examine many scenarios and provide simple tools for comparison. Various combinations of relative importance factors can be examined, determining new alternative rankings. By developing a Microsoft® Excel-based MCDA tool, the user is provided with a method to document and audit the various decision-making processes. In the Excel workbook, the decision-making process is an iterative procedure that can easily be adapted to illustrate new situations or include additional information.

MCDA DEVELOPMENT

Determination of Relevant Criteria and Alternatives

In the scope of work defined by the FHWA, one task was to develop a methodology providing ease of determination of culvert rehabilitation through trenchless-technology techniques. Understanding of these techniques was furnished in the literature compilation, providing a setting within which the problem could be solved. CSU, in conjunction with the FHWA, developed a list of inputs, alternatives, and criteria to serve as the basis of the MCDA process. Selection of criteria was based on information gathered during the literature review pertaining to the characteristics of trenchless-technology techniques that allowed judgment of performance of one alternative in comparison to another. Criteria allow the decision maker to adapt the scenario to personal preference. Inputs were chosen for their ability to provide field-evaluation tools that tailor the MCDA workbook to the specific decision-making situation. Each trenchless-technology technique included in the decision-making process is deemed an alternative solution to the problem. In order to provide the specificity required to individualize a given scenario, each alternative was evaluated within the context of the model inputs. Inputs, presented below, provide evaluation tools specific to alternative attributes in the context of the decision-making model:

1. Length of existing culvert
2. Diameter of existing culvert
3. Diameter change or discontinuity within the existing culvert
4. Structural integrity of existing culvert

Limitations of alternatives used in development of the MCDA, in the context of user inputs, are presented in Table 50. During alternative analyzation, it became apparent that information pertaining to several alternatives was incomplete specific to the culvert characteristics under examination. Table 50 does not include swagelining/drawdown and rolldown methods, which were originally investigated in the literature review, due to the deficient information. Reasons for the exclusion of the swagelining/drawdown and rolldown methods are explained in the following section.

Table 50. Alternative Limitations of Model Inputs.

Input	Alternative								
	Sliplining		Close-fit lining		Spirally wound lining	Cured-in-place lining		Spray-on lining	
	Segmental Method	Continuous Method	Deformed/ Reformed Method	Fold and Form Method		Inversion Method	Pulled-in-place Method	Cement-mortar System	Epoxy System
Applicable Length	< 300 m[1] (985 ft)[2]	< 300 m (985 ft)	< 800 m (2,625 ft)	< 210 m (689 ft)	< 300 m (985 ft)	< 900 m (2,955 ft)	< 150 m (495 ft)	< 450 m (1,475ft)	< 450 m (1,475 ft)
Diameter Limitation	7.6-122 cm[3] (3-48 in.)[4]	10-122 cm (4-48 in.)	10-40.6 cm (4-16 in.)	10-61 cm (4-24 in.)	10-122 cm (4-48 in.)	10-122 cm (4-48 in.)	10-122 cm (4-48 in.)	7.6-122 cm (3-48 in.)	7.6-122 cm (3-48 in.)
Diameter Change/ Discontinuity	Severe Prohibits[5]	Severe Prohibits	Allowable	Allowable	Allowable	Allowable	Allowable	Allowable	Allowable
Structural Integrity	RI[6]	RI	NA[7]	NA	RI	RI	RI	DE[8]	DE

[1]m – meter, [2]ft – feet, [3]cm – centimeters, [4]in. – inches, [5]Prohibits – Existence of prohibits the use, [6]RI – Restores structural integrity, [7]NA – Not applicable to structurally deteriorated culverts, [8]DE – Does not enhance structural integrity

Alternative attributes were then analyzed in the context of the predetermined criteria. Criteria were intended to provide a tool for determining the user-established preference in relation to the alternatives. Evaluation of alternative attributes in the context of the criteria proved to have elements of uncertainty and imprecision. Analysis was anticipated to provide sufficient information to quantitatively weigh each alternative within the context of each criterion. Criteria used for analysis were:

1. Design life of lining method
2. Capacity reduction of the existing culvert after installation
3. Resistance to abrasion and corrosion of lining method
4. Time required for installation
5. Requirement for flow bypass of the flow during installation
6. Extent of digging required during installation

7. Cost of lining method
8. Safety of crew during installation
9. Existence of water quality concerns after installation of lining

Examination of alternatives, in the context of model inputs and analysis criteria, suggested that insufficient information applicable to the culvert rehabilitation decision-making process was available for several alternatives. Swagelining/drawdown and rolldown methods were eliminated from the decision-making model because limited information was available on cost of installation. In addition, insufficient information was available on installation details such as safety of workers during installation and amount of required digging for installation.

The final culvert lining alternatives incorporated into the MCDA model were:

1. Segmental Sliplining
2. Continuous Sliplining
3. Close-fit Lining Deformed/Reformed
4. Close-fit Lining Fold and Form;
5. Spirally Wound Lining
6. Cured-in-place pipe Lining, Inversion
7. Cured-in-place pipe Lining, Pulled-in-place
8. Spray-on lining, Cement-mortar
9. Spray-on lining, Epoxy

Alternative Ratings

Using information obtained during the literature review and survey, alternatives were rated to allow the MCDA to identify how well an alternative satisfies a criterion. Rating scales were developed for each criteria dependant of the variability of the alternatives. Range of the rating scales was arbitrary, rating scales needed only to appropriately reflect the differences among alternatives. Operation of the MCDA is based on a predetermined set of alternative ratings. A summary of the alternative ratings used in the MCDA is presented in Table 51.

Table 51. Alternative Rating Scales.

Criteria	Alternative								
	Sliplining		Close-fit lining		Spirally Wound Lining	Cured-in-place lining		Spray-on lining	
	Segmental Method	Continuous Method	Deformed/ Reformed Method	Fold and Form Method		Inversion Method	Pulled-in-place Method	Cement-mortar System	Epoxy System
Design Life	4	4	4	3	3	5	5	1	2
Capacity Reduction	2	2	5	5	5	5	5	4	4
Abrasion and Corrosion Resistance	3	3	3	4	4	4	4	1	2
Installation Time	5	3	3	3	4	2	2	1	1
Flow Bypass Requirements	4	4	1	3	4	1	1	1	1
Digging Requirements	5	1	3	3	3	2	2	5	5
Cost	4	4	3	3	2	1	1	5	5
Safety	4	3	3	3	3	3	3	5	5
Environmental Concerns	4	4	3	3	4	1	1	1	1

Design Life

Design life was rated based on the design life of the common liner materials presented in the literature review. Design life of the material used in the nine alternatives included in the decision analysis ranged from 20 to 100 years. The spray-on lining cement-mortar system had the shortest design life and the cured-in-place inversion installation methods had the longest. Presented below is the rating scale for the design life criterion:

100 years	5
75 years	4
50 years	3
30 years	2
20 years	1

Capacity Reduction

Each alternative was rated based on the reduction of the capacity of the culvert after installation of the liner. Capacity reduction was fairly significant for the two (2) sliplining methods, while the other methods produced minimal to almost zero reduction. Presented below is the rating scale for capacity reduction:

Significant	1
Potential	3
Minimal	5

Abrasion and Corrosion Resistance

Abrasion and corrosion resistance was rated on the ability of the common liner materials presented in the literature review to resist corrosion and abrasion. The spray-on lining cement-mortar system provided the worst resistance to abrasion and corrosion; where as, the fold and form, spirally wound lining, cured-in-place inversion installation method, and cured-in-place pulled-in-place method were all rated equally as the best alternatives for abrasion and corrosion resistance. Presented below is the rating scale for abrasion and corrosion resistance:

Worst	1
Best	4

Installation Time

Installation time was rated on the length of time required to install a culvert liner. Installation time included consideration of machinery setup, amount of digging required if applicable, required time of installment, and necessary monitoring and testing after installation is complete. Spray-on liners required the least amount of time to install, and segmental slipliners require the longest amount of time to install. Presented below is the rating scale for installation time:

Longest	1
Moderate	2
Minimal	3
Shortest	4

Flow Bypass Requirements

Flow bypass requirements were rated on whether an alternative required circumvention of the flow to a secondary channel during installation. Though no alternative required bypassing the flow at all times, segmental sliplining and spirally wound lining typically did. It is rarely necessary to bypass the flow for the deformed/reformed method for close fit lining, the cured-in-place methods, and the spray-on lining methods. Presented below is the rating scale for flow bypass requirements:

Always Required	1
Usually Required	3
Not Required	5

Cost

Cost was rated based on the average cost given by case studies and survey results presented in the literature review. Spray-on lining methods were the least expensive, and the cured-in-place lining methods were the most expensive. Presented below is the rating scale for the cost criterion:

Most Expensive	1
Least Expensive	5

Safety

Safety ratings were based on the safety of the installers. Consideration was given to the machinery involved and whether installer entry was required during the installation process. Presented below is the rating scale for the safety criterion:

High Risk	1
Low Risk	5

Environmental Concerns

Environmental concern was rated based on the necessity of chemical use, such as chlorine or resins, during installation. Spray-on lining methods and the cured-in-place lining methods were considered to have the greatest environmental concerns. Presented below is the rating scale for environmental concerns:

Major	1
Minimum	5

Methods of Determining Alternative Ranking

There are many MCDA methods with the basic difference between them illustrated by the scoring process. There are two (2) general categories of methods: value-based methods and outranking-based methods. Value-based methods assign a rating (or score) to an alternative based upon how well that alternative satisfies a specific criterion. For example, assume a 1 to 5 rating scale is implemented with 5 representing the best value. In a value-based method, a rating of 4 is exactly twice as good as a rating of 2. The range of the rating scale is arbitrary and can be selected to meet the desires of the decision makers. However, once a rating scale is defined, rating values assigned to each of the alternatives for a specific criterion need to be carefully applied so that scores appropriately reflect the differences in the alternatives. In contrast, the ratings assigned in outranking methods place little value on how well an alternative satisfies a specific criterion. What is important is only whether one alternative is preferred (or better) than another. The degree of preference is not necessarily considered (although in some outranking methods it can be). In an outranking method, the preferred alternative tends to be the one that has the highest performance in the largest number of criteria.

Three (3) MCDA alternative ranking methods were included in this project. The Weighted Average Method and the Discrete Compromise Programming Method are value-based methods and the PROMETHEE method is an outranking method. Users can select a method of their choice or they can compare the results of all three (3) methods. By comparing the results of all three (3) methods, the impact of the type of MCDA method on the solution can be determined. Usually the results of all three (3) MCDA methods will be similar with only minor differences in the alternative rankings. It is recommended that the Weighted Average Method be the first choice in this application for culvert-rehabilitation strategies since it is a simple decision process. If the process produces alternatives with equal ranks, the Discrete Compromise Programming method will usually be able to provide more discrimination and produce a non-equal ranking. Finally, the PROMETHEE method should be considered if the basic data is not very precise.

Weighted Average Method

The Weighted Average Method (WAM) is a value-based method where the actual value of the performance measure is used to assign the alternative ranking. A 1 to 5 rating scale is used in the WAM, with a value of 1 indicating the worst performance and a value of 5 the best performance. The relative importance of each criterion is determined using relative importance factors assigned by the decision maker. Relative importance factors are then normalized to produce a set of normalized criterion weights. Each designated alternative rating is then multiplied by the normalized weight. The equation in Figure 25 is used to determine the overall score for each alternative.

$$S_j = \sum_{i=1}^{4} W_i * R_{i,j}$$

where,

S	=	overall score for alternative j
W	=	weight
R	=	relative importance of criterion i

Figure 25. Equation. S subscript j.

Since the summation of the normalized weights must equal 1, the overall score will be in the range of 1 to 5. Alternatives are ranked based on the resulting score with the highest score given a rank of 1.

Discrete Compromise Programming Method

A value-based method, Discrete Compromise Programming Method (CP), uses a rating scale of 0 to 1, with a value of 1 representing the best performance and a value of 0 the worst. CP converts the 1 to 5 scale from the WAM to the necessary 0 to 1 scale. CP uses the equation in Figure 26 to weight the relative importance factors.

$$R_{i,j} = \left[\frac{Actual_{i,j} - Worst_i}{Best_i - Worst_i} \right]^p$$

where,

R	=	CP rating metric;
Actual	=	actual rating of alternative;
Worst	=	worst rating of any alternative for a specified criterion;
Best	=	best rating of any alternative for a specified criterion; and
p	=	exponent determining the additional emphasis on the CP metric rating value.

Figure 26. Equation. R subscript i,j.

The exponent *p* can be a value of either 1 or 2. When *p* equals 1 each rating metric rescales the original rating scale to a 0 to 1 scale. When *p* equals 2, however, greater significance is given to the largest CP rating metric values. Overall scores for each alternative are computed as described in the WAM. Alternatives are then ranked based on the resulting score.

PROMETHEE Method

The PROMETHEE Method is based on determination of preference and indifference. Every alternative is compared pairwise to each of the other alternatives. A preference value of 1 is assigned if 1 alternative is better than (or preferred to) the performance of another, with respect to a specific criterion, without considering the magnitude of the performance difference. A preference value of 0 is assigned if the alternative is equal or inferior to the other alternative. In PROMETHEE the decision maker is considered to have a strict preference for the action of highest value.[(100)] Preference values determined from the pairwise comparisons are then analyzed to develop an overall rating value for each alternative. These overall rating values are on a scale of +1 to -1. An overall rating of +1 means that an alternative is strictly preferred to all other alternatives while an overall rating of -1 implies that an alternative is inferior to all other alternatives. Compared with the Weighted Average Method and Discrete Compromise Programming Method, the PROMETHEE method is less influenced by the actual magnitude of the basic data. A disadvantage to the PROMETHEE method is that the pairwise comparisons and the process to calculate overall rating values may be harder to understand by the decision maker.

Methodology

Once the culvert characteristics are determined, the relative importance factors defined, and the method of alternative ranking selected, the MCDA employs the appropriate alternative ranking equation and a scoring of alternatives is presented. The methodology used in the culvert-lining decision analysis to determine an alternative score is displayed in the flow chart presented in Figure 27. In Figure 27, the right-angle-cornered boxes contain functions that required user action; the round-cornered boxes represent functions inherent to the MCDA program.

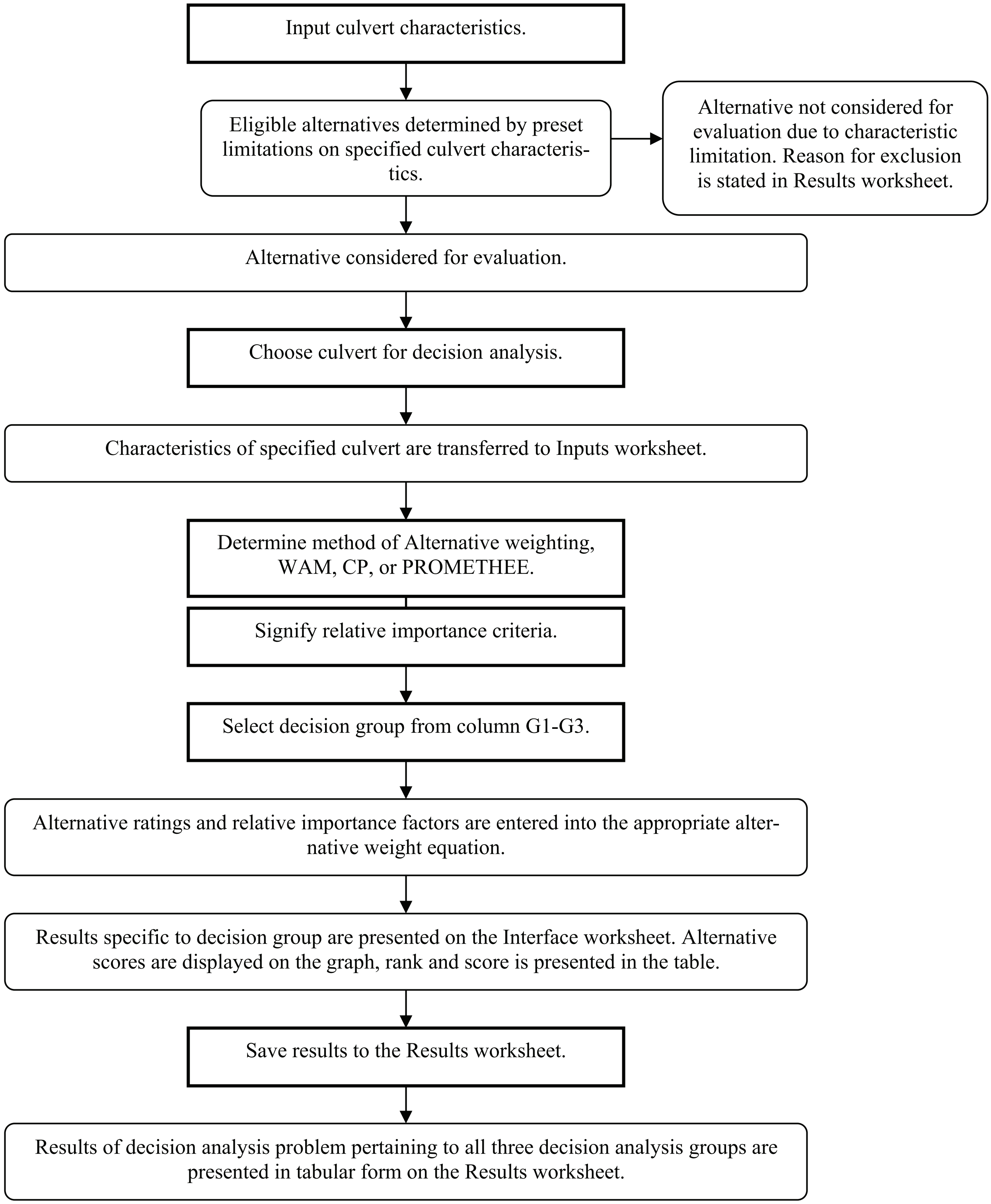


Figure 27. Flow Chart. MCDA Methodology.

Summary

A methodology providing ease of determination of culvert rehabilitation through trenchless-technology techniques was developed using MCDA principles. Using information provided by the literature review, a discrete list of culvert-rehabilitation alternatives and relative importance criterion were developed. Rating scales for each alternative were created dependant on the ability of an alternative to satisfy a specific criterion. Three (3) alternative ranking methods were included in the MCDA. The Weighted Average Method and the Discrete Compromise Programming Method are value-based methods and the PROMETHEE method is an outranking method. The Weighted Average Method is easily explained and understood. It is recommended that the weighted average method be the first choice in this application for culvert-rehabilitation strategies since it is a familiar decision process. Discrete Compromise Programming will usually provide more discrimination and produce a non-equal ranking. The PROMETHEE method is most valuable when the basic data are not very precise. Additionally, a methodology was presented of how the MCDA inputs the alternative ratings and relative importance factors into alternative ranking equations to output an alternative score.

APPLICATION OF MULTI-CRITERIA DECISION ANALYSIS

A workbook was created in Microsoft® Excel to facilitate the MCDA process. Users enter culvert characteristics on the Culvert Characteristics worksheet. In addition to information pertinent to operation of the MCDA, room is provided on the Culvert Characteristics worksheet to create a culvert database. Information pertaining to six (6) culverts can be entered. On the Inputs worksheet, the user chooses one (1) of the six (6) culverts to be analyzed. Once a culvert is selected, the four (4) culvert characteristics necessary for operation of the MCDA are displayed on the Inputs worksheet. Relative importance of criteria and method of alternative ranking are selected by the user on the Interface worksheet. Three (3) relative importance scenarios can be entered, potentially representing three (3) varying decision scenarios or decision makers. When a user selects a method of alternative ranking, Excel activates the worksheet pertaining to the selected method. Alternative ratings are saved in the Basic Data worksheet and appear in the alternative ranking worksheets. Results of the alternative ranking computation may be viewed in two (2) places. Results appear on the Interface worksheet in graphical and tabular forms. Additionally, results pertaining to the three (3) relative importance of criteria scenarios are saved to the Results worksheet. Also displayed on the Results worksheet is a table detailing exclusions, if any, of alternatives and the reasons for exclusion. User direction can be accessed on the Directions worksheet.

Note: In the Microsoft® Excel workbook, the Security Level should be set on "Medium" or "Low" (Tools → Macro → Security). If the Security Level is set on "High," the macro will not run.

Application Procedure

An application procedure was developed for decision maker use of the Culvert Liner Decision Analysis Microsoft® Excel workbook. The following steps are intended as a guideline for use of the decision-analysis model. All measurements should be recorded in feet and inches, where specified.

1. A field-site survey should be performed to assess culvert characteristics. Four (4) culvert characteristics, presented in Section 5.3.1, are imperative for the decision-analysis model. Culvert length and diameter are needed. Additionally, knowledge of existence of changes in diameter and/or discontinuities along the culvert is required. It is also necessary to discern if the culvert requires restoration of structural integrity.
2. Open the "Culvert Rehabilitation Decision Analysis" Microsoft® Excel workbook. Begin on the Home worksheet. The Home worksheet guides the user through the MCDA process and should be returned to after completion of a designated action.

3. Click on the first box, titled "Begin by entering the culvert characteristics on the Culvert Characteristics Worksheet. Click this box to go to the Culvert Characteristics Worksheet." This will take the user to the Culvert Characteristics worksheet. Figure 28 presents the Home Worksheet and draws attention to the first box.

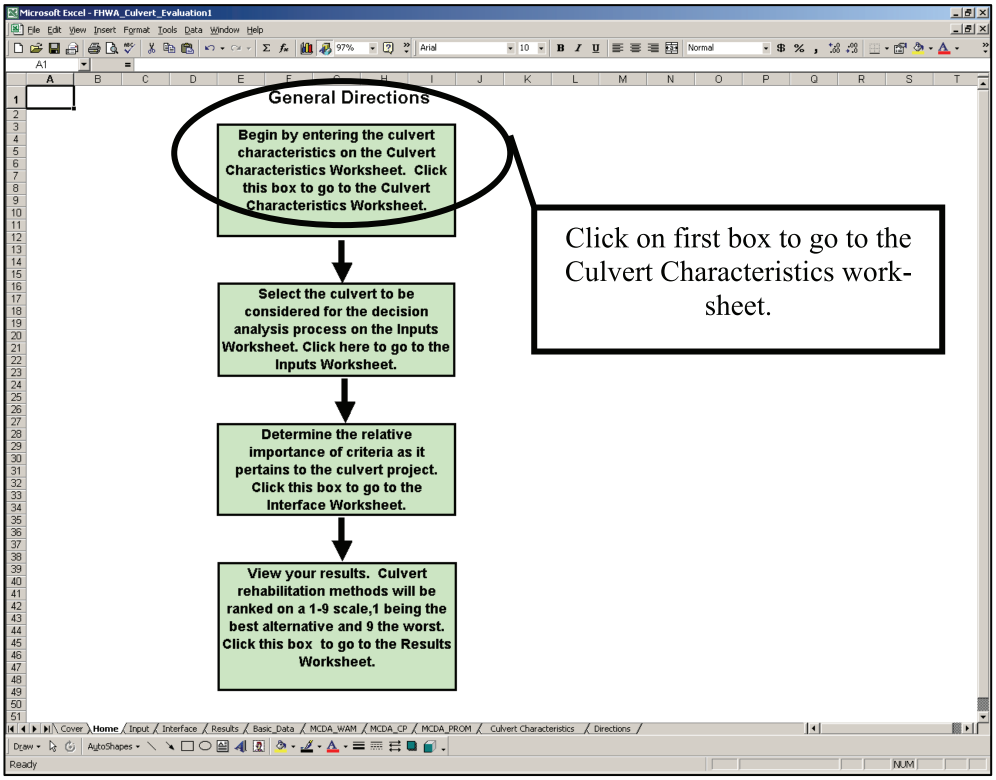


Figure 28. Screenshot. MCDA Home Worksheet, Navigates to Culvert Characteristics Worksheet.

4. Six (6) distinct culverts, and thereby six (6) individual decision problems, can be analyzed in the workbook. It is not necessary to enter information pertaining to six (6) culverts. Begin by entering the information pertaining to the first culvert into the area titled "Culvert A" and continue entering information in the areas titled "Culvert B-F," or leave the area blank if no further culverts are to be included in the analysis.

5. In the Culvert Characteristics worksheet, presented in Figure 29, the user is required to fill in the four (4) characteristics pertinent to the operation of the model. Highlighted in Figure 29 are the Culvert A data entry area, the areas of required input, and the Return to Home Worksheet button. Cells requiring input necessary for the function of the MCDA are highlighted in green on this worksheet. Other culvert characteristic information is included on the worksheet to allow the user to develop a database if desired. First, the user enters the length of the culvert under examination, which must be answered in feet. Second, the user enters the diameter of the culvert, which must be answered in inches. Dropdown boxes are provided to answer the third and fourth questions. Selections are made by clicking the highlighted box, then clicking on the down arrow and selecting the appropriate answer.

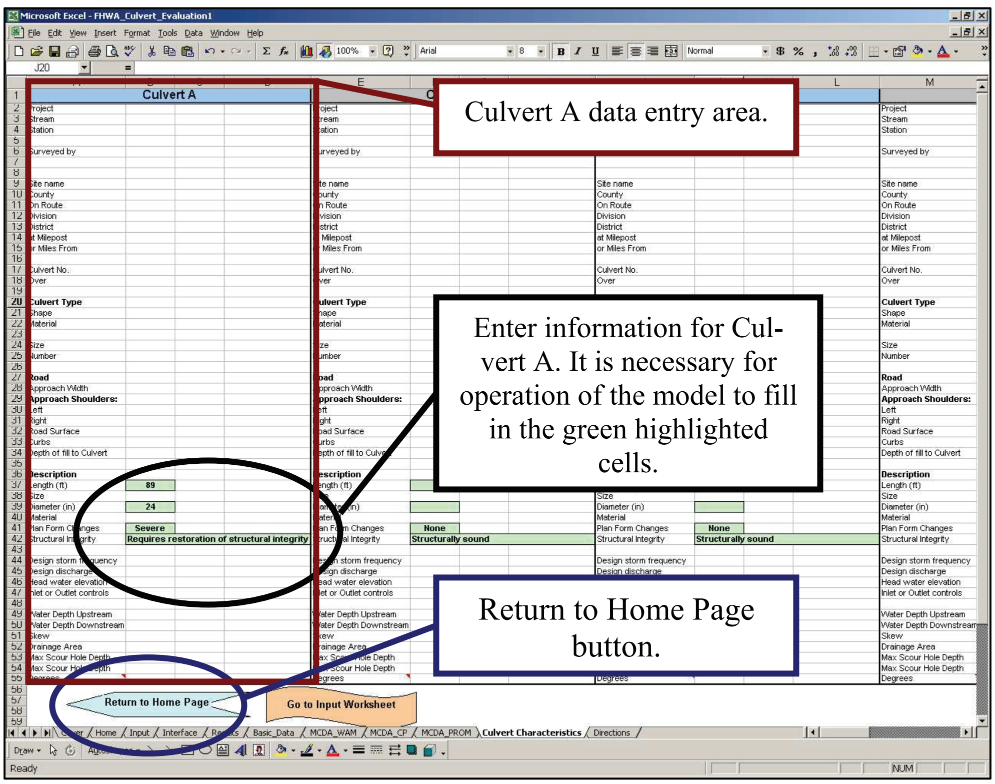


Figure 29. Screenshot. MCDA Culvert Characteristics Worksheet, Navigates to the Inputs Worksheet.

6. Once finished entering pertinent culvert characteristics, click the “Return to Home Worksheet” button to continue with the analysis.
7. Click on the second box on the Home Worksheet, titled “Select the culvert to be considered for the decision analysis process on the Inputs Worksheet. Click here to go to the Inputs

Worksheet." This action takes the user to the Inputs worksheet. Figure 30 depicts the Home Worksheet with the second box highlighted.

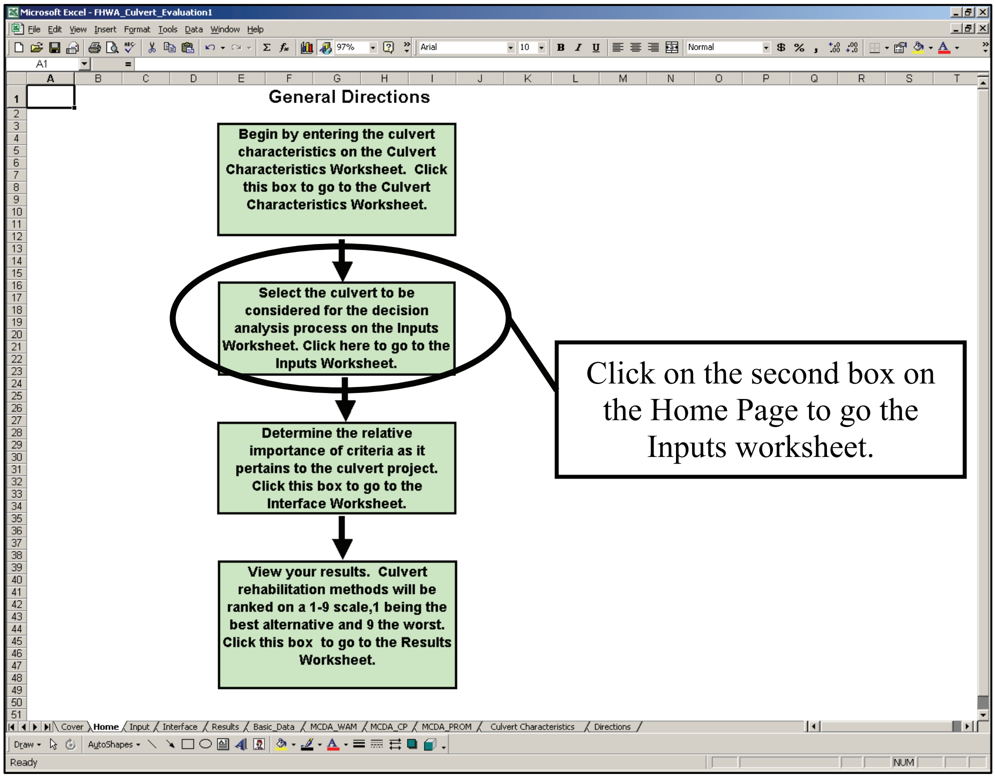


Figure 30. Screenshot. MCDA Home Worksheet.

8. Once the Inputs worksheet is activated, select the culvert pertinent to the current decision problem by clicking on the blue box, then the down arrow and choose the appropriate culvert, Culvert A-Culvert F. Figure 31 depicts the Inputs worksheet, accentuated in Figure 31 are the culvert selection area and the Return to Home button.

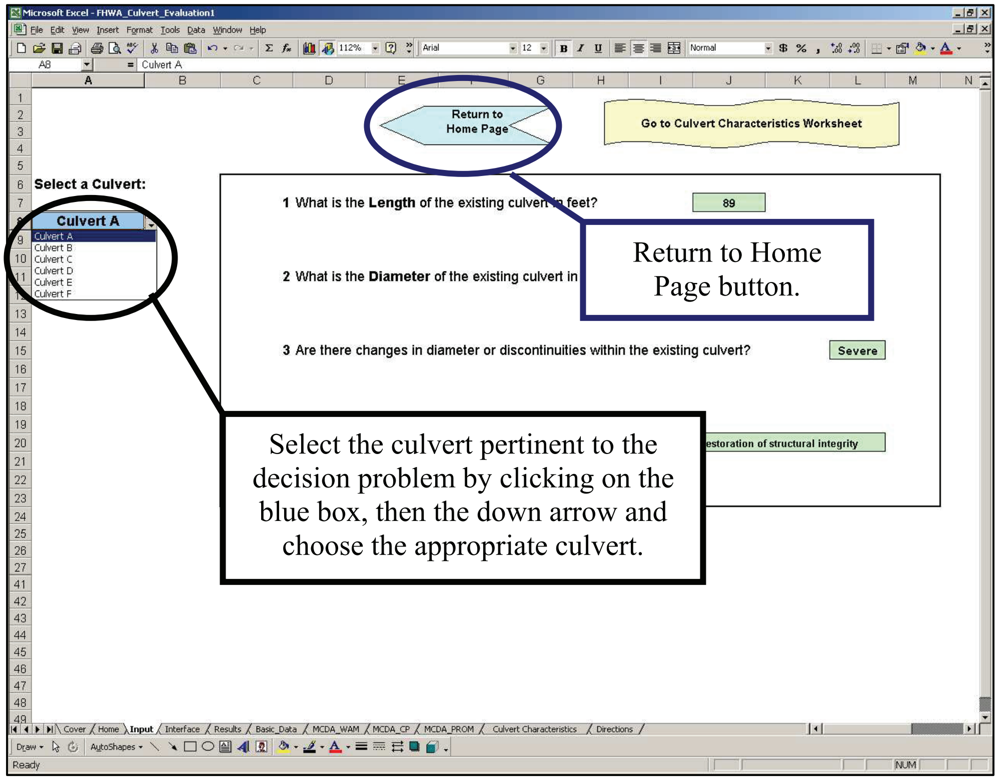


Figure 31. Screenshot. MCDA Inputs Worksheet.

9. Once finished selecting the applicable culvert, click the "Return to Home Worksheet" button to continue with the analysis.

10. Next, on the Home worksheet, click on the third box entitled "Determine the relative importance of criteria as it pertains to the culvert project. Click this box to go to the Interface Worksheet." This action takes the user to the Interface Worksheet. Presented in Figure 32 is a screenshot of the Home worksheet with the third box highlighted.

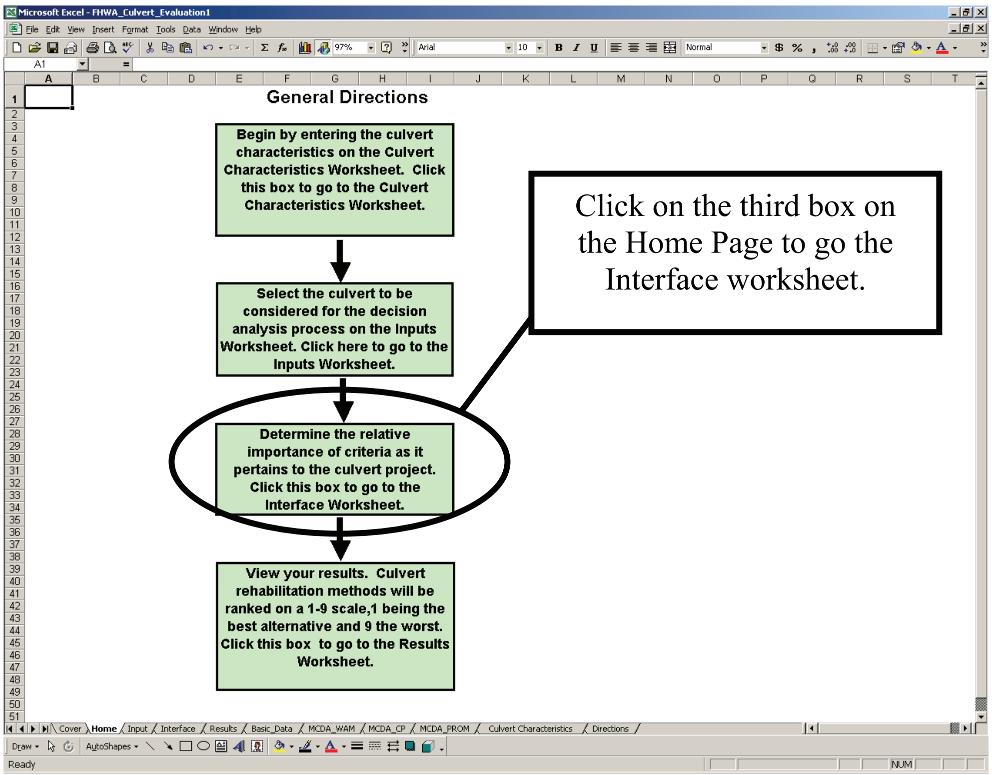


Figure 32. Screenshot. MCDA Home Worksheet.

11. Delimitate the relative importance of the criteria as discussed in Section 5.3.1. Relative importance factors must be on a scale of 1 to 4, 1 being the least important and 4 being the most important. Enter relative importance factors in the columns labeled G1-G3 in the "Relative Importance" box. It is convention to leave the values in column G1 equal to 1; this provides the user with a consistent comparative scenario where all decision criteria are of equal importance. Figure 33 presents a picture of the Interface worksheet. Highlighted in Figure 33 are the areas pertinent to determination of relative importance factors.

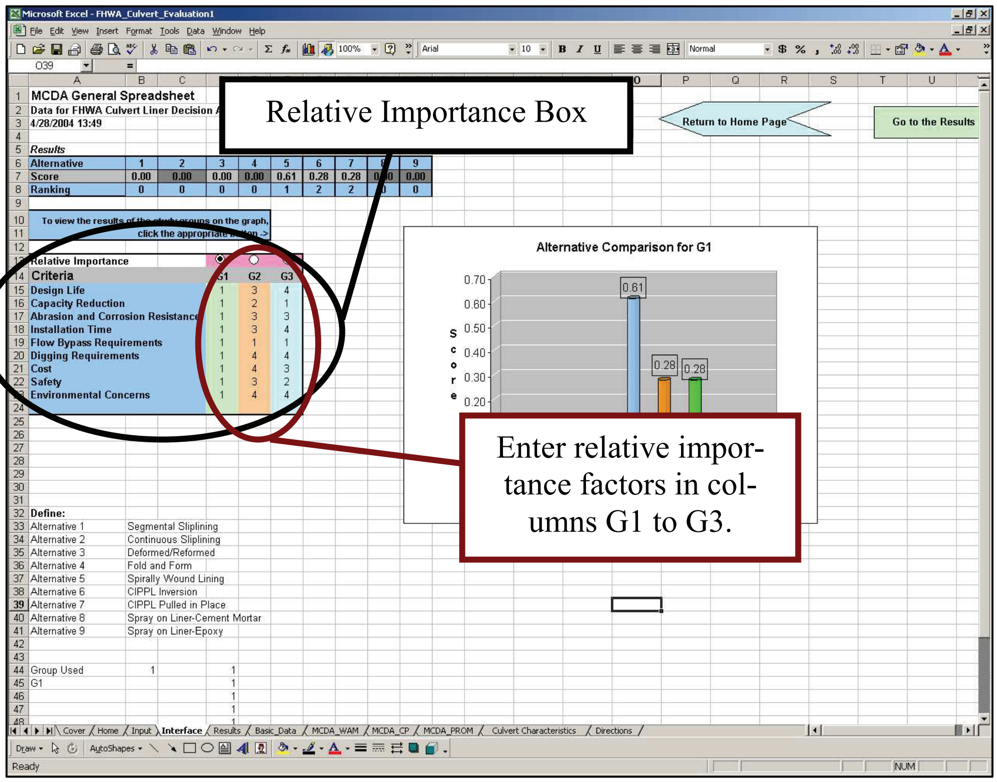


Figure 33. Screenshot. Interface Worksheet and Relative Importance Determination.

12. Navigation between the various relative importance scenarios is done by selecting the circle on top of the appropriate columns labeled G1 to G3.

13. Determine the method of alternative ranking. Methods of alternative ranking are described in Section 5.3.3. Selecting WAM scores the alternatives on a more conventional scale, giving equal significance to each relative importance factor. CP will give more weight to the better performing alternative relative to the other alternatives. Choosing the PROMETHEE method scores each alternative in comparison to the other alternatives, PROMETHEE is a performance-based ranking. In the screenshot presented in Figure 34, the area where the method of alternative ranking is selected has been highlighted.

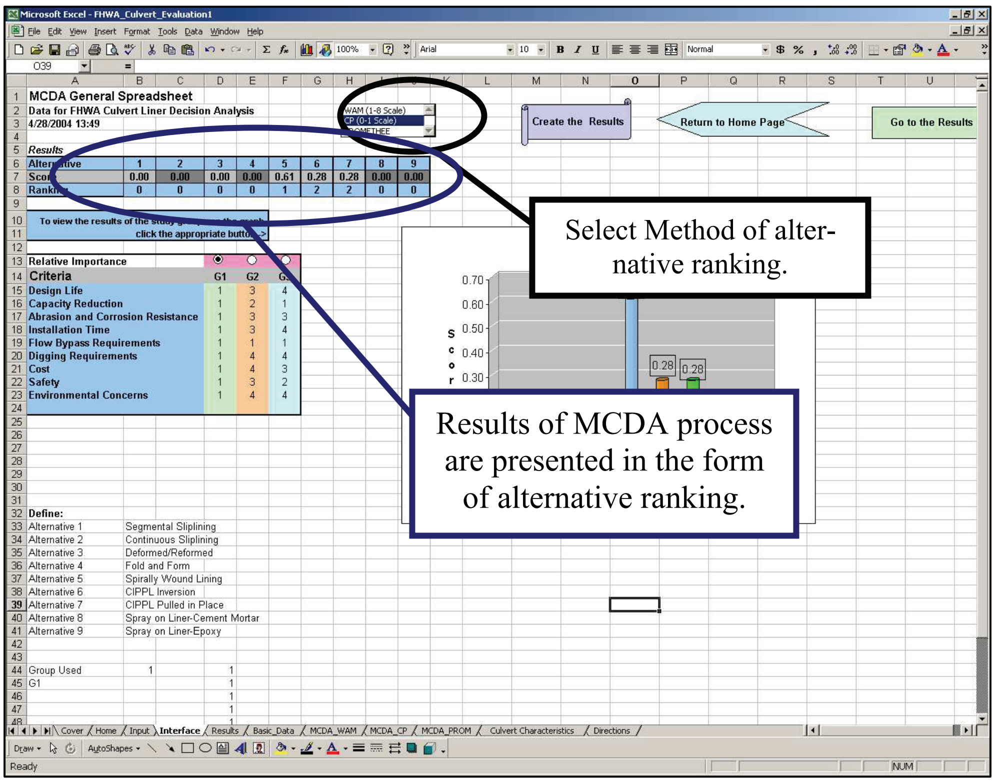


Figure 34. Screenshot. MCDA Interface Worksheet, Determine Method of Alternative Ranking.

14. Click the "Create the Results" button to save the scenario to the Results worksheet. All three (3) relative importance scenarios, G1 through G3, will be saved, though only one (1) decision analysis problem can be saved to the Results worksheet at a time.

15. Click the “Return to Home Worksheet” button. Navigation buttons pertinent to steps 14 and 15 are highlighted in the screenshot presented in Figure 35.

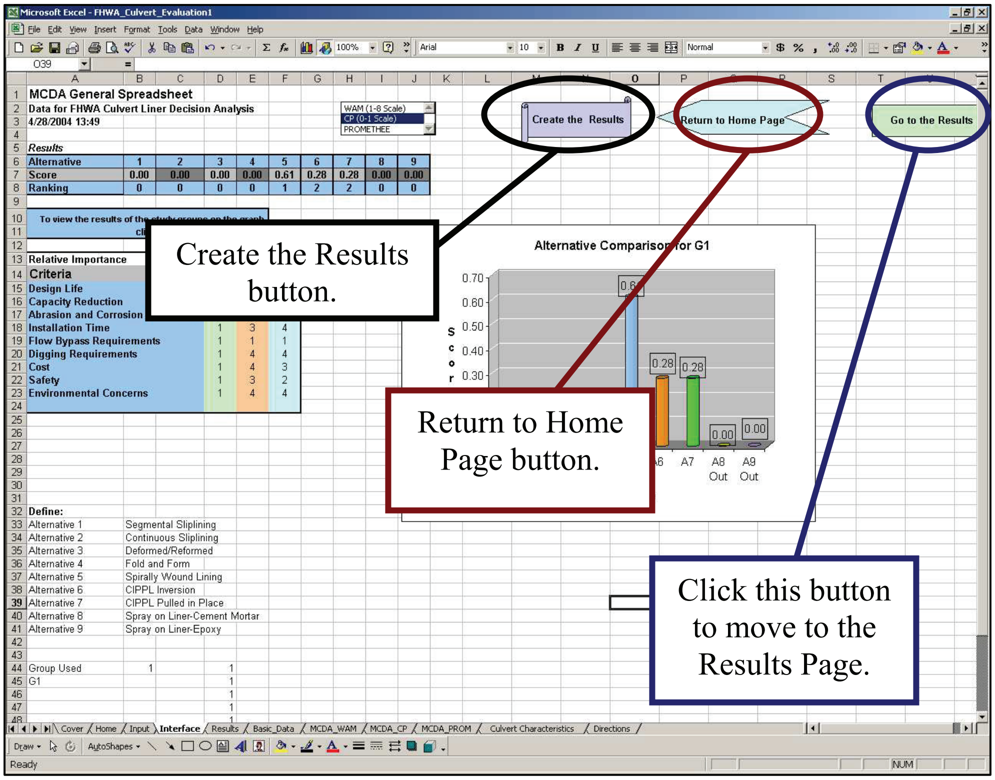


Figure 35. Screenshot. Interface Worksheet Navigation Buttons.

16. On the Home worksheet, click the fourth box, titled "View your results. Culvert rehabilitation methods will be ranked on a 1 to 9 scale, 1 being the best alternative and 9 the worst. Click this box to go to the Results Worksheet." This process is highlighted in the screenshot presented in Figure 36.

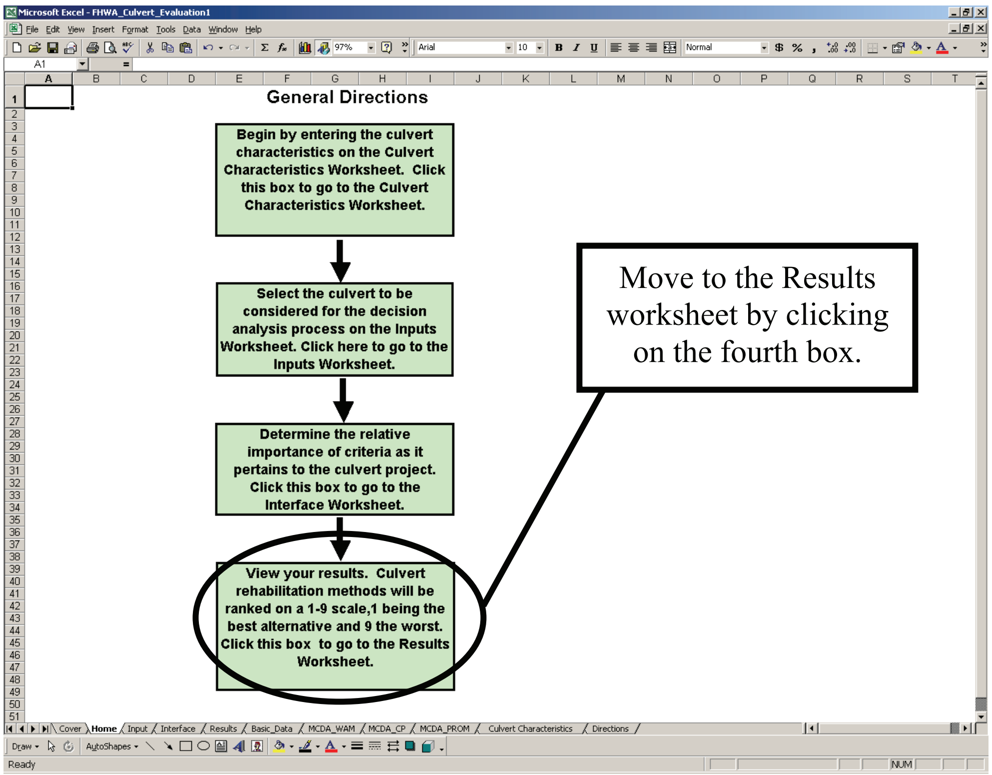


Figure 36. Screenshot. MCDA Home Worksheet, Navigates to the Results Worksheet.

17. Results are displayed in two (2) charts on the Results worksheet. A score and ranking of the alternatives is provided first for all three (3) relative importance scenarios. Secondly, a chart was provided to inform the user of eligibility of a criterion for consideration. If an alternative was eliminated the chart reads "Out" in the appropriate column. It is then seen which of the four (4) required culvert characteristics' limitations caused an alternatives exclusion. The Results worksheet is presented in Figure 37.

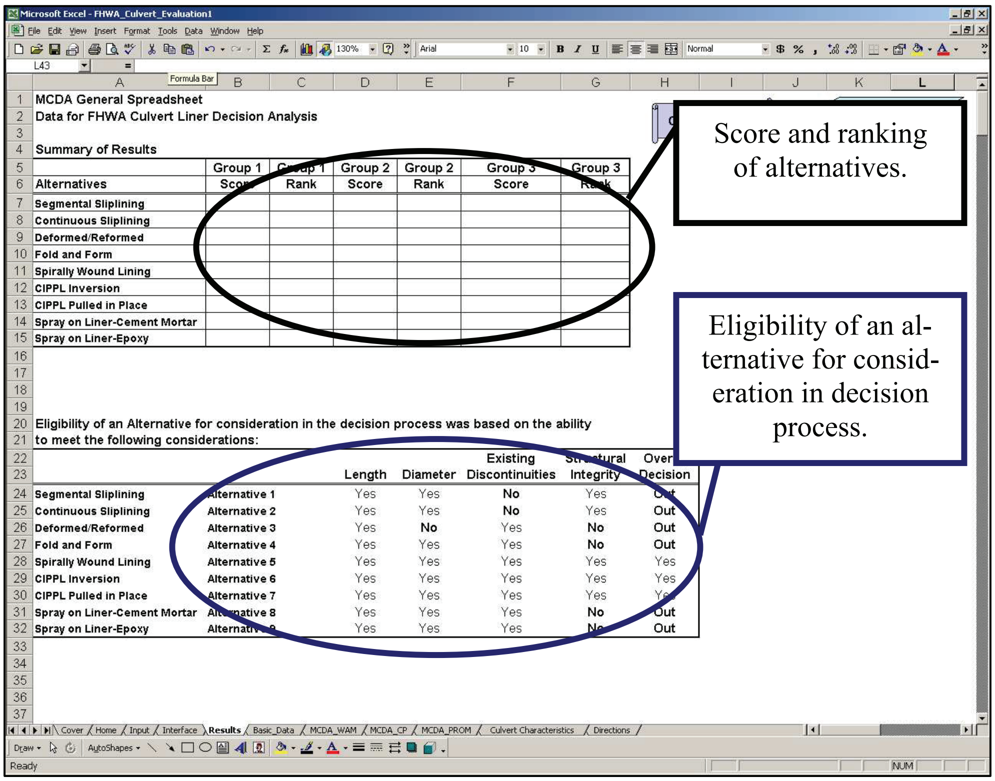


Figure 37. Screenshot. MCDA Results Worksheet.

18. Click the “Clear the Table” button to begin a new analysis. The button to clear the table is highlighted in Figure 38.

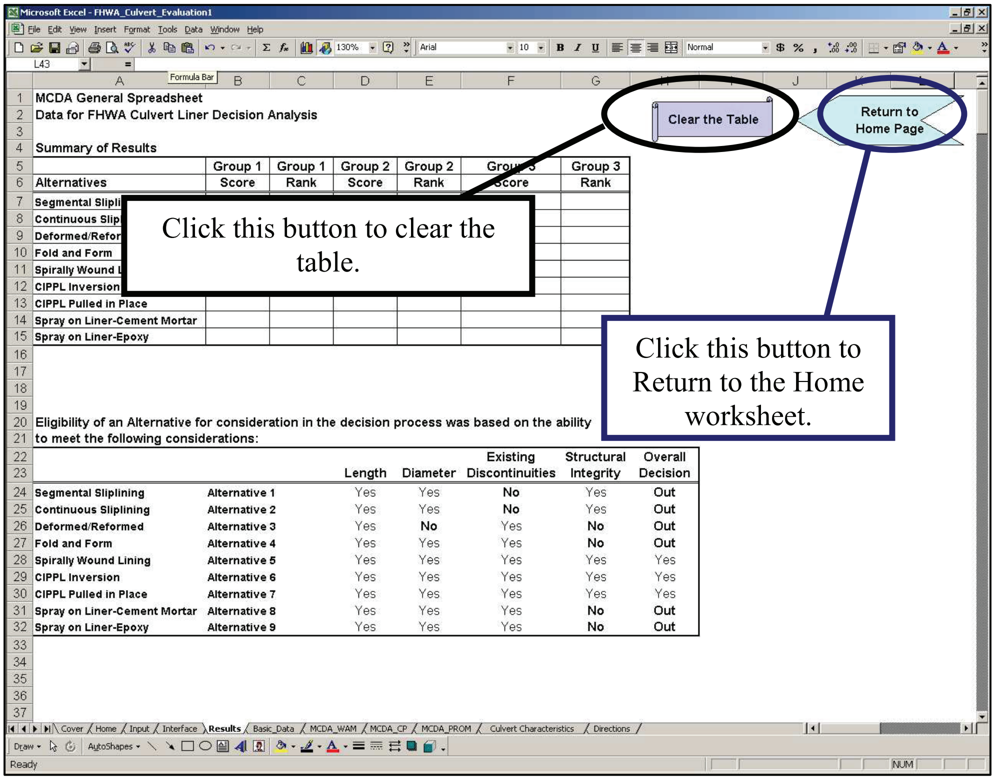


Figure 38. Screenshot. Results Worksheet, Clear the Table and Return to Home Worksheet.

19. To begin a new analysis, return to Home worksheet and follow steps 1 through 18.

EXAMPLE APPLICATION

Paragon Engineering Ltd. published an article by Kupskay (2001) titled *Coquitlam Capital Works: B&B Relines Deep Culverts in Coquitlam Improvement Project*. Kupskay’s case study presented the lining of two (2) corrugated metal pipe culverts in the City of Coquitlam, located approximately thirty (30) miles east of Vancouver.[55] Each year the City undertakes a complete overhaul of a residential neighborhood, including offering residents a chance to upgrade their streets in a cost-shared basis. The Neighborhood Improvement Project of 2001 involved the upgrading and replacement of underground infrastructure in advance of repaving scheduled for later in the year. Decision makers in this study were the City of Coquitlam who developed and primarily funded the project, and the residents who were required to prioritize neighborhood improvements and share project costs.

Two (2) pipes were rehabilitated in this study; one (1) was the Oneida Drive pipe, which was constructed of corrugated metal. Sections of the Oneida Drive pipe were missing from the bottom for lengths up to twelve (12) inches. There existed a short section where the top of the pipe had settled and was approaching ten (10) percent loss in ovality. Replacement of the culvert was ruled out because the depth of digging required was 4.42 meters (14.5 feet) to 5.5 meters (18 feet) below the road surface. 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. Details of this study, specifically the Oneida Drive pipe, have been incorporated into the following example, to illustrate the use of the MCDA.

Input Culvert Details

Initially, the culvert details were entered into the Culvert Characteristics worksheet, under the column labeled "Culvert A." In reference to the question regarding discontinuities and changes in diameter, "Severe" was selected due to the loss in ovality of the corrugated metal pipe. By selecting "Severe," the MCDA automatically eliminated segmental sliplining and continuous sliplining from the list of viable alternatives. This limitation was installed because the commonly used material for the sliplining process is polyethylene and according to the ASTM F 585 (2000) *Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers*,[15] polyethylene pipe can accommodate reasonable irregularities in external loading or in line and grade but excessive bending should be avoided. Due to the extent of deterioration and missing sections of pipe, the question regarding structural integrity was answered "Requires restoration of structural integrity." Selection of this option eliminated the alternatives cement-mortar spray-on lining, epoxy spray-on lining, close-fit lining fold and form method, and close-fit lining deformed/reformed method. Methods of spray-on lining are non-reinforcement methods[8] intended to halt corrosion and repair small leaks. Three (3) alternatives were considered for culvert rehabilitation in this example, the alternatives were spirally wound lining, cured-in-place lining inversion method, and cured-in-place lining pulled-in-place method. Figure 39 presents the Culvert Characteristics worksheet with the necessary culvert parameters entered.

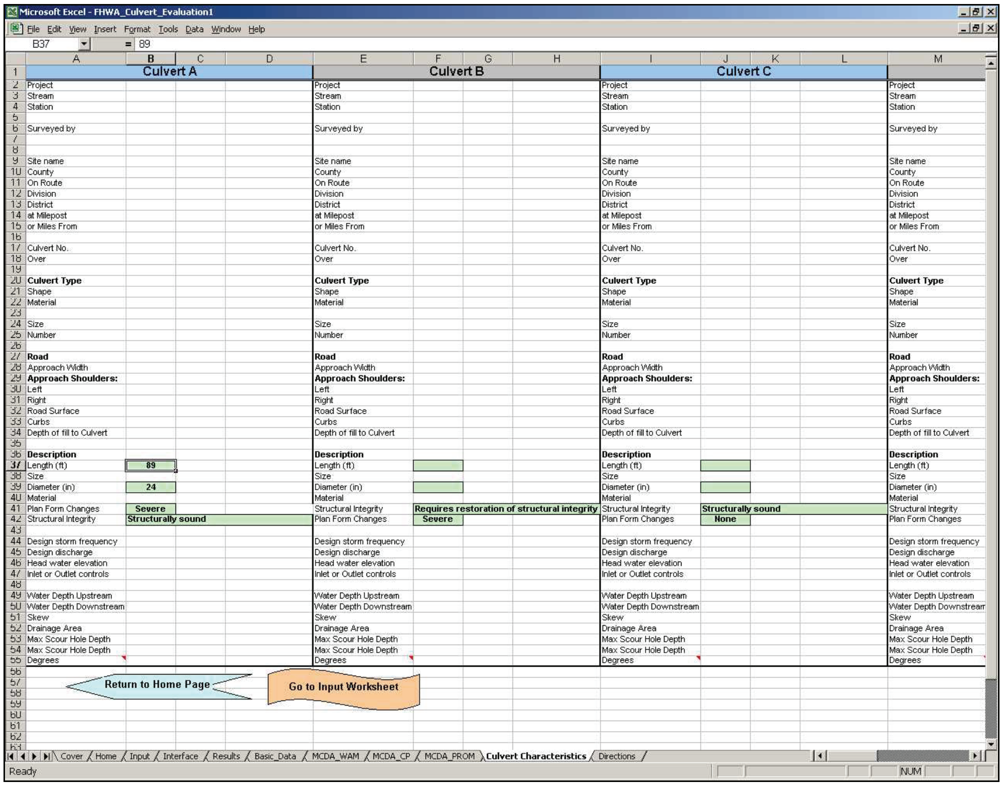


Figure 39. Screenshot. Input Worksheet for Coquitlam Improvements Project.

Next, the Inputs worksheet was selected. Culvert A was chosen in the dropdown box.

Determine Relative Importance Factors

Relative Importance factors were entered into the columns labeled G1 through G3 in the Interface worksheet. Details specific to the criteria outlined in the MCDA were not available from the article; therefore, relative importance factors were theorized for three (3) scenarios. In the first scenario, all criteria were of equal significance in ranking of relative importance factors. A subjective interpretation of relative importance factors for the case study details presented above was inputted into the column labeled G2 for the second scenario. In the second scenario, avoidance of flow bypass was given a high priority. This scenario was intended to represent the residents' preferences and the potential disputation bypass of the flow could create in day-to-day life. A variation of the relative importance factors used in the second scenario was entered for the third scenario. In the third scenario, cost of the project was given a highest priority, intending to represent the preferences of the decision makers for the City. Alternative weight was initially determined using the Weighted Average Method. Figure 40 presents a screenshot of the Interface worksheet with the aforementioned relative importance factor scenarios and selection of the Weighted Average Method for determination of alternative ranking.

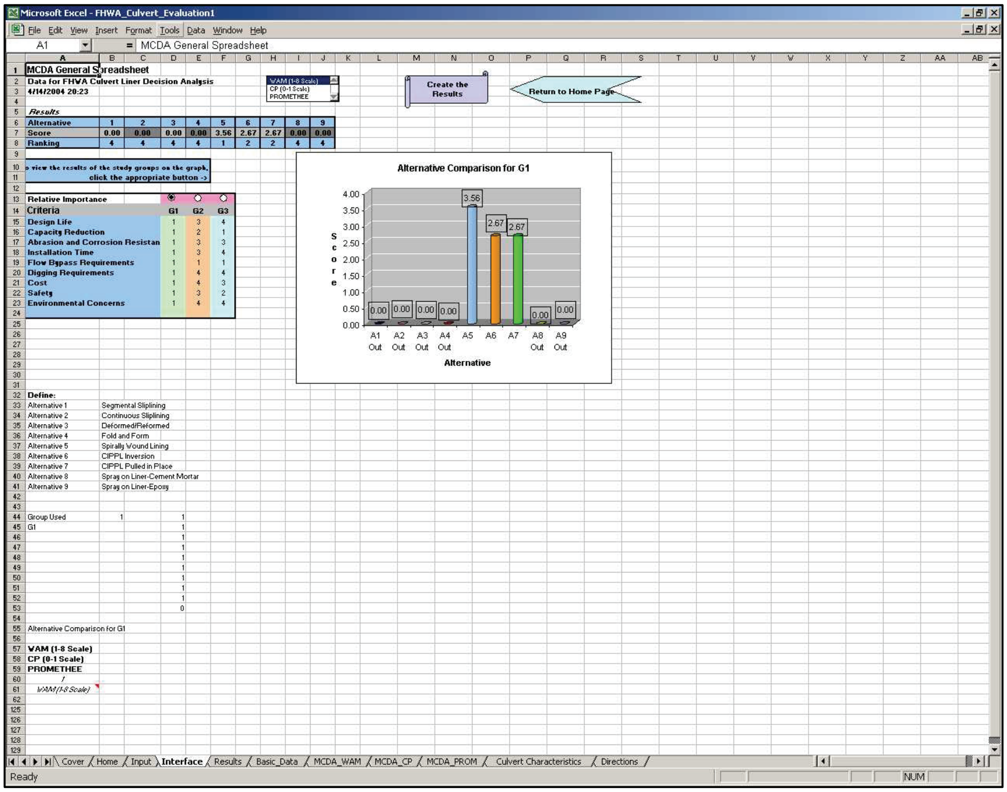
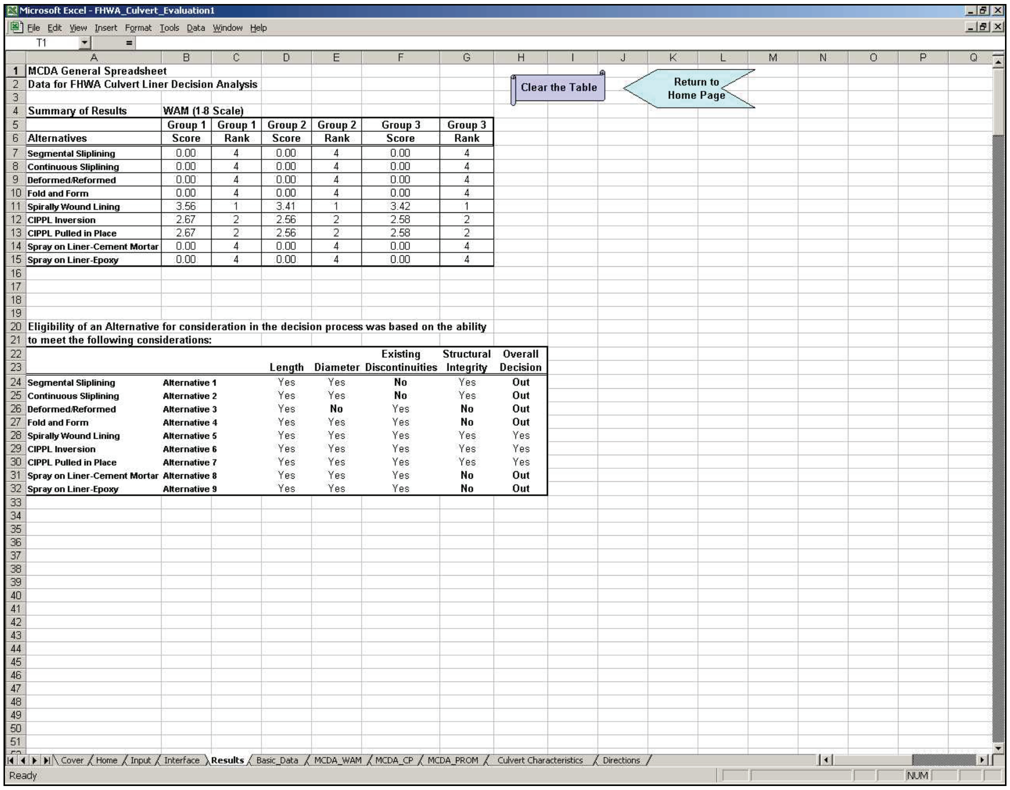


Figure 40. Screenshot. Interface Worksheet with Relative Importance Factors.

View Results

Clicking on the "Create the Results" button saved the results of the three (3) relative importance factor scenarios to the Results worksheet. Figure 41 illustrates the Results worksheets, with the alternative-ranking outcome from the previously presented relative importance factors.



MCDA General Spreadsheet
Data for FHWA Culvert Liner Decision Analysis

Summary of Results WAM (1-8 Scale)

Alternatives	Group 1 Score	Group 1 Rank	Group 2 Score	Group 2 Rank	Group 3 Score	Group 3 Rank
Segmental Sliplining	0.00	4	0.00	4	0.00	4
Continuous Sliplining	0.00	4	0.00	4	0.00	4
Deformed/Reformed	0.00	4	0.00	4	0.00	4
Fold and Form	0.00	4	0.00	4	0.00	4
Spirally Wound Lining	3.56	1	3.41	1	3.42	1
CIPPL Inversion	2.67	2	2.56	2	2.58	2
CIPPL Pulled in Place	2.67	2	2.56	2	2.58	2
Spray on Liner-Cement Mortar	0.00	4	0.00	4	0.00	4
Spray on Liner-Epoxy	0.00	4	0.00	4	0.00	4

Eligibility of an Alternative for consideration in the decision process was based on the ability to meet the following considerations:

		Length	Diameter	Existing Discontinuities	Structural Integrity	Overall Decision
Segmental Sliplining	Alternative 1	Yes	Yes	No	Yes	Out
Continuous Sliplining	Alternative 2	Yes	Yes	No	Yes	Out
Deformed/Reformed	Alternative 3	Yes	No	Yes	No	Out
Fold and Form	Alternative 4	Yes	Yes	Yes	No	Out
Spirally Wound Lining	Alternative 5	Yes	Yes	Yes	Yes	Yes
CIPPL Inversion	Alternative 6	Yes	Yes	Yes	Yes	Yes
CIPPL Pulled in Place	Alternative 7	Yes	Yes	Yes	Yes	Yes
Spray on Liner-Cement Mortar	Alternative 8	Yes	Yes	Yes	No	Out
Spray on Liner-Epoxy	Alternative 9	Yes	Yes	Yes	No	Out

Figure 41. Screenshot. Results of the Coquitlam Case Study Decision Analysis.

According to Figure 41, the highest rated alternative in all three (3) scenarios is spirally wound lining and the second rated alternative was consistently cured-in-place lining inversion method and cured-in-place lining pulled-in-place method. Numerical weights for the alternatives included in the model can be found on the Basic Data worksheet. Comparison of the three (3) methods on the Basic Data worksheet shows that spirally wound lining is better weighted for cost, environmental concerns, flow bypass requirements, digging requirements, and time required for installation. Weights were equal for the three (3) methods for safety considerations, abrasion and corrosion resistance, and potential capacity reduction after installation of the liner. Cured-in-place lining inversion method and cured-in-place lining pulled-in-place method were better weighted than spirally wound lining for design life. Figure 42 presents the Basic Data worksheet.

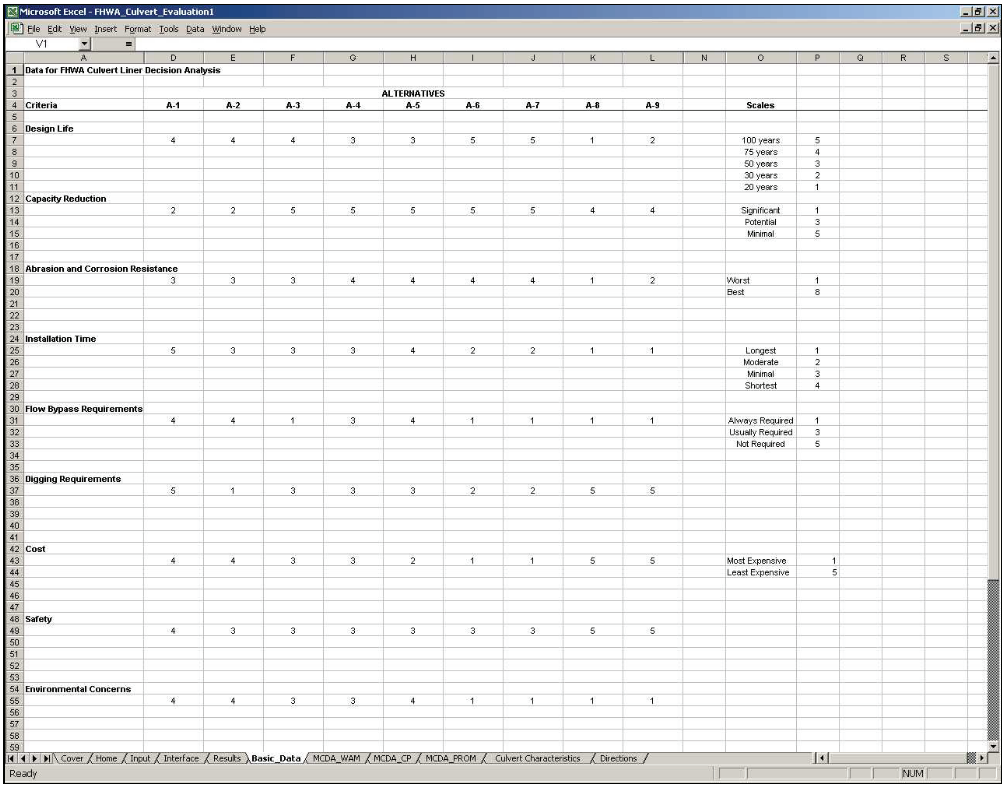


Figure 42. Screenshot. Basic Data Worksheet.

Comparison of Methods of Alternative Ranking

Ranking of alternatives in the previous example were determined by the Weighted Average Method. As previously described, two (2) other methods of alternative ranking are available, CP and PROMETHEE. Table 52, Table 53, and Table 54 provide a comparison of the results originated from the three (3) alternative ranking methods for the Coquitlam case study example.

Table 52. Weighted Average Method.

Summary of Results	WAM (1-8 Scale)

Alternatives	Group 1 Score	Group 1 Rank	Group 2 Score	Group 2 Rank	Group 3 Score	Group 3 Rank
Segmental Sliplining	0.00	4	0.00	4	0.00	4
Continuous Sliplining	0.00	4	0.00	4	0.00	4
Close-fit lining Deformed/Reformed	0.00	4	0.00	4	0.00	4
Close-fit lining Fold and Form	0.00	4	0.00	4	0.00	4
Spirally wound lining	3.56	1	3.41	1	3.42	1
Cured-in-place lining Inversion	2.67	2	2.56	2	2.58	2
Cured-in-place lining Pulled-in-place	2.67	2	2.56	2	2.58	2
Cement-mortar Spray-on lining	0.00	4	0.00	4	0.00	4
Epoxy Spray-on lining	0.00	4	0.00	4	0.00	4

Table 53. Discrete Compromise Method.

Summary of Results	CP (0-1 Scale)

Alternatives	Group 1 Score	Group 1 Rank	Group 2 Score	Group 2 Rank	Group 3 Score	Group 3 Rank
Segmental Sliplining	0.00	0	0.00	0	0.00	0
Continuous Sliplining	0.00	0	0.00	0	0.00	0
Close-fit lining Deformed/Reformed	0.00	0	0.00	0	0.00	0
Close-fit lining Fold and Form	0.00	0	0.00	0	0.00	0
Spirally wound lining	0.61	1	0.56	1	0.57	1
Cured-in-place lining Inversion	0.28	2	0.25	2	0.23	2
Cured-in-place lining Pulled-in-place	0.28	2	0.25	2	0.23	2
Cement-mortar Spray-on lining	0.00	0	0.00	0	0.00	0
Epoxy Spray-on lining	0.00	0	0.00	0	0.00	0

Table 54. PROMETHEE Method.

Summary of Results	PROMETHEE

Alternatives	Group 1 Score	Group 1 Rank	Group 2 Score	Group 2 Rank	Group 3 Score	Group 3 Rank
Segmental Sliplining	0.00	0	0.00	0	0.00	0
Continuous Sliplining	0.00	0	0.00	0	0.00	0
Close-fit lining Deformed/Reformed	0.00	0	0.00	0	0.00	0
Close-fit lining Fold and Form	0.00	0	0.00	0	0.00	0
Spirally wound lining	0.32	1	0.26	1	0.29	1
Cured-in-place lining Inversion	-0.02	9	-0.08	9	-0.04	9
Cured-in-place lining Pulled-in-place	-0.02	9	-0.08	9	-0.04	9
Cement-mortar Spray-on lining	0.00	0	0.00	0	0.00	0
Epoxy Spray-on lining	0.00	0	0.00	0	0.00	0

It can be seen in Table 52, Table 53, and Table 54 that spirally wound lining is consistently the highest ranked alternative for both decision makers and in the scenario where all criteria are of equal weight.

Summary

Two (2) corrugated metal pipe culverts in the City of Coquitlam were rehabilitated in Kupskay's case study titled *Coquitlam Capital Works: B&B Relines Deep Culverts in Coquitlam Improvement Project.* One of the culverts, the Oneida Drive culvert, was considered in an example evaluation of the MCDA. Decision makers represented in the example were the City of Coquitlam and the residents of the neighborhood where the culvert rehabilitation was to take place. Priority for the City was theorized to be the cost of rehabilitation; residents were hypothesized to give precedence to flow bypass requirements due to the potential disruption to everyday life. In Kupskay's case study, the close-fit fold and form method was the chosen technique for culvert rehabilitation. The close-fit fold and form method was not considered in the MCDA process because this method is not considered to provide structural integrity to the rehabilitated culvert. Structural integrity was emphasized in the example due to loss of the ovality and deteriorated portions of the existing culvert. Comparison of the three (3) methods of alternative ranking consistently resulted in spirally wound lining as the best alternative for both decision makers.

CHAPTER 6 – CONCLUSION

Trenchless-technology techniques for culvert rehabilitation have experienced increasing use in the United States. Due to higher traffic density, social and environmental impacts, and high construction costs associated with open-cutting techniques, State DOTs, consultants and Federal agencies, such as the FHWA, have turned toward trenchless technology as a cost-effective solution to culvert rehabilitation. In the past, culvert-lining techniques were developed on a project-by-project basis due to lack of standards and specifications. CSU was contracted to develop written procedures and standards on trenchless technologies for culvert pipe liners for the FLH-FHWA. Accomplishment of this goal was achieved by dividing the study into three (3) tasks. First, a thorough literature review was performed and a survey of Federal agency personnel conducted. Secondly, a Multi-Criteria Decision Analysis tool in Microsoft® Excel was constructed. Lastly, a final report was compiled that included the results of the literature review, the survey, and a complete description of the creation and instruction for use of the MCDA.

In order to meet the objectives of Task 1 of this study, a thorough review of the literature on trenchless technology was conducted. Various sources were obtained utilizing several searching techniques. Information gathered from these sources regarding liner costs, manufacturers, and contractors was incomplete. An informational survey was developed and distributed in order to obtain information that was more complete. From the background review, a relationship between culvert lining and trenchless technology was conjectured. Five (5) methods applicable to culvert rehabilitation were reviewed and described according to a finite list of characteristics. The five (5) methods reviewed were: sliplining, close-fit lining, spirally wound lining, cured-in-place pipe lining, and spray-on lining.

To meet the goals of Task 2, the data and information compiled in the literature review and survey were used to construct a framework for the decision-analysis tool. Information was incomplete and inadequate for several methods; these methods were eliminated from the decision framework. Resulting was a final list of methods, which were:

- Sliplining segmental
- Sliplining continuous
- Close-fit lining deformed/reformed
- Close-fit lining fold and form
- Spirally wound lining
- Cured-in-place pipe lining inversion
- Cured-in-place pipe lining pulled-in place

- Spray-on lining cement-mortar
- Spray-on lining epoxy

A list of criteria was determined that the decision maker indicates preference for in the decision-analysis tool. These criteria were:

- Design life
- Capacity reduction
- Abrasion and corrosion resistance
- Installation time
- Flow bypass requirements
- Digging requirements
- Cost
- Safety
- Environmental concerns

Each alternative was given a performance score in the context of each criterion, based on information assembled in the literature review and survey. Three (3) MCDA alternative ranking methods were included in this project. The Weighted Average Method and the Discrete Compromise Programming Method are value-based methods and the PROMETHEE method is an outranking method. Users can select a method of their choice or they can compare the results of all three (3) methods. It is recommended that the Weighted Average Method be the first choice for alternative ranking in this project.

Four (4) culvert characteristics were imperative to the operation of the MCDA; these characteristics were:

- Culvert length
- Diameter of culvert
- Existence of changes in diameter and/or discontinuities along the culvert
- Necessity of restoration of structural integrity

In the Excel MCDA, alternative rating scores and relative importance criteria are entered into alternative weighting equations resulting in a list ranking the alternatives.

In the Excel workbook, one (1) additional criterion could be added as well as five (5) subcriteria per criterion. An example of subcriteria would be to further divide cost into categories such as cost of installation, cost of liner, etc. If information was available, one (1) alternative could be added to the MCDA. Information exists to extend the diameter limitation from 122 centimeters (48 inches) to 164 centimeters (60 inches).

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(70) ASTM D 883 – Terminology Relating to Plastics.
(71) ASTM D 2240 – Test Method for Rubber Property—Durometer Hardness.
(72) ASTM F 1216 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube (1998).
(73) ASTM D 5813 – Standard Specification for Cured-In-Place Thermosetting Resin Sewer Pipe (1995).
(74) ASTM D 695 – Test Method for Compressive Properties of Rigid Plastics (2001).
(75) ASTM D 903 – Test Method for Peel or Stripping Strength of Adhesive Bonds.
(76) ASTM D 1682 – Test Methods for Breaking Load and Elongation of Textile Fabric.
(77) ASTM D 3039 – Test Method for Tensile Properties of Fiber-Resin Composites.
(78) ASTM D 3567 – Practice for Determining Dimensions of "Fiberglass" (Class-Fiber-Thermosetting Resin) Pipe and Fittings.
(79) ASTM D 3681 – Test Method for Chemical Resistance of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe in a Deflected Condition.
(80) ASTM D 3839 – Practice for Underground Installation of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe.
(81) ASTM D 4814 – Specification for Automotive Spark—Ignition Engine Fuel.

(82) ASTM F 1743 – Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (1996).
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(85) AWWA C602 – Standard for Cement-Mortar Lining of water Pipelines in Place-4 in (100 mm) and Larger (2000).
(86) ASTM A 615 – Standard Specification for Deformed and Plain Billet Steel Bars for Concrete Reinforcement.
(87) ASTM C 94 – Standard Specification for Ready-Mixed Concrete.
(88) ASTM C 260 – Air Entraining Admixtures for Concrete.
(89) ASTM C 494 – Standard Specification for Chemical Admixture for Concrete.
(90) ASTM C 796 – Standard Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam.
(91) ASTM C 869 – Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete.
(92) ASTM D 256 – Test Method for Determining the Pendulum Impact Resistance of Notched Specimens of Plastics.
(93) ASTM D 1248 – Specification for Polyethylene Plastic Molding and Extrusion Material.
(94) ASTM D 2321 – Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications.
(95) ASTM D 2417 – Specification for Perforated, Laminated Wall Bituminized Fiber Pipe for General Drainage.
(96) ASTM D 2584 – Standard Test Method for Ignition Loss of Cured Reinforced Resins.
(97) ASTM D 5260 – Standard Classification for Chemical Resistance of Poly(Vinyl Chloride) (PVC) Homopolymer and Copolymer Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds.
(98) ASTM F 949 – Standard Specification for Poly(Vinyl Chloride) (PVC) Corrugated Sewer Pipe With a Smooth Interior and Fittings.
(99) ASTM F 1803 – Standard Specification for Poly (Vinyl Chloride) (PVC) Closed Profile Gravity Pipe and Fittings Based on Controlled Inside Diameter.
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(102) ASTM Standards on CD ROM (2001). Volume 08.02 – Plastics (II): D2383-D4322.
(103) ASTM Standards on CD ROM (2001). Volume 08.03 – Plastics (III): D4329-latest.

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(111) ISCO Industries (2002). Snap-Tite Culvert Liners. http://www.isco-pipe.com, Downloaded May 31, 2002.

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(116) Pipe material selection policy of the FHWA Federal Lands Highway Division obtainable from http://www.efl.fhwa.dot.gov/design/manual/pddm.pdf.

APPENDIX A – LITERATURE COMPILATION

ASTM Standards Sources:

1. ASTM Standards on CD ROM (2001). Volume 08.01 – Plastics (I): D256-D2343.(101)
2. ASTM Standards on CD ROM (2001). Volume 08.02 – Plastics (II): D2383-D4322.(102)
3. ASTM Standards on CD ROM (2001). Volume 08.03 – Plastics (III): D4329-latest.(103)
4. ASTM Standards on CD ROM (2002). Volume 08.04 – Plastic Pipe and Building Products.(23)
5. ASTM (1999). Compilation of Standards Related to Trenchless Technology. Baltimore, MD.(3)

Government Agency Sources:

1. California Department of Transportation (1995). Culvert Rehabilitation Using Plastic Pipe Liners. Design Information Bulletin 76 (DIB-76), http://www.dot.ca.gov/hq/oppd/dib/db76.htm, Downloaded August 22, 2001.(104)
2. Iseley, T. and S. B. Gokhale (1997). Trenchless Installation of Conduits Beneath Roadways. National Cooperative Highway Research Program (NCHRP) – Synthesis of Highway Practice 242. Transportation Research Board, National Research Council, National Academy Press, Washington DC.(2)
3. New York Department of Transportation (2001). New Standard Specification Section 602 Rehabilitation of Culvert and Storm Drain Pipe. Engineering Instruction 01-028 (EI 01-028), http://www.dot.state.ny.us/cmb/consult/eib/files/ei01028.pdf, down-loaded May 22, 2002.(105)
4. New York Department of Transportation (2001). Design Guidelines for Rehabilitation of Culvert and Storm Drain Pipe. Engineering Instruction 01-029 (EI 01-029), http://www.dot.state.ny.us/cmb/consult/eib/files/ei01029.pdf, Downloaded May 22, 2002.(106)
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6. United States Forest Service (2003). Summary of Trenchless Technology for Use with Forest Service Culverts. Draft.(9)

Other Agencies, Organizations, Contractors, and Manufacturers Sources:

1. Advantica Technologies, Inc. (2002). Swagelining™ – The Best PE Lining System in the World for Oilfields and Industrials Pipelines. http://www.swagelining.com/index.html, Downloaded July 7, 2002.(43)
2. American Association of State Highway and Transportation Officials (1999). Culvert Inspection and Rehabilitation. Highway Drainage Guidelines, Volume XIV, Washington DC.(37)
3. American Pipe & Plastics, Inc. (2002). AM-LinerII – Sewer Pipeline Rehabilitation System. http://www.amliner.com, Downloaded July 7, 2002.(108)
4. American Water Works Association (2000). Standard for Cement-Mortar Lining of Water Pipelines in Place – 4 in. (100 mm) and Larger. Denver, CO.(83)
5. AWWA M28 – Rehabilitation of Water Mains. 2nd Edition, Manual of Water Supply Practices M-28, Denver, CO (2001).(8)
6. Gray, W.W.S. (1996). Trenchless Technology for Sewer Rehabilitation. Civil Engineering News, 8(2):24.(44)
7. Gwaltney, T. (1998). Pipeline Rehabilitation & Repair. In: Pipelines in the Constructed Environment, Proceedings of the 1998 Pipeline Division Conference, Castonovo, J. and J. Clark (Eds.), American Society of Civil Engineers.(109)
8. Hastak, M.H. and S. Gokhale (2000). System for Evaluating Underground Pipeline Renewal Options. Journal of Infrastructure Systems, 6(3):105.(110)
9. International Organization for Standardization (1992). Techniques for Rehabilitation of Pipeline Systems by the Use of Plastics Pipes and Fitting. Technical Report 11295 (ISO/TR 11295), Geneva, Switzerland.(6)
10. ISCO Industries (2002). Snap-Tite Culvert Liners. http://www.isco-pipe.com, Downloaded May 31, 2002.(111)
11. Iseley, T. and M. Najafi (1995). Trenchless Pipeline Rehabilitation. Prepared for the National Utility Contractors Association.(5)
12. Iseley, T., M. Najafi, D. Bennett (1994). Trenchless Pipeline Rehabilitation With Plastic Materials. In: Buried Plastic Pipe Technology, 2nd Volume – ASTM Special Technical Report (STP) 122, Proceedings of Buried Plastic Pipe Technology Symposium, Eckstein, D. (Ed.), Baltimore, MD.(112)
13. National Association of Sewer Service Companies (1999). Wastewater Collection Systems Maintenance and Rehabilitation. Specification Guidelines 10th Edition, Chambersburg, PA, available from http://www.nassco.org/publications.html, Downloaded May 31, 2002.(14)
14. Oxner, K.B. and T. Allsup (1999). Advances in Cured-In-Place Pipe Rehabilitation for Pressurized Piping Systems. Insituform Technologies, Inc., http://www.insituform.com/resourceroom/rr2_14.pdf, Downloaded May 31, 2002.(113)

15. Plastics Pipe Institute (1995). Guidance and Recommendations on the Use of Polyethylene (PE) Pipe for the Sliplining of Sewers. Guideline Document – Guide 1/95, the Society of the Plastics Industry, Inc., Washington DC.(36)
16. Ultraliner (2002). Ultraliner PVC Alloy Pipeliner Specification and Installation Process. http://www.ultraliner.com/, Downloaded June 17, 2002.(45)

FHWA Contributed Resources:

1. FHWA provided the following:

- Information detailing the scope of the project during a meeting held April 12, 2002 with Roger Surdahl, Eric Brown, Dr. Christopher Thornton, and Michael Robeson
- FP-96 "Standard Specification for Construction of Roads and Bridges on Federal Highway Projects"(114) for review and possible inclusion in the literature review
- Names and contact information for additional FHWA personnel contacts
- Feedback for informational survey development
- Names and contact information for additional FHWA personnel contacts

2. FHWA provided the following list of additional resources and comment:

- Short Paper comparing Insituform and cement-mortar lining, http://www.ameron.com(115)
- Pipe material selection policy of the FHWA Federal Lands Highway Division obtainable from http://www.efl.fhwa.dot.gov/design/manual/pddm.pdf(116)
- Other than these three sources, all familiar sources were obtained
- Contech Construction Products, Inc.; A2 Liner Pipe, for sanitary and storm sewer rehabilitation and repair
- Suggested that more manufacturers should be contacted for information

3. FHWA provided the following comment:

- The list looked complete and could not provide any additional resources

APPENDIX B – INFORMATIONAL SURVEY

Culvert Pipe Liners:

Development of Guidelines and Specifications Survey

Name of Agency/DOT/Organization:______________________________

Location of Agency/DOT/Organization (city, state):____________________

Name:____

Position/Title:____

Will you allow us to contact you for more information if needed?

YES ○ **NO** ○

If yes, please fill in your Phone #, Fax # and E-mail for future contact purposes.

Phone #:________________________

Fax #:________________________

E-mail:____

Are you interested in receiving a copy of the summary of the survey results?

YES ○ **NO** ○

This survey is intended to provide Colorado State University, in conjunction with the Federal Highway Administration (FHWA), information for the development of guidelines and specifications for the use of culvert pipe liners. This survey will focus on five (5) current methods of lining existing pipes for rehabilitation purposes. These methods include: Sliplining (SL), Close-fit Lining (CFL), Spirally Wound Lining (SWL), Cured-In-Place Lining (CIPPL) and Spray-On Lining (SOL).

For survey purposes, each method is defined:

Sliplining (SL): Sliplining involves the process of inserting a flexible, usually thermoplastic, liner of smaller diameter directly into the deteriorated pipe. Liners are inserted into the host pipe 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 to provide a watertight seal. The liner can be installed in segments (segmental sliplining) or by one continuous liner (continuous sliplining).

Close-Fit Lining (CFL): 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 temporarily modified in cross section prior to installation. The modified liner is then winched into place and reformed/re-rounded to provide a close-fit with the existing culvert. Liner diameters can be temporarily reduced with a static die or series of compression rollers or folded into a "C"-, "U"- or "H"-shape.

Spirally Wound Lining (SWL): This technique utilizes interlocking profile strips, most commonly made from PVC, to line the deteriorated pipe. The coiled, interlocking profile strips are fed through a winding machine that mechanically forces the strips to interlock and form a smooth, continuous, spirally wound liner. During the interlocking process, a sealant is applied to each joint to form a watertight seam. As the material is wound and snapped together, it is spirally wound into the existing pipe.

Cured-In-Place Pipe Lining (CIPPL): Cured-in-place pipe lining, also known as "in-situ lining", involves the insertion of a flexible fiber tube coated with a thermosetting resin into the existing pipe. The tube is inserted by hydrostatic inversion, air inversion or by mechanically pulling the liner in place. Once installed, the resin is cured under ambient conditions or through applied heat provided by circulating stream or hot water throughout the tube.

Spray-On-Lining (SOL): Spray-on-lining techniques utilize a machine that is inserted into an existing culvert. The machine is pulled through the pipe at a constant speed while centrifugally spraying the lining material onto the wall of the existing pipe. Cement-mortar and epoxy are the two most common types of materials used for lining. For man-entry culverts, cement-mortar applications can be reinforced with wire mesh.

General Information:

1. Has your agency/DOT/organization been involved with the design or installation of pipe liners? YES ○ NO ○ ***if No, please go to 16***

2. When was the first time your agency/DOT/organization became familiar with the practice of lining pipes for rehabilitation purposes? Year ________

3. Which types of pipe liners has your agency/DOT/organization designed or installed:

☐ SL Approximately how much pipe________ Feet ○ Meters ○
☐ CFL Approximately how much pipe________ Feet ○ Meters ○
☐ SWL Approximately how much pipe________ Feet ○ Meters ○
☐ CIPPL Approximately how much pipe________ Feet ○ Meters ○
☐ SOL Approximately how much pipe________ Feet ○ Meters ○

4. What standards/specifications/guidelines were used for the design and installation of the pipe liners?

☐ Manufacturers Please list sources________________________________

____

____

____

☐ ASTM Please list specific standards________________________

____

____

____

☐ Government/State Please list sources________________________________

____

____

____

☐ Own Please list sources____________________

____

____

☐ Other Please list sources____________________

____

____

5. Which types of pipe liners have proven to be the easiest to install?

☐ SL ☐ SWL ☐ SOL

☐ CFL ☐ CIPPL

Why?:____

____

6. Which types of pipe liners have proven to be the most successful?

☐ SL ☐ SWL ☐ SOL

☐ CFL ☐ CIPPL

Why?:____

____

7. Which types of pipe liners have proven to be the most unsuccessful?

☐ SL ☐ SWL ☐ SOL

☐ CFL ☐ CIPPL

Why?:____

____

8. Which types of pipe liners have proven to be the most expensive?

☐ SL ☐ SWL ☐ SOL

☐ CFL ☐ CIPPL

Why?:____

____

9. Which types of pipe liners have proven to be the least expensive?

☐ SL ☐ SWL ☐ SOL

☐ CFL ☐ CIPPL

Why?:____

____

10. Can you provide an average general cost associated with any lining method?

YES ○ NO ○ *if No, please go to 11*

☐	SL	Average General Cost______	Per Linear Foot ○	Per Linear Meter ○
☐	CFL	Average General Cost______	Per Linear Foot ○	Per Linear Meter ○
☐	SWL	Average General Cost______	Per Linear Foot ○	Per Linear Meter ○
☐	CIPPL	Average General Cost______	Per Linear Foot ○	Per Linear Meter ○
☐	SOL	Average General Cost______	Per Linear Foot ○	Per Linear Meter ○

Comments:____

____

____

11. Can you provide a design life generally associated with any lining method?

YES ○ NO ○ *if No, please go to 12*

☐	SL	General Design Life______Years
☐	CFL	General Design Life______Years
☐	SWL	General Design Life______Years
☐	CIPPL	General Design Life______Years
☐	SOL	General Design Life______Years

Comments:____

____

____

12. Do you currently have any maintenance procedures for installed liners?

YES ○ NO ○ *if No, please go to 13*

If yes, please specify:_________________________________

____

____

____

____

____

____

13. Are you aware of any environmental issues associated with any of the liners?

YES ○ NO ○ *if No, please go to 14*

If yes, please specify:____

14. Can you provide a listing of any manufacturers or contractors of these lining methods in and/or outside your geographical area?

YES ○ NO ○ *if No, please go to 15*

Manufacturer or Contractor	Contact Information (i.e. Phone #, Fax #, Address, Website, etc.)

15. Can you provide any project specific information (i.e. project description, type of liner used, cost) associated with any documented case studies? YES ○ NO ○

If yes to 15, please fill out the project specific information section on the following page.

16. Are you interested in receiving a copy of the specifications and guidelines for culvert pipe liners?
YES ○ NO ○

We appreciate and thank you for your time and effort.

17. Additional Comments?____

Project Specific Information:

Project Name (if applicable)____

____

Published Source (if applicable)______________________________________

____

Project Description____

____

____

____

1. Indicate the type of pipe liner used for this project:

   ☐ SL ☐ SWL ☐ SOL

   ☐ CFL ☐ CIPPL ☐ Other____________________

   Comments:____

   ____

2. Year in which project was completed_________

3. Time to complete installation ______days______hours

4. Total cost of project___________

5. Length of pipe lined________ft ◯ m ◯ Original size of lined pipe______in ◯ mm ◯

6. Material of lined pipe:

   ☐ Steel ☐ Concrete ☐ Copper ☐ Corrugated Metal

   ☐ Iron ☐ PVC ☐ Other____________________

   Comments:____

   ____

7. Was more than one type of pipe liner investigated prior to installation?

YES ○ NO ○ *if No, please go to 9*

If yes, what were they?

☐ SL ☐ SWL ☐ SOL

☐ CFL ☐ CIPPL ☐ Other____________________

Comments:____

8. What was the deciding factor(s) in choosing the type of pipe liner?____________

9. Additional project comments?____________________________________

10. Can you provide information pertaining to additional projects?

YES ○ NO ○

If yes, can we contact you regarding these additional projects YES ○ NO ○

We appreciate and thank you for your time and effort.

APPENDIX C – LIST OF AGENCY RESPONDENTS

Bureau of Land Management – Fairbanks, AK
Bureau of Reclamation – Denver, CO
Arkansas Department of Transportation – Little Rock, AR
Caltrans (California Department of Transportation) – Sacramento, CA
Colorado Department of Transportation – Denver, CO
Colorado Department of Transportation – Durango, CO
Connecticut Department of Transportation – Newington, CT
Idaho Department of Transportation – Boise, ID
Louisiana Department of Transportation & Development – Baton Rouge, LA
Maryland State Highway Administration (Response #1) – Baltimore, MD
Maryland State Highway Administration (Response #2) – Baltimore, MD
Michigan Department of Transportation – Lansing, MI
Missouri Department of Transportation – Jefferson City, MO
Mississippi Department of Transportation – Jackson, MS
Montana Department of Transportation – Helena, MT
Nevada Department of Transportation – Carson City, NV
New Hampshire Department of Transportation – Concord, NH
Ohio Department of Transportation – Columbus, OH
Oregon Department of Transportation – Salem, OR
Tennessee Department of Transportation – Nashville, TN
Vermont Agency of Transportation, Maintenance & Aviation Division – Montpelier, VT
Wisconsin Department of Transportation – Madison, WI
U.S. Forest Service – Cass Lake, MN
U.S. Forest Service – Laramie, WY
U.S. Forest Service – Cleveland, TN
U.S. Forest Service (Ottawa National Forest) – Ironwood, MI
U.S. Forest Service (Shasta-Trinity National Forest) – Redding, CA
National Park Service (Zion National Park) – Springdale, UT
National Park Service (Pacific West Region) – Oakland, CA
URS Corporation – Denver, CO

APPENDIX D – SUMMARY OF AGENCY RESPONSES

Table 55. Summary of Agency Responses.

Respondent Number	Agency	Location	Familiar With Pipe Rehabilitation Methods	Liners Designed or Installed	Standards/Specifications	Easiest to Install	Proven Most Successful	Proven Most Unsuccessful	Proven Most Expensive	Proven Least Expensive	Average General Cost		Design Life	
			Yes (Year) or No	Liner (Length Installed in ft)							Liner	Cost	Liner	Years
1	BLM	AK	NO	N/S[1]	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
2	BOR	CO	Yes (1985)	Sliplining (1,000)	Bureau Specifications; AWWA M11	Slip-lining	Slip-lining SOL	None	SOL	Slip-lining	N/S	N/S	N/S	N/S
3	DOT	AR	Yes (1994)	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
4	DOT	CO-Denver	Yes (Unknown)	CIPPL (600) Other (200)	Colorado DOT Specifications; Manufacturer's Specifications	CIPPL	CIPPL	N/S	CIPPL	N/S	N/S	N/S	N/S	N/S
5	DOT	CO-Durango	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
6	DOT	CT	Yes (1980)	Sliplining (100s) CIPPL (1000s) Other (100s)	ASTM Standard: F 1216; FHWA Culvert Repair Practices Manual; Manufacturer's Specifications	Slip-lining	Slip-lining	N/S	CIPPL	Slip-lining	N/S	N/S	N/S	N/S
7	DOT	ID	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
8	DOT	LA	Yes (1991)	Sliplining (500) CIPPL (200)	Manufacturer's Specifications	Slip-lining	Slip-lining	N/S	N/S	N/S	N/S	N/S	N/S	N/S
9	DOT	MD[1]	Yes (1990)	SOL (2,000) Other (500)	ASTM Standard: A 615; Manufacturer's Specifications	SOL	SOL	N/S	Other	SOL	SOL	10-25 PSF[2]	All	10-50

[1]N/S – not supplied, [2]PSF – price per square foot, [3]PLF – price per linear foot

Table 55 (cont.). Summary of Agency Responses.

Respondent Number	Agency	Location	Familiar With Pipe Rehabilitation Methods	Liners Designed or Installed	Standards/Specifications	Easiest to Install	Proven Most Successful	Proven Most Unsuccessful	Proven Most Expensive	Proven Least Expensive	Average General Cost		Design Life	
			Yes (Year) or No	Liner (Length Installed in ft)							Liner	Cost	Liner	Years
10	DOT	MD[1]	Yes (1980)	Sliplining (500) Other (6,000)	Maryland DOT Specifications	Other	Slip-lining Other	N/S	Sliplining	Other	Other	15-30 PSF[2]	Slip-lining Other	50 15
11	DOT	CA	Yes (1983)	Sliplining (100,000) CFL (500) SWL (200) CIPPL (500) SOL (22,000)	ASTM Standards: C 796, C 869, D 256, D638, D 790, D 1784, D 2122, D 2152, D 2412, D 2444, D 2584, D 5260, D 5813, F 714, F 894, F 949, F 1216, F 1504, F 1697, F 1743, F 1803; Caltrans Specifications; Southern California Greenbook; Caltrans Information Bulletin No. 76 - Culvert Rehabilitation Using Plastic Liners; Caltrans Study #F90TL15 - Culvert Restoration Techniques; FHWA Culvert Repair Practices Manual; Manufacturer's Specifications	SL SWL Other	SL	SWL CFL	CIPPL	SL Other	Sliplining	55-107 PLF[3]	Slip-lining CFL SWL CIPPL SOL	50 50 50 50 <50

[1]N/S – not supplied, [2]PSF – price per square foot, [3]PLF – price per linear foot

Table 55 (cont.). Summary of Agency Responses.

Respondent Number	Agency	Location	Familiar With Pipe Rehabilitation Methods	Liners Designed or Installed	Standards/Specifications	Easiest to Install	Proven Most Successful	Proven Most Unsuccessful	Proven Most Expensive	Proven Least Expensive	Average General Cost		Design Life	
			Yes (Year) or No	Liner (Length Installed in ft)							Liner	Cost	Liner	Years
12	DOT	MI	Yes (1990)	Sliplining (10,000) CFL (120) CIPPL (1,000) SOL (120)	ASTM Standards: F 1216, F 1743; Michigan DOT Specifications; Manufacturer's Specifications	Slip-lining	Slip-lining	N/S	CIPPL	Slip-lining	N/S	N/S	N/S	N/S
13	DOT	MO	Yes (1986)	Sliplining (a lot)	Missouri DOT Specifications; Manufacturer's Specifications	Slip-lining	Slip-lining	Slip-lining	N/S	N/S	N/S	N/S	N/S	N/S
14	DOT	MS	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
15	DOT	MT	Yes (1985)	Sliplining (1,000)	Montana DOT Specifications	Slip-lining	Slip-lining	Slip-lining	N/S	N/S	N/S	N/S	Slip-lining	20
16	DOT	NH	Yes (1995)	Sliplining (7,700)	ASTM Standards: D 1248, F 714; New Hampshire DOT Specifications	Slip-lining	Slip-lining	N/S	N/S	N/S	N/S	N/S	N/S	N/S
17	DOT	NV	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
18	DOT	OH	Yes (Unknown)	Sliplining (N/S) CIPPL (N/S)	ASTM Standards: F 894, F 121; Ohio DOT Specifications; Manufacturer's Specifications	Slip-lining	Slip-lining	N/S	CIPPL	Slip-lining	N/S	N/S	N/S	N/S

[1]N/S – not supplied, [2]PSF – price per square foot, [3]PLF – price per linear foot

Table 55 (cont.). Summary of Agency Responses.

Respondent Number	Agency	Location	Familiar With Pipe Rehabilitation Methods	Liners Designed or Installed	Standards/Specifications	Easiest to Install	Proven Most Successful	Proven Most Unsuccessful	Proven Most Expensive	Proven Least Expensive	Average General Cost		Design Life	
			Yes (Year) or No	Liner (Length Installed in ft)							Liner	Cost	Liner	Years
19	DOT	OR	Yes (1999)	Sliplining (800) CFL (125) SWL (250) CIPPL (380)	ASTM Standards: D 2657, F 585, F 714, F 1216, F 1743, F 1698; Manufacturer's Specifications	All	All	None	CIPPL	Slip-lining	Slip-lining CFL SWL CIPPL	200 PLF[3] 120 PLF[3] 300 PLF[3] 300 PLF[3]	N/S	N/S
20	DOT	TN	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
21	DOT	VT	Yes (1988)	Sliplining (20,000) CIPPL (300) Other (600)	Vermont DOT Specifications; Manufacturer's Specifications	Slip-lining	Slip-lining CIPPL	Other	Slip-lining	Other	N/S	N/S	N/S	N/S
22	DOT	WI	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
23	FS	CA-Shasta	Yes (1982)	Sliplining (1,500)	Manufacturer's Specifications	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
24	FS	MN	Yes (2000)	Sliplining (775)	ASTM Standards: D 2321, D 2412, D 3350; Manufacturer's Specifications	Slip-lining	Slip-lining	Slip-lining	Slip-lining	Slip-lining	Slip-lining	50 PLF[3]	N/S	N/S

[1]N/S – not supplied, [2]PSF – price per square foot, [3]PLF – price per linear foot

Table 55 (cont.). Summary of Agency Responses.

Respondent Number	Agency	Location	Familiar With Pipe Rehabilitation Methods	Liners Designed or Installed	Standards/Specifications	Easiest to Install	Proven Most Successful	Proven Most Unsuccessful	Proven Most Expensive	Proven Least Expensive	Average General Cost		Design Life	
			Yes (Year) or No	Liner (Length Installed in ft)							Liner	Cost	Liner	Years
25	FS	MI-Ottawa	Yes (2000)	Sliplining (50)	ASTM Standards: C 94, C 150, C 260, C 494, C 618, D 2417, D 3350; Plastics Pipe Institute; USFS Specifications; Manufacturer's Specifications	Slip-lining	Slip-lining	Other	Other	Other	Slip-lining	150-200 PLF[3]	N/S	N/S
26	FS	TN	Yes (1995)	Sliplining (200)	ASTM Standards: D 3212, F 949; Manufacturer's Specifications	Slip-lining	Slip-lining	N/S	N/S	N/S	Slip-lining	30 PLF[3]	N/S	N/S
27	FS	WY	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
28	NPS	Pacific West	Yes (1994)	Sliplining (5,000) CFL (500)	FHWA FP-96; Caltrans Specifications; Manufacturer's Specifications	Slip-lining	Slip-lining CFL	SWL CIPPL	CIPPL	Sliplining	Slip-lining CFL	25-40 PLF[3] 50-80 PLF[3]	N/S	N/S
29	NPS	UT	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S
30	URS Corporation	CO	No	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S	N/S

[1]N/S – not supplied, [2]PSF – price per square foot, [3]PLF – price per linear foot